MILFORD FORGE PHASE 1 TOPICAL REPORT

Overview

The Milford FORGE deep well site is located 350 km south of Salt Lake City and 16 km north-northeast of Milford, Utah, in the actively extensional eastern Great Basin (Figure 1). A large amount of geoscientific data has been acquired over a 40-year period, starting with intensive geothermal exploration during the late 1970s. The work included geological mapping, gravity and magnetotelluric surveys, and the drilling, logging, sampling, and study of numerous shallow (~80) and deep (> 20) wells. The latter include Acord-1, a 3.8 km deep well in the middle of north Milford Valley, west of the FORGE deep drill site. As detailed in the April 27 report, the FORGE deep well site is situated centrally between three, deep, non-productive wells which have thermally conductive gradients and temperatures of more than 175°C at less than 3 km depth. Crystalline bedrock (granite and gneiss) occurs at about 500 m depth beneath the center of the site, and numerous faulting trends should promote successful permeability stimulation.

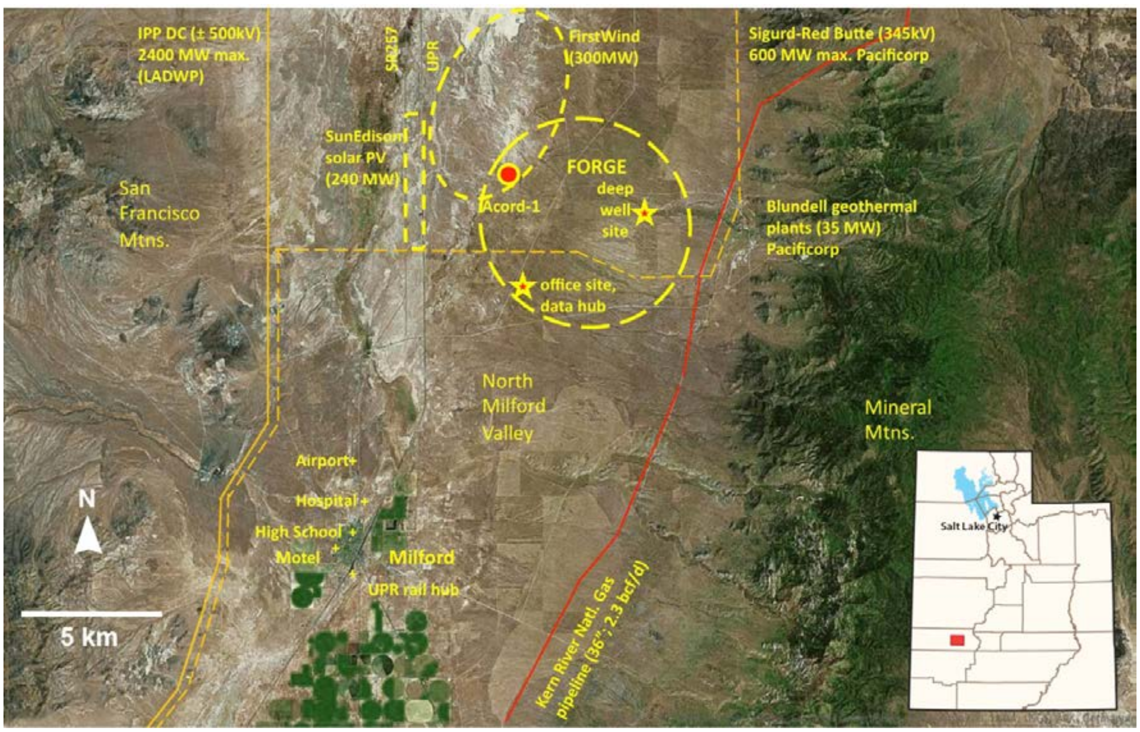

Figure 1. *Location of the FORGE deep well site near Milford, Utah, showing infrastructure and physiography. The site lies in an energy corridor between the Rockies and southern California. Background satellite image from Google Earth.*

The Milford FORGE site is centrally placed within an energy corridor between the Rocky Mountains – Colorado Plateau and southern California, and is adjacent to wind, solar-PV, and traditional geothermal power facilities. The site is on Utah State Land (School and Institutional Trust Lands Administration – SITLA) and private land (Smithfield-Murphy Brown Inc), with the two entities enthusiastically supporting both the FORGE concept and the potential for the project to demonstrate geothermal power possibilities. Few environmental issues exist – there is more than 8 km (5 miles) of existing road access across the 5 km^2 site, which can be reached through public roads maintained by the county all-year around. The project has already secured sufficient groundwater, and is in the process of increasing the water right to provide additional flexibility for cooling during long-term flow-tests. The site is a 15 minute drive from Milford town where there are accommodations and eating establishments.

The Milford site satisfies the thermal, geological, access, infrastructural and environmental constraints stipulated by the DOE for a FORGE laboratory. The present topical report (May 23 2016) reviews the main project site characteristics.

Results

Lithologies. - Based on surrounding wells, the main lithologies beneath the FORGE deep well site likely comprise crystalline basement rocks made up of Precambrian gneiss and Tertiary plutons, Tertiary basin-fill composed of volcanic strata, and Quaternary basin fill made of fluvial-lacustrine sedimentary deposits (Figure 2). Most gneiss-plutonic contacts are intrusive, but some are represented by faults and zones of cataclasis. All of the other major breaks in rock types are marked by unconformities. The pre-alteration gneiss mineralogy is made up of biotite, hornblende, K-feldspar, plagioclase, quartz, and sillimanite, and isotopic dating indicates Proterozoic metamorphism ~1720 Ma. The plutonic rocks include diorite, granodiorite, quartz monzonite, syenite, and granite, which contain variable amounts of biotite, clinopyroxene, hornblende, K-feldspar, magnetite-ilmenite, plagioclase, and quartz. The oldest intrusion was emplaced ~25 Ma followed by younger intrusion events at ~18 Ma and 11 to 8 Ma. Laboratory measurements of a small set of drill core plugs indicate these crystalline rocks have very high compressive strength, a porosity of 0.13%, and a matrix permeability of 0.3 microdarcies. High temperatures in the upper crust beneath this region may be related to the source of the Quaternary rhyolite domes and flows in the adjacent Milford Mountains.

Hydrothermal alteration is identified based on petrography and XRD analyses. Alteration is widespread, but weak, and is made up of quartz, illite, chlorite, mixed-layered clays, epidote, leucoxene, hematite, calcite, anhydrite, and K-feldspar, which partly replaced precursor minerals or was deposited into open spaces (Figure 3). Temperature-sensitive phases lack well-defined depth zonation, which suggest that most of the alteration formed during earlier periods of hydrothermal activity associated with Tertiary magmatism. Modern hydrothermal activity is responsible for steam-heated, acid alteration in the vicinity of fumaroles and steaming ground north of the Negro Mag fault, and silica sinter deposition along the Opal Mound fault.

Structure and Geophysics. - Deformation in the Milford FORGE area is the product mainly of two distinct tectonic events: middle Tertiary plutonism in east-west oriented belts including the Mineral Range granitic rocks, and late Tertiary to Recent, east-west oriented Basin and Range extension starting ~17 Ma. The younger faulting episode has produced predominantly north-south trending fault zones that define the horst-graben morphology. The Opal Mound fault is a prominent high-angle normal fault along the west side of Roosevelt Hot Springs that dips east and offsets surficial deposits of alluvium and silica sinter. Additional north-south trending normal faults are expected to occur in basement rocks to the west beneath the alluvial cover but are blind to the surface.

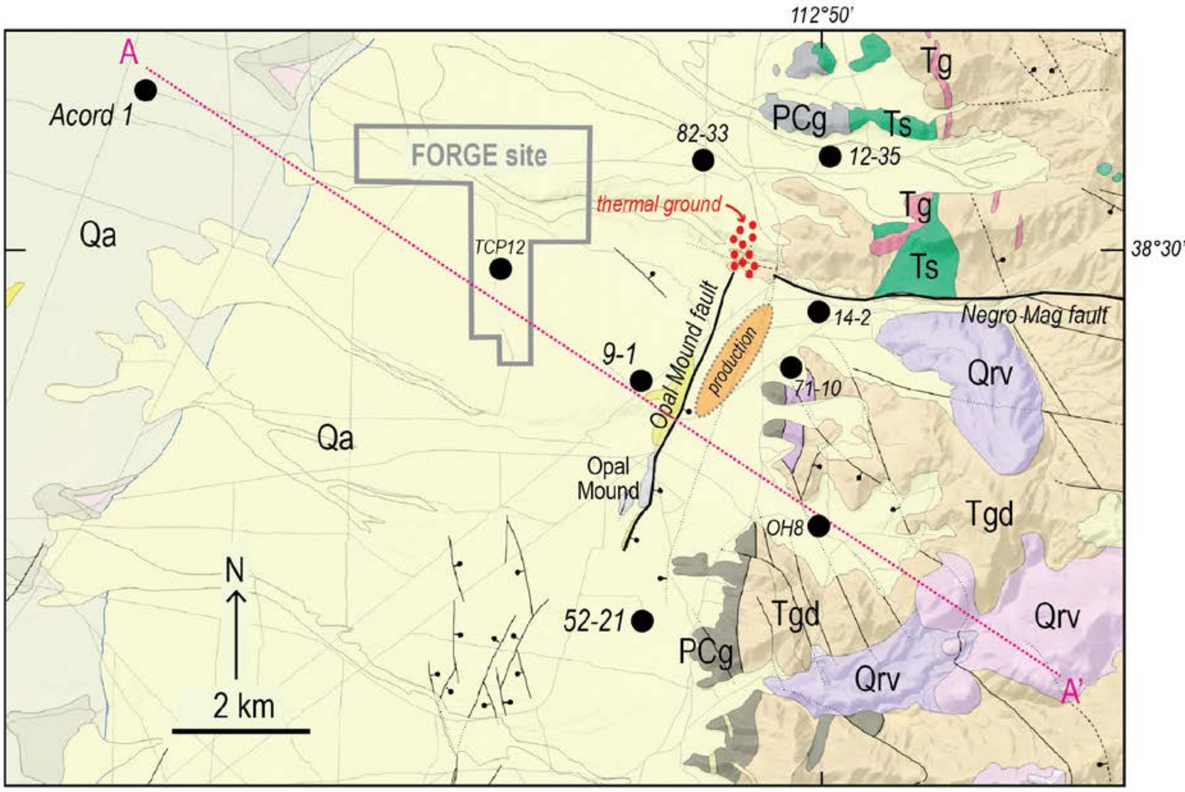

Figure 2. *Geologic map of the FORGE deep well site, Milford, Utah (Nielson et al., 1986; Hintze et al., 2003; Rowley et al., 2005; Kirby, 2012). For clarity, only a few of the many wells are shown; these are described later. Abbreviations for map units: Qa=Quaternary alluvium and claystone; Qrv=Quaternary rhyolite volcanic rock; Tgd=Tertiary granodiorite; Tg=Tertiary granite dike; Ts=Tertiary syenite; PCg=Precambrian gneiss.*

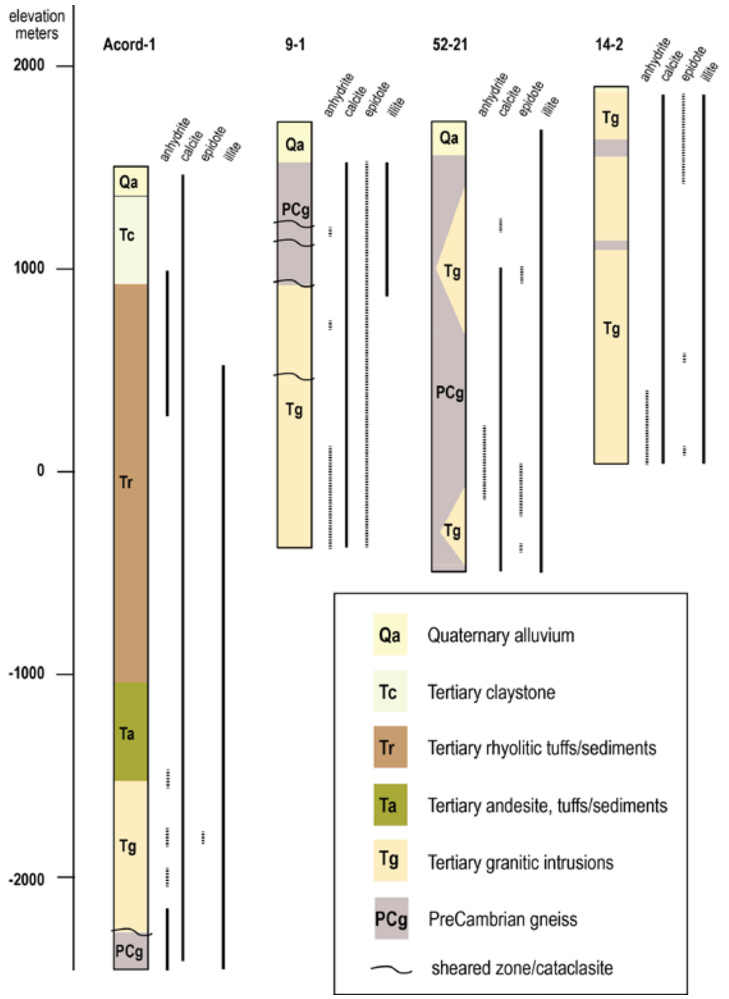

Figure 3. *Stratigraphic logs for four deep wells in the study area surrounding the FORGE deep well site, Milford, Utah. Sources of data: Acord-1 (Sweeney, 1980; Welch, 1980; Hintze and Davis, 2003; 9-1 (Glenn et al., 1980; Capuano and Cole, 1982); 52-21 and 14-2 (Glenn and Hulen, 1979; Capuano and Cole, 1982).*

East-west oriented faults also are important; they have been active in the late Tertiary but may have originated much earlier. Most prominent of these across the central Mineral Mountains is the Negro Mag fault (Figure 2), although numerous others exist defining an exposed E-W graben. Finally, lineament analysis shows that the crystalline rocks exposed in the Mineral Mountains exhibit densely spaced jointing with azimuths in diverse compass directions. The multi-phase tectonomagmatic deformation shaping the central Mineral Range area undoubtedly has affected the lithology below the FORGE deep drill site as well. Therefore the reservoir rock should respond favorably to stimulation and support development of a distributed, connected permeability structure.

Gravity and magnetotelluric (MT) data constrain the basement surface and depth to crystalline rock, and reflect a 3 km-deep basin within the regional Basin and Range geometry (Figure 4). The center is steep walled and V-shaped, and the axis is oriented north-south, perpendicular to Basin and Range extension. Outward and upward, the basement contact flattens to form a gently dipping surface that extends beneath the FORGE deep drill site, where the depth to crystalline basement varies from over 1000 m on the western side to about 500 m on the eastern side.

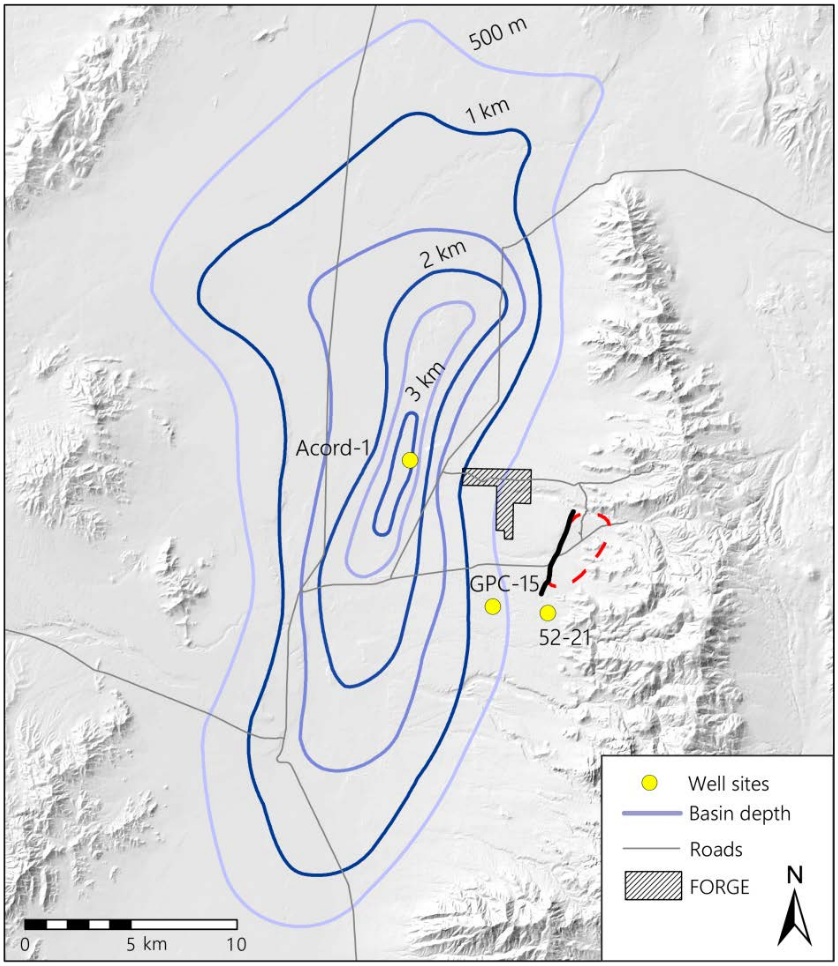

Figure 4. *Map of the basin depth model derived from geophysical data (Allis et al., 2016; Hardwick et al., 2016). The black shaded area indicates the location of the FORGE deep well site, the heavy black line is Opal Mound fault, the red dashed line is the Roosevelt Hot Springs hydrothermal system. The three "well sites" are where there are geophysical wireline logs that have been used in the interpretation.*

Thermal Regime. - The 80 thermal gradient wells (mostly less than 200 m depth) and more than 20 deep wells down to 3.8 km depth provide a rich dataset to characterize the thermal regime. The isotherms at 200 m depth delineate the high heat flow over the hydrothermal upflow zone of the Roosevelt Hot Springs system east of the Opal Mound fault, and the shallow outflow in the groundwater to the northwest (Figure 5). Interpretation of the heat flow regime, which is conductive west of the Opal Mound fault, allows prediction of the temperatures at up to 4 km depth (Figure 6 shows the isotherms at 3 km depth).

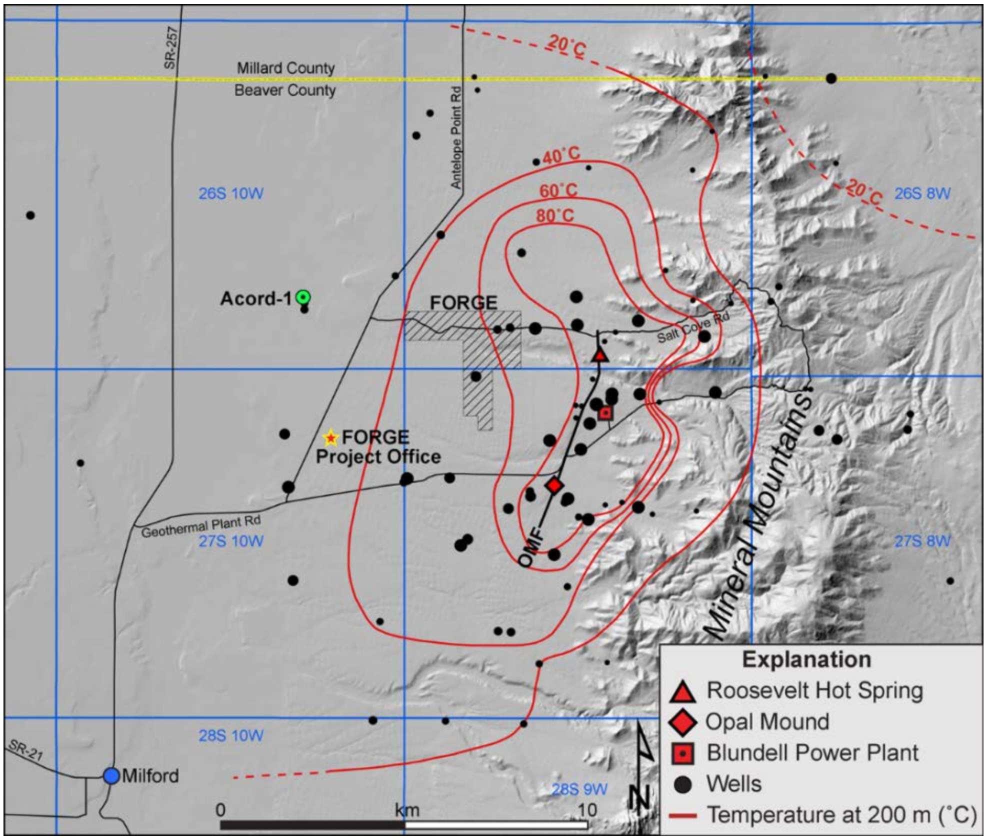

Figure 5. *Temperature at 200 m depth beneath and in the vicinity of the FORGE deep drill site. The size of the filled circle at each well location represents the degree of certainty of the temperature data, which constrain the geometry and positions of isotherms. The largest diameter circle represents wells greater than 200 m depth where the temperature was measured. The smallest diameter circle represents wells about 50 m deep requiring temperature extrapolation to depth. Toward the east, contours represent the temperature at 200 m below the 1830 m (6000 ft) above sea level (asl) datum, which is the onlap elevation of the alluvial fan against the Mineral Mountains. This allows the contours to be smoothed across the ridges and valleys, but requires that higher-elevation wells be extrapolated to greater depths (down to 405 m from the surface). Toward the west, the contours are at 200 m depth from the surface, and near SR-257 in the middle of the valley this is at about 1325 m asl (4345 ft asl; ground surface about 5000 ft asl or 1525 m asl). OMF is the Opal Mound fault.*

The thermal regime beneath the FORGE deep well site is highlighted in Figure 7. The predicted regime passes through the middle of the temperature-depth zone required by DOE in the FOA for the FORGE site. There are three deep wells (Acord-1, 9-1 and 82-33) surrounding the site, so uncertainties in the temperatures at likely reservoir depth are small (± 15°C). A NW-SE cross-section shows the relationship between granitic/gneissic bedrock and temperature (Figure 8). The granite/gneiss - basin fill contact is interpreted from gravity measurements. Logging of the Acord-1 well cuttings indicates a minor amount of andesite in the lower part of the basin fill interlayered with volcaniclastics and tuffs. Deviation of the FORGE deep wells toward the southeast is advocated at present, but final decisions on location and deviation will await the characterization research in Phase 2 of this project.

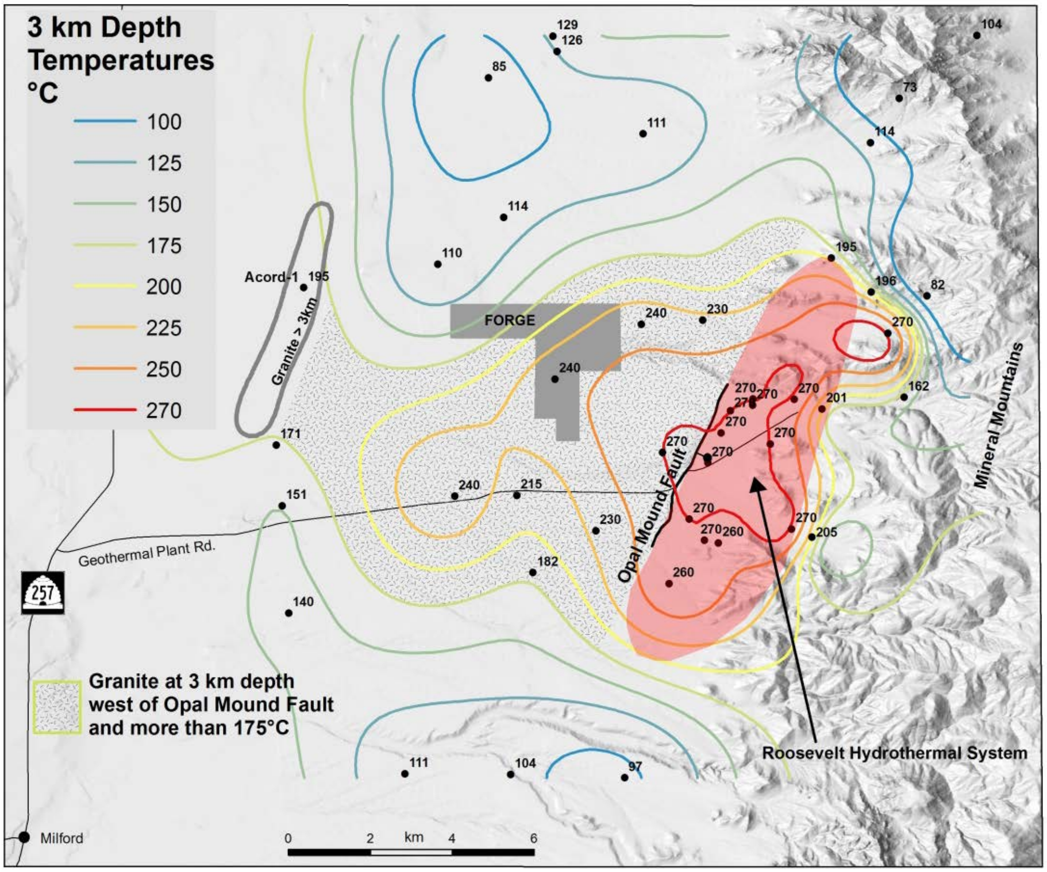

Figure 6. *Contours of temperature at 3 km depth derived from observations in deep wells and geotherms fitted to thermal gradient wells. Temperature contours have been smoothed using kriging options in ESRI's ArcMap software, and typically have a geostatistical mean uncertainty of ± 13°C depending on adjacent well data. The stipple highlights where granite at that depth is hotter than the minimum reservoir temperature constraint of 175ºC. Granite hotter than 175ºC extends significantly west and north of Acord-1, but has not been shown because of inadequate well control. The red shading shows the extent of the Roosevelt Hydrothermal System based on pressure measurements in deep wells.*

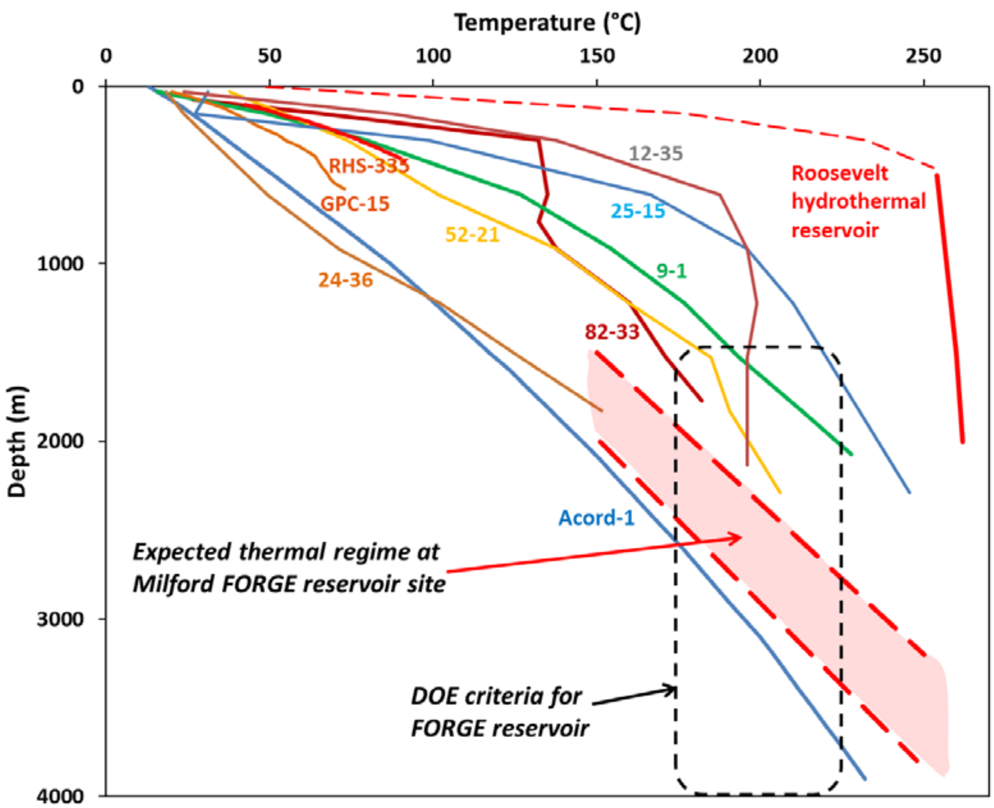

Figure 7. *Likely thermal regime at the FORGE deep drill site based on profiles in surrounding deep wells, and the thermal gradients in shallow wells. The two red dashed lines bound the likely uncertainties. The nearest wells to the site are 9-1 and 82-33, and are mostly in granite; the only wells mostly in basin fill are Acord-1, GPC-15 and RHS-335 (OH4). Productive wells tapping the Roosevelt hydrothermal system lie east of the Opal Mound fault with near-surface temperature profiles that follow boiling-point-for-depth conditions. The hydrothermal well profiles represent pre-development conditions; subsequent fluid production has lowered some of these profiles by more than 300 m (Allis and Larsen, 2012).*

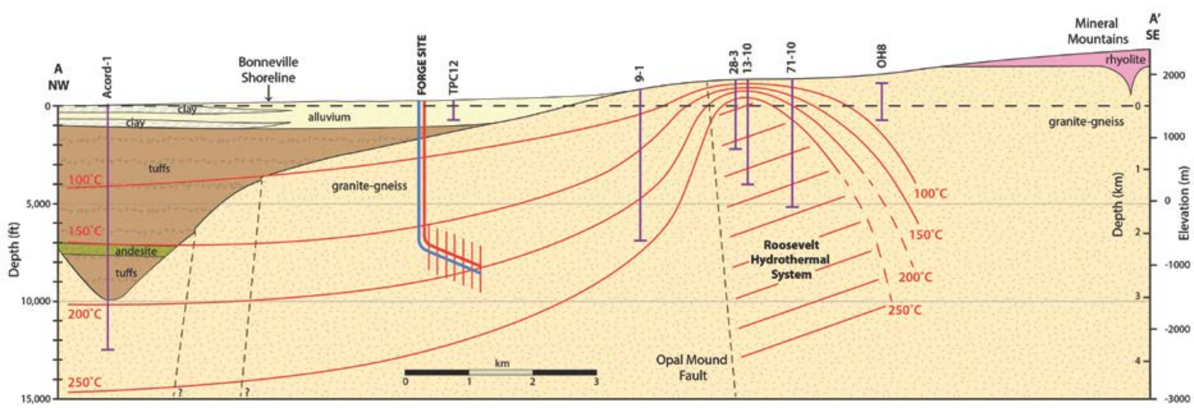

Figure 8. *Geologic cross section A-A' from Figure 2, showing the stratigraphy, structure, and thermal regime of the FORGE deep well site. The zero datum for the depth axes is at 1524 m (5000 ft) asl. Precambrian gneiss and Tertiary plutonic rocks are undifferentiated and isotherms are interpreted from well measurements.*

A 3D depiction of the thermal regime and its relation to the granitic bedrock is shown in Figure 9. A large area of anomalously high conductive heat flow, covering over 100 km^2, surrounds the FORGE deep well site. At 2000 and 4000 m depth beneath the FORGE deep well site, the rocks are expected to be hot, ranging from 175 to more than 250°C. The volume of crystalline basement rock having a temperature of more than 175ºC down to 4 km depth exceeds 100 km^3. The Opal Mound fault forms the eastern boundary to this large conductive thermal regime, separating it from Roosevelt Hot Springs to the east where convective hydrothermal heat flow prevails and covers a smaller area of ~10 km^2.

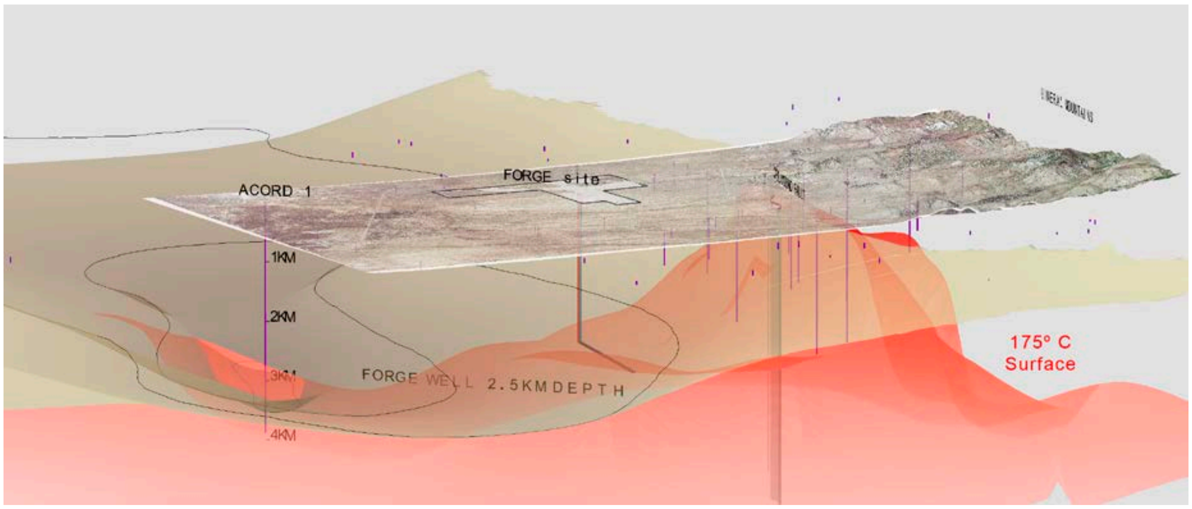

Figure 9. *Snapshot from the 3-D model showing both the granite surface and the 175°C surfaces. Blue lines are wells. No vertical exaggeration.*

Rock Strength. - Lab testing indicates crystalline basement rocks are very strong, with very low porosity and permeability. The compressive strength was measured at three separate confining pressures, 0, 2800, 8000 psi, giving average values of $2.8 x 10^4$, $6.0 x 10^4$, and $9.0 x 10^4$ psi, respectively. The porosity is 0.13% and the permeability, measured with state of the art equipment used for shales and mudstones, is 0.3 microdarcies. Thus it is likely that the porosity and permeability at the field-scale will be controlled by the presence or absence of fractures.

Seismicity and Stress. - Natural seismicity in the Milford region over the period 1965-2012 is relatively quiet in the vicinity of the FORGE deep wells site, with regional events associated with tectonic movements (Figure 10). Most natural seismicity is clustered near Milford (0.46 to 3.87 M), the site of the 4.1M earthquake in 1908, with diffuse low magnitude activity occuring beneath the Mineral Mountains. Based on borehole breakouts, earthquake focal mechanisms, and the orientations of faults and joints, the maximum compressive stress is oriented NNE-SSW (~000-010°) and the minimum compressive stress is oriented WNW-ESE (~090-100°) in the FORGE area, consistent with regional patterns of Basin and Range extension. There is no temporal correlation between seismicity near Roosevelt Hot Springs and production/injection over the last 30 years (Figure 11).

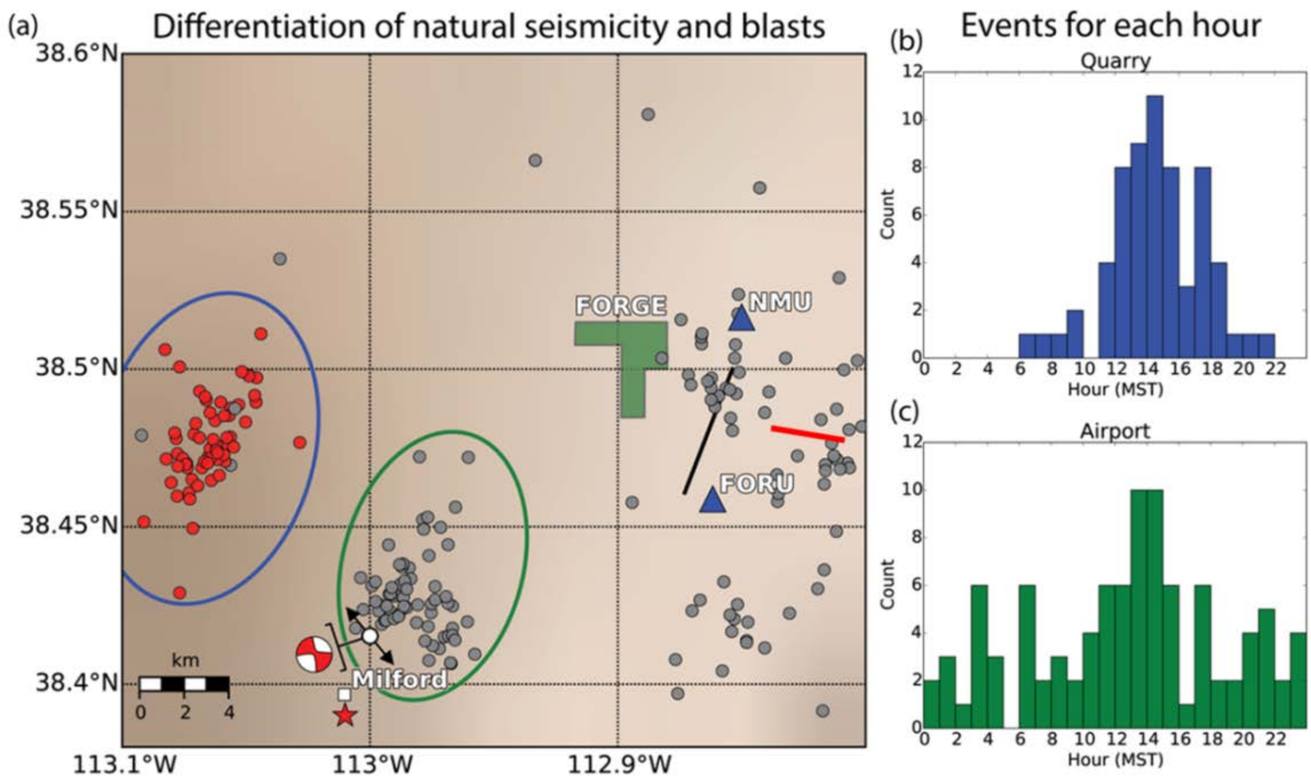

Figure 10. *Compilation of seismic events in the period 1965-2012. Grey-filled circles represent natural earthquakes due to tectonic stresses, and the red-filled circles represent quarry blasts. The ellipses refer to the events within the histograms. The blue triangles are seismic stations; the green polygon represents the FORGE deep drill site. The white square represents the center of Milford, UT and the red star is the epicenter of the 1908 earthquake, magnitude 4.1. The white circle represents the April 10, 1998MW 3.8 earthquake with T-axis and focal mechanism (displayed offset from T-axis). The red line between NMU and FORU is the earthquake swarm detected by Zandt et al. (1982). (b) shows the blasts as a function of time of day (these events occurring during daylight hours) and (c) shows that the natural seismicity occurs during all hours of the day; 62 of the 201 events displayed are blasts.*

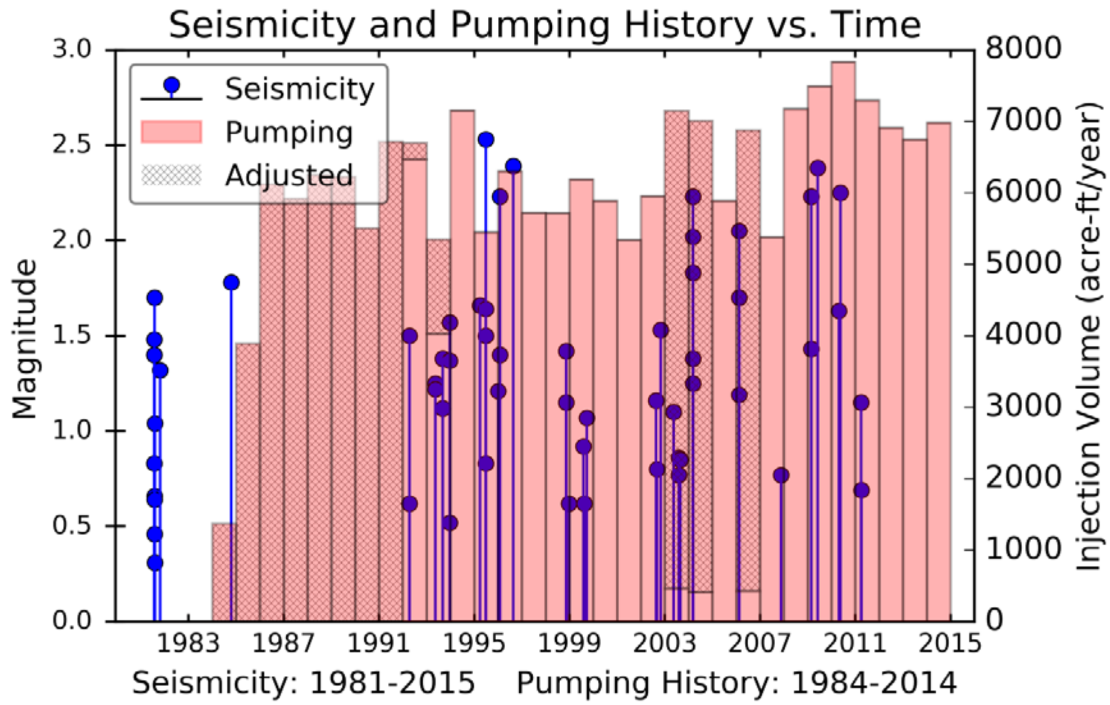

Figure 11. *Pattern of local seismicity (M > 1.5) during the 30 years of production and injection at the Blundell geothermal power plants. There is no obvious correlation between the development and seismicity. Volume of 6500 acre-ft is equivalent to 2 billion gallons or about 7.7 million metric tons.*

Hydrological Regime. – Uniform pre-production pressure profiles for deep wells in the Roosevelt Hot Springs system east of the Opal Mound fault indicate a hydrostatic pressure head that is up to 3 MPa higher than wells on the west side of the Opal Mound fault (Figure 12). This simply reflects the separation of the Roosevelt hydrological regime from that of Milford FORGE, with relatively impermeable rock under the latter as required for EGS.

The shallow groundwater regime across the FORGE deep well site is controlled by the west sloping potentiometric surface and an unconfined aquifer hosted in alluvial gravels. Geochemical data trace shallow hydrothermal outflow to the northwest and west, consistent with temperature profiles in gradient wells. Groundwater at pump rates of more than 100 gal/min is available from shallow wells towards the center of the north Milford valley. This groundwater is chemically benign, non-potable, and suitable for EGS heat transfer experiments.

With its heat content, pre-existing structure, favorable stress regime, land access from owners, available water, low environmental impact, deep knowledge base, and access to power transmission and markets, the Milford FORGE deep well site readily meets the DOE geoscientific criteria for development of an EGS laboratory.

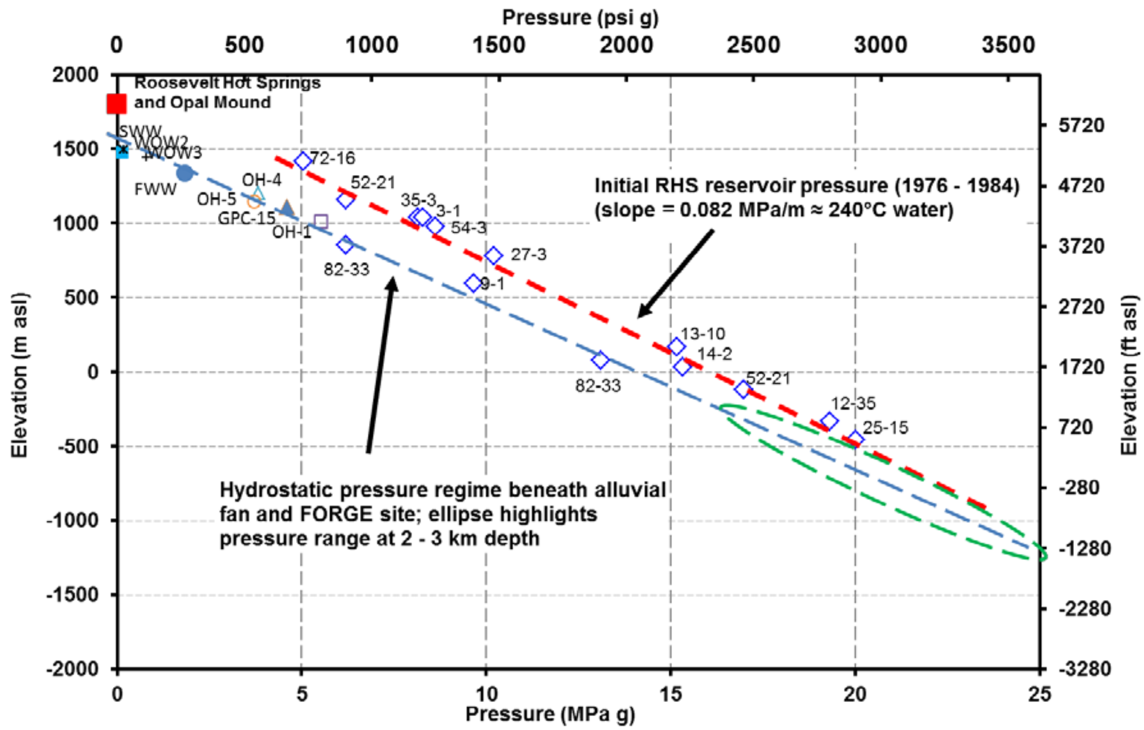

Figure 12. Pressure trends derived from wells in the Roosevelt Hot Springs hydrothermal system and in the wells west of the Opal Mound fault. Pressures in Roosevelt Hot Springs wells represent pre-production data (Faulder, 1994). Where no other data exist, the pressure control point is assumed to be at the mid-screen depth (elevation) or at total depth.

Lessons Learned – Milford FORGE Phase 1

1. New Thermal Data

When the FORGE FOA was released, we recognized that our proposed site had substantial thermal data. However, when additional downhole thermal data in reports, theses, published papers, and PacifiCorp-Energy's old box files were discovered during Phase 1, the magnitude of the exploration during the late 1970s became fully apparent. This site has a rich dataset of exploration data. At least five companies were drilling thermal gradient wells here competing to identify the best location for a power plant in addition to the DOE-supported research of the University of Utah. Unravelling the locations of these wells proved challenging. This was in the pre-GPS days when well locations were defined in terms of section descriptions and distances from section corners. With the help of air photos which showed access roads and in some places pull-offs where a rig could have drilled a well, over 90% of the wells were locatable. A small percentage (less than 10%) required closer scrutiny, and several wells had different well names, were a few hundred yards apart but with the same temperature profile, and had identical depths. In these cases we suspected there was just one well that was logged, with one company (perhaps illegally) accessing a competing company's well to gain a quick, cheap thermal gradient well. Discussion about this with one of the exploration geologists active at the Roosevelt Hot Springs KRGA at the time confirmed that moonlighting and cutting off padlocks on wellheads was not uncommon. We also found a letter on file from one company to another suggesting the sharing of thermal data, and the other company refusing to share. The exploration environment at that time was very competitive.

As the prospect activity focused down to one developer (Phillips Geothermal), the data from these wells was preserved, in large part due to the assistance in the DOE-Geothermal grant program supporting research into the hydrothermal characteristics of the resource. Many reports from these times are held in the Library at EGI (University of Utah). Although the wellfield operator has changed several times over the 30 years of power production, old box files in two containers at the Blundell power plant preserve much of the early exploration data. PacifiCorp-Energy has been very supportive in allowing us to search these files for relevant data.

The new thermal data discovered during Phase 1 have reduced uncertainties and confirmed that the Milford FORGE site is ideally suited to hosting the proposed EGS laboratory.

2. SITE Choice

At proposal time we recognized that a checkerboard pattern of land ownership in North Milford Valley could be a constraint in locating the best site for the FORGE project. To the northwest we have the FirstWind (SunEdison) wind farm, with the 3.8 km-deep Acord-1 well located between two wind turbine array lines (1 km apart), and several km to the east is the PacifiCorp-Blundell geothermal power facility. Three, widely-spaced sites for the FORGE laboratory were proposed – one at the Acord-1 well site (originally labeled “A”), another over 3 km to the east of on a Smithfield half section (“B”; section 31, near the eastern edge of a wind turbine line), and the third being 4 km south of Acord-1 on Smithfield’s section 11 (“C”), over 1 km south of the turbine arrays. We had support for the project from the surrounding landowners and permission to enter their property as part of the project. Both FirstWind and PacifiCorp supported the project as long as we didn’t interfere with or affect their operations.

As the thermal data for the site was assembled and reviewed, it became clear that although all three of the proposed locations appeared to meet the FORGE temperature-depth constraints, the best site was section 32 immediately east of site B, and largely owned by Utah State Institutional Trust Lands Administration (SITLA). This section had higher heat flow and temperatures, the granite surface was shallower, it was east of the wind turbine arrays, and still 4 km west of (and separate from) the hydrothermal system tapped by the Blundell production wells. In addition, this section has a very supportive landowner (a state government agency) whose mission is to generate revenue for its beneficiaries, primarily public schools in Utah (see http://trustlands.utah.gov/our-agency/what-are-trust-lands/). The Utah Geological Survey has worked with SITLA for many decades helping the agency identify resource potential in their 3.5 million acres. This close relationship helped SITLA recognize that a successful FORGE site offers a prospect of geothermal revenue in the future. There is no revenue being generated from this section at the moment.

From our initial proposal of three possible widely-spaced sites, we shifted our focus to a new 2 square mile target centered on Section 32 (primarily SITLA ownership), and two adjoining half-sections of Smithfield/Murphy-Brown. The original site C on a Smithfield section has become our preferred site for groundwater extraction when compared to Section 32, because of the shallower water level, cooler groundwater temperatures, proven well productivity, and its location on a future power line to the FORGE site (for powering pumps). The original site A at Acord-1 is still part of our project, and Smithfield are supportive of the project attempting to clean out that well so that it is available for testing tools at high temperature and pressure.

3. **Communication**

Phase 1 has confirmed the importance of the project having good communications systems. The value of keeping all stakeholders informed as the project proceeded was always considered important, and when a site visit was offered during Phase 1, all stakeholders expressed a wish to participate. A couple of stakeholders could not attend and have since confirmed that when a second site visit is organized, they would like to attend. At this stage we plan on a second site tour in late summer or fall after confirmation that the site has survived the down-select process for Phase 2.

Part of good external communications is also individual, face-to-face meetings with key stakeholders. During Phase 1, such meetings took place with SITLA, Smithfield, BLM, Beaver County, Milford High School, PacifiCorp Energy, FirstWind, Utah Division of Water Rights, Utah DEQ Division of Water Quality (and, of course, DOE Geothermal Office; see Stakeholder update). We realize that keeping the FORGE site website up to date is also critical as the project grows, and the public, or stakeholders, have questions about progress. The Milford High School has offered space for a seismometer on school grounds, and for a live display in a common area where kids can see local seismicity.

Internal communications systems for project participants are also going to be very important, especially as the project grows with numerous sub-contractors and researchers. Project managers quickly realized that with the amount of diverse data being compiled at this site during Phase 1, a spatial GIS system accessible to all participants was crucial (this was set-up at the UGS). Similarly, the numerous draft reports, publications, and related material that required input from many participants also required a private project website where material could be inspected, reviewed, and updated where appropriate (this was set-up at EGI). As the spread of participating researchers grows, this website will be an essential tool in keeping everyone up to date with progress. During Phase 2B with its emphasis on site characterization surveys, being aware of, coordinating, and ensuring adherence to environmental constraints will also be very important.

4. **Insights on New Infrastructure Costs**

Getting power and an adequate water supply to the FORGE deep well site are the main infrastructure issues. Initially, it was thought the biggest demand for water would be the hydrofracturing operations. The oil industry typically uses about 5 million gallons for multi-stage fracturing in a well, so having at least 3 million gallons of storage on site and a pumping capacity of up to 500 gallons per minute (gpm) seemed to fit the needs. This could be supplied by up to 3 large supply wells. The storage tanks could be (re)filled in about 4 days at 500 gpm. So an initial estimate of water requirement over multiple years was thought to be a water right of 50 acre-ft/y of non-consumptive use (16 million gallons per year). This was acquired while the proposal was being prepared.

However, it was realized during Phase 1 that there may be an ongoing water demand during circulation tests, mainly for cooling of the produced hot water prior to reinjection. Some hot water may be evaporated to assist with cooling, and the water loss is considered consumptive. Another form of cooling could be by mixing the circulating water with a similar flow rate of cool water (assuming the produced water is at close to 200°C), and the injection temperature will be less than about 100°C. If the circulating water flow is 200 gpm, and the flow test is sustained for 6 months, then the additional cooling water of about 200 gpm for six months is 50 million gallons or close to 150 acre-ft. This volume of water has to be continuously injected back into the groundwater regime beneath the site to keep the circulation flow rate in the deep wells constant. If there are losses into the granite, then additional make-up water is required. Clearly, being able to use considerably greater than 50 acre-feet per year of groundwater is desirable at the FORGE site.

The project has applied for replacement water rights for 250 acre-ft/year of non-consumptive use for geothermal purposes, and 50 acre-feet of consumptive use for general purposes, including "residential" use (bathroom and septic tank) in the project office (applications at: http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=71-5429 and http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=71-5430). In addition, the MOU with Murphy-Brown (Smithfield) grants an addition 50 acre-ft/year of free water, and the opportunity to purchase at $50/acre-ft an additional 150 acre-ft/y. Use of this water will require a change application. The Murphy-Brown water is designated as irrigation water, which means it is 62% consumptive and the remained is non-consumptive.

It is fortuitous that the north Milford Valley is one of very few water extraction regions of Utah which is still open to groundwater applications, including for geothermal use. Groundwater quality is the main reason that the south Milford Valley is heavily developed with irrigated crops and is closed to new allocations, whereas the north Milford Valley has not been developed. The groundwater in north Milford Valley is a mixture with geothermal water that flowed from the Roosevelt Hot Spring system, and is less suitable for crops.

The cost of the groundwater supply wells, pumps, the pipeline to the deep wellsite, and some nearby disposal wells will be part of the techno-economic analysis in Phase 2A.

A power line to supply pump power and related project needs at the deep wellsite will be about 6.5 miles length. A preliminary estimate from Rocky Mountain Power for a 480 V 200 amp line is about $600,000. The per-mile rate for an above-ground line is $84,000 per mile, and underground service is close to twice this. As with the water, more detailed costs will be part of the techno-economic analysis in Phase 2A.

5. Site Location in Energy Corridor

At the time of proposal preparation it was not fully appreciated how the FORGE site is strategically located in an energy corridor between the Rockies and southern California. There is a growing transmission infrastructure here, with PacifiCorp Energy commissioning the Sigurd – Red Butte line (crosses 500 m south of the FORGE site) and the Milford-Beaver line in the last 12 months. A 3000 MW HVDC line between Wyoming and southern California proposed by Transwest Express LLC (http://www.transwestexpress.net/) is waiting for Record of Decision from the BLM. This line parallels the existing IPP HVDC line (2400 MW) and is located about 10 km west of the FORGE site. The SunEdison 240 MW solar PV farm about 5 km to the west is expected to be commissioned this summer (2016), and the 306 MW windfarm adjacent to the FORGE site has been generating for several years. As mentioned earlier, the Blundell geothermal plants are 4 km east of the FORGE site. Finally, between the FORGE site and the Blundell plant is the 36 inch Kern River natural gas pipeline, serving 10 million customers in southern California.

The north Milford Valley is therefore a possibly unique microcosm of future energy generation and transmission with its renewable power generation, and the natural gas transmission. Peaking natural gas-fired power plants are often cited as the complement to variable wind and solar generation. The FORGE site offers a vision of what future geothermal power production can offer to this energy mix when tight hot granite is able to fractured allowing heat to be swept for emissions-free, base-load power generation.

Conclusions

Challenges

Accessing adequate surface area with a fracture network and guaranteeing long-term thermal extraction potential are the fundamental issues that have challenged all previous EGS projects. This starts with exploration and site characterization to ensure that the reservoir has the desirable characteristics, and that a fracture system can be developed by hydraulic stimulation. Even where an adequate reservoir is identified, drilling a highly deviated well into hot granite will challenge drilling technologies that are currently used. After the reservoir is accessed by drilling and the wells are completed for long-term integrity and isolation, stimulation technologies are a serious challenge.

All successful EGS projects (e.g., Raft River, Soultz-et-Foret, Desert Peak) are supported by a single fracture network. Our triaxial testing of the reservoir rock at the Milford site, combined with recent experience in South Korea where wellhead pressures exceeded 100 MPa (14,500 psi), demonstrate the difficulty of creating new fractures in strong, intact crystalline rock. Accordingly, a pre-existing fault-fracture mesh that will respond favorably to stimulation producing a connected permeability structure, as at Raft River, is an essential ingredient.

Managing the rate of thermal decline and heat transfer is just one of several critical challenges. Others include fluid circulation at low pressure and production for power generation, predicting and mitigating ground deformation and induced seismicity, and improving the tools used for sustaining, monitoring, and imaging the reservoir. These issues enfranchise requirements for improved exploration and reservoir characterization technologies, drilling and completion methods, stimulation protocols, reservoir management methods and surveillance, and surface facilities/operations.

New Technologies

The geothermal and petroleum communities have developed shared interests and there are numerous opportunities for technology transfer and adaptation (see letters of support below). Examples include horizontal or extended reach well technology – steering, rate of penetration, high temperature cementing, isolation technology (sliding sleeves, plug and perforation, coiled tubing), sophisticated simulations for fracturing and production, and reservoir management considerations. Bringing petroleum technologies into the geothermal industry provides opportunities for FORGE. It is somewhat ironic that some of these methodologies were applied in geothermal HDR operations long before they were routinely adopted in the petroleum industry. As a case in point stimulation techniques were first pioneered at the Los Alamos Hot Dry Rock project in the early 1980s, including microseismic monitoring, pumping large volumes of slickwater at high rates, and use of calcium carbonate as a fluid loss additive. With the exception of isolation technologies, this trip to the past is reminiscent of technologies adopted in recent years in the oilfield. How can FORGE re-enfranchise some of these methods, concepts, insights back into geothermal extraction? How can this be done effectively and safely and with limited environmental impact?

The Overarching Vision

Our goal is to achieve step-changing improvements over earlier EGS demonstrations. The Utah FORGE laboratory, consisting of 2 or more wells, will be established, and R&D projects designed to develop new tools for EGS development will be tested. The essential objectives of the project are to:

- Test and prove multistage stimulation technologies that are effective and environmentally benign,
- Create and image a network of appropriate fluid conductivity pathways interconnecting the wells,
- Circulate water through the stimulated fracture network for sufficient time to characterize heat exchange, and to undertake numerical simulations that model long term resource potential,
- Provide a facility where high-temperature logging and fracture imaging tools and equipment such as pumps can be tested, and expert teams can visit and test novel stimulation and heat exchange techniques,
- Provide a site that showcases to the public, stakeholders, and the energy industry that EGS technologies have the potential to contribute significantly to power generation in the future, and
- Provide educational and research opportunities at all levels from grade school to graduate programs.

FORGE Utah site offers a unique location in a desolate part of the state where sensitive flora and fauna are absent. The closest community is Milford (population of 1400), located 16 km from the site. Local support for renewable energy projects, including geothermal, biogas, wind, and solar, dates back more than three decades. The site is accessible year-round and has a well-developed infrastructure, and it is situated within a renewable energy corridor. The groundwater regime will provide a sufficient supply of water that is non-potable and that is not used for other agricultural activities or human consumption. The site has benefited from several decades of geothermal research focused on understanding the Roosevelt Hot Springs system. Geologic processes have created a large volume of hot crystalline rock (100 km^3) at drillable depths with suitable temperatures for EGS development. Long term seismic monitoring demonstrates the risk of induced seismicity is low. The analysis of all Phase I data show that technical and environmental risks are low and that the FORGE Utah site is exceptionally well suited for advancing all the technologies required for widespread EGS development.

CASA
EXPLORATION

1800 Post Oak Blvd., Suite 380 ° Houston, TX 77056 ° 832.325.2300

31 March 2016

Dr. Joseph Moore
Energy & Geoscience Institute
University of Utah
423 Wakara Way, Suite 300
Salt Lake City, UT 84108

RE: FORGE Utah Proposal to Department of Energy

Dear Dr. Moore:

As Chairman of the Energy & Geoscience Institute (EGI) Advisory Board, I am pleased to write this letter of interest to EGI in regard to your proposal to the United States Department of Energy related to developing a Frontier Observatory for Research in Geothermal Energy (FORGE) in Utah. Based on our review of the proposal and conversations with you, EGI Director Ray Levey, and Casa staff with related expertise, I understand that the objectives of FORGE research include R&D related to Enhanced Geothermal Systems (EGS). As the FORGE objective is to achieve step-changing improvements over earlier field techniques for engineered thermal reservoir development, Casa recognizes many of the same technologies could have parallel application for HPHT hydrocarbon reservoirs.

Among the many strengths EGI offers our company is the outstanding history of collaboration between varied players in the energy industry, with unique focus on producing high-value cost-shared research that answers the pertinent questions facing the industry. This research has continuously helped move the industry, and Casa Exploration, into the future. As Chairman of the EGI Advisory Board and CEO of one of EGI's Corporate Associate members, I see not only potential for success at EGI, but also the valuable contributions this relevant research brings to the industry's focus on HPHT hydrocarbon reservoirs.

We anticipate the R&D planned for FORGE will have cross-cutting applications to the oil and gas industry. Casa Exploration will likewise be very interested in the outcomes of this project.

Please keep me informed about your progress.

Sincerely,

Steve Bell
CEO
CASA Exploration

Via Emilia, 1
20097 San Donato Milanese (MI) - Italy
Tel. +39 02 520.1
eni.com

March 8, 2016

Dr. Joseph Moore
Energy & Geoscience Institute
University of Utah
423 Wakara Way, Suite 300
Salt Lake City, UT 84108

RE: EGI Proposal to the Department of Energy; "Frontier Observatory for Research in Geothermal Energy (FORGE) – Milford Site, Utah"

Dear Dr. Moore:

I am pleased to write this letter of interest to the Energy & Geoscience Institute in regard to your proposal to the United States Department of Energy related to developing a Frontier Observatory for Research in Geothermal Energy (FORGE) in Utah. We understand that the objectives include R&D related to Enhanced Geothermal Systems (EGS). The objective is to achieve step-changing improvements over earlier field techniques for engineered thermal reservoir development. We recognize many of the same technologies could have parallel application for HPHT hydrocarbon reservoirs. For example, directional drilling, advanced completion and stimulation techniques, reservoir simulation, and new generation logging would be multiple technology domains that would have direct application.

As you are aware, Eni has a long and successful history of collaboration with the Energy & Geoscience Institute in both the Geothermal and Fossil Energy fields and is a strong supporter of the cross-disciplinary nature of EGI's research and of EGI's unique geoscience and engineering expertise.

I or one of my colleagues would be pleased to consider supporting EGI's FORGE project in a Technical Review Capacity so that the industry has a voice in the project's direction. We anticipate the R&D planned for FORGE will have cross-cutting applications to the oil and gas industry and vice versa, Eni will be very interested in the outcomes of this project.

Please keep me informed about your progress.

Sincerely,

Dr. Jonathan Craig
Senior Vice President, Exploration & Unconventional Resources,
Eni Upstream,
Milan, Italy