

# SANDIA REPORT

SAND2016-8929

Printed September 2016

ORIGINALLY SUBMITTED FOR DOE REVIEW, April 2016

## Frontier Observatory for Research in Geothermal Energy: Phase 1 Topical Report Fallon, NV

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## 1. OVERVIEW OF PHASE 1 ACTIVITIES

The Department of Energy (DOE) Frontier Observatory for Research in Geothermal Energy (FORGE) is to be a dedicated site where the subsurface scientific and engineering community can develop, test, and improve technologies and techniques for the creation of cost-effective and sustainable enhanced geothermal systems (EGS) in a controlled, ideal environment. The establishment of FORGE will facilitate development of an understanding of the key mechanisms controlling a successful EGS. Execution of FORGE is occurring in three phases with five distinct sub-phases (1, 2A, 2B, 2C, and 3). This report focuses on Phase 1 activities.

During Phase 1, critical technical and logistical tasks necessary to demonstrate the viability of the Fallon FORGE Project site were completed and the commitment and capability of the Fallon FORGE team to execute FORGE was demonstrated. As part of Phase 1, the Fallon FORGE Team provided an assessment of available relevant data and integrated these geologic and geophysical data to develop a conceptual 3-D geologic model of the proposed test location. Additionally, the team prepared relevant operational plans for full FORGE implementation, provided relevant site data to the science and engineering community, engaged in outreach and communications with interested stakeholders, and performed a review of the environmental and permitting activities needed to allow FORGE to progress through Phase 3. The results of these activities are provided as Appendices to this report.

The Fallon FORGE Team is diverse, with deep roots in geothermal science and engineering. The institutions and key personnel that comprise the Fallon FORGE Team provide a breadth of geoscience and geoengineering capabilities, a strong and productive history in geothermal research and applications, and the capability and experience to manage projects with the complexity anticipated for FORGE. Fallon FORGE Team members include the U.S. Navy, Ormat Nevada Inc., Sandia National Laboratories (SNL), Lawrence Berkeley National Laboratory (LBNL), the United States Geological Survey (USGS), the University of Nevada, Reno (UNR), GeothermEx/Schlumberger (GeothermEx), and Itasca Consulting Group (Itasca). The site owners (through direct land ownership or via applicable permits)—the U.S. Navy and Ormat Nevada Inc.—are deeply committed to expanding the development of geothermal resources and are fully supportive of FORGE operations taking place on their lands.

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## 2. RESULTS

### 2.1. Geologic Model

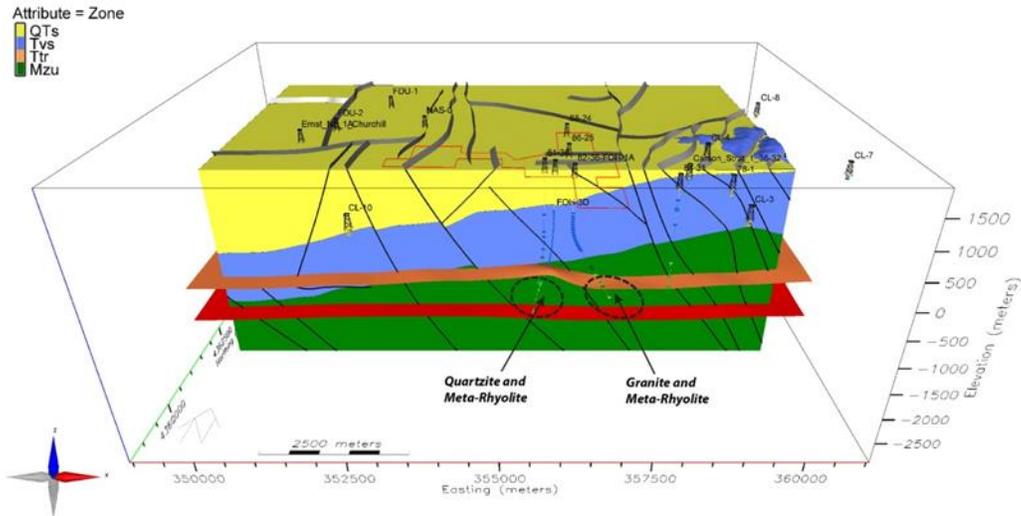
The proposed FORGE at Fallon, NV, covers ~4.5 km<sup>2</sup> in the southeastern part of the Carson Sink in west-central Nevada, ~12 km southeast of the City of Fallon. The Carson Sink is a large late Miocene to recent composite basin within the Basin and Range geologic province. This site was specifically selected for its extensional tectonic setting, abundance of available data, existing infrastructure, and documented temperatures, permeability, and lithologic composition of target test zones in crystalline basement beneath the basin. The site is located on two parcels that include land owned by the Naval Air Station Fallon (NASF) and leased and owned by Ormat Nevada, Inc. In addition, about 40 km<sup>2</sup> of surrounding lands are open and available for monitoring and instrumentation activities. Existing facilities at the Fallon FORGE site include an excellent network of roads, abundant wells, available storage for equipment and supplies at the NASF, and an established infrastructure for electrical and water resources, all of which will facilitate significant research and development activities. The nearby communities of Fallon and Reno also provide superior infrastructure and research facilities for this project. A total of 12 geothermal wells and 34 temperature gradient holes have been drilled for geothermal exploration within the NASF and Ormat lease area. This includes 7 geothermal wells and 4 temperature gradient holes on the FORGE site and 5 geothermal wells and 30 temperature gradient holes within the NASF and Ormat monitoring areas.

Multiple preexisting data sets were reviewed to characterize the stratigraphic and structural setting of the area and develop a 3D conceptual geologic model. Available geologic data sets included detailed geologic maps, >14,000 m of cuttings and core, petrographic data, borehole imaging of fractures, fault kinematic information, down-hole temperature logs, fluid geochemistry, and well flow tests. In addition, available geophysical data sets included detailed gravity, regional magnetic, magnetotelluric, seismologic, and ~270 km of seismic reflection profiles. Data quality was generally good with relatively low uncertainty. Based on synthesis of the above data sets, a 3D geologic model was developed for the Fallon FORGE site and immediate surroundings, incorporating 100 km<sup>2</sup> to a depth of 3.8 km. Details associated with the model are provided in the Conceptual Geologic Model provided in Appendix A. The 3D model depicts the major stratigraphic and structural relations, the 175 to 225°C thermal window for FORGE, and location and volume of potential EGS reservoirs. In descending order, the main stratigraphic units in the area include: (1) Late Miocene to Quaternary basin-fill sediments up to 1.5 km thick, (2) Miocene volcanic and lesser sedimentary rocks (0.7-1.1 km thick), and (3) Mesozoic basement consisting of Triassic-Jurassic metavolcanic and metasedimentary rocks intruded by Jurassic-Cretaceous granitic plutons. Four wells in the area penetrate the entire Neogene section and terminate in Mesozoic basement. The seismic reflection profiles and gravity models indicate that the site occupies a broad, gently west-tilted fault block or half graben, which is cut by widely spaced (~0.4-3.5 km), northerly striking, primarily east-dipping normal faults, all with less than ~200 m of relative displacement. Borehole imaging of drilling induced fractures and fault kinematic data from nearby bedrock exposures indicate an extensional stress regime and a WNW-trending extension direction. Quaternary faults have not been observed within the proposed FORGE site.

The documented temperatures, permeability, lithologic composition of potential reservoirs, and structural setting demonstrate that the Fallon FORGE site contains a sufficient volume of rock

that is within the criteria specified for FORGE, while also residing within a favorable stress regime with no evidence of an active hydrothermal system. Requisite temperatures of 175 to 225°C are attained between required depths of 1.5 to 4 km, as evidenced by down-hole temperature logs. Cuttings and core demonstrate that crystalline rocks abound in the Mesozoic basement (e.g., granite, quartzite, and metavolcanic rocks) at these depths. Flow testing of wells, a relatively simple Cenozoic structural setting, and high electrical resistivity values together indicate low permeability within the basement rocks. Borehole imaging and modeling of the stress regime further suggest that the basement contains abundant N- to NNE-striking preexisting fractures, which approximately parallel  $S_{Hmax}$  and are therefore favorably oriented for stimulation. High extensional strain rates in the area are also conducive to increasing permeability through reactivation of shear fractures during hydraulic stimulation. Further, multiple features indicate the absence of an active hydrothermal system, including lack of permeability encountered in wells, lack of convective temperature profiles, lack of prominent shallow thermal anomalies, lack of Quaternary faults, lack of a favorable structural setting for geothermal activity, lack of surface hot springs or steam vents, and no indication of paleo-hot spring activity, such as sinter or travertine. There are at least three possible, competent target formations for stimulation, incorporating  $>3 \text{ km}^3$  in the Mesozoic basement: (1) Triassic to Jurassic felsic metavolcanic rocks, (2) Jurassic quartzite, and (3) Jurassic to Cretaceous granitic intrusions.

In summary, while additional data will further refine the model, the Fallon site is an ideal location for FORGE from both a regional and local perspective. On a local scale, key FORGE criteria are met at Fallon, specifically requisite temperatures (175-225°C) between the required depths (1.5-4 km) in competent crystalline lithologies with low permeability in a favorable stress regime and no evidence of an active hydrothermal system. On a regional scale, Fallon is experiencing relatively high strain rates, occupies part of an extensional basin (half graben) characteristic of most of the Basin and Range province, and resides in an amagmatic setting, which epitomizes the bulk of the existing geothermal systems and, more appropriately, potential EGS development sites within the Great Basin region. We therefore conclude that Fallon is an ideal location for a field laboratory dedicated to EGS research.



**Figure 1. 3D model of potential EGS reservoirs in Mesozoic crystalline basement rock, including meta-rhyolite, quartzite, and granite in the central to eastern parts of the proposed FORGE site at Fallon. Several deep wells in this area provide lithologic, thermal, and permeability data for these volumes. These reservoirs lie between the 175°C and 225°C isotherms, as shown by the orange and red planes projecting out of the model, respectively. Note the widely spaced faults and relatively coherent structural blocks between the faults lying at the requisite depths and temperatures for development. The Mesozoic basement in this area is characterized by low permeabilities, as evidenced by well tests and high resistivity values.**

## 2.2. NEPA

The proposed Fallon FORGE project area is approximately 1,115 acres (387 Ormat leased or owned, 728 NASF) within and adjacent to the NAS Fallon (NASF) and Ormat lease areas. The total acreage for monitoring is 9,856 acres (3,842 Ormat leased or owned plus 6,014 NASF, exclusive of the main FORGE site and areas of no surface occupancy). Ormat has three BLM leases (NVN-079104, NVN-079105, NVN-079106) that have been unitized under the Bunejug Unit Agreement and two parcels of purchased private land.

Two NEPA documents serve as the primary foundation for permitting and additional environmental and cultural work required at the Fallon FORGE site: the Salt Wells EIS (OEPC Control Number FES 11-12) and the NAS Fallon Programmatic EIS.

The Salt Wells EIS (OEPC Control Number FES 11-12) was completed in 2011 (as was the previous 2008 Environmental Assessment) to support geothermal development work at the Salt Wells Known Geothermal Resources Area (KGRA) and focused on private and leased grounds in the eastern Carson sink. It provides NEPA analysis for exploration and development of a geothermal well field, power plant, and transmission line on private and leased properties. All of the land outside the NAS Fallon fence-line and included in the Fallon FORGE site was covered under this EIS. The Navy was a cooperating agent but not a signatory on this 2011 EIS.

The NAS Fallon Programmatic EIS served a similar purpose and includes all developable lands inside the NAS Fallon fence line. In March, 1991 NAS Fallon (NASF) completed the Programmatic EIS (PEIS) for Geothermal Energy Development, NASF. The purpose of the PEIS was to support geothermal exploration and proposed development activities at NAS Fallon. In 2005, a 50-year development contract (N62473-06-C-3021) was awarded by the Navy to

Ormat Nevada Inc. to develop and sell power from a geothermal plant to be constructed on NAS Fallon. The NAS PEIS was the supporting environmental document allowing this agreement. This contract was mutually dissolved in 2012 because Ormat determined through deep drilling that the postulated hydrothermal resource in basement rocks beneath NAS Fallon did not exist.

Environmental analyses have been conducted by the BLM and Navy. The Exploration EA completed in 2008 and Utilization EIS completed July 2011 (OEPC Control Number FES 11-12) provide NEPA analysis for exploration and development of a geothermal well field, power plant, and transmission line on private and BLM properties. The Navy's PEIS for Geothermal Energy Development at NAS Fallon provides the same level of analysis on NAS Fallon property. The Fallon FORGE team believes that these documents are sufficient to support the commencement of operations at the Fallon FORGE site. While the Navy will need to complete an internal evaluation of all of these documents before this work will commence on the Navy-owned land, the Navy acknowledges that data generated during both the EIS processes and other activities on base are sufficient for completion of NEPA requirements on Navy land in support of FORGE. The Navy is committed to working with BLM to complete all NEPA-related work on NAS Fallon property before the close of Phase 2A. As evidence that a site development pathway exists, numerous wells within and immediately surrounding the proposed Fallon FORGE site have been permitted previously. An Environmental Information Synopsis is provided in Appendix C.

### **2.3. Plan Development**

Associated with Phase 1 activities, six separate planning documents were prepared. These include the Fallon FORGE:

- Data Dissemination and Intellectual Property Plan
- Communications and Outreach Plan
- Sample and Core Curation Plan
- Preliminary Induced Seismicity Mitigation (PISM) Plan
- Environmental Safety and Health (ES&H) Plan
- Research and Development Implementation Plan

Each of these plans, inventories of data used in the development of the geologic model, data uploaded to the GDR, and permitting data are provided as appendices. Additionally, an update to the team's stakeholder engagement is included as Appendix H.

During Phase 1, the Fallon FORGE team developed its plans through careful thought and extensive discussion. The process of disseminating FORGE data in a manner that ensures data integrity and distribution to the community in a timely manner requires careful consideration, as addressed in the Data Dissemination Plan. The importance of communication and outreach to stakeholders cannot be underestimated and as the Communications and Outreach plan shows, there is a broad community that must be engaged as FORGE moves forward. The Sample and Core Curation Plan was developed on the shoulders of giants, with the processes used at the San Andreas Fault Observatory at Depth (SAFOD) serving as model for the collection, preservation, and distribution of physical samples obtained at FORGE. While a final Induced Seismicity Mitigation Plan (ISMP) will be developed in Phase 2, the information gathered to date and

described in the Preliminary ISMP indicates a very low risk of any significant impact related to induced seismicity that would occur during operations at the Fallon FORGE site. Safety of the worker and the environment is paramount in the execution of FORGE. DOE requires that all work performed by the Department and its contractors follow a broad set of requirements for Integrated Safety Management (ISM). The ES&H plan described in Appendix K complies with this DOE requirement and is structured to design or engineer safety of the worker and the environment into the execution of FORGE. The vision for FORGE is a dedicated Enhanced Geothermal Systems (EGS) field laboratory and a complementary R&D program that focuses on the science and technology necessary to bring the EGS concept to fruition and ultimately lead to commercialization. The Research and Development plan, provided in Appendix L, describes our team's plan and vision for FORGE, the structure under which site activities will be conducted, the process for issuing and managing R&D solicitations, interactions with DOE and the Science and Technology Analysis Team (STAT), and dealing with conflicts of interest.

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### **3. LESSONS LEARNED**

During Phase 1, at least two significant lessons were learned by members of the team. The first being the importance of communication, both between team members and with interested stakeholders, is critically important to project success. Of particular note with respect to stakeholder interaction is the need to explain stimulation activities that are integral to the development of EGS. More than any time in the past, the issue of “fracking” (the spelling reflects that of the press) is now on the broader public’s radar. Making the distinction between oil & gas stimulation activities and those planned at FORGE is vital to public acceptance of FORGE. Our interactions with local stakeholders were quite positive; however, the Fallon FORGE team knows it must remain vigilant and engaged to maintain excellent relations with the community of Fallon.

The second lesson learned is that achieving the goals of FORGE will not come cheap. Working in the subsurface is neither easy nor inexpensive. Within a constrained budget, the selection of drillhole locations, construction methods, and number of holes (i.e., production, injection, monitoring, and test holes) needs to be carefully considered. Drilling will be the second largest expenditure (after competitive R&D solicitations) during FORGE operations. A robust geologic model becomes even more important as it will constrain targeting of wells intended for stimulation. Further, the resource depth will have a significant impact on drilling cost and, therefore, on what FORGE can accomplish with fixed annual budgets. Additionally, because of real-world budgetary constraints it is imperative to identify and focus on the most relevant variables specific to understanding and implementing EGS development and breaking down existing barriers to development—that will be a major charge for the Science and Technology Analysis Team.

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## 4. CONCLUSION

The vision for FORGE is a dedicated EGS field laboratory and a complementary R&D program that focuses on the science and technology necessary to bring the EGS concept to fruition and ultimately lead to commercialization. This vision has driven the planning associated with Phase 2 and Phase 3 of the Fallon FORGE team.

During Phase 2A, 2B, and 2C, the Fallon FORGE site will be instrumented and readied to test new technologies and techniques in Phase 3. In Phase 2A, an Environmental Information Volume will be completed while a schedule to complete the NEPA process and obtain required permits will be completed. Additionally, preliminary telemetered seismic monitoring of the site will be deployed to complement existing seismic monitoring activities at the Fallon FORGE site. During Phase 2B all reviews, permits, and approvals initiated in Phase 2A will be obtained in accordance with NEPA and other local and state regulations. It is anticipated that these permits will be obtained early in Phase 2B and additional site characterization allowed by NEPA and applicable permits to begin. Phase 2B will also include the completion of the Induced Seismicity Mitigation Plan that will incorporate recorded site MEQ data and associated analyses into a Probabilistic Seismic Hazard Analysis, Criteria for Damage and Vibration, and Mitigation Actions for field testing. In 2C the site is brought to readiness for FORGE implementation through, at a minimum, additional surface and subsurface site characterization, deployment of high resolution seismic monitoring, geologic model refinement, and reservoir modeling. Additionally, a Science and Technology Analysis Team (STAT) will be assembled to provide technical guidance to the FORGE team and to ensure DOE objectives are incorporated in FORGE execution. As a result of working with the STAT to assess current technology, establish technical baseline information and performance metrics for FORGE work, and review the FORGE implementation plan, topics for the first round of competitive solicitations will be developed and a draft solicitation produced. Where applicable and appropriate, DOE may elect to have the Fallon FORGE team incorporate testing of methods and tools developed by separately funded DOE researchers into FORGE activities.

Upon entering Phase 3 of the project, the Fallon FORGE site will move toward full implementation, and at least two full-diameter wells will be constructed at appropriate sites, incorporating directional and extended-reach drilling techniques as needed to best take advantage of local geological conditions (e.g., rock types, geologic structures, and in-situ stress state) determined in earlier phases. After baseline testing of each well, the subject rock mass will be stimulated to create an operating reservoir, and testing will be performed to characterize reservoir extent, hydraulic characteristics, and heat-exchange performance. Based on results of these analyses, additional stimulations will then be designed, executed, and characterized as needed. Alternative and experimental stimulation techniques will be employed as available. The project will endeavor to create the most efficient and sustainable EGS to date that can serve as a prototype for EGS development elsewhere. Alongside these EGS development efforts, R&D directed toward EGS development and subsurface science and engineering will be supported through an expansive and competitive R&D program open to the broader scientific and engineering community. To the extent practicable, existing wells at the Fallon FORGE site will be used to support these R&D efforts and additional fit-for-purpose wells will be constructed as R&D requirements evolve.

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## **APPENDIX A. CONCEPTUAL GEOLOGIC MODEL**

# CONCEPTUAL GEOLOGIC MODEL

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Fallon, NV

## NAS FALLON



*Geothermal Research  
Observatory*

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# CONCEPTUAL GEOLOGIC MODEL

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Fallon, NV

## 1 EXECUTIVE SUMMARY

The proposed Frontier Observatory for Research in Geothermal Energy (FORGE) at Fallon, NV, covers ~4.5 km<sup>2</sup> in the southeastern part of the Carson Sink in west-central Nevada, ~12 km southeast of the City of Fallon. The Carson Sink is a large late Miocene to recent composite basin within the Basin and Range province. This site was specifically selected for analysis of its suitability for FORGE due to its extensional tectonic setting, abundance of available data, existing infrastructure, and documented temperatures, permeability, and lithologic composition of target test zones in crystalline basement beneath the basin. The site is located on two parcels that include land owned by the Naval Air Station Fallon (NASF) and leased and owned by Ormat Nevada, Inc. In addition, about 40 km<sup>2</sup> of surrounding lands are open to monitoring and instrumentation activities. Existing facilities at the Fallon FORGE site include an excellent network of roads, abundant wells, available storage for equipment and supplies at the NASF, and an established infrastructure for electrical and water resources, all of which will facilitate significant research and development activities. The nearby communities of Fallon and Reno also provide superior infrastructure and research facilities for this project. A total of 12 geothermal wells and 34 temperature gradient holes have been drilled for geothermal exploration within the NASF and Ormat lease area. This includes 7 geothermal wells and 4 temperature gradient holes on the FORGE site and 5 geothermal wells and 30 temperature gradient holes on the NASF and Ormat monitoring areas.

Multiple preexisting data sets were reviewed to characterize the stratigraphic and structural setting of the area and develop a 3D conceptual geologic model. Available geologic data sets included detailed geologic maps, >14,000 m of cuttings and core, petrographic data, borehole imaging of fractures, fault kinematic information, down-hole temperature logs, fluid geochemistry, and well flow tests. In addition, available geophysical data sets included detailed gravity, regional magnetic, magnetotelluric, seismologic, and ~270 km of seismic reflection profiles. Based on synthesis of the above data sets, a 3D geologic model was developed for the Fallon FORGE site and immediate surroundings, incorporating 100 km<sup>2</sup> to a depth of 3.8 km. The 3D model depicts the major stratigraphic and structural relations, the 175 to 225°C thermal window for FORGE, and location and volume of potential EGS reservoirs. In descending order, the main stratigraphic units in the area include: (1) Late Miocene to Quaternary basin-fill sediments up to 1.5 km thick, (2) Miocene volcanic and lesser sedimentary rocks (0.7-1.1 km thick), and (3) Mesozoic basement consisting of Triassic-Jurassic metavolcanic and metasedimentary rocks intruded by Jurassic-Cretaceous granitic plutons. Four wells in the area penetrate the entire Neogene section and terminate in Mesozoic basement. The seismic reflection profiles and gravity models indicate that the site occupies a broad, gently west-tilted fault block or half graben, which is cut by widely spaced (~0.4-3.5 km), northerly striking, primarily east-dipping normal faults, all with less than ~200 m of displacement. Borehole imaging of drilling induced fractures and fault kinematic data from nearby bedrock exposures

indicate an extensional stress regime and a WNW-trending extension direction. Quaternary faults have not been observed within the proposed FORGE site.

The documented temperatures, permeability, lithologic composition of potential reservoirs, and structural setting demonstrate that the Fallon FORGE site contains sufficient rock volumes well within the criteria specified for FORGE, while also residing within a favorable stress regime with no evidence of an active hydrothermal system. Requisite temperatures of 175 to 225 °C are attained between required depths of 1.5 to 4 km, as evidenced by down-hole temperature logs. Cuttings and core demonstrate that crystalline rocks abound in the Mesozoic basement (e.g., granite, quartzite, and metavolcanic rocks) at these depths. Flow testing of wells, a relatively simple Cenozoic structural setting, and high electrical resistivity values together indicate low permeability within the basement rocks. Borehole imaging and modeling of the stress regime further suggest that the basement contains abundant N- to NNE-striking preexisting fractures, which approximately parallel SHmax and are therefore favorably oriented for stimulation. High extensional strain rates in the area are also conducive to increasing permeability through reactivation of shear fractures during hydraulic stimulation. Further, multiple features indicate the absence of an active hydrothermal system, including lack of permeability encountered in wells, lack of convective temperature profiles, lack of prominent shallow thermal anomalies, lack of Quaternary faults, lack of a favorable structural setting for geothermal activity, lack of surface hot springs or steam vents, and no indication of paleo-hot spring activity, such as sinter or travertine. There are at least three possible, competent target formations for stimulation, incorporating >3 km<sup>3</sup> in the Mesozoic basement: (1) Triassic to Jurassic felsic metavolcanic rocks, (2) Jurassic quartzite, and (3) Jurassic to Cretaceous granitic intrusions.

In summary, the Fallon site is an ideal location for FORGE from both a regional and local perspective. On a regional scale, it is experiencing relatively high strain rates, occupies part of an extensional basin (half graben) characteristic of most of the Basin and Range province, and resides in an amagmatic setting, which epitomizes the bulk of the geothermal systems within the Great Basin region. On a local scale, key FORGE criteria are met at Fallon, specifically requisite temperatures (175-225°C) between the required depths (1.5-4 km) in competent crystalline lithologies with low permeability in a favorable stress regime and no evidence of an active hydrothermal system. We therefore conclude that Fallon is an ideal location for a field laboratory dedicated to EGS research.

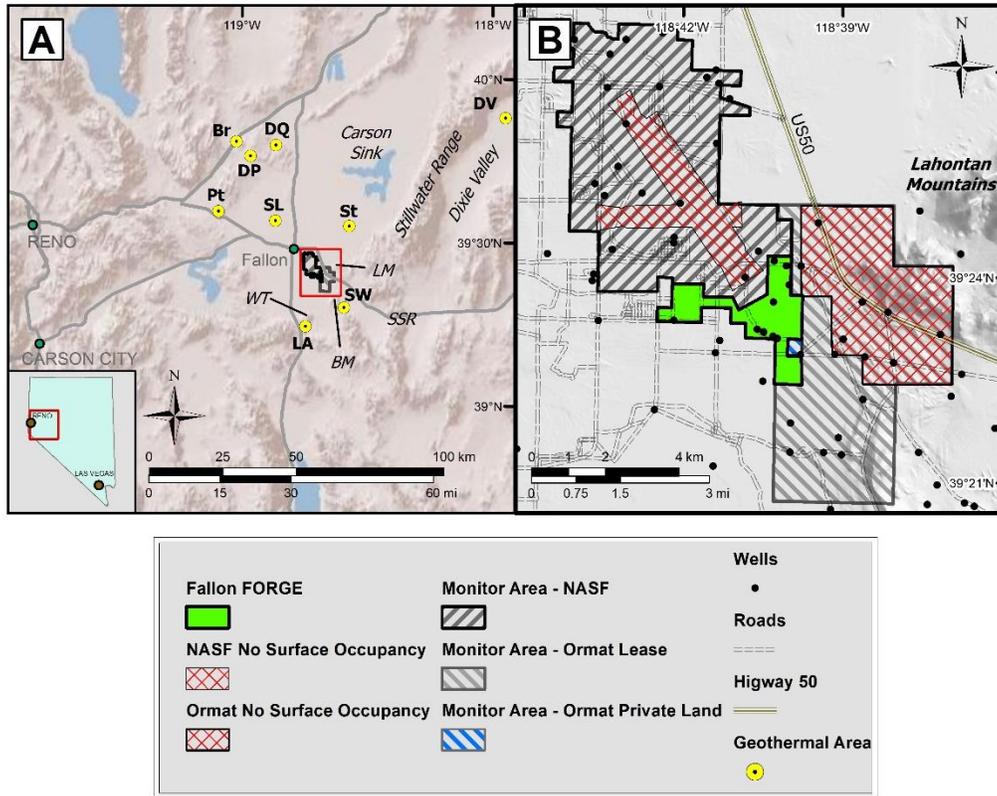
## 2 INTRODUCTION

The Frontier Observatory for Research in Geothermal Energy (FORGE) project offers a unique opportunity to develop the technologies, techniques, and knowledge needed to make enhanced geothermal systems (EGS) a commercially viable electricity generation option for the USA. The objective of this project is to establish and manage FORGE as a dedicated site, where the subsurface scientific and engineering community will be eligible to develop, test, and improve new technologies and techniques in an ideal EGS environment. This will allow the geothermal and other subsurface communities to gain a fundamental understanding of the key mechanisms controlling EGS success, in particular how to generate and sustain fracture networks in the spectrum of basement rock formations using different stimulation technologies and techniques. This critical knowledge will be used to design and test methodologies for developing large,

economically sustainable heat exchange systems, thereby paving the way for a rigorous and reproducible approach that will reduce industry development risk. Essential to this process is a comprehensive site for characterization, monitoring instrumentation, and data collection that will capture a higher-fidelity picture of EGS creation and evolution processes than any prior demonstration. A dedicated FORGE allows for the highly integrated comparison of technologies and tools in a controlled and well-characterized environment, as well as the rapid dissemination of technical data to the research community, developers, and other interested parties.

The objective of this document is to describe available geological, geophysical, and geochemical data for the proposed FORGE site at Fallon, Nevada, and integrate these data sets into a comprehensive, 3D conceptual geologic model for the site. The proposed Fallon FORGE site lies within and adjacent to the Naval Air Station Fallon (NASF) ~12 km southeast of the town of Fallon, Nevada, in the broad Carson Sink basin in west-central Nevada (Figure 1). Fallon was specifically selected for analysis of its suitability for FORGE due to its extensional tectonic setting, abundance of available data, existing infrastructure, and documented temperatures, permeability, and lithologic composition of potential reservoirs in crystalline basement beneath the basin, as described in detail below. All of these attributes facilitate development of a site dedicated to testing and improving new EGS technologies and techniques by the subsurface scientific and engineering community.

Previously completed geologic, geophysical, and geochemical studies in the region, as well as ongoing research projects, provide a firm foundation upon which to evaluate the feasibility of the Fallon site for FORGE. For example, detailed studies of the stratigraphic and structural framework of the region, including in-depth analyses of most of the known geothermal fields in the area, such as Salt Wells, Desert Peak, Brady's, Soda Lake, and Lee-Allen (e.g., Hinz et al., 2008, 2010, 2011, 2014; Faulds et al., 2006; 2010a, 2010b, 2011, 2012; McLachlan et al., 2011; Blake and Davatzes, 2012), have been completed, allowing for direct comparison of the FORGE site to known hydrothermal systems in the region. In addition, a detailed gravity survey and derivative depth-to-basement maps of the entire Carson Sink were recently completed (Faulds et al., 2014). Furthermore, the DOE-funded Nevada play fairways project involved detailed analysis of the geothermal potential of the Carson Sink and surrounding region (Faulds et al., 2016; Attachment C). Key available data sets from the proposed Fallon site include detailed geologic mapping, numerous bore-holes, stress data, thermal data, well-test data, geochemistry, detailed gravity surveys, magnetotelluric (MT) data, and seismic reflection profiles. As described below, this abundance of data has allowed for detailed examination of the Fallon site, with analysis of more than 14,000 m of cuttings and core and 270 km of seismic reflection profiles underpinning development of the 3D model. Integration of the multiple data sets into the 3D model has, in turn, permitted assessment of the volume, permeability, and structural and stratigraphic character of potential EGS reservoirs at the Fallon site.



**Figure 1. A. General location map of the proposed Fallon FORGE site in west-central Nevada. B. More detailed location map showing land status and major access roads. Abbreviations for physiographic features shown in italics: BM, Bunejug Moutains; LM, Lahontan Mountains; SSR, Sand Springs Range; WT, White Throne Mountains. Abbreviations for geothermal fields in the Carson Sink area shown in bold: Br, Bradys; DP, Desert Peak; DQ, Desert Queen; DV, Dixie Valley; LA, Lee-Allen; Pt, Patua; SL, Soda Lake; St, Stillwater; SW, Salt Wells.**

The Fallon FORGE site covers ~4.5 km<sup>2</sup> in the southeastern part of the large composite basin of the Carson Sink in west-central Nevada, ~12 km southeast of the City of Fallon (Figure 1A). The site is located on two parcels that include land owned by the NASF and Ormat Nevada, Inc. (Figure 1B and Figure 2). The site is bound by (1) the NASF on the northwest, (2) parts of the Fallon agricultural district to the north, west, and south, (3) Carson Lake wetlands at the base of the White Throne Mountains to the south, and (4) Ormat lease lands to the east, which include parts of the Lahontan and Bunejug Mountains. Ormat has both privately held land and geothermal leases. The Ormat lease area includes portions of 12 sections (7426 acres) used in part for seasonal cattle grazing. A project Environmental Assessment (EA) covering geothermal exploration and development was completed in 2008 for the Ormat lease area. Most of the surrounding lands in the Ormat lease area and NASF are open to monitoring and instrumentation activities. However, NASF will not allow any ground disturbance nor any activities that would affect flight operations within and immediately surrounding their runways. In addition, the northeastern part of the Ormat lease block, primarily in the higher ground of the Lahontan Mountains, contain archeological sites and are therefore “no surface occupancy zones”. However, per the Ormat lease agreements, if there becomes a need for surface occupancy for FORGE related activities, the “no surface occupancy” contingency may be negotiated and

revised if the BLM, with Native American consultation, and the FORGE operators both agree on the perceived need for access and any access restrictions that might be imposed if occupancy is granted. Despite these restrictions, this leaves ~4.5 km<sup>2</sup> for development of infrastructure on the FORGE site and another ~40 km<sup>2</sup> for monitoring and instrumentation on the surrounding lands.

Existing facilities at the Fallon FORGE site include an excellent network of roads, abundant wells, available storage for equipment and supplies at the NASF, and an established infrastructure for electrical and water resources, all of which will facilitate significant research and development activities. The network of paved and dirt roads makes the site fully accessible (Figure 2 and Figure 3). For example, access to the site can be attained from multiple roads that intersect U.S. Highway 50, including the paved access road of Macari Lane that traverses southwest through the center of the Ormat lease area. Many additional paved and gravel roads are present on the NASF and in the agricultural areas that border much of the site (Figure 3). NASF facilities lie directly north-northwest of the proposed FORGE site (Figure 2 and Figure 3). NASF is fully supportive of this project and will therefore supply equipment, storage, and other needs, as necessary.

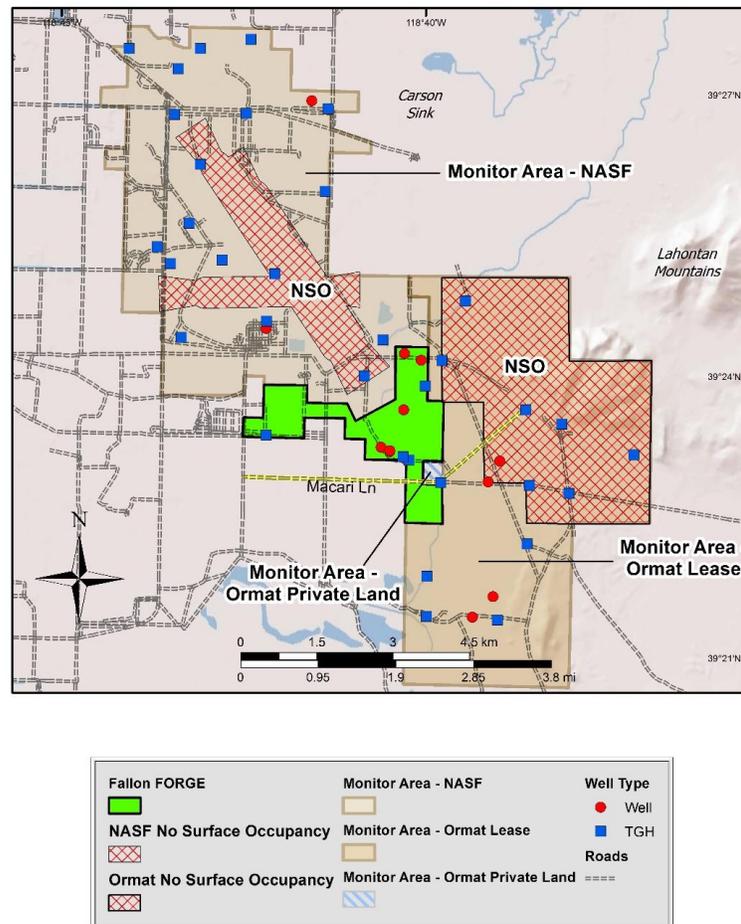
A total of 12 geothermal wells and 34 temperature gradient holes have been drilled for geothermal exploration within the NASF and the Ormat lease area (Figure 2). This includes 7 geothermal wells, 4 temperature gradient holes on the FORGE site, 5 geothermal wells, and 30 temperature gradient holes on the NASF and Ormat monitoring areas. Four exploration wells within the FORGE site (82-36, 61-36, 88-24, and 86-25; Figure 3) are available for use in the project. Several additional wells are available for monitoring outside the central FORGE site within the NASF and Ormat lease area, including numerous temperature gradient holes. Some additional well sites have been permitted but not yet drilled. The abundant well data provide significant subsurface control for the site. Data from these wells were synthesized with available geophysical and geological data to generate a detailed 3D model of the FORGE site, as discussed in subsequent sections of this report.

In addition to the wells, a wide range of equipment is available at the NASF for use in this project. This includes one separator that is ~5 m high and 3 m in width, one weir box, a downhole pump with a surface drive, step up transformer, and surge protector. The NASF also has a spare well-head kit and cable connect, which are used to connect power to a downhole submersible pump. There are dirt/gravel roads to access each drill pad from existing public gravel/dirt and paved roads (see Figure 2 and Figure 3). Drill pads range in size from 60 x 70 m (200' x 225') to 90 x 76 m (300' x 250'). Three drill pads have existing sumps, with 82-36 being the largest at 84 x 31 x 2.4 m (275' x 100' x 8'); 61-36 is large, but half the size of the 82-36 pad at 31 x 6 x 2 m (100' x 20' x 7'), and the 86-25 pad is relatively small at 18 x 3 x 2 m (60' x 10' x 6'). Sumps have been backfilled on the 88-24 and 82-19 drill pads.

Water for the EGS experiments at the FORGE site will be sourced from well 84-31 within the Ormat lease lands. This well lies ~11 km southeast of the edge of a well-defined basalt aquifer that provides water to the community of Fallon and NASF (Figure 3). This basalt aquifer has been studied thoroughly by the USGS (Glancy, 1986; Maurer and Welch, 2001) and does not extend into the proposed FORGE site. The geothermal reservoir(s) proposed for use for FORGE are neither hydraulically nor geologically connected to the Fallon basalt aquifer or to any ground water aquifers used by the community. Fluids used in the FORGE project will be geothermal

fluids, drawn from geothermal reservoirs. These waters do not meet drinking water standards due to high temperature and chemistry.

Nearby communities also provide superior infrastructure for this project. For example, the town center of Fallon (~12 km to the northwest) affords abundant hotels, restaurants, and stores for personnel and supplies. In addition, the Reno metropolitan area, only 100 km west of Fallon, offers all the accoutrements of a major city in terms of needed resources and equipment for FORGE research activities, development, conference and workshop facilities, and a major university that houses both the Great Basin Center for Geothermal Energy (GBCGE) and the Great Basin Science Sample and Records Library (GBSSRL). The GBSSRL serves as a repository for samples, records, and information on the geology of Nevada and the Great Basin region, including cuttings, core, and logs from geothermal and oil-gas wells drilled in the Carson Sink and other parts of Nevada.



**Figure 2. Map of the Fallon FORGE site with adjacent FORGE monitor areas on the NASF and Ormat lease area with geothermal wells, temperature gradient holes, and accessible roads shown. Note that no surface occupancy zones correspond to the vicinity of the runways at NASF and the northeastern part of the Ormat lease area. Other parts of the NASF and Ormat lease block are accessible for instrumentation and monitoring, and full research and development is allowed on the Fallon FORGE site. A close-up of the Forge site is shown in Figure 3.**

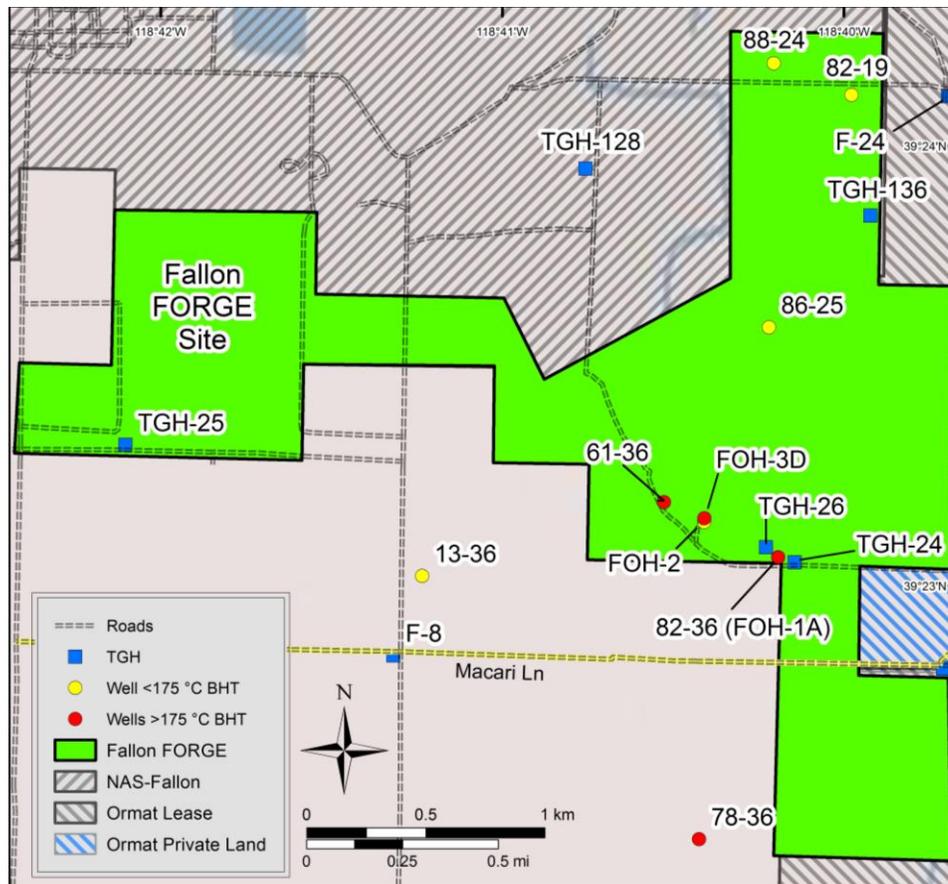


Figure 3. Map of Fallon FORGE site, showing geothermal wells, temperature gradient holes, and accessible roads. Approximately 4.5 km<sup>2</sup> has been cleared for research experiments and development.

### 3 GEOLOGIC SETTING

#### 3.1 REGIONAL SETTING

The Carson Sink lies within the Basin and Range province directly northeast of the Walker Lane belt (Figure 4; Stewart, 1988; Faulds and Henry, 2008). The Walker Lane is a system of strike-slip faults that accommodates ~20% of the dextral motion (~1 cm/yr) between the North American and Pacific plates (Hammond and Thatcher, 2004). Major tectonic events affecting this region and relevant to the FORGE site include: (1) Mesozoic contractional tectonism, involving arc volcanism, back arc sedimentation and volcanism, and some east-directed folding and thrusting; (2) early Tertiary erosion, which beveled the preexisting arc and related thrust sheets, producing an erosional surface with considerable relief by the Oligocene; (3) the ignimbrite flare-up in late Oligocene time, involving eruption of voluminous ash-flows from calderas in central Nevada and deposition of the ash-flow tuffs in deep paleovalleys across western Nevada; (4) mafic to intermediate composition volcanism in Miocene time related to the ancestral Cascade arc; (5) regional east-west to west-northwest extension from early Miocene time to present; and (6) dextral shear from the late Miocene to present associated with Pacific-

North American plate motion, northwestward propagation of the Walker Lane into the region, and concomitant retreat of the ancestral Cascade arc to the northwest.

The present physiography of the region, including the broad basin of the Carson Sink and adjacent mountain ranges, has been primarily shaped by Miocene to recent extensional tectonism. Regional studies constrain the onset of regional extension to ~17-15 Ma to the northeast of Fallon (Fosdick and Colgan, 2008) and ~15-12 Ma in the Wassuk Range area to the south (Stockli et al., 2002). A 14 Ma north-striking basaltic dike swarm exposed in both the Bunejug Mountains and in Rainbow Mountain may correspond to the onset of extension in the Salt Wells area (Bell et al., 2010; Hinz et al., 2011). The base of the Miocene lacustrine sedimentary section is locally interlayered with the upper part of the ~16 to 12 Ma basaltic andesite and rhyolite lavas in the Lahontan Mountains (Bell et al., 2010). These sediments probably represent initial sedimentary accumulation in half grabens in the region. Extensional tectonism was primarily responsible for producing the composite basin of the Carson Sink, as seismic reflection and gravity data indicate that a series of half grabens comprises the Carson Sink. The deeper basins such as the Salt Wells basin and the southern Carson Sink probably record a continuous basin-fill sedimentary record from ~12 Ma to present. Most of the surrounding mountain ranges, especially on the east, north, and northwest sides of the Carson Sink, are tilted fault blocks typical of the Basin and Range province (e.g., John, 1995a; Faulds et al., 2010a, 2012; Hinz et al., 2011, 2014). Quaternary faults abound in the region but are scarce in the southeastern Carson Sink (Figure 5), with Quaternary slip rates minimal in the vicinity of the proposed FORGE site (Figure 6 and Figure 7).

Geodetic, fault kinematic and well-bore data indicate that a west-northwest-trending extension direction has dominated the Carson Sink region from the late Miocene to present (Hickman and Davatzes, 2010; Faulds et al., 2010a; Blake and Davatzes, 2012; Kreemer et al., 2012, 2014; Hinz et al., 2014; Jolie et al., 2015). Slip and dilation tendency is therefore greatest on moderately to steeply dipping, NNE-striking faults. Figure 8 shows dilation potential and summed slip and dilation potential (e.g., Morris et al., 1996; Ferrill et al., 1999) on Quaternary faults in the region.

The Walker Lane initially developed in late Miocene time (~10-9 Ma) and has been propagating northwestward since its inception in concert with the San Andreas fault (Faulds and Henry, 2008). The San Andreas fault terminates northward at the Mendocino triple junction offshore of northern California. The Walker Lane essentially mimics the San Andreas and terminates in northeastern California directly inland of the triple junction. Despite its proximity to the Walker Lane (Figure 4), the Carson Sink region is dominated by extensional structures rather than dextral shear or wrench faulting. The terrane to the south and southwest of the Carson Sink is dissected, however, by strike-slip faults of the Walker Lane (Hinz et al., 2008, 2010), and a major northwest-striking dextral fault may bound the Carson Sink on the southwest.

The northern Walker Lane directly west and to the northwest of Fallon is one of the youngest parts of the Pacific-North American plate boundary, having developed in the past ~5 Ma (Faulds and Henry, 2008). As the Walker Lane terminates northwestward, ~1 cm/yr of dextral shear is transferred to northwest-trending extension in the northwestern part of the Great Basin (Faulds et al., 2004). Enhanced extension results in greater dilation, which in turn fosters fluid flow and geothermal activity. This region of enhanced extension has a greater density of known

hydrothermal systems than other parts of the Basin and Range province and currently hosts about a dozen geothermal power plants (Figure 4; Faulds et al., 2012). Similar to most of the Great Basin, however, geothermal activity in this region is amagmatic (i.e. no mid to upper crustal magmatic heat sources), as volcanism generally ceased 10-3 Ma.

Due to its location directly northeast of the northern Walker Lane, the Carson Sink area has some of the higher strain rates in the Great Basin region (Figure 4 and Figure 9), as evidenced by GPS geodetic data (Kreemer et al., 2012, 2014). For example, dilatation in the Fallon area is twice that of southwestern Utah and more than four times that of the Snake River Plain. High strain rates and rocks that are critically stressed (or near critically stressed) for frictional failure in the current stress field not only favor conventional geothermal energy production (Hickman et al., 1998; Barton et al., 1998) but also facilitate EGS research and development, because the ability to increase permeability through reactivation of shear fractures during hydraulic stimulation is more readily accomplished under such conditions (e.g., Hickman and Davatzes, 2010; Chabora et al., 2012; Dempsey et al., 2013). The lack of magmatism also imparts more predictability in determining the stress field, as transient stress-field perturbations induced by mid to upper crustal intrusions and associated inflation and/or deflation of magma chambers would be absent.

Although high heat flow (Blackwell and Richards, 2004) and high extensional to transtensional strain rates (Kreemer et al., 2012) have generated relatively high geothermal gradients in the Carson Sink and surrounding parts of the Great Basin (e.g., Coolbaugh et al., 2005), development of conventional hydrothermal systems in this region is still challenging. An abundance of hot dry wells in the region demonstrates the many challenges of locating adequate permeability at depth. Favorable structural settings (Figure 10; Faulds et al., 2006, 2011, 2013; Faulds and Hinz, 2015) and geophysical signatures (e.g., Wannamaker et al., 2013) for sufficient permeability and fluid flow comprise a relatively small fraction of the region and involve limited volumes of hot rock. Thus, finding sufficient permeability for geothermal production is clearly more of an impediment for exploration and development of conventional hydrothermal resources than temperature in this region. The volumetric extent of hot, impermeable rock is simply far greater than that of hot permeable rock. Considering the high heat flow and high geothermal gradient across nearly all of the Great Basin, there is clearly enormous potential for successful EGS development throughout the region.

From a regional perspective, the proposed Fallon FORGE site thus represents an ideal site for a field laboratory dedicated to EGS research, as it lies in a region experiencing relatively high strain rates, occupies part of an extensional basin (half graben) characteristic of most of the Basin and Range province, and resides in an amagmatic setting, which epitomizes the bulk of the geothermal systems within the Great Basin region.

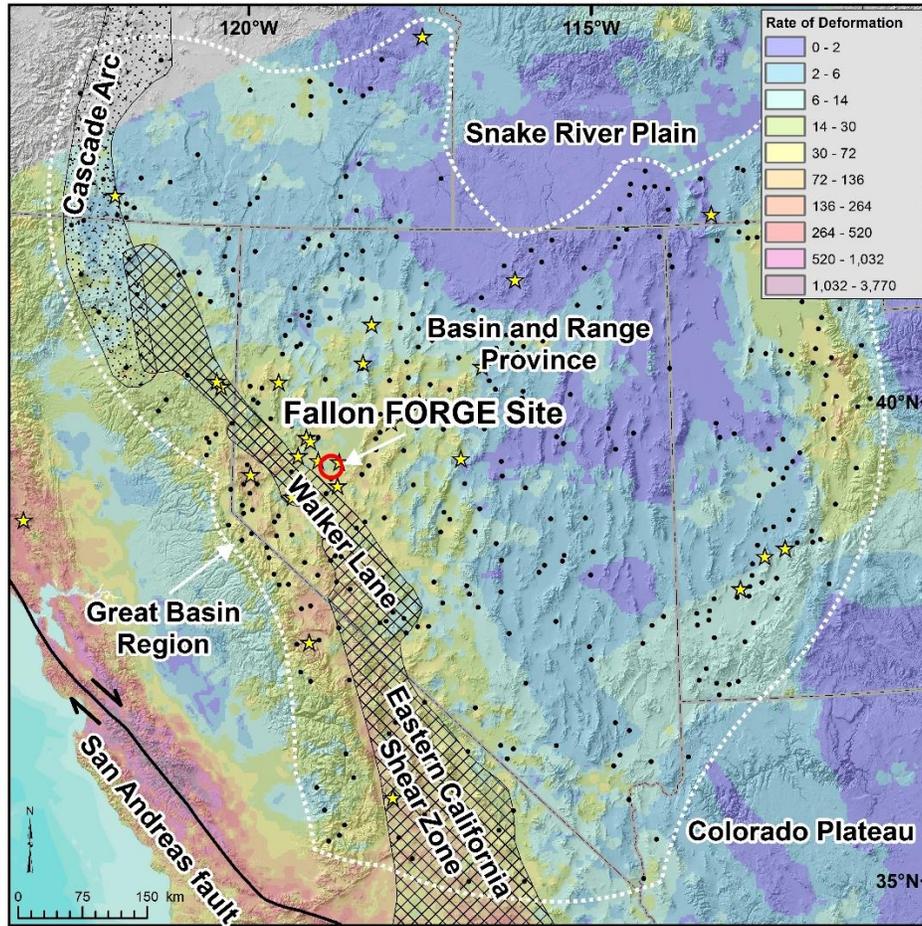
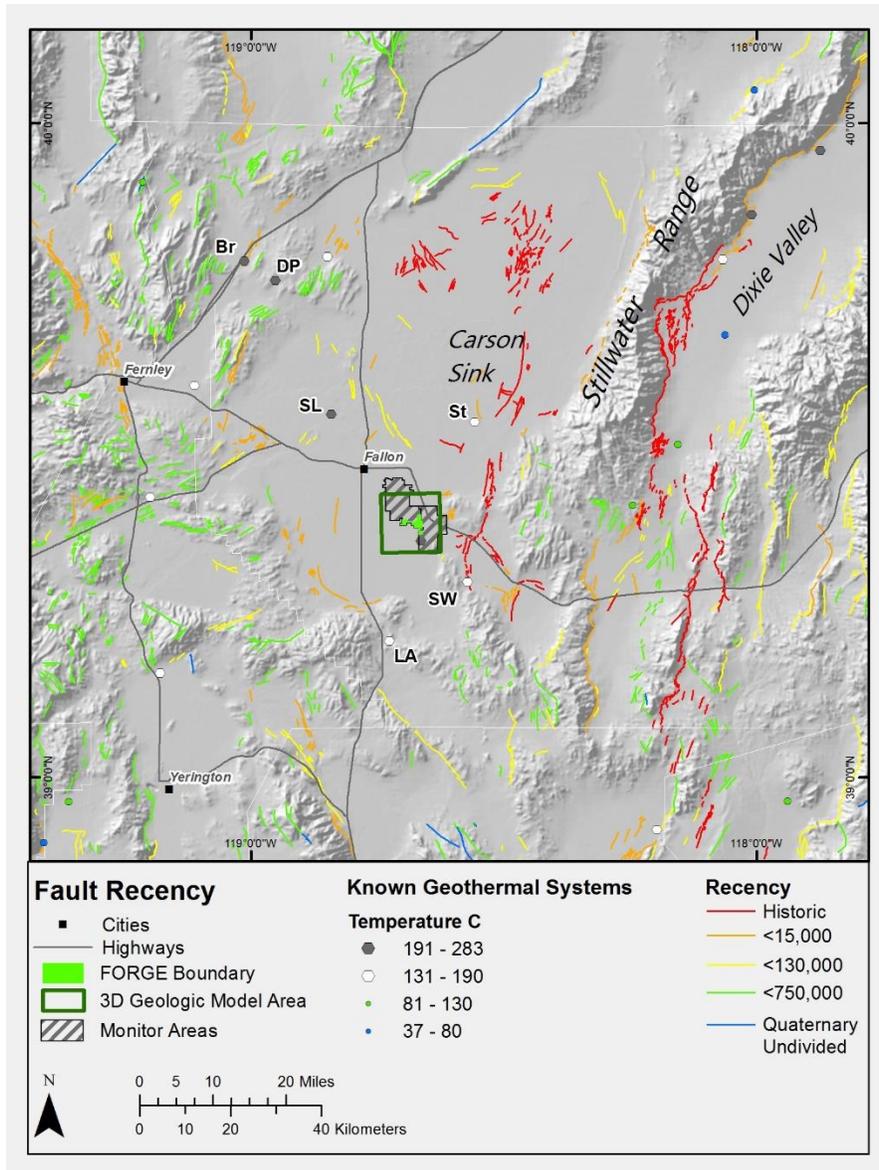
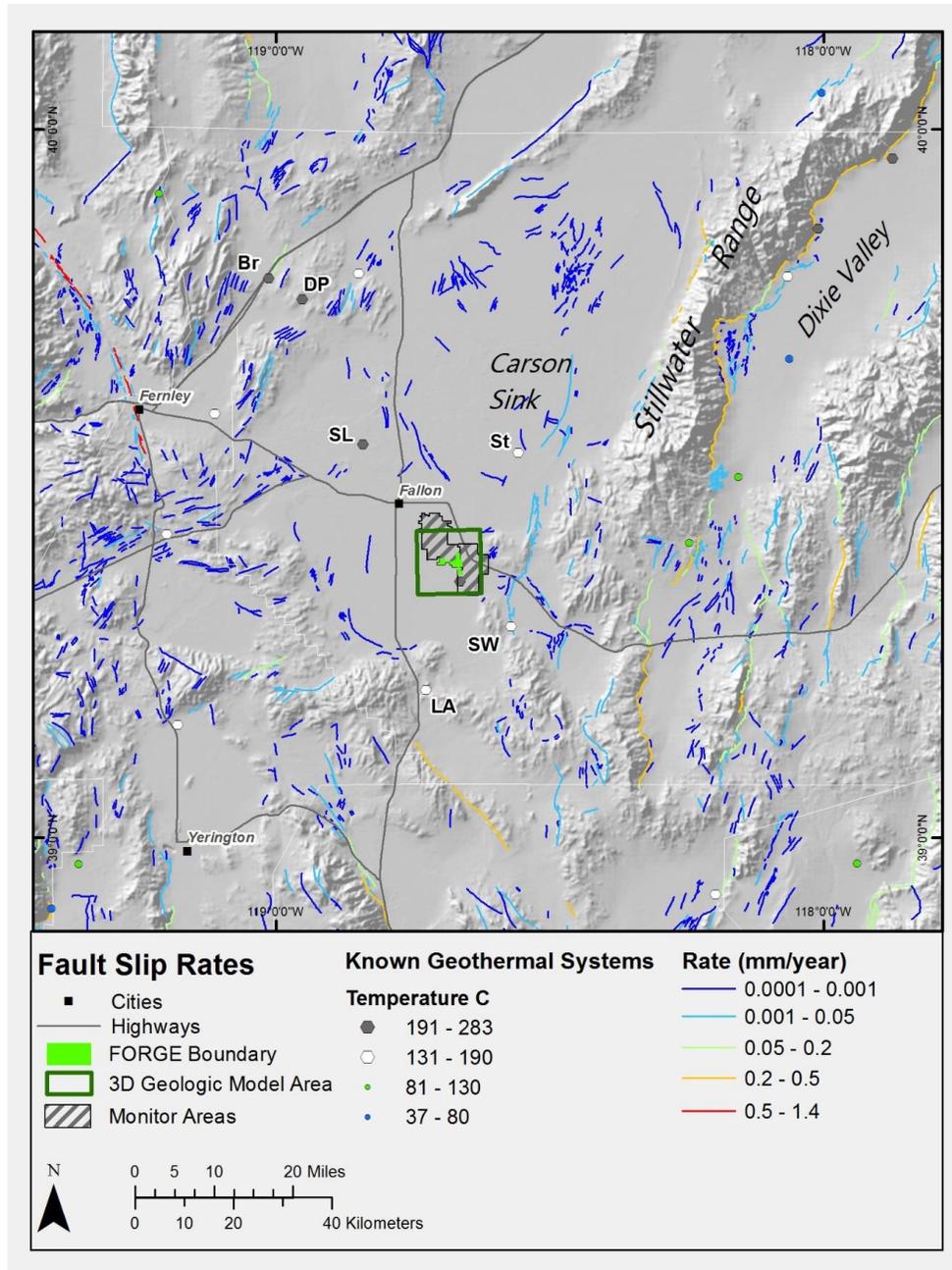


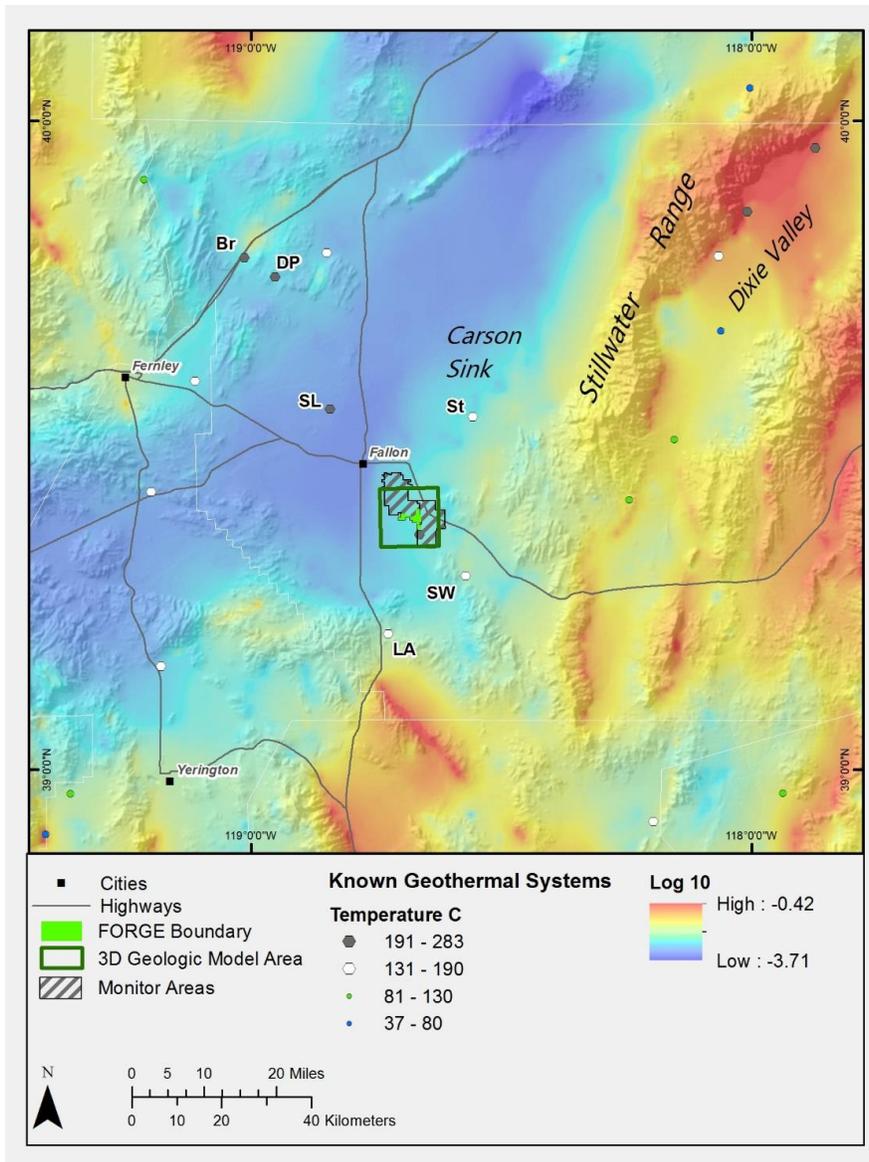
Figure 4. Map of the Great Basin region showing strain rates (from Kreemer et al., 2012), known geothermal systems (black dots), and geothermal power plants (yellow stars). Strain rates reflect the second invariant strain rate tensor, with warmer colors showing higher strain rate (nonstrain,  $10^{-9}/\text{yr}$ ). Red circle surrounds the Fallon FORGE site.



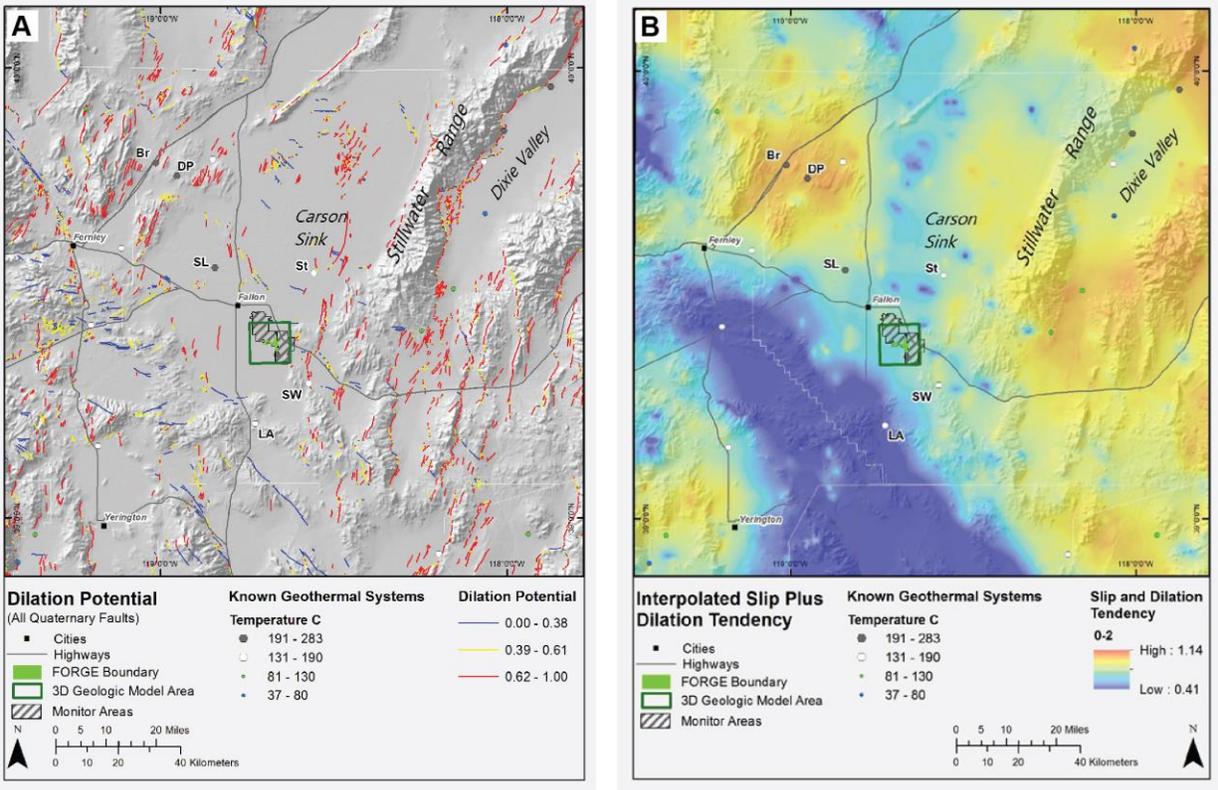
**Figure 5. Age of Quaternary faults in the Carson Sink region. The green box encompasses the area of the 3D geologic model described in Section 5. Abbreviations of nearby geothermal fields: Br, Bradys; DP, Desert Peak; LA, Lee-Allen; SL, Soda Lake; St, Stillwater; SW, Salt Wells.**



**Figure 6. Slip rates of Quaternary faults in the Carson Sink region. The green box encompasses the area of the 3D geological model described in Section 5. Abbreviations of nearby geothermal fields: Br, Bradys; DP, Desert Peak; LA, Lee-Allen; SL, Soda Lake; St, Stillwater; SW, Salt Wells.**



**Figure 7. Interpolation of slip rates on Quaternary faults in the Carson Sink region. The slip rate of normal and strike-slip faults was log-transformed (converted to Log10) for each fault segment. The vertices of the fault line segments were converted to a point dataset so that an interpolated map could be generated. Interpolated maps of slip rate and log base 10 of the slip rate were created using inverse distance weighting with a power of 1, using the following criteria: cell size 1000 m, fixed search radius of 20 km, minimum number of points = 1. Note that the proposed Fallon FORGE site lies in an area devoid of Quaternary faults and thus also occupies an area with minimal slip rates. The green box encompasses the area of the 3D geological model described in Section 5. Abbreviations of nearby geothermal fields: Br, Bradys; DP, Desert Peak; LA, Lee-Allen; SL, Soda Lake; St, Stillwater; SW, Salt Wells.**



**Figure 8. Slip and dilation tendency on Quaternary faults in the Carson Sink region in an extensional regime, with the least principal stress trending west-northwest. A. Dilation tendency or potential on Quaternary faults (e.g., Ferrill et al., 1999). B. Interpolated sum of the slip and dilation potential on Quaternary faults. The vertices of the fault line segments were converted to a point dataset so that an interpolated map could be created. An interpolated map was produced using inverse distance weighting with a power of 1 and the following criteria: cell size 1000 m, fixed search radius of 20 km, and minimum number of points equal to 1. Contoured sum of slip and dilation tendency on Quaternary faults. The Fallon FORGE site lies in an area with relatively low slip and dilation tendency due to the lack of Quaternary faults. This does not preclude, however, slip and dilation on preexisting or new fractures in response to hydraulic stimulation. The green box encompasses the area of the 3D geological model described in Section 5. Abbreviations of nearby geothermal fields: Br, Bradys; DP, Desert Peak; LA, Lee-Allen; SL, Soda Lake; St, Stillwater; SW, Salt Wells.**

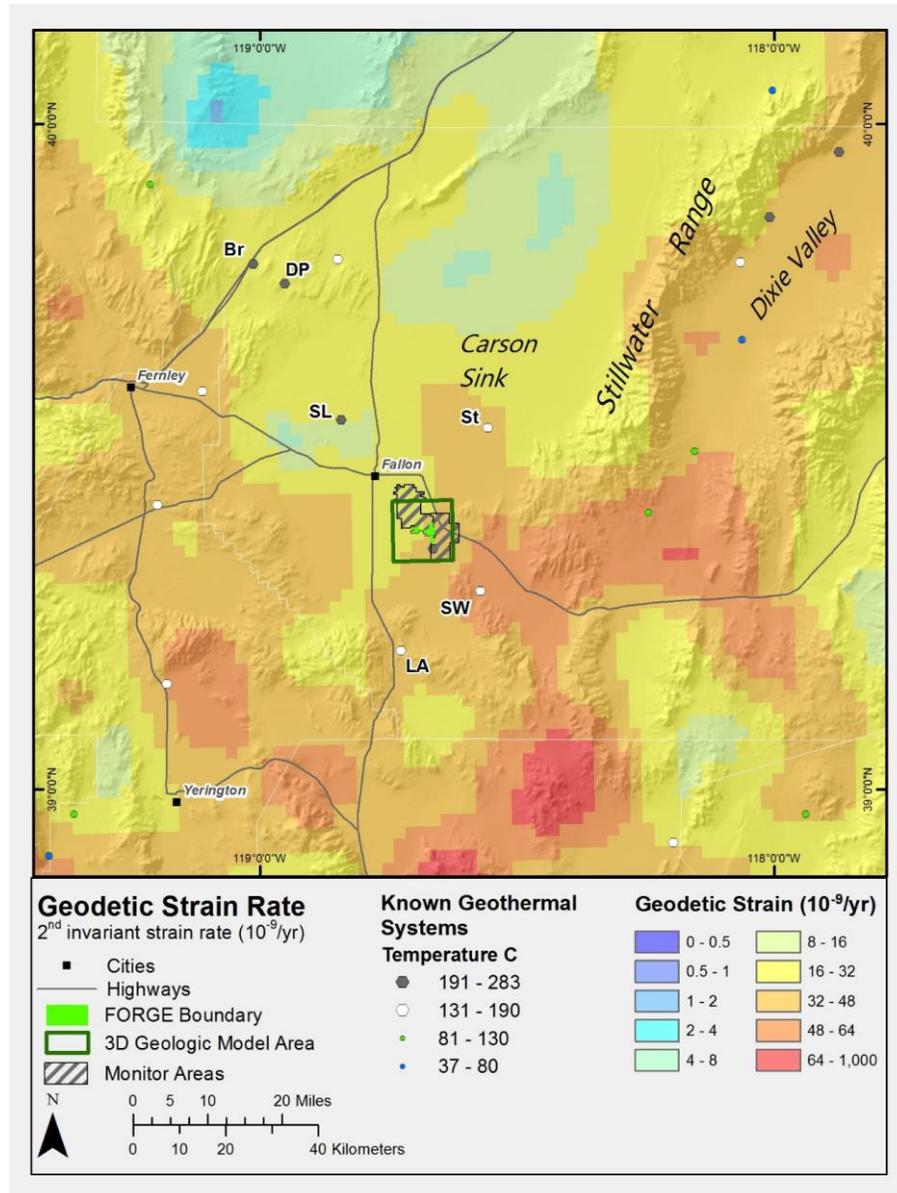
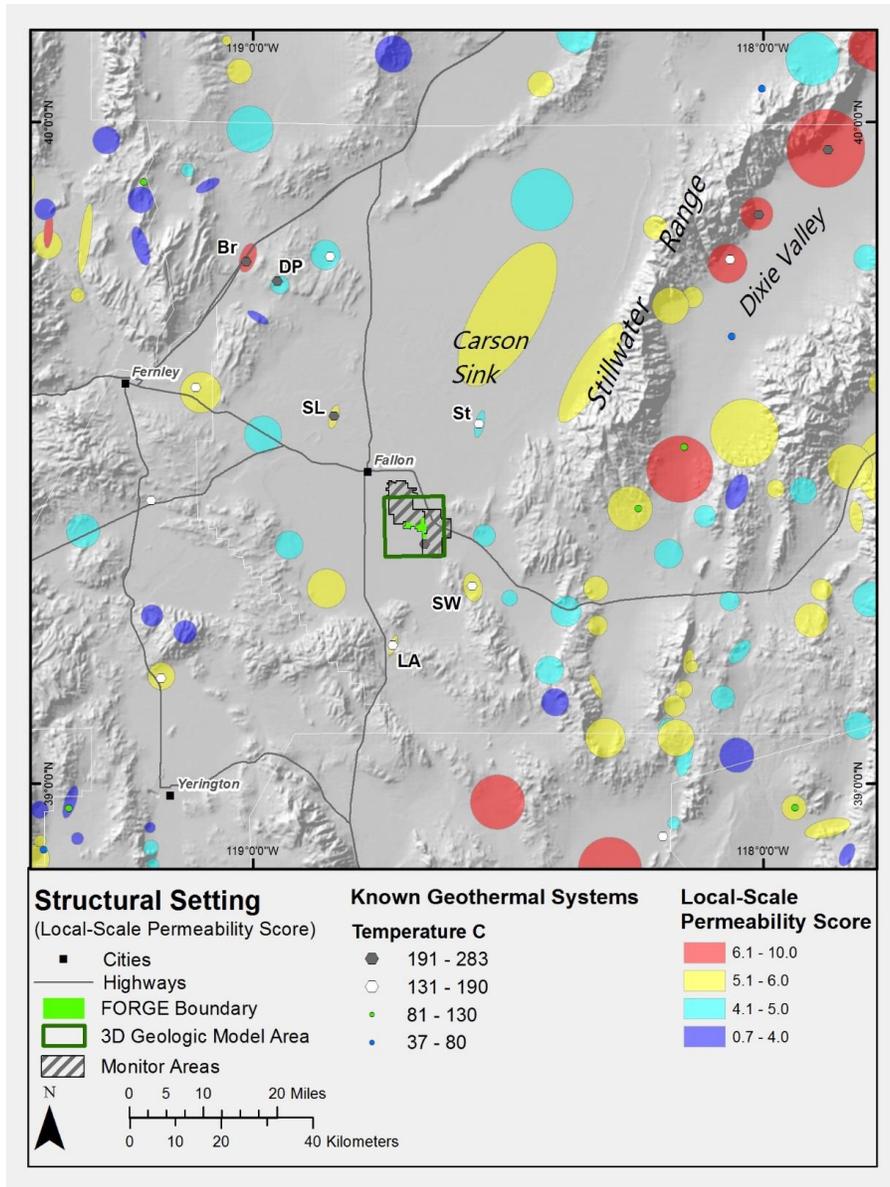


Figure 9. Second invariant of the geodetic strain rate for the Carson Sink region in western Nevada. The Fallon FORGE site lies in an area of relatively high regional strain rates, typical of most of the northwestern Great Basin. The green box encompasses the area of the 3D geological model described in Section 5. Abbreviations of nearby geothermal fields: Br, Bradys; DP, Desert Peak; LA, Lee-Allen; SL, Soda Lake; St, Stillwater; SW, Salt Wells.



**Figure 10. Favorable structural settings identified in the Carson Sink region. Colors denote local permeability scores based on relative weighting of type of structural setting and ages, slip rates, and slip and dilation tendencies on Quaternary faults. Favorable structural settings cover ~10% of the area and are sparse in the southern Carson Sink and absent at the proposed FORGE site. The green box encompasses the area of the 3D geological model described in Section 5. Abbreviations of nearby geothermal fields: Br, Bradys; DP, Desert Peak; LA, Lee-Allen; SL, Soda Lake; St, Stillwater; SW, Salt Wells.**

### 3.2 LOCAL SETTING OF THE FALLON FORGE SITE

The Fallon site lies in the southeastern part of the large composite basin of the Carson Sink in west-central Nevada (Figure 1 and Figure 11). Although high temperatures (>175oC) have been encountered at depths of 1.5 to 3.0 km beneath the site (as described in detail in section 4.3 below), the lack of permeability has hampered conventional development of this resource. This makes it an ideal test site for EGS research and development. It is also important to note that no surface hot springs or fumaroles are present at the surface. In addition, no indications of paleo-

hot spring activity, such as sinter or travertine, have been observed on the surface in the area. Thus, there is no evidence for a recent, conventional hydrothermal system at Fallon.

The stratigraphic section of the Carson Sink in the vicinity of the Fallon site primarily consists of late Miocene to Quaternary basin-fill sediments, Miocene volcanic and sedimentary rocks, Oligocene ash-flow tuffs, and Mesozoic granitic and metamorphic basement (Faulds et al., 2015; Hinz et al., 2016). The site is covered by Quaternary deposits, including alluvial fan, eolian, and lacustrine sediments (Morrison, 1964; Bell and House, 2010). The underlying volcanic section is dominated by middle Miocene mafic lavas, with lesser intermediate composition flows. The volcanic units are associated with the ancestral Cascades arc, which has retreated to the northwest since the late Miocene in response to the growth of the transform plate boundary and northwestward propagation of the Walker Lane. The lower part of the Tertiary section may locally contain late Oligocene ash-flow tuffs that fill paleovalleys cut into Mesozoic basement. The Neogene section rests nonconformably on heterogeneous Mesozoic basement, which consists of low- to medium-grade Triassic-Jurassic metasedimentary and metavolcanic rocks intruded by granitic plutons of probable Cretaceous age. Mesozoic granitic plutons are widespread in the area and comprise a large proportion of the basement rocks (Figure 11; Page, 1965; Stewart and Carlson, 1978; Satterfield, 2002; Hinz et al., 2008, 2010, 2014). The Mesozoic units developed in a transitional region between a magmatic arc centered to the west in the Sierra Nevada region and a back arc setting to the east. Notably, no bedrock units crop out at the proposed site. However, four wells (61-36, FOH-3D, 82-36, and 84-31) penetrate the entire Neogene section and bottom out in Mesozoic basement, and many additional wells bottom out in the basin-fill sediments and Miocene volcanic section. As described in detail in subsequent sections, cuttings and core from the abundant wells combined with geophysical data greatly elucidate the subsurface distribution of rock types at Fallon.

The structural framework of the Carson Sink region is dominated by Miocene to recent extensional features, including systems of north- to north-northeast-striking normal faults (Figure 12). Seismic reflection data reveal that the Carson Sink is composed of a series of half grabens, including a west-tilted half graben in the Fallon area (Hastings, 1978; Gray et al., 2013; Faulds et al., 2015; Hinz et al., 2016). Thus, the Carson Sink as a whole is a large composite basin formed by late Miocene to recent regional extension (Hastings, 1979; Faulds et al., 2015). The Carson Sink region also contains a series of extensional anticlines and synclines (i.e., extensional accommodation zones; cf., Faulds and Varga, 1998), resulting from flips in the predominant dip direction of normal fault systems. Extensional anticlines result from the overlap of oppositely dipping systems of normal faults that dip toward one another, whereas extensional synclines result from overlapping normal fault systems that dip away from one another. The west-tilted half graben appears to compose the western limb of a northerly trending extensional anticline (cf., Faulds and Varga, 1998) that lies directly east of the primary FORGE site beneath the Ormat lease area (Hinz et al., 2014; 2016).

Quaternary faults have not been observed within the proposed FORGE site (Figure 5 and Figure 11), and no significant historic seismicity has occurred at the site. The nearest Quaternary scarp lies ~5 km southeast of the southeastern corner of the primary FORGE site and cuts late Pleistocene lacustrine sediments (Hinz et al., 2011). The USGS Quaternary fault and fold database (USGS, 2006) does show a Quaternary fault 2.5 km east of the FORGE site, but recent

analysis indicates that this scarp is probably a late Pleistocene shoreline rather than a fault (Bell and Hinz, unpublished data). The Rainbow Mountains fault ~10 km east of the site (Figure 12) ruptured in a M6.3 earthquake in 1954, accommodating oblique normal-dextral motion (Caskey et al., 2004). The Rainbow Mountains fault terminates southward in the vicinity of the Salt Wells geothermal field. Increased permeability associated with the horse-tailing southern end of this fault probably accounts for the hydrothermal activity at Salt Wells (Hinz et al., 2014). Because most geothermal systems in the Great Basin region are proximal to Quaternary faults (Bell and Ramelli, 2007), the absence of Quaternary faulting at the Fallon FORGE site may account for the lack of sufficient permeability in the area.

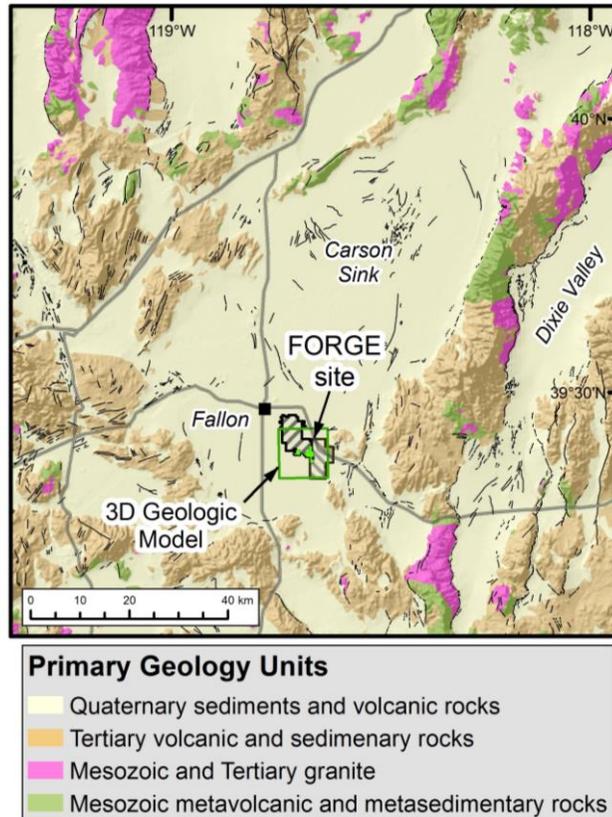


Figure 11. Generalized geologic map of the Carson Sink region. Quaternary faults are shown as black lines.



#### 4 FORGE PARAMETERS – DESCRIPTION AND ANALYSIS OF DATA

Substantial amounts of preexisting geological, geochemical, and geophysical data were available for analysis for the proposed Fallon FORGE site. For example, detailed geologic maps cover the entire FORGE site and all surrounding areas at scales ranging from 1:31,680 to 1:24,000 (Figure 13) and furnish critical information on the surface distribution of lithologies and structures. Substantial subsurface controls on the stratigraphy, structure, stress regime, thermal character, and permeability of the site are provided by 221 bore-holes, including geothermal wells, oil exploration wells, and temperature gradient holes (Figure 14; Attachment A, Tables A1 and A2). The FORGE site contains seven geothermal wells with abundant data sets for each well. The specific down-hole logs and well tests are listed in Attachment A (Table A1). Another five geothermal wells reside in the FORGE monitor area (Figure 14; Attachment A, Table A2) and 17 more wells reside proximal to the FORGE site and monitor areas. In addition, geophysical data including detailed gravity, magnetotelluric, and 14 seismic reflection profiles further constrain the subsurface geology. Both a regional seismic and a local micro-earthquake array also define the seismologic character of the site. All of these data sets permit development of a detailed conceptual geologic model of the Fallon site and a robust assessment of its suitability for FORGE. In order to establish the fundamental building blocks of the model, this chapter describes the various data sets in detail, grouping them into seven major categories: (1) stratigraphic, (2) structural, (3) thermal, (4) fluid geochemical (5) alteration, (6) well flow testing, and (7) geophysical, which includes discrete subsections on gravity-magnetics, magnetotelluric (MT), seismologic, and seismic reflection data.

Each of these data sets are discussed in context of the key characterization and qualification criteria for an ideal FORGE site (Figure 15). These criteria include: (1) temperatures between 175 and 225 °C, (2) low permeability, (3) crystalline bedrock (not a sedimentary basin), (4) depth between 1.5 and 4 km, (5) favorable stress regime, and (6) the lack of an existing hydrothermal system. The temperature conditions of the FORGE site are provided by well logs, fluid geochemistry, and a 3D thermal model. Permeability conditions are characterized by well flow tests, MT models, stress data, and the 3D geological model. The lithologic units that make up the FORGE site are delineated by detailed geologic maps, core and cuttings from wells, petrographic data, reflection seismic profiles, a 3D geologic model, and MT models. The depth of potential reservoirs at the Fallon FORGE site is constrained by well paths, reflection seismic profiles, gravity models, MT models, and the detailed 3D geologic model. No hydrothermal system has been identified on the FORGE site, as evidenced by temperature data, well tests, MT models, the overall structural setting, and the distribution of Quaternary faults. The relevance of each data type to the six major FORGE qualification criteria is tabulated at the beginning of each data section.

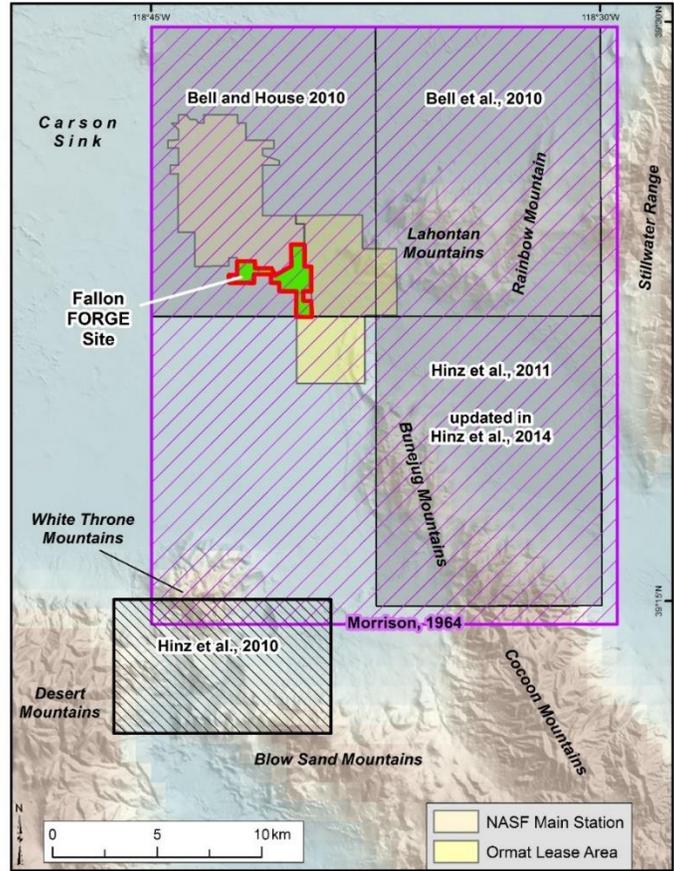


Figure 13. Existing published geologic maps for the Fallon FORGE site and surrounding area.

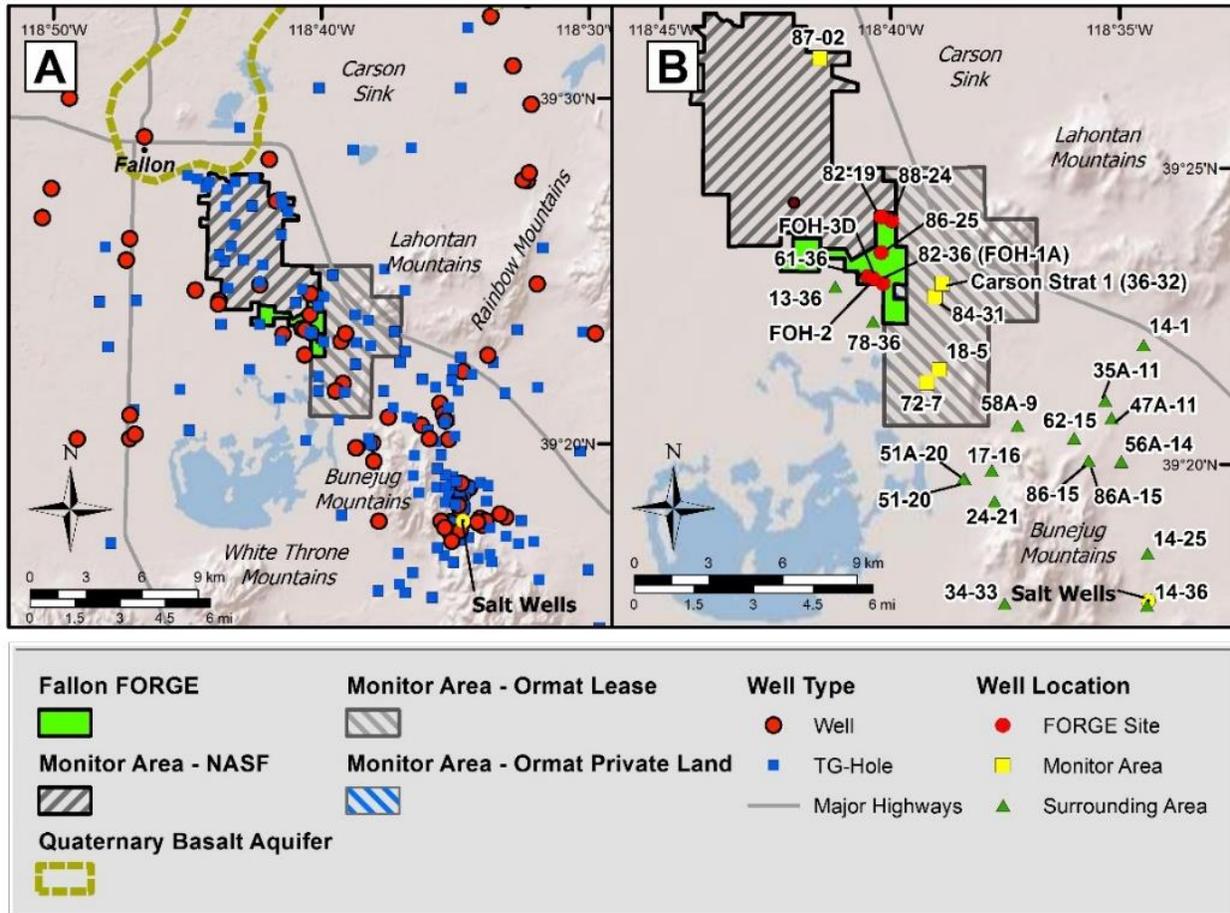


Figure 14. A. Geothermal wells, temperature gradient holes, and oil exploration holes within an ~15 to 20 km radius of the FORGE site. Includes 76 wells and 145 TGHs in total. B. Geothermal wells on the FORGE site (Attachment A, Table A1), on the FORGE monitor area (Attachment A, Table A2), and in the nearby area (Attachment A, Table A3) with available data listed per well.

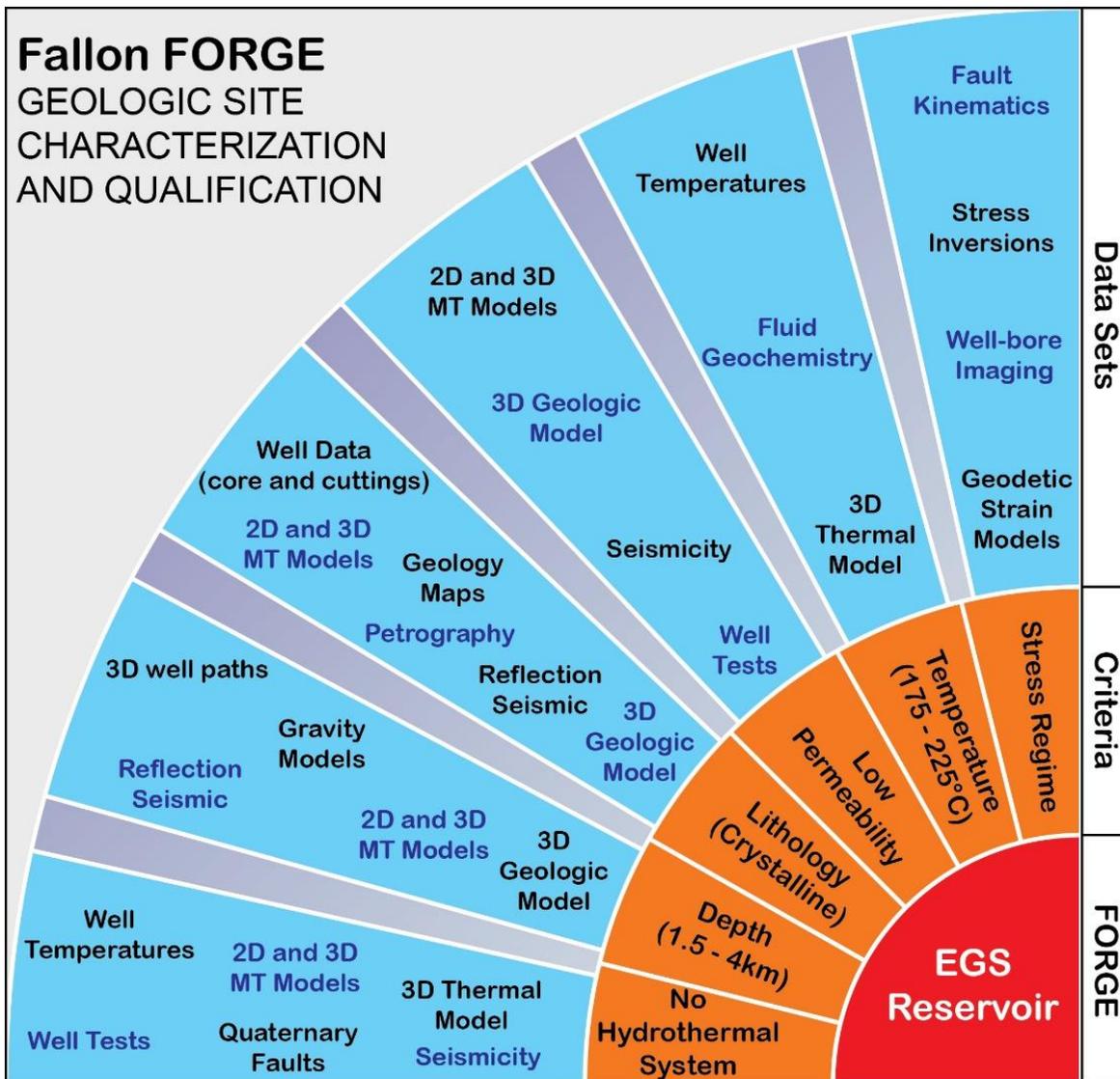


Figure 15. Major data sets utilized for documenting primary criteria for the FORGE program at the proposed Fallon site.

## 4.1 STRATIGRAPHIC DATA

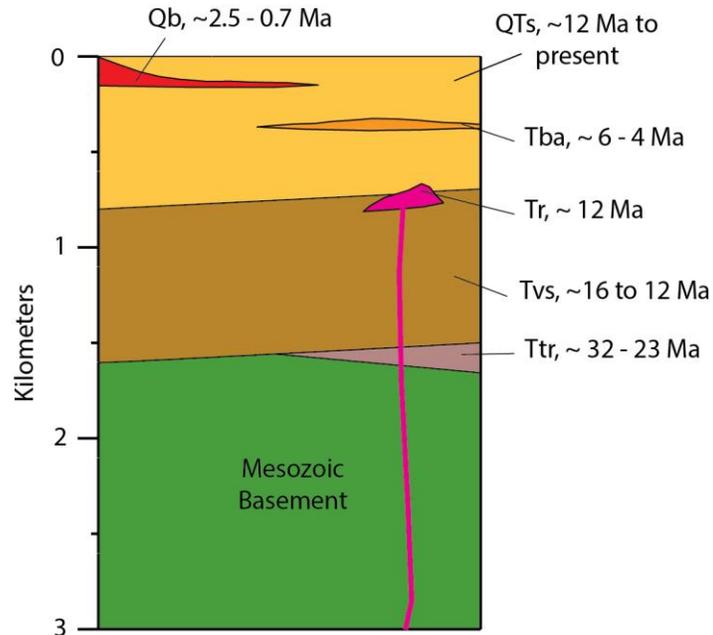
### 4.1.1 Surface Lithologic Data

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant			✓			

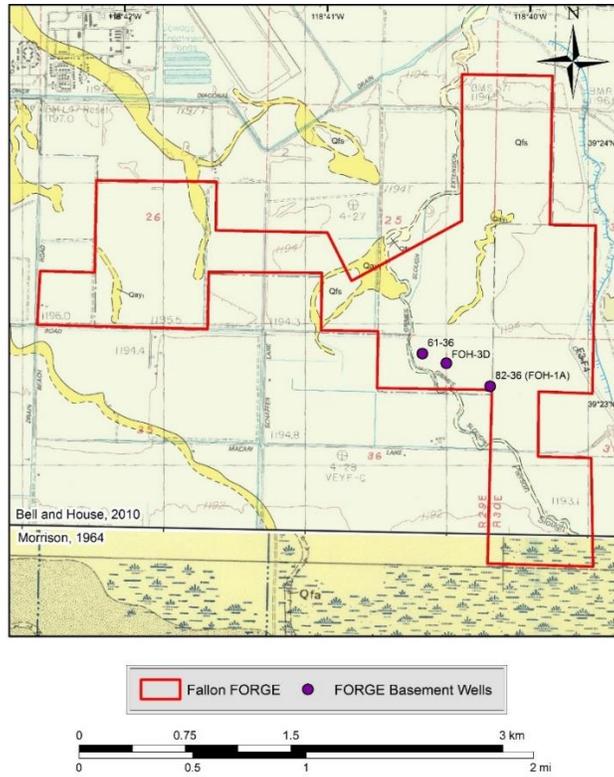
Published detailed geologic maps (Figure 13) define the stratigraphic framework of the Fallon area and place constraints on the subsurface geology of the proposed FORGE site. The Carson Sink in the vicinity of the Fallon site is covered by Quaternary deposits, including alluvial and lacustrine sediments (Morrison, 1964; Bell and House, 2010). A sequence of Quaternary basalt flows, ranging from 2.5 to 0.7 Ma (Maurer and Welch, 2001; Bell and House, 2010), is interbedded with the QTs basin fill deposits near the City of Fallon (Figure 16). The base of this section of basalts is ~180 m deep and provides an approximate local Quaternary/Tertiary marker in the QTs stratigraphy, indicating that most of the basin fill sediments are late Miocene to Pliocene in age. No bedrock units crop out in the proposed site (Figure 17). However, bedrock is exposed in the Lahontan Mountains to the east (Bell and House, 2010; Bell et al., 2010), Bunejug Mountains to the southeast (Hinz et al., 2011, 2014), and White Throne Mountains/Lee-Allen geothermal area to the south (Hinz et al., 2008, 2010). The stratigraphic section exposed in the Lahontan and Bunejug Mountains consists of ~16 to 12 Ma basaltic andesite lavas and ~12 Ma dacite and rhyolite domes and lava flows interfingering with or capping the upper section of Miocene mafic lavas. In the Lahontan Mountains the Miocene lavas are locally capped by ~12 to 4 Ma lacustrine sediments, and these late Miocene to Pliocene sediments are locally capped by ~4 Ma basalt flows. Similar to the Lahontan and Bunejug Mountains, a sequence of mafic and felsic lavas, as well as fluvial-lacustrine sediments spanning ~12 to 5 Ma, is exposed in the White Throne Mountains south of the FORGE site. The Miocene section locally rests on Oligocene ash-flow tuffs and Mesozoic basement rocks, including metasedimentary and granitic rocks in the Lee-Allen area. Mesozoic basement rocks are not exposed in the Lahontan or Bunejug Mountains. Oligocene ash-flow tuffs are also not exposed in nearby mountain ranges and have not been observed in cuttings and core at the Fallon site, but they do crop out in the Lee-Allen area and are encountered in deep wells at Stillwater, about 20 km south and north of the FORGE site, respectively. The exposures of Jurassic-Cretaceous quartz diorite and tonalite and Triassic-Jurassic metamorphic rocks at Lee-Allen are the closest outcrops of Mesozoic basement to the FORGE site. However, widespread exposures of the Mesozoic basement are found in the Stillwater Range and Sand Springs Range to the east of the Fallon FORGE site.

*Data Quality and Uncertainty:* The published geologic maps of the area are high quality and display stratigraphic relations in significant detail for both the Quaternary and bedrock geology. Typically, contacts on these maps are located within  $\pm 10$  m or less, thanks to excellent aerial photo coverage and imagery for the entire area. The first detailed geologic map that covered the area was by Morrison (1964) at 1:31,680 scale. Morrison focused primarily on the Quaternary geology but also provided the first stratigraphic summary of the Tertiary volcanic stratigraphy in the Bunejug and Lahontan Mountains. More recently, detailed 1:24,000 scale maps have been completed (Figure 13) that include the Grimes Point quadrangle (Bell et al., 2010), Lahontan

Mountains quadrangle (Bell et al., 2010), the Bunejug Mountains quadrangle (Hinz et al., 2011), and the Lee-Allen Geothermal area (Hinz et al., 2010). Stratigraphic relations are nicely constrained by geochronologic data, including nine  $^{40}\text{Ar}/^{39}\text{Ar}$  dates from the Lahontan and Bunejug Mountains (Hinz et al., 2011, 2014, unpublished data) and five additional  $^{40}\text{Ar}/^{39}\text{Ar}$  dates from the Lee-Allen geothermal area (Hinz et al., 2010, unpublished data).



**Figure 16. Generalized stratigraphic column showing major lithologic units within and proximal to the proposed Fallon FORGE site. Qb-2.5 to 0.7 Ma basalt flows; QTs-late Miocene to Quaternary basin-fill sediments; Tba, late Miocene-early Pliocene mafic lavas; Tr, ~12 Ma rhyolite lavas; Tvs-Miocene volcanic and lesser sedimentary rocks; Ttr, Oligocene ash-flow tuffs; Mzu-Mesozoic basement undivided.**



**Figure 17. Detailed geologic map of the Fallon FORGE site (from Bell et al., 2010, and Morrison, 1964). The map units consist of middle to late Holocene lacustrine and alluvial sediments. Deep wells that intersect the Mesozoic basement are shown for reference (purple dots).**

#### 4.1.2 Well Lithology Data

Data Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant			✓	✓		✓

In phase 1 of this project, 14,135 m of core, cuttings, and thin sections of core and cuttings were reviewed for wells from the Fallon FORGE site and monitor area to refine subsurface controls on the stratigraphic and structural framework (Figure 18). In addition, ~20,000 m of core and cuttings were briefly reviewed from publically available data in the surrounding areas. This information is critical for defining the composition and depth of potential EGS targets at the Fallon site and evaluating the site for any evidence of ongoing hydrothermal activity. Only three wells had core available, and none of these had core from the Mesozoic basement. FOH-2 was cored from 622-1234 m (2041 to 4048 ft) depth, but core was only preserved at 3 m (10 ft) increments every 15 m (50 feet). Well 18-5 was cored from 107-914 m (352 to 3000 ft) depth, and well 51-20 was cored from 216-1100 m depth (710 to 3610 ft). For the 18-5 well, 100% of core is preserved, and a skeletonized sample set of the 51A-20 core is preserved with samples at <15 m (< 50 ft) intervals. Core was evaluated by hand lens, and cuttings were examined in detail under a high-power binocular microscope. Petrographic thin sections of core and cuttings were also available for most wells at ~30 m (100 ft) intervals and were used in tandem with the physical core and cuttings samples to confirm lithologic data (Figure 19; Table 1).

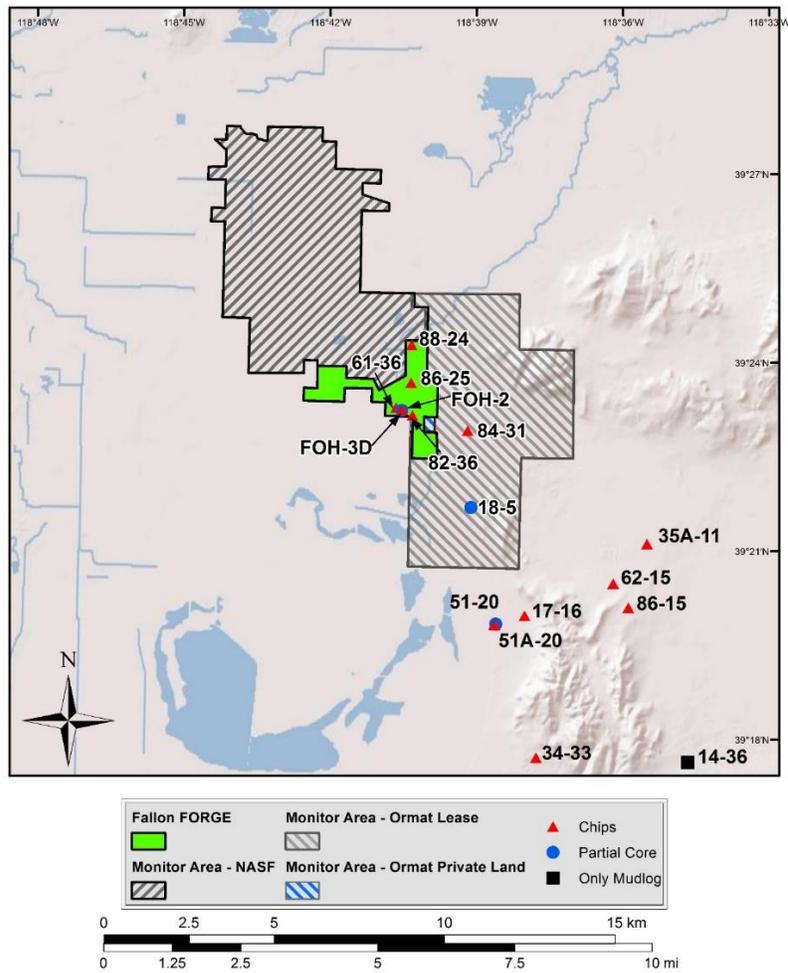
Within the primary FORGE footprint and designated surrounding FORGE monitor area, four wells (Figure 18 and Figure 19; wells 61-36, FOH-3D, 82-36, and 84-31) penetrate the entire Neogene section and terminate in Mesozoic basement. Late Miocene to Quaternary basin-fill sediments (QTs) are 0.1 to 1.4 km thick and overlie Miocene volcanic and lesser sedimentary rocks. The volcanic section is 0.7 to 1.1 km thick and is dominated by Miocene basaltic andesite lavas (Tba). In addition to Tba, five other volcanic units were distinguished within the cuttings and core, including volcanic breccia (Tvb), lithic tuff (Tlt), dacite (Td), andesite (Ta), and hornblende andesite (Tha). As evidenced by numerous drill holes, seismic reflection profiles, and gravity data, the total thickness of the Neogene section ranges from ~1.3 to 2.8 km in the project area. Overall, the volcanic section remains close to 1 km thick, whereas the Neogene sediments that sit on top of the volcanic rocks thicken toward the downthrown sides of discrete half grabens. Based on stratigraphic position and mineralogy, units Tba, Td, Tha, and Tvb all probably correlate with units mapped in the Bunejug Mountains and Lahontan Mountains (Hinz et al., 2011; Bell and House, 2010; and Bell et al., 2010). No evidence for recent hydrothermal activity (e.g., opaline sinter) was identified in samples from the basin-fill sediments.

The Neogene section rests nonconformably on heterogeneous Mesozoic basement, which consists of low- to medium-grade Triassic-Jurassic metavolcanic and metasedimentary rocks intruded by granitic plutons of probable Jurassic and/or Cretaceous age (Figure 19). The Mesozoic units exposed in the wells include plutonic rocks (quartz monzonite, Mzqm), metasedimentary rocks (quartzite, Mzq; and marble, Mzm), and metavolcanic rocks (ash-flow tuffs and volcaniclastic sediments, Mzt; felsic volcaniclastic sediments and altered basaltic andesite lavas, Mazba). The metavolcanic and metasedimentary rocks are locally contact

metamorphosed and/or hydrothermally altered, probably as a result of intrusion by one or more plutons. The highly altered basement units were logged as undivided metamorphic rocks (Mzum), because the parent lithology could not be confirmed through petrography or evaluation of the cuttings under high-power binocular microscope. All of these units are intersected by deep geothermal wells directly south of the FORGE area in the Carson Sink and southeast in the Salt Wells basin area (Figure 20).

In order of decreasing abundance, major lithologies in the Mesozoic basement include: (1) metamorphosed felsic ash-flow tuff, (2) meta-basaltic andesite, (3) quartzite, (4) granite, (5) slate, and (6) marble. The metamorphosed ash-flow tuff may correlate with the  $\sim 225 \pm 30$  Ma Rochester Rhyolite (McKee and Burke, 1972; Vikre, 1997), a regionally extensive unit that is well exposed in the Humboldt Range  $\sim 100$  km to the north of the FORGE site. Overall, the Mesozoic units are typical of much of western Nevada and formed in the back-arc region of the Sierran arc (e.g., Oldow, 1984; Busby-Spera, 1988; Lutz and Hulen, 2002; Figure 20 and Figure 21).

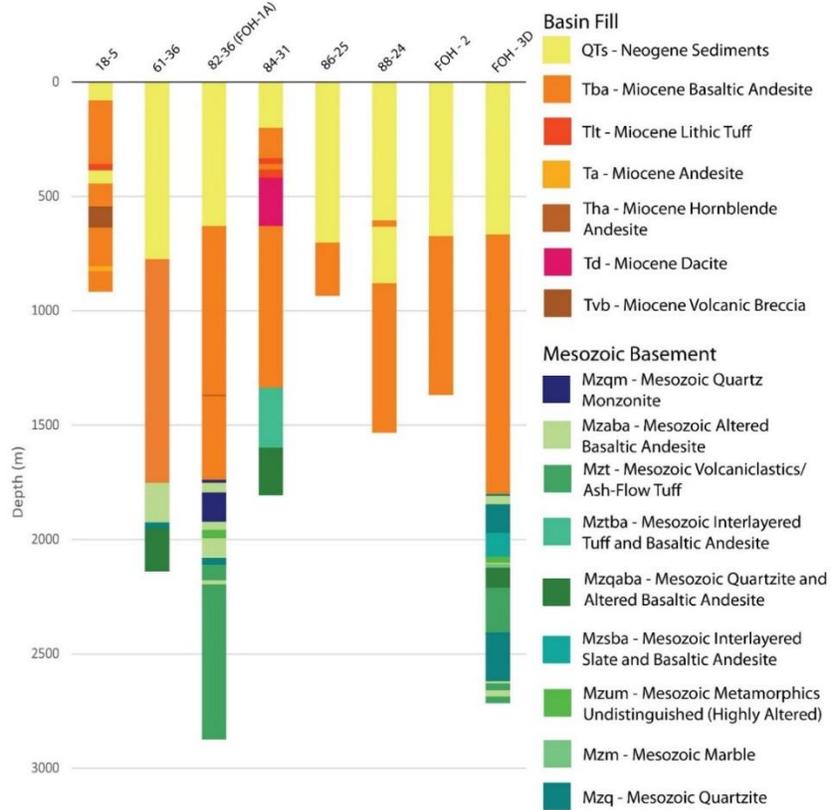
*Data Quality and Uncertainty:* For wells with complete or partial core, including 18-5 and FOH-1, respectively, the depths to unit contacts are very accurate, consistently  $< 3$  m (10 ft). For wells with cuttings, the accuracy of depths of Cenozoic unit contacts are mostly  $\pm 3$  m (10 ft) and locally  $\pm 6$  to 10 m (20 to 33 ft). The accuracy of depths of Mesozoic unit contacts recognized through cuttings are mostly  $\pm 3$  m (10 ft) and locally  $\pm 15$  m (50 ft). The areas with the largest error margin involve accurately defining the Cenozoic/Mesozoic nonconformity, where it consists of altered Tertiary volcanic rocks in depositional or fault contact with altered Jurassic-Triassic metavolcanic rocks. Locally, the nonconformity is defined by altered Tertiary mafic lavas resting on altered metamorphosed mafic lavas, or altered Tertiary tuffs against altered Mesozoic meta-tuffs. In these areas, petrographic data were closely evaluated to analyze subtle differences in primary and secondary mineralogy. Accuracy for these intervals typically ranges from  $\pm 30$  to 60 m (100 to 200 ft).



**Figure 18. Moderate to deep geothermal wells on the FORGE site, FORGE monitor area, and nearby region with cuttings or core available for evaluation. All wells on the FORGE site and FORGE monitor area were reviewed in detail. Wells in the surrounding region were reviewed more generally, with a focus on the depth to basement and on distinguishing the basement lithologies.**

**Table 1. Unit descriptions from wells at the FORGE site and FORGE monitor area (Figure 19)**

Unit	Name	Description
<b>Cenozoic</b>		
QTs	Sediments	Light to medium gray silt to coarse sand, rounded grains of quartz, lithic fragments, feldspars, micas, and clay (ordered from most to least abundant) in a clast-dominated, carbonate cemented lithic sandstone. Uncommonly interlayered with reworked tuffs. Rarely altered to clays and chlorite. Miocene to Holocene in age.
Tvb	Volcanic breccia	Poly-lithologic, sub-rounded to sub-angular clast-dominated breccia. Mafic volcanic clasts include porphyritic, aphanitic, or vesicular basaltic andesite. Clast size ranges from 1 mm to 10 cm. Probable Miocene age.
Tlt	Lithic tuff	Medium to dark gray tuff with sparsely dispersed lithic fragments (locally reworked as a mudflow deposit) are within a commonly crystal rich matrix. Miocene.
Td	Dacite	Light gray, weakly vesicular, sparsely porphyritic (<5% of crystals are porphyritic acicular hornblende crystals) dacite; sparse biotite in some flows. Probable Miocene age and correlates with dacite mapped in the southwest corner of the Lahontan Mountains quadrangle (Bell et al., 2010). Age is probably ~12 Ma.
Ta	Andesite	Medium gray, sparsely porphyritic andesite with phenocrysts of pyroxene up to 1 mm long. Groundmass is aphanitic and glassy. Probable Miocene age.
Tha	Hornblende andesite	Light gray porphyritic hornblende andesite with 1-2 mm hornblende and plagioclase crystals in an aphanitic, glassy matrix. May correlate with Tha mapped in the northwest corner of Bunejug Mountains quadrangle, where Tha is locally interbedded in the upper part of the ~16 to 12 Ma section of Tba (Hinz et al., 2011).
Tba	Basaltic andesite	Dark gray aphanitic and locally sparsely porphyritic basaltic andesite. Phenocrysts include mostly plagioclase and lesser olivine and pyroxene. Chlorite, calcite and clay alteration is fairly common with trace epidote and pyrite alteration. Quartz and calcite veins distributed sparsely throughout this unit. Unit correlates with Tba exposed in the Bunejug Mountains and Tb at Rainbow Mountain; both outcrops dated at ~16 to 12 Ma (Hinz et al., 2011, 2014, unpublished data; Bell et al., 2010).
<b>Mesozoic</b>		
Mzqm	Quartz monzonite	White, fine- to medium-grained quartz monzonite. Weak to moderate chlorite alteration with calcite and trace prehnite in voids. Jurassic-Cretaceous. Numerous Jurassic to Cretaceous granitic intrusions in southern Stillwater and Sand Springs Ranges to east. Other nearby granitic outcrops, as at Lee-Allen geothermal area, have not been dated, but are probably broadly correlative.
Mzum	Metamorphics undivided	Interlayered white to light gray quartzite, white marble, and tan to buff micaceous schist. Quartzite, the most common lithology, is fine-grained and weakly annealed. Marble, of moderate abundance, has minor component of quartz in calcareous dominated matrix. Trace schist with moderate to strong foliation from muscovite. Mzum is highly altered, possibly due to hydrothermal alteration and/or contact metamorphism in Mesozoic related to granite intrusion. Alteration locally increases near granite. Triassic- Jurassic.
Mzq	Quartzite	White to pale green quartzite with chlorite-pyrite alteration. May correlate with Jurassic Boyer Ranch quartzite in Stillwater Range (Speed and Jones, 1969).
Mzqaba	Interlayered quartzite and meta-basaltic andesite	White to light gray quartz, with trace interstitial calcite, weakly annealed quartzite interlayered with green-gray to brown weakly porphyritic altered basaltic andesite. Trace pyrite is disseminated in quartzite, and basaltic andesite has significant clay alteration as well as chlorite overprinting groundmass. Jurassic.
Mzaba	Meta-basaltic andesite	Gray-green, aphanitic to fine-grained basaltic andesite, moderately to highly altered to clay and chlorite. Some sections are mottled red to purple color. Less commonly epidote and pyrite as alteration minerals. Jurassic in age.
Mztba	Interlayered metamorphosed tuff and meta-basaltic andesite	Pale green, gray, and red mottled ash-flow tuff, glassy matrix with trace to 0.5% pyrite and chlorite. Ash layers <3 m (10 ft) thick and interlayered with aphanitic basaltic andesite flows with olivine and plagioclase groundmass. Triassic-Jurassic.
Mzsba	Interlayered slate and meta-basaltic andesite	Very fine-grained, dark gray, moderately foliated, locally carboniferous slate interlayered with dark gray to brown weakly porphyritic plagioclase rich basalt. Triassic to Jurassic in age.
Mzt	Meta-ash-flow tuffs and volcanioclastic sediments	Light gray-green, pale red and/or maroon fine-grained, generally non-welded, weakly metamorphose ash-flow tuffs. Lithic fragments as well as porphyritic crystals of plagioclase and quartz common in a microcrystalline groundmass. Chlorite, clay, and trace epidote alteration is common. Triassic to Jurassic in age.
Mzm	Marble	White to light gray quartz-bearing marble. Triassic to Jurassic in age.



**Figure 19. Lithologies of the 8 deepest wells on the Fallon FORGE site and the surrounding monitor area (Figure 18). In this figure, depth corresponds to well path distance, not true vertical depth. All available cuttings, core, petrographic thin sections of cuttings and core, and down-hole logs for these wells were reviewed in Phase 1 of this project. Detailed unit descriptions are in Table 1.**

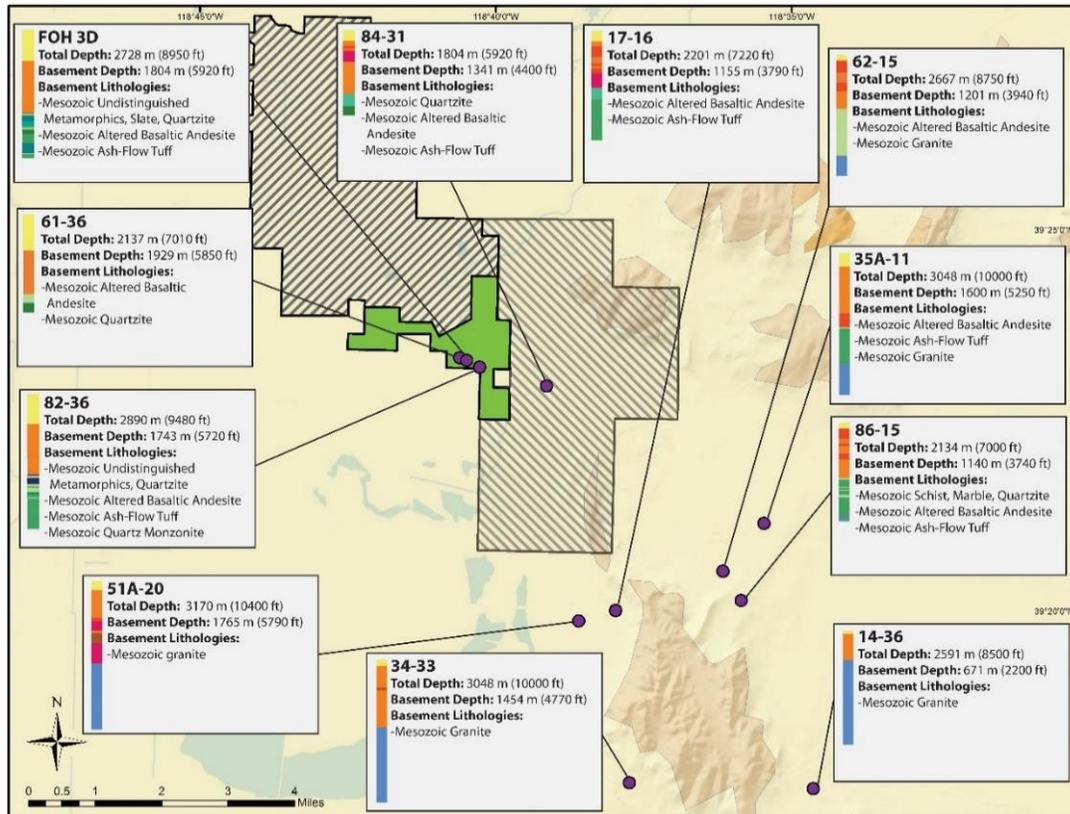
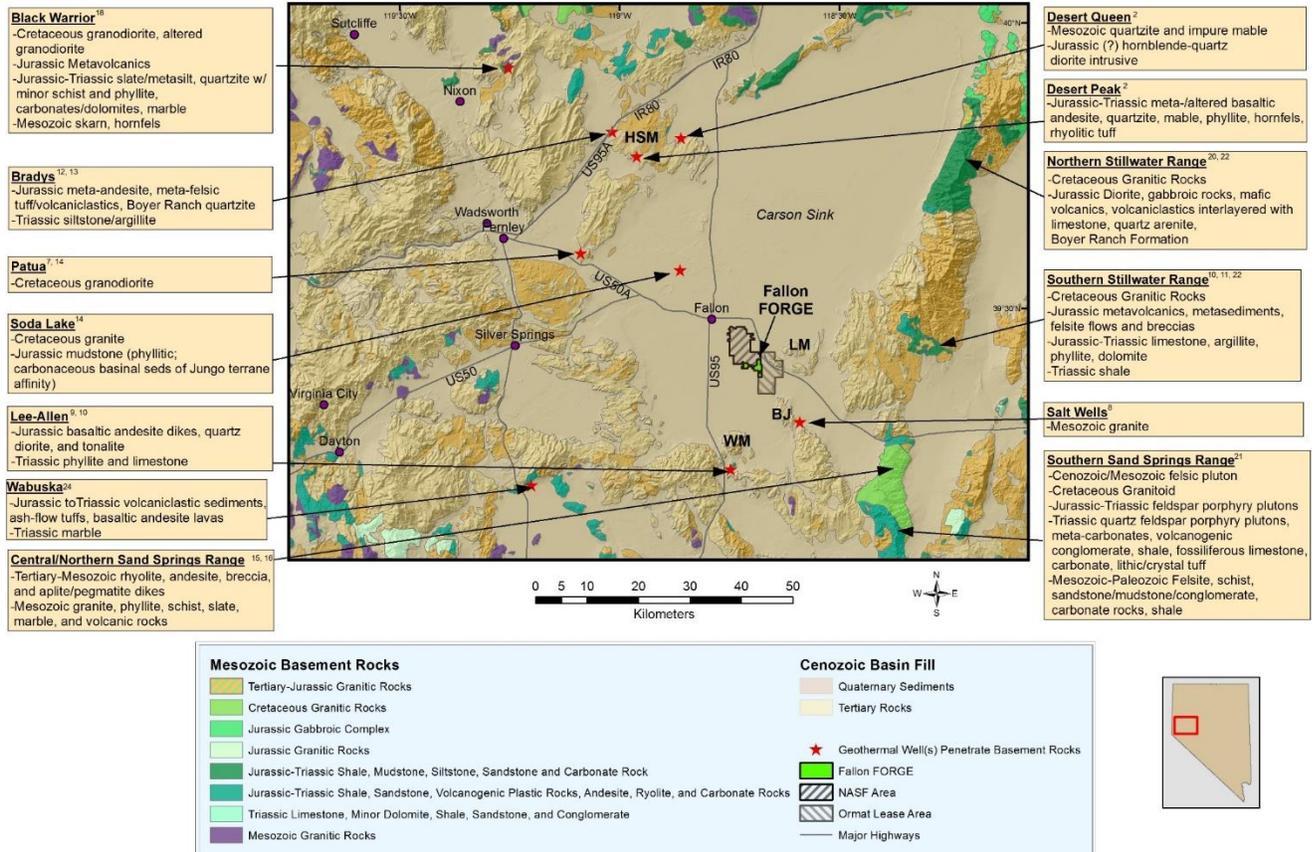


Figure 20. Cenozoic and Mesozoic stratigraphy of all wells at Fallon FORGE and in the immediate surrounding area that penetrate the entire Cenozoic section and terminate in the Mesozoic basement.



**Figure 21. Regional geologic map of the Carson Sink area highlighting the distribution of known Mesozoic basement lithologies exposed in ranges and intersected by deep geothermal wells. The base map is simplified from Stewart and Carlson (1978). Red stars correspond to known geothermal areas with basement characterized from outcrops and/or deep wells. Labels: BJ, Bunejug Mountains; HSM, Hot Springs Mountains; LM Lahontan Mountains; WM, White Throne Mountains. References noted in this figure: <sup>1</sup>Barton et al., 2000; <sup>2</sup>Benoit et al., 1982; <sup>3</sup>Buer and Miller, 2010; <sup>4</sup>Dilek and Moores, 1995; <sup>5</sup>Hinz et al., 2013b; <sup>6</sup>Ernst et al., 2008; <sup>7</sup>Garg et al., 2015; <sup>8</sup>Hinz et al., 2014; <sup>9</sup>Hinz et al., 2008; <sup>10</sup>Hinz et al., 2010; <sup>11</sup>John, 1995b; <sup>12</sup>John and Silberling, 1994; <sup>13</sup>Lutz and Hulen, 2002; <sup>14</sup>Lutz et al., 2010; <sup>15</sup>McLachlan, personal communication; <sup>16</sup>UNR, 1962; <sup>17</sup>Oldow, 1984; <sup>18</sup>Sadowski, personal communication; <sup>19</sup>Speed, 1974; <sup>20</sup>Speed and Jones, 1969; <sup>21</sup>Satterfield, 2002; <sup>22</sup>Willden and Speed, 1974; <sup>23</sup>Wyld, 2002.**

### 4.1.3 Petrographic Data

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant	✓		✓	✓		✓

Numerous thin sections exist for cuttings and core of samples from FORGE site wells, wells on the monitor areas, and bedrock units exposed in nearby areas analyzed and mapped by Hinz et al. (2008, 2010, 2011, 2014). These include 431 thin sections from wells and 96 thin sections from surface outcrops in the Lahontan Mountains, Bunejug Mountains, Cocoon Mountains, and the Lee-Allen geothermal area (Figure 13 and Table 2). Petrographic data are necessary for refining the lithology and depth of potential EGS targets, as well as for characterizing hydrothermal alteration and history. Most of the preexisting thin sections available from the FORGE area wells were reviewed to confirm and/or modify the original lithologic logs, so that accurate lithologic data would be available for comparison against 2D seismic profiles, MT profiles, gravity inversions, and for constructing the 3D geologic model. In addition, no petrographic evidence was found for recent geothermal activity. The petrographic data are summarized in the preceding well lithology section of this report. Many of the thin sections of core and cuttings from the FORGE site wells have been previously described in detail with a specific focus on alteration mineralogy (Jones and Moore, 2013), and these results are summarized in the alteration section of this report.

Thin sections were also available from previously completed detailed geologic mapping in nearby areas to the south and east of the FORGE site. Thin sections from these areas have previously been used to confirm lithologic map units and for selecting unaltered samples for  $^{40}\text{Ar}/^{39}\text{Ar}$  dating. Multiple thin sections exist for the Mesozoic granitic and meta-sedimentary units exposed at the Lee-Allen geothermal area, the closest surface outcrop of Mesozoic basement units to the Fallon FORGE area (Figure 1).

*Data Quality and Uncertainty:* The manufacturing of thin sections was high quality in all cases, both for samples from surface outcrops, core, and from cuttings. In the case of cuttings, there is nearly always a small percentage of contamination, typically <1-5% of exotic cuttings that fall down the well bore into any given sample interval. During evaluation of the cuttings in thin section or under a binocular microscope, it is usually easy to identify the exotic chips and focus the analysis on the in situ lithology.

**Table 2. Thin-section inventory of core and cutting samples**

Well or Map Area	Number of Thin Sections	Depth Range (ft)	Depth Range (m)	Approx. Interval (ft)	Approx. Interval (m)
FOH 3D	87	70 - 8950	21 - 2728	100	31
82-36	100	160 - 9490	49 - 2893	95	29
84-31	62	100 - 5900	30 - 1798	95	29
18-5	29	358 - 3000	109 - 914	95	29
61-36	72	130 - 6970	40 - 2125	100	31
88-24	50	110 - 5910	34 - 1801	100	31
FDU-2D	31	1540 - 4500	469 - 1372	100	31
Bunejug and Cocoon Mountains	54	Surface Outcrops	Surface Outcrops	N/A	N/A
Lahontan Mountains	5	Surface Outcrops	Surface Outcrops	N/A	N/A
Lee-Allen Geothermal Area	37	Surface Outcrops	Surface Outcrops	N/A	N/A

Note: Data were gleaned from wells and from nearby detailed geologic mapping (Jones and Moore, 2013; Hinz et al., 2010, 2011, unpublished mapping).

## 4.2 STRUCTURAL DATA

### 4.2.1 General Structural Setting

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant		✓			✓	✓

Permeability, stress regime, and likelihood of discovering an active hydrothermal system are critical parameters for developing a successful FORGE and are all strongly dependent on the overall structural setting of an area (e.g., Curewitz and Karson, 1997; Faulds et al., 2011; Faulds and Hinz, 2015). Detailed geologic maps, fault-slip data, and well-bore imaging collectively provide a comprehensive data set with which to evaluate the structural setting of the Fallon FORGE site. The structural framework within and surrounding the proposed Fallon FORGE site, including the Carson Sink and bounding mountain ranges to the northwest, north, and east, is characterized by northerly striking normal faults and gently to moderately tilted fault blocks (Figure 12). The southwestern margin of the Carson Sink is probably bound by strands of the Walker Lane dextral shear zone. The Carson Sink itself is largely composed of a series of half grabens containing as much as 3 km of basin-fill sediments. In contrast to parts of the northern Carson Sink (Faulds et al., 2015) and the neighboring Bunejug Mountains and Lee-Allen area (Hinz et al., 2008, 2011, 2014), the structural setting of the southeastern Carson Sink in the vicinity of the FORGE site appears to be relatively simple, with no major basin-bounding faults and a paucity of mapped faults. The apparent lack of structural complexity, lack of Quaternary faults, and absence of a favorable structural setting for geothermal activity (Figure 10; e.g., Faulds et al., 2011) in this area indicate that a hydrothermal system is unlikely, thus satisfying an important criteria for the FORGE site.

In the subsections below, we describe the geometry and kinematics of observed faults in the area, as gleaned from detailed geologic maps to the east and south, and then discuss the stress regime, as defined by borehole imaging of drilling-induced fractures and inversion of fault-kinematic data from nearby bedrock exposures. As discussed in subsequent sections, detailed gravity surveys and 14 seismic reflection profiles help to further constrain the structural setting, demonstrating that a gently west-tilted half graben cut by widely spaced normal faults underlies the entire FORGE site (Figure 12 and Figure 22).

#### 4.2.2 Geometry and Kinematics of Faults

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant		✓			✓	

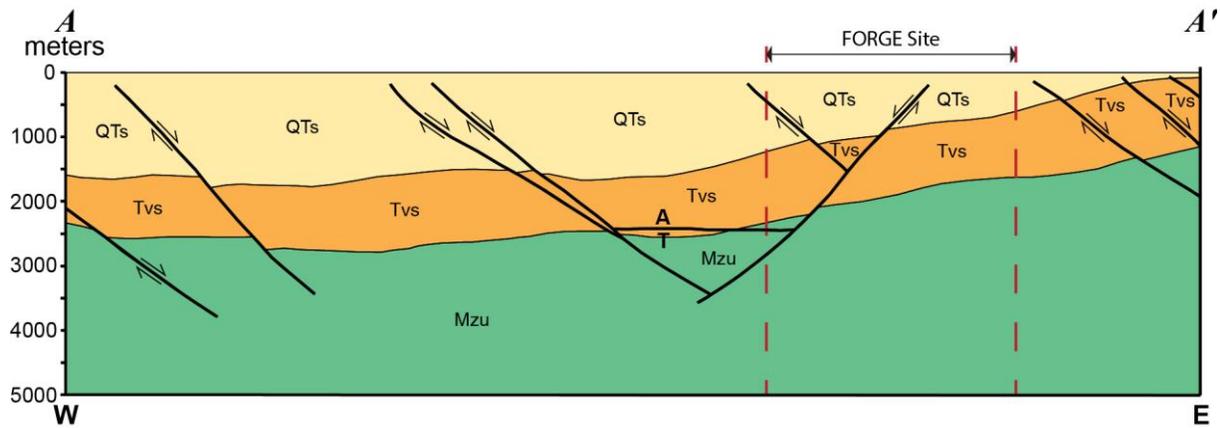
The structural framework of rock units, including the age, geometry, density, and kinematics of faults, greatly affects the mechanical properties of rocks and significantly affects both fluid flow and the response to hydraulic stimulation (e.g., Genter et al., 2010). In the Fallon region northerly striking normal faults dominate and bound gently to moderately tilted fault blocks, as exemplified by excellent exposures in nearby mountain ranges (Hinz et al., 2010, 2011). The Lahontan and Bunejug Mountains region directly east of the FORGE site contain two prominent east-dipping faults, the ~25 km-long Rainbow Mountain fault zone and the ~15 km-long Fourmile Flat fault zone (Figure 12). In addition, numerous north-northwest- to north-northeast-striking normal faults with 10s to 100s of meters of displacement cut the Mio-Pliocene strata in these ranges. These normal faults comprise multiple dip domains throughout the region, yielding several accommodation zones (cf., Faulds and Varga, 1998), including three extensional synclines, two extensional anticlines, and one transverse zone (Figure 12). The Fallon FORGE site lies on the western limb of an anticlinal accommodation zone, the axis of which is exposed in the western Bunejug and Lahontan Mountains. The extensional syncline in the Bunejug Mountains is reflected by the distribution of poles to layering in the Miocene volcanic bedrock (Figure 23). The extensional fold axis trends N17°E, consistent with a WNW-trending extension direction in the area. The eastern limb of the syncline has fewer data points, because much of the bedrock in this structural domain is concealed by Quaternary surficial deposits.

Most of the north-northwest- to north-northeast-striking faults in the Lahontan and Bunejug Mountains have accommodated dip-slip normal or nearly pure normal slip (Figure 24), indicating a west-northwest-trending extension direction (Hinz et al., 2014). However, the 1954 historic rupture of the north-striking Rainbow Mountain fault zone had a dextral component of up to 1 m (strike-slip magnitude dominated over normal slip). Analysis of slip data collected from exposed fault surfaces in the Bunejug Mountains along the Rainbow Mountain fault zone indicate that episodic dextral slip has been accommodated by this fault zone throughout its history. However, cumulative dextral slip relative to normal slip is probably very small (Hinz et al., 2014).

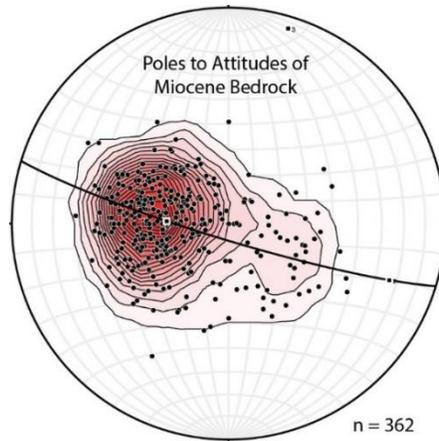
In addition to the published geologic maps, high resolution Q1 quality LiDAR data and 1:12K scale, low sun-angle aerial photos have previously been collected over the area to evaluate for

potential Quaternary fault scarps. There are no documented Quaternary faults on the proposed Fallon FORGE site or in the proposed NASF/Ormat FORGE monitor area (Calvin et al., 2012). In addition to the 1954 earthquake, the Rainbow Mountain fault zone, ~10 km east of the proposed Fallon FORGE area, ruptured two other times in the past ~20,000 years (Caskey et al., 2004). A small Quaternary fault segment ~0.5 km long occupies the west-northwest part of the Bunejug Mountains quadrangle (Hinz et al., 2011) and sits ~7-8 km southeast of the proposed Fallon FORGE site.

*Data Quality and Uncertainty:* The distribution of Quaternary fault activity across the four 1:24K scale map areas, including coverage of the FORGE site, was evaluated with Q1 quality LiDAR data and/or 1:24K scale, low sun-angle aerial photos. Thus, Quaternary faults are located with a high level of precision and very low uncertainty for the entire area ( $\pm 10$  m or less). Older faults cutting bedrock units in the nearby mountain ranges are generally located within  $\pm 10$ -30 m.



**Figure 22. East-west geologic cross section across the proposed Fallon FORGE site. Margins of site are shown by dashed red lines. Location of cross section is shown in Figure 12.**



**Figure 23. Equal-area stereographic projections of poles to bedding and layering of Miocene strata exposed in the Bunejug Mountains quadrangle (Hinz et al., 2011, 2014, unpublished data). Data points shown by black dots. n = number of data points. Kamb contour intervals at 2 sigma, 2.4% of the area. Two clusters reflect extensional folding, with loci at ~N3°E, 27°E and ~N26°E, 24°W. Fold axis derived from cylindrical best fit = trend N17°E, plunge 6°; significance = 3 sigma.**

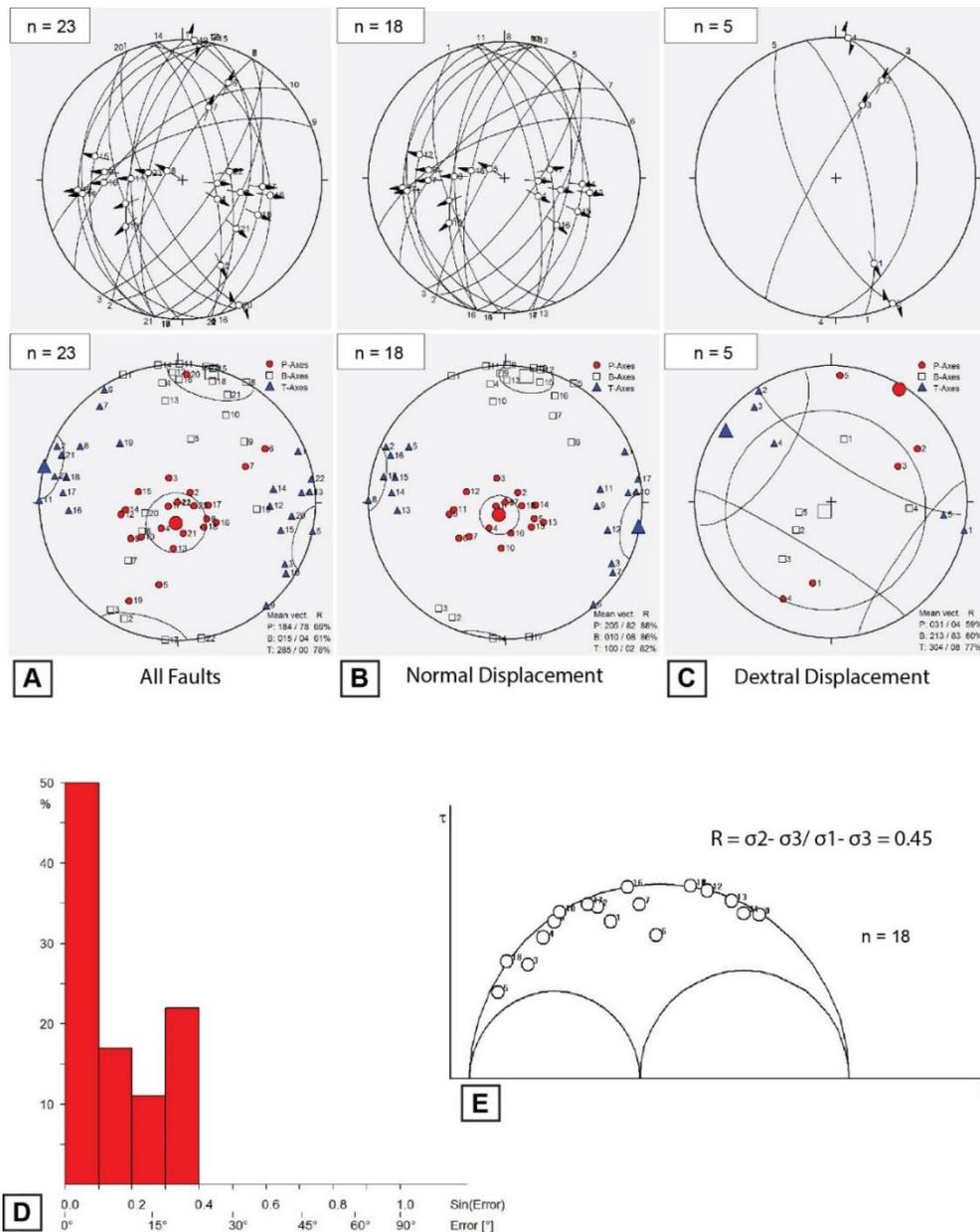


Figure 24. (A, B, C) Lower hemisphere stereographic projection of great circles of exposed faults in the Bunejug Mountains quadrangle (Hinz et al., 2011, 2014, unpublished data). n = number of data points. Arrows indicate slip directions inferred from striae and other kinematic indicators (e.g., Riedel shears). PBT axis diagrams, showing the orientations of principal strain axes for each measured fault. Large symbols are mean vectors to all P, B and T axes and represent the strain field. R-squared values of 88%, 86%, and 82%, respectively for the P, B, and T axes in group C. (D) Histogram comparing angle of the measured versus calculated shear strain within the fault plane. Angles <15 to 20° generally correspond to a single stress field (e.g. Sippel et al., 2009). (E) Mohr's circle plot, stress ratio  $R = 0.45$ , which is typical of dominantly pure extensional versus transtensional or strike-slip.

### 4.2.3 Stress Regime

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant		✓			✓	

Detailed knowledge of the stress regime, combined with data on the strength parameters of rock units and spacing and orientation of fractures and faults, will help to guide EGS experiments and allow for predictive analysis of the results (e.g., Moeck et al., 2009; Davatzes and Hickman, 2009, 2010). The local stress regime for the Fallon FORGE site was determined through previous studies (Blake and Davatzes, 2012; Blake et al., 2015) focusing on (1) the analysis of geophysical image log data for wells FOH-3D, 61-36, 86-25 and 88-24 (Figure 3; Appendix A); and (2) inversion of fault slip data from the Bunejug Mountains area directly east of the site, which includes the Salt Wells geothermal field. The nature of the stress regime is one of the most critical factors governing the mechanical response of rock units to hydraulic stimulation.

**Well-Bore Imaging:** In previous studies, image logs from these four wells were analyzed using the software WellCAD to map the orientation of natural fractures and bedding orientation along with drilling induced structures, such as breakouts, petal-centerline fractures, and tensile fractures (Figure 25 and Figure 26; Table 3; Blake and Davatzes, 2012; Blake et al., 2015). These induced structures result from concentration of normal stress acting tangentially to the borehole wall, with the enhancement of compression or tension generating breakouts and tensile fractures, respectively. Petal-centerline fractures form below the drill bit during drilling due to a stress concentration that creates tension tangential to the wellbore floor (Li and Schmidt, 1999; Davatzes and Hickman, 2010; Garza-Cruz and Davatzes, 2010).

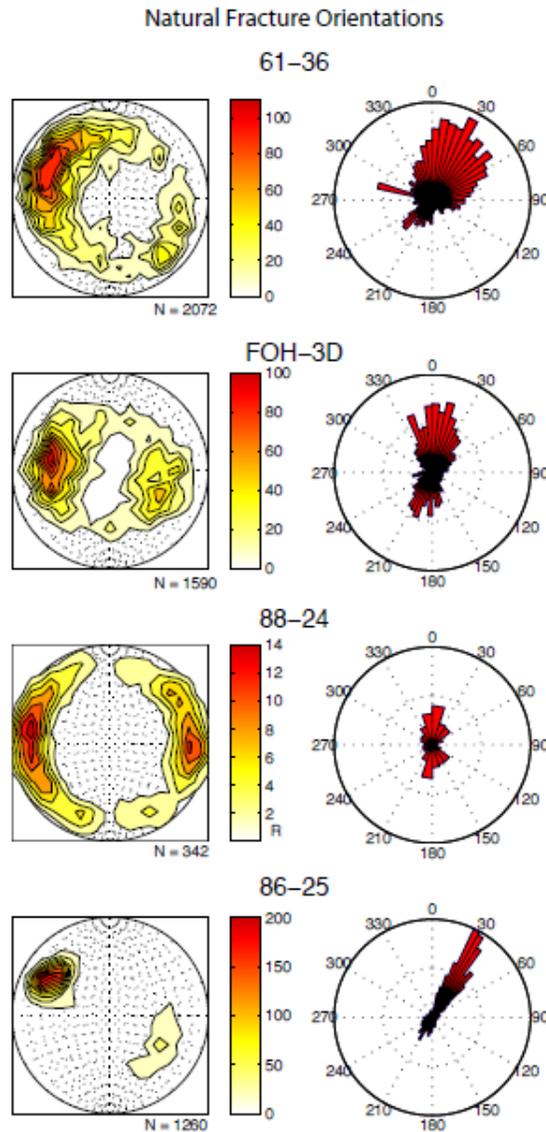
Analysis of these data was performed in MATLAB using custom scripts (Blake and Davatzes, 2012; Blake et al., 2015). Both FOH-3D and 61-36 terminated within the depth range (>1.5 km) and lithology (Mesozoic basement) that fall within the FORGE criteria. Data are available from both the Cenozoic and Mesozoic sections. Wells 88-24 and 86-25 terminated in the Cenozoic stratigraphy and did not reach the Mesozoic basement. Analyses from all wells provide components for characterization of the local stress state in 3D space within the FORGE site (Figure 25).

**Table 3. Structural and Stress Data Derived from Image Logs**

Exploration Hole	88-24	86-25	61-36	FOH-3D
Image Log Type	UBI	FMI	FMI	FMS, ABI
Depth analyzed in feet (meters)	2710-5010 (826-1527)	1525-3050 (465-930)	2570-7025 (783-2141)	6463-8950(1970-2728)
Fracture Orientation (avg)	001	025	015	010
Fracture Dip (avg)	77.5	62.9	65.5	59.5
Bedding Orientation (avg)	001	025	015	015
Bedding Dip (avg)	65.9	68.4	55.3	56.2
S <sub>Hmax</sub> Orientation (avg)	005±26	026±25	021±28	007±12

The stress heterogeneity of the volume pierced by the wellbore is demonstrated in Figure 26. The three types of induced structures are represented in each well and were used to calculate the orientation of minimum horizontal stress. By aligning the induced structures, the stress heterogeneity with depth is easier to visualize. FOH-3D and 61-36, the two wells that meet the requirements for FORGE both in depth to basement and temperature have different distributions of induced structures. The induced structures in FOH-3D fall tightly around the calculated minimum principle horizontal stress within the crystalline rock. As depth increases with the 61-36 data, the induced structures collapse around the mean minimum principal stress orientation roughly within the bottom 300 m that intersect this same crystalline rock. Although the variation in stress is smaller within the crystalline rock, it is still present. Overall, the slight variations (~20°) found in these data sets, whether in the fracture strike orientation or in the maximum horizontal stress orientation, will be useful for predictive analysis of future stimulation of an EGS reservoir at the Fallon FORGE site. Some heterogeneity in fracture and stress orientation results in an increase in the range of optimally-oriented fractures over the depths analyzed.

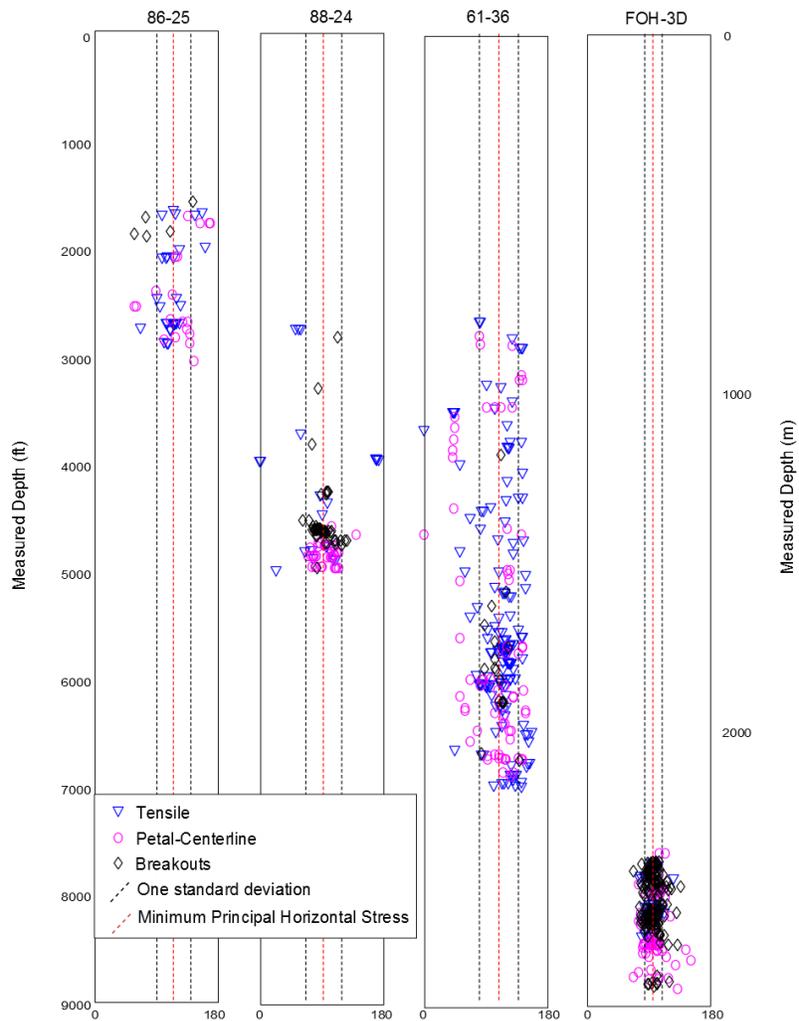
The strike orientations of the natural fractures calculated from the image logs appear to correlate with the overall structural setting in this portion of the Carson Sink. The average strike of fractures is ~013°, and the average maximum horizontal stress is 015° (Figure 25). Within this part of the Basin and Range province, the predominant strike of normal faults is ~N-S to NNE, and the current extension direction trends WNW. Thus, the findings from the image logs are compatible with the regional geologic setting (Figure 10). Figure 27 shows that the SHmax orientations calculated for the Fallon FORGE site are also very similar to that determined for several geothermal fields in the area.



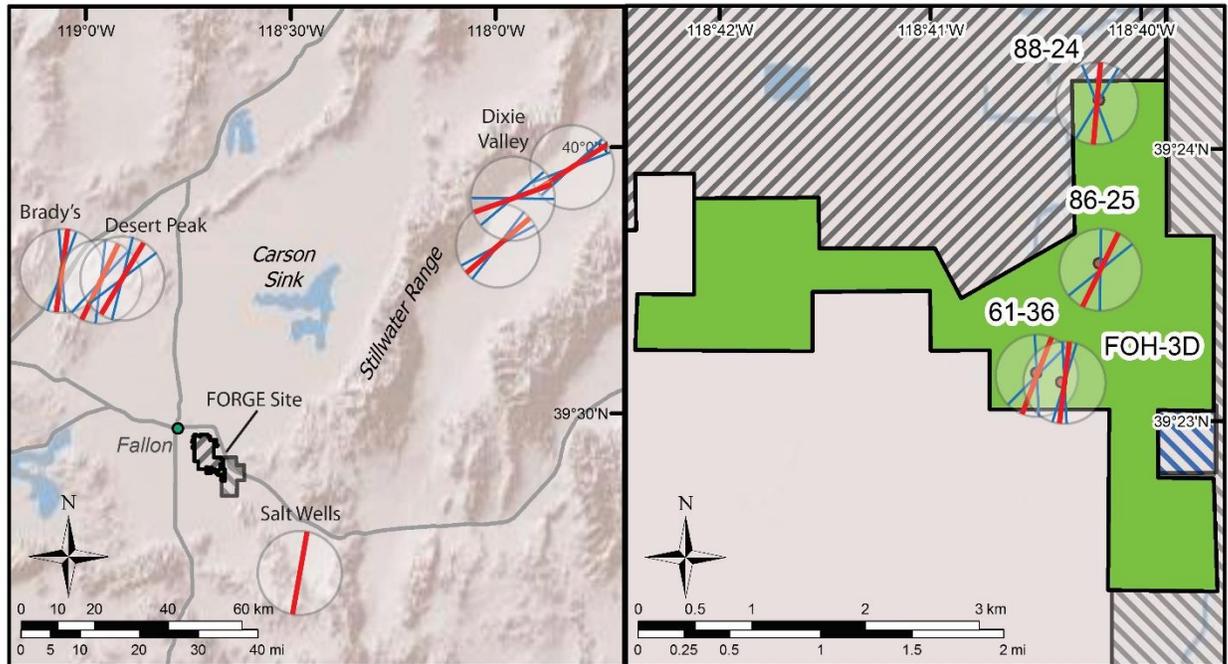
**Figure 25. On the left are the contoured poles to planes of the fractures mapped within the image logs of the four wells analyzed and on the right are rose diagrams of fracture strikes that were mapped from these same data.**

As described above, a great amount of work had previously been completed to determine the principal stress orientations at NASF by mapping natural and induced structures within image logs from the 88-24, FOH-3D, 61-36, and 86-25 wells and analyzing those mapped structures. Throughout the Basin and Range province, including the Carson Sink region, principal stress orientations have also been acquired through focal mechanisms, in-situ stress measurements (e.g., Hickman et al., 2000; Davatzes and Hickman, 2010), fault slip data (Bellier and Zoback, 1995), alignments of volcanic structures (Zoback et al., 1989), and geodetic measurements of strain (Bennett et al., 2003; Hammond and Thatcher, 2004; Kreemer et al., 2009) as a way to thoroughly understand the extensional setting and the state of stress (Figure 27). Detailed stress

information from geothermal systems are helpful for development of a field, particularly in locating wells and predicting reservoir response to pressure changes due to injection and/or production activities (Barton et al., 1997; Curewitz and Karson, 1997; Heffer, 2002; Davatzes and Hickman, 2009; Faulds et al., 2006). Recent work by Siler et al. (2016b) at the Brady's geothermal field synthesized the stress state, orientations, interactions, and likelihood to dilate or slip of faults in order to visualize the areas within the field most useful to target for geothermal fluid flow. Within the potential EGS system at Fallon, a complete understanding of stress state, the structural setting, and the heterogeneity of the principal stresses is an important tool for constraining the interaction of fractures during stimulation and the orientation that these fractures will dilate, slip, and grow (Rutledge et al., 2004).



**Figure 26. Mapped induced structures with depth along each of the studied boreholes with the calculated minimum horizontal stress based on these data. The stress heterogeneity decreases with depth, but the stress does continue to vary within the crystalline rock (deeper than ~1800 m). X-axis in degrees.**



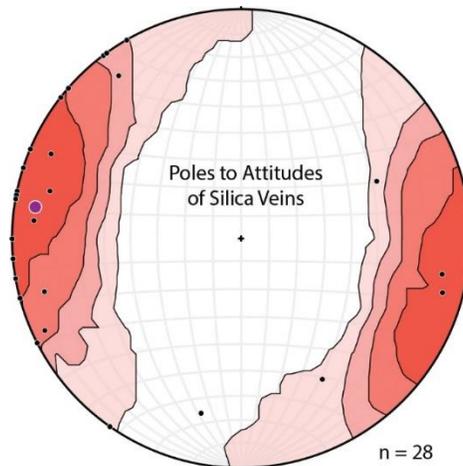
**Figure 27.  $S_{Hmax}$  orientations shown by red lines with error margins shown by blue lines (modified from Blake and Davatzes, 2012; Blake et al., 2015). Data are plotted for all depth ranges in measured well bores. Data derived from the following for individual geothermal fields: Desert Peak, wells 23-1 (Robertson-Tait et al., 2004) and DP 27-15 (Davatzes and Hickman, 2009; Hickman and Davatzes, 2010); Brady's (Moos et al., unpublished data); Dixie Valley (Barton et al., 1998; Hickman et al., 2000 and references therein); and Fallon (Blake and Davatzes, 2012).**

*Inversion of Fault-Slip Data:* Previous studies on strain data and the inferred stress conditions in the Bunejug Mountains and Salt Wells geothermal area complement the stress analyses from well data at the Fallon FORGE site and include summaries of bedding attitudes, extensional fold axes, fault kinematics, and vein orientations (Hinz et al., 2011, 2014, unpublished data). Fault surface exposures in Miocene bedrock included a range of north-northwest- to east-northeast-striking fault segments, and both west- and east-dipping fault populations (Figure 24a, Hinz et al., 2011, 2014, unpublished data). Slip azimuths cluster into two primary sets, one indicating approximate east-west extension and the other indicating north-south oriented dextral-oblique to pure strike-slip motion on pre-existing normal faults (Figure 24b, c). Stress inversions of these data for the extensional set indicate a vertically oriented maximum principle stress ( $\sigma_1$ ) and a least principle stress ( $\sigma_3$ ) trending west-northwest (Figure 24b). The distribution of strain axes in group (B) is generally consistent with a single stress field orientation (Figure 24d). The results of analysis of the normal displacement group (B) are  $P = \sigma_1 = 205^\circ/82^\circ$ ;  $B = \sigma_2 = 010^\circ/08^\circ$ ;  $T = \sigma_3 = 100^\circ/02^\circ$  (trend/plunge). The T-axis is the extension direction, which trends N80°W.

Stress inversion of the kinematic data for the dextral slip data (Figure 24c, Hinz et al., 2011, 2014, unpublished data) indicate subhorizontal orientations for  $\sigma_1$  and  $\sigma_3$ . These orientations are similar to the derived focal mechanisms of the 1954 Rainbow Mountain and Dixie Valley earthquakes (Doser, 1986), and to the results of stress-inversions of kinematic data collected along the 1954 fault scarps in the central Nevada seismic belt (Caskey et al., 1996, 2004). The

Rainbow Mountain fault zone is dominantly a normal-slip structure. However, the data from fault surfaces collected in the bedrock exposures in the Bunejug Mountains area and from the 1954 faults indicate episodic dextral slip along north-northwest- to northeast-striking normal fault segments. This pattern may characterize other key faults in the central Nevada seismic belt, such as the Fairview Peak fault zone.

Silica veins in outcrops of Miocene bedrock and silicified late Quaternary sediments provide additional data from which stress orientations have been inferred (Hinz et al., 2014, unpublished data). Silica veins in the bedrock were only observed near silicified sediment and in areas of hydrothermally altered bedrock, generally within the modern-day thermal anomaly at Salt Wells. Figure 28 shows poles to planes of 28 veins. They have an average strike of N9°E and dip of 80°E. The average orientation of the silica veins implies a least principle stress ( $\sigma_3$ ) trending N81°W, and along with bedding attitudes and fault slip data, collectively support a WNW-trending extension direction in the Salt Wells-Bunejug Mountains area. These relations are compatible with the stress orientations garnered from well-bore imaging at the Fallon FORGE site.



**Figure 28. Equal-area stereographic projections of density contour of poles to silica veins cutting Miocene bedrock and Quaternary sediments from the Salt Wells geothermal area (Hinz et al., 2011, 2014, unpublished data). Kamb contour intervals = 2 sigma, 23.7% of the area. Mean attitude = N9°E, 80°SE; significance = 3 sigma.**

*Data Quality and Uncertainty:* The fracture and stress data were calculated from structures mapped from geophysical images of the borehole walls, and with these data comes certain assumptions and uncertainties (Figure 26). Imaging of different geophysical properties and lack of complete wellbore coverage introduce uncertainties within the data set. However, the compilation of four detailed fracture and stress datasets provides overlap of these uncertainties.

In boreholes generally 1-5 km in depth, it is reasonable to assume that one principal stress is vertical, consistent with Andersonian fault mechanics theory (Anderson, 1951). If the borehole deviates less than 12°-15° from this stress direction, the azimuth of breakouts corresponds to the azimuth of  $S_{\min}$ , the azimuth of tensile fractures to  $S_{\max}$  (Peska and Zoback, 1995), and the

average of petal centerline fractures to the azimuth of Shmin (Davatzes and Hickman, 2010; Garza-Cruz and Davatzes, 2010 and references therein). All of the lengths of wells analyzed were less than 15° deviated.

Lastly, the image quality of the data sets can introduce uncertainty. All of the data sets analyzed, however, had relatively good quality images of the recorded geophysical properties. Throughout analysis, the quality of the data set was given a ‘1’ to ‘3’ ranking for each structure, which varied based on the type of log analyzed and the mapped feature. This basis for uncertainty was described in Blake and Davatzes (2012) and provided a measurement of relative uncertainty for these analyses. A ‘1’ feature has very low uncertainty, whereas a ‘3’ feature has very high uncertainty.

The primary uncertainty in the fault-slip data is the age of faulting. Many of the faults and veins cut only Miocene strata and thus may reflect a preexisting stress field. However, data from faults and veins cutting Miocene strata show no statistical difference from those cutting Quaternary deposits. In addition, the inferred stress directions from the fault-slip data is very similar to that derived from the borehole imaging. This suggests that the fault-slip data primarily reflect a relatively recent stress field. We should also note that the derived stress orientations from fault surface data have R-squared values of 88%, 86%, and 82%, respectively for the P, B, and T axes (Figure 24b). R-squared is the fraction by which the variance of the errors is less than the variance of the dependent variable. An R2 of 1 indicates that the regression line perfectly fits the data, whereas an R2 of 0 indicates that the line does not fit the data at all. Generally, at least a 50% R-squared value is needed to validate regression models. The poles to bedding and poles to silica veins were contoured with Kamb contour methodology. The Kamb contour method employs a variable counting circle size that varies as a function of the number of data points. Kamb contours can be advantageous to 1% area plots for data sets that have  $n < 100$  or for data  $n > 100$  and that have moderate to high scatter. Cylindrical best fit of poles to bedding and average pole to silica vein attitudes are both calculated at 3 sigma, and this error estimate clearly confines the estimate of least principal stress to an orientation of about N80°W.

### 4.3 THERMAL DATA

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant	✓			✓		

Temperature data are absolutely critical for evaluating the suitability of a site for FORGE, as relatively high temperatures (175-225oC) between 1.5 and 4 km are required for the site. Abundant temperature data are available across the Fallon FORGE site and surrounding area from 136 (combined count) temperature gradient holes and geothermal wells (Figure 29). Temperature logs are available for all moderate to deep wells on the FORGE site and for most of the wells in the surrounding area. Full profile equilibrated temperature logs are available for all temperature gradient holes drilled post-2000 and for more than half of the wells drilled from the

1970s through the 1990s. Maximum down-hole temperature data are available for the older temperature gradient holes that do not have the full incremental temperature profiles preserved.

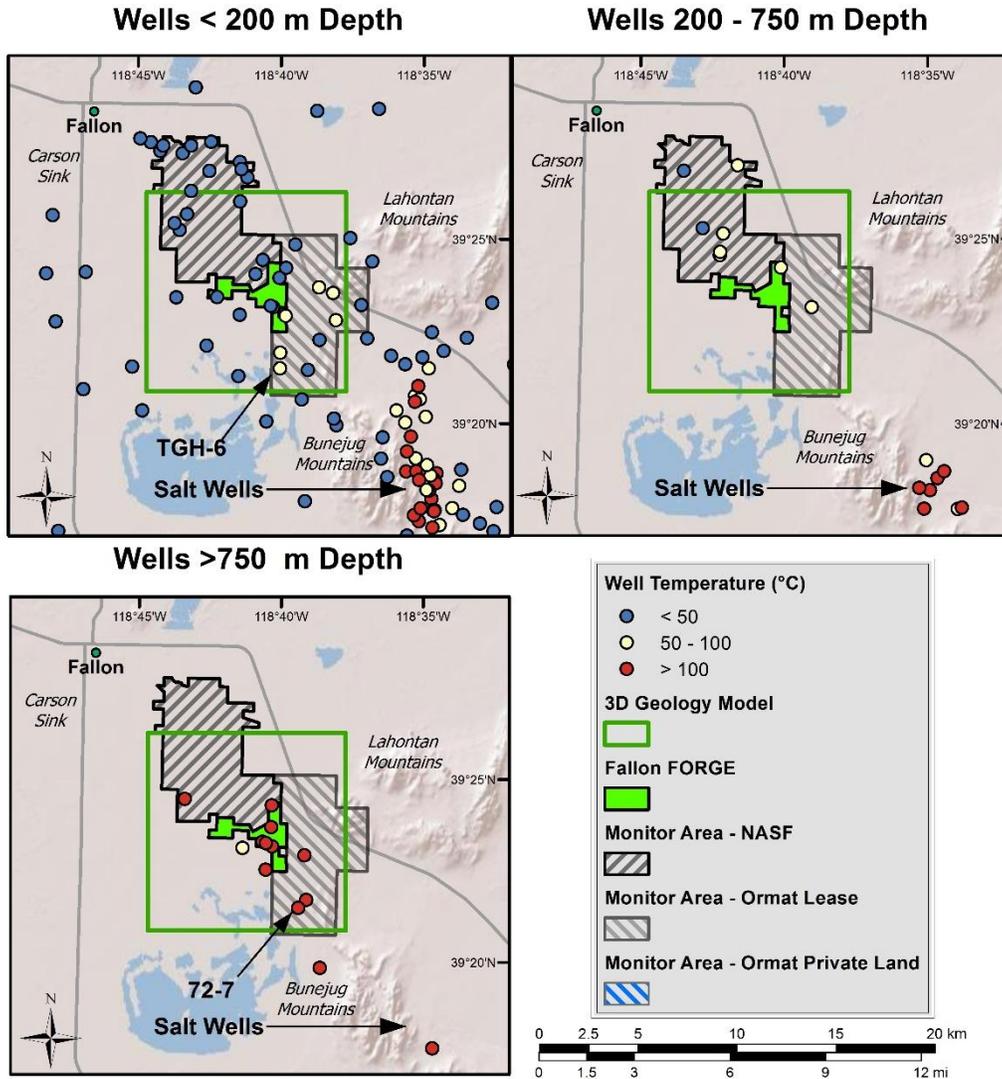
Geothermal exploration in the southeast portion of the Carson Sink has been ongoing since 1973, when Phillips Petroleum initiated a drilling program that included 28 shallow gradient holes. In total, about 60 temperature gradient holes were drilled in the area during the 1970s and 1980s between Phillips Petroleum, Anadarko, Hunt Oil, the Navy GPO, and the USGS (Bruce, 1979; Trexler et al., 1981; Katzenstein and Bjornstad, 1987; Benoit, 1990; Combs et al., 1995; Ross et al., 1996; Desormier, 1997). This early work identified a prominent shallow thermal anomaly ~5 km long, elongate north-northeast, transecting the southeast part of the Ormat lease area, and became known as the Carson Lake geothermal prospect (Benoit, 1990). The locus of this anomaly lies ~3 km southeast of the southeast corner of the FORGE site (Figure 12 and Figure 29). The temperature gradient well with the greatest thermal gradient is TGH-6, which was drilled to a 50 m depth, had a bottom-hole temperature of 77°C, and remains open and flowing today. Silica and cation geothermometry from fluids collected in TGH-6 indicate apparent equilibration temperatures of ~140°C (Figure 29; see section 4.4). In 1981, Unocal drilled vertical slim hole 72-7 one km east of TGH-6 to 881 m total depth and recorded a maximum down-hole temperature of 131°C. At the time petroleum companies were primarily interested in resources >100 MWe, so after the 1980s, the petroleum companies moved on from the region when it was clear that high enthalpy hydrothermal resources (e.g., similar to The Geysers or Cerro Prieto) were unlikely. Ormat drilled a couple of wells within the Carson Lake shallow thermal anomaly, including well 84-31 (Figure 30), which has an 82 °C/km temperature gradient, marginally higher than the wells on the FORGE site. In addition to a slightly higher temperature gradient, 84-31 exhibits a nearly isothermal profile from ~200 to 1000 m depth (Figure 31), suggesting vertical fluid circulation and the presence of permeability in the Miocene section. This fluid circulation is likely to be related to the Carson Lake geothermal system, which does not extend to the FORGE site based on the conductive temperature gradients observed in the deep FORGE wells.

Multiple deep exploration wells and additional temperature gradient holes were drilled on and adjacent to what has become the FORGE site, about 3 km north and northwest of the primary part of the Carson Lake shallow thermal anomaly. The three deepest wells include 61-36, 82-36, and FOH-3D, with all drilled on NASF to 2124 to 2530 m true vertical depths. These wells terminate in Mesozoic basement rocks, where they reach maximum bottom-hole temperatures of 192° to 214°C (Figure 30 and Figure 31). In the Miocene-Pliocene section of the wells in the FORGE site (~ < 1500 m depth), there are some relatively minor steps in the temperature profiles that are likely associated with some fluid movement at these shallow depths (Figure 31). At deeper depths (>1500 m), the temperature profiles all follow similar, nearly linear gradients, which are indicative of a conductive thermal regime. Assuming a seasonal average surface air temperature of 20 °C, the temperature gradients for the deepest FORGE site geothermal wells are 75 °C/km (FOH-3D), 76 °C/km (82-36), 78 °C/km (61-36), and 79 °C/km (88-24). These fall above the upper range of values determined in a Nevada statewide conductive temperature gradient model constructed by Blackwell and Coolbaugh, which range from ~15 to 75°C/km across the state (Coolbaugh et al., 2005).

In summary, temperature data from several wells in the proposed FORGE site indicate that a conductive regime is present in the Mesozoic basement, with measured temperatures above the FORGE cutoff (175°C) at the necessary depth. Thus, the Fallon site satisfies multiple criteria for the FORGE program.

*Data Quality and Uncertainty:* Prior to ~1990, temperature gradient-hole locations were generally manually located on maps. From the 1990s forward, many of the temperature gradient holes were located by GPS, and thus the locations are much more accurate. Geothermal wells drilled prior to 1985 predate the required permitting by the Nevada Department of Minerals (NDOM). Many of the geothermal well locations were also manually placed on maps. Wells drilled after 1985 were required to have surveyed well locations filed with the NDOM permit. Most pads for the geothermal wells can also be located in the field even if the wells have been plugged and abandoned. These pads help to confirm the locations of the wells and were thus cross-checked on air photos. During detailed geologic mapping by Hinz from 2007 to 2011 of the Lee-Allen geothermal area, the Salt Wells geothermal area, and the Lahontan Mountains (Hinz et al., 2008, 2011, unpublished data), the locations of many older abandoned temperature gradient wells were measured with GPS coordinates, and the locations were updated in the well databases as necessary.

All wells drilled on the Fallon FORGE site have accurate locations. The temperature data are also accurate for the Fallon FORGE site wells in terms of measurement precision. However, there is some uncertainty in whether the down-hole temperature logs were all fully equilibrated. Non-equilibrated temperature profiles are usually offset from the in-situ geothermal gradient, depending on whether they were collected following injection testing (in which case the temperature profiles are usually cooler than natural temperatures at the same depths), or collected after or during flow tests (in which case the temperature profiles are usually relatively elevated for a given depth).



	< 200 m	200 - 750 m	> 750 m
< 50 °C	65	2	0
50 - 100 °C	21	8	1
> 150 °C	20	6	13

Figure 29. Maximum down-hole temperatures for temperature gradient holes and geothermal wells for the Fallon FORGE region. These include 106 bore-holes >200 m deep, 16 holes 200 to 750 m deep, and 14 wells >750 m deep.

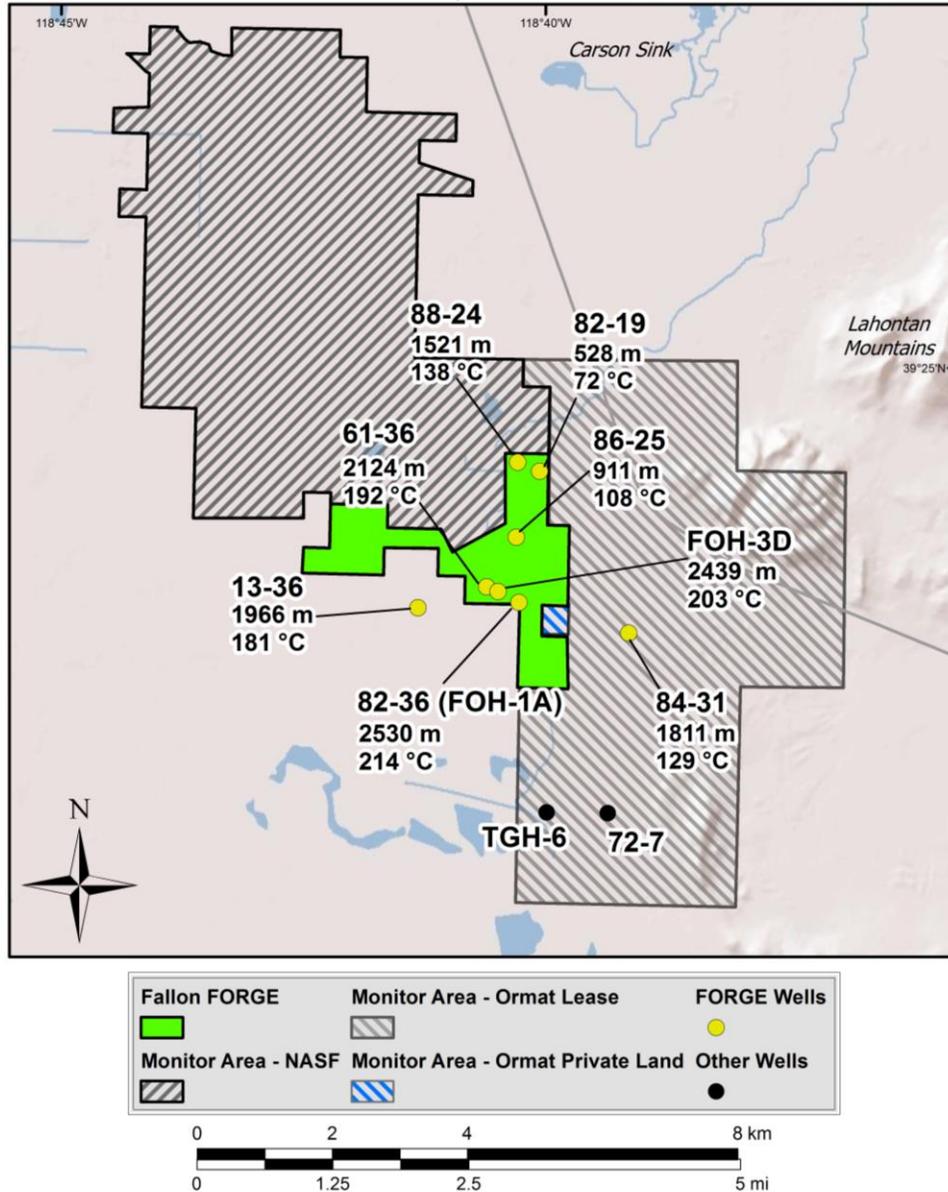
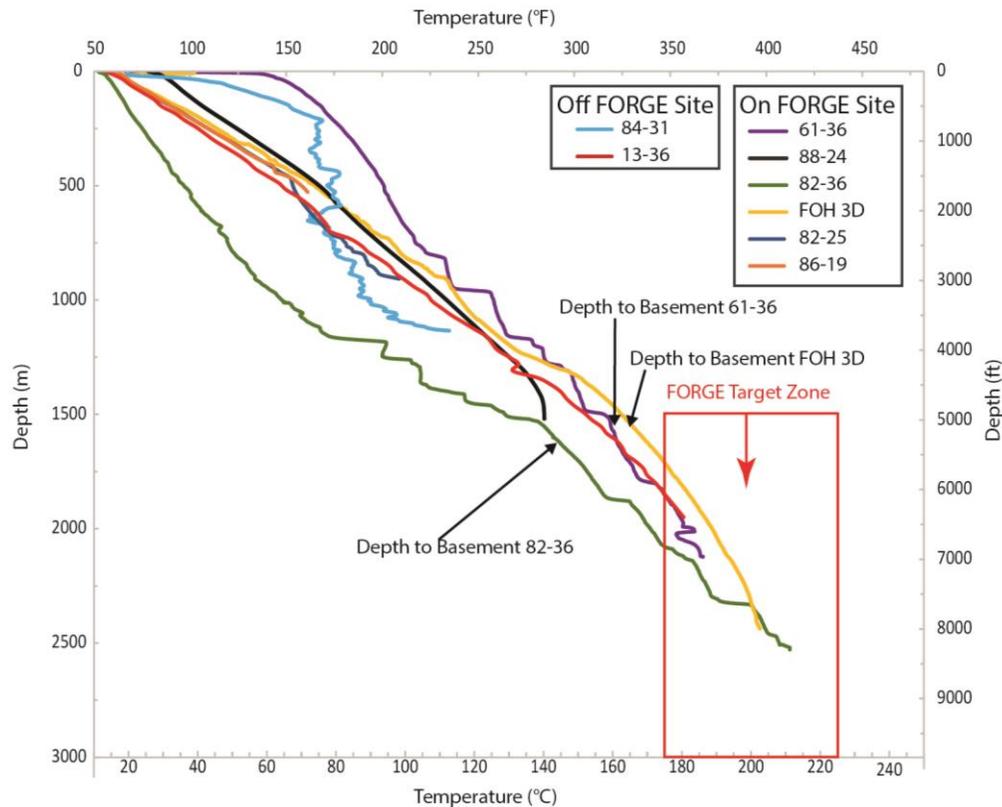


Figure 30. Fallon FORGE site with adjacent NASF and Ormat lease area showing the moderate to deep geothermal wells discussed in the text and/or with temperature profiles presented in Figure 31. Depths are true vertical depth (adjusted for deviated wells), and temperatures are maximum down-hole temperatures.



**Figure 31. Well temperature profiles for Fallon FORGE. Profiles from wells 61-36 and 82-36 are not equilibrated temperature (collected under flowing or injection conditions). All other wells are equilibrated profiles. Depth is true vertical depth, adjusted for well path deviation from vertical. Depth to basement noted for the three wells that intersect the FORGE target zone. The target zone for FORGE is designated as 1.5 to 4 km depth and 175 to 225°C per DOE-GTO FOA guidelines.**

#### 4.4 FLUID GEOCHEMICAL DATA

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant	✓					

Fluid geochemistry is imperative for evaluating a site for FORGE, as constraints are needed on both subsurface temperatures and levels of mixing of fluids from various depths. For the Fallon area, limited reliable fluid geochemistry data are available from wells in and near to the FORGE site. However, analyses for samples from four wells that passed initial quality control criteria (charge balance) are presented in Tables 4 and 5 below. Wells FOH-3D, 61-36, and 88-24 are located within the central part of the proposed FORGE site (refer to Figure 29 for well locations), and well TGH-6 is located to the southeast of the FORGE site in the FORGE monitoring area of Ormat.

**Table 4. Available geochemistry data for wells within the proposed FORGE site.**

Well	FOH-3D	FOH-3D	FOH-3D	FOH-3D	61-36	88-24	88-24	88-24
Sample	2-0200	3-0300	4-0615	05-1045		Weir	5000	3500
<b>pH</b>	8.78	8.72	8.65	8.7	8.1	8.1	7.8	8.2
<b>Li</b>	2.77	2.99	2.48	2.519	2.2	1.8	1.7	1.8
<b>Na</b>	1345.8	1336	1234	1320	3000	3380	3320	3310
<b>K</b>	162.6	155	168.3	158.1	80	122	125	124
<b>Ca</b>	49.2	46.9	49.29	50.1	32.0	19.2	19.2	18.0
<b>Mg</b>	0.079	0.083	0.06	0.225	0.9	2.7	2.6	2.6
<b>SiO2</b>	205.7	326	204	239.9	230	177	173	176
<b>B</b>	15.87	15.11	13.7	14.5	69.0	98.6	95.9	96.2
<b>Cl</b>	2140	2120	2011	2105	4400	4570	4570	4580
<b>F</b>	3.9	3.9	3.7	4.2	0.0	1.0	1.1	1.0
<b>SO4</b>	214	210	176	172	350	450	425	433
<b>HCO3</b>	71.3	60.6	58.5	60.6	340	724	719	720
<b>CO3</b>	21	22.8	21	22.8	0.0	-	-	-
<b>TDS</b>	4220	4300	4080	4200	8700	9555*	9462*	9472*

**Note:** These data meet initial quality-control criteria (ionic charge balance within  $\pm 5\%$ ). Units for dissolved solutes are mg/L; pH in standard units. \*Calculated TDS.

**Table 5. Available geochemistry data for wells adjacent to FORGE site.**

Well	TGH-6	TGH-6	TGH-6	TGH-6
<b>pH</b>	6.9	8	7.1	6.6
<b>Li</b>	-	2.3	-	-
<b>Na</b>	1210	1350	1250	1400
<b>K</b>	41	41.5	34.5	32
<b>Ca</b>	68	70	71.7	70
<b>Mg</b>	2	3.1	3.78	2.9
<b>SiO2</b>	110	104	128	120
<b>B</b>	9.2	-	10.8	14
<b>Cl</b>	2034	2138	2090	2200
<b>F</b>	2	1.4	1.8	0.5
<b>SO4</b>	106	58	54.7	62
<b>HCO3</b>	182	189.7	158	-
<b>CO3</b>	-	-	-	-
<b>TDS</b>	3764*	3958*	3803*	3904*

**Note:** These data meet initial quality-control criteria (ionic charge balance within  $\pm 5\%$ ). Units for dissolved solutes are mg/L; pH in standard units. \*Calculated TDS.

All samples are classified as alkali-chloride waters, containing relatively low dissolved sulfate and bicarbonate. In addition, all fluids are mature fluids, given their low magnesium contents, as elevated magnesium indicates that the fluids have mixed with shallower, non-equilibrated groundwater.

Applying traditional cation geothermometry relationships to the geochemistry dataset indicates apparent high temperatures at depth at the Fallon FORGE site. The data suggest that fluids have partially equilibrated at two different temperatures: (1) a higher temperature between 240-260°C, and (2) a more moderate temperature between 140-160°C (as indicated by Giggenbach's Na-K geothermometer relationship; Giggenbach, 1988) (Figure 32).

Samples from well FOH-3D indicate the highest apparent equilibration temperatures, ranging between 220-260°C using various Na-K geothermometry relationships (Figure 32; Table 6). The silica geothermometer suggests slightly lower equilibration temperatures (~190°C) for these same samples, which are consistent with measured bottom-hole temperatures (BHT's) in this well. The silica geothermometer is believed to re-equilibrate more rapidly than the Na/K geothermometers, and thus may be reflecting temperatures near the well bore, whereas the Na/K geothermometer may be preserving a thermal signature from deeper parts of the system, as this geothermometer is slower to re-equilibrate.

Samples from the two other wells inside the proposed FORGE site (61-36 and 88-24) overall suggest more moderate fluid equilibration temperatures (~140-170 °C) for both the silica and cation geothermometers (Table 6). This may suggest that the wells are accessing a fluid source at shallower depths than the FOH-3D well. The data also suggest that this inferred shallower fluid is chemically distinct from the deep fluid, with higher measured total dissolved salts (TDS). This may reflect stratigraphic and/or structural separation from the deeper fluid, which has preserved its unique chemical signature (Table 4). More data are required to resolve the characteristics of the hydrochemical system at the proposed FORGE site.

Well TGH-6 lies more than 2 km south of the south edge of the FORGE footprint. It is located in an area where an existing hydrothermal system may be active, specifically the Carson Lake geothermal system (e.g., Benoit, 1990; see section 4.3). The silica and cation geothermometer results for samples from this well demonstrate reasonable agreement, suggesting that the geothermal fluids have equilibrated at ~140°C.

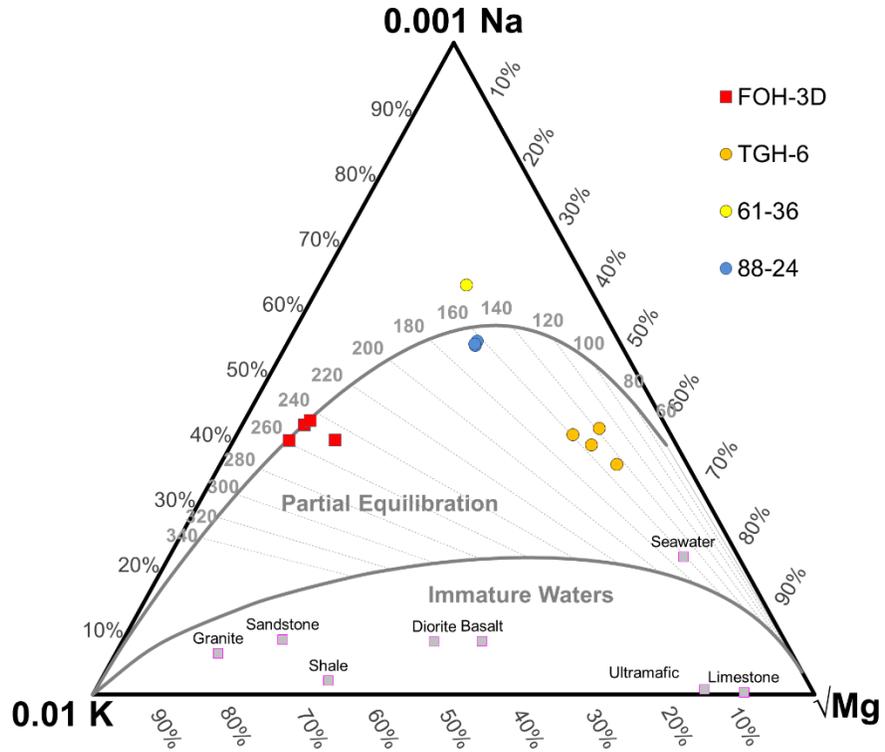


Figure 32. Giggenbach plot illustrating the Na-K geothermometry relationships for the fluid samples within and adjacent to the FORGE project site (from Giggenbach, 1988). Temperatures in °C.

**Table 6. Geothermometry results for the Fallon water samples. All values in °C.**

Sample Name	Quartz cond. (Fournier, Potter, 1982)	Quartz adiabatic (Fournier, 1977)	Na/K (Fournier, 1979)	Na-K-Ca (Fournier, Truesdell, 1973)	Na/K (Giggenbach, 1988)	K/Mg (Giggenbach, 1988)
TGH-6	142.8	137.2	139.0	148.7	158.5	126.8
TGH-6	139.6	134.6	133.2	145.6	152.9	120.4
TGH-6	151.7	144.7	126.9	139.3	146.9	111.9
TGH-6	147.8	141.5	116.4	132.9	136.8	113.6
FOH-3D2-0200	182.5	169.7	233.8	223.9	247.9	250.3
FOH-3D3-0300	217.4	197.1	230.1	221.6	244.4	246.4
FOH-3D4-0615	182.0	169.2	245.1	230.0	258.4	259.7
FOH-3D5-1045	193.6	178.5	233.0	222.7	247.1	222.1
61-36	190.5	176.0	124.9	157.7	145.0	162.8
88-24	172.3	161.5	142.8	179.7	162.2	159.1
88-24	170.7	160.2	145.5	181.7	164.8	160.2
88-24	171.9	161.2	145.1	181.9	164.5	160.4

**Data Quality and Uncertainty:** The analytical uncertainties associated with these data are low, as analyses were conducted at commercial laboratories following established standard operating protocols for analyzing the chemical composition of aqueous samples. The greatest uncertainty surrounds the context and sampling location of these samples (i.e., from what depths and/or geological units are these fluids sampled from). The results presented here represent fluids sampled at the wellhead, and to better link the results to specific formations and depths, knowledge of fluid feed zone locations in each well is required. The uncertainties associated with the geothermometry results are also relatively high, because the application of geothermometry equations to the raw aqueous geochemistry data requires multiple assumptions about the reservoir conditions, reservoir mineralogy, timing of fluid equilibration, mixing relationships, and flow history. Nonetheless, when integrated and interpreted alongside other geoscientific datasets, geothermometry results are a useful addition to understand hydrologic and geothermal systems. If selected as a potential site for FORGE in Phase 2, additional sampling and data integration will be undertaken to better constrain these factors.

## 4.5 ALTERATION DATA

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant	✓	✓				✓

Alteration data are important to compile to help determine the extent of any hydrothermal activity and better define the mechanical properties and permeability of rock units. Alteration mineralogy of core and cuttings samples from the FORGE area wells has previously been studied for the purposes of hydrothermal exploration and general characterization of the physical properties of the stratigraphic units. Petrographic analyses of hydrothermal vein and XRD analyses of clays were completed in 2013 during a phase of geothermal exploration for conventional hydrothermal resources on NASF (Jones and Moore, 2013). X-ray diffraction (XRD) was performed on samples from FOH-3, 82-35, 61-36, 84-31, 88-24, FDU-2D, and 18-5 (Figure 18 and Figure 30) to evaluate the clay mineral distribution with depth. The chips were analyzed by the Energy and Geoscience Institute (EGI) at the University of Utah using their Bruker D8 Advance X-ray diffractometer. As described by Jones and Moore (2013), phases were estimated using the TOPAS software with the Rietveld method, which fits the peak intensities calculated from crystalline structure to the observed X-ray powder using a least squares fit. In addition, a handheld reflectance spectro-radiometer was previously used on core and cuttings, respectively from FOH-2 and 84-31 to assess the alteration mineralogy (Calvin and Rasmussen, unpublished data). The technique is sensitive to molecular bonds and is particularly useful for diagnostically identifying a wide range of clay minerals. In previous pilot studies on geothermal drill core, phyllosilicates, zeolites, opal, calcite, iron oxides, and hydroxides have been successfully identified (Calvin and Pace, 2016).

The alteration mineralogy within geothermal systems can be classified as argillic, phyllic and propylitic. Argillic alteration occurs in the lower temperature portions of geothermal systems (< 225°C); phyllic indicates temperatures of 225°C to 250°C; and propylitic reflects >250°C. Several types of alteration were observed in thin section in the core and cuttings from wells in the Fallon area. Based on petrographic analyses, the main argillic alteration zone within the analyzed wells lies within the Miocene to Pliocene sediments with little open vein fill. The phyllic alteration zone within the studied wells was mainly in the volcanic and volcanoclastic rocks and included veins filled with botryoidal quartz, chlorite, epidote, laumontite, and calcite with some smectite overprinting. The propylitic alteration zone was within the crystalline rock and is distinct from the metamorphism in these units. This zone includes actinolite, epidote, adularia, and plagioclase overprinted by chlorite, illite, quartz, and calcite.

Clay minerals in geothermal systems are temperature sensitive. The occurrence of smectite suggests temperatures less than 180°C, interlayered smectite-illite or smectite-chlorite suggest temperatures between 180°C and 225°C and, finally, illite and epidote are stable above 225°C (Henley and Ellis, 1983; Reyes, 1990, Jones and Moore, 2013). Within the wells sampled, the occurrence of smectite was mainly within the Miocene to Pliocene sediments. A higher-

temperature environment with interlayered smectite-illite was found deeper than smectite in all of the analyzed wells, and illite was generally found at still deeper levels. One notable exception includes a zone in well 82-36 where smectite-illite appears at ~2300 m depth at a level otherwise dominated by illite alteration.

The presence of argillic alteration fits with the current temperature regime recorded in the FORGE site wells. However, the phyllic and propylitic mineral alteration assemblages represent higher temperatures than observed in the FORGE site wells and thus almost certainly represent fossil hydrothermal activity. Epithermal mineralization and alteration associated with Miocene volcanism was widespread across the region and was probably responsible for extensive alteration of the Miocene volcanic and sedimentary rocks in the Rainbow Mountains-Lahontan Mountains region (Morrison et al., 1964; Bell et al., 2010). Epithermal mineralization and alteration was also associated with the Mesozoic arc magmatism. Alteration in the Mesozoic basement may have a long and complicated history, including Mesozoic and Tertiary hydrothermal activity. No age dates have been acquired on the hydrothermal veins identified in thin section from the bore-hole samples at the FORGE site. The veins are found in Mesozoic and Miocene strata, and may be found in Pliocene strata. However, strata of Pliocene age have not been recognized at the Fallon FORGE site.

In summary, only the argillic alteration is compatible with the current thermal regime at the FORGE site. The observed phyllic and propylitic alteration was observed in Miocene and Mesozoic rocks and is not compatible with the current thermal conditions. Thus, it probably represents an older (presumably pre-Pliocene) hydrothermal system. In addition, the well temperature profiles show primarily conductive heat flow characteristics, and the permeability measurements are low, particularly in the lower Tertiary and in the Mesozoic sections. These relationships and the current thermal regime suggest that a major hydrothermal resource has not been found on the FORGE site.

*Data Quality and Uncertainty:* X-ray diffraction (XRD) analysis is used to identify crystalline structures of minerals and to estimate their volumetric contribution to a sample. The distribution and abundance of clay minerals were determined through X-ray diffraction analysis on both whole rock and clay samples. Two or more clay-sized fractions were taken of each sample for analysis through grinding the sample, separating <2 micrometer size fraction, placing it in a centrifuge, which is then placed on a glass slide where it is air dried, glycolated and heated before analysis. The samples are then analyzed using an XRD to determine the spectra produced by the crystalline structure of the clay mineral within the sample. To ensure accuracy of the XRD analyses, the entire powder pattern was analyzed so that peak overlap was minimized (Jones and Moore, 2013). The XRD detection limit of mineral proportions in mixed samples is typically 2%. Thus, phases present in the samples that make up < 2% may not be reported.

## 4.6 WELL FLOW TESTING DATA

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant	✓	✓		✓		✓

Well flow testing is essential for defining the permeability of rock units and is thus critical for evaluating a potential site for FORGE. There are a total of seven wells on the ~4.5 km<sup>2</sup> Fallon FORGE site, six of which have complete temperature data (Figure 30). Four of the wells (88-24, 86-25, FOH-2, and 82-19) terminate in the Miocene volcanic rocks, reaching depths of 528 to 1530 m, and three of the wells (82-36, 61-36, and FOH-3D) terminate in the Mesozoic basement, reaching depths of 2125 to 2530 m. Multiple well tests have been conducted on five of the wells, including two of the three wells that intersect basement (Table 1). The types of well tests have included injectivity tests and multiple types of flow tests.

Well 82-36 was tested for production flow capacity, and this well did not provide sustainable production due to low permeability. Production wells typically need an injectivity index of greater than 1.00 gpm/psi (0.55 lpm/kPa). Based on the information from the injection test carried out on the 82-36 well (GeothermEx; Figure 33, and Figure 34), the injectivity index was calculated to be 0.27 gpm/psi (0.15 lpm.kPa) (Figure 33). Using the data collected from the pressure fall-off after the injection test, reservoir parameters were estimated. The injectivity index was calculated at a value of 0.14 gpm/psi (0.08 lpm/kPa; Figure 33) for the pressure fall-off. A permeability-thickness product (kh) of 299 millidarcy-feet (md-ft) (0.092  $\mu\text{m}^2\text{-m}$ ) was calculated along with a skin factor (s) of -2.5 (Figure 34). These values indicate low permeability of formations intercepted by this well during drilling and completion, and this is therefore a non-productive well.

Well 61-36 was also tested for production capacity, and similar to the 82-36 well, this well did not provide sustainable production due to low permeability. As mentioned above, production wells typically need to have an injectivity index of greater than 1.00 gpm/psi (0.55 lpm/kPa). Based on the information from the injection test carried out on the 61-36 well (GeothermEx; Figure 36, Figure 37, and Figure 38), the injectivity index was calculated to be 0.62 gpm/psi (0.34 lpm/kPa) (see Figure 37). Using the data collected from the pressure fall-off after the injection test, reservoir parameters were estimated. The injectivity index was calculated at a value of 0.80 gpm/psi (0.44 lpm/kPa; Figure 37) for the pressure fall-off. A permeability-thickness product (kh) of 4,430 md-ft (1.37  $\mu\text{m}^2\text{-m}$ ) was calculated along with a skin factor (s) of 0.0 (Figure 38). These values are higher than for well 82-36, but still indicate low-permeability of the intercepted rock units. Consequently, this is also a non-productive well.

After pump testing both 61-36 and 82-36 for 30 days each, the flow rate was determined to be unsustainable based on downhole pressure bubbler tube data. The wells demonstrated pseudo-steady-state flow behavior, based on a linear drawdown of pressure, suggesting the wells were pulling from a closed reservoir. Analytical reservoir modeling of the data was performed using

the data collected throughout the pump test. By using known temperatures at depth, known geology, and assuming single-phase fluid and a reservoir height of ~300 m and diameter of 400 m, the permeability thickness (transmissivity) was calculated at 5,000 md-ft (1.52  $\mu\text{m}^2\text{-m}$ ) by GeothermEx.

Well 88-24 records the highest injectivity index at 9.50 gpm/psi (5.22 lpm/kPa). This well is ~1500 m deep and just touches the upper boundary of the FORGE target zone depth, but only reaches 140°C and does not reach the FORGE target temperature. The permeability zones are ~610 to 637 m deep (~2000-2090 ft) in a layer of basaltic andesite lavas and possibly also at 1200 to 1300 m deep (4000 to 4300 ft) in Miocene volcanic rocks (Figure 19). It is not surprising that layers of higher permeability are present in these formations, as would be expected in nearly any Cenozoic basins or sequences of Miocene volcanic rock. Moreover, well 88-24 does not reach Mesozoic basement nor does it reach the requisite minimum temperature of 175°C. Thus, the higher-permeability zones in this well lie well above the FORGE target zone in terms of depth, lithologies, and temperature.

Well 86-25 reaches nearly 1 km in depth and also has low injectivity. Injectivity tests in 82-19 show a range in values from 1 to 9.5 gpm/psi (0.55 to 5.22 lpm/kPa). However, this well only reaches ~908 m depth, 100 °C, terminates in the Tertiary volcanic section, and does not provide much constraint on the permeability in the FORGE target zone in the Mesozoic basement >1.5 km deep.

Well 84-31, ~1 km east of the FORGE site (on the Ormat lease area) has a permeable zone at about 215 m depth (700 ft) at a probable fault contact between basin-fill sediments (QTs) and Miocene volcanic rocks (Tvs). Unlike the well temperature profiles at the Fallon FORGE site, well 84-31 also records a nearly isothermal profile between ~200 to 1000 m depth (Figure 31). Both the permeability in the upper part of 84-31 and the shape of the well temperature profile are consistent with a hydrothermal signature associated with the Carson Lake hydrothermal system well to the east of the Fallon FORGE site, as evidenced by the shallow temperature anomaly defined by temperature gradient holes (see Section 4.3). This signature is related to the Carson Lake hydrothermal system east of the Fallon FORGE site, which, as mentioned previously, is associated with a shallow temperature anomaly defined by temperature gradient holes.

In summary, wells 82-36 and 61-36 have low permeability based on the well testing results from injection tests. These two wells constitute two of the three deep wells on the FORGE site that were completed in Mesozoic basement and that intersect the target temperatures (175 to 225°C) and depths (1.5 to 4 km deep) specified as FORGE criteria.

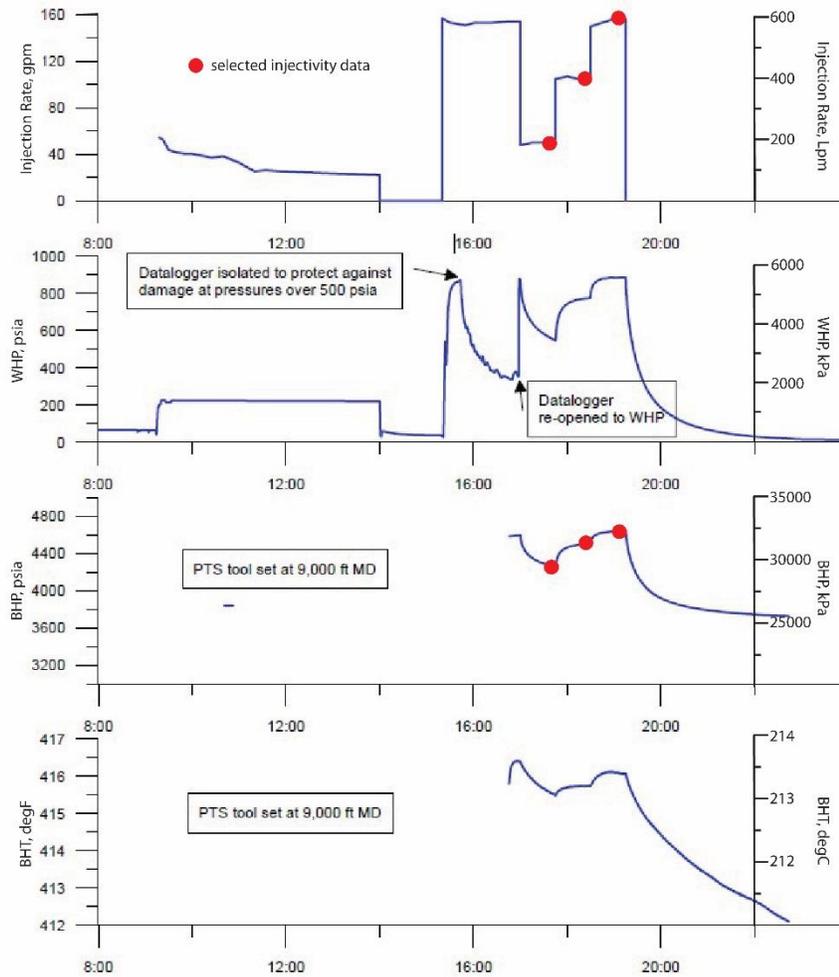
*Data Quality and Uncertainty:* Multiple tests have been conducted on two wells (82-36 and 61-36) intersecting the Mesozoic basement at the requisite FORGE target depths. The instrumentation for these well tests was of good quality, and the determinations of low permeability were determined using two test methods (step-rate injection and pressure fall-off). The consistency of the results indicates that there is little uncertainty in the conclusion that the Mesozoic formations at the location of these two wells consistently have low permeability. Additional uncertainties are associated with whether or not the wells were ideally placed with respect to possible permeable structures within the FORGE site. However, the consistently conductive temperature profiles do not show indications of nearby reservoirs, nor have any

potential structures been observed at the surface, nor have they been imaged in seismic and electrical surveys.

**Table 7. Well test data on the Fallon FORGE site.**

Exploration Hole	82-36	61-36	88-24	86-25	82-19	
Depth (ft)	8301.0	6970.9	5000	3000	1735	
Depth (m)	2530	2125	1530	930	529	
Injection Test	gpm/psi	0.27	0.62	9.50	1	1-9.5
	lpm/kPa	0.14	0.34	5.22	0.55	0.55-5.22
Artesian	Temp (°F/°C)	231/110.6	195/90.6	170/76.7	n/a	n/a
	Max Flow (gpm/lpm)	30/113.6	30/113.6	64/242.3	n/a	n/a
Air Lift	Max Temp (°F/°C)	n/a	248/120	160/71.1	n/a	n/a
	Ave. Temp (°F/°C)	n/a	198/92.2	140/60	n/a	n/a
	Max Flow (gpm/lpm)	n/a	950/3596.1	220/832.8	n/a	n/a
	Ave. Flow (gpm/lpm)	n/a	60/227.1	91/344.5	n/a	n/a
Nitrogen Lift	Max Temp (°F/°C)	311/155	236/113.3	194/90	n/a	n/a
	Ave. Temp (°F/°C)	Surges	n/a	85/29.4	n/a	n/a
	Max Flow (gpm/lpm)	796/3013.2	148/560.2	531/2010.1	n/a	n/a
	Ave. Flow (gpm/lpm)	Surges	n/a	80/302.8	n/a	n/a
Pump Test	Max Temp (F/C)	255/123.9	240/115.6	n/a	n/a	n/a
	Ave. Temp (F/C)	245/118.3	230/110	n/a	n/a	n/a
	Max Flow (gpm/lpm)	100/378.5	450/1703.4	n/a	n/a	n/a
	Ave. Flow (gpm/lpm)	60/227.1	230/870.6	n/a	n/a	n/a

Note: The injection tests provide information for calculation of the injectivity index, which is used for estimating the production potential of the various wells.



**Figure 33. Data for injection test on well 82-36 on March 4, 2014, showing surface injection rate, surface injection pressure, downhole pressure, and downhole temperature data and graphs.**

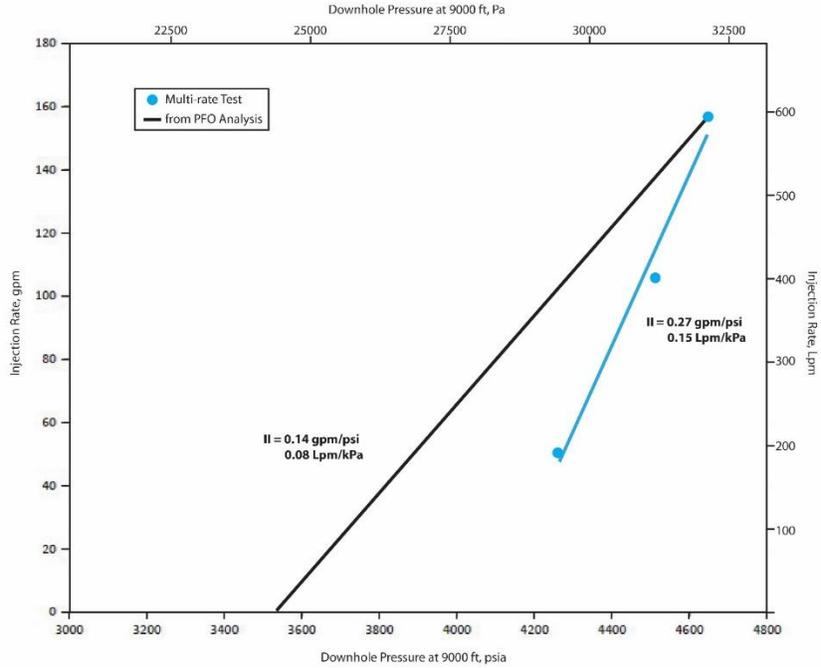


Figure 34. Injctivity index (II) data from well 82-36 for injection test conducted on March 4, 2014.

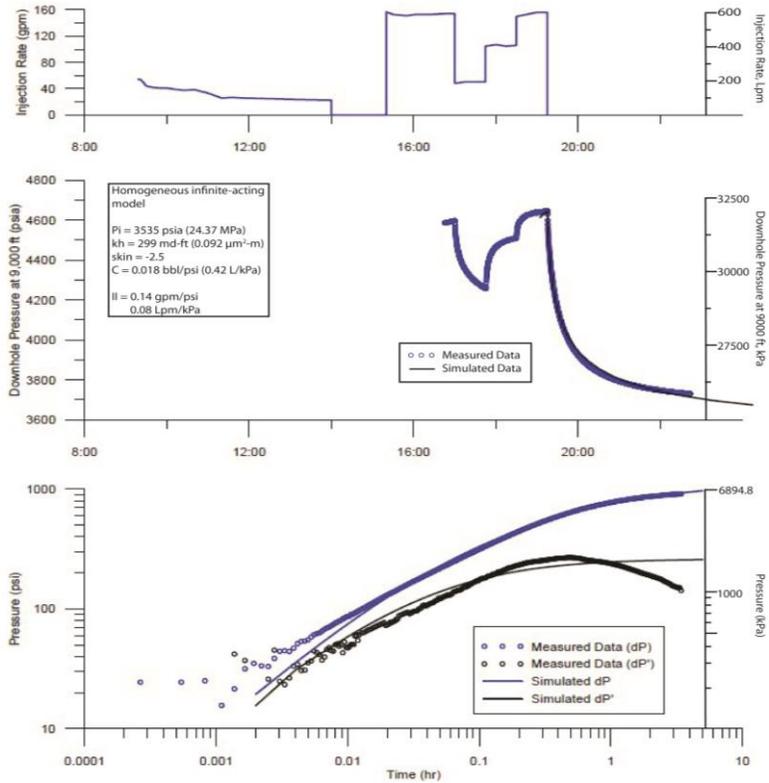


Figure 35. Pressure fall-off data for well 82-36 for injection test conducted on March 4, 2014, which illustrates the injection rate, the downhole pressure at 9,000 ft (2743.2 m), and analytical match for best-fit (line) of the measured pressure data (points).

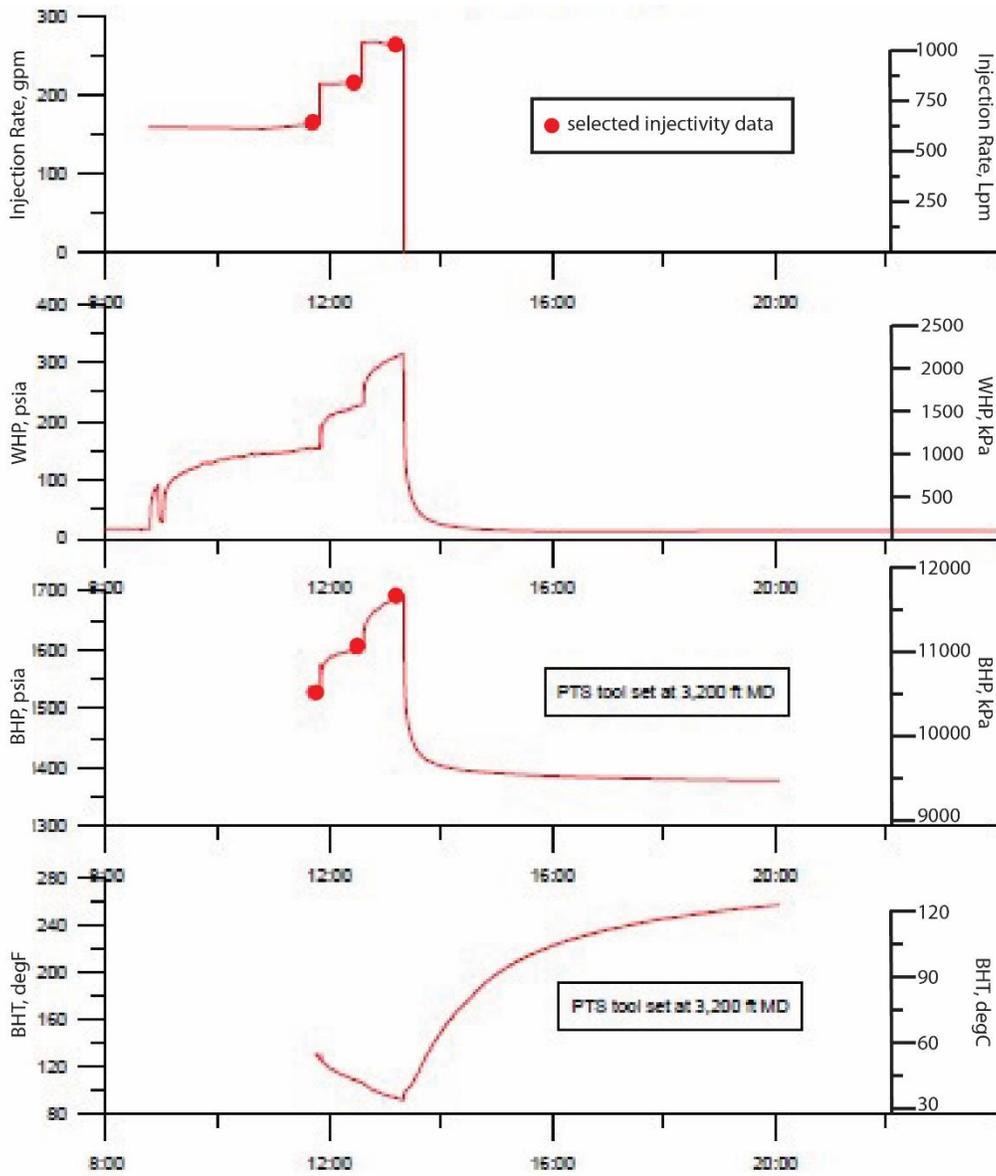


Figure 36. Injection test for well 61-36 conducted on March 7, 2014 showing surface injection rate, surface injection pressure, downhole pressure, and downhole temperature data and graphs.

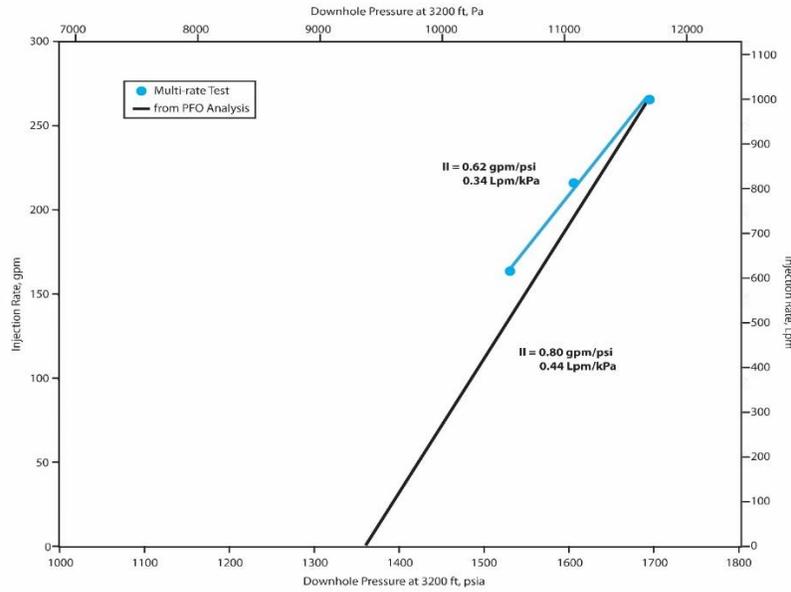


Figure 37. Injunctivity index (II) data for well 61-36 for injection test conducted on March 7, 2014.

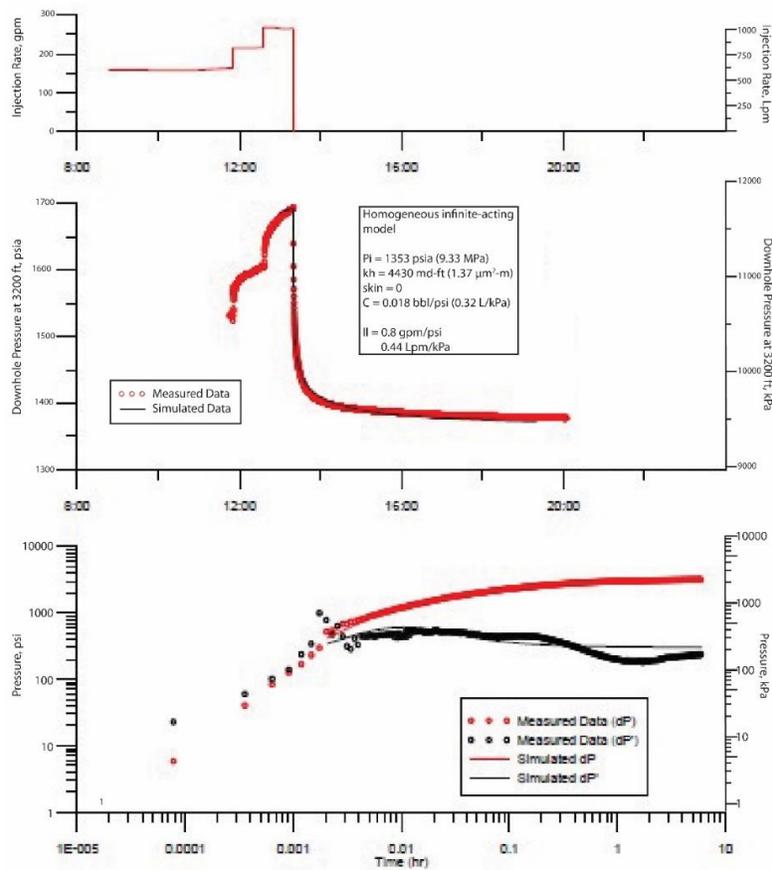


Figure 38. Fall-off pressure data for well 61-36 for injection test conducted on March 7, 2014. This figure is illustrating the injection rate, the downhole pressure at 9,000 ft (2743.2 m), and analytical match for best-fit (line) of the measured pressure data (points).

## 4.7 GEOPHYSICAL DATA

Substantial previously acquired geophysical data provide important subsurface controls on the stratigraphic and structural framework of the Fallon FORGE site, particularly in regards to the overall architecture of the Carson Sink basin, spacing of major faults, and vulnerability to earthquakes. The most salient data sets include detailed gravity surveys, magnetotelluric data, and seismic reflection data. In the latter case, 14 seismic reflection profiles criss-cross the southern Carson Sink in and around the FORGE site. These data sets and their general quality and uncertainty are described in the subsections below.

### 4.7.1 Gravity and Magnetic Data

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant			✓	✓		

Potential field methods are useful for imaging geologic units and structures that are associated with lateral contrasts in crustal density and magnetic properties (remnant magnetization or the concentration and type of magnetic minerals). Rock-property contrasts may arise from various sources -- occurring within a rock unit, (e.g., lateral facies changes), across geologic structures (faults or folds), or at contacts with other rock units. Such contrasts generate potential field variations (or anomalies) that can facilitate mapping and modeling of the subsurface, because they relate directly to shape, depth, and rock properties of a source. As a result, gravity and magnetic data can be effectively used to resolve the geometry and origin of sources, particularly when combined with other geologic constraints.

Potential field methods are useful in geothermal settings, because they commonly highlight structural features (fault or fracture zones, or geologic contacts) that may play a role in guiding geothermal fluids, or may be activated during stimulation of a geothermal field. They are particularly useful in areas throughout the northwestern Great Basin, where the physical properties of the Mesozoic basement or mafic-intermediate volcanic and intrusive rocks contrast strongly with the surrounding tuffaceous and sedimentary rocks to produce prominent gravity and magnetic anomalies. In addition, they may be used to map alteration and hydrothermal deposits, where geothermal fluid flux results in characteristic changes to the density and rock-magnetic properties. At the regional scale, they are also useful for constraining basin geometry.

In the Fallon FORGE study area, contrasts between basin-fill sediments, volcanic rocks, and Mesozoic basement rocks generate a distinguishable pattern of gravity and magnetic anomalies that can be used to infer subsurface geologic structure. We analyzed existing gravity and aeromagnetic data to assess regional crustal structures and aid in development of the Fallon 3D geologic model. Sources of data employed in this study include a gravity database of nearly 8000 gravity stations (collected both regionally and across several detailed surveys) and a regional aeromagnetic compilation.

*Gravity Data:* A database of nearly 8000 gravity stations spanning a ~130 x 130 km area centered on the Carson Sink was compiled from databases developed by Zonge International and Ormat Technologies, Inc. for the University of Nevada, Reno (UNR) (Figure 39). Data were compiled from 15 sources, consisting of both public domain and privately contracted datasets held under the care of UNR and made available for this study.

The largest data set (6898 stations comprising 13 of the 15 sources) was processed by Zonge in 2013. Data from the Zonge survey encompassed the entire Carson Sink and included 1,243 new stations acquired at approximately 400, 800, and 1600 m intervals. The station distribution for this survey was designed to complete regional gravity coverage in the Carson Sink area and included available public and private gravity coverage from previous surveys. Specifically, the Zonge gravity survey yielded the following products for the entire Carson Sink:

- Complete Bouguer anomaly @ 2.67 gm/cc reduction density.
- Complete Bouguer anomaly at 2.50 g/cc Contour Map (Figure 40).
- Horizontal gradient magnitude contour map.
- 1st vertical derivative contour map.
- Interpreted depth to Mesozoic basement (Figure 41), incorporating drill-hole intercept values.

The Zonge data set provides excellent regional coverage of the Carson Sink and helps to infer the location of major faults, as well as the thickness of basin-fill sediments and depth to Mesozoic basement throughout the basin. Depth to basement profiles were derived from this data set for each seismic reflection line and used to constrain interpretations of faults and thickness of the Neogene sections along the profiles (Figure 39).

Two additional surveys, contracted and processed by Ormat, were provided for use in this study and were merged with the Zonge data. The most important consists of a detailed survey (200 m grid of stations) that covers the eastern portion of the proposed FORGE site (Figure 42). This survey provides an exceptional opportunity to map density contrasts and infer geologic contacts most relevant to FORGE activities. These data were incorporated into the interpretation of the seismic reflection data, particularly in constraining the location of faults in the eastern part of the FORGE site.

All data were reduced using standard gravity methods (Blakely, 1995) that correct for multiple parameters (e.g., earth-tides, instrument-drift, latitude, elevation, Earth's curvature, and terrain) to yield complete Bouguer anomalies that reflect lateral variations in crustal density. Data were gridded using minimum curvature algorithms at the regional scale (500m grid), using all of the data, and for the high-resolution survey (100 m grid) spanning the eastern half of the FORGE site (Figure 42 and Figure 43). In order to remove a regional field, a residual gravity map was derived by subtracting an upward continued (by 1000 m) grid from the original survey. These maps emphasize anomalies arising from variations in density in the shallow subsurface and can aid in identifying faults and contacts.

*Magnetic Data:* Aeromagnetic data were derived from a statewide compilation of Nevada (Kucks et al., 2006). A regional International Geomagnetic Reference Field (IGRF) was removed from the data. The compilation spanning the study area and most of the regional

surroundings consists of a single survey flown at 2743 m (9,000 ft) barometric elevation (nominally 1524 m [5000'] above terrain in the immediate area around the FORGE site) with flight lines oriented east-west and spaced 3218 m (2 mi) apart (U.S. Geological Survey, 1972). The original digital line data are no longer available – a grid was created from digitizing contours and individual locations of maxima and minima from the originally published maps. These data are of low enough resolution to preclude resolving features at the local scale around the FORGE site (in comparison typical modern high-resolution surveys are flown at 100-400 m (1/4-1/16 mi) spacing at 30-60 m above terrain). However, these data do provide some constraints on regional structures.

A pseudo-gravity (or magnetic potential) transformation (Blakely, 1995) was applied to magnetic data in order to isolate broad magnetic features that are commonly masked by high-amplitude shallow magnetic sources (Figure 44 and Figure 45). The pseudo-gravity transform converts a magnetic anomaly into one that would be observed if the magnetic distribution of the body were replaced by an identical density distribution. This results in simplifying magnetic anomalies by centering them over their sources and facilitates interpretations. A residual magnetic map of the pseudo-gravity was derived by subtracting an upward continued (by 100 m) grid from the original survey, in order to remove a broad crustal field.

Various derivative and filtering methods can also be useful to delineate structures such as intra-basin or basin-bounding faults or contacts. Maximum horizontal gradients (MHG; Blakely and Simpson, 1986) of gravity and pseudo-gravity, which reflect abrupt lateral changes in the density or magnetization of the underlying rocks, respectively, tend to lie over the edges of bodies with near vertical boundaries and help in estimating the extent of buried sources. These were calculated for both residual gravity (CBA) and magnetic (pseudo-gravity) grids.

The contrast in density and magnetic properties between pre-Cenozoic crystalline basement and the overlying Tertiary volcanic rocks and unconsolidated alluvium produces a distinctive pattern of gravity and magnetic anomalies at contacts or across faults that juxtapose contrasting units. Distinct changes in character (amplitude and wavelength) can also result from alteration along faults and fracture zones due to the circulation of hydrothermal fluids in the near-surface. Gravity and magnetic maps of the study area and surroundings (Figure 40, Figure 42, Figure 43, Figure 44, and Figure 45) reveal the extent of regional anomaly sources and were therefore used to trace inferred faults, fractures, and contacts.

In general, the gravity lows over the valleys reflect moderately deep sedimentary basins filled with lower density alluvial deposits, whereas gravity highs are associated with dense basement and Tertiary igneous rocks. Steep gradients at several locations likely indicate the presence of normal faults. Some of these correspond to mapped Quaternary fault scarps (e.g., in the southern Carson Sink and along margins of the Salt Wells basin), but others are seen only through geophysical methods (e.g., southwest of the Bunejug Mountains). Prominent gravity highs correspond to the mountains bounding the southern Carson Sink (Dead Camel, White Throne, and Blow Sand Mountains, Figure 42) and also follow the Bunejug and Lahontan Mountains directly bounding the study area to the south and east, respectively (Figure 42). Prominent gravity lows occur over the southern Carson Sink and Salt Wells basins.

The available gravity data provide important constraints on the location of faults, thickness of basin-fill sediments, and depth to Mesozoic basement within and adjacent to the Fallon FORGE site. Depth to basement profiles were derived from the Zonge gravity survey for each of the interpreted seismic reflection profiles and integrated with well data. Synthesis of these data was then utilized to infer the location of major faults (with offsets > ~100 m) and thickness of the Neogene section along each profile. In the eastern part of the study area, where high-resolution surveys were available, data are sufficient to resolve subtler density contrasts that may reflect fault zones that involve relatively small offsets (< ~100 m) or slight property changes (e.g., due to alteration or precipitation of material along a fault or fracture zone).

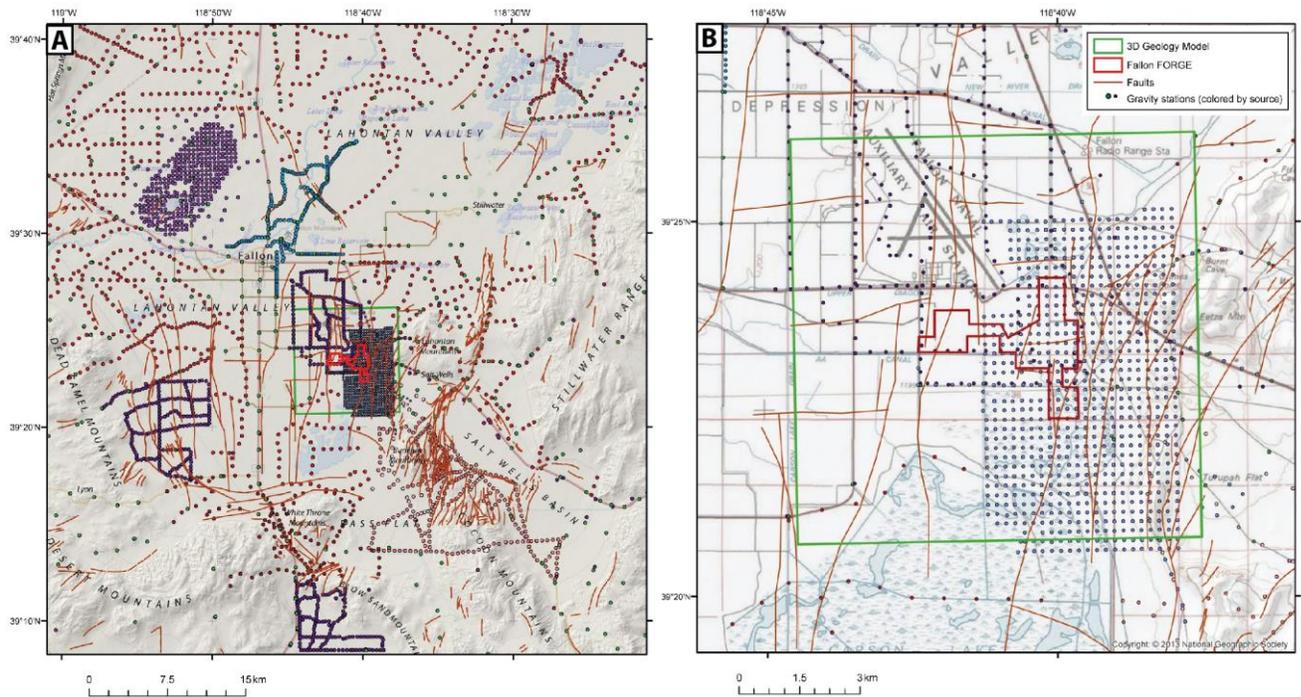
Gravity station coverage is heterogeneous across the study area. In places where gravity stations are sparse, structural interpretations are poorly constrained. A detailed survey spanning the eastern half of the FORGE area (Figure 39 and Figure 43) reveals several relatively continuous, elongate, north-south trending structures extending from the front of the Lahontan Mountains westward into the valley. These structures are sub-parallel to mapped faults in the area and have a similar spatial recurrence (nominally 0.5-1 km spacing).

Modeling of the gravity data (e.g., lack of abrupt gradients and major discontinuities) indicates that the density of faulting is relatively low within the FORGE site (Figure 42 and Figure 43). In contrast, higher fault densities are predicted east of the FORGE site in an area broadly coincident with the Carson Lake geothermal system. These data corroborate other observations that an active hydrothermal system is not present beneath the FORGE site.

High-amplitude magnetic anomalies in this region are generally caused by moderately to strongly magnetic mafic volcanic rocks that crop out at the surface or are buried at shallow depths. Moderate highs reflect moderately magnetic rocks (such as tuffs) or buried mafic volcanic rocks within the basin. Magnetic lows are typically associated with weakly magnetic silicic and sedimentary rocks or may be associated with reversely magnetized units. In areas of active or fossil geothermal activity, neutral values may reflect hydrothermal alteration of an originally magnetic unit. Magnetic highs in the area occur over the Bunejug and western Lahontan Mountains that bound the FORGE site to the southeast and northeast, respectively, as well as the White Throne and Blow Sand Mountains to the south of the Carson Sink and western Stillwater Range directly east of the Carson Sink (Figure 44). The structural grain interpreted from the magnetic data (Figure 44 and Figure 45) mimics the trend of mapped faults and/or gravity-inferred contacts. However, structural interpretations made from the magnetic map are limited by the relatively low-resolution of existing magnetic data.

*Data Quality and Uncertainty:* Gravity data in the Carson Sink were generally acquired using a Scintrex CG-5 gravimeter and a LaCoste and Romberg (L&R) Model-G gravimeter. The CG-5 gravity meter has a reading resolution of 0.001 milligals and a typical repeatability of less than 0.005 milligals. The L&R gravity meter has a reading resolution of 0.01 milligals and a typical repeatability of 0.02 milligals. The basic processing of gravimeter readings to calculate the Complete Bouguer Anomaly was performed using the Gravity and Terrain Correction software version 7.1 for Oasis Montaj by Geosoft LTD. The uncertainty in the aeromagnetic data is estimated to be <5 nT based on analogous aeromagnetic surveys also conducted in the 1970's (e.g., Connard et al., 1983).

Gravity and magnetic anomalies can be generated by more than one configuration of subsurface lithologies, alteration, and faulting. For this reason, a significant degree of uncertainty is present in the location of any structure modeled from these surveys alone. In this FORGE study, however, the gravity and magnetic data are not used as a primary source for estimating any of the critical FORGE site parameters. Instead, these data play a supporting role. The lack of significant structures identified by these surveys confirms conclusions reached using more definitive analyses (e.g., temperatures, well depths, and flow tests), and thus they reduce the primary uncertainties in the critical parameters by providing a measure of corroboration.



**Figure 39. Index of the Fallon FORGE area showing gravity station coverage. The Forge site is outlined in red at right center. A. Regional coverage. B. Coverage for the FORGE 3D model area (green box) and immediate surroundings.**

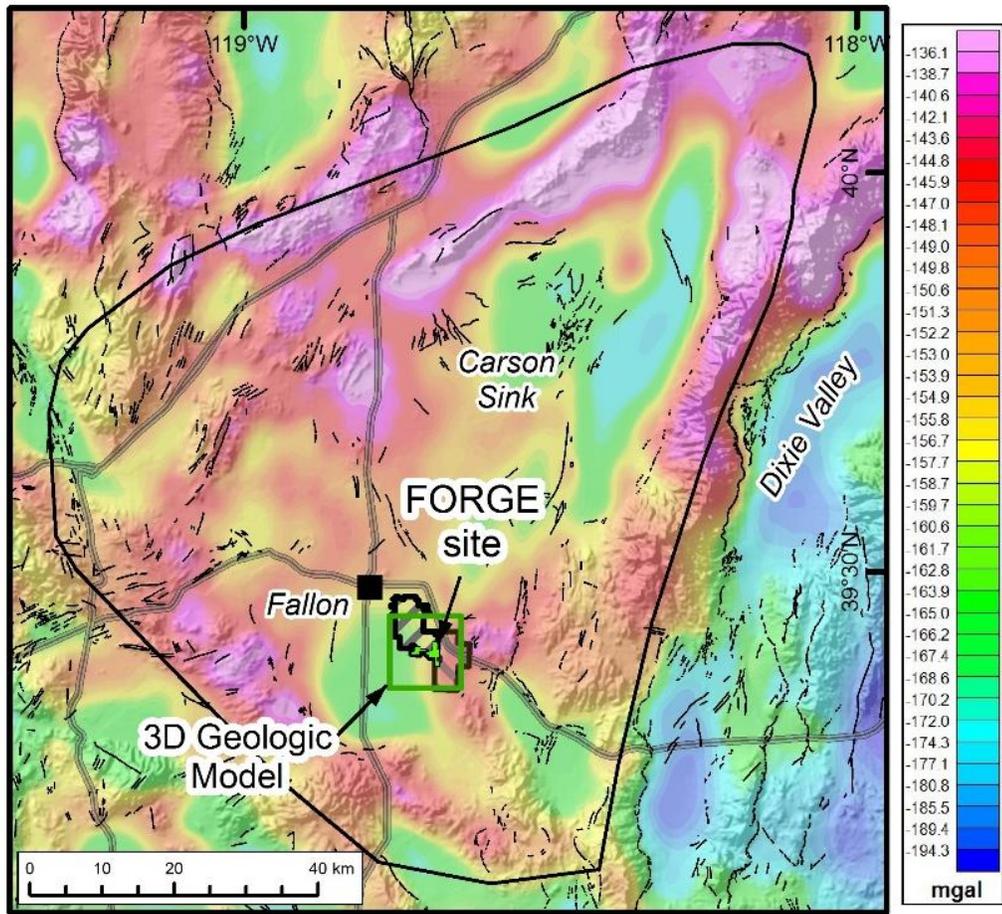


Figure 40. Gravity complete Bouguer anomaly at 2.50 g/cc contour map (from Faulds et al., 2014).

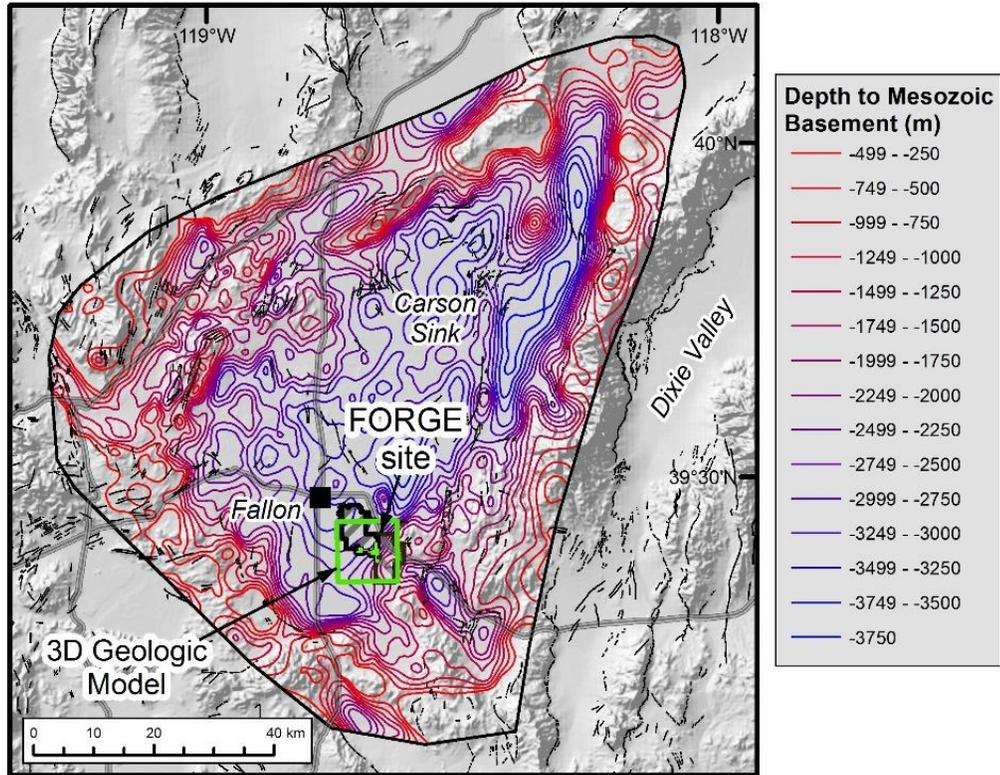
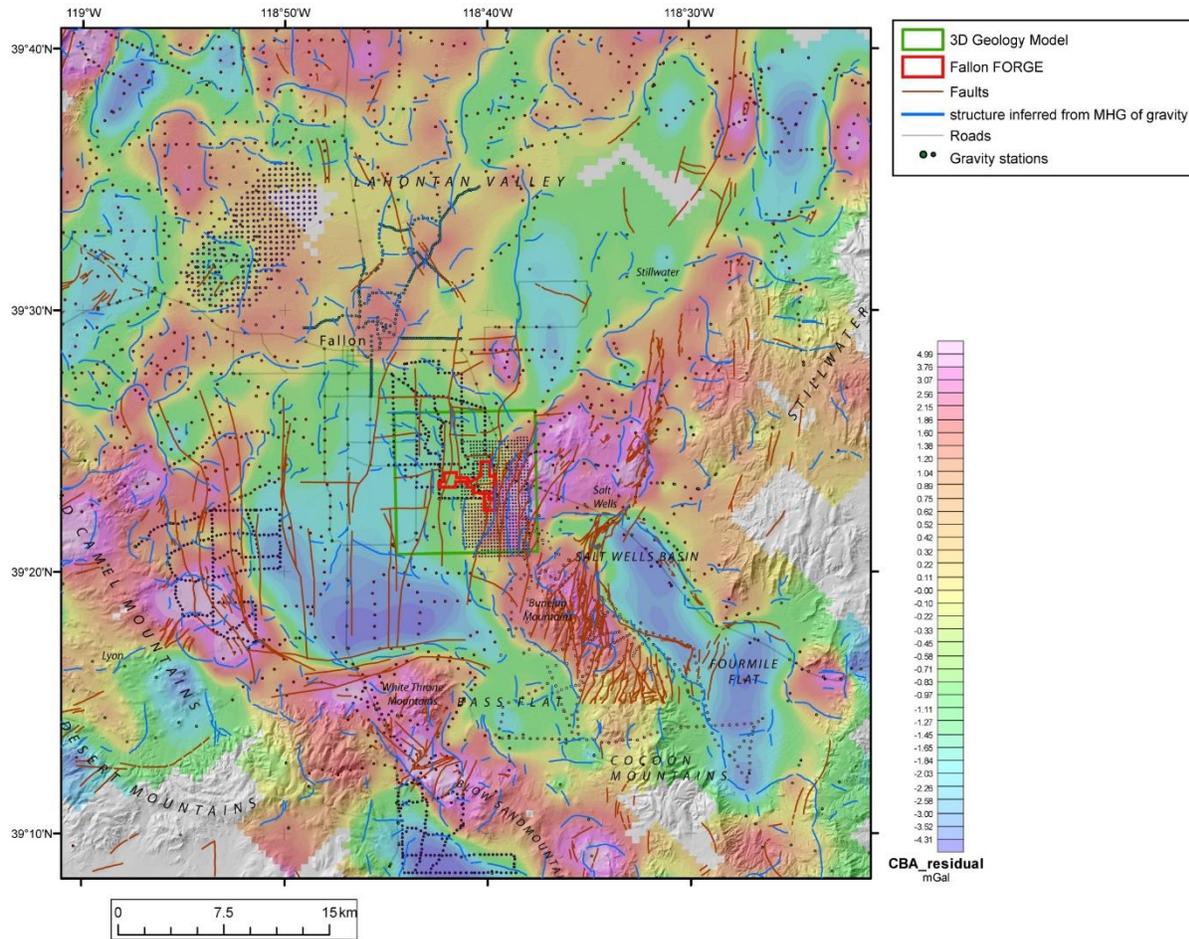
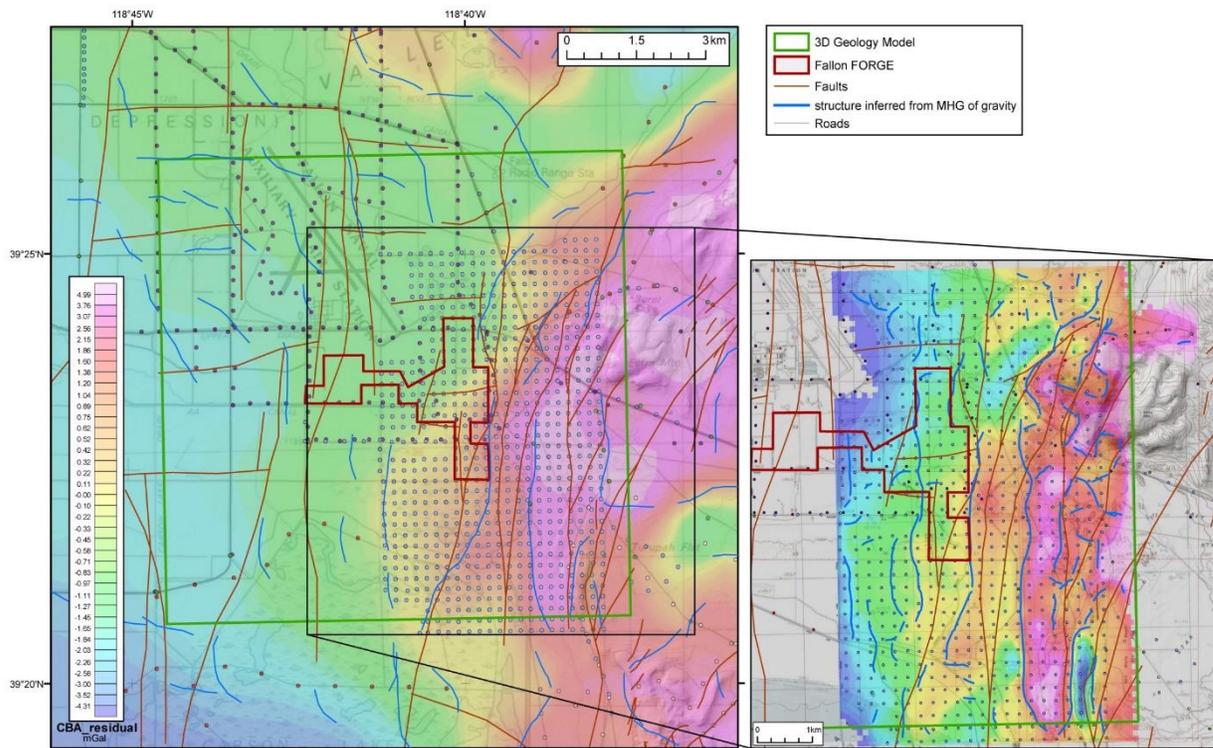


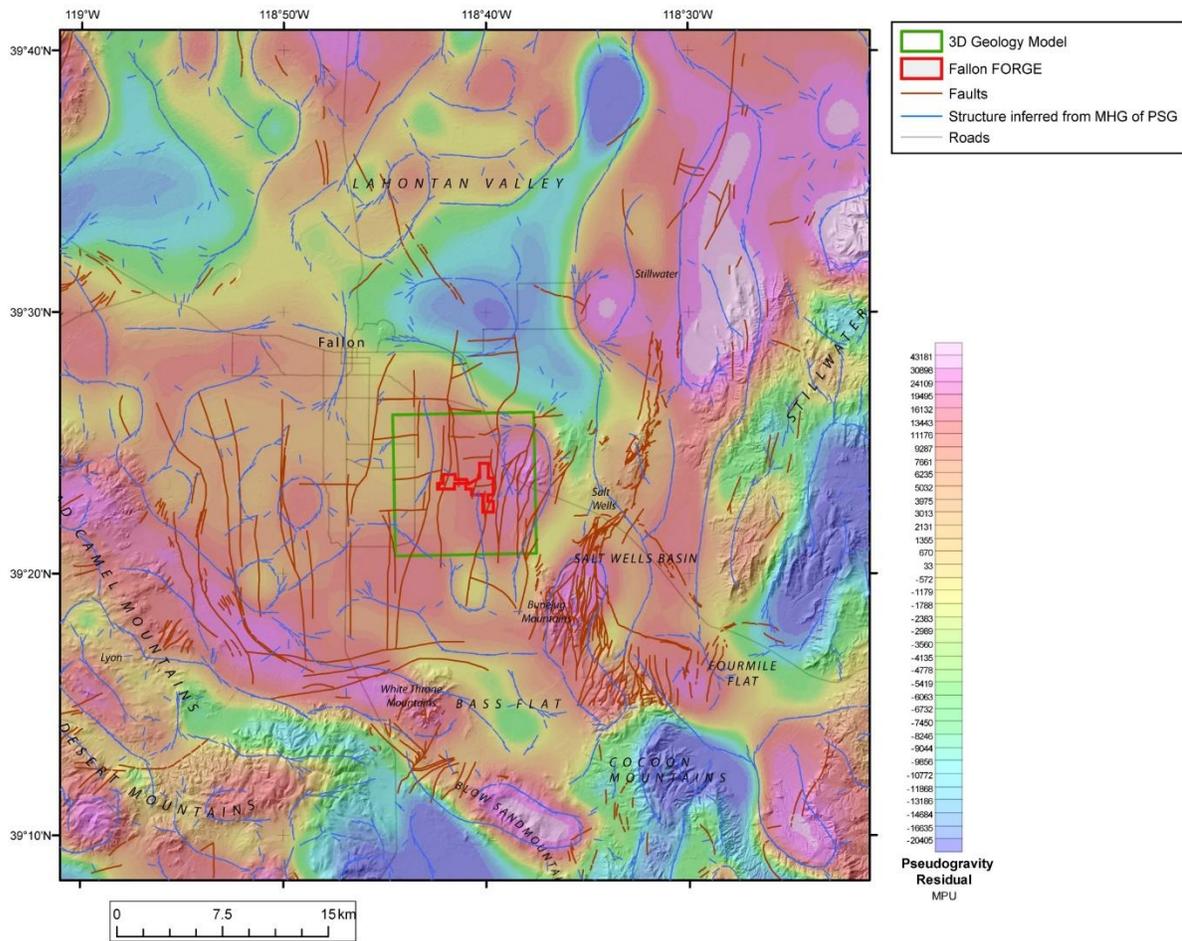
Figure 41. Interpreted depth to Mesozoic basement for the Carson Sink based on gravity data (from Faulds et al., 2014).



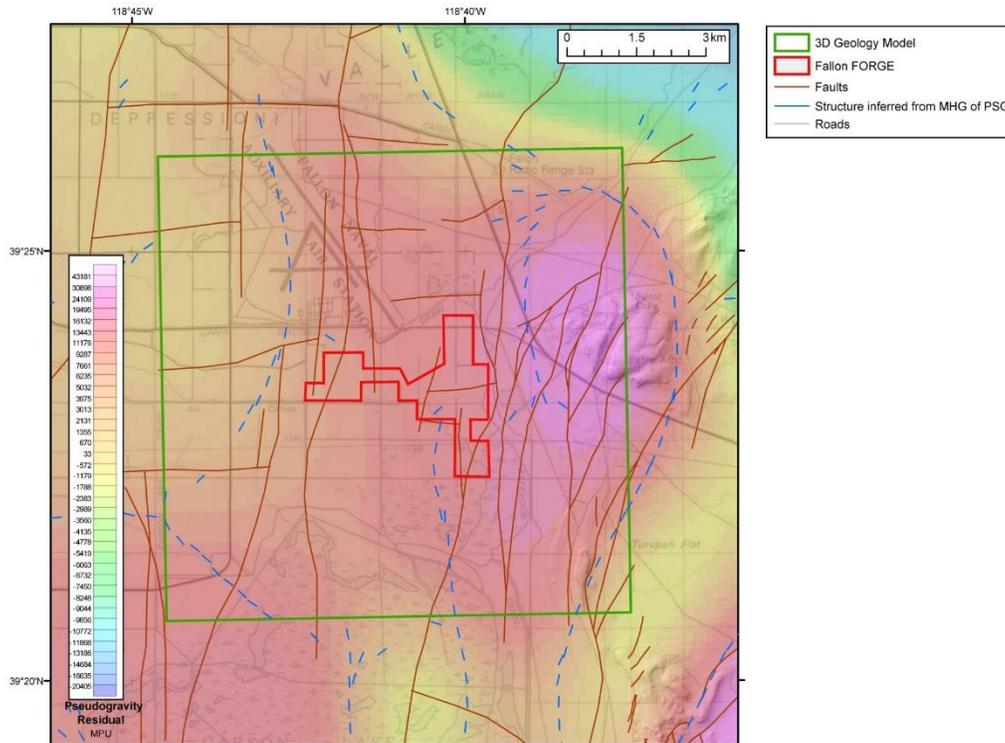
**Figure 42. Regional map of the residual CBA gravity across the Fallon FORGE area and surroundings showing inferred faults (brown) and density contrasts (blue) inferred from the maximum horizontal gravity gradients. Faults surrounding the Carson Sink were generally inferred from geologic mapping, whereas many of the faults within the Carson Sink, particularly those within and proximal to the FORGE site, were inferred from seismic reflection profiles and do not cut the upper Quaternary basin-fill sediments. The FORGE site is shown in red at right center.**



**Figure 43. Map of residual CBA gravity across the Fallon FORGE 3D model area, overlain with inferred faults (brown) and density contrasts (blue) inferred from the maximum horizontal gravity gradients. Faults within and directly adjacent to the FORGE site do not cut the upper Quaternary basin fill and were inferred from interpretation of seismic reflection profiles. Inset shows a high-resolution residual gravity grid (and corresponding density contrasts) derived from a detailed survey spanning the eastern half of the FORGE area (light purple station symbols that are distributed in a 200 m grid pattern).**



**Figure 44. Regional map of the residual pseudo-gravity (magnetic potential) across the Fallon FORGE area and surroundings showing mapped faults (brown) and density contrasts (blue) inferred from the maximum horizontal magnetic gradients. Faults surrounding the Carson Sink were generally inferred from geologic mapping, whereas many of the faults within the Carson Sink, particularly those within and proximal to the FORGE site, were inferred from seismic reflection profiles and do not cut the upper Quaternary basin-fill sediments.**



**Figure 45. Map of the Residual Pseudo-gravity (Magnetic Potential) across the Fallon FORGE 3D model area, overlain with mapped faults (brown) and magnetic contrasts (blue) inferred from the maximum horizontal pseudo-gravity gradients. Faults within and directly adjacent to the FORGE site do not cut the upper Quaternary basin fill and were inferred from interpretation of seismic reflection profiles.**

#### 4.7.2 Magnetotelluric Data

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant		✓	✓	✓		✓

Magnetotelluric (MT) data provide information on the electrical resistivity of the subsurface. Electrical resistivity (or the inverse electrical conductivity) is dependent on rock porosity, the degree of fluid saturation, alteration, and the salinity of groundwater. In hydrothermal systems, low resistivity areas have been shown to correspond in some cases to geothermal reservoirs. Conceptual models integrating temperature, lithology, structure, alteration, and fluid geochemistry have been successfully used to evaluate the presence and extent, or absence of a hydrothermal system. MT data at Fallon are specifically utilized to assess the likelihood of hydrothermal activity in the Mesozoic basement at the Fallon FORGE site and thus the potential of these rocks to host an EGS reservoir.

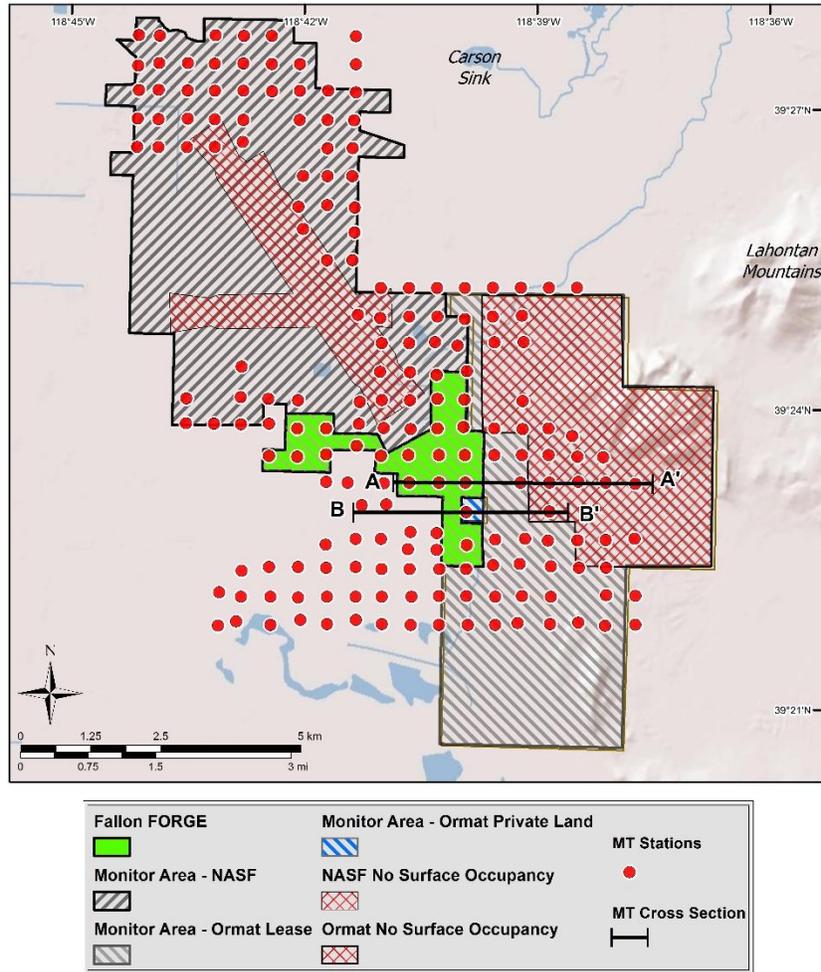
An MT study was conducted over the proposed Fallon FORGE site area by Fugro Gravity and Magnetics Services under contract to CH2M Hill for the Navy Geothermal Program Office. The survey included 181 soundings of full component tensor broadband MT and produced an average of 9.5 MT soundings per day throughout the field session. Information about the acquisition, analysis and interpretation of the MT survey are described in a final report from CGG and Chinook Geoconsulting, Inc. The 181 MT sites were located on a 500 m by 500 m grid (Figure 47) and were designed to best assess the resistivity pattern over the southeast corner of NASF. By coincidence, this MT survey was centered over the Fallon FORGE site.

The analysis of the data set was performed by Chinook Geoconsulting, Inc., which generated 1D, 2D and 3D inversions of the data. The 2D and 3D inversions were performed using CGG RLM-2D and 3D MT codes. The 3D full tensor complex impedances used a frequency range of 0.0032 Hz to 3,162 Hz, using 4 frequencies per decade, on a 384 core cluster for the inversion. Blind inversions were completed using varying 3D parameters to satisfy the data and to ensure it was also geologically reasonable. The 1D MT modeling allows for variation in depth only and provides a different way to characterize the data set. Static distortion effects (topography for example) build up at this scale and make this form of modeling less accurate, whereas these same effects are not seen in 2D or 3D modeling. Mesh details for both the 2D and 3D models are provided in Table 8. Within the 3D model, because the survey area is relatively flat, the layer thickness is 5 m for the cells within the topography, and it increases by 6% per layer up to 100 m at -1,500 m mean sea level (msl). Beneath these, the layer thickness increases by 20% down to the bottom of the mesh.

The resistivity patterns in the MT data generally follow stratigraphy across the modeled FORGE area. The Miocene to present basin-fill sediments (QTs) correspond to the upper, westward thickening low-resistivity zone in the profiles (Figure 47 and Figure 48). Lithologic logs and alteration data indicate substantial clay in the basin-fill sediments, consistent with the observed low resistivity. The Miocene volcanic rocks (Tvs) generally correspond to intermediate resistivity values, and the Mesozoic basement corresponds to high resistivity. In particular, the MT profiles show a depth where the rocks become dramatically more resistive, from quite low resistivity of  $\leq 5$  ohm-m into very high resistivity rocks with corresponding 100's of ohm-m resistivity. The intermediate resistivity associated with the Miocene volcanic rocks is typical of a rock unit that would have some alteration and/or have somewhat elevated porosity and permeability due to fractures or sedimentary interbeds. Petrographic and XRD analyses indicate alteration of the Miocene bedrock, and some wells indicate moderate permeability in some of the volcanic layers in the upper ~1 km (e.g., well 88-24). Thus, both local alteration and/or permeability within the Miocene volcanic rocks may contribute to the intermediate resistivity values. The high resistivity in the Mesozoic basement signifies hard rock with very low porosity and permeability with few open fractures. These patterns are generally consistent between profiles across the model area. It should be noted that high temperature propylitic alteration and dense metamorphic and plutonic rocks will produce similar MT signatures. No doming or arching of the base of the conductive layer was observed that might indicate the central upwelling portion of a geothermal system. Instead, the deep high resistivity zone is consistent with the occurrence of propylitically altered metamorphic and plutonic rocks observed in the wells, whose alteration is likely caused by older periods of intrusion, metamorphism, and alteration.

*Data Quality and Uncertainty:* The MT data were processed for impedances and magnetic transfer functions by using a remote reference scheme performed in the field office in Fallon. Prior to the survey, noise was expected from a variety of sources in the acquisition area, including powerlines, pipelines, radar, communications, and electric fences. Pre-survey planning moved or cancelled stations to try and minimize noise contamination, and the shape of the grid is in part a result of this planning (Figure 46). Throughout the survey, the natural signal level varied with artificial noises from powerlines, pipelines, and radar stations. However, data quality was very good with only one repeated station, and little cultural noise contamination was evident in the data. One factor possibly influencing the overall lack of noise is the low conductivity in the near-surface over most of the survey area. In the shallow section, to a few hundred meters in depth, the resistivity is (mostly) less than 6 ohm-m.

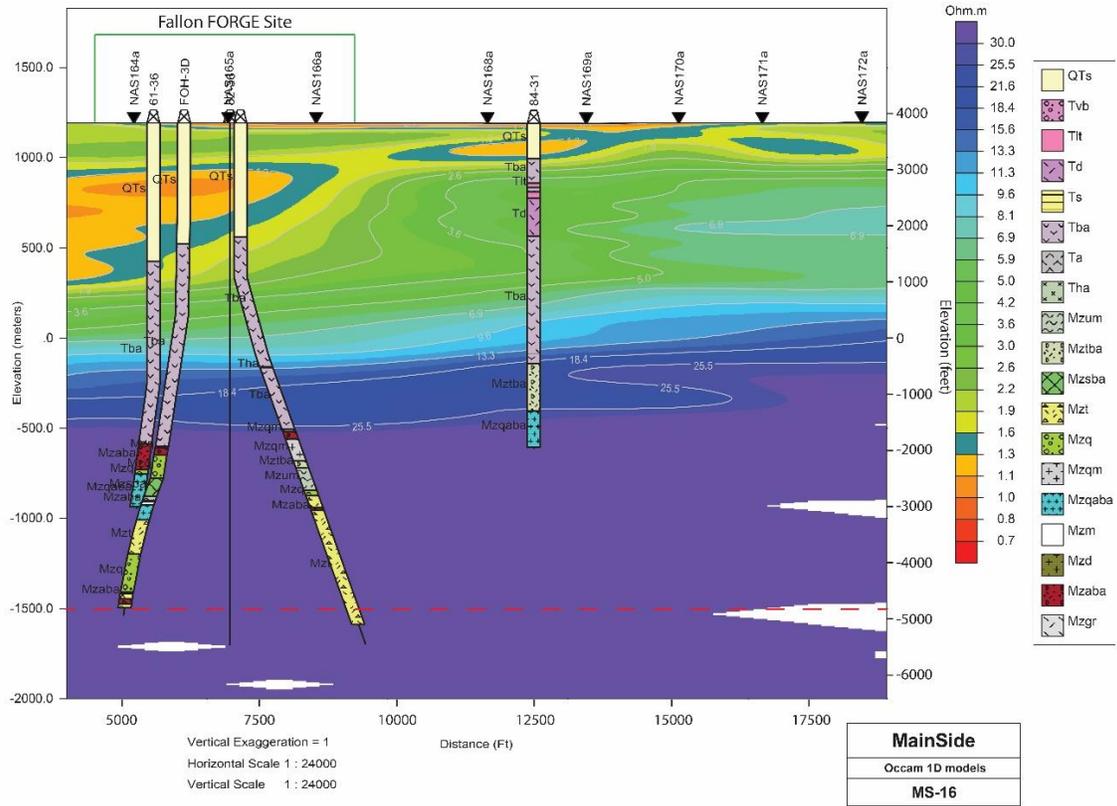
Uncertainty in the interpretation of the MT survey results is present, because, as mentioned above, deep high-resistivity zones can be produced by either propylitic alteration associated with an active geothermal system, propylitic alteration associated with older, extinct hydrothermal alteration, or by dense metamorphic and plutonic rocks without alteration. However, this uncertainty is reduced by consideration of other data types, including well logs, chips, core, and subsurface temperature data, which indicate the lack of on-going hydrothermal flow.



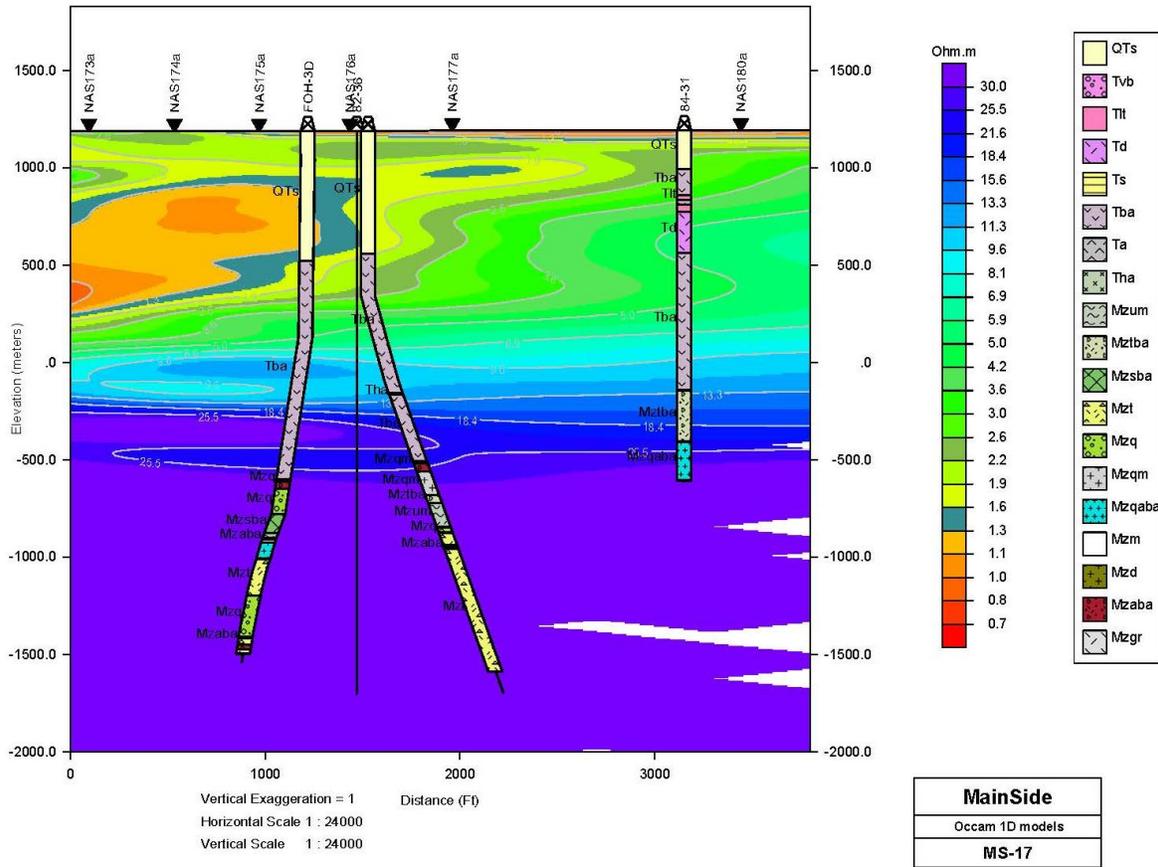
**Figure 46. MT station locations on the Fallon FORGE site and adjacent areas. Locations of MT profiles MS-16 and MS-17 are shown by the lines A-A' and B-B', respectively.**

**Table 8. Properties of mesh for 2D and 3D Models**

2D Model		3D Model	
Property	Specifications	Property	Specifications
Orientation	90°	Orientation	N0°E
Number of cells in X/Z Direction	84-166 x 90-93	Number of cells in X/Y/Z Direction	100 x 110 x 112
Number of cells total	7,728-10,556	Number of cells total	1,232,000
Model size in X/Z Direction	112-116 km x 61 km	Model size in X/Y/Z Direction	134 km x 136 km x 52 km
Cell Area, Model Core	125 m x 5-100 m	Cell Area, Model Core	167 m x 167 m
Cell Thickness, Topography	5 m	Cell Thickness, Topography	5 m
Cell Thickness, Deep	100 m		



**Figure 47. East-west MT profile MS-16 with projected well paths for 61-35, FOH-3D, 82-36, and 84-31 (west to east). View in this profile is looking north, west to the left, and east to the right. This line runs across wells 61-36, FOH-3D, and 82-36. 84-31 is projected a short distance from the north. The local boundaries of the intersection with the FORGE site are bracketed by the green lines above the profile. Lithologic units correspond to units described in the well lithology section of this report. Scale is 1:1 with no vertical exaggeration; meters are shown on vertical scale and feet on horizontal scale.**



**Figure 48. East-west MT profile MS-17 with projected well paths for FOH-3D, 82-36, and 84-31 (west to east) from the north. View in this profile is looking north, west to the left, and east to the right. This is the next east-west profile south of MS-16, wells are projected in from the north. Lithologic units correspond to units described in the well lithology section of this report. Scale is 1:1 with no vertical exaggeration; meters are shown on vertical scale and feet on horizontal scale.**

#### 4.7.3 Seismicity and Micro-Earthquake (MEQ) Data

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant					✓	✓

There are two main purposes in analyzing and ultimately carefully monitoring seismicity in Enhanced Geothermal Systems (EGS) projects: (1) using and applying seismic data to understand the dynamic response of the subsurface at the FORGE site, and (2) assessing the hazard and risk associated with induced seismicity during EGS experiments. Available seismological data for the study area was compiled using the Nevada earthquake catalogue of Slemmons et al. (1965) for earlier events and the Nevada Seismological Laboratory (NSL)

catalogue for instrumental events over the past several decades. This was supplemented with additional events from the U.C. Berkeley Seismograph Stations catalogue, University of Utah seismograph stations catalogue, published investigations of individual earthquakes, and historical accounts.

Only low level seismicity has been recorded in the Fallon FORGE project area, although several major earthquakes occurred 10 to 60 km east of the site in 1954 (Figure 49). The 1954 earthquakes had magnitudes ranging from 6.1 to 7.1, and each ruptured the ground surface. The closest principal surface rupture was ~10 km to the east of the FORGE area along the Rainbow Mountains fault zone. Table 9 lists the most significant recorded earthquakes in the vicinity of the FORGE area on the regional seismic network. Since the early 1970s, the area has been monitored by a regional seismic network that can record minor earthquakes. This network is administered by the Nevada Seismological Laboratory (NSL) at UNR and contains more than 300 seismometers, with 9 stations lying within ~75 km of the Fallon FORGE site (<http://www.seismo.unr.edu/Monitoring>).

The time-frequency of earthquakes and the distance from an earthquake epicenter to a point of interest (grid cell in model) were considered for modeling. Accordingly, a hybrid map was constructed that modeled earthquake occurrence density inversely weighted by distance (Figure 50). To approximate an inverse-distance-weighted sum of earthquake occurrence, the following procedures were completed: (1) Earthquakes were summed for each grid cell in the model at four different distances (radii): 20 km, 10 km, 5 km, and 2.5 km. (2) These four earthquake grids were then summed together to produce an overall earthquake activity map, effectively weighted inversely by distance (Figure 50). It should be noted that these data are restricted to the past ~150 years, with robust databases from only the past several decades. These data may be biased depending on the position of a particular area within the overall earthquake cycle, which can be thousands to tens of thousands of years long in this region. For example, the Dixie Valley area ~50 km to the east of the FORGE site shows a distinct loci of activity associated with the major earthquakes in 1954 and subsequent aftershock sequences.

Within the southern Carson Sink, six earthquakes were recorded within 6.6 km of the FORGE site (dePolo, unpublished). The largest occurred in 1930, a time when the ability to locate an earthquake was poor. Thus, this location is probably poorly defined. The 1930 event was a moderate earthquake, assigned a magnitude 4.5. In 1958 a magnitude 3.4 earthquake occurred in the area, but its epicenter may also be slightly mislocated. None of the minor earthquakes recorded in the area appear to have occurred directly under the FORGE project area.

**Table 9. Earthquakes in the Fallon FORGE Project Area**

Date	Latitude	Longitude	Magnitude	Distance - Direction
04/12/1930	39.4 N	-118.8 W	M4.5	6.6 km WNW
02/16/1958	39.4 N	-118.6 W	M3.4	5 km E
02/08/1974	39.334 N	-118.702 W	M2.2	5.4 km S
10/16/2004	39.3952 N	-118.6184 W	M1.97	3.8 km E
12/16/2010	39.4254 N	-118.7017 W	M1.5	3 km N
02/20/2011	39.364 N	-118.5945 W	M2.35	5.4 km E

To begin better monitoring of the background seismicity, a micro-earthquake (MEQ) seismic network at NASF started operating in 2004 prior to the possible development of a geothermal resource at the southeast corner of the main side of the base. The network consists of ten 3-component, 4.5 Hz short-period downhole sensors, which cover roughly a 10 by 10 km area around the southeast corner of NASF (Figure 51). Each station uses Nanometrics Triden/Janus system to record and then transmit data to a central site, where they are then forwarded to ports of RM-4 Bridge multiplexers. The RM-4 converts serial data into UDP IP packets and places them on an acquisition computer, which runs NaqsServer network data acquisition software. Currently, the network has five stations that are transmitting data. A few additional stations are deployed, but sensors on these instruments need to be repaired or replaced, which will be a priority in Phase 2.

Data for the MEQ network were recorded from 2004 to 2008, in 2011, and then from 2014 through present. Although the goal was to record seismic activity in the southeast part of NASF, most or all of the events that were recorded lie well beyond the outline of the array. Therefore, the accuracy of event locations is lower than would be the case for events occurring within or closer to the array. In the summer of 2015, it was determined that the sensor threshold was set too high to record micro-seismic events, and it was therefore lowered to match the appropriate level for use in the FORGE project. After this threshold was lowered, 134 events were recorded through the middle of January 2016. All of these were regional events, with no events recorded in the vicinity of the FORGE site. In combination with the Advanced National Seismic System (ANSS) and NSL data (<http://www.seismo.unr.edu/Monitoring>), the data from the NASF network suggest that the FORGE area is characterized by a low level of natural seismic activity. The recent assessment of and changes to the equipment and parameters has enabled the network to (1) provide important background data for the project site, and (2) be effectively utilized during subsequent phases of the FORGE project.

***Data Quality and Uncertainty:*** Seismic networks have expanded through time, and the ability to record and accurately locate lower-magnitude earthquakes has improved dramatically. Thus, the threshold of earthquake magnitudes was established for different time intervals (Table 10) based on the density and quality of the seismic network for that period. Plots were made of earthquakes that occurred during seven different time periods. These time periods were determined by how the earthquakes were recorded, such as from historical accounts versus using local instrumental data. The plots show the number of earthquakes versus their magnitudes and tend to form a linear relationship, whereby the earthquakes of a given magnitude range are "completely" recorded (this is the classic b-value relationship or magnitude-frequency relationship for earthquakes in an area). A minimum magnitude estimate for each time period was then made based on the level at which the number of events falls off of the linear relationship, and events below that magnitude were not used in further analyses of these data. Once the lower earthquake threshold was established for different time intervals, the distribution of earthquakes across the study area was then established (Figure 49). In essence, the seismological database summarizes the faulting history in the study area over the past ~150 years, but with relatively comprehensive data from only the past several decades. These data may therefore be biased depending on the position of a particular area within the overall earthquake cycle, which can be thousands to tens of thousands of years long in this region. Even on modern networks, not all earthquakes are recorded, which leads to some uncertainties in

earthquake completeness. Earthquake magnitudes are likely estimated within a few tenths of a magnitude outside the seismic network, and more precisely within the network. For instrumental recordings in recent decades, earthquake locations are likely within a few kilometers in western Nevada, where the NSL network is focused.

For the inverse weighted sum of earthquake activity in the Carson Sink region (Figure 50), estimated error (in log-scale units) ranges from a high of 0.5 at the low end of the earthquake sum scale (-0.3) to a “low” of 0.25 at the high end of the earthquake sum scale (3.4). Because of the log scale, the actual value of the error is higher at the high end. Low-end error of 0.5 is based on ½ the value induced by earthquake clusters in low quake-prone areas of the map, times ½ the value reduced in weight to account for less-likely occurrence of clusters in some parts of the map. High-end error of 0.25 is based on ½ range of perceived likely variation in earthquake density in high-earthquake-prone areas, based on observed heterogeneity on the map.

**Table 10. Time Periods and Earthquake Magnitude Completeness Values**

Time Period	Lower Threshold Magnitude	Notes
1860s - 1930	M5.5	Historical records
1931 - 1969	M4.5	Regional seismic networks
1970 - 1979	M2.75	Early UNR seismic network
1980 - 1992	M2.25	Increase of instruments in UNR seismic network
1993 – May 9, 2006	M2.0	Addition of southern Nevada network
May 10, 2006 - March 21, 2008	M1.2	EarthScope Bigfoot Array Deployed
March 22, 2008 - Oct. 2014	M1.5	Contemporary NSL network

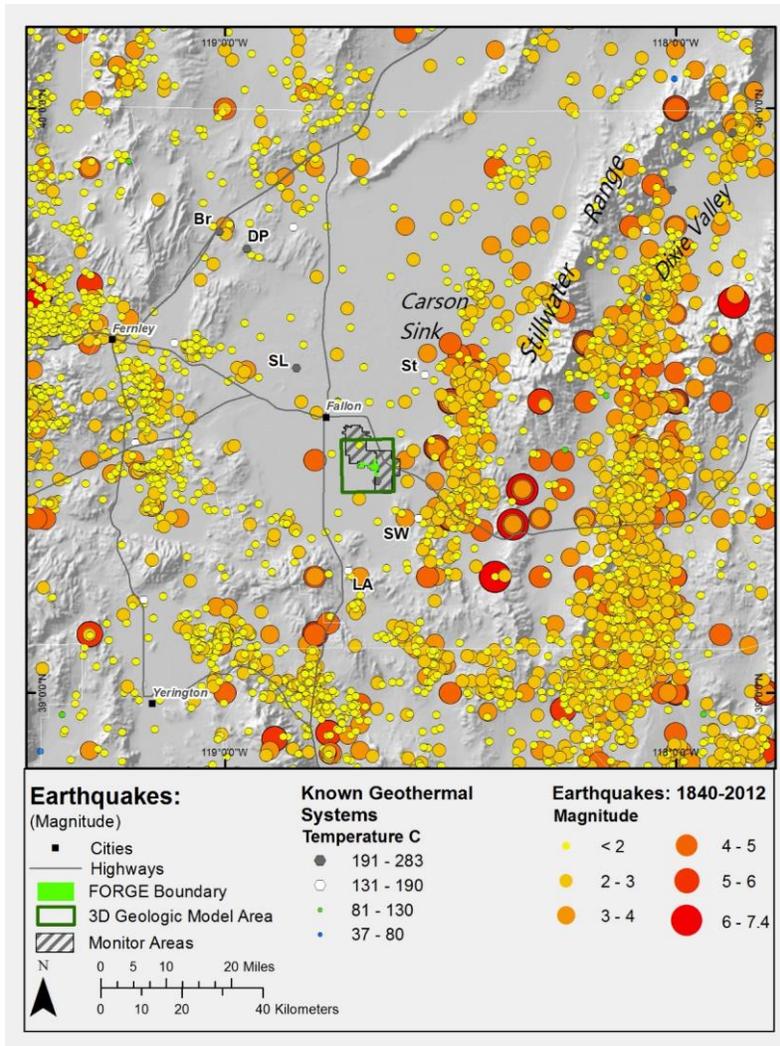
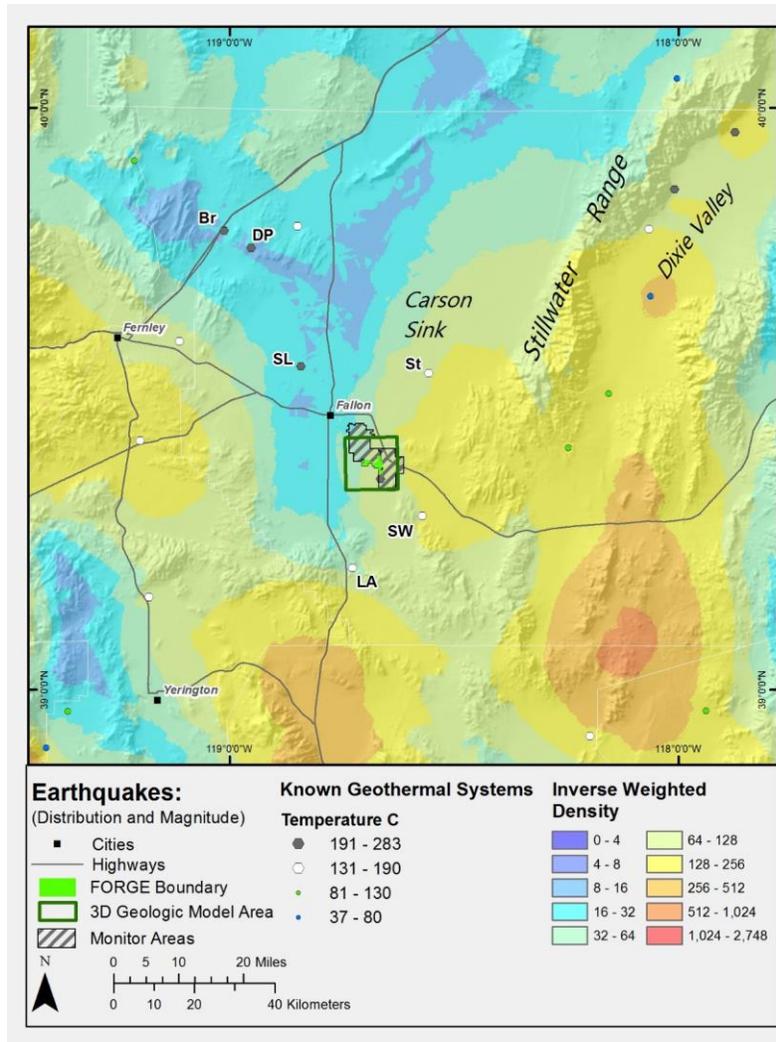


Figure 49. Historic seismicity in the Carson Sink region.



**Figure 50. Inverse weighted sum of earthquake activity in the Carson Sink region. This is a model of the density of the time-frequency occurrence of earthquakes, inversely weighted by distance. Earthquakes were summed for each grid cell in the model at four different distances (radii): 20 km, 10 km, 5 km, and 2.5 km. These four earthquake grids were then summed together to produce an overall earthquake activity map, effectively weighted inversely by distance.**

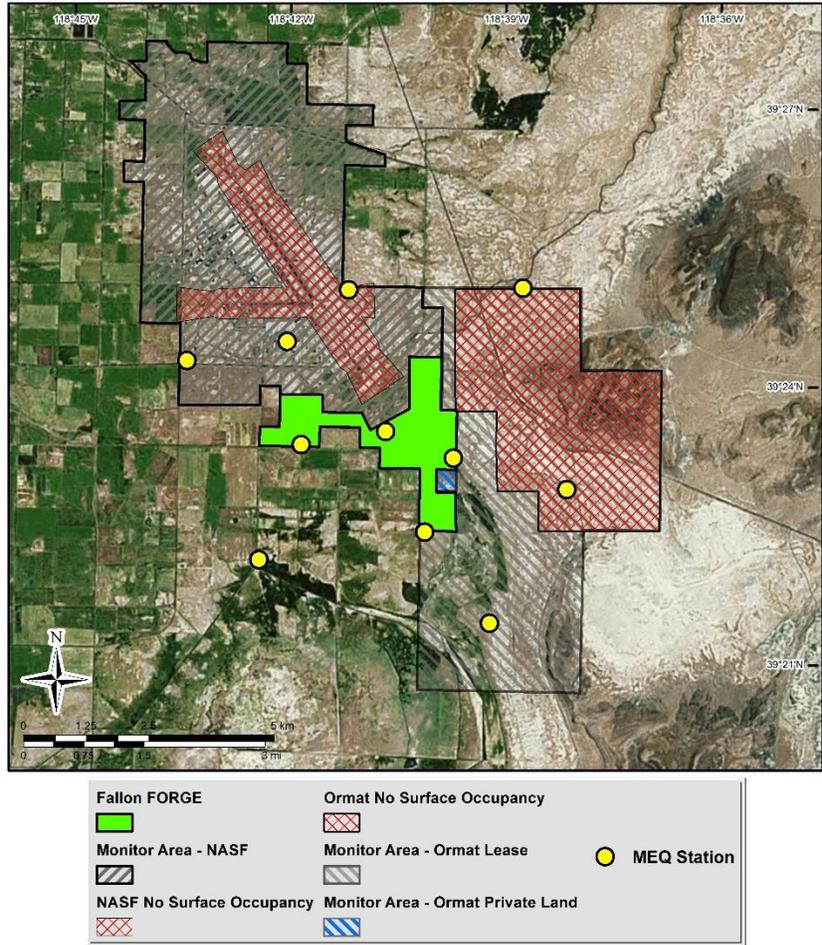


Figure 51. Micro-seismic stations within and proximal to the proposed Fallon FORGE site.

#### 4.7.4 Seismic Reflection Data

Relevance to FORGE Criteria						
Criteria	Temperature	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
Relevant		✓	✓	✓		✓

About 270 km (~167 miles) of seismic reflection profiles were interpreted for the southern Carson Sink within and near the Fallon FORGE site (Figure 52). Interpreted profiles are shown in Attachment B. The profiles constrained the general structural framework of the area, including basin architecture, thickness of major stratigraphic units, and location and spacing of faults. The profiles were also used as the basis for constructing cross sections across the project area, which in turn were used as the primary building blocks of the 3D conceptual model.

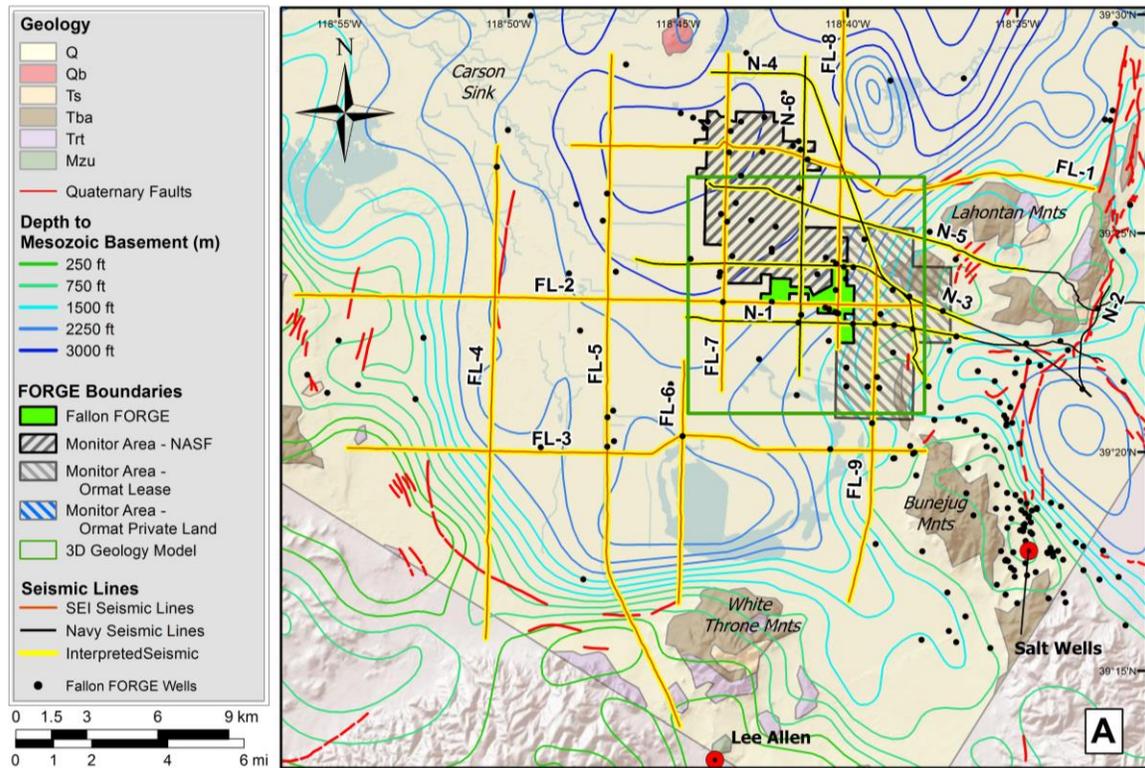
When properly processed, the peaks and troughs in a surface seismic reflection profile represent abrupt changes in seismic impedance. Seismic impedance is the product of seismic propagation velocity and density. Accordingly, these peaks and troughs, also called reflection events, indicate marked changes in velocity and/or density. A major assumption in the surface seismic reflection method is that these changes in velocity and density (the peaks and troughs) correspond to changes in rock properties (e.g. lithology).

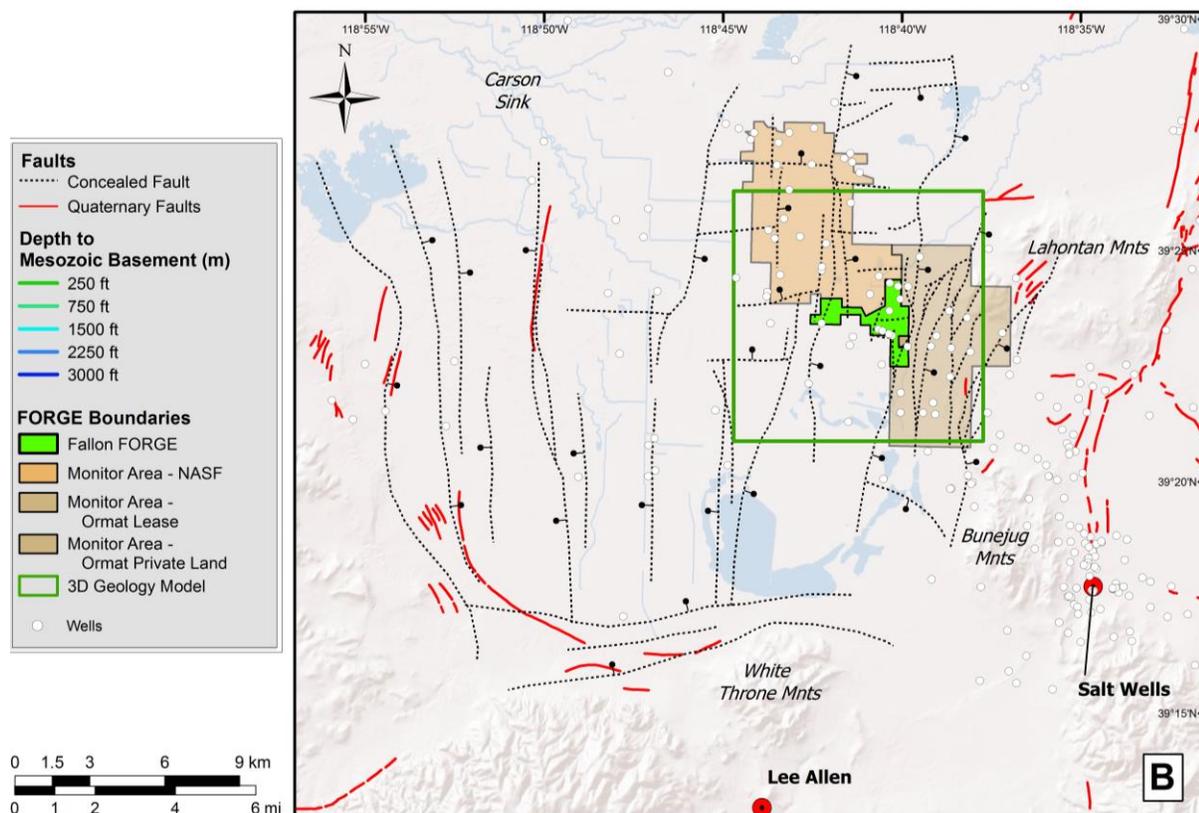
Surface seismic reflection methods have found widespread success in the oil and gas industry, and are beginning to be used in the geothermal arena. In oil and gas environments, sedimentary rocks are laid down in long nearly horizontal layers. These layers are locally cut by faults which lead to vertical offsets of these beds. Seismic reflection profiles over such areas show a series of reflection events which are coherent over long lateral distances. These reflection events commonly correspond to changes in lithology, and show vertical offsets when cut by faults. As part of the interpretation process, their lateral positions and arrival time on the profile can be picked. With the wealth of velocity data available in these areas, time picks can be converted to depth, leading to maps of fault locations, bed thickness, and depth.

In contrast, much of the Great Basin region is dominated by volcanic and metamorphosed rocks, with a high degree of structural complexity. With the exception of valley fill, the long coherent reflection events seen in sedimentary basins are lacking. One further complication in applying reflection seismic methods in much of this region is the dearth of velocity information. In most cases the only available velocity information needed to convert from time to depth are relatively unreliable move out velocities generated during processing. Nonetheless, when integrated with well data and gravity-derived depth estimates, arrival times of a limited number of formations can be picked and converted to depth. Surface mapping and gravity data are also useful in constraining fault locations. Although not nearly as detailed and reliable as maps produced in broad sedimentary basins, these results can be integrated into a geological model to identify structural style elements.

About 177 km (109 miles) of existing 2D seismic reflection data from nine separate profiles were obtained from Seismic Exchange, Inc. (SEI) for the southern Carson Sink. In addition, 93 km from five profiles were provided by the Navy. The acquisition vintage of the SEI profiles ranges from the early 1970's to mid-1980's; these data were originally acquired by the oil industry. The Navy profiles were acquired in 1994 by Northern Geophysical of America, Inc. Of the two groups of profiles, 83 km (51 miles) were proximal to the FORGE site, thus providing an excellent grid with which to constrain the stratigraphic and structural framework of the area.

The SEI profiles were only available as scanned images of paper plots of processed data. The digital data (SEGY files) were available for the Navy profiles, but no re-processing was carried out due to the limited scope and budget of Phase I of this project. Thus, for all Carson Sink lines, we used the original processing applied by the companies in the case of the SEI profiles, which did not include migration. The time domain, scanned paper plots were therefore used in the interpretation. For the Navy profiles, we used migrated data processed by Optim, Inc., in 2011 using their proprietary method. Figure 52 shows a base map for the southern Carson Sink seismic reflection lines, and interpreted profiles are shown in Attachment B.





**Figure 52. A. Base map showing seismic reflection profiles from the southern Carson Sink overlain on sedimentary basin-fill depths and generalized geologic map. Black dots are wells in the area. Large red dots are known geothermal systems. Quaternary faults are shown in red. The FORGE site is shaded in green, and the 3D model is outlined in green. B. Base map showing interpreted faults from seismic reflection profiles (see interpreted profiles in Attachment B). All faults in the vicinity of the FORGE site are concealed beneath Quaternary sediments and do not cut late Pleistocene-Holocene sediments. Actual Quaternary faults are shown in red. Bar-balls on downthrown sides of faults.**

For scanned paper images of an un-migrated profile (the SEI profiles), a time domain flow was pursued. Gravity derived depths to formation boundaries were available for the southern Carson Sink and were converted from depth to time. Similarly, if nearby well data were available, formation tops from these wells were converted from depth to time. These were then plotted on top of the scanned seismic profile. These profiles were then interpreted for faults and lithologies on the time domain images. Interpreted contacts and faults were then hand digitized. These digitized points were then converted from time to depth. The result of this process was a table of NAD83 UTM coordinates for each picked horizon or fault. These tables were incorporated into the 3D geological models.

Time to depth and depth to time conversions were critical steps in this work flow. Before these conversions can be performed, a detailed and reliable interval velocity model covering the area of the seismic profile must be in hand. The quality of the time/depth conversion is directly related to the quality of the interval velocity model. In oil and gas areas, interval velocity models are typically developed using a combination of well sonic logs and vertical seismic profile (VSP) velocity data, also called check-shot data. Well log sonic velocities are derived from very high frequency measurements. They are commonly known to differ from low frequency seismic

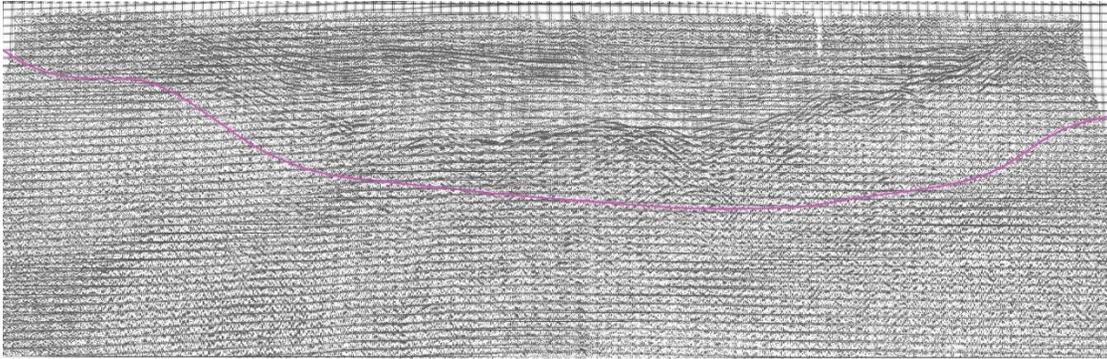
velocities by as much as 10%. For this reason, well log sonic velocities are usually “check-shot corrected” before being incorporated into interval velocity models for time/depth conversion. In modern times, interval velocity estimates can be supplemented by the expensive process of pre-stack depth migration velocity analysis. With the wealth of velocity data available in many sedimentary basins, reliable interval velocity models can be produced.

The situation in the Carson Sink is markedly different. Very few sonic logs are available, and VSP or check-shot data are virtually nonexistent. An alternative is to use interval velocities derived from stacking velocities, also called normal moveout (NMO) velocities. Interval velocities inferred from NMO velocities therefore served as the method used in this project.

NMO velocities are derived during processing. In unstacked seismic data, reflection events from a single reflector will arrive at later and later times with increasing offset between the source and receiving geophone. NMO velocities are corrections, which flatten reflection events in unstacked seismic data. They compensate for the additional time it takes a seismic wave to go from source to reflecting boundary to geophone associated with offset.

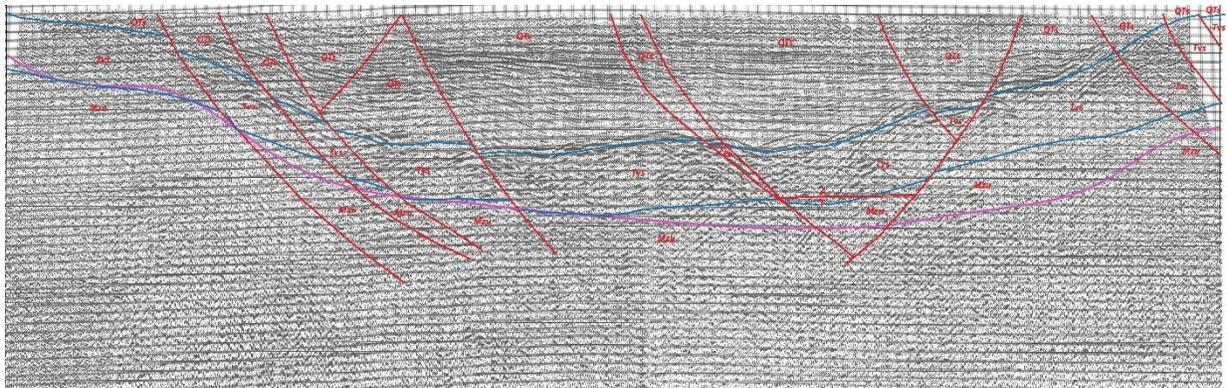
NMO velocities can be closely approximated as a root mean square (RMS) average of the interval velocities along the seismic ray path. Dix (1955) developed an algorithm for inverting interval velocities from NMO velocities. This inversion process is notoriously unstable. Very small changes in NMO velocities can lead to large changes in interval velocity. This instability grows with increasing time or depth. In spite of this instability, NMO derived interval velocities are commonly the only path open for performing time/depth conversions.

Fortunately, the NMO velocities derived in processing the seismic profiles used in this project were listed on the scanned images. For each profile, an interval velocity model was obtained from the NMO velocities using a program included in the Seismic Unix (SU) processing package (Cohen and Stockwell, 2008). In particular, the SU program `velconv` implements the Dix (1955) algorithm. It has options for converting NMO velocities to interval velocities in time or depth, as well as producing tables of depth as a function of time or time as a function of depth. For each scanned image profile, an interval velocity model was developed using the posted NMO velocities and SU program `velconv`. If gravity and well log formation tops were available for that particular profile, their depths were converted to time using the depth to time tables produced by this same program. Figure 53 shows one such profile that extends through the FORGE site in the southern Carson Sink. The magenta line in Figure 53 shows the top of the Mesozoic basement inferred from gravity data after depth to time conversion.

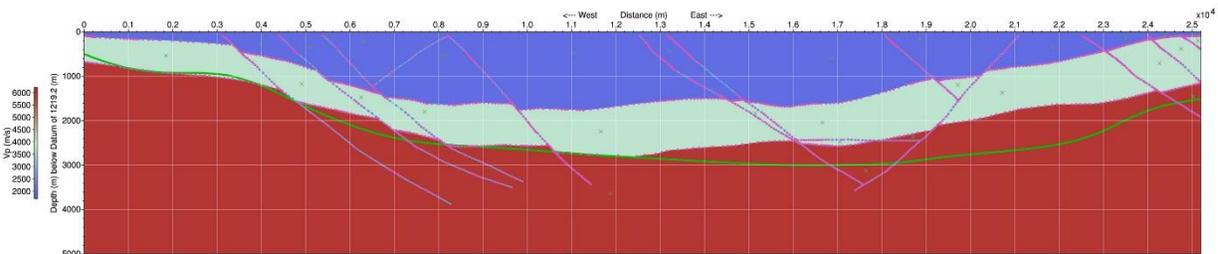


**Figure 53. Seismic reflection profile FL2 of the southern Carson Sink (looking north). The magenta line shows the gravity inferred top of Mesozoic basement after depth to time conversion. Seismic data are owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.**

Guided by the well and gravity data, these profiles were then interpreted. Tops of a limited number of lithologies and fault locations were drawn on the profiles. These were then hand digitized and converted from time to depth. Figure 54 shows the interpreted profile FL2 from the southern Carson Sink. Figure 55 displays the interpretation picks shown in Figure 54 after conversion from time to depth using the NMO derived interval velocity model.



**Figure 54. Interpreted profile FL2 from the southern Carson Sink (looking north). Normal faults are shown in red, and lithologic contacts are blue. QTs, Late Miocene to Quaternary basin-fill sediments; Tvs, Miocene volcanic and sedimentary rocks; Mzu, Mesozoic basement undivided. Note that the Seismic data are owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.**



**Figure 55. Time to depth converted picks of interpreted horizons and faults from profile FL2.**

For the migrated Navy profiles, a depth domain approach was followed. Since the gravity and well data were already in depth, there was no need to convert these to time. These plots were then used for interpretation. Since interpretations of the Navy profiles were already in depth, they were passed on directly for incorporation into the geological model.

The seismic reflection data indicate that the proposed Fallon FORGE site is underlain by a gently west-tilted half graben cut by widely spaced generally east-dipping normal faults (see interpreted profiles in Attachment B). Most of the faults dip moderately to steeply and accommodated relatively minor offset, typically ranging from ~100-200 m. The largest faults generally strike north to north-northeast, but several minor faults (generally <100 m offset) strike ~east-west. Typical spacing of the northerly striking normal faults ranges from ~0.4 to 3.5 km in the vicinity of the project area (Figure 52B).

**Data Quality and Uncertainty:** The quality of the seismic reflection data is good in the Neogene basin fill but degrades significantly below the top of the Miocene volcanic section. The seismic waves are attenuated significantly in volcanic rocks and thus resolution of distinct reflectors and contacts becomes difficult below that level. Thus, the gravity profiles and any available well data were used to constrain the contact between the Tertiary volcanic section and Mesozoic basement. Seismic resolution or uncertainty is the ability to distinguish separate features, or the minimum distance between two features so that they can be defined separately. Seismic resolution is controlled by wavelength (e.g., Yilmaz, 2001). In order for two nearby reflective interfaces to be distinguished well, they have to be about 1/4 wavelength in thickness (Rayleigh Criterion). The dominant frequency in profiles analyzed for this project is ~20 Hz. Typical velocities are about 4 km/sec. Since wavelength equals velocity divided by frequency, typical wavelength would be about 200 m. This would, in turn, imply that the resolution is as great as ~50 m in the basin-fill, possibly lower at shallow levels characterized by lower velocities. This level of resolution only applies to well-imaged basin-fill Neogene sediments. Below that level, resolution would be much poorer (>100-200 m). Although these data are not up to modern standards in hydrocarbon-rich basins, they do provide critical data on the thickness of basin-fill sediments, general basin architecture, and spacing of major faults. They also provide important data with which to guide future seismic reflection surveys in a potential Phase 2 utilizing the most modern techniques.

## 5 DISCUSSION

### 5.1 SUMMARY OF STRATIGRAPHIC AND STRUCTURAL FRAMEWORK

The stratigraphic and structural framework of the proposed Fallon FORGE site and surrounding area is well characterized due to previously completed detailed geologic mapping (Figure 13), abundant well data (Figure 14), and geophysical data sets, including detailed gravity (Figure 43) and MT surveys (Figure 46), 14 seismic reflection profiles (Figure 52 and Attachment B), and regional seismological data (Figure 49).

The detailed geologic mapping, detailed lithologic logs of >14,000 m of cuttings and core from multiple wells (well lithology data), petrographic data from more than 500 thin sections from cuttings, core, and nearby outcrops, and down-hole alteration and geochemical data constrain the stratigraphy of the area. All data sets are compatible with one another and reveal a relatively

consistent stratigraphic section across the area. In descending stratigraphic order, the major lithologic units are as follows (Figure 16).

- Late Miocene to Quaternary basin-fill sediments (QTs), consisting predominantly of alluvial and lacustrine deposits (up to 1.5 km thick), with sparse lenses of mafic volcanic rock. A sequence of 2.5 to 0.7 Ma basalt flows intercalated in the upper part of the basin fill 8 km northwest of the FORGE site (Figure 16) indicates that most of the basin fill is late Miocene to Pliocene in age. The basin-fill sediments thicken from < 100 m to > 1.4 km thick from east to west in the area consistent with the presence of a west-tilted half graben. The basin-fill sediments are characterized by good reflectivity in the seismic reflection profiles, allowing for imaging of faults, and relatively low-resistivity probably due to substantial clay, as supported by the analysis of cuttings. The base of the basin-fill sediments is constrained by prominent reflectors in the seismic profiles and by well data.
- Middle to late Miocene volcanic and lesser sedimentary rocks (Tvs), dominated by basaltic andesite lavas with lesser volcanic breccia, tuff, dacite, and andesite. The Miocene rocks are well exposed in the nearby Bunejug and Lahontan Mountains, with similar lithologies and thicknesses found in cuttings and core at the FORGE site. The thickness of the Miocene volcanic rocks appears to be relatively consistent across the region, ranging from ~0.7 to 1.1 km. The base of the Miocene section (i.e., nonconformity at the top of the Mesozoic basement) is difficult to discern on the reflection profiles but was constrained by four wells and gravity modeling. The volcanic section images poorly on the seismic reflection profiles and yields intermediate resistivity values (Figure 47 and Figure 54). The total thickness of the Neogene section (basin-fill sediments and Miocene volcanic rocks) ranges from ~1.7 to 2.8 km in the project area. Oligocene ash-flow tuffs, although present in the region, were not observed in the cuttings and core from the Fallon site.
- Mesozoic crystalline basement (Mzu) consisting of Triassic-Jurassic metavolcanic and metasedimentary rock, including rhyolitic tuff, quartzite, marble, and mafic lavas, all locally intruded by Jurassic-Cretaceous granite. The basement rocks consistently yield high resistivity values, consistent with low permeability, as supported by the well tests. The Mesozoic basement was penetrated by four wells. Available data suggest that meta-rhyolite and quartzite are two dominant lithologies in the area, attaining thicknesses of ~500 m and 200 m, respectively. It is important to note that metamorphic rocks dominate over granite in much of the Great Basin region east of the Sierra Nevada. Thus, the basement rocks at Fallon are broadly representative of the region. As discussed below, the Mesozoic basement at Fallon contains several potential reservoirs of sufficient volume for research and development of EGS technologies. Although thus far penetrated by only four wells within or proximal to the project site, excellent analogues of the basement lithologies are exposed in nearby mountain ranges, including the Lee-Allen area ~20 km south of the FORGE site and the Stillwater Range ~30 km to the northeast.

Similar to the stratigraphy, the structural framework is well defined by multiple mutually supporting data sets, including detailed geologic mapping, fault kinematic data, borehole imaging, gravity data, and seismic reflection profiles. Collectively, these data sets indicate that the structural framework of the proposed Fallon FORGE site has the following characteristics.

- A gently west-tilted half graben underlies the entire site (Figure 22).
- The half graben is cut by widely spaced, relatively minor normal faults (Figure 22 and Figure 52B).
- Faults in the area are characterized by the following:
  - Displacement of generally <200 m.
  - Spacing of ~0.4 to 3.5 km (Figure 52B).
  - Moderate to steep dips. Note that subhorizontal to gently dipping faults in the interpreted profiles (Attachment A) result from apparent dips on faults that are subparallel to the profiles.
  - North to north-northeast strikes, although sparse E-W-striking faults are also present in some areas.
  - East-dipping faults appear to dominate and accommodated the west tilt of the half graben.
- Borehole imaging of drilling induced fractures and fault kinematic data indicate an extensional stress regime and a WNW-trending extension direction.

Extension in this region probably began in middle Miocene time and has continued episodically to the present. Quaternary faults and historic earthquakes in the region (Figure 5 to Figure 7, Figure 49 and Figure 50) attest to the active tectonic environment of the region. Accordingly, geodetic data demonstrate that the Fallon area occupies a region of relatively high transtensional to extensional strain (Figure 4). However, despite relatively high regional strain rates, no Quaternary faults have been observed within or proximal to the Fallon FORGE site. This may account for the lack of hydrothermal activity at Fallon, as most geothermal systems in the region are associated with Quaternary faults (Bell and Ramelli, 2007). It is also important to note that favorable structural settings for geothermal activity, such as step-overs, major fault terminations, and accommodation zones (e.g., Faulds and Hinz, 2015), appear to be absent at the Fallon site, which also suggests a low probability of the presence of an active hydrothermal system.

## 5.2 3D GEOLOGIC MODEL

In order to provide a conceptual model and assess the distribution and character of potential EGS reservoirs, we developed a 3D geologic model encompassing the area within and around the Fallon FORGE Site. The model spans 100 km<sup>2</sup> and is centered on the Fallon site, extending 10 km in the north-south direction and 10 km in the east-west direction (Figure 11). The geologic model extends from the surface, which ranges between ~1200 to 1350 m above sea level, to a depth -2500 m below sea level, spanning ~3.8 km.

The 3D geologic modeling was done in EarthVision software, using methods similar to several recent contributions in this arena (Moeck et al., 2009, 2010; Faulds et al., 2010b; Jolie et al., 2012, 2015; Hinz et al., 2013a; Siler and Faulds, 2013; Siler et al., 2016a, b). The 3D geologic model consists of 28 faults within the 100 km<sup>2</sup> area. The fault geometries are constrained by the

interpretations of 14 seismic reflection profiles (Figure 56) and the traces of faults mapped in the Bunejug and Lahontan Mountains along the eastern edge of the 3D geologic model volume (Figure 11, Figure 12, and Figure 13). The 3D model consists of four lithologic units, with the contacts between units defined by interpretation of the 14 seismic reflection profiles and downhole lithologic interpretations from 24 wells within and proximal to the 3D geologic model (Figure 57 and Figure 58).

For effective 3D modeling of the stratigraphy and structural features, the stratigraphic units described in detail in Section 4.1 (Table 1 and Figure 19) were lumped into four lithologic units. The four units are, from oldest to youngest: (1) undivided Mesozoic basement, consisting of Mesozoic metasedimentary, metavolcanic, and plutonic units (Mzu); (2) Oligocene rhyolitic ash-flow tuffs (Ttr); (3) Miocene volcanic and sedimentary rocks, consisting primarily of basaltic and basaltic andesite lava flows (Tvs); and (4) late Miocene to Quaternary undivided sediments (QTs). The total modeled volume of 366.5 km<sup>3</sup> consists of 130 km<sup>3</sup> of Mzu, 3.5 km<sup>3</sup> of Ttr, 111 km<sup>3</sup> of Tvs, and 122 km<sup>3</sup> of QTs (Figure 58 and Table 11).

Two major faults sets are evident in the modeled area, a primary north-striking set and a secondary east-striking set (Figure 59 and Figure 60). The north-striking faults dip both east and west, though the east-dipping faults dominate and primarily control the gently west-tilted half graben that constitutes this portion of the Carson Sink (Figure 58 and Figure 60). The west-tilted half graben occupies the western limb of an extensional anticline, the axis of which lies just east of the eastern edge of the 3D geologic model. The dominant east-dipping faults are relatively widely spaced (~1.5 km), all with displacement of less than ~200 m. This geometry of widely-spaced subparallel faults, contrasts with significantly more complex structural settings at similarly modeled conventional hydrothermal systems in the region. For example, the Brady's geothermal system contains dozens of closely spaced and intersecting fault strands within an ~1.5 km-wide step-over in a normal fault zone (Siler and Faulds, 2013; Siler et al., 2016b). Such comparisons suggest that the fault structure at the Fallon FORGE site is not conducive to hosting a conventional geothermal system (Figure 61).

It is also important to note that Figure 59 shows that faults within the 3D model volume have an average strike of 003o, which is compatible with the average orientation of natural fractures imaged in four wells at the site (Figure 25). This suggests a strong correspondence between macro- and micro-scale structures at the Fallon FORGE site. It is also important to note that the predominant orientation of the macro-scale faults and micro-scale fractures is approximately orthogonal to SHmin, and thus these structures are in a favorable orientation for hydraulic stimulation.

**Table 11. Volumes of Rock Units in 3D Model**

	Total volume modeled (km <sup>3</sup> )	Total modeled volume 175-225 °C (km <sup>3</sup> )	Total volume within FORGE area (km <sup>3</sup> )	Total volume 175-225 °C within FORGE area (km <sup>3</sup> )
All Units	366.5	65	16.6	8
QTs	122	0.2	3.2	0.1
Tvs	111	18	4.8	4.7
Ttr	3.5	1.8	0	0
Mzu	130	45	8.6	3.2

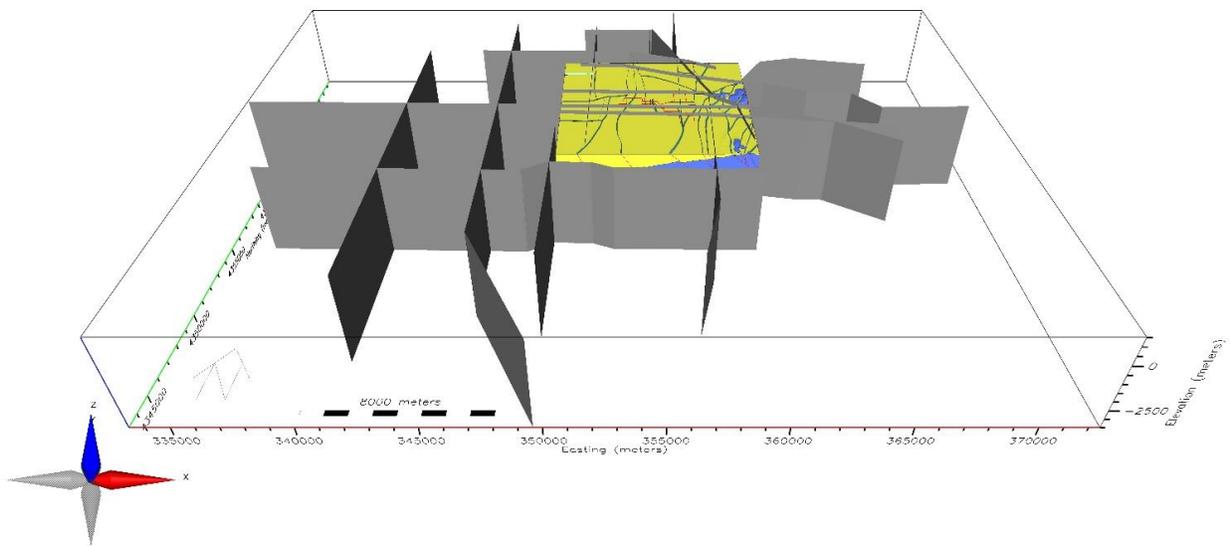
Note: Volume of the geologic model for each of the 4 modeled lithologic units. Column 1, total modeled volume (100 km<sup>2</sup> areal extent). Column 2 modeled volumes falling within 175-225°C. Column 3 modeled volumes within the Fallon Geothermal Research Observatory Site (4.6 km<sup>2</sup> areal extent). Column 4 modeled volumes within the Fallon Geothermal Research Observatory Site and falling within 175-225°C. All volumes calculated to a depth of -2500 m bsl or ~3800 m bgs.

Uncertainty in the 3D geologic interpretations was calculated based on relative distance from the input datasets (Figure 62 and Figure 63). The primary input datasets utilized for constraining the subsurface 3D geologic geometry are the lithologic logs along the well paths and seismic reflection profiles. The distance between the locations of these datasets and all locations within the 3D geologic model were calculated. We also assume that uncertainty increases with depth, so relative uncertainty with increasing distance from the surface was also calculated. Relative uncertainty was calculated by fitting these distances to logarithmic relative uncertainty curves (Figure 63). Very near to input data, relative uncertainty in the 3D modeled geologic interpretation is very low (i.e. we have high confidence in the geologic interpretation). With increasing distance from each input dataset, relative uncertainty increases progressively. Past a distance of 500 m, the characteristic spacing of the wells used for lithologic analyses, the progressive increase in relative uncertainty with distance lessens. Relative uncertainty between zero and one was calculated for the twenty-four wellbores with lithologic data and the seismic reflection profiles (Figure 62 and Figure 63). The relative uncertainty volumes for all the input datasets were summed to produce a cumulative relative uncertainty for the 3D volume for which the 3D geologic model was constructed (Figure 62 and Figure 63).

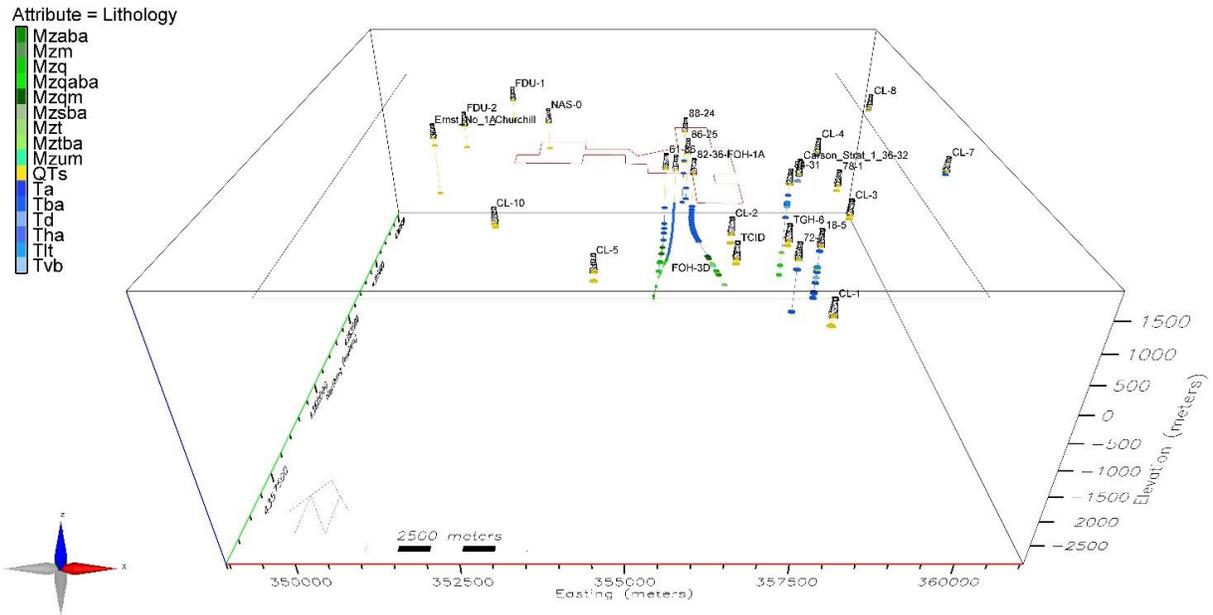
The relative uncertainty analysis indicates that we have relatively high confidence in the modeled geologic relationships as a result of a high density of data within the Fallon FORGE site (Figure 63). We also have relatively high confidence in the modeled geologic relationships directly to the east of the Fallon site. However, adjacent to the Fallon site to the north, west, and south the density of downhole lithologic data and seismic reflection data are less, relative to the center of the Fallon site, and the uncertainty in the modeled geologic relationships is therefore higher.

A 3D subsurface temperature model was interpolated based on downhole temperature measurements in eight wells (FDU-1, FDU-2, 88-24, 82-19, 84-31, 82-36, FOH-3D, and 61-36) within and proximal to the Fallon FORGE site (Figure 64). A minimum tension gridding algorithm was used to interpolate temperatures into data-sparse areas. The subsurface temperature model is well constrained within the Fallon FORGE site proper, with temperature

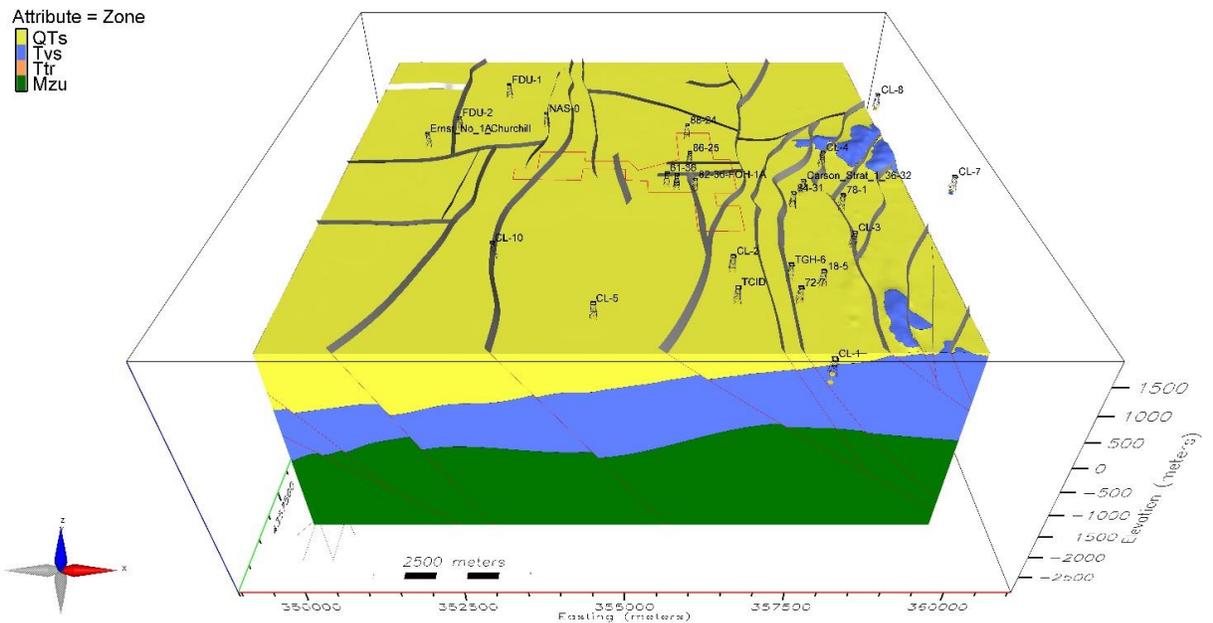
logs from 88-24, 82-19, 82-36, FOH-3D, and 61-36, all within the FORGE site. Three of these wells, 61-36, FOH-3D and 82-36, extend to ~2200-2600 m below ground surface (bgs), so the 3D temperature model is well constrained to at least 2600 m bgs. Based on this temperature model, the spatial locations of the 175°C and 225°C isotherms were calculated. The 175°C isotherm lies at ~1700-1900 m bgs, whereas the 225°C isotherm lies at ~2400-2800 m bgs (Figure 64). Within the 366.5 km<sup>3</sup> total modeled volume, 65 km<sup>3</sup> of crystalline rock lie between the 175°C and the 225°C isotherms (Figure 65 and Figure 66, Table 11). Within the Fallon FORGE site 8 km<sup>3</sup> of crystalline rock, including both Miocene volcanic rock and Mesozoic granitic and metamorphic basement, lie between the 175°C and the 225°C isotherms (Table 11), and all of this volume lies within the required depths for the project of 1.5 to 4.0 km.



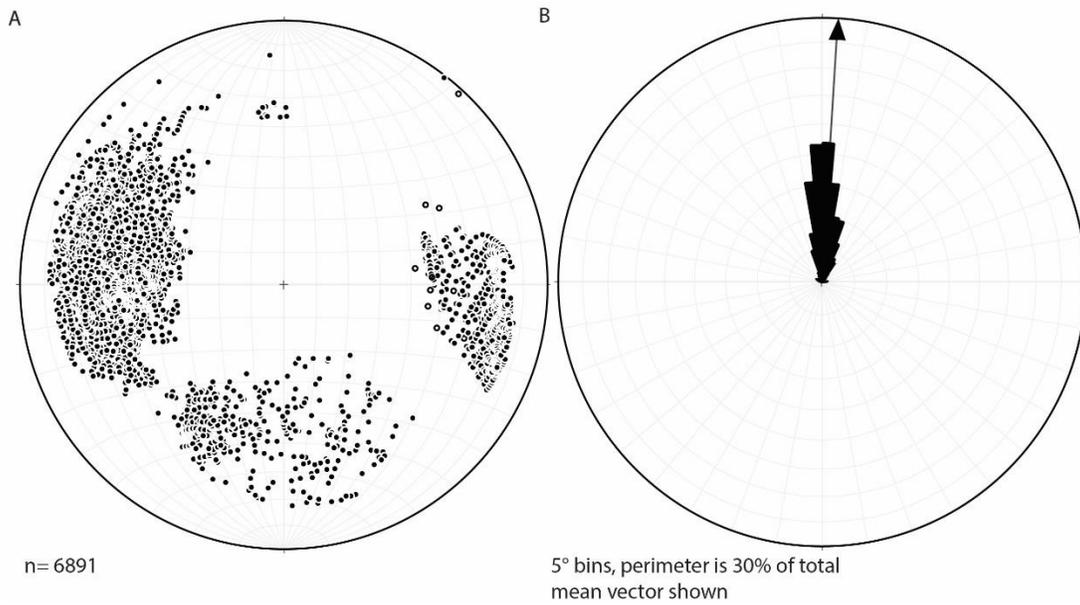
**Figure 56. 3D perspective looking north at the 14 seismic reflection profiles (in grey) that were interpreted and synthesized in construction of the 3D geologic model, which is shown in the center-left of the image. Modeled fault planes are shown in green. The proposed Fallon FORGE site is shown within the 3D geologic model area in red outline.**



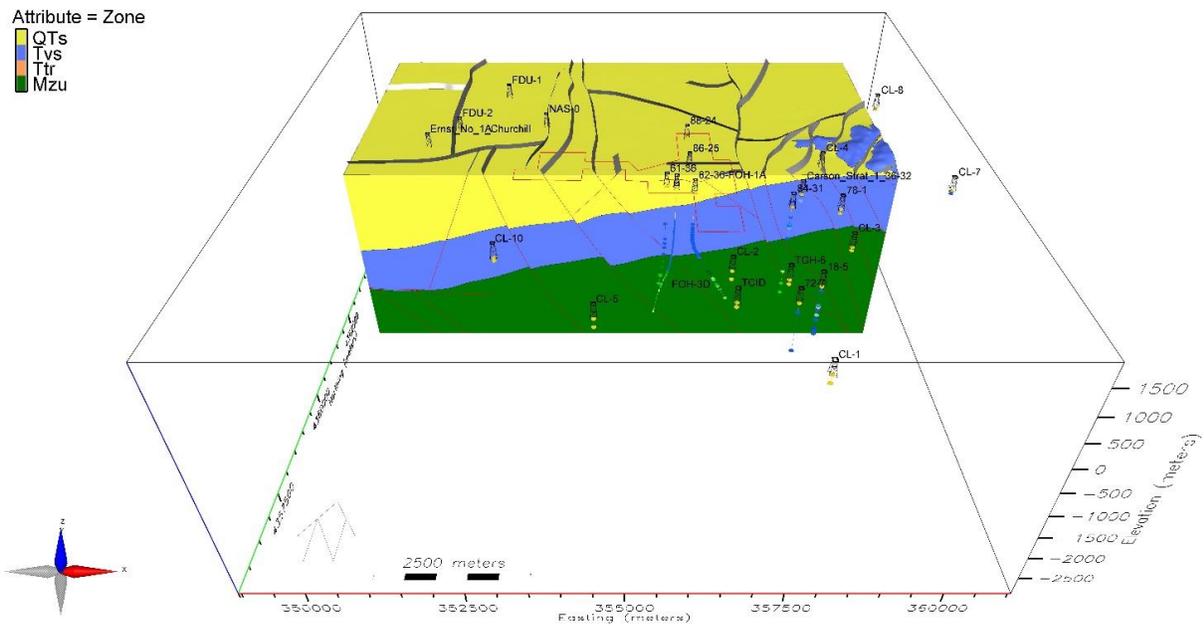
**Figure 57. 3D perspective view looking north of the downhole lithologic logs that were synthesized in construction of the 3D geologic model. Green lithologies are Mesozoic basement units, blue are Tertiary volcanic and yellow are Quaternary-Tertiary sediments. The range of the 3D geologic model is shown in blue. The proposed Fallon FORGE site is shown within the 3D geologic model area in red outline.**



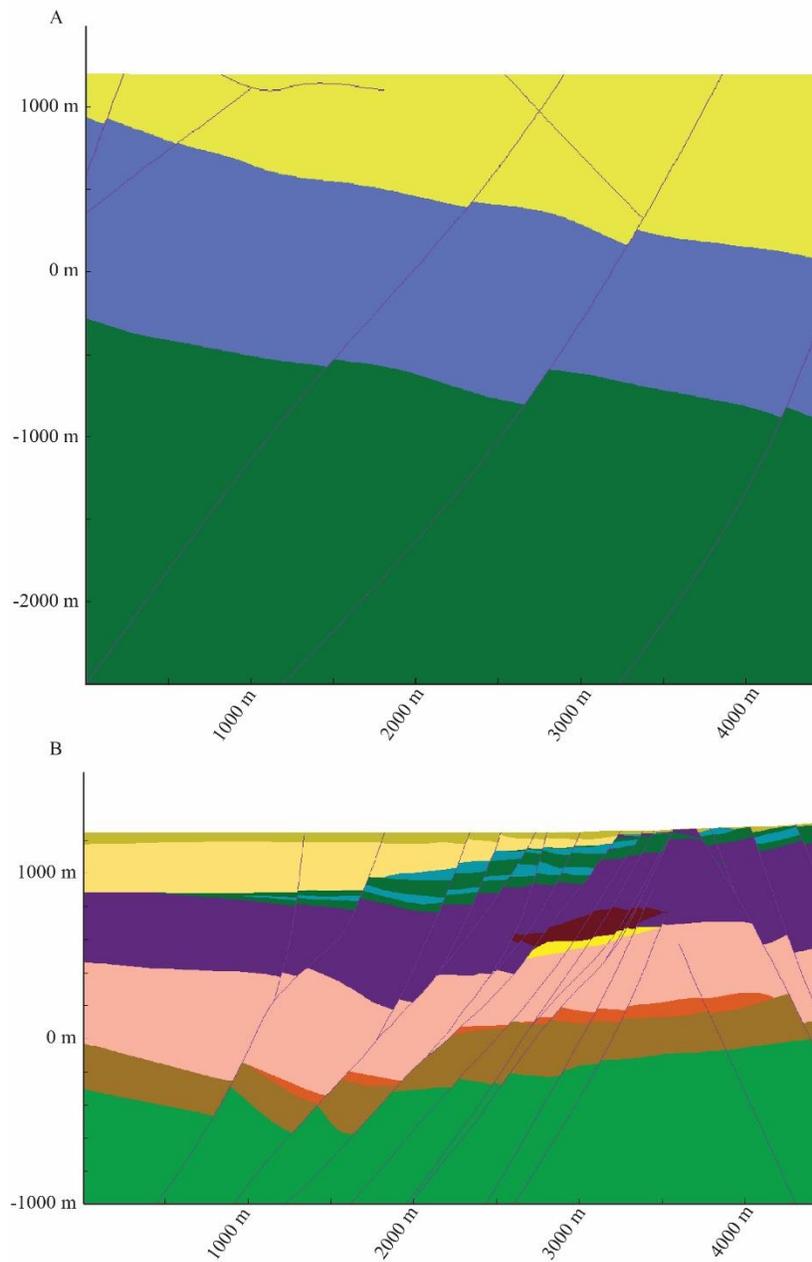
**Figure 58. 3D perspective looking north at the 3D geologic model. Mesozoic undivided basement (Mzu) in green, Miocene volcanic rock (Tvs) in blue, and late Miocene-Quaternary sediments (QTs) in yellow. Modeled fault planes are shown in gray. Green rig symbols denote the surface location of the 24 wells that were analyzed for downhole lithologic data. The proposed Fallon FORGE site is shown by the red outline.**



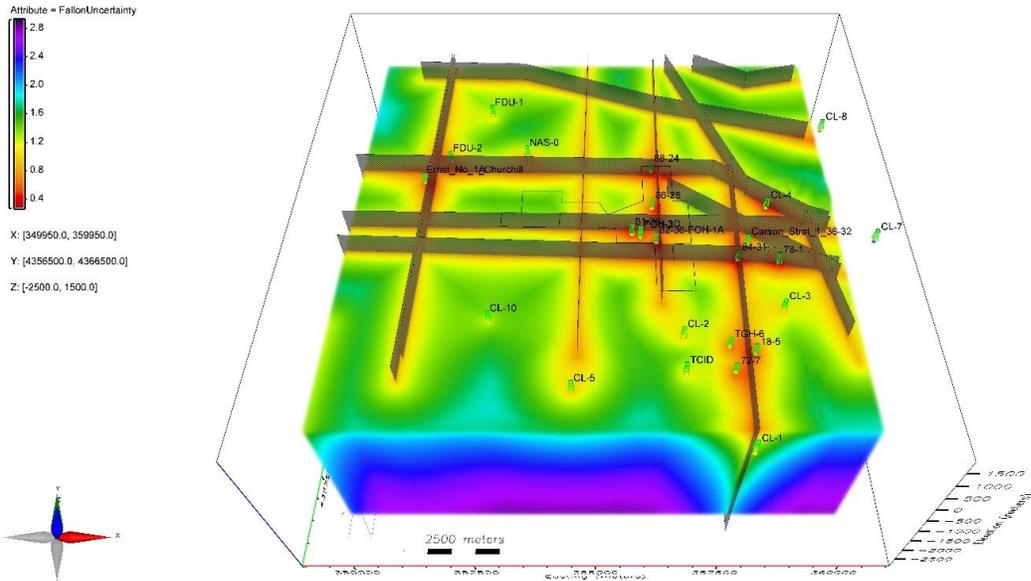
**Figure 59. A) Poles to fault planes, and B) rose diagram of the strike of faults in the 3D geologic model. Fault planes were measured for strike and dip at 50 m spacing. Poles (A) indicate that north-striking and east-dipping faults dominate the area. Rose diagram (B) shows the mean plane strikes 003°.**



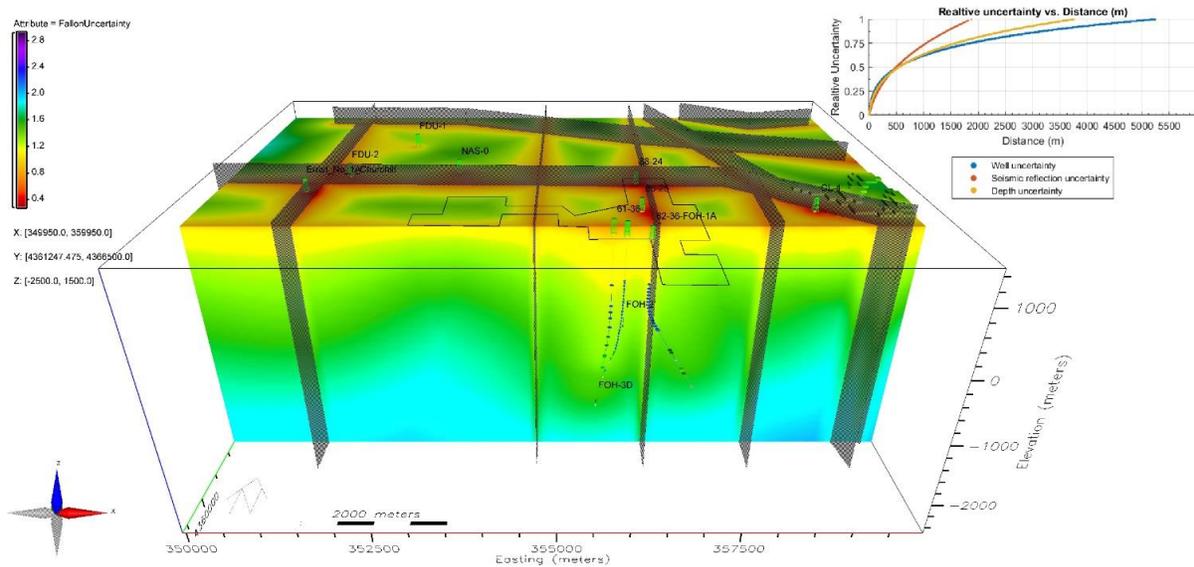
**Figure 60. 3D perspective looking north of the 3D geologic model. The model is sliced in the east-west direction through the Fallon FORGE site. Mesozoic undivided basement (Mzu) in green, Miocene volcanic rocks (Tvs) in blue, and Quaternary-Tertiary sediments (QTs) in yellow. Modeled fault planes are shown in gray. Green rig symbols denote the surface locations of the 24 wells that were analyzed for downhole lithologic data. The proposed Fallon FORGE site is shown by the red outline. The widely spaced (~1.5 km), synthetic, east-dipping normal faults all have < 200 m displacement.**



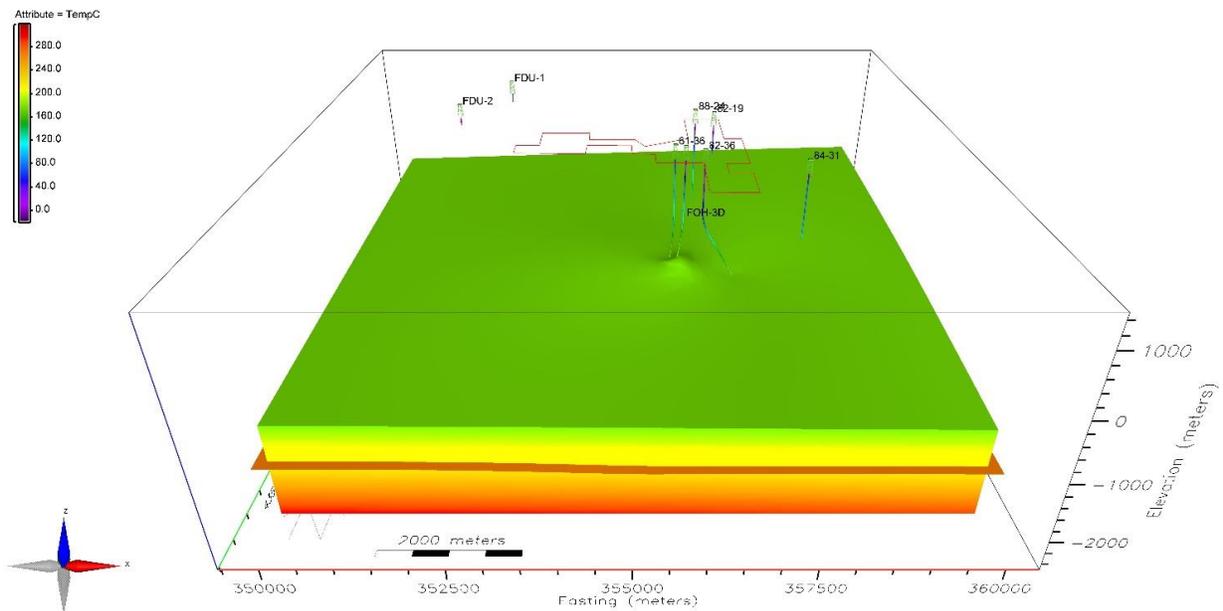
**Figure 61. Cross-sections through 3D geologic models at (A) Fallon FORGE site, and (B) Bradys geothermal system (Siler et al., 2016b). Both models were built with similar data and similar data density. The dense anastomosing fault system at Bradys hosts natural geothermal fluid flow at several intervals between elevations of ~1000 to -500 m. The faults at Fallon are widely spaced by comparison and not conducive to hosting a conventional geothermal system.**



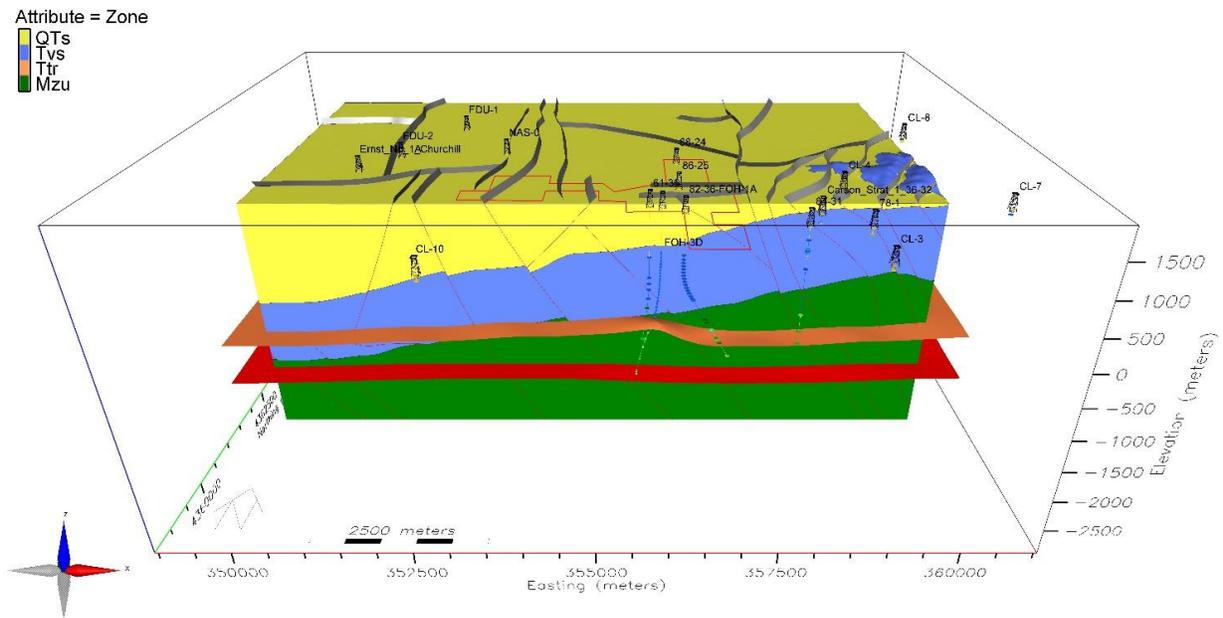
**Figure 62. 3D perspective looking north at relative uncertainty in the 3D geologic interpretations. Warm colors correspond to low relative uncertainty and cool colors correspond to high relative uncertainty. Black planes denote the location of the seismic reflection profiles that pass through the proposed Fallon FORGE site. The Fallon site is outlined in black.**



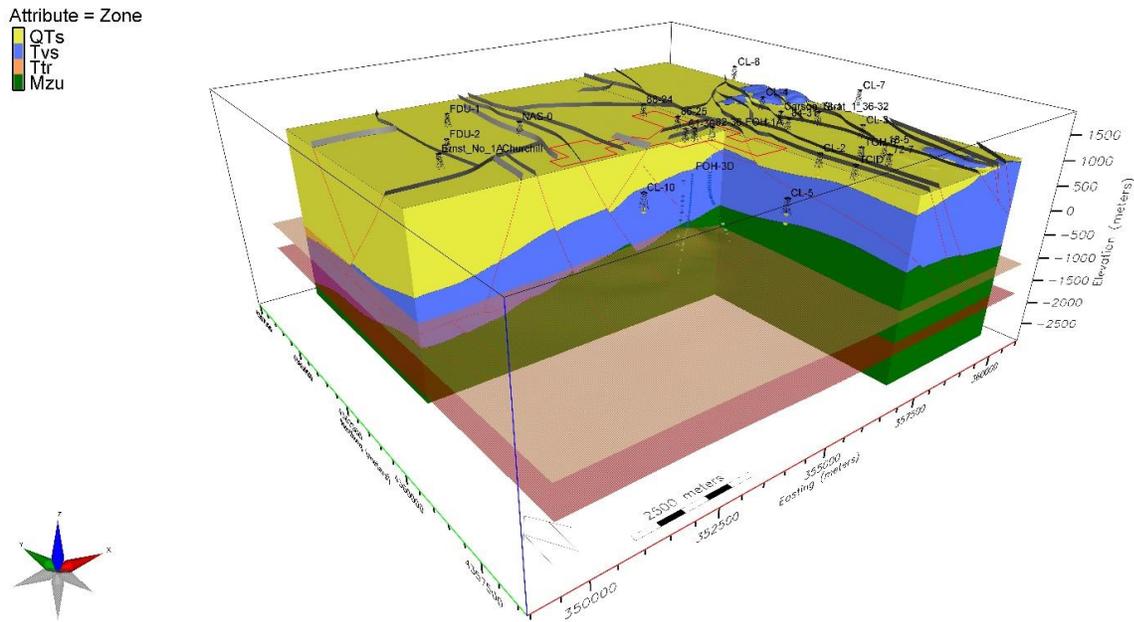
**Figure 63. 3D perspective looking north at relative uncertainty in the 3D geologic interpretations. The 3D relative uncertainty model is sliced in the east-west direction through the Fallon FORGE site. Warm colors correspond to low relative uncertainty and cool colors correspond to high relative uncertainty. Green rig symbols denote the surface locations of the 24 wells analyzed for downhole lithologic data. Black planes denote the location of the seismic reflection profiles that pass through the Fallon site. The Fallon site is shown is outlined in black. Inset shows relative uncertainty vs. distance from data for the surface, the 24 well paths, and the 14 seismic reflection profiles used in construction of the 3D geologic model. Relative uncertainty increases logarithmically with distance from the surface, the well paths with lithologic data, and the seismic reflection profiles. Each relative uncertainty curve was adjusted such that a relative uncertainty of 0.5 corresponds to a distance of ~500 m.**



**Figure 64. 3D perspective looking north at the interpolated 3D temperature model. The 8 wells with equilibrated temperature logs used in this interpolation are shown. The 3D temperature model is sliced at the 175°C isotherm. The 225°C isotherm is shown in orange extending from the 3D temperature model. The Fallon FORGE site is outlined in light red.**



**Figure 65. 3D perspective looking north at the 3D geologic model. The model is sliced in the east-west direction through the Fallon FORGE site. Mesozoic undivided basement (Mzu) is in green, Miocene volcanic rocks (Tvs) in blue, and late Miocene-Quaternary sediments (QTs) in yellow. The 175°C isotherm is shown in orange, and the 225°C isotherm is shown in red extending from the 3D model. The Fallon FORGE site is outlined in red.**



**Figure 66. Oblique view of the Fallon FORGE 3D geologic model looking ~NE. Model is sliced east-west and north-south through the Fallon FORGE site. The 175°C (orange, transparent) and 225°C (red, transparent) modeled isotherms are both shown.**

### 5.3 PRIMARY FORGE CRITERIA

Evaluation of the multiple geologic and geophysical data sets in Section 4, as well as development of the 3D model, permitted assessment of the major qualifying criteria for FORGE for the Fallon project area. Supporting data and interpretations for each criteria are summarized below and listed in Table 12. All six criteria are satisfied for the Fallon site, each by multiple data sets, greatly reducing uncertainty across all criteria.

**Table 12. Relevancy to FORGE Criteria**

Relevance to FORGE Criteria						
Criteria	Temperature (175-225 °C)	Low Permeability	Lithology (crystalline)	Depth (1.5-4 km)	Stress Regime	No Hydrothermal System
General Stratigraphy			✓			
Well Lithology Data			✓	✓		
Petrographic Data	✓		✓	✓		
Structural Data		✓			✓	✓
Fault Kinematics		✓			✓	
Stress Regime		✓			✓	
Thermal Data	✓			✓		
Fluid Geochemistry	✓					
Alteration	✓	✓				✓
Well Tests	✓	✓		✓		✓
Gravity and Magnetic Data			✓	✓		
Magnetotelluric Data		✓	✓	✓		✓
EQ Seismology					✓	✓
Seismic Reflection Data		✓	✓	✓		✓
<b>TOTAL</b>	<b>✓</b>	<b>✓</b>	<b>✓</b>	<b>✓</b>	<b>✓</b>	<b>✓</b>

**Temperature (175-225 °C):** Well temperature data provide direct evidence that the Fallon FORGE site has temperature conditions within the specified 175 to 225°C range. Three wells penetrate the 175°C isotherm on the Fallon FORGE site and record maximum bottom-hole temperatures (BHTs) of 192° to 214°C (Figure 30, Figure 31, Table 13). The depth to the 175°C isotherm ranges from 1712 to 2079 m, is consistently below the requisite minimum depth of 1500 m below ground surface, and is also below the contact between the Cenozoic strata and the Mesozoic metamorphic and granitic basement rocks (Figure 31). Well FOH-3D penetrates a vertical thickness of 727 m between the 175°C isotherm and 203°C at the bottom of the hole. Based on all available well data, the 3D thermal model indicates that the true vertical thickness between the 175 and 225°C isotherms ranges from 700 to 900 m across the FORGE site.

**Table 13. Primary temperature and depth parameters for FORGE well intersecting the 175°C isotherm.**

Well	Depth of 175°C isotherm (m)	Bottom hole temperature (°C)	Total well depth (m)	Vertical range within 175 to 225 °C (m)
FOH-3D	1712	203	2439	727
61-36	1855	192	2124	269
82-36	2079	214	2530	451
13-36*	1826	181	1966	140

Note: All depths are true vertical depths for deviated wells in meters below ground surface  
\*Well 13-36 is 0.5 km SSW of the FORGE site boundary on private property

Fluid geochemistry provides complementary evidence of the thermal regime. Samples from well FOH-3D indicate equilibration temperatures of ~190°C using the silica geothermometer (Table 6). These are consistent with measured 203°C bottom-hole temperatures (BHT's) in this well. Cation geothermometers for this well suggest higher temperatures (220-260°C), which may be reflecting slow fluid recharge from a hotter, deeper fluid source.

Clay alteration and hydrothermal vein minerals collected from chip and core samples indicate phyllic alteration in the Tertiary volcanic rocks and propylitic alteration in the basement rocks. These alteration assemblages are associated with 225 to 250°C and >250°C temperatures, respectively, which are greater than the measured temperatures observed in the same wells that these samples were collected from. It is probable that these minerals represent a fossil thermal regime and do not correspond to the modern thermal regime as recorded in the wells. For example, epithermal mineralization and alteration associated with Miocene volcanism was widespread across the region and was probably responsible for appreciable alteration of the Miocene volcanic strata at this site. The Mesozoic basement may have been altered in the Tertiary and/or the Mesozoic.

In summary, the well temperature data demonstrate that the Fallon site satisfies the temperature criteria for FORGE. Complementing the well temperature data, the geothermometry calculations from fluid geochemistry data generally agree with the measured well temperatures.

*Uncertainty in Temperatures:* Temperatures at depth at the Fallon FORGE site are well constrained by several downhole temperature logs, which collectively indicate that the Mesozoic section at Fallon is within the FORGE temperature (175-225°C) and depth (1500-2500 m) windows. Significant errors could occur if wells have not been given time to equilibrate after drilling and before temperature surveys are conducted. Some individual temperature surveys at the Fallon FORGE site are not believed to be fully equilibrated (refer to Section 4.3). However, the effects of this are more prominent in the shallow Miocene-Pliocene section. In the Mesozoic section, where the proposed FORGE reservoir would be located, all available deep temperature logs indicate a dominantly conductive thermal regime and that the targeted temperature/depth criteria are met. Thus, the overall uncertainty as to whether the Fallon FORGE site meets these criteria is low.

Additional uncertainties are introduced when temperatures are interpolated from well data into the remaining volume of the proposed FORGE site. The 3D temperature model (Figure 64 and Figure 65) predicts a relatively smooth varying temperature surface, indicating that wells reached broadly similar temperatures at similar depths. This lack of spatial variability increases

confidence in the ability to interpolate temperatures throughout the modeled volume. Additionally, the conductive temperature gradients support a consistent and smoothly varying temperature regime at depth, because in the absence of convection, conductive heat flow seeks to minimize temperature gradients.

**Low Permeability:** Well-test data provide direct evidence for low permeability conditions at the Fallon FORGE site, particularly in the Mesozoic basement rocks (Table 7, Figure 33 to Figure 38). Two of the three deep wells, 82-36 and 61-36, that intersect the Mesozoic basement and the 175°C isotherm recorded sub-economic injectivity test results with values of 0.14 and 0.34 lpm/kPa, respectively. Several of the wells, (e.g., 88-24; Table 7) encountered moderate, local permeability in the Miocene and Pliocene volcanic rocks and sediments, which are generally confined to the uppermost 1 km of Cenozoic strata. Distributed stratigraphic permeability in the Cenozoic strata is common in contemporary basins throughout the Basin and Range province and does not indicate corresponding permeability in the Mesozoic basement nor does it suggest the presence of a hydrothermal system.

In addition to direct well-test data, multiple other data sets provide additional evidence that the strata below 1.5 km depth have low permeability. The resistivity patterns in the MT data generally follow stratigraphy across the modeled FORGE area and are not disrupted laterally by apparent localized hydrothermal activity (Figure 47, Figure 48). Most importantly, the MT profiles show a consistent depth at 1.5 to 2.0 km where the rocks become dramatically more resistive, from quite low resistivity of  $\leq 5$  ohm-m to very high resistivity rocks with corresponding 100's of ohm-m resistivity. The high resistivity in the Mesozoic basement signifies hard rock with very low porosity and permeability with few open fractures. The limited fluid geochemistry data set suggests two fluid types in the FORGE area: (1) a cooler fluid with high TDS ( $>8000$  mg/L) that is inferred to flow from the Mio-Pliocene units, and (2) a hotter, less saline fluid ( $\sim 4000$  mg/L TDS) that is inferred to originate from the Mesozoic basement. The chemically distinct geochemical pattern implies limited mixing between the Mesozoic and the Cenozoic strata, consistent with low permeability. Furthermore, the shape of the temperature profiles for the deep wells are broadly conductive with relatively minor steps possibly associated with minor fluid movement, principally in the Miocene volcanic and sedimentary rocks. The absence of a strong convective signal in the temperature profiles indicates that there are not major high-angle permeable zones, such as along faults within the proposed FORGE site.

The structural setting and absence of known Quaternary fault activity at the Fallon FORGE site both correspond to limited permeability geologic settings. Faults interpreted through evaluation of 2D reflection seismic profiles are widely spaced compared to structurally complex regions associated with amagmatic hydrothermal systems (Siler et al., 2016b). Specific structural settings known to be associated with enhanced permeability, such as major normal fault terminations or step-overs are not observed in the 3D geologic model.

In summary, multiple data sets indicate low permeability conditions for the Fallon FORGE site, particularly for the Mesozoic basement.

*Uncertainty in Permeability:* The most conclusive evidence of low permeability is provided by the well tests, and errors associated with this determination can be considered minimal, provided the wells have been properly drilled without damaging formation porosity and permeability.

Additional data support the assessment of low permeability at well sites, thus reducing the uncertainty in the conclusion. These additional data are also important for reducing uncertainty in the conclusion that low permeability extends throughout the bulk of the proposed Fallon FORGE site volume. Perhaps principal among these other data types is the conductive temperature gradients observed at depths below 1 km, and the similar temperatures obtained in multiple wells at similar depths, as shown by the 3-D temperature model. The lack of significant vertical temperature perturbations and conductive temperature regimes reduce the uncertainty of the conclusion that the 3-D model volume is dominated by low permeability. As described above, the additional data sets of MT, Quaternary faults and structural patterns, seismic reflection data, and fluid geochemistry are used to reach similar conclusions. Even though the individual uncertainties of each of these additional data are higher than that of well tests and temperature gradients, their combined effect is to produce a consistent prediction of low permeability. In essence, the hypothesis of low permeability is being tested with multiple perspectives, and each time a similar conclusion is reached, the hypothesis is strengthened. This is reflected in part by the integrated result of a smoothly varying 3D temperature model.

**Crystalline Lithology:** Three wells penetrate the Mesozoic basement on the Fallon FORGE site at about 1.5 to 1.7 km depth. Based on analyses of cuttings and core, including petrographic analyses, the Mesozoic basement is composed of metavolcanic rocks, metasedimentary rocks, and granitic rocks (Figure 18, Figure 19; Table 1). The parent lithologies of the metavolcanic rocks consist mostly of felsic volcanics with lesser mafic rocks. The metasedimentary rocks are almost entirely composed of quartzite. These units correlate with regional stratigraphy around the Carson Sink and much of western Nevada, as exhibited in regional well lithologic logs in the basins and extensive exposures in the mountain ranges (Figure 20 and Figure 21).

In addition to the well data, modeled depth to basement across the FORGE site, based on inversions of gravity and MT data, both correspond to consistent metamorphic and/or granitic basement (Figure 40 to Figure 43, Figure 47, Figure 48). The geophysical inversions in combination with 2D reflection seismic profiles and well data have provided a framework for depicting the top of the Mesozoic basement across the Fallon FORGE site. In summary, the data sets are consistent with metamorphic and granitic basement across the entire FORGE site with depths to basement ranging from ~1.5 km along the eastern margin of the FORGE site to > 2 km at the western margin of the site.

*Uncertainty in Crystalline Lithology:* The uncertainty in identification of crystalline lithologies in the drill cuttings can be considered negligible from the perspective of geological identification. Of potentially greater significance is the interpolation of those crystalline lithologies into the remaining volume of the proposed FORGE site. In this case, the availability of detailed gravity data, MT data, and seismic profiles play key roles. Any one of these geophysical surveys by itself carries an appreciable degree of uncertainty at the depths at which crystalline rocks occur. However, combined together in the 3D model, they provide a more powerful and consistent tool for interpolating/extrapolating depth to basement with reduced uncertainty into the remaining FORGE volume. The geophysical data also consistently predict that the elevation of the top of crystalline rocks forms a relatively gently dipping surface, only moderately interrupted by faults. A smoothly varying surface is easier to model, thus further reducing uncertainty.

**Depth (1.5-4 km):** Multiple wells and geophysical data provide key indications of the lithologic units, permeability, and the temperature conditions at depths below 1.5 km (Figure 19, Figure 30, Figure 31, Figure 41, Figure 47, and Figure 48). In particular, three wells penetrate to 2124 to 2530 m depth (true vertical depth) within the FORGE site. All three of these wells penetrate the top of the Mesozoic basement between 1.5 and 1.7 km depth and penetrate the 175°C isotherm at 1.7 to 1.9 km depth. Gravity inversions across the entire Carson Sink area provide regional depth to Mesozoic basement with  $\pm 250$  m resolution. Locally, the MT profiles across the FORGE site show a consistent depth at 1.5 to 2.0 km where the rocks become dramatically more resistive. This corresponds to the Mesozoic basement and signifies hard rock with very low porosity and permeability and few open fractures. The 3D thermal model indicates the top of the smoothed 175°C isotherm is at 1.7 to 1.9 km depth across the FORGE site. The three deep wells at the Fallon FORGE site all indicate very low permeability in the Mesozoic basement, below 1.5 km depth (Table 7).

*Uncertainty in depth:* The three wells drilled into basement rocks reached from 600 to 900 m below the minimum depth threshold for the FORGE volume. This overlap is much greater than the uncertainty of the depth measurements in the holes themselves, especially since down-hole surveys were used to compensate for deviations in the hole trajectories. The holes also served as a constraint and guide for interpolating the depth of temperature contours and lithologies in the model, as described above, reducing the uncertainty that the required parameters are present at the necessary depths. The gravity inversions also helped calibrate the seismic sections and interpret the MT survey, all of which were combined in a comprehensive 3D model whose unified output also serves to increase confidence and reduce uncertainties in the depth projections of critical parameters.

**Stress Regime:** Stress data inferred from drilling-induced fractures imaged in bore-hole logs and from regional fault studies indicate that the Fallon FORGE site resides in a simple extensional environment with  $\sigma_1$  oriented vertically and  $\sigma_2$  and  $\sigma_3$  oriented horizontally, with an R-value stress ratio of  $\sim 0.5 = (\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$ . Analyses of drilling-induced fractures from four of the wells on the Fallon FORGE site indicate Shmin oriented N85°W to N64°W (Figure 26, Figure 27). Analyses of fault surface data and Quaternary hydrothermal veins from the Salt Wells geothermal area indicate Shmin oriented N80°W (Figure 24, Figure 28). These data are also similar to stress analyses at the Bradys and Desert Peak geothermal fields (Figure 27). The consistency between the local and regional stress regime characterization reduces the uncertainty of the analyses of the Fallon FORGE site. These stress data are also fitting with a structural setting dominated by generally N- to NNE-striking normal faults in the Fallon FORGE area and much of the surrounding region.

*Uncertainty in Stress Regime:* The availability of bore-hole measurements with which to model the stress regime in several wells in the proposed FORGE site greatly reduces the uncertainty in the stress regime assignment. Extrapolation of the stress regime over the remaining volume of the proposed FORGE site is relatively easy, because stress regimes tend to be relatively constant over broad regions, as evidenced by the similar stress conditions noted at the Bradys and Desert Peak geothermal fields located some distance away. Additional data from surface faults and veins, as described above, provide further corroboration to reduce uncertainty.

**No Hydrothermal System:** The well test data, temperature profile data, MT data, fluid geochemistry data, and structural data all individually and collectively indicate that the Fallon FORGE site is not connected with a hydrothermal system. The well temperature profiles show a dominantly conductive pattern rather than convective for the FORGE site. The resistivity patterns in the MT data generally follow the primary stratigraphic units and do not appear to reflect any significant hydrothermal activity. The fluid geochemistry indicates that fluids are not readily mixing between the Mesozoic and Cenozoic stratigraphic units. The well tests demonstrate ubiquitous low permeability at depths >1.5 km, particularly in the Mesozoic basement. Additionally, the structural setting is not complex, is not associated with Quaternary fault activity, and does not contain a favorable structural setting for geothermal activity (e.g., fault step-over or major fault termination). Thus, based on structural geology, this site is not expected to have high permeability or to host a hydrothermal system. Finally, a regional play fairway analysis shows that the area has relatively low values of combined permeability and play fairway potential (Attachment C, Figure C3 and Figure C4), while also having a very high degree-of-exploration (Attachment C, Figure C5). Collectively, these relationships indicate that it is very unlikely that an active hydrothermal system resides within the proposed Fallon FORGE site.

*Uncertainty of Lack of Hydrothermal System:* Given the presence of potentially economic temperatures at potentially economic depths to produce electricity, the only missing parameter for a viable geothermal system is permeability (over a sufficiently large interconnected volume). Hence, the uncertainties of not having an active hydrothermal system are similar to the uncertainties in defining permeability. Fundamental in this regard are the measurements of low permeability in two wells that penetrate into the target FORGE depth range of 1.5 to 4.0 km. Uncertainties in the permeability measurements themselves can be considered low, and the key remaining uncertainty is the confidence in projecting low permeability to the remainder of the proposed FORGE volume. This is especially true given the known tendencies of permeability to vary drastically over short distances due to the presence or absence of suitable structure.

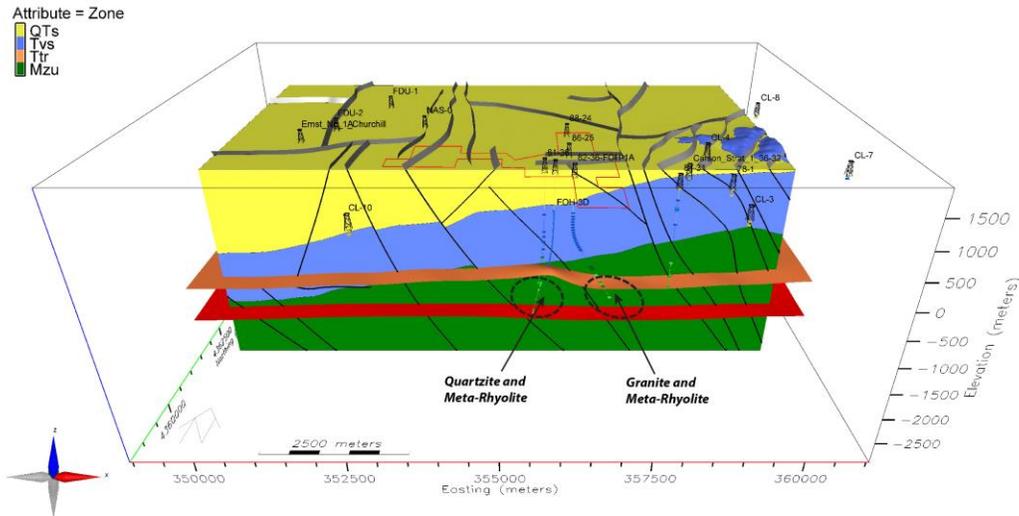
Fortunately, the other data sets provide key information for assessing permeability over broader volumes. Key among these parameters is temperature gradient, which in all deep holes is decidedly conductive in nature. This provides confidence (reduces uncertainty) that the wells are not suffering from drill-related formation damage, nor do they represent “near-misses” at the depths to which they penetrated, because otherwise, greater perturbations in the conductive gradients would be present.

Further evidence that can be used to increase confidence in the lack of a viable geothermal system at even greater distances from the tested wells includes the MT survey (no domal feature in the overlying clay zone) and the structural assessment (low fault density and lack of favorable structural setting). Interestingly, the overall pattern of hydrothermal alteration, beginning with a clay zone at shallow depths and passing to a propylitic zone within basement rocks, is consistent with geothermal activity, but in this case, uncertainty is high because a lack of interconnected vein systems, the nearly ubiquitous presence of this style of alteration in older host rocks in Nevada, and the lack of radiometric dating, all suggest that little confidence can be placed on the alteration zoning itself in defining the presence of active geothermal flow. The lack of fluid geochemical signatures, which could indicate fluids passing from one depth to another, suggests

that, in fact, a viable hydrothermal system is not present. Combined modeling of all factors yields one conclusion consistent with all data; that being that a hydrothermal system is not present. The uncertainty of the combined model is less than the uncertainties of the component parts.

Finally, a regional perspective on the likelihood of geothermal activity is provided by a recently completed play fairway favorability model (Faulds et al., 2015; Attachment C), which supports the low expectation of geothermal activity, and recognizes the relatively high degree of exploration in the FORGE site, which, as expressed in the parameters above, reduces uncertainty in the assignment. Potential targets for EGS experiments (Table 12) are satisfied within a relatively large volume of the Mesozoic basement rocks in the proposed FORGE site at Fallon. The 3D model shows that about 8 km<sup>3</sup> of crystalline rock lie between the 175°C and the 225°C isotherms at depths ranging from ~1.5 to 3.8 km. On the basis of the detailed lithologic logs and petrographic data, we estimate that much of this volume (>3.2 km<sup>3</sup>) resides in competent lithologies conducive to hydraulic stimulation, such as meta-rhyolite, quartzite, and granite (Figure 19). These basement rocks have low permeability, as demonstrated by flow tests (Figure 33 to Figure 38), and consistently yield high resistivity values (Figure 47 and Figure 48), suggesting little if any current hydrothermal activity. The structural framework is also conducive to EGS research, because a favorable setting for geothermal activity is absent and faults are widely spaced (Figure 10 and Figure 54). Nonetheless, borehole imaging demonstrates that fractures are abundant and favorably oriented in the current stress field for stimulation, as the dominant fracture sets are roughly parallel to  $S_{Hmax}$ , which is well defined in this area based on analysis of both drilling induced fractures and fault kinematic data. Thus, there are several relatively coherent blocks with sufficient volumes of competent rock primed for EGS experiments.

There are at least three possible, competent target formations in Mesozoic basement for stimulation in the FORGE project area: (1) Triassic to Jurassic felsic metavolcanic rocks, (2) Jurassic quartzite, and (3) Jurassic to Cretaceous granitic intrusions. Figure 67 shows two possible reservoirs within metavolcanic rocks and quartzite in the central to eastern part of the FORGE site. It is also important to reiterate that relatively high strain rates in the region (Figure 4) would facilitate reactivation of shear fractures during hydraulic stimulation. Furthermore, the lack of magmatic activity and minimal seismicity optimizes predictive analysis of the stress field throughout the site, as local perturbations are unlikely in this relatively stable setting.



**Figure 67. 3D model of potential EGS reservoirs in Mesozoic crystalline basement rock, including meta-rhyolite, quartzite, and granite in the central to eastern parts of the proposed FORGE site at Fallon. Several deep wells in this area provide lithologic, thermal, and permeability data for these volumes. These reservoirs lie between the 175°C and 225°C isotherms, as shown by the orange and red planes projecting out of the model, respectively. Note the widely spaced faults and relatively coherent structural blocks between the faults lying at the requisite depths and temperatures for development. The Mesozoic basement in this area is characterized by low permeabilities, as evidenced by well tests and high resistivity values.**

#### 5.4 FUTURE WORK – ADDITIONAL DATA NEEDS

Although substantial geologic, geochemical, and geophysical data have previously been amassed for the Fallon area, thus permitting assessment of its potential for hosting FORGE, additional data are required for fully characterizing the site. These data needs primarily involve better characterization of the subsurface in order to more specifically target potential EGS reservoirs and select drilling sites. Data needs include the following:

- Analogue studies of potential reservoir rocks: Analogue studies of Mesozoic basement in nearby mountain ranges to better characterize composition and structural features. This would include detailed analysis of the distribution, orientation, and density of various structural features, such as bedding, foliations, and fractures. Excellent exposures for such studies are present in the Stillwater Mountains, Sand Springs Range, and in the Lee- Allen area (Figure 11).
- Geochronology studies:  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of key volcanic units from cuttings and core, including lenses of mafic lavas intercalated in the basin-fill sediments, to better constrain the stratigraphy as well as the age of alteration and faulting.
- Gravity and magnetic surveys: More work can be done with existing data, including more extensive quality control and reprocessing of the data sets. Further processing should be applied to help determine source depths and better constrain source geometries. More importantly, high-resolution 2D ground profiles of gravity and magnetics should be planned along key transects across the FORGE area and coordinated with other geophysical investigations, such as seismic reflection surveys. In addition, performing a dense gravity grid survey (e.g., similar to the existing high-resolution survey spanning the eastern half of the FORGE area), as well as a high-resolution aeromagnetic survey would facilitate high-resolution mapping of subsurface

structures. High resolution gravity and magnetic data covering the entire FORGE area will enable rigorous 3D modelling of the potential field data, a task which has not been performed in previous work. 3D geophysical modelling of potential field data is important because it can be used to help characterize basin geometry and resolve intra-basin and basin-bounding faults and fracture zones that may be susceptible to hydrothermal flow or activated during stimulation. Furthermore, such a potential field modelling exercise can be used to validate the 3D geological model built for the FORGE area using two independently derived datasets (i.e., gravity and magnetics).

- MEQ network: Enhancement and expansion of the micro-earthquake network is needed to provide a more detailed understanding of background seismicity and also fully deploy a network capable of monitoring EGS activities at the site.
- Fluid geochemistry: Additional analyses of fluid geochemistry in all available wells to better characterize the fluids present at Fallon, understand potential fluid flow pathways and mixing relationships, and improve the geothermometry estimates.
- Seismic reflection data: Acquisition of 3D seismic within and proximal to the proposed site to better image fine-scale faults cutting basin-fill sediments and stratigraphic relations. This may include a 3D seismic array covering the 100 km<sup>2</sup> 3D model area and a few additional 2D profiles extending across the margins of the southeastern Carson Sink, which would image basin-bounding faults and possibly define the structural margins of the Carson Lake geothermal system to the southeast of the proposed FORGE site.
- Drilling (slimline) and core sampling: Drilling and collection of core from potential EGS reservoir rocks and utilization of the most innovative borehole imaging techniques to better constrain rock mechanical properties and reservoir characteristics at the site. For example, core and borehole imaging from this hole would be used to better delineate stratigraphic and structural relationships, determine strength parameters for potential reservoir rocks and refine estimates of the stress regime. Collection of rock property data from core samples (e.g., density, porosity, permeability, magnetic susceptibility, and thermal conductivity) will be used to refine geophysical inversions (gravity and magnetic) models, constrain formation permeability, and improve thermal models.
- Refine 3D conceptual model: Incorporate all new data and synthesize with previously acquired data sets to refine the 3D model, with a specific aim of elucidating potential EGS reservoir characteristics, such as location, volume, composition, geometry and density of preexisting fractures, and permeability.

## 6 CONCLUSIONS

This document described the geologic setting and available geological, geophysical, and geochemical data sets for the proposed FORGE site at Fallon, Nevada, and integrated these data sets into a comprehensive, 3D conceptual geologic model for the site (Figure 66). The Carson Sink is a large late Miocene to recent composite basin within the northwestern Great Basin, which is experiencing some of the highest extensional strain rates within the Basin and Range province (Figure 4). The Fallon site occupies 4.5 km<sup>2</sup> on two parcels that include land owned by the Naval Air Station Fallon (NASF) and leased and owned by Ormat Nevada, Inc. (Figure 1 and Figure 2). In addition, about 40 km<sup>2</sup> of surrounding lands are open to monitoring and instrumentation activities. The site has excellent infrastructure, including a well maintained network of roads, abundant wells, available storage for equipment and supplies at the NASF, and access to electrical and water resources. A total of 12 geothermal wells and 34 temperature gradient holes have previously been drilled for geothermal exploration within the NASF and Ormat lease area (Figure 14).

Multiple preexisting data sets were reviewed and analyzed in this report. These include the following.

- Comprehensive information on the stratigraphic framework provided by:
  - Surface lithologic data as furnished by detailed geologic maps of the entire area (Figure 13).
  - Well lithologic data, including >14,000 m of cuttings and core (Figure 19).
  - Petrographic data from cuttings and core, as well as nearby bedrock exposures.
- Structural data from multiple data sets:
  - General structural framework as provided by the detailed geologic maps and regional syntheses (Figure 12 and Figure 13).
  - Geometry and kinematics of faults.
  - Stress regime, as furnished by borehole imaging of drilling induced fractures and fault kinematic data (Figure 25 and Figure 27).
- Thermal data, as provided by down-hole temperature logs from multiple wells (Figure 31).
- Fluid geochemical data (Figure 32 and Table 4, Table 5, Table 6).
- Alteration data gleaned from cuttings and geochemical analyses.
- Well flow testing data (Figure 33 to Figure 38).
- Gravity and magnetic data (Figure 40 and Figure 42).
- Magnetotelluric data (Figure 46 and Figure 47).
- Regional seismicity and local micro-earthquake data (Figure 49 and Figure 51).
- Seismic reflection data, including 14 profiles totaling ~270 km across the southern Carson Sink (Figure 52A).

The above data sets were utilized to define the stratigraphic and structural framework and provide the building blocks for developing a comprehensive 3D geologic model of the proposed Fallon site. In descending order, the main stratigraphic units in the area include: (1) Late Miocene to Quaternary basin-fill sediments up to 1.5 km thick, (2) Miocene volcanic and lesser sedimentary rocks (0.7-1.1 km thick), and (3) Mesozoic basement consisting of Triassic-Jurassic

metavolcanic and metasedimentary rocks intruded by Jurassic-Cretaceous granitic plutons. The structural framework is characterized by a broad, gently west-tilted fault block or half graben, which is cut by widely spaced, northerly striking normal faults with relatively minor displacements (< ~200 m displacement). These data sets were also reviewed in the context of the key characterization and qualification criteria for an ideal FORGE site (Figure 15 and Table 12). These criteria include: (1) temperatures between 175°C and 225°C, (2) low permeability, (3) crystalline bedrock (not a sedimentary basin), (4) depth between 1.5 and 4 km, (5) favorable stress regime, and (6) the lack of an existing hydrothermal system. The 3D model provides critical subsurface control on the stratigraphic, structural, and thermal framework of the area, including delineating the location in 3D space of the 175°C and 225°C isotherms (Figure 65 and Figure 66), and allows for evaluation of the FORGE criteria across the entire 3D volume of the Fallon site.

All major criteria for FORGE are satisfied at the proposed Fallon site (Table 12 and Figure 15). The required temperature conditions of the FORGE site were provided by well logs, fluid geochemistry, and the 3D thermal model. Low permeability conditions were characterized by well flow tests, MT models, stress data, and the 3D geological model. The crystalline lithologic units that reside in the subsurface at the FORGE site were delineated by detailed geologic maps, core and cuttings from wells, petrographic data, reflection seismic profiles, MT models, and the 3D geologic model. The 1.5-4 km depth of potential targets for EGS experiments was constrained by well paths, reflection seismic profiles, gravity models, MT data, and the 3D model. The lack of an active hydrothermal system was demonstrated by temperature data, well tests, MT models, the overall structural setting, and the lack of Quaternary faults. Potential competent target formations for stimulation at the site include Triassic to Jurassic felsic metavolcanic rocks, Jurassic quartzite, and Jurassic to Cretaceous granitic intrusions. Moreover, on the basis of the 3D model, we identified at least two possible target zones for EGS experiments in the Mesozoic basement (Figure 67), which satisfy all FORGE criteria. Additional data needs to refine these selections in a possible Phase II of this project were also described.

In summary, the documented temperatures, permeability, lithologic composition of potential reservoirs, and structural setting demonstrate that the Fallon FORGE site contains sufficient rock volumes well within the criteria specified for FORGE, while also residing within a favorable stress regime with no evidence of an active hydrothermal system. All of these attributes facilitate development at Fallon of a site dedicated to testing and improving new EGS technologies and techniques by the subsurface scientific and engineering community.

## ATTACHMENT A: WELL DATA SUMMARY

Numerous wells exist on the FORGE site and in the surrounding region. These include geothermal wells, temperature gradient holes, and oil exploration wells, each with variable down-hole data. Listed in this attachment are geothermal wells organized according to location on the FORGE site, FORGE monitor area, or surrounding area (Tables A1, A2, and A3). Well locations are shown in Figure A1, following the tables.

**Table A1. Geothermal wells on the FORGE site.**

Well Name	61-36	82-19	82-36 (FOH-1A)	86-25	88-24	FOH-2	FOH-3D
Well Type	-	-	Observation	-	-	Observation	Observation
Depth (ft)	7004	1733	8999	2990	4991	4488	8959
Depth (m)	2135	528	2743	911	1521	1368	2731
Temp. (°F)	378	161	417	226	280	320	379
Temp. (°C)	192	72	214	108	138	160	193
Year Completed	2013	2014	2014	2014	2012	1986	2005
Perforation depth span (ft)	2500-7021	1500-2000	4000-9000	2500-3050	3945-4022, 4215-5020	-	7000-9000
Perforation depth span (m)	762-2140	457-610	1216-2743	762-930	1202-1226, 1285-1530	-	2134-2743
Cuttings/Core	Cuttings	Cuttings	Cuttings	Cuttings	Cuttings	Cuttings + Core	Cuttings
Petrographic Thin Sections	Yes (72)	-	Yes (100)	-	Yes (50)	-	Yes (87)
Fluid Inclusion Analyses	-	-	Yes	-	-	-	Yes
Mudlogs	2013	-	2014	2014	2012	-	2005
Fluid Geochemistry	Yes	-	-	-	Yes	-	Yes
3 Month Equilibrated Temp	-	2014	2014	-	2012	-	2005
Static PTS	2013	2014	2014	2014	2012	-	2005
Flowing PTS	2013	-	2013	-		-	-
Injection Test	2014	2014	2014	2014	2014	-	-
Air Lift	2013	2014	-	2014	2012	-	2005
Nitrogen Lift	-	-	2013	-	2013	-	
Pump Test	2014	-	2014	-	-	-	-
E-Logs	2013	2014	-	2014	2012	-	2005
Image Logs	2013	2014	-	2014	2012	-	2005

**Table A2. Geothermal wells on the FORGE monitor area.**

Well Name	18-5	72-7	84-31	87-02	Carson Strat 1 (36-32)
Depth (ft)	3000	2992	5942	1915	1401
Depth (m)	914	912	1811	584	427
Temperature (°F)	255	268	264	140	190
Temperature (°C)	124	131	129	60	88
Date Completed	2012	1981	2008	-	1996
Mudlogs	Yes	-	Yes	-	-
Cuttings/Core	Cuttings + Core	Cuttings	Cuttings	Cuttings	Cuttings
Petrographic Thin Sections	Yes (29)	-	Yes (62)	-	-
Injection Test	2012	-	-	-	-
Air Lift	-	-	2009	-	-

**Table A3. Geothermal wells in the area surrounding the FORGE site or monitor areas.**

Well Name	Depth (m)	Depth (ft)	Date Completed	Cuttings/Core	Mudlogs	Temperature Logs	E-Logs
13-36	1966	6450	2010	Cuttings	yes	-	2010
14-1	896	2940	2009	Cuttings	yes	-	-
14-25	213	700	1985	-	-	-	-
14-36	2591	8500	1981	-	yes	-	-
17-16	2199	7213	2007	Cuttings	yes	2007	2007
19-21	-	-	-	-	-	-	-
24-21	3051	10,011	-	Cuttings	-	-	-
34-33	3051	10,011	2009	Cuttings	yes	2009	-
35A-11	3057	10,031	2009	Cuttings	yes	2009	-
47-11	-	-	-	-	-	-	-
47A-11	230	755	2008	Cuttings	yes	-	-
51-20	110	3610	-	Cuttings + Core	-	-	-
51A-20	3176	10,421	-	Cuttings	yes	-	-
56A-14	229	750	2008	Cuttings	yes	-	-
58-9	-	-	-	-	-	-	-
58A-9	117	385	2008	Cuttings	yes	-	-
62-15	2666	8745	2008	Cuttings	yes	-	-
78-36	1689	5540	2010	Cuttings	yes	2010	-
86-15	2134	7000	2007	Cuttings	yes	-	-

<b>86A-15</b>	229	750	2008	-	yes	-	2008
<b>FDU-1</b>	454	1490	1996	-	-	-	-
<b>FDU-2</b>	1343	4407	1996	-	-	2013	-

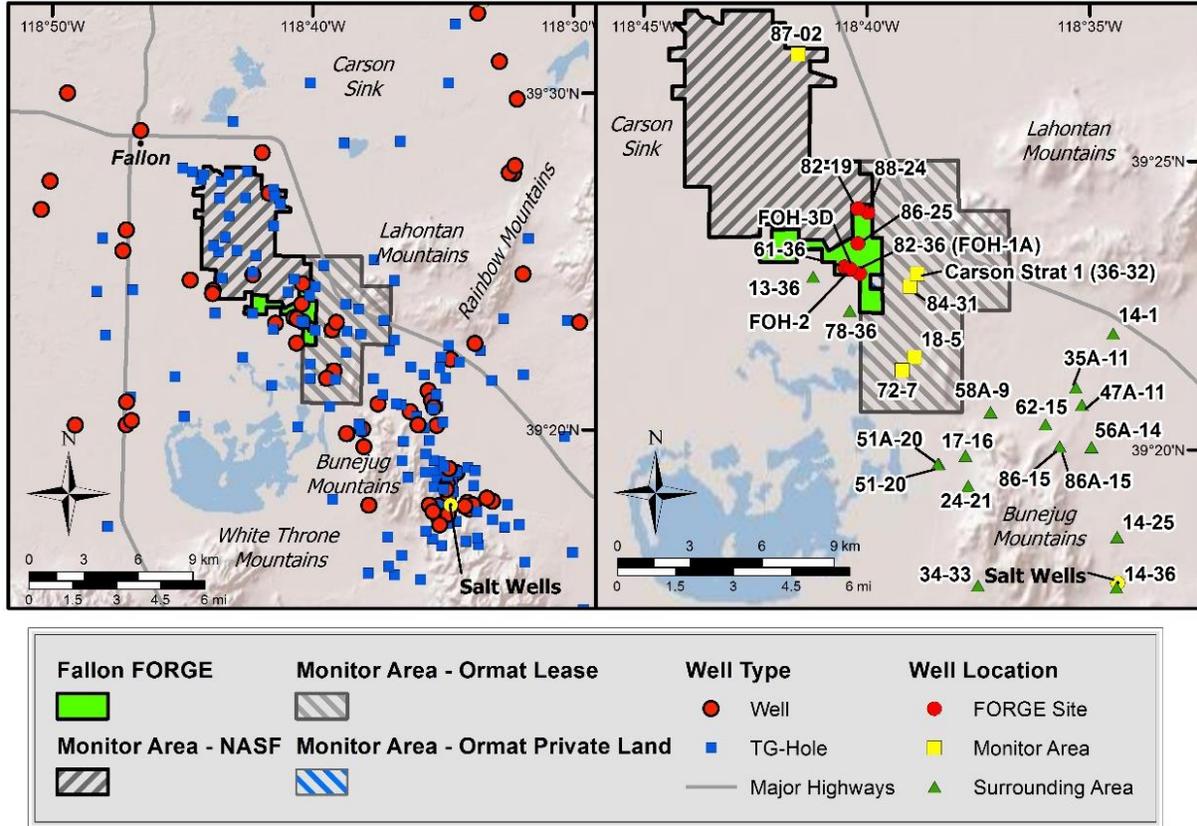


Figure A1. Geothermal wells, temperature gradient holes, and oil exploration holes within a ~15 to 20 km radius of the FORGE site. Includes 76 wells and 145 TGHs in total (*left*). Geothermal wells on the FORGE site (Table A1), on the FORGE monitor area (Table A2), in the nearby area (Table A3) with data listed available per well (*right*).

## ATTACHMENT B: INTERPRETATIONS OF SEISMIC REFLECTION PROFILES

Fourteen seismic reflection profiles, totaling 270 km in length, were interpreted from the southern Carson Sink within and proximal to the proposed Fallon FORGE site (Figure B1). All interpreted profiles are shown below. Five profiles (N-1, N-3, N-4, N-5, and N-6) were provided by the Navy Geothermal Program Office. The Navy profiles were originally acquired in 1994 and were reprocessed and migrated by Optim, Inc., in 2011. The Navy profiles are non-proprietary, public domain data.

The license to interpret nine additional profiles (FL1 to FL9) was acquired from Seismic Exchange, Inc. (SEI), in Houston, Texas. These profiles were originally acquired by the oil industry in the 1970s and 1980s. These data are owned and controlled by SEI, but UNR has the license to interpret the data and publish these interpretations upon review by SEI. Only scanned images of un-migrated paper plots were available for the SEI profiles, but as discussed in the text, velocity models and gravity data permitted time to depth conversions of interpreted contacts and faults. However, details on the original velocity models and processing parameters (including shotpoint locations) are proprietary for the SEI profiles. Thus, the interpreted profiles obtained from SEI are shown below without such parameters. All interpreted profiles were incorporated into the 3D geological model for the proposed Fallon FORGE site.

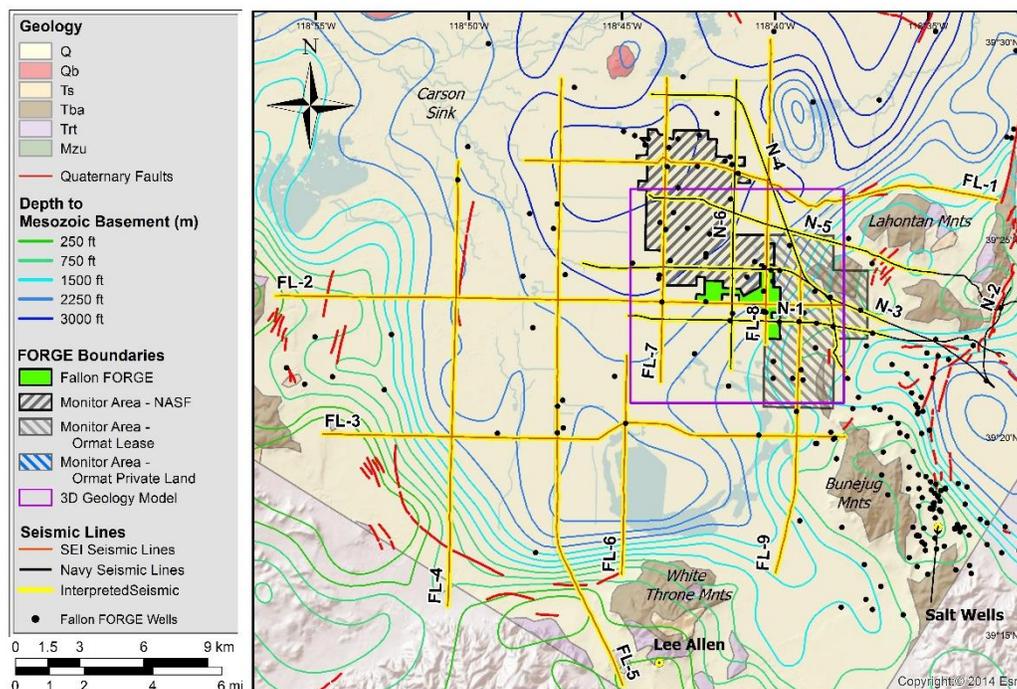
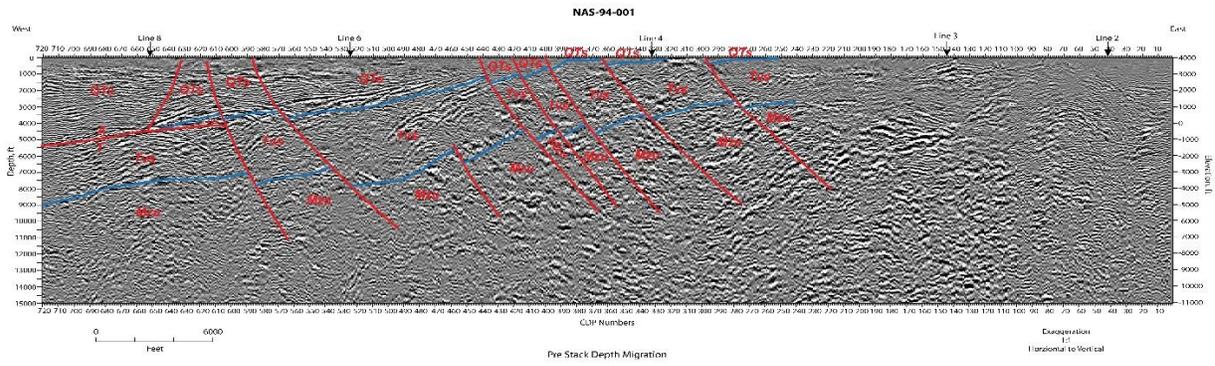
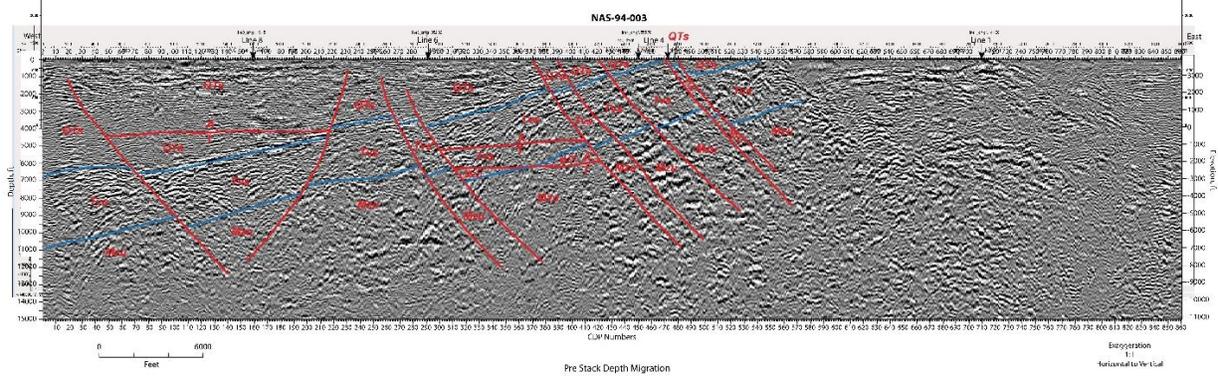


Figure B1. Generalized geologic map of the FORGE area near Fallon, NV, showing locations of interpreted seismic reflection profiles (red and black seismic lines highlighted in yellow to show areas interpreted), Quaternary faults (red lines), and depth of Mesozoic basement. The FORGE area is in green and surrounding monitor areas are shown by gray hashes. Black dots are wells with available data from logs, cuttings, or core.

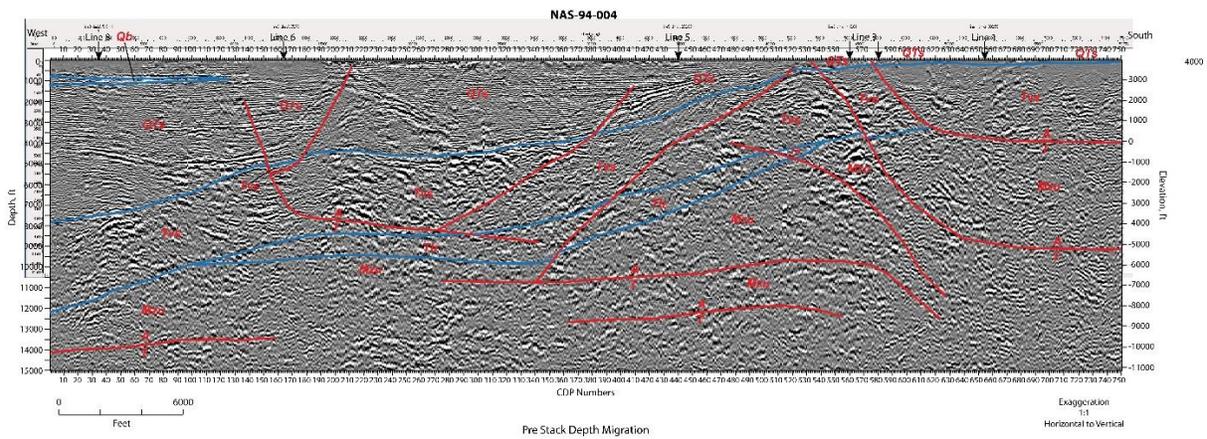
### Profile N-1



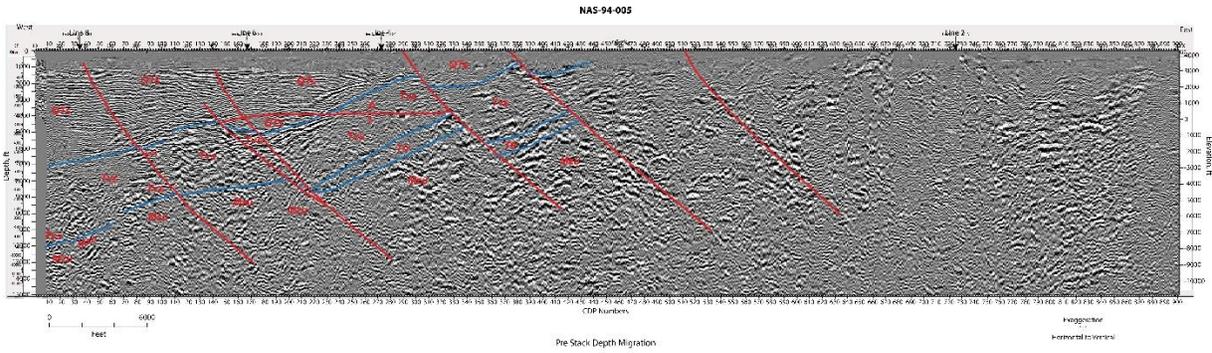
### Profile N-3



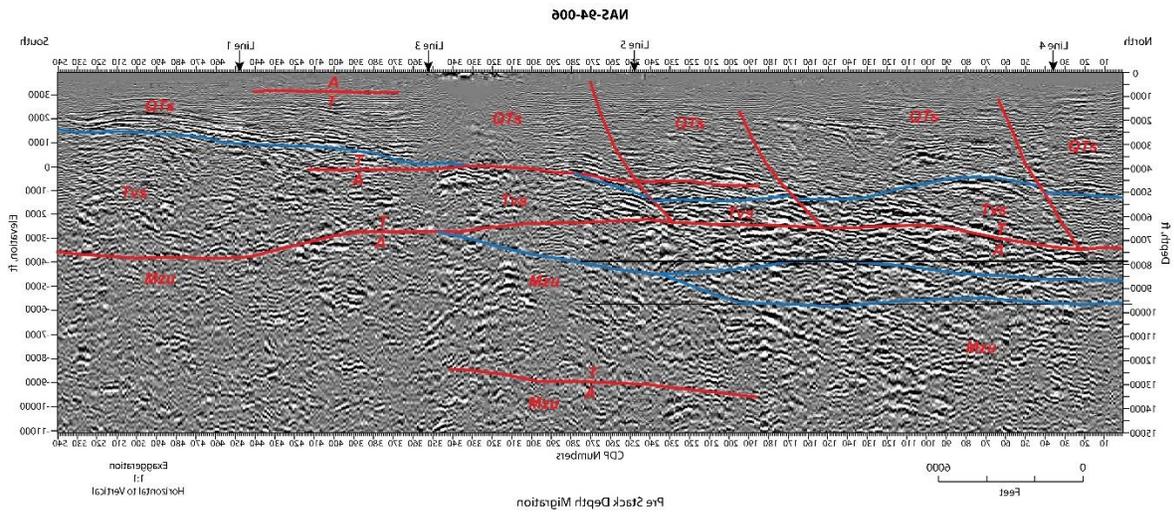
### Profile N-4



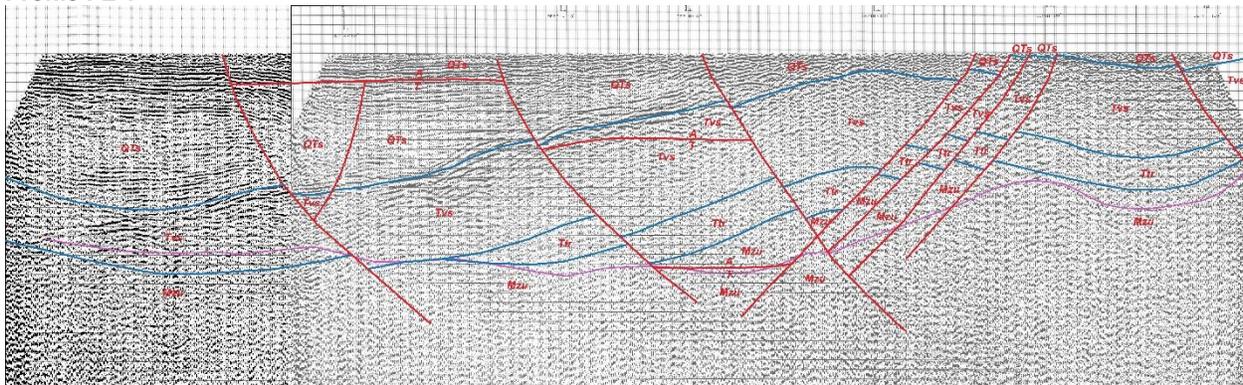
### Profile N-5



### Profile N-6

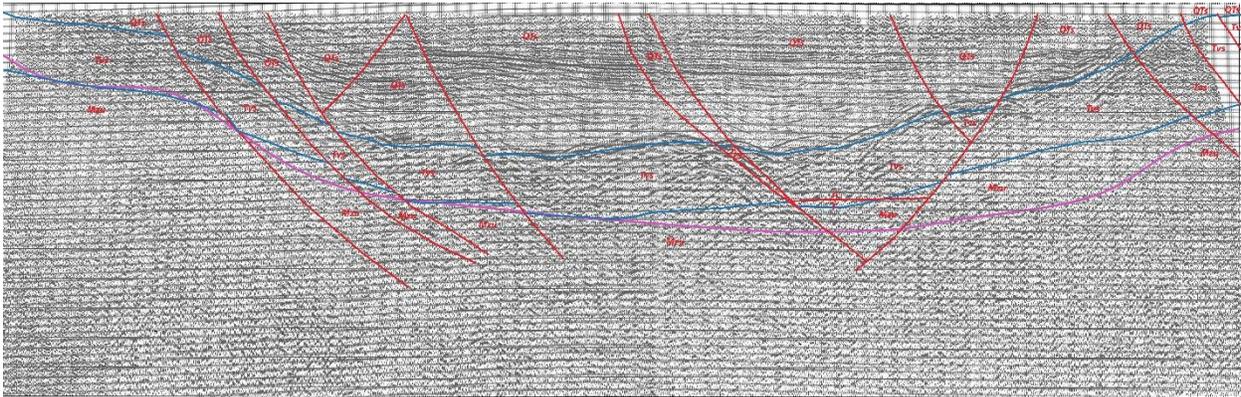


### Profile FL-1



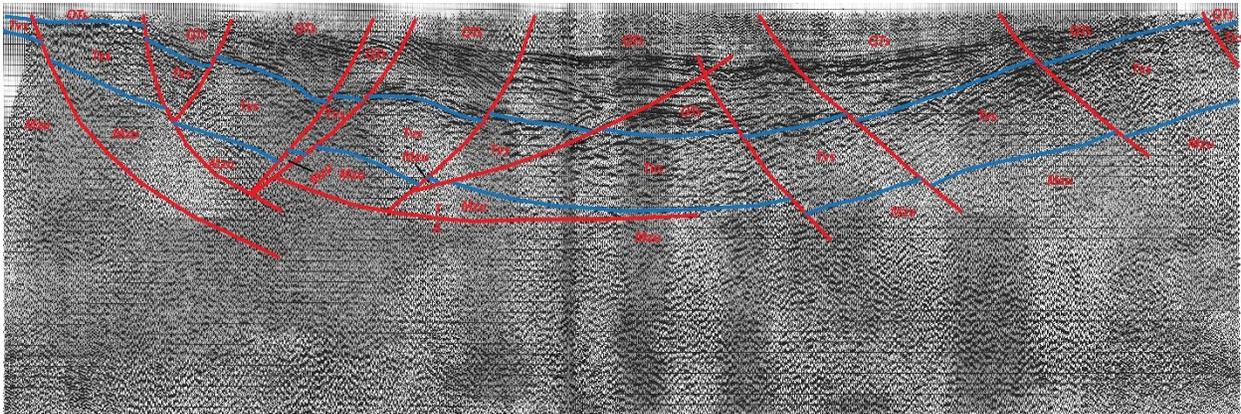
Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

**Profile FL-2**



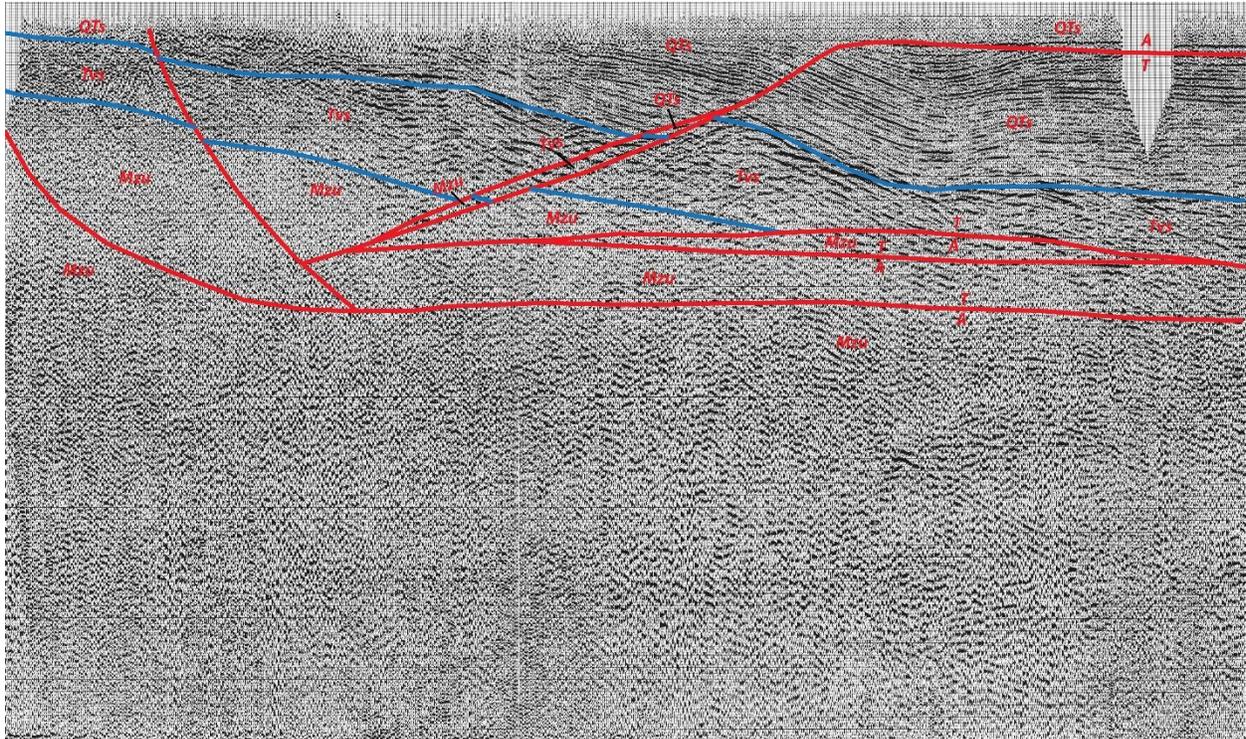
Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

**Profile FL-3**



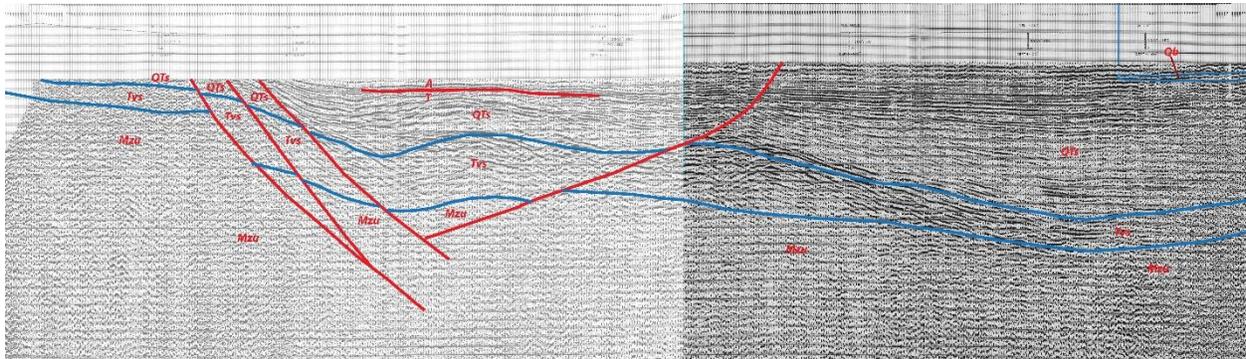
Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

**Profile FL-4**



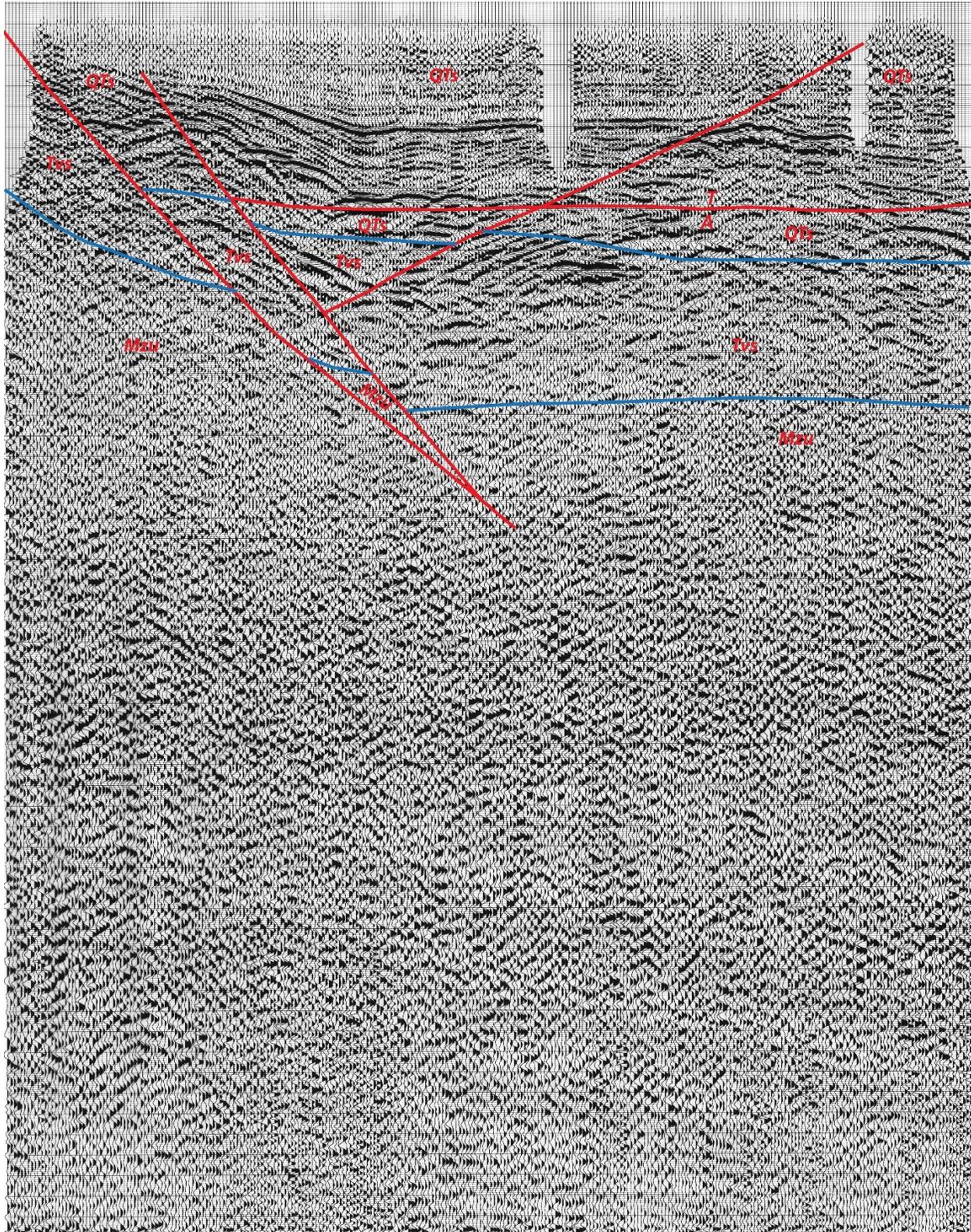
Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

**Profile FL-5**



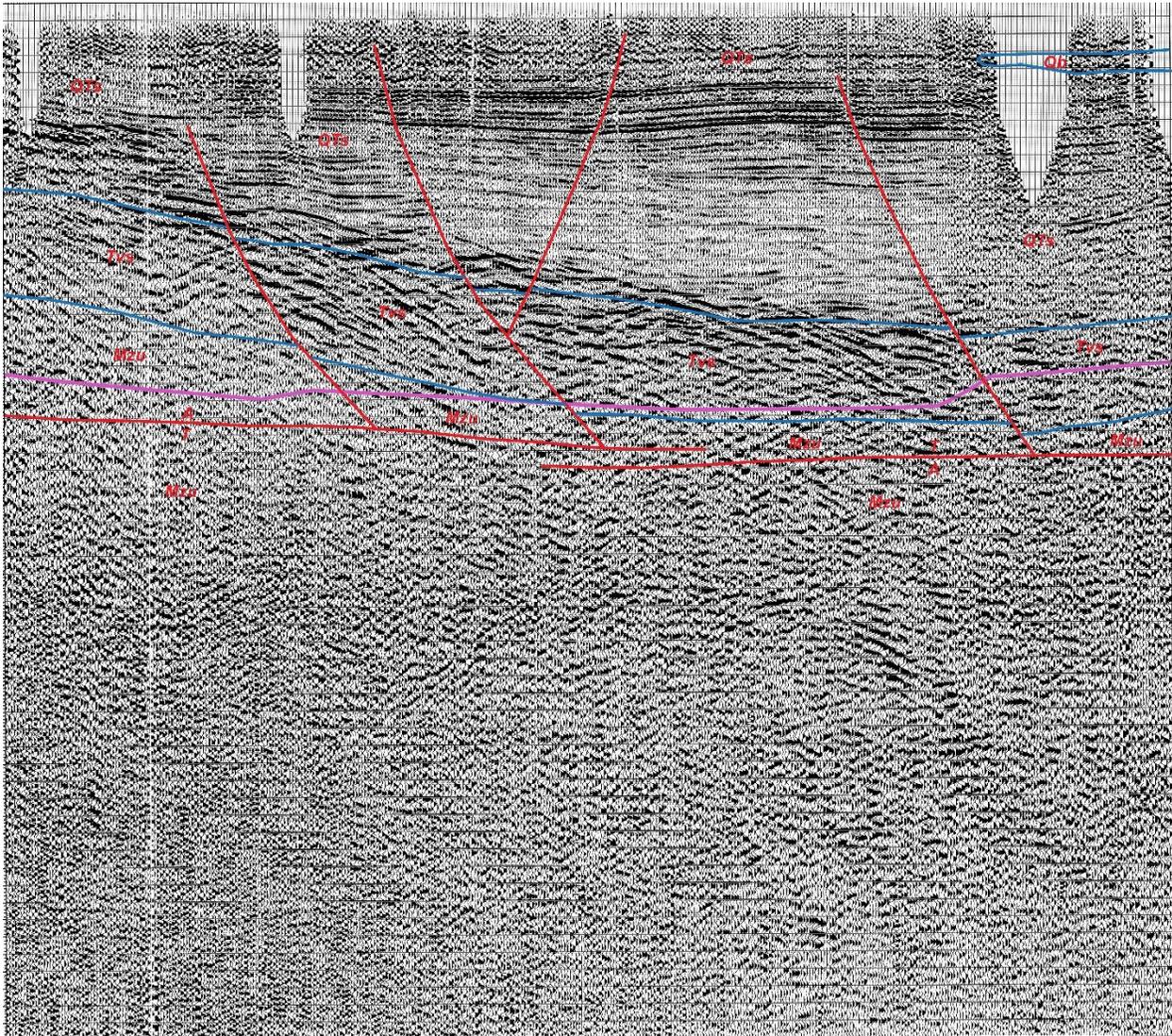
Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

Profile FL-6



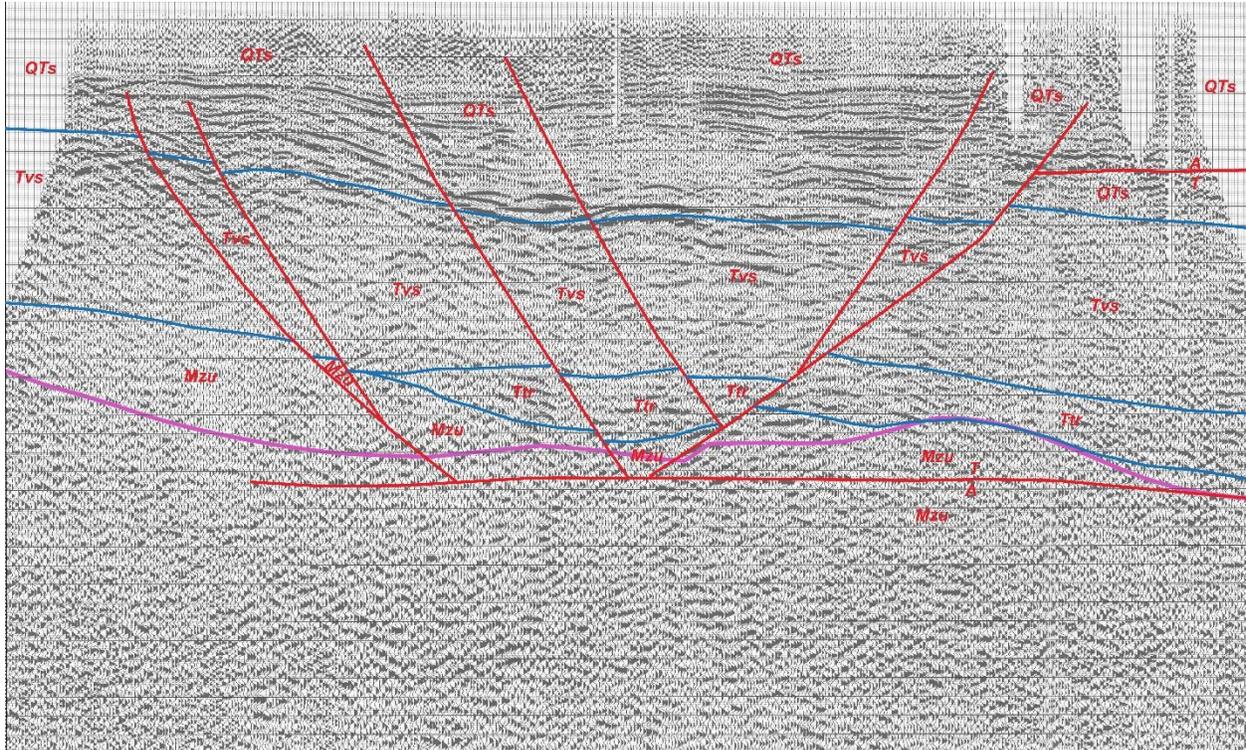
Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

Profile FL-7



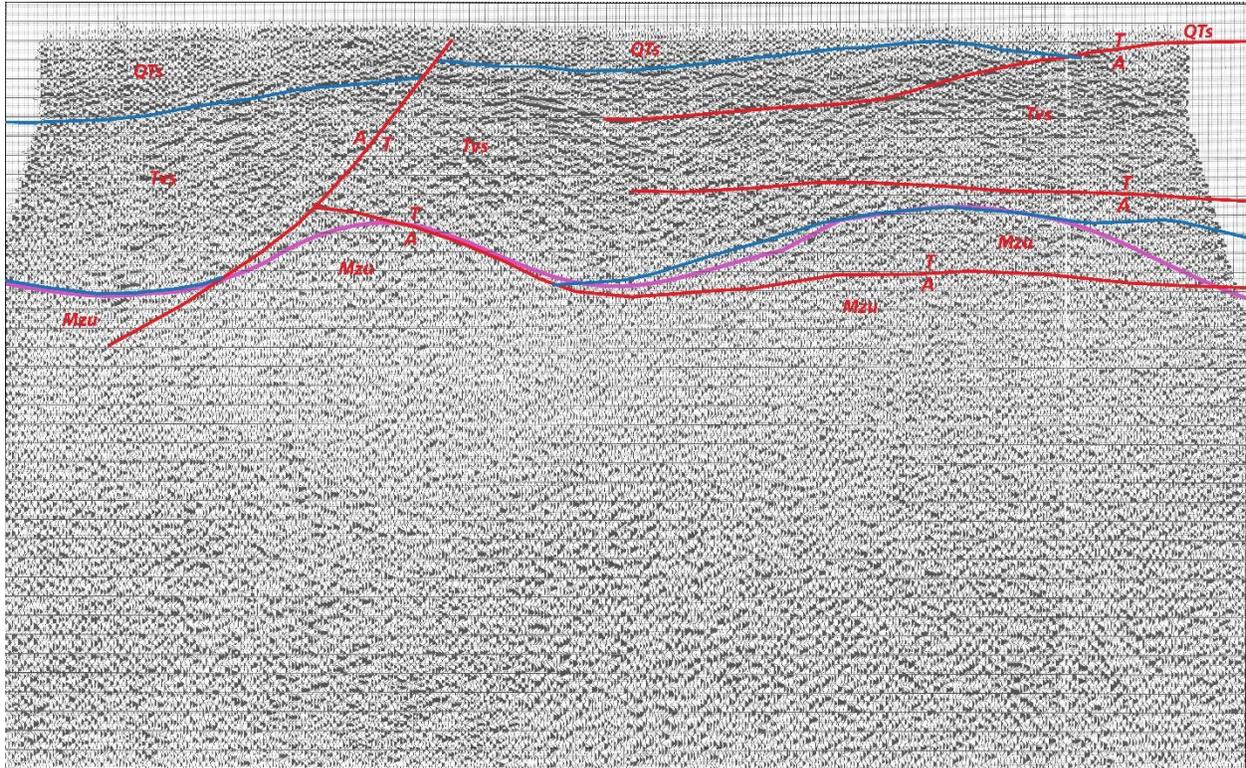
Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

Profile FL-8



Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

Profile FL-9



Seismic data owned or controlled by Seismic Exchange, Inc.; interpretation is that of the University of Nevada, Reno.

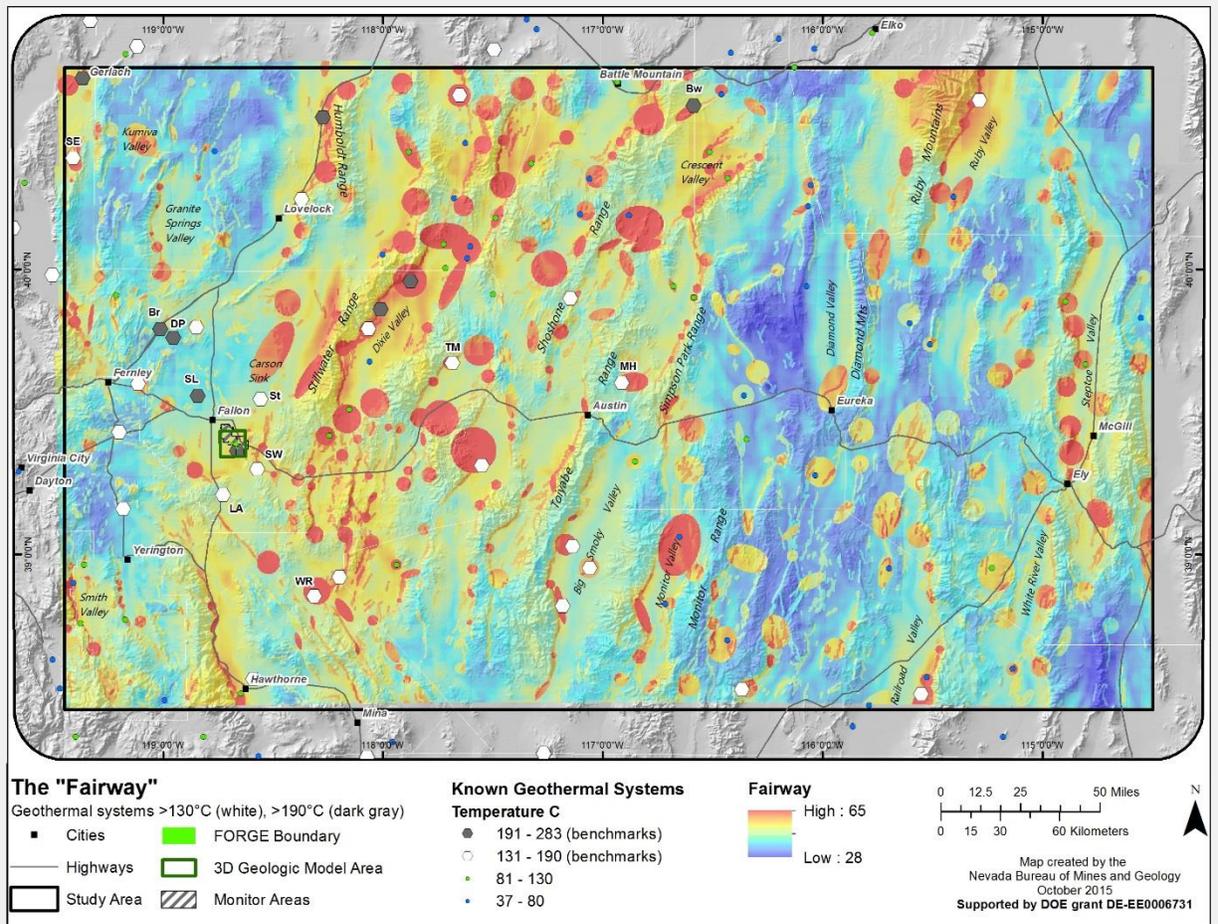
## ATTACHMENT C: PLAY FAIRWAY ANALYSIS

Several regional data sets were recently synthesized into a detailed statistical analysis of geothermal play fairways of a broad transect across the Great Basin of Nevada (Figure ; Faulds et al., 2015, 2016). This analysis employed an expert-guided, fuzzy logic system (e.g., Dixie Valley; Iovenitti et al., 2012) guided and constrained by spatial statistics, including weights-of-evidence and logistic regression. The model integrated each input data set into two key hierarchical components considered necessary for an economic geothermal reservoir (the “play”) to form: 1) permeability and 2) heat. The major contributing sections in this fairway model include: 1) regional permeability (regional strain and stress), 2) intermediate-scale permeability (distribution of Quaternary faults), 3) local permeability (favorable structural settings), and 4) availability of heat. In addition, direct evidence from fluid geochemistry and degree of exploration, which incorporates well data, depth to water table, and regional aquifers, were integrated to better define exploration opportunities. A major aspect of developing the play fairway model was determining the composition of the key hierarchical components (i.e., individual evidence layers) and the relative weights assigned to each both within and between each parameter. The determination of weights was aided by establishing benchmarks based on known geothermal activity and using weights-of-evidence and logistic regression to define weights based on spatial correlations. Figure shows the modeling workflow. The methodology is discussed in detail in Faulds et al. (2015). Of relevance here is how the proposed Fallon FORGE site scores in the fairway model relative to known hydrothermal systems in the region and thus whether it is likely to host a natural hydrothermal system itself.

The Fallon FORGE site yields relatively low values of combined permeability and overall fairway scores. The fairway values are calculated from both the combined permeability and heat. Values of combined permeability range from 13.9 to 49.75 across north-central Nevada, with the values from 34 high-temperature ( $\geq 130^{\circ}\text{C}$ ) geothermal systems averaging 35.38. The Fallon FORGE site has a significantly lower, combined permeability score of 26.5 (Figure ) due primarily to the lack of both Quaternary faults and a favorable structural setting. The fairway score at Fallon is 43 (Figure ), compared to a range from ~28 to near 65 in north-central Nevada, with the 34 high-temperature geothermal systems yielding an average of 51.37.

An additional method for evaluating the likelihood of encountering an active geothermal system is assessing the degree-of-exploration for a given area. The degree-of-exploration modeling for the Carson Sink region incorporates two types of information (Faulds et al., 2015). The first assesses the ability of a geothermal system to remain blind without active surface thermal manifestations, and the second considers the thoroughness of past geothermal exploration efforts. Blindness factors incorporated into the model include depth to the water table, the distribution of Quaternary playa deposits and young alluvium, and the distribution of the carbonate aquifer. Hot springs are less likely to form where the water table is deep, which is not the case at Fallon. Thermal springs are also less likely to form where shallow permeable aquifers are present, because these aquifers can capture and entrain thermal fluids rising from depth. The Carson Sink does contain some shallow permeable aquifers, which could hinder development of thermal springs. However, the second major component of the degree-of-exploration model involves assessing the thoroughness of exploration through drilling. Degree-of-exploration assignments were made to the well database depending on the depth of the hole and the depth of the water

table. Degree-of-exploration increases with well depth. A 2-km-radius of influence was used for the well data, and the maximum “degree-of-exploration” from wells within that radius was assigned to each grid cell. Abundant drill holes and several relatively deep wells within the proposed Fallon FORGE site indicate a very high degree-of-exploration (Figure ), among the highest in the region. This indicates that discovery of a hydrothermal system is very unlikely within the proposed FORGE site at Fallon, particularly within the 4.5 km<sup>2</sup> footprint.



**Figure C1. Geothermal play fairway model of central Nevada. The Fallon FORGE site lies in the western part of a broad region in which as many as 9 parameters were combined to estimate the favorability for geothermal activity (Faulds et al., 2015). Warmer colors indicate higher fairway values. The proposed FORGE site lies in an area of moderate favorability.**

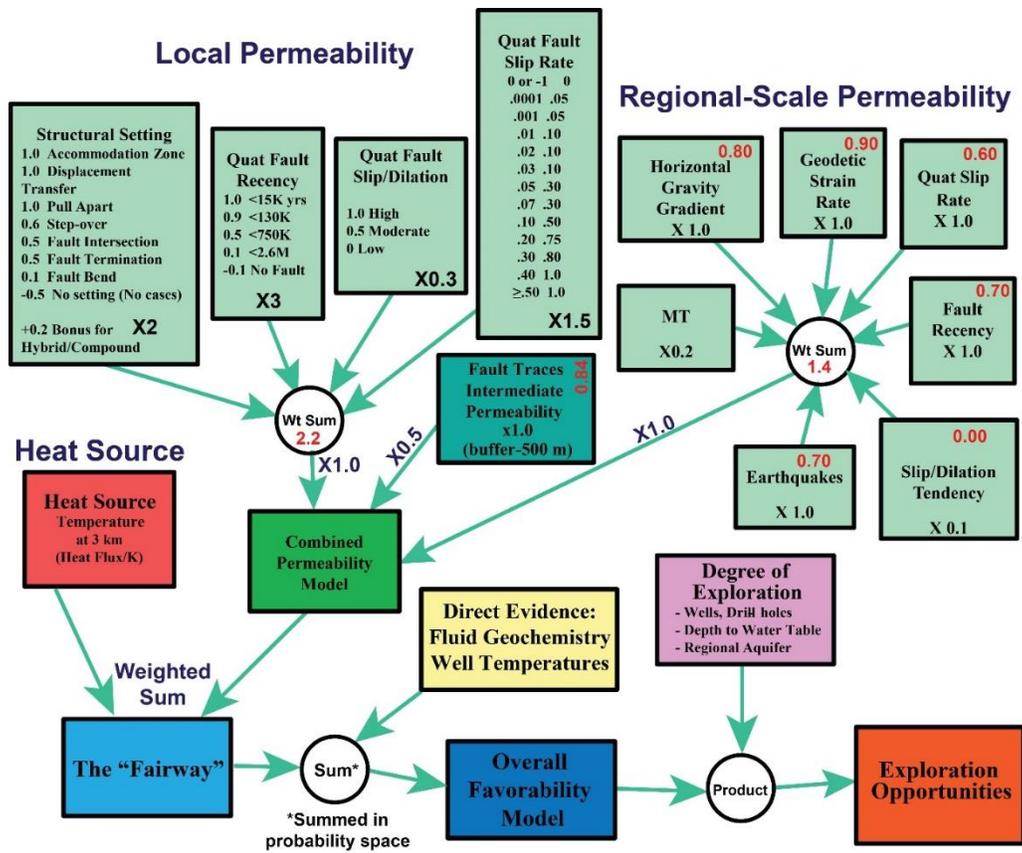


Figure C2. Nevada play fairway modeling workflow. Red numbers indicate relative weights determined from weights of evidence. Black numbers indicate expert driven weights used in the analysis. In all cases, the expert driven weights took into account the statistical analyses.

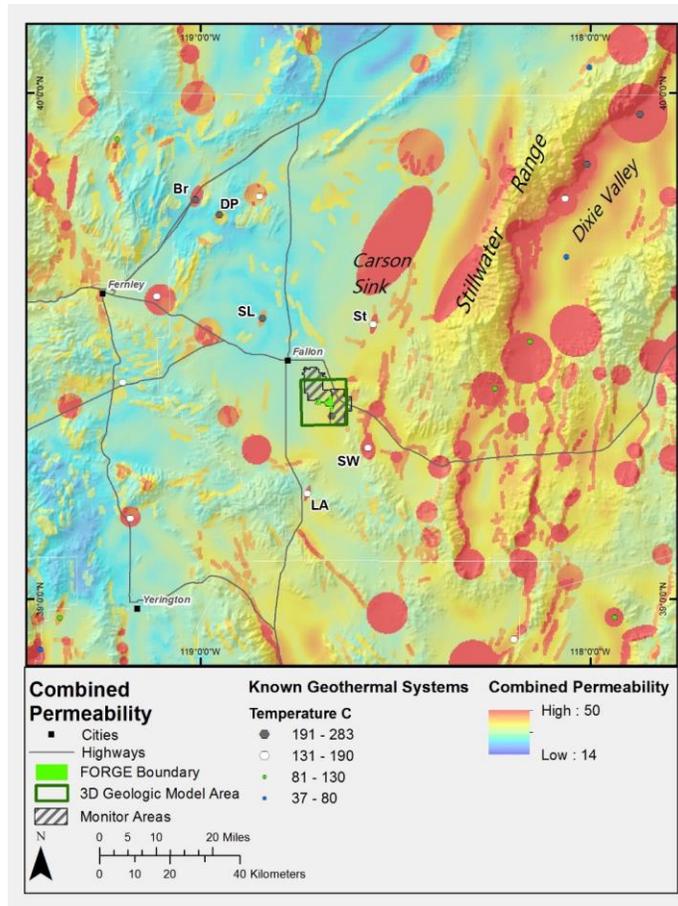
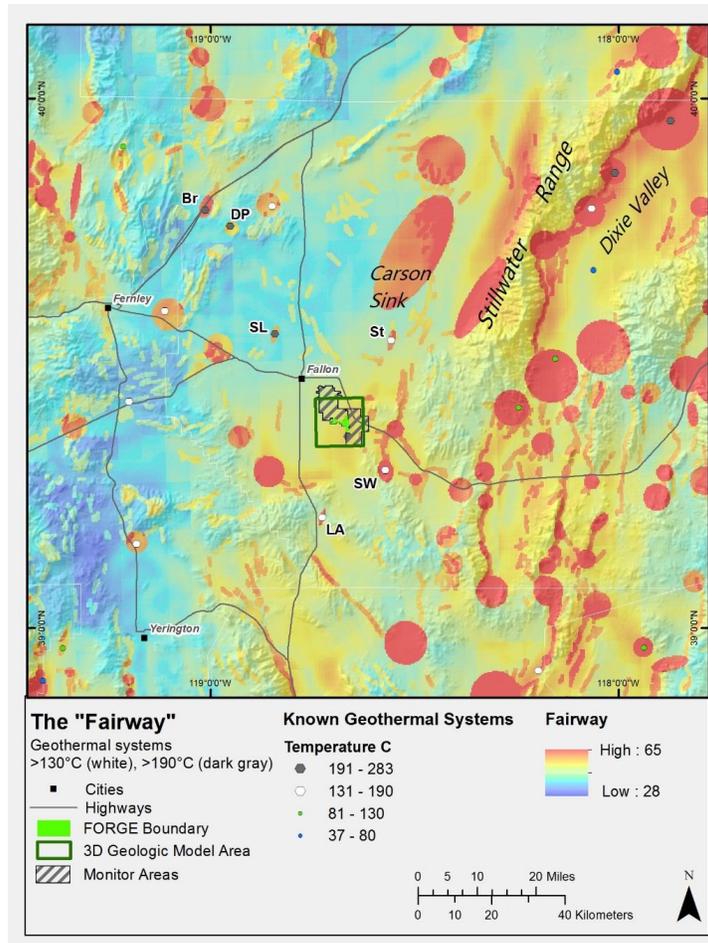


Figure C3. Combined permeability map for the Carson Sink region. Figure shows the major parameters and their relative weightings that are incorporated in the combined permeability model. The Fallon FORGE project area has relatively low values of combined permeability.



**Figure C4. Play fairway map for the Carson Sink region. The Fallon FORGE site has a significantly lower score for play fairway compared to known geothermal systems in the region. Figure shows the major parameters and their relative weightings that are incorporated in this model. See Faulds et al. (2015) for detailed descriptions of the methodology.**

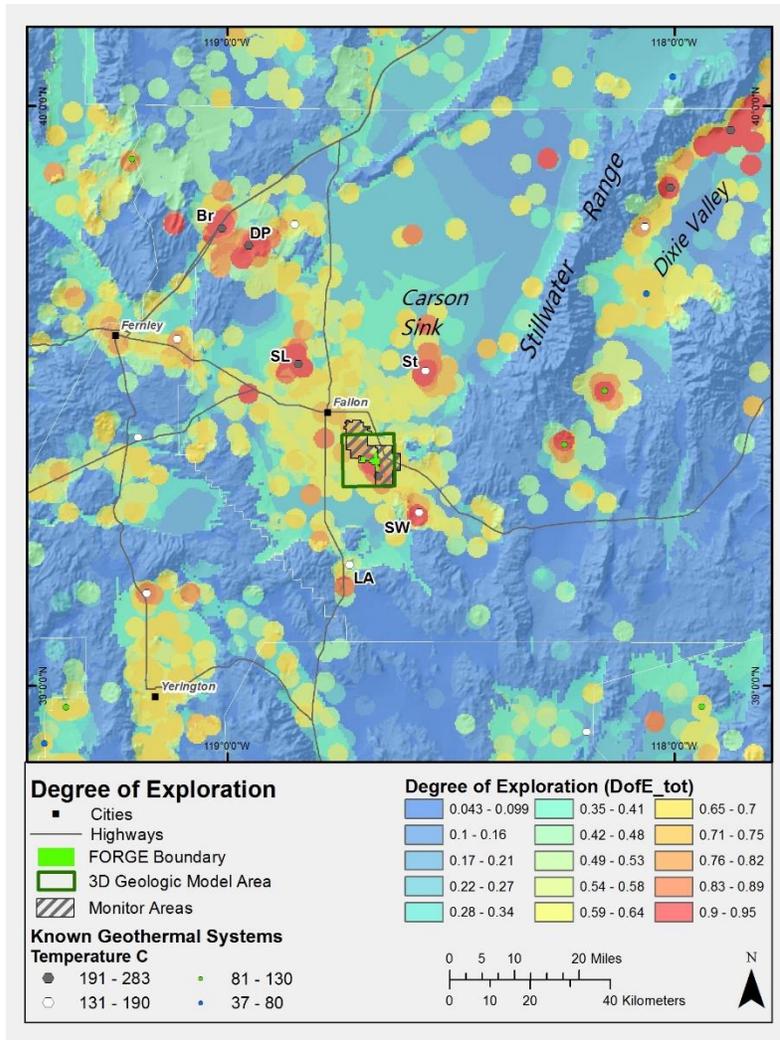


Figure C5. Degree-of-exploration model for the Carson Sink region. Note that the Fallon FORGE site has a very high degree-of-exploration, suggesting that discovery of a new hydrothermal system is unlikely within the proposed FORGE footprint.

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**APPENDIX B. UPDATE ON CHARACTERIZATION DATA UPLOADED  
TO THE GDR DATA ARCHIVE**

# UPDATE ON CHARACTERIZATION DATA UPLOADED TO THE GDR DATA ARCHIVE

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Fallon, NV

## NAS FALLON



*Geothermal Research  
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## UPDATE ON CHARACTERIZATION DATA UPLOADED TO THE GDR DATA ARCHIVE

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### Fallon, Nevada

All data used in characterization of the Fallon FORGE site and construction of the Fallon 3D geologic model has been uploaded to the Geothermal Data Repository (GDR). This includes downhole lithologic data interpreted from core, cuttings, and mud logs; downhole image log and geophysical data; digital elevation data; geologic map data; petrographic data; geologic cross-sections, gravity and magnetic data; magnetotelluric data; down hole temperature data; shallow temperature data; well testing data; seismic reflection data; and seismicity data.

The Fallon 3D geologic model has also been uploaded to the GDR.

The data uploaded to the GDR for the Fallon, NV, site is captured in Table 1, below.

**Table 1. Data uploaded to the GDR for the Fallon, NV, site**

<b>Data Description</b>	<b>File Name</b>	<b>Date Uploaded</b>
x,y,z downhole temperature data for wells in and around the Fallon FORGE site	FallonFORGEWellTemps.txt	4/21/2016
3D model range, FORGE site outline	FallonFORGEGISPolygons.zip	4/21/2016
3D geologic model of the Fallon FORGE site	FallonFORGE3DGeologicModel.txt	4/21/2016
x,y,z text file of the downhole lithologic interpretations in the wells in and around the Fallon FORGE site	FallonFORGEWellLithologies.txt	4/21/2016
Temperature log from well 17-16	17-16_TEMP.pdf	3/31/2016
Mud log from well 13-36	13-36_mudlog.tif	3/31/2016
Mud log from well 35A-11	35A-11_mudlog.tif	3/31/2016
FORGE area GIS polygons	FORGE boundary layers.lpk	3/31/2016
Mud log from well 86-15	86-15_mudlog.tif	3/31/2016
Temperature log from 35A-11	35A-11_temp.tif	3/31/2016
Temperature log from 34-33	34-33_temp.tif	3/31/2016
Mud log from well 78-36	78-36_mudlog.tif	3/31/2016
Digital elevation model	Nevada DEM	3/31/2016
Geologic map of Nevada	Geologic Map of Nevada	3/31/2016
Geologic Map of the Bunejug Mountains Quadrangle Churchill County Nevada	Geologic Map of the Bunejug Mountains Quadrangle Churchill County Nevada	3/31/2016
Geologic Map of the Lahontan Mountains Quadrangle Churchill County Nevada	Geologic Map of the Lahontan Mountains Quadrangle Churchill County Nevada	3/31/2016
Geologic Map of Grimes Point Quadrangle Churchill County Nevada	Geologic Map of Grimes Point Quadrangle Churchill County Nevada	3/31/2016
Hydrogeology at Fallon	Maurer and Welch 2001	3/31/2016
Major Carson Sink roads	NDOT major roadways	3/31/2016
GIS data	Fallon_FORGE_GDR.mpk	3/31/2016
Flow test from well FOH-3	FOH-3 Flow Test.xls	3/31/2016
EQ hypocenters	USGS Query_EQs.csv	3/31/2016
Temperature pressure log from well 61-36	61-36_WellTempPressLog.xlsx	3/31/2016
Survey of well 61-36	61_36Survey_TGHBHT.xlsx	3/31/2016
2 meter temperature probe data	2mTemperatureProbe.zip	3/31/2016
Pressure log from well 13-36	13-36_BHP.zip	3/31/2016
Temperature log from 13-36	13-36_TEMP.zip	3/31/2016
Well survey from well 13-36	13-36_XMAC.zip	3/31/2016
Survey of well 13-36	13-36_SURVEY.zip	3/31/2016
Mud log from well 47A-11	47A-11_MUDLOG.zip	3/31/2016
Mud log from well 51A-20	51A-20_MUDLOG.zip	3/31/2016
Mud log from well 56A-14	56A-14_MUDLOG.zip	3/31/2016
Mud log from well 58A-9	58A-9_MUDLOG.zip	3/31/2016

<b>Data Description</b>	<b>File Name</b>	<b>Date Uploaded</b>
Mud log from well 14-1	14-1_MUDLOG.zip	3/31/2016
Temperature log from well 78-36	78-36_TEMP.zip	3/31/2016
Mud log from well 17-16	17-16_MUDLOG.zip	3/31/2016
Mud log from well 61-36	61-36_MUDLOG.zip	3/31/2016
Mud log from well 62-15	62-15_MUDLOG.zip	3/31/2016
Well test from well 82-36	82-36 well test.zip	3/31/2016
Temperature pressure log from well 84-31	84-31_PT.zip	3/31/2016
Temperature pressure log from well 82-36	82-36 PT logs.zip	3/31/2016
Temperature log from well 8431	84-31_TEMP.zip	3/31/2016
Mud log from well 86-25	86-25_MUDLOG.zip	3/31/2016
Gamma log from well 86A-15	86A-15_SEMBLANCE_GAMMA.zip	3/31/2016
Mud log from well 84-31	84-31_MUDLOG.zip	3/31/2016
Sonic log from well 17-16	17-16_SONICWAVE.zip	3/31/2016
Mud log from well 86A-15	86A-15_MUDLOG.zip	3/31/2016
Fallon area well collars	FORGE area wells.zip	3/31/2016
Heat flow data	HeatFlow.zip	3/31/2016
Temperature log from well FOH-3	FOH-3_TEMP.zip	3/31/2016
Siesmic reflection profiles	NavySeismicLines.zip	3/31/2016
Radiogenic heat data	Radiogenic_Heat_Generation.zip	3/31/2016
Temperature gradient data	Temperature_Gradient_Measurements.zip	3/31/2016
Magnetotelluric data	MT.zip	3/31/2016
Mud log from well 34-33	34-33_MUDLOG.zip	3/31/2016
Mud log from well 88-24	88-24_MUDLOG.zip	3/31/2016
Mud log from well FOH-3	FOH3_MUDLOG.zip	3/31/2016
Mud log from well 82-36	82-36_MUDLOG.zip	3/31/2016

## **APPENDIX C. ENVIRONMENTAL INFORMATION SYNOPSIS**

# ENVIRONMENTAL INFORMATION SYNOPSIS

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Fallon, NV

## NAS FALLON



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# ENVIRONMENTAL INFORMATION SYNOPSIS

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## NAS Fallon

### INTRODUCTION

The proposed Naval Air Station (NAS) Fallon FORGE project area is approximately 1,115 acres (387 Ormat leased or owned, 728 NASF) within and adjacent to the NAS Fallon (NASF) and Ormat lease areas. The total acreage for monitoring is 9,856 acres (3,842 Ormat leased or owned plus 6,014 NASF, exclusive of the main FORGE site and areas of No Surface Occupancy). Ormat has three BLM leases (NVN-079104, NVN-079105, NVN-079106) that have been unitized under the Bunejug Unit Agreement and two parcels of purchased private land.

Two NEPA documents serve as the primary foundation for permitting and additional environmental and cultural work required at the Fallon FORGE site. The Salt Wells EIS (OEPC Control Number FES 11-12) and the NAS Fallon Programmatic EIS.

The Salt Wells EIS (OEPC Control Number FES 11-12) was completed in 2011 (along with a previous 2008 Environmental Assessment) to support geothermal development work at the Salt Wells Known Geothermal Resources Area (KGRA) and focused on private and leased grounds in the eastern Carson sink. It provides NEPA analysis for exploration and development of a geothermal well field, power plant and transmission line on private and leased properties. All of the land outside of NAS Fallon fence line included in the Fallon FORGE site was covered under this EIS. The Navy was a cooperating agent on this 2011 EIS but not a signatory.

The NAS Fallon Programmatic EIS served a similar purpose and includes all developable lands inside the NAS Fallon fence line. In March, 1991 NAS Fallon (NASF) completed the Programmatic EIS (PEIS) for Geothermal Energy Development, NASF. The purpose of the PEIS was to support geothermal exploration and proposed development activities at NAS Fallon. In 2005, a 50-yr development contract (N62473-06-C-3021) was awarded by the Navy to Ormat Nevada Inc. to develop and sell power from a geothermal plant to be constructed on NAS Fallon. The NAS PEIS was the supporting environmental document allowing this agreement. This contract was mutually dissolved in 2012 because Ormat determined through deep drilling that the postulated hydrothermal resource (370-400 degree F) in basement rocks beneath NAS Fallon did not exist.

The following outlines environmental issues and protection measures designed to address these concerns on the Fallon FORGE site as well as the likely path required to obtain any remaining permits required to perform FORGE activities.

### ENVIRONMENTAL ISSUES AND PROTECTION

Appendix E of the Final Environmental Impact Statement, Salt Wells Energy Projects, (OEPC Control Number FES 11-12) dated July 2011, outlines the environmental protection measures and best management practices (BMP) that govern Fallon FORGE activities on leased and private land. In addition to the requirements and conditions stated in the project permits,

geothermal lease stipulations, and conditions of approval, the project proponents are committed to implementing the best management practices as appropriate for each of the proposed actions.

The Fallon FORGE team would inform all personnel, as well as well drilling, testing, and supply contractors, of the team's policy regarding protection and undue degradation of the environment. These measures are intended to prevent all unacceptable impacts from occurring as a result of these operations, as is required under the special stipulations of the Federal geothermal leases.

#### **FIRE PREVENTION**

The well sites and access roads would be cleared of all vegetation, and the areas would be maintained during drilling operations. The potential well sites are located in very sparsely vegetated areas. All construction and drilling equipment would be equipped with exhaust spark arresters. Fire extinguishers would be available on the drill pad sites and around the drilling rig. Water that is used for construction, dust control, or drilling would be available for firefighting. Personnel would be allowed to smoke only in designated areas. Any special permits required for burning of slash or trash, other fires, welding, etc., would be obtained before these operations are conducted.

#### **PREVENTION OF SOIL EROSION**

No soil erosion problems are anticipated from this project because the topography is gentle and cut and fill for construction of the well sites and access roads have been minimized. On-site storm water would be collected in the sump. Off-site storm water would be intercepted in ditches and channeled to energy dissipaters as necessary to minimize erosion. BLM and State of Nevada best management practices for storm water would be followed, as applicable.

#### **SURFACE AND GROUND WATER QUALITY PROTECTION**

The locations of the drill pads and access roads will be selected to minimize the potential for surface water pollution during construction, drilling, and testing. New access roads would not cross any riparian areas and only existing roadways would be used to cross through riparian areas.

Only non-toxic, non-hazardous drilling mud and drilling mud additives would be utilized. Waste drilling mud, drill cuttings and any runoff from the well pad would be discharged into the lined containment basin to prevent water quality degradation. The well bores would be cased with steel casing to prevent inter-zonal migration of the fluids, protect ground water, and reduce the possibility of uncontrolled well flow ("blowouts"). See also waste disposal measures. The team would comply with any requirements prescribed by the Nevada Bureau of Water Quality Planning (BWQD).

#### **AIR QUALITY PROTECTION**

Fugitive dust generated during construction and travel over access roads and drill pads would be minimized by watering the roads and pads during construction and during extended road use. Vehicle speeds would also be limited on unpaved roads. The team may use burning as a method to control vegetation and dispose of materials that are cleared as part of the drill pad construction. The team would obtain all necessary burning permits during required months and would contact the Fall/Churchill Fire Department and the BLM prior to any burning.

The team would comply with any requirements prescribed by the Nevada Bureau of Air Pollution Control (BAPC) concerning emissions of air pollutants from the drilling rig engines, burning, and non-condensable gases from the geothermal fluid during flow tests.

#### **NOISE PREVENTION**

To abate noise pollution, mufflers would be used on all drilling rig engines. Construction and drilling noise would be minimized through operational practices, which to avoid or minimize practices that typically generate high noise levels or distinctive noise impacts. The closest sensitive receptor is a private residence located approximately two miles from the closest drilling location.

#### **PROTECTION OF PUBLIC HEALTH AND SAFETY**

There is a possibility of encountering hazardous non-condensable gases while drilling and testing. The three main gases associated with geothermal resources in the area are steam, hydrogen sulfide (H<sub>2</sub>S), and carbon dioxide (CO<sub>2</sub>). Noxious or dangerous amounts of gases have not been associated with other geothermal wells drilled in the area; however, a contingency plan has been prepared to protect against exposure to noxious gasses such as H<sub>2</sub>S. Detection systems would be installed at the wellhead to protect against exposure.

Public health and safety would be protected through safety training and instructions to work crews and contractors and compliance with State of Nevada and Federal Occupational Safety and Health Administration regulations in addition to the emergency contingency plans prepared by the team.

#### **PROTECTION OF FISH, WILDLIFE, AND PLANT RESOURCES**

Direct impacts to wildlife habitat and botanical resources would be minimized by clearing only those small areas required for the construction of the drill pads and development and improvement of necessary access roads. Biological surveys conducted of the area indicate that presence of endangered, threatened or sensitive plant or animal species within the areas of construction or operations is unlikely. Prior to construction, a new biological survey may be conducted to characterize the existing plant and animal species on site, and define mitigation measures (if necessary) to avoid impacts of wildlife, special status species, and habitat.

Project-related vehicles (whether driven by employees, contractors, or suppliers) traveling on unpaved roads in the project area would be limited to a speed of 35 miles per hour to reduce the potential for vehicle collisions with wildlife.

The well site would be reclaimed to promote the reestablishment of native plant and wildlife habitat following abandonment of the wells. The team would work cooperatively with the BLM to prevent the introduction and establishment of noxious weeds as a result of this project. This may include ensuring that equipment and vehicles used in the project are washed or inspected to prevent the introduction of noxious weeds; that any hay or straw bales used for erosions control would be weed-free; and that weed prevention and treatment measures would be specified for reclamation.

#### **PROTECTION OF CULTURAL RESOURCES**

Previous cultural resource surveys of the area indicate significant cultural resources may be discovered in the area. All areas proposed for disturbance, including well sites and proposed

access roads, would be surveyed by an archeologist acceptable to the BOR, Navy, and BLM. Any areas containing significant cultural resources would be avoided. If avoidance is not possible, the eligibility of the resources would be determined and an appropriate data recovery plan would be implemented in a manner acceptable to the BLM and Navy. The team, contractors, and suppliers would be informed about the sensitivity of the area and reminded that all cultural resources are protected and if uncovered shall be left in place and reported to the site representative.

#### **WASTE DISPOSAL**

A lined containment basin/sump would be located on each drilling pad and all drilling fluids not contained in the well bore or mud mixing tanks would be contained in the containment basin. After drilling operations are completed, the liquids from the containment basin either would be allowed to evaporate, pumped back down the well, or disposed of in accordance with the requirements of the Nevada Bureau of Water Quality Planning (BWQP). The remaining solid contents, typically consisting of non-toxic drilling mud and cuttings, would be tested as required by the BWQP. If non-toxic and as authorized by the BWQP, these materials would be spread and dried on the well site, then buried in the on-site containment basin in conformance with the applicable requirements of the BWQP and BLM. If burial on site is not authorized, the solids would be removed and either used as construction material on private lands or disposed of in a facility authorized by the BWQP to receive and dispose of these materials. After the materials buried in the containment basin have been compacted and stabilized, the containment basin area would be reclaimed. Solid waste materials generated during the drilling (bags, containers, etc.) would be accumulated on site, collected by a licensed waste hauler, and deposited at a facility authorized to receive and dispose of these materials.

#### **MONITORING**

The team would conduct regular visual inspections of the drill pad and access roads to detect and correct any operational problems. The drilling fluids (air, mud, water, and/or foam) and drilling cuttings would be monitored by visual inspection and chemical analysis by drilling personnel, contract geologists, and the contract mud engineer to detect any problems which may occur down hole.

#### **PERMITTING PATH**

Environmental analyses have been done by the BLM and Navy. The Exploration EA completed in 2008 and Utilization EIS completed July 2011 (OEPC Control Number FES 11-12) provide NEPA analysis for exploration and development of a geothermal well field, power plant and transmission line on private and BLM properties. The Navy's PEIS for Geothermal Energy Development at NAS Fallon provides the same level of analysis on NAS Fallon property. The Fallon FORGE team believes that these documents are sufficient to support the commencement of operations at the Fallon FORGE site. While the Navy will need to complete an internal evaluation of all of these documents before this work will commence on the Navy owned land, the Navy acknowledges that data generated during the EIS processes as well as other activities on base are sufficient for them to complete NEPA requirements on Navy land in support of FORGE. The Navy is committed to working with BLM to complete all NEPA related work on NAS Fallon property before the close of Phase 2A.

As evidence that a site development pathway exists, numerous wells have been previously permitted within and immediately surrounding the proposed Fallon FORGE site. A summary of permitted wells is provided below:

Drilled and not commercial:

- Ormat leases: Two wells drilled: 84-31 and 18-5. These wells were drilled and completed under approved existing permits.
- NAS: Five exploration wells were drilled by the Navy GPO and one by Ormat for the Navy GPO: 82-36 (drilled by Ormat), FOH-3D, 61-36, 88-24, 86-25, and 82-19. The Navy GPO has been doing work at the Naval Air Station Fallon since the early 1990's, but recent exploration ramped back up in 2012. This included the acquisition of geophysical surveys, the deepening of an existing exploration hole, drilling out the mud in another existing hole, the drilling of 9 shallow temperature gradient holes and 5 intermediate to deep exploration holes. This work was performed under a Category Exclusion Agreement and the Ormat/NASF EIS. However, future activities for the FORGE project would require a new NEPA agreement with the NASF installation which would take at most 4 months. The NASF installation itself will need to provide approval, which could take at most 6 months, concurrent with the NEPA approval.

The Navy properties that make up the Fallon FORGE site are primarily fee Simple lands, where the Navy owns all surface and subsurface rights. The project lands controlled by Ormat held under BLM leases for Geothermal Resources in Unit Areas N79104, N79105, N79106) with total size of 7426 acres. All three leases were unitized on May 14, 2009. The Ormat leases expire on 8/30/2016. In accordance with the lease agreements, all three leases can be extended for an additional 5 years without any work being performed on the leased land. Or as long as there is activity/work (like FORGE) being performed on a lease and payments are current, the leases are extended indefinitely. Evidence of activity is currently being gathered to process the extension.

Permits required and approximate times to bring the Fallon FORGE site to full operation are shown in Table 1, below. For exploration and drilling activities on Navy land, NAS Fallon may

**Table 1. Permitting Timetable.**

<b>Necessary Permitting</b>	<b>Time Period to Acquire</b>
FAA Permit	45 days
NDEP UIC Permit	4 months
NDOM drilling permit	2 weeks
Drilling Permit	1 Month
DNA	1 – 2 Months
Dig Permit	1 month
CATEX	1 month
Access Request Form from Navy	2 weeks
Utility Locate	2 weeks
ECATTS Training	1 day
Oil Spill Manifest	1 day

issue a Categorical Exclusion (CATEX). Drilling activities can begin with the approval of geothermal drilling permit. Because the site disturbances were analyzed in the EIS, new drilling sites may need to be permitted with additional field surveys and a Determination of NEPA Adequacy (DNA) may be required. An FAA permit is needed because of the proximity of the site to the air field at NASF. The Nevada Division of Minerals (NDOM) grant permits for drilling and requires sundry notices for well work. The Nevada Division of Environmental Protection (NDEP) grants permits for and oversees underground injection. The Navy and BLM would also require safety and digging permits along with an oil spill manifest. The Navy also requires use of the Environmental Compliance Assessment, Training, and Tracking System (ECATTS) and requires access requests for non-military personnel. Activities can be pursued concurrently.

**APPENDIX D. UPDATED SITE CHARACTERIZATION DATA  
INVENTORY**

# UPDATED SITE CHARACTERIZATION DATA INVENTORY

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Fallon, NV

## NAS FALLON



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## UPDATED SITE CHARACTERIZATION DATA INVENTORY

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### Fallon, Nevada

Site characterization at Fallon, NV, and construction of the Fallon 3D geologic model synthesized all available surface and subsurface data. These data include downhole lithologic data interpreted from core, cuttings, and mud logs; downhole image log and geophysical data; digital elevation data; geologic map data; petrographic data; geologic cross-sections, gravity, and magnetic data; magnetotelluric data; downhole temperature data; shallow temperature data; well testing data; seismic reflection data; and seismicity data.

Data used in construction of the 3D geologic model for the Fallon site is represented in Table 1, below.

**Table 1. Data used in construction of the 3D geologic model for the Fallon site.**

<b>Data Description</b>	<b>File Name</b>	<b>Date Uploaded</b>
x,y,z downhole temperature data for wells in and around the Fallon FORGE site	FallonFORGEWellTemps.txt	4/21/2016
3D model range, FORGE site outline	FallonFORGEGISPolygons.zip	4/21/2016
x,y,z text file of the downhole lithologic interpretations in the wells in and around the Fallon FORGE site	FallonFORGEWellLithologies.txt	4/21/2016
Temperature log from well 17-16	17-16_TEMP.pdf	3/31/2016
Mud log from well 13-36	13-36_mudlog.tif	3/31/2016
Mud log from well 35A-11	35A-11_mudlog.tif	3/31/2016
FORGE area GIS polygons	FORGE boundary layers.lpk	3/31/2016
Mud log from well 86-15	86-15_mudlog.tif	3/31/2016
Temperature log from 35A-11	35A-11_temp.tif	3/31/2016
Temperature log from 34-33	34-33_temp.tif	3/31/2016
Mud log from well 78-36	78-36_mudlog.tif	3/31/2016
Digital elevation model	Nevada DEM	3/31/2016
Geologic map of Nevada	Geologic Map of Nevada	3/31/2016
Geologic Map of the Bunejug Mountains Quadrangle Churchill County Nevada	Geologic Map of the Bunejug Mountains Quadrangle Churchill County Nevada	3/31/2016
Geologic Map of the Lahontan Mountains Quadrangle Churchill County Nevada	Geologic Map of the Lahontan Mountains Quadrangle Churchill County Nevada	3/31/2016
Geologic Map of Grimes Point Quadrangle Churchill County Nevada	Geologic Map of Grimes Point Quadrangle Churchill County Nevada	3/31/2016
Hydrogeology at Fallon	Maurer and Welch 2001	3/31/2016
Major Carson Sink roads	NDOT major roadways	3/31/2016
GIS data	Fallon_FORGE_GDR.mpk	3/31/2016
Flow test from well FOH-3	FOH-3 Flow Test.xls	3/31/2016
EQ hypocenters	USGS Query_EQs.csv	3/31/2016
Temperature pressure log from well 61-36	61-36_WellTempPressLog.xlsx	3/31/2016
Survey of well 61-36	61_36Survey_TGHBHT.xlsx	3/31/2016
2 meter temperature probe data	2mTemperatureProbe.zip	3/31/2016
Pressure log from well 13-36	13-36_BHP.zip	3/31/2016
Temperature log from 13-36	13-36_TEMP.zip	3/31/2016
Well survey from well 13-36	13-36_XMAC.zip	3/31/2016

<b>Data Description</b>	<b>File Name</b>	<b>Date Uploaded</b>
Survey of well 13-36	13-36_SURVEY.zip	3/31/2016
Mud log from well 47A-11	47A-11_MUDLOG.zip	3/31/2016
Mud log from well 51A-20	51A-20_MUDLOG.zip	3/31/2016
Mud log from well 56A-14	56A-14_MUDLOG.zip	3/31/2016
Mud log from well 58A-9	58A-9_MUDLOG.zip	3/31/2016
Mud log from well 14-1	14-1_MUDLOG.zip	3/31/2016
Temperature log from well 78-36	78-36_TEMP.zip	3/31/2016
Mud log from well 17-16	17-16_MUDLOG.zip	3/31/2016
Mud log from well 61-36	61-36_MUDLOG.zip	3/31/2016
Mud log from well 62-15	62-15_MUDLOG.zip	3/31/2016
Well test from well 82-36	82-36 well test.zip	3/31/2016
Temperature pressure log from well 84-31	84-31_PT.zip	3/31/2016
Temperature pressure log from well 82-36	82-36 PT logs.zip	3/31/2016
Temperature log from well 8431	84-31_TEMP.zip	3/31/2016
Mud log from well 86-25	86-25_MUDLOG.zip	3/31/2016
Gamma log from well 86A-15	86A-15_SEMBLANCE_GAMMA.zip	3/31/2016
Mud log from well 84-31	84-31_MUDLOG.zip	3/31/2016
Sonic log from well 17-16	17-16_SONICWAVE.zip	3/31/2016
Mud log from well 86A-15	86A-15_MUDLOG.zip	3/31/2016
Fallon area well collars	FORGE area wells.zip	3/31/2016
Heat flow data	HeatFlow.zip	3/31/2016
Temperature log from well FOH-3	FOH-3_TEMP.zip	3/31/2016
Siesmic reflection profiles	NavySeismicLines.zip	3/31/2016
Radiogenic heat data	Radiogenic_Heat_Generation.zip	3/31/2016
Temperature gradient data	Temperature_Gradient_Measurements.zip	3/31/2016
Magnetotelluric data	MT.zip	3/31/2016
Mud log from well 34-33	34-33_MUDLOG.zip	3/31/2016
Mud log from well 88-24	88-24_MUDLOG.zip	3/31/2016
Mud log from well FOH-3	FOH3_MUDLOG.zip	3/31/2016
Mud log from well 82-36	82-36_MUDLOG.zip	3/31/2016

## **APPENDIX E. UPDATED PERMITTING INVENTORY**

# UPDATED PERMITTING INVENTORY

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Fallon, NV

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## UPDATED PERMITTING INVENTORY

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### Fallon, NV

The original Permitting Inventory was initially submitted under our response to the Funding Opportunity Announcement (DE-FOA-0000890). All new data or updates to existing data generated during Phase 1 that support the Environmental Information Synopsis and the ability to meet NEPA and other permitting/regulatory compliance requirements by the end of Phase 2B area are reflected in this update.

No new permits have been issued for the proposed Fallon FORGE site during Phase 1 activities. Multiple discussions between all lease holders involved have occurred to ensure that all parties understand the commitment to the project and the potential for utilization of the lands for future phases of FORGE. These meetings are documented in the community outreach section of the Topical Report. All permits, as agreed upon by the parties involved, will be issued by the Navy for work in Phase 2B.

Below is the Permitting Inventory modified after the initial FOA submission. This inventory is subject to revisions throughout this project and will be updated as necessary.

### **SURFACE OWNERSHIP**

Ownership:

- BLM: Ormat leased land, 3 leases (MVN-079104, MVN-079105, MVN-079106), two parcels of purchased private
- DOD: Fallon Naval Air Station

Total acreage of proposed site (see Appendix A, site map):

Main FORGE site = 1115 acres (387 Ormat leased or owned, 728 NAS)

Total acreage available for monitoring = 9856 acres (3842 Ormat leased or owned plus 6014 NAS, exclusive of Main FORGE site and areas of No Surface Occupancy.

Within the Ormat leases, the area of No Surface Occupancy is part of the National Historic Preservation Act and access, if needed, would require additional approval from BLM and the impacted parties. Within the NAS areas of No Surface Occupancy are defined by the Naval Air Strip and Fly Zones and are non-negotiable.

Total acreage components:

- Contiguous sections: all land positions are contiguous
- Parcels that can be combined (please describe): All three Ormat leases have been unitized (see Bunejug Unit Agreement, Appendix E)

## ENVIRONMENTAL AND CULTURAL CONDITIONS

Existing environmental activities:

- Environmental Impact Statement complete (see Ormat/Navy EIS and the NASF Category Exclusion Agreement)

Nearby population center density: Fallon, NV 8,390 people

- Distance: 12 km

Nearby wildlife habitats (endangered species / habitat): Desert ecology, riparian, seasonal wetlands, migratory bird flyways (~5-8 km)

Nearby scenic vistas: Grimes Point (~5 km)

Nearby Areas of Critical Environmental Concern or Wilderness Areas: Stillwater National Wild Life Refuge (~8 km)

Nearby wetlands or scenic waterways: Stillwater National Wild Life Refuge (~8 km)

Nearby Native American Tribes: Paiute-Shoshone at Fallon Indian Reservation (~15 km) and Walker River Indian Reservation (~40 km)

Potential for landslides, or excessive subsidence as a result of induced seismic activity: none

Existence of historic structures or identified cultural resources in the immediate vicinity of the proposed project area: Grimes Point National Recreation Trail (~5 km)

A review of any potential issues associated with the National Historic Preservation Act (NHPA):

Within the northeast sector of the Ormat leased land there is an area designated “No Surface Occupancy.” This area falls under the NHPA. If there becomes a need for surface occupancy for FORGE related activity, the No Surface Occupancy contingency may be revised if the BLM, with Native American consultation, and the FORGE operator both agree on access and access restrictions related to the particular need.

An indication of whether public opposition is likely (i.e., letters of support from local municipalities or County, negative or positive press surrounding existing development at the proposed site): Given the prior geothermal activities on the Ormat leased land and the NASF, there is no indication of potential public opposition. Prior to initiating activities at the FORGE site an extensive public outreach campaign will be conducted.

## PERMITTING STATUS

Approved well permits:

- Drilled and not commercial

Ormat leases: Two wells drilled: 84-31 and 18-5. These wells were drilled and completed under approved existing permits.

NAS: Five exploration wells were drilled by the Navy GPO and one by Ormat for the Navy GPO: 82-36 (drilled by Ormat), FOH-3D, 61-36, 88-24, 86-25, and 82-19. The Navy GPO has been doing work at the Naval Air Station Fallon since the early 1990's, but recent exploration ramped back up in 2012. This included the acquisition of geophysical surveys, the deepening of an existing exploration hole, drilling out the mud in another existing hole, the drilling of 9 shallow temperature gradient holes and 5 intermediate to deep exploration holes. This work was performed under a Category Exclusion Agreement and the Ormat/NASF EIS. However, future activities for the FORGE project would require a new NEPA agreement with the NASF installation which would take at most 4 months. The NASF installation itself will need to provide approval, which could take at most 6 months, concurrent with the NEPA approval. Other permits acquired to perform these geothermal exploration techniques:

Necessary Permitting	Time Period to Acquire
FAA Permit	45 days
NDEP UIC Permit	4 months
NDOM drilling permit	2 weeks
Drilling Permit	1 Month
DNA	1 – 2 Months
Dig Permit	1 month
CATEX	1 month
Access Request Form from Navy	2 weeks
Utility Locate	2 weeks
ECATTS Training	1 day
Oil Spill Manifest	1 day

## MINERAL RIGHTS

Mineral rights ownership:

- Federal

## LEASE STATUS

The Navy properties that make up the Fallon FORGE site are primarily Fee Simple lands, where the Navy owns all surface and subsurface rights. The project lands controlled by Ormat held under BLM leases for Geothermal Resources in Unit Areas N79104, N79105, N79106) with total size of 7426 acres. All three leases were unitized on May 14, 2009. The Ormat leases expire on 8/30/2016. In accordance with the lease agreements, all three leases can be extended for an additional 5 years without any work being performed on the leased land. Or as long as there is activity/work (e.g., FORGE) being performed on a lease and payments are current, the leases are extended indefinitely. Evidence of activity is currently being gathered to process the extension.

## **WATER AVAILABILITY**

Water availability on site: Geothermal water for re-injection/stimulation is available from Well 84-31, located due east from the Main FORGE site within Ormat lease MVN-079104. Flow tests indicate a potential capacity of ~600 gpm. If re-injection continues or is expected to continue beyond 30 days, a UIC (Underground Injection Control) permit will be requested. However, any well used for stimulation/injection at the FORGE site will be required to have a UIC permit. Additional water rights would be purchased from an existing water canal right owner, as needed. The canal flows through the Ormat leased land.

Water availability at 1.5 km (Well 84-31) distance or possibly one of the Navy wells to the north (e.g., 88-24).

- Status of existing infrastructure to transport water: Pipeline will have to be constructed to provide water from 84-31. Pipeline would be contained within the FORGE site.
- Potential barriers to development of transport infrastructure: None.

Water rights (select those that apply and describe):

- Included/secured with land/lease deal: In Nevada, geothermal water from 84-31 can be used for re-injection without water rights.
- Can be purchased easily: Non-potable water for daily operations at the site will be purchased from one of several local commercial suppliers that Ormat has used and delivered by truck to the site and stored in surface tanks. Potable water will be purchased from Culligan or a similar supplier.

Other local water demands for agricultural or other purpose: Area is used for grazing and agriculture.

## **STATE AND LOCAL REGULATIONS**

Solid waste disposal standards: Trash must be brought to a dump, recyclable material must be properly recycled (metal scraps, aluminum).

Noise standards: See (Appendix C).

Air quality standards: See (Appendix C).

Drinking water and aquatic life protection: See attached (Appendix C).

## **TRANSMISSION ACCESSIBILITY**

Proximity to transmission and distribution infrastructure: The project location is within close proximity to multiple potential interconnection points and existing transmission infrastructure (~8 km away). This infrastructure is available for additional interconnection and transmission through the utility's (NV Energy) standard processes.

## **YEAR-ROUND ACCESSIBILITY**

Year round access (weather): All access roads are accessible and drivable all year round.

**APPENDIX F. DATA DISSEMINATION AND INTELLECTUAL  
PROPERTY PLAN**

# DATA DISSEMINATION AND INTELLECTUAL PROPERTY PLAN

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Fallon, NV

## NAS FALLON



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# DATA DISSEMINATION AND INTELLECTUAL PROPERTY PLAN

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Fallon, NV

## DATA DISSEMINATION APPROACH AND NGDS NODE DEVELOPMENT

### OVERVIEW

A data system/Node that is compatible with the NGDS will be developed in Phase 2 of the Fallon, NV, FORGE project. The Node will be a public, web-accessible interface to the NGDS that allows for structured uploading of Fallon FORGE project data. It will include appropriate options for establishment of a remote web server, a Node, and appropriate interfaces and processes for connection to the NGDS through the central aggregator. FORGE Node site maintenance and operations will be the responsibility of the Fallon FORGE Site Management Team (SMT) which will employ expertise within our institutions for node development and contracted expertise, if required. Data generated during the course of the project, either by the Fallon FORGE Team, competitively selected R&D projects, or others associated with the Fallon FORGE site will be submitted to the FORGE Node. All projects will be required to sign a letter of commitment to upload all data acquired in conjunction with the Fallon FORGE site. Data submitted to the Geothermal Data Repository before the FORGE Node is operational will be ported to the FORGE Node. The data dissemination plan is described below.

### DATA DISSEMINATION PLAN

A high priority goal of our Fallon FORGE project team is to ensure that all data acquired in conjunction with the site be made available to the public in as close to real time as possible. A second high priority goal is to ensure that posted data is of high quality. The guidelines for data dissemination and quality control will depend on the type of data. We have identified four types of data that will be acquired in association with the Fallon FORGE site:

1. Data that supports metadata:  
All levels of Fallon FORGE data products will have appropriate metadata available to enable users to make full use of the data or data products. Some metadata will be included with the observational data by the data loggers. Other kinds of metadata will include data quality measurements made by the FORGE team, data analysis parameters and such base parameters as the latitude, longitude and elevation of FORGE instrumentation.
2. Data acquired by the SMT for site characterization, monitoring, and R&D
3. Data acquired in conjunction with DOE FOA funded R&D projects and data acquired by International Partners that provide their own R&D funding
4. Data acquired under previously agreed upon Intellectual Property protections

All acquired data, independent of type, will be uploaded or linked to the FORGE node in near real-time, as governed by processing constraints. An example of data that will not be stored on the FORGE node is microseismic monitoring data—these data will be uploaded in real time to an LBNL server dedicated to induced seismicity. The FORGE node will provide a link to these data sets. Other continuous, large volume data sets may be handled in a similar manner. To protect the scientific integrity of the project PIs, the near real-time data uploaded to the FORGE node will have an identifying “tag” indicating that the data has not been vetted for quality control. Quality control of the data will be the responsibility of the generator. Following the upload of near real time data, the project PIs will have a four- month window in which to vet their data and, if necessary, upload revisions to the FORGE node. Data revised during the four-month vetting period will be identified by a “tag” indicating that the data has undergone quality control review and is considered to be of high quality and reliable. Data not revised during the four-month period will also be considered to be of high quality and reliable, but will be tagged to indicate that there were no revisions to the originally submitted data. There will be two exceptions. First, all data acquired by the SMT (Type 1 and 2) will be continuously vetted and updated on the FORGE node. The goal is to ensure that outside PIs or potential PIs have the most up to date information regarding the characteristics and monitoring of the FORGE site to facilitate their research and/or to help develop a research project in response to an R&D solicitation. The second exception involves data identified as protected by an Intellectual Property (IP) agreement (Type 4). Any agreements establishing IP protected data will be made in collaboration with the project leads generating the data and with the SMT, STAT, and DOE. Access to data uploaded to the FORGE node that is IP protected will remain the exclusive right of the generator for a period of five years during which time it will be password protected.

To conduct research at the Fallon FORGE site or in conjunction with the Fallon FORGE project, project leads will agree to and sign a letter of commitment to abide by the data dissemination and quality control plan defined above. In the case of a FOA call for R&D issued by DOE, acceptance of responses will be contingent upon the inclusion of the signed letter of commitment in the FOA response. For non-DOE funded projects, such as collaborations with international partners or private sector stakeholders, prior to approval of such projects by the SMT, STAT and DOE, the signed letter of commitment must be provided by the project leads.

## **NGDS NODE DEVELOPMENT**

### **DATA NODE HARDWARE**

A NGDS compliant FORGE node will be deployed on the Amazon Web Services (AWS) cloud. AWS is the leading cloud provider, offering a secure, reliable, and scalable computing environment. There are many computing services provided by AWS; for data node development the Elastic Compute Cloud (EC2) will provide all the computing resources necessary. An EC2 instance with 4 CPUs, 32 GB or RAM, and 6 TB of storage will be used for the initial deployment.

### **DATA NODE SOFTWARE**

The software package “Node-in-a-Box” (NIAB) available through the NDGS will be used to implement the FORGE data node software services. NIAB was developed under the NGDS

Architecture, Design, and Testing Project to allow for the easy deployment of a NGDS compliant data node. NIAB is based on open source standards and extends a storage management product called CKAN. NIAB provides the entire software infrastructure for hosting a NGDS compliant node which includes the ability to upload structured and unstructured data sets through a web interface, publish metadata information about the data sets to the central aggregator node, manage data sets and metadata over time, and host web services to expose highly structured data sets (Tier 3). NIAB is a stable platform and has been successfully deployed by number of government institutions. While a custom NGDS solution could be implemented it would be expensive and one would lose many of the benefits of using an open source solution. Functionality that is desired but not currently available in NIAB can be added by anyone and those added features will be made available to everyone.

### DATA SUBMISSION

Metadata describing the data sets is a critical step in making data available to the greater scientific community. The NGDS aggregator node will harvest the metadata records stored on our data node and add those records to the NGDS Catalog. Every data set (resource) uploaded to the data node will have associated metadata that describes the contents of the data set. The metadata will conform to the NGDS standards and all required fields will be populated.

Data sets uploaded to the data node (NIAB) will fall into one of three categories:

- Tier 1 – Data that is unstructured (text, images, etc.).
- Tier 2 – Data that has some structure by does not conform to NGDS content model.
- Tier 3 – Data that is highly structured and can be validated against NGDS content model schemas.

When data is uploaded through the web interface it will be marked at the appropriate category level. Tier 3 data is structured as Excel spreadsheets and must conform to one of the NGDS content model definitions. Excel templates for Tier 3 data can be found at <http://schemas.usgin.org/models/>. Before uploading Tier 3 data to the node it will be validated at <http://schemas.usgin.org/validate/cm>. Once the appropriately structured data is successfully validated it can be uploaded to the data node as Tier 3 data. After it uploads, Tier 3 data can be published as an Open Geospatial Consortium (OGC) web service. We will encourage funded principal investigators to upload to the FORGE node data sets (resources) that conform to Tier 3 standards and which will then be made available as OGC web services (WFS or WMS).

### IMPROVEMENT TO NIAB

While the NIAB provides all the capability to be a NGDS compliant data node it does lack some features. Specific to this plan will be the ability to limit the access to a data set for a given period of time (moratorium) and flags for data vetting (QA) by PIs which are not currently available. Since NIAB and CKAN is open source it will be possible to modify code to add these or other features that may become necessary. The Scrum methodology will be used to manage the software project effort. Scrum enforces iterative and incremental development and promotes daily face-to-face communication between all team members. At the end of each iteration, typically 2-4 weeks, the current state of the software being developed is presented in a demo to all stakeholders. This promotes continuous feedback from the customers/stakeholders to ensure

a quality software system is delivered at the end of the development effort. All developed software will have design documents, be fully commented, reviewed by peers, and unit tested.

## **INTELLECTUAL PROPERTY (IP) MANAGEMENT**

As a Federally Funded Research and Development Center, Sandia National Laboratories has protocols in place to address IP issues and has rights to technical data. Prior to any agreement with a funded contractor, any issues related to IP and data rights will be negotiated and plans will be developed as part of the contractual agreement. The template for the IP and data plan agreement between the Sandia Corporation and a company is provided in the following Attachment.

## ATTACHMENT

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### INTELLECTUAL PROPERTY AND TECHNICAL DATA MANAGEMENT PLAN BETWEEN SANDIA CORPORATION and COMPANY

This Intellectual Property Management Plan (the “IP Management Plan”) is effective as of the date of the last signature (the “Effective Date”) by Sandia Corporation (“Sandia”), manager and operator of Sandia National Laboratories (“SNL”) for the United States Department of Energy (“DOE”) under contract DE-AC04-94AL85000 (the “Prime Contract”), a Delaware corporation whose principal place of business is located in Albuquerque, New Mexico, and \_\_\_\_\_ (“\_\_\_\_\_”) located at \_\_\_\_\_ (individually, “Party” and collectively, “Parties”). Terms in this IP Management Plan that are capitalized have the meanings set forth in Exhibit A of this IP Management Plan.

#### **I. Background**

1. This IP Management Plan is established to govern the management and disposition of INTELLECTUAL PROPERTY directly resulting from joint research and/or development between Sandia and \_\_\_\_\_ directed to \_\_\_\_\_ (the “Joint Work”).
2. The IP Management Plan objectives include:
  - a. Promoting the patenting, licensing, and rapid commercialization of SUBJECT INVENTIONS when the public good is best served by controlling the activities of those commercializing the SUBJECT INVENTIONS and/or by providing economic rewards necessary to encourage commercial partners to make the investment required to move an early stage technology to the market, and
  - b. Promoting the rapid dissemination of breakthrough scientific discoveries and technological innovations for the public good.
3. All actions by Sandia documented in this IP Management Plan are subject to available funding from DOE to Sandia.
4. This IP Management Plan shall not be used to obligate or commit funds or as the basis for the transfer of funds. This IP Management Plan does not commit any Party to take any actions; the actions of each Party are independent of the actions of the

other Party. In no event shall either Party be required to perform work outside the scope of the Joint Work.

5. Each Party will bear all costs, risks and liabilities incurred by it arising out of efforts under this IP Management Plan, and neither Party shall have any right to any reimbursement, payment or compensation of any kind from the other hereunder.

## **II. Title to SUBJECT INVENTIONS and Other PROJECT INTELLECTUAL PROPERTY**

1. Inventorship or authorship of PROJECT INTELLECTUAL PROPERTY and PROJECT TECHNICAL DATA will be determined in accordance with applicable U.S. patent, trademark and copyright law and any corresponding state laws.
2. Each Party shall retain title to their BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY used during the Joint Work. Each Party's BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY shall be identified as such and shall contain such proprietary markings pursuant to any separate non-disclosure agreement(s) governing such disclosures between the Parties.
3. The U.S. Government will not normally require delivery of confidential or trade secret-type BACKGROUND TECHNICAL DATA developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.
4. The U.S. Government retains unlimited rights in PROJECT TECHNICAL DATA produced under Government financial assistance awards, including the right to distribute to the public. One exception to the foregoing is that invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.
5. Each Party shall have the right to use the other Party's PROJECT TECHNICAL DATA, and PROJECT INTELLECTUAL PROPERTY along with the related BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY identified in Exhibit B for the sole purpose of carrying out the Joint Work, but may not disclose the other Party's PROJECT TECHNICAL DATA, PROJECT INTELLECTUAL PROPERTY, BACKGROUND INTELLECTUAL PROPERTY and BACKGROUND TECHNICAL DATA to any person or third party except with written permission of the other Party and under suitable confidentiality obligations pursuant to a separately executed non-disclosure agreement. Each Party shall establish and implement specific measures and protocol to protect such information and data from disclosure. Exhibit B will be amended to

include additional BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY that the Participants mutually agree is relevant to accomplish the Joint Work.

6. Each Party shall solely own SUBJECT INVENTIONS and other PROJECT INTELLECTUAL PROPERTY developed solely by its employees and agents and shall obtain patent protection for SUBJECT INVENTIONS at its sole discretion.
7. SUBJECT INVENTIONS and PROJECT INTELLECTUAL PROPERTY and PROJECT TECHNICAL DATA jointly developed by the Parties shall be jointly owned by the Parties. Any jointly developed SUBJECT INVENTIONS and/or PROJECT TECHNICAL DATA may be protected by one or more patent applications filed by either Party. The Party filing the patent application directed to jointly developed SUBJECT INVENTIONS and/or PROJECT TECHNICAL DATA shall notify the other Party in a timely manner.
8. Unless agreed to otherwise, the Party filing a patent application on a SUBJECT INVENTION and/or PROJECT TECHNICAL DATA, whether solely or jointly owned, shall pay all preparation and filing expenses, prosecution fees, issuance fees, post issuance fees, patent maintenance fees, annuities, interference expenses, and attorneys' fees for that patent application and any resulting patent(s). The Parties will use all reasonable efforts to cooperate with each other with respect to the preparing, filing and prosecuting any such patent applications.
9. Upon at least two weeks' notice to the other Party, any Party will be free to submit for publication the results of PROJECT INTELLECTUAL PROPERTY and PROJECT TECHNICAL DATA that the Party solely owns, provided due consideration is given to protection of patentable subject matter.

### **III. Licensing of SUBJECT INVENTIONS and PROJECT INTELLECTUAL PROPERTY**

1. The Parties may enter into one or more separate agreements to facilitate the filing of patent applications and/or licensing of the jointly developed SUBJECT INVENTIONS and PROJECT INTELLECTUAL PROPERTY and PROJECT TECHNICAL DATA. Any such license that a Party may grant shall be subject to a reservation of certain rights to the Federal Government, which include Government use rights, march-in rights and U.S. Competitiveness.
2. Any license pursuant to Section III.1 that a Party may grant will reserve the option to permit private or public educational institutions to use the jointly developed SUBJECT INVENTIONS and PROJECT INTELLECTUAL PROPERTY on a royalty-free basis for

research, development and/or education, but not for commercial purposes, subject to confidentiality requirements. Sandia shall also retain the right to non-exclusively license the SUBJECT INVENTIONS and PROJECT INTELLECTUAL PROPERTY and PROJECT TECHNICAL DATA that it solely and jointly owns as background intellectual property to cooperative research and development agreement (“CRADA”) participants and work for others agreement (“WFO”) sponsors.

#### **IV. Warranties and Representations**

1. Nothing in this IP Management Plan shall be construed as:
  - a. a warranty or representation by either Party as to the validity or scope of any right included in the BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY;
  - b. an obligation to furnish any information beyond that listed in the BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY; or
  - c. creating in either Party any right, title or interest in or to the inventions, patents, technical data, computer software or software documentation solely owned by the other Party.
2. Disclaimer. ALL INFORMATION, TESTS AND RESULTS BY EITHER PARTY ARE PROVIDED “AS IS”, AND NEITHER PARTY MAKES ANY REPRESENTATIONS, WARRANTIES OR GUARANTEES OF ANY KIND, EXPRESS OR IMPLIED, REGARDING ANY SERVICES, INFORMATION, TESTS OR RESULTS, INCLUDING WITHOUT LIMITATION ANY WARRANTIES OF TITLE, MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, RESULT, USE, OR NON-INFRINGEMENT THEREOF.
3. Limitation of Liability. In no event shall either Party be liable to the other for any punitive, exemplary, special, incidental, consequential or other indirect damages (including, but not limited to, lost profits, lost revenues and lost business opportunities) arising out of or relating to this IP Management Plan, regardless of the legal theory under which such damages are sought, and even if the Parties have been advised of the possibility of such damages or loss.

#### **V. Term/Termination**

1. This IP Management Plan shall commence on the Effective Date and continue until completion of the Joint Work, unless terminated earlier in accordance with this IP Management Plan.

2. Either Party may terminate this IP Management Plan for any reason upon at least sixty (60) days written notice (“Notice of Termination”) to the other Party. Should the IP Management Plan be terminated prior to completion of the Joint Work, the Parties may continue to use the other Party’s PROJECT TECHNICAL DATA, and PROJECT INTELLECTUAL PROPERTY along with the BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY listed in Exhibit B solely to the extent needed to complete the Joint Work.
3. Sections IV, VI, VII and VIII and obligations regarding confidentiality shall survive the termination or expiration of the IP Management Plan.

## **VI. United States Government Interests**

1. It is understood that the United States Government (through any of its agencies or otherwise) has funded research, Contract No. DE-AC04-94AL85000 - United States DOE’s National Nuclear Security Administration, during the course of or under which any of the PROJECT INTELLECTUAL PROPERTY was conceived or made. The United States Government is entitled, as a right, to a non-exclusive, non-transferable, irrevocable, paid-up license to practice or have practiced the PROJECT INTELLECTUAL PROPERTY for governmental purposes. The Parties also agree and understand that the United States Government retains “march-in” rights, in accordance with the procedures set forth in 37 CFR 401.6 and any supplemental regulations promulgated by the DOE.

## **VII. Dispute Resolution**

1. Any dispute between the Parties relating to the management of Project Intellectual Property, as provided for in this IP Management Plan, or to the interpretation of this IP Management Plan, shall be referred to the Parties’ respective officers, as designated below. Through the designated officers, the Parties agree to first attempt informal resolution of disputes, within a reasonable period of time and in a fair and equitable manner, taking into consideration the objectives of the Joint Work and any laws, statutes, rules, regulations or guidelines to which the involved Parties are subject.

The designated officers and their contact information are as follows:

**For Sandia:**

Name:

Address:

Telephone:

Email:

**For \_\_\_\_\_:**

Name:

Address:

Telephone:

Email:

2. If the designated officers are unable to resolve the issues presented before them, and if the dispute cannot be settled through negotiation, the Parties agree first to try in good faith to settle the dispute by mediation administered by the American Arbitration Association under its Commercial Mediation Procedures before resorting to arbitration, litigation, or some other dispute resolution. If within 30 days after service of a written demand for mediation, the mediation does not result in settlement of the dispute, then any unresolved issues shall be settled by arbitration administered by the American Arbitration Association in accordance with its Commercial Arbitration Rules, and judgment on the award rendered by the arbitrator(s) may be entered in any court having jurisdiction thereof.

**VIII. Miscellaneous**

1. Except as provided herein, any commitment of funds, intellectual property rights, disclosure of proprietary information, or other resources needed to carry out the objectives set forth herein shall be made under separate agreements.
2. It is understood that any work done or actions taken by Sandia must be in accordance with the terms and conditions of the Prime Contract between Sandia and the DOE for the operation of SNL; and must be in accordance with any successor contracts for the operation of SNL. In the case of any conflict between this IP Management Plan and the Prime Contract for the operation of Sandia, the Prime Contract shall take precedence.
3. This IP Management Plan shall be construed in accordance with the laws of the State of Delaware.

4. The Parties hereto are independent contractors and not joint venturers or partners.
5. The Parties acknowledge that they are subject to and agree to abide by the United States laws and regulations (including the Export Administration Act of 1979 and Arms Export Control Act) controlling the export of technical data, computer software, laboratory prototypes, biological material, and other commodities. The transfer of such items may require a license from the cognizant agency of the U.S. Government or written assurances that it shall not export such items to certain foreign countries and/or foreign persons without prior approval of such agency. Neither Party represents that a license is or is not required or that, if required, it shall be issued.
6. This IP Management Plan incorporates by reference **Exhibits A and B** [below] and embodies the entire understanding between the Parties with reference to the subject matter hereof, and no statements or agreements by or between the Parties, whether orally or in writing, except as provided for elsewhere in Section VI, made prior to or at the signing hereof, shall vary or modify the written terms of this IP Management Plan. Neither Party shall claim any amendment, modification, or release from any provisions of this IP Management Plan by mutual agreement, acknowledgment, or otherwise, unless such mutual agreement is in writing, signed by the Parties, and specifically states that it is an amendment to this IP Management Plan.
7. Neither Party shall use the name of the other Party or the name of any employee thereof in any sales promotion, advertising, or any other form of publicity without the prior written approval of the other Party.

IN WITNESS THEREOF, the parties hereto have executed or approved this IP Management Plan on the dates below their signatures.

COMPANY NAME

SANDIA CORPORATION

By: \_\_\_\_\_

By: \_\_\_\_\_

Date: \_\_\_\_\_

Date: \_\_\_\_\_

Name:

Name:

Title:

Title: Senior Manager, Industry Partnerships

## **EXHIBIT A**

### **Definitions:**

1. “BACKGROUND INTELLECTUAL PROPERTY” means the INTELLECTUAL PROPERTY identified by the Parties that was in existence prior to or is first produced outside of the Joint Work and is necessary for the performance of the Joint Work. BACKGROUND INTELLECTUAL PROPERTY may also include trade secrets of the Parties that were in existence prior to or are first produced by the Parties outside of work under this IP Management Plan to the extent that such trade secrets do not otherwise constitute or become SUBJECT INVENTIONS as defined herein.
2. “BACKGROUND TECHNICAL DATA” means information, in hard copy or in electronic form, including, without limitation, documents, drawings, models, designs, data memoranda, tapes, records, software and databases developed before or independent of performance under the Award that is necessary for the performance of the Joint Work.
3. “INTELLECTUAL PROPERTY” means technical information, inventions, developments, discoveries, know-how, methods, techniques, formulae, algorithms, data, processes and other proprietary ideas (whether or not patentable or copyrightable). INTELLECTUAL PROPERTY also includes patent applications, patents, copyrights, trademarks, mask works, and any other legally protectable information, including computer software.
4. “INVENTION” means any discovery or a new composition, device, method, system, software, process or design developed from study and experimentation that is or may be patentable or otherwise protectable under Title 35 of the United States Code, or any novel variety of plant that is or may be protected under the Plant Variety Protection Act (7 U.S.C. 2321 et seq.).
5. “PROJECT INTELLECTUAL PROPERTY” means and includes all INTELLECTUAL PROPERTY first conceived, discovered, developed, reduced to practice and/or generated during the performance of the Joint Work.
6. “PROJECT TECHNICAL DATA” means information (in hard copy or in electronic form) including, without limitation: documents, drawings, models, designs, data, memoranda, taps, records, software and databases developed during the performance of the Joint Work.
7. “SUBJECT INVENTION” means any INVENTION of a Party that is conceived or first actually reduced to practice in the performance of the Joint Work.

## EXHIBIT B

### **Sandia's BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY**

Invention Disclosure (SD # \_\_\_\_\_; Company # \_\_\_\_\_)

Title: " \_\_\_\_\_ "

Inventors: \_\_\_\_\_

### **Company's BACKGROUND TECHNICAL DATA and BACKGROUND INTELLECTUAL PROPERTY**

Invention Disclosure (SD # \_\_\_\_\_; Company # \_\_\_\_\_)

Title: " \_\_\_\_\_ "

Inventors: \_\_\_\_\_

## **APPENDIX G. COMMUNICATIONS AND OUTREACH PLAN**

# COMMUNICATIONS AND OUTREACH PLAN

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Fallon, NV

## NAS FALLON



*Geothermal Research  
Observatory*

# COMMUNICATIONS AND OUTREACH PLAN

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## Fallon, Nevada

This document is a comprehensive and innovative plan for communications, education, and outreach to support efforts by the Naval Air Station (NAS) Fallon FORGE project team to maintain sound operations and increase geothermal science and technology literacy.

### INTRODUCTION

The NAS Fallon FORGE project team maintains a fundamental commitment to strategic communications, outreach, and education related to enhanced geothermal systems (EGS) and the FORGE project. Led by Sandia National Laboratories, the team has experience managing large science-based field operations that require substantial communications with stakeholders and partners. We recognize the value of internal and external communications to maintain sound operations. Our strategic outreach efforts, begun in Phase I, will continue into Phases 2 and 3 with a range of activities designed to keep stakeholders informed. We are also committed to a robust education initiative that reaches students in grades K-12 with energy curricula based in science, technology, engineering, and math (STEM) best practices and creates research and development opportunities for undergraduate, graduate, and post-doctoral students. The Fallon FORGE team takes seriously its role in reducing global reliance on fossil fuels and its responsibility for communicating the benefits of research that stimulates the commercial development of EGS systems.

### COMMUNICATIONS GOALS AND OBJECTIVES

- Together with our public and private sector partners, implement a coordinated proactive outreach strategy, consistent with DOE/EERE approved branding, to support the selection and operation of the Fallon, NV, site for Phases 2 and 3.
- Provide communications support for technical teams and future activities.
- Identify and publicize best practices and success stories that will contribute to the development of a collaborative national geothermal strategy.
- Communicate the relevance of EGS to a wider community and educate those who may benefit from its value.
- Communicate the benefits of sharing EGS data and collaborating to share and disseminate EGS and FORGE information, including the results from the Fallon FORGE project.

### PROGRAM BACKGROUND

FORGE, [Frontier Observatory for Research in Geothermal Energy](#), is a U.S. Department of Energy Office of Energy Efficiency and Renewable Energy's (EERE) Geothermal Technologies Office program directed at establishing a dedicated site where the subsurface science and engineering community can develop, test and improve technologies in an ideal EGS environment. Essentially, FORGE seeks to implement an underground "rock laboratory" that

will be the target of experimentation that advances EGS technology, vastly increasing the potential for geothermal power production nationwide.

Today, the United States produces about 3.5 gigawatts (GW) of geothermal electricity, which is less than 0.5% of the country’s energy needs. According to the U.S. Geological Survey (USGS), the successful development of EGS techniques would open the door to more than 500GW of geothermal electricity production in the United States. The multi-year FORGE program addresses this potential, and is divided into three phases (see Figure 1). During Phase 1, the site selection process, five locations were selected for continued planning and conceptual geologic modeling. Further down select will occur in Phase 2 in preparation for full site characterization at the selected location. Full implementation of FORGE occurs during Phase 3.

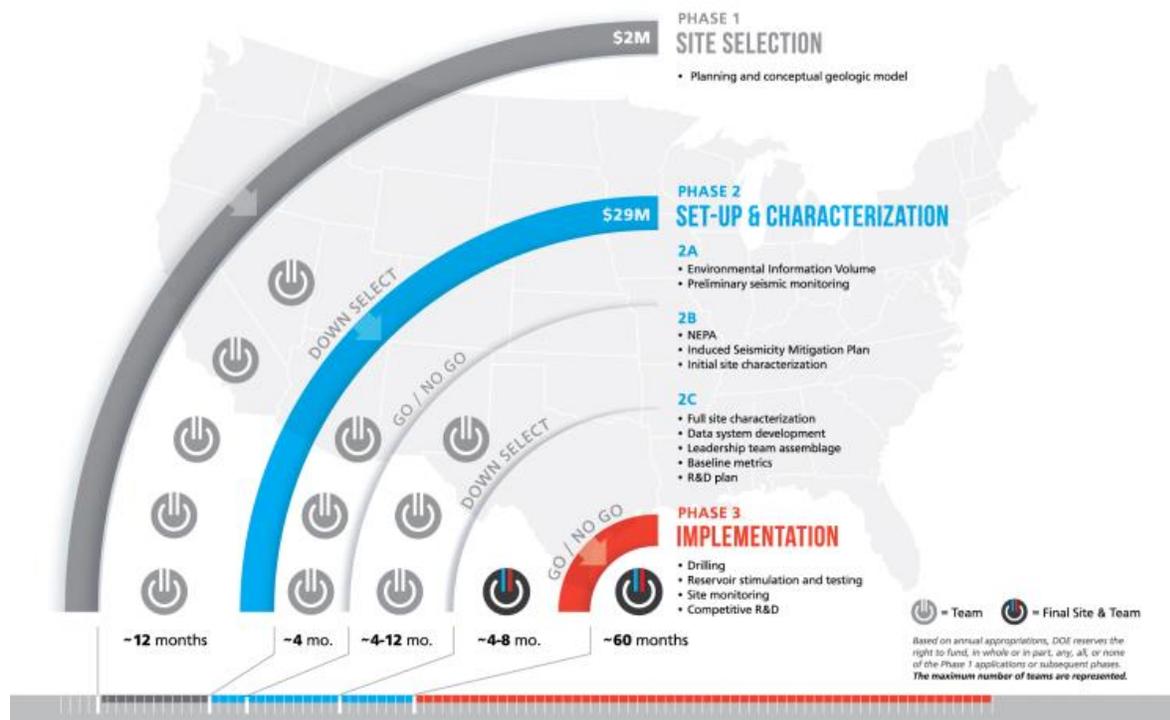


Figure 1. The three phases of FORGE: site selection, characterization, and implementation

## ABOUT THE PROPOSED FALLON FORGE SITE

Today, Nevada generates 600 megawatts (MW) of geothermal power. The USGS estimates Nevada’s geothermal heat resource potential at more than 100,000 MW.

The proposed Fallon FORGE site at the Naval Air Station Fallon (NASF) is one of only five sites selected by DOE for preliminary Phase 1 work. After a competitive further down-select process between Phases 1 and 2, DOE will choose one site (Phase 2c) for the remaining five years of focused Phase 3 FORGE research and development work.

Based on a survey of dozens of areas in the western United States, the Fallon FORGE site was chosen because it has a target zone in crystalline basement rock at depths between 5,000 and 7,500 feet that has temperatures greater than 350°F and low permeability. These characteristics have been determined by DOE to be ideal for implementing the FORGE underground laboratory, where EGS techniques will be developed and tested.

The Fallon FORGE site lies within and adjacent to the Naval Air Station Fallon (NASF) and includes land that has been leased by Ormat Nevada Inc. for geothermal development. More than 45 wells have been drilled for geothermal exploration in the Fallon area. However, no commercially productive geothermal resource has been found; the wells have attractive temperatures, but permeability is low. The Fallon FORGE site includes a 1.7 square mile area where 4 deep exploration wells have already been drilled; this is the area where FORGE drilling and testing activities will occur. An additional 15.4 square miles will be used for instrumentation and monitoring of FORGE activities.

Site characterization, drilling, stimulation, testing, and the results of various subsurface experiments from the Fallon FORGE site will be made available to all interested communities through public data access, news releases, published articles, meetings, and other appropriate venues.

## CRITICAL PROJECT MILESTONES

- Project deliverables: April 27, 2016
- Phase 2 application: May 23, 2016
- Oral presentation to DOE: June 2016

## SITUATIONAL ANALYSIS

The following location-specific topics will be addressed in NAS Fallon communications with target audiences. The team's approach to these topics demonstrates a keen awareness of the Fallon community and acknowledges the importance of public perception related to geothermal energy development.

1. **Water use:** Identify the source(s) of water for the project, estimate how much water will be needed, and predict the impacts, if any, of water consumption on the community and environment.
2. **Induced micro-seismicity (man-made micro-earthquakes):** Define how micro-earthquakes might be induced by injection and production. Address how seismicity is currently monitored and reported in nearby geothermal fields and within the Fallon FORGE area and what type of monitoring will be necessitated by the EGS work. Address the potential impacts of induced micro-seismicity and anticipated mitigations.
3. **Culture and environment:** Identify potential impacts to the environment and known cultural sites in the Fallon FORGE project area and anticipated mitigations.
4. **NASF mission:** Identify any potential impacts to NASF mission and anticipated mitigations.

5. **Community relations:** Identify the local communities likely to be interested in the project and establish a plan to meet their needs for accurate and timely information about the FORGE project.
6. **Education:** In collaboration with NASF, identify educational outreach opportunities for engaging K-12 students and educators. Identify and collaborate with universities. Identify possible internship opportunities through the national laboratories, university partners, and geothermal industry partners.

## TARGET AUDIENCES

Based on the situational analysis and the team's knowledge of the interested parties, we have identified both a primary and secondary audience to which we will target Fallon FORGE communications. These include, broadly, the following:

### Primary audience

- Partners in the Fallon FORGE project (NAS Fallon and others)
- Tribal, State, and local governments and government agencies
- Local communities
- Congressional delegations
- State legislators
- Federal agencies (DOE, DoD, USGS, BLM, Navy)
- U.S. Department of Energy Geothermal Technologies Office (GTO) program managers
- Local water agencies
- Energy research and development (R&D) community, including graduate students
- Geothermal developers
- Public- and private-sector geothermal research community

### Secondary audience

- Public interest and watchdog groups
- Utility companies and transmission system operators
- Nevada Public Utilities Commission
- Local media outlets
- Interested citizens

## KEY MESSAGES

In response to the situational analysis, and recognizing our diverse audience, we propose a set of five key messages and supporting points to address basic concerns and present information about the Fallon FORGE project. The messaging addresses potential economic and environmental impacts and the value of EGS to the local community. The key messages will frame consistent talking points for stakeholder outreach and will be the basis for evolving targeted communications as the project moves from Phase 1 into Phases 2 and 3.

### **1. Sustainable EGS is a valuable addition to the energy supply of the United States and the global community, and FORGE-enabled research is critical to the widespread implementation of EGS.**

- In spite of its resource potential, the technological impediments to widespread development of EGS have limited its role in the U.S. energy mix.
- The Fallon FORGE project will allow for fundamental research and development of new technologies for EGS reservoir creation, characterization, and utilization.
- EGS offers huge potential for power production (USGS mean estimate: 518 GW) with no CO2 emissions and could replace traditional energy sources (coal, gas, and oil generation).
- EGS research contributes to energy security by enabling long-term reliable energy sources with potential for intrastate deployment.
- Technologies developed via FORGE could significantly expand the geothermal industry in the United States.
- EGS can unlock the benefits of geothermal energy as the ultimate renewable source: it is dispatchable, reliable, stable, commercial, and offers the highest level of security for our energy production.
- EGS could provide employment alternatives to traditional energy sector jobs.

### **2. FORGE will help maintain Nevada's position as an international leader in renewable energy.**

- Implementation of technologies developed in the Fallon FORGE may help Nevada achieve its goal of 25% renewable energy by 2025. The USGS estimate of EGS potential in Nevada is more than 100,000 MW.
- The Fallon FORGE project supports the state's reputation as an innovator and opens the door for partnerships with high-tech and other industries in Nevada.
- EGS R&D may demonstrate the technological feasibility of a clean energy source that can be widely deployed.
- Geothermal power is baseload and flexible, valuable qualities for Nevada's future generation resources.

### **3. A world-class EGS research project located at NAS Fallon would be valuable to the local community.**

- Increase the community's visibility
- Provide income for local businesses
- Lead to possible workforce development opportunities
- Broaden K-12 students' knowledge of renewable energy technologies through outreach and field trips
- Offer media training opportunities
- Provide educational opportunities and beneficial experience through student internships

### **4. The U.S. Navy is a strong supporter of FORGE and a leading innovator for national energy security.**

- EGS could be an important source of resilient energy for military bases.
- Feasibility demonstration at NAS Fallon could pave the way for widespread implementation of EGS at other DoD facilities.
- Continued collaboration between DoD and DOE will improve energy security.
- Fallon FORGE project activity will facilitate DoD's mandate to reduce fossil fuel use.
- Use of EGS will expand DoD's geothermal resource base.
- A multi-lab and industry project associated with a DoD facility creates partnership opportunities between other government agencies, local industries, and academia.

### **5. The NAS Fallon site is an excellent proposed location for the FORGE project.**

- Wells are already available, bedrock conditions (crystalline rock) are conducive to relatively easy drilling, and there is abundant local drilling experience.
- Subsurface conditions (geology, temperature) are well known.
- A multi-station seismic monitoring array has been operating for years, with an extensive seismic catalog that has been substantially refined through research by USGS and other organizations.
- High temperatures found at shallow depths reduce drilling costs.
- The project has developed a preliminary water use plan to minimize impact on nearby water users.
- Fundamental environmental work has been performed on both the BLM withdrawn land as well as the existing BLM leases.

## COMMUNICATION TACTICS AND OUTREACH METHODS

The following table outlines the outreach methods (meetings, emails, reports, newsletters, teleconferences, websites, social media, internships, classroom engagements, etc.), a description of the intended audience, conveyed information and material contents, and the frequency of the activities.

**Table 1. Fallon FORGE project communications by method and audience**

Communication Method	Audience Description	Frequency	Responsibility
Face-to-face, Skype, and teleconference meetings with key partners and stakeholder groups	Local officials, congressional staff, research community, etc.	Quarterly or as needed	Tech team
Project web sites with additional resources (video, webinar links, PDF documents)	All targets	Ongoing	Tech team
Email and GovDelivery bulletins/newsletters	DOE, stakeholders, GTO news subscribers (12,000)	Quarterly or as needed	SNL/LBNL Comms, coordinate w/GTO
Publications that support outreach: Fact sheets, infographics, FAQs, etc.	All targets	Available as needed	SNL/LBNL Comms
Social Media (Twitter, Facebook, Periscope) via Lab accounts and stakeholders	All targets	Ongoing	SNL/DOE Comms
Standard briefing packet: PowerPoint presentation template	Primary target	Available as needed	SNL/LBNL Comms
Site Tours	All targets	Monthly or as requested	Tech team
Science education opportunities, curriculum, collaborations with educators to increase geothermal science and technical literacy	K-12 students, teachers, parents	Ongoing	Tech Team, Comms
Professional meetings, targeted conferences/workshops	All targets	As opportunities arise	SNL/LBNL Comms
Industry publications, news releases, blog posts	Research community; e.g., readers of Geothermal Energy Association Weekly and Think Geo Energy Blog	Ongoing	SNL/LBNL Comms
Student internship opportunity (publicize through DOE/EERE Tribal Energy Program)	Undergraduate and graduate students; post-docs; research community; Tribal entities	Annually	SNL/LBNL Comms
Government and industry events, such as Geothermal Energy Association Showcase	Research community/ Congressional staff	Annually	Coordinate w/GTO
Public meetings with updates about workforce development possibilities	Local community	As opportunities arise	Tech Team
Partnering with professional communicators within the Labs and with educational specialists on planning, logistics, technical and legal documentation, etc.	All targets	Ongoing	SNL/LBNL Comms

## FREQUENTLY ASKED QUESTIONS (FAQS)

Based on the key messages, the Fallon FORGE project team has developed a set of FAQs designed to address questions and concerns related to the Fallon site as a location for geothermal research. A subset of the FAQs will be posted on the web site, and the complete set, included below, is also available as a stand-alone document for distribution.

**Table 2. Frequently Asked Questions for the Fallon FORGE project**

<p><b>What is FORGE?</b></p>	<p>FORGE stands for Frontier Observatory for Research in Geothermal Energy. FORGE is a U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Geothermal Technologies Office (GTO) program to investigate potential locations for a national enhanced geothermal systems (EGS) field laboratory. The FORGE program is divided into three phases. During Phase 1, five locations were chosen for continued planning and development of a conceptual geologic model. Fallon is one of the five sites. A down select will occur in Phase 2 in preparation for full site characterization of a single FORGE site that will include required environmental reviews. Full implementation, during Phase 3, will include testing and evaluation of innovative EGS technologies.</p>
<p><b>What are Enhanced Geothermal Systems (EGS)?</b></p>	<p><a href="#">Conventional geothermal systems</a> are located in areas where high subsurface heat, permeable rock, and underground fluid all naturally coexist. These three conditions interact to create a natural underground heat exchanger that transfers heat from the rock to the moving fluids, allowing recovery of the earth’s energy (by drilling wells and producing hot water, steam, or both) to generate electricity. Nearly all geothermal power produced worldwide is supplied by conventional geothermal reservoirs.</p> <p>By contrast, EGS are hot, but with low permeability and a low fluid content. Once an EGS heat source is located—typically in deep, hard rock—researchers drill deep wells and hydraulically stimulate the underground rock to increase permeability, thus creating a geothermal reservoir. Water injected into one or more wells passes through the zone of enhanced permeability, picking up heat along the way, and is extracted in a production well. After reaching the surface, the hot water and/or steam is used to produce power in the same way as in conventional geothermal systems.</p> <p>The practice of manipulating pre-existing fractures in the subsurface to enhance permeability, key to EGS, is a subject of active research in the U.S. and other countries.</p>
<p><b>Who are the key players?</b></p>	<p>With funding from the U.S. Department of Energy’s Geothermal Technologies Office (GTO), the Fallon FORGE project has a team of geothermal experts led by Sandia National Laboratories. The U.S. Navy, led by the Navy Geothermal Program Office, and Ormat Nevada Inc. are key partners in the project because they own or lease the land dedicated to the FORGE project and bring extensive geothermal experience to the team. Both the Navy and Ormat have drilled wells in the area that demonstrate very favorable conditions (temperature, depth, low-permeability rock) for advancing EGS technology. The project team also includes representatives from Lawrence Berkeley National Laboratory; University of Nevada–Reno; U.S. Geological Survey (Menlo Park, California); GeothermEx/Schlumberger; and Itasca Consulting Group, Inc.</p>

<p><b>Which organization(s) are funding this project?</b></p>	<p>Funding for FORGE is provided by the U.S. Department of Energy’s Geothermal Technologies Office.</p>
<p><b>What additional costs, if any, will fall outside project funding?</b></p>	<p>The initial phase of the FORGE project is funded entirely by the U.S. Department of Energy. Future phases will involve cost sharing. FORGE recipients and sub-recipients who are domestic institutions of higher education, national laboratories, federal entities, or domestic non-profit organizations are exempt from cost sharing.</p>
<p><b>What is the relationship between the U.S. Navy and the project?</b></p>	<p>Operations will take place on lands under the control of the U.S. Navy and Ormat Nevada Inc. The Fallon FORGE team will guide the activities with the consent and participation of the U.S. Navy, Ormat Nevada Inc., and the Bureau of Land Management (BLM).</p>
<p><b>What is the role of the BLM?</b></p>	<p>BLM is responsible for permitting most geothermal activities on Federal lands, including land owned by the U.S. Navy. However, the Navy will issue any permits required on Fallon FORGE grounds not within BLM leases.</p>
<p><b>Is National Environmental Policy Act (NEPA) compliance required?</b></p>	<p>Yes, NEPA is required on all Department of Defense (DoD) installations. The 2011 Salt Wells Environmental Impact Statement (EIS) that was completed for the FORGE area will serve as the governing document for future geothermal activities on the NAS Fallon FORGE property. Any additional NEPA requirements associated with FORGE can be derived from the Salt Wells EIS.</p>
<p><b>Is drilling anticipated as part of the project? If so, where and how deep?</b></p>	<p>In Phase 1, the project focuses on developing a conceptual geologic model and planning the activities to occur in later phases. During Phase 2, detailed plans will be developed for EGS experiments that will be conducted at the site. Permits for those activities will be acquired, if needed. In Phases 2C and 3, it is anticipated that multiple deep wells will be drilled at the site to depths ranging from 1,500 m to 2,000 m. Additional shallow wells will be drilled for monitoring subsurface activities. The project will leverage data from existing wells drilled within and near NAS Fallon by Ormat Nevada Inc. and the U.S. Navy.</p>
<p><b>What types of activities are expected to occur in Phase 3 of the FORGE project?</b></p>	<p>Plans for EGS experiments and activities are still under development. Anticipated activities include, but are not limited to, the following:</p> <ul style="list-style-type: none"> <li>• drilling new wells and characterizing the rock fabric and mineralogical composition in detail</li> <li>• conducting injection tests</li> <li>• conducting stimulations of existing and new wells and circulation tests between wells</li> <li>• using innovative well completion techniques that allow for manipulation of fractures in multiple zones within a single well</li> <li>• performing tracer testing using reactive and non-reactive tracers</li> </ul>

	<p>All work undertaken at the site is aimed at understanding how to manipulate the fracture system in a way that enhances permeability while allowing sufficient fluid residence time for heat exchange as the injected water travels through the system to the production well, thus tapping the vast heat reserves in the area. All activities will be closely monitored using a variety of sophisticated techniques, contributing to a thorough understanding of initiating and controlling underground processes.</p>
<p><b>Are there similar EGS experimental sites elsewhere?</b></p>	<p>The Fallon FORGE site is 1 of 5 DOE-funded Phase 1 projects. Ultimately, DOE plans to fund only a single FORGE project. The other Phase 1 FORGE projects are in Nevada, Idaho, Utah, and Oregon. In addition to these projects, EGS is the subject of research and development by various governments, including the United States and the European Union. Dedicated EGS experimental sites have been implemented in the United States (Fenton Hill, New Mexico), the UK (Rosemanowes, Cornwall), and the European Union (Soultz-Sous Forêts, France). In addition, EGS experimentation has been undertaken at several operating geothermal project sites in Nevada (Desert Peak, Bradys), Idaho (Raft River) and California (Coso, The Geysers).</p>
<p><b>Where does the name “Fallon” come from? And where exactly is it?</b></p>	<p>Fallon, Nevada, a community of approximately 8,400 people about 62 miles east of Reno, is the county seat of Churchill County. The city of Fallon lies approximately 7 miles northwest of the proposed FORGE site. Fallon is home to the Naval Air Station (NAS), a training station that has been the home of the U.S. Naval Strike and Air Warfare Center including the TOPGUN training program since 1996. The city of Fallon, NAS Fallon, and the nearby Reno metropolitan area each provide critical infrastructure and facilities that will be useful for the FORGE project.</p>
<p><b>What makes the proposed NAS Fallon site a good location for FORGE?</b></p>	<p>NAS Fallon has all the required characteristics of a world-class EGS site, in terms of depth, temperature, and low permeability. Previous drilling in the area, both on NAS Fallon land and adjacent BLM land leased to Ormat Nevada Inc., has contributed significantly to researchers’ knowledge of the subsurface. None of the wells drilled to date have encountered good permeability in crystalline rock. All of the deeper wells encountered high temperatures in the FORGE required range that are also representative of temperature vs. depth conditions in much of the Great Basin. The site has a willing landowner (the U.S. Navy) with a significant interest in developing new sources of resilient power and a neighboring lease holder (Ormat Nevada Inc.) seeking to realize value from its investment. The site has an existing seismic monitoring network and a massive amount of hot granitic and metamorphic rock at a reasonably shallow depth, which lowers overall costs of drilling and drilling-related activities. Further, relatively high tectonic strain rates and investigated stress states in the area will facilitate hydraulic fracturing of the rock. The site is accessible year-round, and the Fallon FORGE team is closely coordinating with the U.S. Navy to ensure that the important mission of Fallon NAS proceeds without interference from FORGE research and development activities.</p>
<p><b>How much water will this project use?</b></p>	<p>Enhanced geothermal systems need water to operate effectively. The water requirements for FORGE will be on the order of a few million gallons per stimulation, and it is anticipated that up to 3 to 6 wells may be stimulated.</p>

<b>Where will you get the water you need for this project?</b>	The primary source of water for stimulations and other activities will be the geothermal fluid produced from Well 84-31, one of the wells already drilled by Ormat Nevada Inc. This water is from a zone unrelated to shallower reservoirs used for drinking and agriculture in the region.
<b>Will injection of fluids affect seismic activity in the area?</b>	Fluid injection at the FORGE site will cause micro-earthquakes (also referred to as micro-seismicity). Micro-seismicity is related to minor movements along small fractures affected by injection and production activities. Although most micro-seismicity associated with geothermal reservoirs is not felt at the surface, subsurface seismic activity will be carefully monitored by a micro-seismic monitoring network. An Induced Seismicity Mitigation Plan has been developed for the project, detailing mitigation and communication strategies.
<b>Will injection of fluids increase the risk of a significant earthquake?</b>	Micro-seismicity associated with fluid removal and injection has been observed and monitored for decades around several Nevada geothermal fields near Fallon. No injection in or near these fields has been linked to significant earthquakes. Micro-seismic data helps researchers understand subsurface processes and optimize resource use, but micro-seismicity will not increase the risk of a potentially damaging earthquake in Churchill County. As a result of detailed characterization of the subsurface, the FORGE project is designed to avoid faults with the potential to produce damaging earthquakes.
<b>How will the project protect local interests during each Phase?</b>	Unimpeded by the FORGE project, local tribes will continue to access sacred sites, namely the Grimes Point archeological site and Fallon Paiute-Shoshone Reservation and Colony that lie approximately 6 miles to the north and northeast of the Fallon FORGE site. The research project will attract some increased economic activity in the area, particularly in the drilling and hospitality sectors. After completion of the FORGE project, EGS development could have a positive impact on the area in two ways: (1) by demonstrating a new source of clean power that can be replicated in other communities; and (2) by providing the U.S. Navy with resilient power, ensuring that it can continue its important mission at NAS Fallon.
<b>How will you protect cultural sites in and around the FORGE project areas?</b>	Because the FORGE team will use existing access roads and will build minimal infrastructure (a few well pads, wells, and pipelines) in a well-surveyed area, cultural sites will be respected. Any new developments will be planned in such a way as to create no adverse effects or disturbance.
<b>What happens to the site at the end of the 5-year research project?</b>	The infrastructure to be developed for the FORGE project is minimal, consisting of a few well pads, wells, and pipelines, and may continue to be used for experiments, geothermal production, or injection after the FORGE project is finished. If there is no use for this infrastructure at the completion of the project, reclamation will be performed as needed.

## CONCLUSION

The Fallon FORGE project team is committed to supporting communications, education, and outreach efforts to maintain sound operations and increase geothermal science and technology literacy for the duration of the FORGE project.

**APPENDIX H. STAKEHOLDER ENGAGEMENT STATUS UPDATE**

# STAKEHOLDER ENGAGEMENT STATUS UPDATE

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Fallon, NV

## NAS FALLON



*Geothermal Research  
Observatory*

## STAKEHOLDER ENGAGEMENT STATUS UPDATE

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### Fallon, NV

The Stakeholder Engagement Status Update complements the Fallon, NV, Communications and Outreach Plan by detailing the FORGE Phase 1 activities undertaken by the Fallon team to develop stakeholder relationships. The following three tables detail **Media Relations Engagement, One-on-One Engagement, and Meetings and Conferences**, and are current as of May 10, 2016. The Fallon team lead(s) and team participant(s) engaged with media outlets, met individually with stakeholders, and attended meetings and conferences to improve communications, educate stakeholders, form agreements, navigate legal requirements, and ensure dissemination of accurate information about the FORGE project. The content of each table is organized chronologically, starting with the most recent event.

Media relations activities, detailed in Table 1, included a radio interview, a published magazine article and blog posts, and a television appearance. All events were intended primarily to educate stakeholders.

**Table 1. Media Relations Engagement Status Update**

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date	Media Activity	Location	Details	Web link or title of published article or press release	Category of Status Update
James Faulds, University of Nevada–Reno (UNR)		Mar. 4, 2016	Gave interview for a press release or other published article.	Reno, NV	David Stipech, General Manager of KUNR, public broadcasting radio station in Reno, Nevada. Radio interview with Dr. Kevin Carman, Provost, University of Nevada, Reno.  Title: “University research key to realizing Nevada’s geothermal potential.”	<a href="http://kunr.org/post/university-research-key-realizing-nevadas-geothermal-potential#stream/0">http://kunr.org/post/university-research-key-realizing-nevadas-geothermal-potential#stream/0</a>  Title: “University research key to realizing Nevada’s geothermal potential.” KUNR, NPR, March 7, 2016.	Educating stakeholders
James Faulds, UNR	Wendy Calvin, UNR	Nov. 1, 2015	Gave interview for a press release or other published article. Briefed media relations, submitted content (images, text, data). Other: magazine article.	Reno, NV	John Seelmeyer reporter, Fall 2015 issue of <i>Nevada Silver and Blue Magazine</i> , University of Nevada, Reno.	<a href="http://www.unr.edu/silverandblue/archive/2015/fall/NSB_Fall_2015_WEB.pdf">http://www.unr.edu/silverandblue/archive/2015/fall/NSB_Fall_2015_WEB.pdf</a>  Title: “Forging Geothermal Resources through Research,” <i>Nevada Silver &amp; Blue</i> , Fall 2015. Page 25.	Educating stakeholders
James Faulds, UNR		Aug. 21, 2015	Gave interview for a press release or other published article. Other: TV interview.	Reno, NV	Shelby Sheehan, Reporter, News 4, KRNV TV station; a 2-minute TV interview discussing FORGE project and potential impacts on renewable energy.	N/A	Educating stakeholders
James Faulds, UNR	Wendy Calvin, UNR	Aug. 5, 2015	Gave interview for a press release or other published article.	Reno, NV	John Seelmeyer, Nevada Today, University of Nevada, Reno.  Article in <i>Nevada Today</i> describing the FORGE project at Fallon.	<a href="http://www.unr.edu/nevada-today/news/2015/forging-new-geothermal-resources-through-research">http://www.unr.edu/nevada-today/news/2015/forging-new-geothermal-resources-through-research</a>  Title: “Forging New Geothermal Resources through Research.” <i>Nevada Today</i> , August 5, 2015.	Educating stakeholders

The Fallon team’s one-on-one stakeholder engagement, detailed in Table 2, focused primarily on meetings with congressional members and included an opportunity to develop international partnerships.

**Table 2. One-on-One Engagement Status Update**

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date	Who we met	Audience	Location	Summary of Description	Notable Mentions	Category of Status Update
Doug Blankenship, Sandia National Laboratories (SNL)	Mack Kennedy, Lawrence Berkeley National Laboratory (LBNL) Erik Ridley, SNL Jenn Tang, LBNL	Apr. 19, 2016	Anne Clement, Legislative Assistant, Senator Barbara Boxer	Federal, state, and local governments and agencies	Washington, DC	Provided an introduction and overview of the DOE FORGE effort. Provided overview and infographics of the Fallon, NV, site proposed by the Sandia-led team. Responded to questions, concerns, etc., regarding FORGE and the Fallon site.	Very supportive of FORGE and our team.	Other: Educating congressional leaders
Doug Blankenship, SNL	Mack Kennedy, LBNL Erik Ridley, SNL Jenn Tang, LBNL	Apr. 19, 2016	Rachel Carr, Legislative Fellow, Senator Dianne Feinstein	Federal, state, and local governments and agencies	Washington, DC	Introduction and overview of the DOE FORGE effort. Presented introduction, overview and infographics describing the Fallon site proposed by the Sandia-led team. Answered questions and concerns regarding the Fallon site and FORGE.	The Senator is very interested in geothermal energy and supports the FORGE effort, particularly the site proposed by our team.	Other: Educating congressional leaders
Doug Blankenship, SNL	Mack Kennedy, LBNL Erik Ridley, SNL Jenn Tang, LBNL	Apr. 19, 2016	Tim Itnyre, Legislative Director, Congressman Paul Cook (R-CA)	Federal, state, and local governments and agencies	Washington, DC	Introduction and overview of the DOE FORGE effort. Presented introduction, overview and infographics describing the Fallon site proposed by the Sandia team. Answered questions and concerns regarding the Fallon site and FORGE. Congressman Cook’s district also includes several military institutions.	The Congressman is very supportive of the site. Expressed some concerns regarding water use. The concerns arise from expansion plans of geothermal production.	Other: Educating congressional leaders
Doug Blankenship, SNL	Mack Kennedy, LBNL Erik Ridley, SNL Jenn Tang, LBNL	Apr. 19, 2016	Jason Riederer, Legislative Director; Kyle Thomas, Legislative Assistant; Congressman Mark Amodei (R-NV)	Federal, state, and local governments and agencies	Washington, DC	Introduction and overview of the DOE FORGE effort. Presented introduction, overview and infographics describing the Fallon site, with an emphasis on NAS Fallon, proposed by the Sandia-led team. Answered questions and concerns regarding the proposed sites and the FORGE effort. The congressman’s district includes NAS Fallon.	Congressman Amodei is a strong proponent of geothermal energy, the DOE FORGE effort, and the proposed Fallon site.	Other: Educating congressional leaders

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date	Who we met	Audience	Location	Summary of Description	Notable Mentions	Category of Status Update
Doug Blankenship, SNL	Mack Kennedy, LBNL Erik Ridley, SNL Jenn Tang, LBNL	Apr. 19, 2016	Ryan Mulvenon, Senior Advisor, Senator Harry Reid	Federal, state, and local governments and agencies	Washington, DC	Introduction and overview of the DOE FORGE effort. Presented introduction, overview and infographics describing the Fallon site proposed by the Sandia-led team. Answered questions and concerns regarding the proposed sites and the FORGE effort, with an emphasis on the Fallon site and progress to date on Phase 1 work.	Senator Reid is very interested in FORGE, particularly the Fallon site.	Other: Educating congressional leaders
Ann Robertson-Tait, GeothermEx/Schlumberger	Kent Burton, Lobbyist, Geothermal Energy Association	Mar. 17, 2016	PA Ryan Mulvenon, Office of Senator Harry Reid (D-NV)	Federal, state, and local governments and agencies	Washington, DC	We had met the previous day at a Congressional Briefing on geothermal set up by the Geothermal Energy Association (GEA) and the Environmental and Energy Study Institute (EESI). Mr. Mulvenon specifically asked about the FORGE projects while we waited for the briefing, and asserted that Fallon was the best of the five. Because Susan Petty from the Newberry FORGE team and Doug Glaspey from the INL FORGE team were present, I stated my agreement that Fallon was best, but acknowledged the representatives from two competing projects. We agreed to talk in his office the following day. After discussing the Investment Tax Credit issue, I presented the Fallon site's main attributes in detail, responding to Mr. Mulvenon's expression of great interest. I provided the 2-page project summary, and noted that although Fallon, NV, is clearly a superior site from the technical perspective, the ultimate site selection was certain to involve political issues.	Mr. Mulvenon reiterated Sen. Reid's support for the Fallon site. Because he and Sen. Reid were instrumental in setting up the February 2015 meeting between Navy Command in Washington, DC, SW Regional Command, and NAS Fallon Command, which led to a clear understanding of the NAS Fallon mission and constraints on FORGE activities relative to that mission, I thanked him for those efforts.	Approaches and lessons learned in forming agreements, educating stakeholders

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date	Who we met	Audience	Location	Summary of Description	Notable Mentions	Category of Status Update
Ann Robertson-Tait, GeothermEx	Kent Burton, Lobbyist, Geothermal Energy Association	Mar. 17, 2016	Senator Dean Heller (R-NV); Jeremy Harrell, Energy Legislative Assistance	Federal, state, and local governments and agencies	Washington, DC	Sen. Heller is a strong geothermal energy supporter and spoke at the GEA Geothermal Showcase directly after our meeting. After discussing the Investment Tax Credit issue, the discussion turned to FORGE and the Fallon site.	I presented the main attributes of Fallon, provided the 2-page project summary to Sen. Heller and Mr. Harrell, and noted that although Fallon is clearly a superior site from the technical perspective, the decision on which site would be chosen was certain to involve political issues. Sen. Heller thanked me for bringing this to his attention.	Approaches and lessons learned in forming agreements, educating stakeholders
Ann Robertson-Tait, GeothermEx	Kent Burton, Lobbyist, Geothermal Energy Association	Mar. 16, 2016	Rep. Mark Amodei (R-NV) District 2	Federal, state, and local governments and agencies	Washington, DC	Met with Rep. Amodei who immediately expressed his gratitude to be talking to geothermal people about a subject he is genuinely interested in. Presented our 2-page summary of the Fallon FORGE site, and presented a verbal summary of why Fallon is a compelling and attractive site for FORGE. Talking points included: specifics about site characteristics (including access to data); the national importance of and steps toward diversifying energy supply, and leading the world in geothermal energy development; and hosting a world-class research project (that will be able to use existing technology adapted from oil and gas development), water resources, and job creation.	Rep. Amodei is a strong supporter of the project and appreciates why Fallon is a worthy choice for a world-class research project.	Approaches and lessons learned in forming agreements, educating stakeholders
James Faulds, University of Nevada–Reno		Mar. 16, 2016	Ryan Mulvenon on staff of Senator Harry Reid (NV)	Federal, state, and local governments and agencies	Washington, DC	Presented update on the Fallon site and the FORGE effort. Reviewed DOE criteria and site suitability. The Fallon site was discussed in great detail.		Educating stakeholders

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date	Who we met	Audience	Location	Summary of Description	Notable Mentions	Category of Status Update
Mack Kennedy, LBNL	Pat Dobson, LBNL	Feb. 29, 2016	Hiroshi Asanuma, Geothermal Team Leader, Fukushima Renewable Energy Research Institute (FREA), National Institute of Advanced Industrial Science and Technology (AIST), Japan	Public research institutions, international partners	Berkeley, CA	Presented an update on the status of the DOE FORGE site selection process and an overview of the Fallon site. Asanuma presented an overview of FREA/AIST's plan for EGS research and their commitment to partnering with DOE. Specifics of the meeting regarding research interests, financials, etc., were marked confidential.		Other: Develop international partnerships

During Phase 1, Fallon team members presented two published papers at several key scientific conferences, spoke with an education center about forming partnerships to establish programs for outreach and education, and supported STEM education, as summarized in Table 3, below. Additional engagement with key stakeholders included: providing project status and overviews; answering questions; organizing on-site visits; and meeting with the general public, industry partners, and governmental and military agencies.

**Table 3. Meetings and Conferences Engagement Status Update**

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date(s)	Name of Meeting or Conference	Audience	Location	Title of Presentation, Discussion, etc.	Summary of Presentation, Discussions, etc.	Notable mentions	Category of Status Update
Jim Faulds, University of Nevada–Reno (UNR)	John Akerley, Ormat; Andy Tiedeman, Navy Geothermal Program Office (GPO)	Apr. 18, 2016	Update on Fallon FORGE project for Governor's Energy Office for state of Nevada	Federal, state, and local governments and agencies	Carson City, NV	Update on the Fallon FORGE project	Informal presentation using handouts and posters describing the status of the project to three staff members of the Governor's Energy office. After a brief presentation, took questions on the project ranging how geothermal systems work to the potential economic impacts of FORGE on the community.		Educating stakeholders
Mack Kennedy, Lawrence Berkeley National Laboratory (LBNL)	Drew Siler, LBNL	Apr. 14, 2016	Meeting with Lawrence Hall of Science to discuss educational outreach collaboration for FORGE	Federal, state, and local governments and agencies, students and educators	Berkeley, CA	N/A	Presentation of FORGE concept, Fallon site, and discussion of Lawrence Hall of Science's expertise and interest in collaboration.	Lawrence Hall of Science attendees: Craig Strang, Associate Director of the Lawrence Hall of Science, Director of Leadership in Science Teaching; Catherine Halverson, Co-Director of MARE, Director of Communicating Ocean Science, Director of Promoting Climate Literacy; Emily Weiss, Director of PRACTISE; Jemma Foreman, Project Manager, BEETLES Project	Other: Potential educational outreach meeting

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date(s)	Name of Meeting or Conference	Audience	Location	Title of Presentation, Discussion, etc.	Summary of Presentation, Discussions, etc.	Notable mentions	Category of Status Update
Jim Faulds, UNR	John Akerley, Greg Rhodes, Ormat Nevada Inc.; Andy Tiedeman, Navy GPO	Apr. 12, 2016	Meeting with Bureau of Land Management (Lorenzo Trimble) to provide update on FORGE project	Federal, state, and local governments and agencies	Ormat offices in Reno, NV	Update of Fallon FORGE project	Presented update of Fallon site and FORGE, including results of Phase 1 and possible activities in a potential Phase 2. This led to discussion of land status and permitting time frames and procedures.	BLM expressed their willingness for continued cooperation on the project and suggested that we provide another update in 3-4 months.	Lessons learned in forming agreements, educating stakeholders, and navigating legal requirements
Ann Robertson-Tait, GeothermEx		Mar. 17, 2016	Geothermal Energy Association US and International Geothermal Showcase	Government agencies (domestic and international), geothermal developers, students	Washington, DC	Creating New Geothermal Opportunity in High Temperature, Low Permeability Rock Formations: Making a Case for EGS	Geographic limitations of conventional hydrothermal resources, EGS overview (part of the continuum of geothermal resources, estimates of worldwide power generation potential), summary of active EGS projects in the US, how the SNL/LBNL team decided to choose Fallon as a candidate FORGE site, importance of resilient energy for US DoD		Educating stakeholders
Nick Hinz, UNR	James Faulds, Brett Tobin, and Wendy Calvin, UNR; Drew Siler and Mack Kennedy, LBNL; Kelly Blake, Andy Tiedemen, and Andy Sabin, Navy GPO; Doug Blankenship, SNL; Greg Rhodes and Josh Nordquist, Ormat Nevada Inc.; Steve Hickman, Jonathan Glen, and Colin Williams, USGS; Ann Robertson-Tait, GeothermEx	Feb. 22-24, 2016	41st Workshop on Geothermal Reservoir Engineering (Stanford Geothermal Workshop)	Private research institution, public research institutions, Federal, state, and local governments and agencies, students and educators	Stanford University, Stanford, CA	Stratigraphic and structural framework of the proposed Fallon FORGE site	Described stratigraphic and structural characteristics of the Fallon site, including well, temperature, geophysical data, etc. Discussed how site fits all parameters of FORGE, as defined by DOE.  Hinz et al. (2016) Stratigraphic and structural framework of the proposed Fallon FORGE site, <i>Proceedings, 41st Workshop on Geothermal Reservoir Engineering</i> . Stanford University, SGP-TR-209. 12 p.	Presented a paper.	Educating stakeholders

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date(s)	Name of Meeting or Conference	Audience	Location	Title of Presentation, Discussion, etc.	Summary of Presentation, Discussions, etc.	Notable mentions	Category of Status Update
James Faulds, UNR		Feb. 2, 2016	Monthly meeting of the Truckee Meadows Parks Foundation	General public	Reno, NV	Living on the Edge in Western Nevada: Our Rapidly Evolving Geologic Setting	Presented overview of Nevada's geologic setting as part of the Pacific-North American plate boundary and how this setting endows the region in natural resources, such as geothermal energy. Briefly discussed conventional and EGS geothermal systems, including FORGE activities at the Fallon site.	Over 250 people in attendance. Talk was very well received with many questions from the public on geothermal energy.	Educating stakeholders
James Faulds, UNR		Jan. 7, 2016	Monthly meeting of the Nevada Petroleum and Geothermal Society	Broad range of geoscientists from industry, academia, and state-federal agencies	Reno, NV	Geologic setting of the proposed Fallon FORGE site, Nevada: Suitability for geothermal (EGS) research & development	Provided an overview of FORGE and described the geologic setting and overall suitability of the Fallon site. Approximately 60 people were in attendance.		Educating stakeholders
Maryann Villavert, LBNL	Mack Kennedy and Ernie Majer, LBNL	Dec. 14-18, 2015	American Geophysical Union Fall Meeting 2015, December 14-18	Private research institution, public research institutions, international partners, students and educators	San Francisco, CA	Earth and Environmental Sciences Area, Exhibitor Booth	LBNL EESA presented several research topics and activities in the form of Meet-a-Scientist, informal presentations, videos, handouts, and social media twitter chats. Prospective postdocs, students, faculty, industry personnel visited the booth to learn more about LBNL, EESA, and research opportunities. FORGE Q & A included opportunities for future internships, postdoc appointments, and collaborations with faculty and industry.	Interested individuals were curious about when FORGE would start.	Educating stakeholders

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date(s)	Name of Meeting or Conference	Audience	Location	Title of Presentation, Discussion, etc.	Summary of Presentation, Discussions, etc.	Notable mentions	Category of Status Update
James Faulds, UNR	Doug Blankenship, SNL; Nicholas Hinz and Wendy Calvin, UNR; Andrew Sabin, Navy GPO; Josh Nordquist and Peter Drakos, Ormat Nevada Inc.; Mack Kennedy and Drew Siler, LBNL; Ann Robertson-Tait, GeothermEx; Stephen Hickman, Jonathan Glen, Colin Williams, USGS	Sep. 20-23, 2015	39th Geothermal Resources Council Annual Meeting and Geothermal Energy Association Expo	Private research institution, public research institutions, Federal, state, and local governments and agencies, students and educators	Reno, NV	Geologic Setting of the Proposed Fallon FORGE Site, Nevada: Suitability for EGS Research and Development	Presented overview of the stratigraphic and structural framework of the Fallon site, describing how the site meets DOE qualifications for FORGE.  Faulds et al. (2015) Geologic Setting of the Proposed Fallon Forge Site, Nevada: Suitability for EGS Research and Development. <i>GRC Transactions</i> , Vol. 39, 293-301.	Presented a paper.	Educating stakeholders
James Faulds, UNR		Sep. 15, 2015	Congressional briefing on geothermal energy: Energy-Water-Land Connections Briefing Series	Federal, state, and local governments and agencies	Washington, DC	Geothermal Systems: Geologic Origins of a Vast Energy Resource	Described the origins and locations of geothermal energy, conventional geothermal systems, and EGS, as well as challenges and opportunities for the geothermal industry. Described the FORGE effort in general and the Fallon site as an example. Served as panelist answering questions about geothermal energy.		Educating stakeholders
Douglas Blankenship, SNL	Josh Nordquist, Ormat Nevada Inc.	Aug. 25, 2015	Clean Energy Project - Nevada's Innovation System: Accelerating Clean Energy Economic Development	Other: Stakeholders interested in Nevada energy issues	Las Vegas, NV	Panel discussion	This event was held by the State of Nevada and the U.S. Department of Energy in association with the Clean Energy Project event in Las Vegas, NV. Requested by the State of Nevada to be part of a roundtable discussion about new opportunities. Other panel members were DOE personnel, including Trak Shah, Matt Nelson, Mark McCall and Jetta Wong. While the program was focused on Nevada, held discussions about the broader FORGE effort as well as the Fallon site.		Educating stakeholders

Team Lead(s), Affiliation	Team Participant(s), Affiliation	Date(s)	Name of Meeting or Conference	Audience	Location	Title of Presentation, Discussion, etc.	Summary of Presentation, Discussions, etc.	Notable mentions	Category of Status Update
Douglas Blankenship, SNL		Jun. 12, 2015	U.S. Senate & House Renewable Energy and Energy Efficiency Caucus FORGE Briefing	Other: Congressional staffers and others	Washington, DC	The DOE Frontier Observatory for Research in Geothermal Energy: Candidate Sites at Fallon, NV and Coso, CA	Presentation included an overview of the Fallon site and FORGE project. Congressional Caucus presentation.		Educating stakeholders
Andy Sabin, Navy GPO	Doug Blankenship, SNL; Mack Kennedy, LBNL; Jim Faulds, UNR; Ann Robertson-Tait, GeothermEx; A. Tiedeman, Navy GPO; M. Lazaro, Navy GPO	Mar. 12, 2015	Internal Fallon discussion	Other: Navy military leadership, internal meeting	Naval Air Station Fallon, Fallon, NV		Discussed efficacy of FORGE and Fallon mission—it was agreed at this meeting that FORGE should move ahead.	In attendance with the Fallon team were Sen. Harry Reid's office, Navy's CNIN, and NAVFAC leadership	Educating stakeholders

# **APPENDIX I. SAMPLE AND CORE CURATION PLAN**

# SAMPLE AND CORE CURATION PLAN

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Fallon, NV

## NAS FALLON



*Geothermal Research  
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# SAMPLE AND CORE CURATION PLAN

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Fallon, NV

## PURPOSE

The Sample and Core Curation Plan establishes procedures and guidelines for the preservation of core, cuttings, and fluid samples obtained during Fallon, NV, FORGE activities, and distribution of sample data and physical samples to investigators requiring access to these materials.

## SITE SAMPLE ACQUISITION AND HANDLING

Drilled holes supporting the Fallon FORGE effort will involve sample acquisition of one form or another. The general plans for the acquisition and handling of core, cutting and fluids are provided below. FORGE is a significant endeavor and the process for acquiring and handling physical samples will require integration with the sampling systems, activity-specific ES&H requirements, and the requirements of potential principal investigators engaged in sample acquisition. Thus the plan is general in nature and recognizes that detailed procedures for sample acquisition and handling will be needed as site activities evolve. Dedicated on-site space will be established for the handling, and preliminary examination of the collected samples. We expect to be able to create a digital on-line archive of image data similar to the SAFOD core viewer (<http://coreviewer.earthscope.org/>) or the Australian National Virtual Core Library (<http://nvcl.csiro.au/>).

## DRILL CUTTINGS

During rotary drilling operations, cuttings will be collected, described, and logged on a 24-hour basis. The primary responsibility for this activity lies with the contracted mud logging company, but the Fallon FORGE site geologist(s) will supervise the work. Cuttings collection intervals may vary depending on the depth of the hole, penetration rate, lithological contacts, and the requirements of specific principal investigators, but generally will be collected at a maximum of 10 ft. intervals unless otherwise authorized by the Fallon FORGE project management. At each collection interval, cuttings will be collected off the shale shaker onto a collection board or trough to ensure a representative sample is obtained. Following sample collection, the collection board or trough will be cleaned to gather cuttings representing the next interval. The samples will be gently washed, screened, dried and bagged with markings indicating the well name, depth, and time of collection. Because it takes a measurable or calculable amount of time for the collected sample to move from the bottom of the hole to the surface, the recorded depth shall reflect this lag time.

Cuttings will be examined in near real-time. Field microscopes will be equipped to allow digital photographs of the examined cuttings. A field log describing lithology, mineral assemblages and crystallinity, texture, alteration, fracture, vein, or fault locations, will be maintained during the course of drilling and the findings will be posted daily to the FORGE node on the NDGS. Once examined, the cuttings will be preserved and logged into a permanently retained sample log. Samples will be stored temporarily on site until immediate access is no longer required. At that

time the samples will be moved to temporary storage at a near-site warehouse location for the duration of the Fallon FORGE effort. Following the completion of project activities at Fallon FORGE, the samples will be moved to the USGS Core Research Center (CRC) in Denver, CO, or to the Nevada Bureau of Mines and Geology (NBMG) Great Basin Science Sample and Records Library (GBSSRL) in Reno, NV, for preservation and permanent storage.

## DRILLED CORE

The drilling, testing, and examination of core, whether from sidewall samples, spot coring operations, or from continuous wireline coring will be an integral part of the Fallon FORGE development effort.

Depending on the drilling conditions and PI-specific sampling requirements, the core will be obtained using either triple-tube or double-tube systems. For triple-tube systems the core is retained within a thin walled aluminum or polymeric inner-tube assembly that encases the core following removal from the coring assembly. Double-tube systems allow the core to enter a free-floating inner barrel assembly but do not encase the core in a removable liner. In collecting core samples, a trained site geologist will work alongside the rig crew during the core extraction process to ensure the core is handled appropriately. For triple tube systems the core and liner (or core for double tube systems) should be laid out in a single tray on the catwalk or similar structure and wiped down. The entire length of the liner or core will be marked in the standard red-black parallel line method where the red line is to the right of the black line when looking up the hole.

Any core not in a liner it should be carefully aligned and cleaned to allow the application of the red-black markings before moving the core from the catwalk. For core contained in liners, the liner/core will need to be cut in 3-foot lengths to fit in standard core boxes; likewise, it may be necessary to cut the core on the catwalk to fit in standard 3-foot core boxes. The core will then be transported to an on-site logging trailer for final cleaning with water and inspection. If the core is contained in a liner, the core must be pushed out of the liner or the liner split to allow access to the core. When the liner-housed core is laid out in the trailer, the core should be carefully aligned and marked with the red-black line code if the liner were removed. Integer depths will be marked along the core and a detailed field log of the core will be completed for the subject section of core.

We expect to use a multi-sensor core logger (e.g. Geotek MSCL-S) to document properties such as P-wave velocity, gamma density, magnetic susceptibility, electrical resistivity, color imaging, X-ray fluorescence, and natural gamma spectrometry. This is similar to what the International Continental Scientific Drilling Program (ICDP) makes available to their user community. Additionally, new high resolution core infrared spectroscopy may be acquired to document mineralogy and alteration. The core will then be wrapped in cling-type plastic wrap and placed in appropriately marked core boxes. Core descriptions and associated photographs will be uploaded to the dedicated FORGE node and be available through the National Geothermal Data System (NGDS). Core will temporarily be stored on site until immediate access is no longer required. Samples will then be moved to temporary storage at near-site warehouse space for the duration of the FORGE project effort. Following the completion of Fallon FORGE project activities, the samples will be moved to the USGS CRC or to the NBMG GBSSRL for preservation and permanent storage.

Limited sidewall core samples may be obtained to support specific PI-related activities but will not likely be a large part of the drilling operations at the Fallon FORGE site, given the planned direct coring operations. However, in the event sidewall cores are taken, the core will be received from the service company by a Fallon FORGE site geologist. The core will be identified and preserved in a manner consistent with that used to preserve drilled core samples.

## FLUID SAMPLES

Fluid samples used for testing during Fallon FORGE development and operation may be obtained through drill-stem testing through targeted sections of the drilled wells, downhole fluid sampling efforts, during flow/circulation testing, or other methods. As part of the site characterization, monitoring, and R&D conducted by the SMT, each fluid sample will be collected in quadrature. For each sample, one component will be analyzed as soon as possible after collection at an on-site laboratory managed by the SMT for pH, total alkalinity, dissolved silica, and so on. A second component will be sent to a commercial laboratory for major and minor cation and anion analyses, and non-condensable gas analyses. A third component will be sent to a reputable laboratory for stable isotopes analysis (e.g.,  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ). A fourth component will be archived for any further analyses that may be required and/or requested. The resulting data for all components of each fluid sample will be uploaded to the NGDS through the FORGE node. As with the core, the fourth component of each fluid sample will be stored on-site initially and later at a nearby warehouse facility for the duration of the project and then discarded, in accordance with EH&S protocols. Because non-condensable gas samples are difficult to preserve, only liquid samples will be archived. Fluid sampling, handling (e.g. filtering, acidification), and preservation will follow conventional procedures developed for geothermal systems.

If additional samples are requested for DOE-funded R&D projects, collaboration with international partners and private sector researchers (for example, for geochemical tracer studies during stimulation and flow testing), the SMT will provide logistical support for fluid sampling. Sample collection, handling and preservation will be the responsibility of the project leads. The SMT managed on-site laboratory will be made available, if requested by the project leads. All data acquired by these projects will be uploaded to the NGDS through the FORGE node following the Data Dissemination protocols.

## SAMPLE DISSEMINATION

Data collected during the course of the Fallon FORGE effort will be openly available to scientific and engineering community. As described in the data dissemination plan, well data will be available in as close to real-time as practicable. These site derived data will be posted and will also include the raw notes and log sheets from the site geoscientists for the subject samples. The distribution of data through an open data system, as described in the data dissemination plan, is organizationally less complex than the process of distributing physical samples to the scientific and engineering community. Following the lead of the NSF sponsored SAFOD (San Andreas Fault Observatory at Depth) program, protocols will be put in place for physical sample distribution associated with the DOE FORGE program.

During the Fallon FORGE project, all samples will remain the property of DOE and will be stored short-term at the Fallon FORGE site and longer-term (through the course of the project) at

warehouse space near the FORGE facility. After the cessation of site activities, the core will be archived and preserved at the USGS CRC or the NBMG GBSSRL. The distribution processes of Fallon FORGE samples to the science and engineering community is described below:

#### **SAMPLE DISTRIBUTION DURING FORGE OPERATIONS**

A Fallon FORGE Sample Committee (FSC) will be nominated by the FORGE Site Management Team (SMT) in conjunction with the Science and Technology Analysis Team (STAT) and approved by the DOE Geothermal Technologies Office. The members of the FSC will not otherwise be involved in R&D projects being funded through the FORGE initiative. Samples will be made to any qualified investigator, but researchers being funded through the R&D portion of FORGE will be given priority. Requests for samples will be provided to the FORGE Data Manager, who is a separate member of the SMT/STAT teams; the data manager will forward the requests to the FSC for regularly scheduled reviews. The review cycle for proposals will be determined by DOE program needs, occurring regularly enough to accommodate DOE research requirements.

The FORGE project will provide a request form to be submitted by all researchers requesting samples. Requests will contain a description of the requested samples and the proposed studies for which the samples are required. Requesters will provide a description of the procedures and objective of the study, the names and affiliations of collaborators, the name of the funding agency, and the agency's point of contact. In the proposal, the requester will attest that data derived from the supplied samples will be uploaded to the FORGE node on the NGDS. The application will specify when the samples will be returned to the USGS CRC unless circumstances, as described in the proposal, merit the complete destruction of the sample (in which case a sample split or slab will be retained).

Because the FSC's primary charge is to maximize the return from the available FORGE samples, the FSC will recommend to DOE how the samples should be used and who should receive which samples. Once DOE approval is obtained, the Fallon FORGE Data Manager will distribute the samples to the subject investigators. This process is applicable for all core, cuttings, and fluid samples. A digital on-line image archive will be established to assist investigators in selecting core or cutting sections for analysis.

#### **SAMPLE DISTRIBUTION AFTER FORGE OPERATIONS**

Following the cessation of FORGE site operations, all dry samples will be shipped to the USGS CRC or the NBMG GBSSRL. The CRC/GBSSRL will accept these samples either as donated material or DOE-owned material. DOE can retain the option to maintain control of the samples and distribution to researchers, but after the project has ended, there will be recurring costs to maintain the functions of the FSC and associated support from the USGS CRC/GBSSRL. If DOE opts to retain ownership, the process for obtaining and distributing samples is the same as that during Fallon FORGE operations. Once the CRC/GBSSRL assumes ownership (which can occur at any time after the receipt of samples), there are no further costs to DOE. The USGS CRC, a national repository for core and cuttings, will preserve and maintain the samples in perpetuity and allow all interested researches access. Once its ownership begins, CRC will control sample distribution following its own protocol. CRC and GBSSRL allow access to all interested parties and allow samples to be obtained for testing. Given its preservation mission,

however, CRC does not allow for whole sections of core to be removed; they do allow (and provide the service) for sub-cores, slabs, and cutting splits.

Fluid samples will not be stored after the cessation of Fallon FORGE activities unless DOE chooses to maintain a facility to provide the climate controlled environment needed to store such samples.

**APPENDIX J. PRELIMINARY INDUCED SEISMICITY MITIGATION  
PLAN**

# PRELIMINARY INDUCED SEISMICITY MITIGATION PLAN

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Fallon, NV

## NAS FALLON



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# PRELIMINARY INDUCED SEISMICITY MITIGATION PLAN

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Fallon, NV

## 1 INTRODUCTION

### 1.1 PURPOSE AND SCOPE

There are two main purposes of monitoring and analyzing seismicity in Enhanced Geothermal Systems (EGS) projects: (1) assessing the hazard and risk associated with induced seismicity; and (2) using and applying seismic data to understand the dynamic response of the subsurface at the FORGE site. As described in this preliminary Induced Seismicity Mitigation Plan (ISMP), the overall approach at the NAS Fallon FORGE site is to provide sufficient analyses and monitoring to serve both purposes. This preliminary ISMP—which will be updated in Phase 2 of FORGE—presents our approach to assessing the risk and hazard associated with induced seismicity that may occur in response to EGS activities at Fallon, and how seismic monitoring provides data for EGS reservoir assessment.

As stated in the FORGE Funding Opportunity Announcement (FOA), the Fallon FORGE project will follow the guidelines created by the U.S. Department of Energy (DOE), including:

1. The enhanced version of the Protocol for Induced Seismicity Associated with Geothermal Systems (Majer *et al.*, 2012), hereinafter, the Protocol.
2. The latest version of the Best Practices for Induced Seismicity (Majer *et al.*, 2014), hereinafter, the Best Practices.

Both of these documents build upon an earlier document that laid out an initial strategy for evaluating, monitoring and managing induced seismicity (Majer *et al.*, 2008).

The seven steps in the Protocol are:

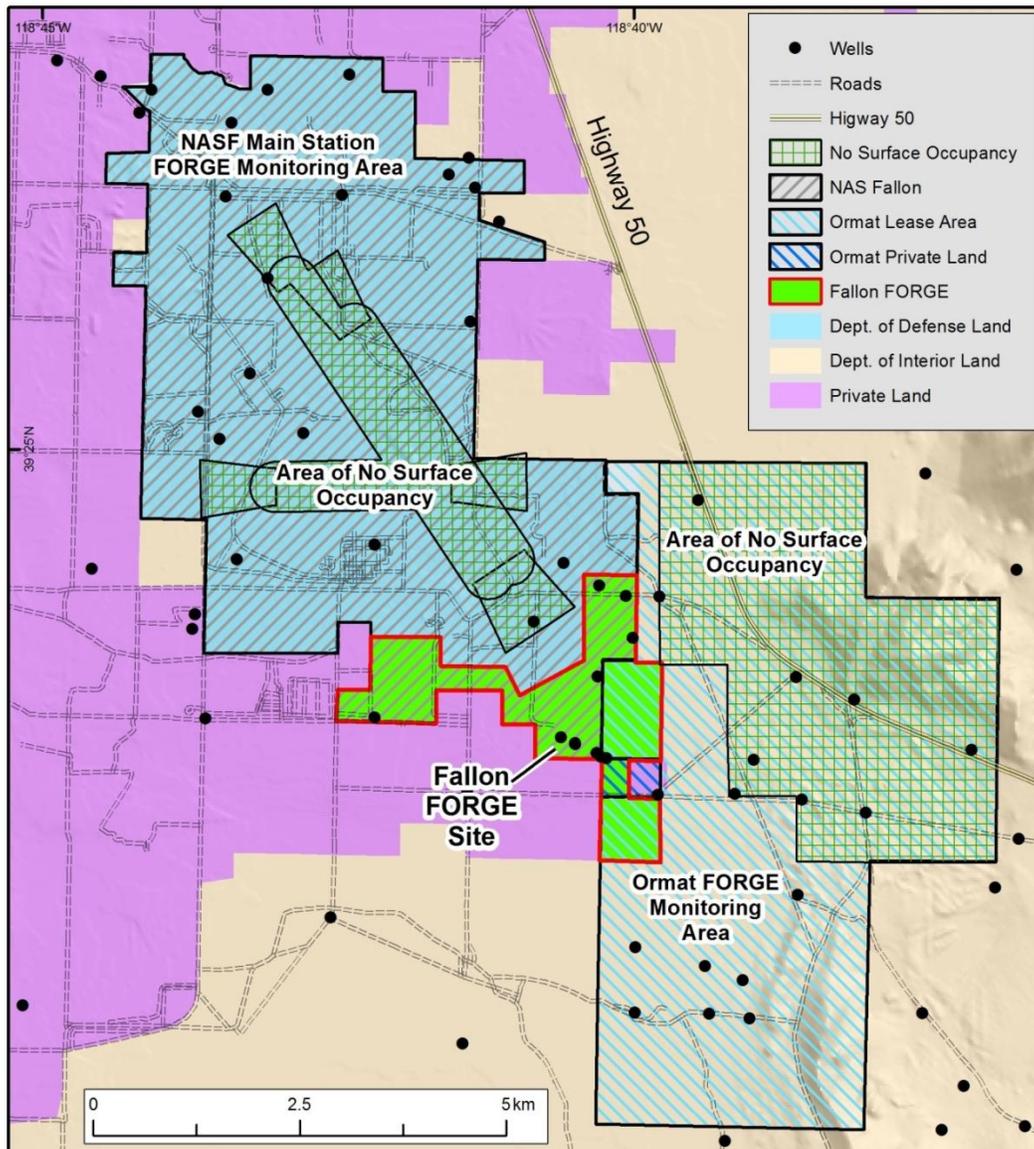
- Step 1: Perform preliminary screening evaluation
- Step 2: Implement an outreach and communication program
- Step 3: Identify criteria for ground vibration and noise
- Step 4: Establish seismic monitoring
- Step 5: Quantify the hazard from natural and induced seismic events
- Step 6: Characterize the risk from induced seismic events
- Step 7: Develop risk-based mitigation plans

The plan presented herein is a description of the approach we will use to address each step in the Induced Seismicity Protocol. In Phase 2 of the FORGE project, a more detailed protocol will be developed based on additional site characterization and development of detailed plans for R&D activities to be conducted at the site.

### 1.2 FALLON SITE OVERVIEW

As shown in Figure 1, the Fallon FORGE EGS project will be carried out on land controlled by Ormat Nevada Inc. (Ormat) and the U.S. Navy at the Fallon Naval Air Station (NAS Fallon). Together with several other participants and stakeholders, Sandia National Laboratory is leading

the Fallon FORGE EGS project. Currently in Phase 1—a stage of initial site characterization, planning and outreach—the Fallon FORGE EGS project will be one of 5 projects to be evaluated for advancement to Phase 2.



**Figure 1. Map of NAS Fallon showing existing wells and the Fallon FORGE site (bright green area)**

The Fallon FORGE project area is located in western Nevada, approximately 12 km southeast of the Fallon city center, in the southeastern portion of a large inter-montane basin known as the Carson Sink (Figure 2). Several conventional hydrothermal geothermal projects are operating in and around the Carson Sink, including Desert Peak, Brady’s Hot Springs, Stillwater, Soda Lake and Salt Wells. These geothermal fields lie within the Humboldt structural zone, a region of high heat flow that is characterized by ENE- to NNE-striking fault zones that bound or pass through mountain ranges and valleys. The major fault system closest to the Fallon FORGE project area is the Rainbow Mountain Fault Zone, located approximately 13 km east of NAS Fallon and 20-40 km SW of the Dixie Valley/Fairview Peak fault system, which is located on the eastern side of the Stillwater Range (see Figure 2).

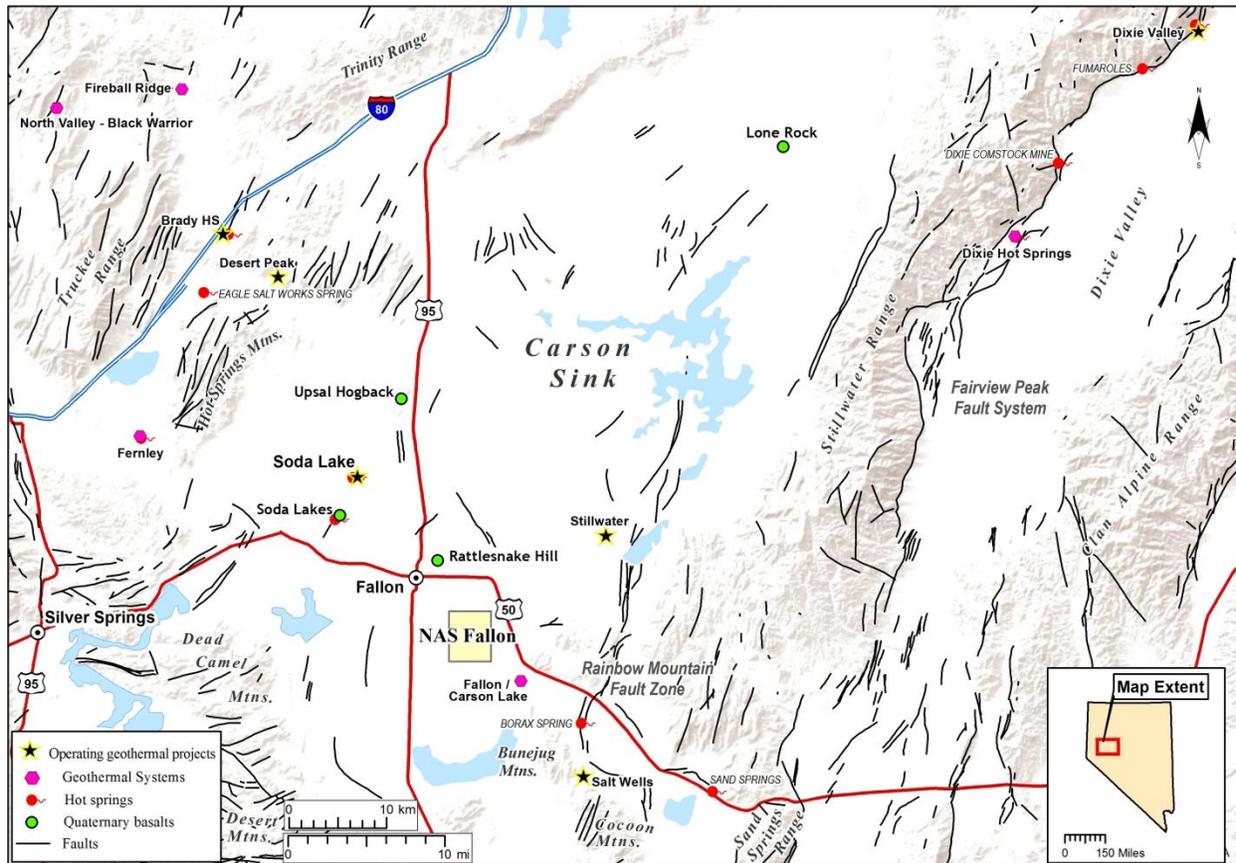


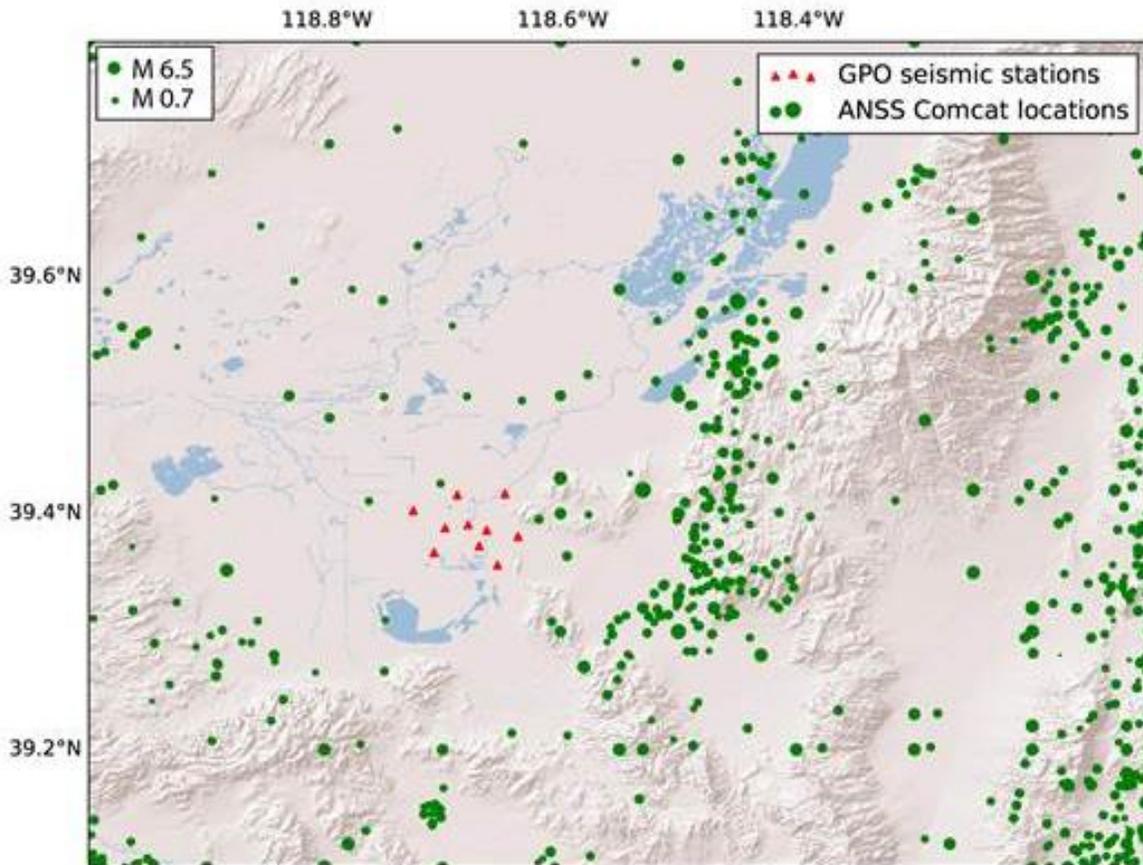
Figure 2. Geothermal fields within the Carson Sink and approximate location of NAS Fallon, the Rainbow Mountain Fault Zone (2), and the Dixie Valley/Fairview Peak fault system.

The following sections of this preliminary ISMP discuss the progress made to date on the various steps of the Protocol and the plans for completing the ISMP in Phase 2 of FORGE.

## 2 PRELIMINARY SCREENING EVALUATION (PROTOCOL STEP 1)

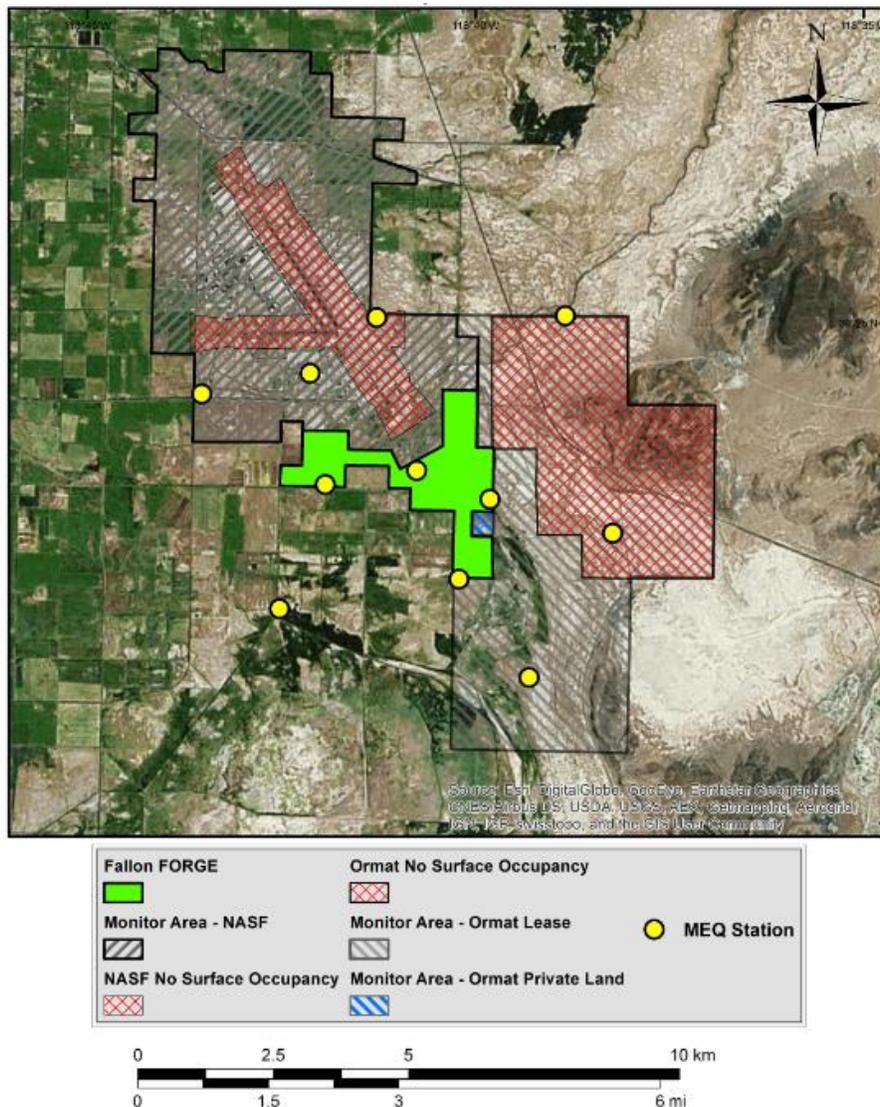
### 2.1 HISTORICAL NATURAL SEISMICITY IN THE FALLON AREA

As shown in Figure 3, below, historical natural seismicity in the region around the proposed FORGE area is relatively low; regional seismicity from the Advanced National Seismic System (ANSS) database since 1916 appears to be primarily associated with the Rainbow Mountain Fault Zone, which is the *closest major fault system to the Fallon FORGE area*. The Richter magnitude ( $M_L$ ) range of the seismic events that have occurred in the area range from 0.0 to 6.8. Larger events are associated mostly with the Rainbow Mountain Fault Zone (east of the NAS Fallon seismic array) and the faults that bound the Stillwater Range (further to the east).



**Figure 3. Earthquakes from 1916 to the present (green dots) around the Fallon FORGE site. Data are taken from the ANSS catalogue, which includes data collected by the Nevada Seismological Laboratory at UNR. NAS Fallon is located near the red triangles (locations of the NAS Fallon seismic monitoring stations).**

The U.S. Navy Geothermal Program Office (GPO) installed a local seismic monitoring array at Fallon (see Figure 4, below) in 2004, prior to the possible development of a geothermal resource at the southeast corner of the main side of the base, and began monitoring background seismicity. The network consists of ten 3-component, 4.5 Hz short-period downhole sensors which cover roughly a 10 by 10 km area around the southeast corner of NAS Fallon (Figure 4). All sensors are installed in dedicated wells that are about 200 feet (60 m) deep. Each station uses a Nanometrics Triden/Janus system to record and then transmit data to a central site where they are then forwarded to ports of RM-4 Bridge multiplexers. The RM-4 converts serial data into UDP IP packets and places them on an acquisition computer, which runs NaqsServer network data acquisition software. Data were recorded periodically by the network from 2004 to 2008, in 2011, and then from 2014 through the present.

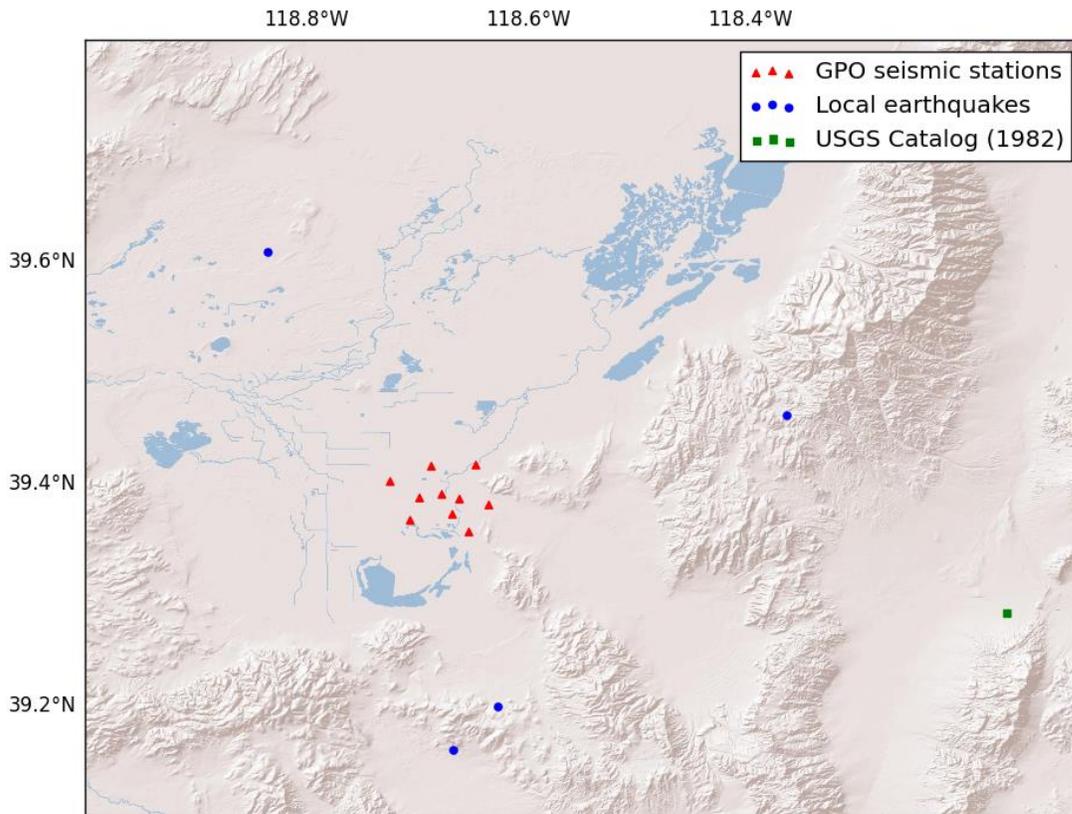


**Figure 4. Locations of the seismic monitoring stations (yellow circles) installed by the GPO at NAS Fallon, in and around the proposed FORGE site (bright green area).**

Although the goal was to record seismic activity in the southeast part of NAS Fallon, most or all of the recorded events are located well beyond the outline of the array. The far field locations result in lower accuracy compared to event locations within and/or closer to the array.

The lack of permeability within the deep resource (as demonstrated in several deep wells drilled in and near NAS Fallon) precluded conventional geothermal development at NAS Fallon; this led to its selection as a candidate FORGE site. In 2015, it was determined that the sensor threshold was set too high to record micro-seismic events; therefore, the threshold was lowered to the appropriate level to detect smaller events typically associated with geothermal production and injection. This work was undertaken using internal GPO funds. Subsequently, 134 events were recorded through the middle of January 2016. Once again, nearly all of these were regional events; as shown in Figure 5 below, only three events were identified as occurring in the area in and immediately around NAS Fallon. In combination with the ANSS data presented above, the

data from the NAS Fallon network indicate that the FORGE area is characterized by a low level of natural seismicity activity.

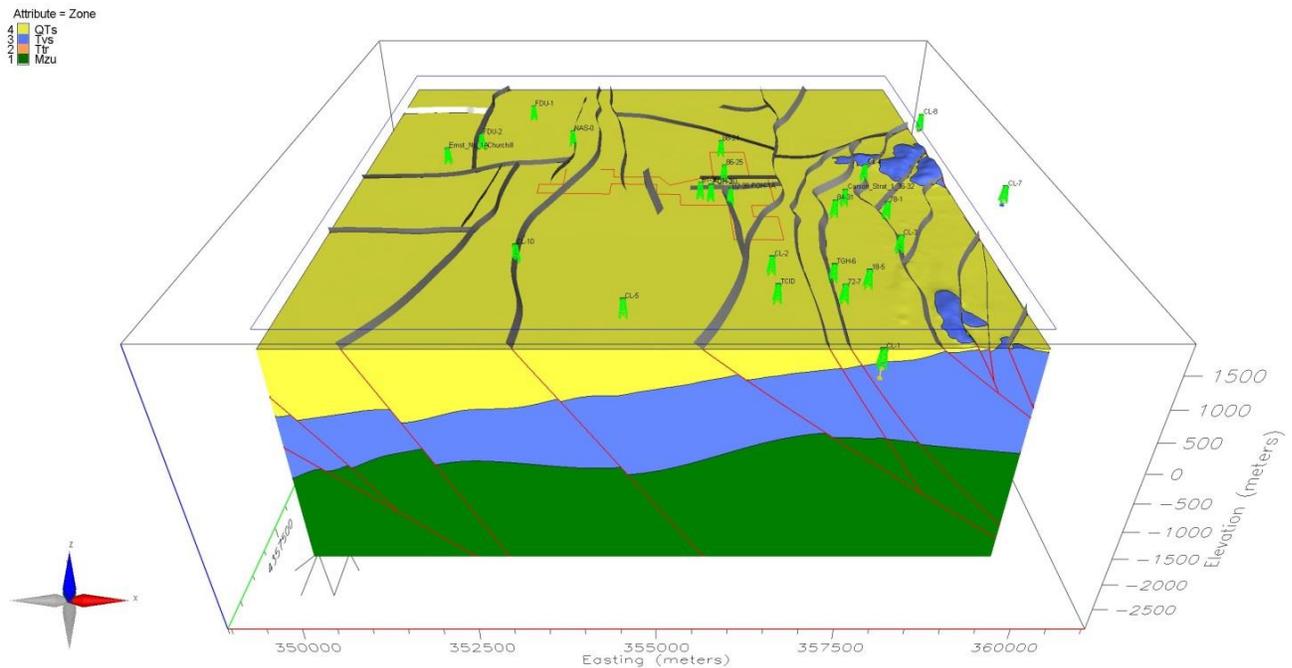


**Figure 5. Seismicity recorded between July 2015 and January 2016 by GPO’s local seismic array installed at NAS Fallon.**

The NAS Fallon seismic array will be improved for the FORGE project. Dedicated wells will be drilled for seismic monitoring, 3-component sensors will be installed, and a refined velocity model will be developed. These improvements will enable robust real-time monitoring during operations, and improved event location accuracy.

## 2.2 FAULTING IN THE FALLON FORGE AREA

The Fallon FORGE team has investigated known faulting in the area. Figure 6 is a 3-D rendering of the faults that have been mapped or interpreted in the subsurface within a 100 km<sup>2</sup> area centered on the FORGE site, as derived mainly from pre-existing seismic reflection data. Detailed geologic mapping in the area shows that these are pre-late Pleistocene age faults, and the available earthquake data discussed above demonstrate a lack of seismicity within and directly adjacent to the Fallon FORGE site. Overall, faulting is sparse within the FORGE site, providing considerable volumes of un-faulted rock in which new EGS wells will be placed.



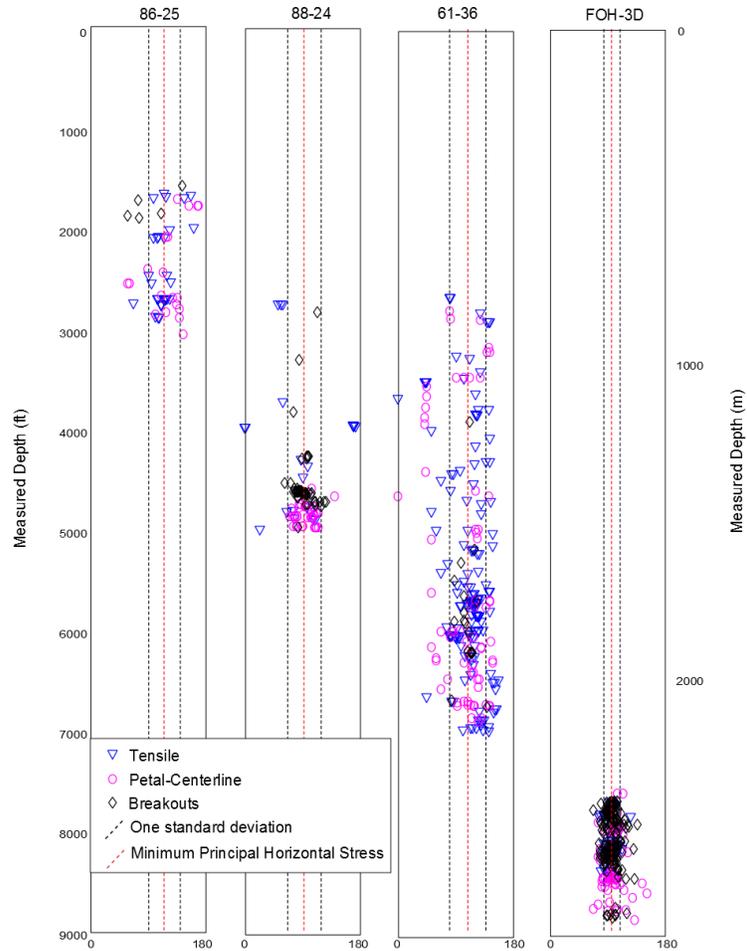
**Figure 6. 3-D fault model of the region around the Fallon FORGE area (outlined on the model surface in red). Shallow and deep wells in the area are shown in bright green. The dark green unit in the subsurface is the basement rock that will be targeted for FORGE activities.**

In Phase 2, the Fallon FORGE team will continue to investigate geologic structure to optimize well locations with respect to major faults.

### 2.3 STATE OF STRESS

As described in the geologic model, there has been a great amount of work to determine the principal stress orientations at NAS Fallon by evaluating the kinematics of natural faults, and from analysis of image logs from the 88-24, FOH-3D, 61-36 and 86-25 wells. To help understand the extensional setting and the state of stress throughout the Basin and Range province, principal stress orientations have also been acquired through focal mechanisms, *in-situ* stress measurements, alignments of volcanic structures, and geodetic measurements of strain (references to this work are included in the geologic model report). Within the potential EGS system at Fallon, a complete understanding of stress state, the structural setting, and the heterogeneity of the principal stresses is being used to understand how the reservoir rock will respond to stimulation, with particular focus on the dilation, slip, and propagation of fractures.

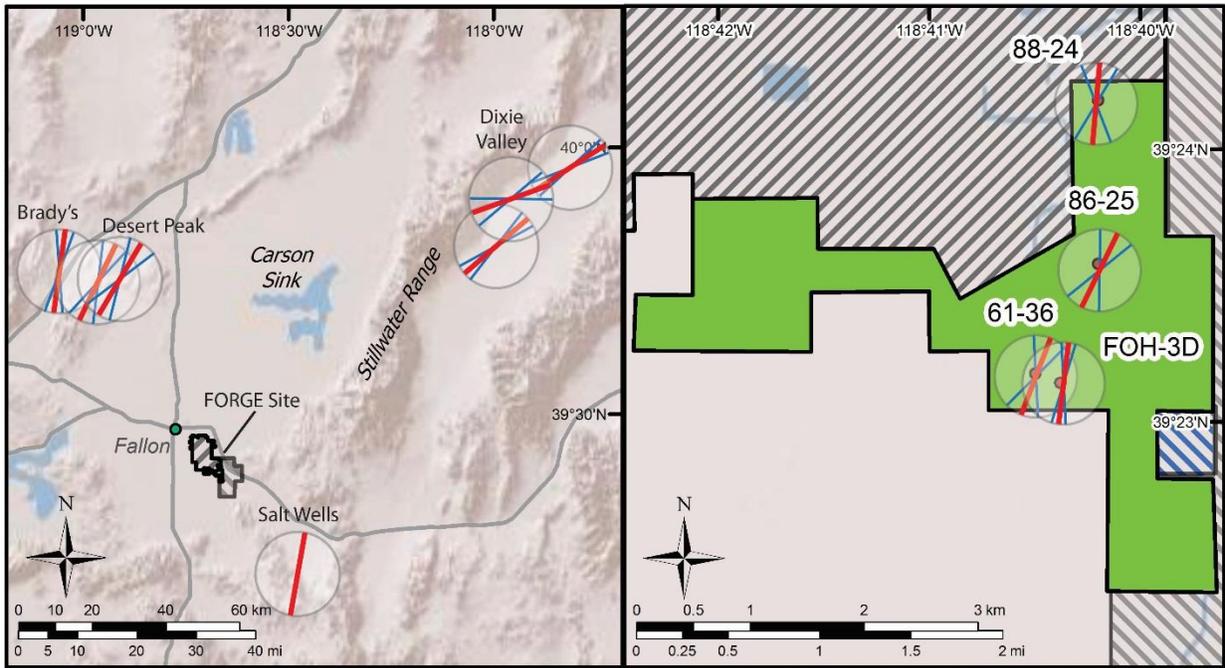
Data from wellbore image logs in the four wells noted above have been analyzed for drilling-induced tensile fractures, borehole breakouts and petal centerline fractures to evaluate the stress orientation. The results are shown in Figure 7 below.



**Figure 7. Borehole failures in wells in the Fallon FORGE area used to evaluate stress orientation.**

As can be seen, the data are consistent with the dominant direction of faulting in the area (NNE), although there is some variation in stress orientation across the drilled area. The variation in stress orientation is lowest in the basement rock, which is the target unit for hydraulic stimulation.

Figure 8, below, presents the orientation of the maximum horizontal stress ( $S_{Hmax}$ ) as determined from borehole failures in wells in Fallon and other nearby geothermal fields, including Brady’s Hot Springs, Desert Peak, Salt Wells and Dixie Valley. Within the Carson Sink (i.e., at all locations other than in Dixie Valley, the  $S_{Hmax}$  direction has a reasonably constant NNE orientation.



**Figure 8. Stress orientations in the Fallon FORGE area (right) and at other nearby geothermal fields (left).**

#### 2.4 ASSESSMENT OF THE MAGNITUDE OF POTENTIAL INDUCED MICRO-SEISMICITY

The nearest population center is Fallon, a town of about 12,000 people, located about 12 km NW of the project area. There are no other population centers within 45 km. On the basis of 1) current data that has informed the geologic model of the site and 2) experience in current and previous DOE EGS demonstration sites in Northern Nevada, Idaho and California, the probability that induced seismicity resulting from activities at the Fallon FORGE site will impact nearby communities is extremely low. A conservative estimate is that a Richter magnitude ( $M_L$ ) 3.0 event might be felt in Fallon, but would cause no significant damage to any known structure or facility.

The size of an earthquake (or how much energy is released) depends on the amount of slip which occurs on a fault, how much stress has accumulated on the fault before slipping, how quickly it fails, and over how large an area failure occurs (Brune and Thatcher, 2002). Considering the distance between the Fallon FORGE area and the city of Fallon, earthquakes generated within the Fallon FORGE area that have the potential to cause damage in Fallon would need to have Richter ( $M_L$ ) magnitudes greater than 4 or 5, and would require slip over relatively large lengths of a fault (Majer *et al.*, 2007).

In addition to the size of the fault, the strength of the rock determines how large an event may potentially be. It has been shown that in almost all cases, large earthquakes (Richter magnitude 6 and above) start at depths of at least 5 to 10 km (Brune and Thatcher, 2002). It is only at depth that sufficient energy can be stored to provide an adequate amount of force to move the large volumes of rock required to create a large earthquake. Experience in other EGS projects shows that induced seismicity is significantly shallower (at depths similar to the depths of the stimulated wells) and events have low magnitudes.

Based on the location and limited spatial extent of the Fallon FORGE area, together with the well-defined, predominantly NNE-trending structures which bound the system, the probability of induced seismic events to be propagated toward nearby communities is exceedingly low. The trend of fractures that are the most likely to shear (causing induced micro-seismicity) is parallel to the main faults in the area (i.e., this zone will propagate in the NNE-SSW direction). In Phase 2, geologic structures will be investigated in more detail to evaluate the likelihood of any hidden and potentially hazardous faults, and the existing seismic monitoring system will be improved and used to monitor all induced seismicity, with particular attention to any seismicity that appears to be migrating toward Fallon.

## **2.5 REVIEW OF LAWS AND REGULATIONS**

Our review revealed no federal, state, or local laws or regulations expressly addressing induced micro-seismicity associated with geothermal activities. However, both federal and Nevada state laws are relevant to induced micro-seismicity, as follows:

### **2.5.1 Geothermal Steam Act of 1970 and Regulations Promulgated Thereunder**

The Geothermal Steam Act of 1970 (30 U.S.C. §§ 1001-1028) authorizes the Bureau of Land Management (BLM), under authority delegated by the Secretary of the Interior, to promulgate regulations that protect the public interest against activities undertaken by geothermal lessees on Federal land (30 U.S.C. § 1023[c]). The BLM's geothermal regulations broadly define drilling operations to include downhole operations undertaken for the purpose of producing geothermal fluids or injecting fluids into a reservoir (43 C.F.R. § 3260.10[a]). The regulations require that all drilling operations comply with applicable law (43 C.F.R. § 3262.10[c]) and be conducted in a manner that minimizes noise and prevents property damage (43 C.F.R. § 3262.11[a][4] & [5]) and that "protects public health, safety, and property" (43 C.F.R. § 3260.11[d]).

In the unlikely event that induced micro-seismicity were to pose a threat to public health or safety or to public or private property, BLM has broad authority to take corrective action. BLM can immediately issue oral (43 C.F.R. § 3260.12[e]) or written orders (43 C.F.R. § 3265.12[a]) with respect to operations causing induced micro-seismicity. BLM may also enter onto the lease and take corrective action at the lessee's expense, draw on the lessee's bond (see 43 C.F.R. Subpart 3214), require modification or shutdown of the lessee's operations, and take other corrective action (43 C.F.R. § 3265.12; see 43 C.F.R. §§ 3213.17 & 3200.4).

### **2.5.2 Safe Water Drinking Act UIC Program**

The Safe Drinking Water Act (42 U.S.C. §§ 300f-300j-26) authorizes the U.S. Environmental Protection Agency to regulate underground injection of fluids under the act's Underground Injection Control (UIC) program. In the State of Nevada, the U.S. Environmental Protection Agency has delegated primary enforcement authority under the UIC program to the Nevada Division of Environmental Protection (NDEP) (NRS § 445A.425[1][c] & NAC § 445A.866). Operators of injection wells must obtain a permit from NDEP (NAC §§ 445A.865-910). NDEP may revoke or suspend the permit upon a determination that the permitted activity endangers human health and can only be regulated to acceptable levels by such action (NAC §§ 445A.865 & .885[1]). In the unlikely event that induced micro-seismicity were to pose a threat to public health or safety, NDEP could revoke the project's injection well permit.

### 2.5.3 State Law Regulating Geothermal Operations

To drill and operate a geothermal production or injection well, Nevada law requires a permit granted by the Nevada Division of Minerals (NDOM, part of the Commission on Mineral Resources) (NRS 534A.060[1]). NDOM may impose conditions on the permit as deemed necessary to protect the public interest (NRS 534.070[4] & [5]), and NDOM may suspend or revoke the permit under the inherent authority of its police power in order to protect the public interest. In the unlikely event that induced micro-seismicity were to pose a threat to public health or safety or public or private property, the Nevada Department of Environmental Production (NDEP) could revoke the project's geothermal well permit.

### 2.5.4 State Tort Law

Our research revealed no case law (in Nevada or in any other U.S. jurisdiction) addressing civil liability associated with induced micro-seismicity. However, as noted in the only known scholarly review of this area of law (Cysper and Davis, 1994), cases addressing damage caused by human-induced vibrations of the earth are analogous and provide support for the application of various tort theories of liability to damage caused by induced micro-seismicity. Applicable tort theories include trespass, strict liability for abnormally dangerous activities, nuisance and negligence. As such, these theories are generally applicable in the unlikely event that induced micro-seismicity were to cause any property damage or personal injury.

Nevada courts have followed common law doctrine on each such theory without relevant variation or elaboration. For example, see:

- *Ransdell v. Clark County*, 192 P.3d 756, 760 (Nev. 2008) and *Countrywide Home Loans, Inc. v. Thitchener*, 192 P.3d 243, 249-50 (Nev. 2008), which address claims of trespass to land;
- *Valentine v. Pioneer Chlor Alkali Co.*, 864 P.2d 295, 297 (Nev. 1993), recognizing liability for abnormally dangerous activities as provided in §§ 519 & 520 of the Restatement (Second) of Torts (1977);
- *Edwards v. Emperor's Garden Restaurant*, 130 P.3d 1280 (Nev. 2006), addressing a claim of private nuisance;
- *Layton v. Yankee Caithness Joint Venture, LP*, 774 F.Supp. 576 (D. Nev. 1991), dismissing on summary judgment nuisance claim against operator of geothermal power plant for alleged injuries caused by normal plant operation); and
- *Butler ex rel. Biller v. Bayer*, 168 P.3d 1055, 1065 (Nev. 2007), listing the elements of a negligence claim).

The Fallon FORGE team will continue to review any legal cases related to induced seismicity throughout the life of the FORGE project.

## 3 COMMUNICATION AND OUTREACH PLAN (PROTOCOL STEP 2)

In Phase 1 of the Fallon FORGE project, the team has identified people and organizations (including community leaders and public safety officials) in the Fallon area that are interested in the project, and has held preliminary discussions about the activities that are expected to take place, including discussions about the possibility of induced seismicity. These meetings provided a venue for gauging interest in the project and identifying concerns. The response from

the city of Fallon and Churchill County has been positive and informing. This process will continue as the project progresses.

We report below on specific aspects of our outreach related to induced micro-seismicity that are planned for implementation in Phase 2; others will be developed as appropriate.

### **3.1 IDENTIFICATION OF EMERGENCY RESPONSE PROVIDERS AND STAKEHOLDERS**

As part of the Phase 1 preparation work on the Fallon FORGE project, representatives of the site operators (Ormat and the U.S. Navy) have identified the local entity with overall responsibility for emergency response: Churchill County's Local Emergency Planning Committee (LEPC), a representative group of emergency responders, planners, business and industry representatives, health care providers, elected officials, citizens and media that work together on community safety issues. Among other members, the LEPC includes the County Sheriff's Office and School District, the City of Fallon, the local fire department, the Fallon Paiute Shoshone Tribe, the Fallon Police Department, and NAS Fallon. The project will be presented to the LEPC in detail, including the activities and associated seismic response, details of the micro-seismic monitoring system, and the process for monitoring and mitigating any risks associated with induced micro-seismicity. Using a procedure followed at two previous EGS projects in Churchill County, the site operators will coordinate with LEPC periodically as the project proceeds, typically before initiating stimulation and testing activities.

### **3.2 DAILY COMMUNICATIONS PLAN**

DOE and geothermal operators have established a well-defined communication process that addresses the needs of the local community and DOE. This process was implemented successfully at two other EGS projects in Nevada: the Desert Peak and Brady's Hot Springs EGS projects, providing a guide for future EGS sites. Therefore, the following will be undertaken to maintain daily communications from the Fallon FORGE site:

- Implementing independent, duplicated micro-seismic monitoring and reporting systems on-site and at Lawrence Berkeley National Laboratory (LBNL), allowing DOE to monitor micro-seismic activity in real time.
- Sharing the daily project reports with DOE every day. The report describes on-site activities, process analysis, the micro-seismic event log, and the associated interpretation by LBNL.
- Providing weekly update reports from the project team to DOE and its Technical Monitoring Team (TMT) covering the process results, analysis, and trends.
- Operating a real-time induced micro-seismicity web site hosted at LBNL that is open to the public, including a catalogue and map showing the locations of events.

These activities are designed to enable effective daily communication about the projects and any associated induced seismicity.

### **3.3 FALLON FORGE PHASE 2 OUTREACH PLAN**

Among others, the Fallon FORGE team is planning the following outreach activities related to the project at large, providing opportunities to introduce and discuss induced seismicity:

- A series of meetings with the community, stakeholders, regulators and public safety officials (including the LEPC) to discuss technical and non-technical aspects of the project in advance of activities being initiated;

- Educational outreach for K-12 students and teachers in Fallon;
- Continuing the dialogue with the Churchill Economic Development Authority (CEDA) and other interested community members about the FORGE project and its benefits to the community;
- Planning for visits to the FORGE site by community members and other interested stakeholders before the start of operations and during periods of drilling, hydraulic stimulations, and other technical activities (with proper consideration of associated safety issues); and
- Developing a program for issuing periodic project updates and holding project-related events that celebrate EGS innovations and breakthroughs resulting from the Fallon FORGE project.

In addition to dissemination of more general information about the Fallon FORGE project, these will provide opportunities for discussions about induced micro-seismicity.

## 4 CRITERIA FOR GROUND VIBRATION AND NOISE (PROTOCOL STEP 3)

### 4.1 INTRODUCTION

The Protocol identifies the steps for identifying and evaluating existing standards and criteria to understand the applicable existing regulations for ground-borne noise and vibration impact assessment and mitigation that have been developed and may be applicable to the Fallon FORGE project. These standards and criteria apply to damage to buildings, interference with human activities (including industrial, commercial, research and medical activities) and wildlife habitat. In Phase 2 of the Fallon FORGE project, existing criteria developed for other industries (*i.e.*, not specifically for EGS projects) will be evaluated to determine their applicability, considering the proximity to EGS activities and the likely frequency (of occurrence) and magnitudes of induced micro-seismic events.

### 4.2 PRELIMINARY ANALYSIS OF THE IMPACTS OF MICRO-SEISMICITY AT THE FALLON FORGE PROJECT

The historical seismic data from past natural events indicate that Fallon site lies in an area of relatively low seismicity. For induced micro-seismicity associated with FORGE activities, the data indicate that local or Richter ( $M_L$ ) magnitudes will be mostly less than 1.0, with occasional events with  $M_L$  of 1.5 to 2.0. Microseismic data from other EGS sites show that the source area (fracture area which fails) is relatively small and varies in diameter from 10 to 40m. Source lengths in this size range will produce high-frequency vibrations that are unlikely to cause any structural damage. At the European EGS project at Soultz-sous-Forêts in France, an induced event with a Richter ( $M_L$ ) magnitude of 2.9 induced event had a frequency of around 80 Hz. This is relatively high frequency and is unlikely to cause any structural damage.

A direct measurement of particle acceleration (or velocity) and the frequency associated with it are more meaningful as there have been many observations and studies done to compare structural damage to these parameters. These studies are more associated with mining and subsidence; however, the correlations between with structural damage and particle acceleration/frequency component are valid for induced seismicity as well (Majer *et al.*, 2014). One of the most widely used standards for such situations is the German standard DIN 4150-3 (DIN 4150-3:1999 “Structural Vibration – Part 3: Effects of Vibration on Structures”). For

example, particle velocity of up to 5mm/s at 10-50 Hz or particle velocity up to 15mm/s at 50-100Hz is unlikely to cause any structural damage, as noted in Majer *et al.* (2014). There are ranges of such calculated values for industrial, residential and old buildings that need to be preserved.

Noise is another factor that is considered at this stage of the project. Based on our initial analysis of the likely depth and magnitudes of events, observations of noise around NAS Fallon and the distance to the City of Fallon, it is unlikely that noise created by any induced micro-seismicity will lead to any inconvenience to the local population.

#### **4.3 FURTHER WORK IN PHASE 2**

In Phase 2, the Fallon FORGE team will undertake additional work related to ground vibration and noise, including:

- With input from stakeholders, identifying any buildings or other structures that might be particularly sensitive to vibration;
- Selecting locations for ground motion sensors/accelerometers within NAS Fallon and the City of Fallon;
- Installing the motion sensors and establishing a base line for ground motions.

## **5 ESTABLISH A MICRO-SEISMIC MONITORING NETWORK (PROTOCOL STEP 4)**

### **5.1 PROGRESS AND FUTURE PLANS FOR THE NAS FALLON SEISMIC ARRAY**

In EGS projects like FORGE, seismic monitoring enables characterization of background seismicity, (*i.e.*, by establishing a baseline) and helps to understand regional fault-related deformation and ambient stress/strain around the target EGS area. This has been discussed above in Step 1 (Preliminary Screening Evaluation).

Typically, regional networks are not adequate for providing a detailed understanding of seismicity nor for monitoring induced micro-seismicity in an EGS project for two reasons:

1. Compared to events typically generated in EGS projects (that have Richter magnitudes of less than 2, down to -1 or less), their sensitivity is tuned to larger events (Richter magnitude 2 or higher).
2. The spacing between stations is relatively large (tens of km or more), the location accuracy of events within a small EGS area is poor.

As noted above, a seismic monitoring array is already established at Fallon, and since 2015 (in its more sensitive configuration) has detected many regional events in the area, but none within the confines of the array. Nevertheless, it has detected events around the array, to distances far greater than two times the radius of the FORGE target area, a distance recommended in the Protocol.

In Phases 2 and 3, the NAS Fallon seismic array will be improved to enable it to be used effectively in the FORGE project. In addition to the existing 10 stations in shallow boreholes (depth of 200 ft/60 m), dedicated wells will be drilled for seismic monitoring, 3-component sensors will be installed, and a refined velocity model will be developed. These improvements

will provide more detail in the baseline data collected before site operations begin, and enable robust real-time monitoring during operations and improved event location accuracy. Temporary densification of the array during operations will be planned after determining the optimum number and locations of additional surface or shallow borehole stations needed to ensure location accuracy during stimulation and other operations at the site.

During EGS stimulations and other operational activities, the monitoring array will be used to detect and map the progress of fracturing and the interconnection between fractures that enhance permeability within the low-permeability basement rock beneath the Fallon FORGE site. High quality data will be necessary to determine the success of stimulation activities, understand the evolution of permeability within the EGS reservoir, and provide credible scientific evidence to demonstrate that the project does not pose a threat to public safety.

It is well within the FORGE mission to have an array of seismic sensors that is capable of locating events with Richter ( $M_L$ ) magnitudes as low as -1 (possibly -2) with an accuracy of 50 m at most, with a bandwidth of 0.1 Hz to 1 kHz. In addition, the array will be designed to provide sufficient data coverage to produce accurate moment tensor and source mechanism information. Considering that FORGE is the site of robust underground experiments designed to understand the mechanics by which permeability can be increased to enable commercial production rates from EGS wells, the Fallon FORGE site will have an array that is suitable for all required purposes (accurate event locations, source mechanisms, accurate moment tensors, and other purposes yet to be defined. In other words, the Fallon seismic array will be highly instrumented and have a detailed velocity model that will improve our understanding of what is happening at depth.

In its current configuration, the micro-seismic monitoring system at NAS Fallon is being used as a first phase of monitoring the background seismicity down to Richter ( $M_L$ ) magnitude 0 with an accuracy of a few hundred meters, thus meeting the initial requirements of seismic monitoring during Phase2a.

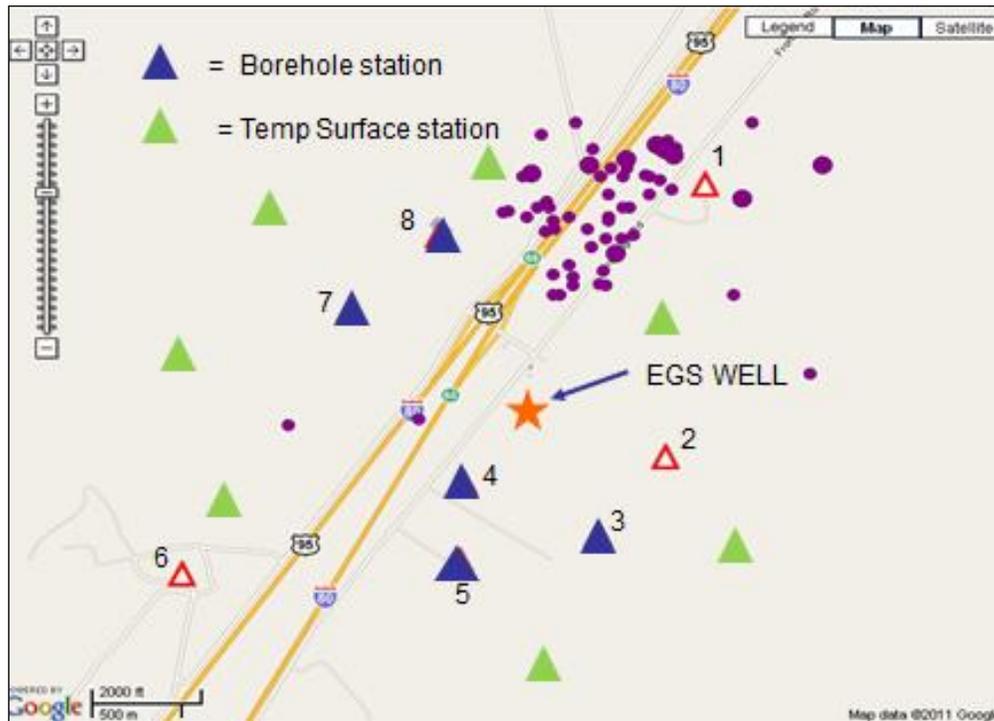
## **5.2 EXAMPLE: BRADY'S HOT SPRINGS SEISMIC MONITORING ARRAY**

Figure 9, below, shows the layout of a currently operating micro-seismic monitoring system installed at the Brady's Hot Springs geothermal field, which (like Fallon) is also located in Churchill County, Nevada. This current system is a multi-station station array with five borehole stations and three surface stations that is capable of detecting and locating in real time micro-seismic events down to magnitude 0 or lower. The system is capable of collecting data that can be used to locate events with a precision of 100 meters, derive source parameters of moment tensors, fault plane solutions, stress drops associated with individual events, and fault rupture dimensions. All of these capabilities are highly useful for EGS projects.

The system includes eight stations that are roughly centered around well 15-12 (the well that was stimulated). Each station is capable of digitizing three channels of data at 24-bit resolution at 500 samples per second. The data from the digitizers is transmitted to a central site with spread spectrum radios over an RS232 internet-compatible digital link at real-time data rates with time-stamps, using GPS corrected data. The central acquisition site has real-time data acquisition and detection software that selects individual events automatically and discriminates between micro-seismic events and spurious events such as noises created by traffic (Brady's is adjacent to a major interstate highway), wind and other noise. (The Fallon array will be tuned to discriminate actual events from noise created by aircraft operating out of NAS Fallon.) The data are

transmitted automatically to LBNL, where all processing is carried out in real time. Each surface station of the array has a 3-component 4.5 Hz geophone that is buried in the near surface (1 to 2 feet in depth) and oriented such that the horizontal components are oriented NS and EW.

Five of the stations have a buried 3- component 8 Hz borehole geophone in 300-foot-deep bore holes (BP-3, -4, -5, -7 and -8). The borehole stations significantly improved sensitivity during stimulation operations.



**Figure 9. The micro-seismic monitoring array at Brady's Hot Springs, the site of a stimulation of well 15-12.**

The temporary augmented array (indicated by green triangles in Figure 9) collect continuous data (24-bit, 500 samples per second) using 3-component 2 Hz geophones that were deployed before, during, and after the EGS stimulation activities. These temporary surface stations were used to determine a more complete (moment tensor) mechanisms of the micro earthquakes, and for studying long-period noise. Data from the surface stations also improved the spatial uniformity of hypocenter-location resolving power throughout the EGS project area. Data were recovered during site visits, by exchanging digital storage cards that have the capacity to record for at least 3 months.

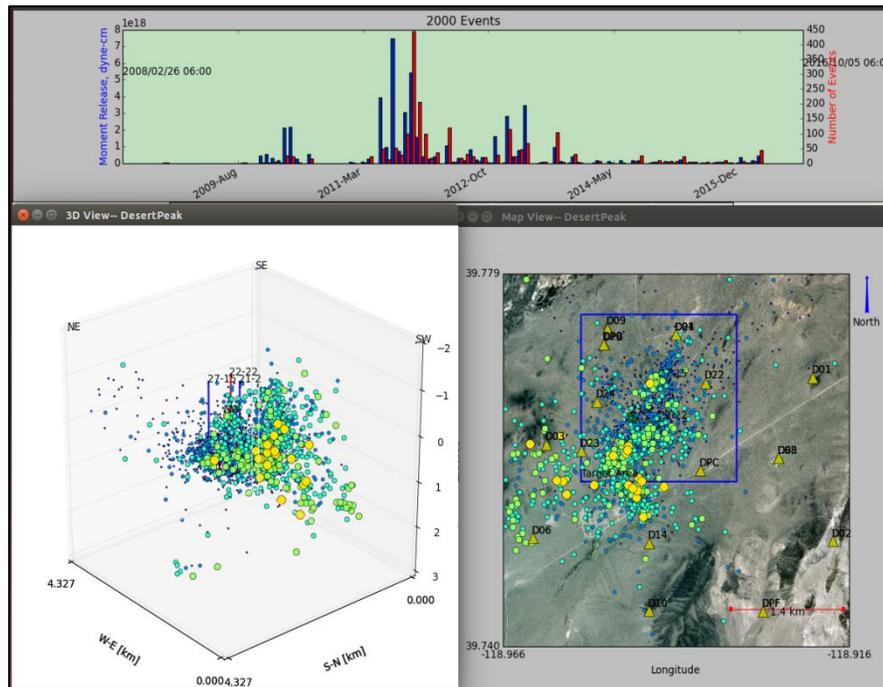
## 6 QUANTIFY HAZARD FROM NATURAL AND INDUCED SEISMIC EVENTS (PROTOCOL STEP 5)

### 6.1 LESSONS LEARNED FROM SIMILAR EGS PROJECTS IN NEVADA

Although the historical seismicity at the Fallon FORGE site and the prospect of creating potentially damaging micro-seismic events are both very low, the hazards associated with ground shaking due to induced and natural seismicity need to be investigated. The first step is to use empirical data from relevant case histories. In the case of Fallon, the nearby Desert Peak and

Brady’s Hot Springs EGS projects provide useful information. Experiences at these two projects provide an indication of how the Fallon site may respond to injection activities.

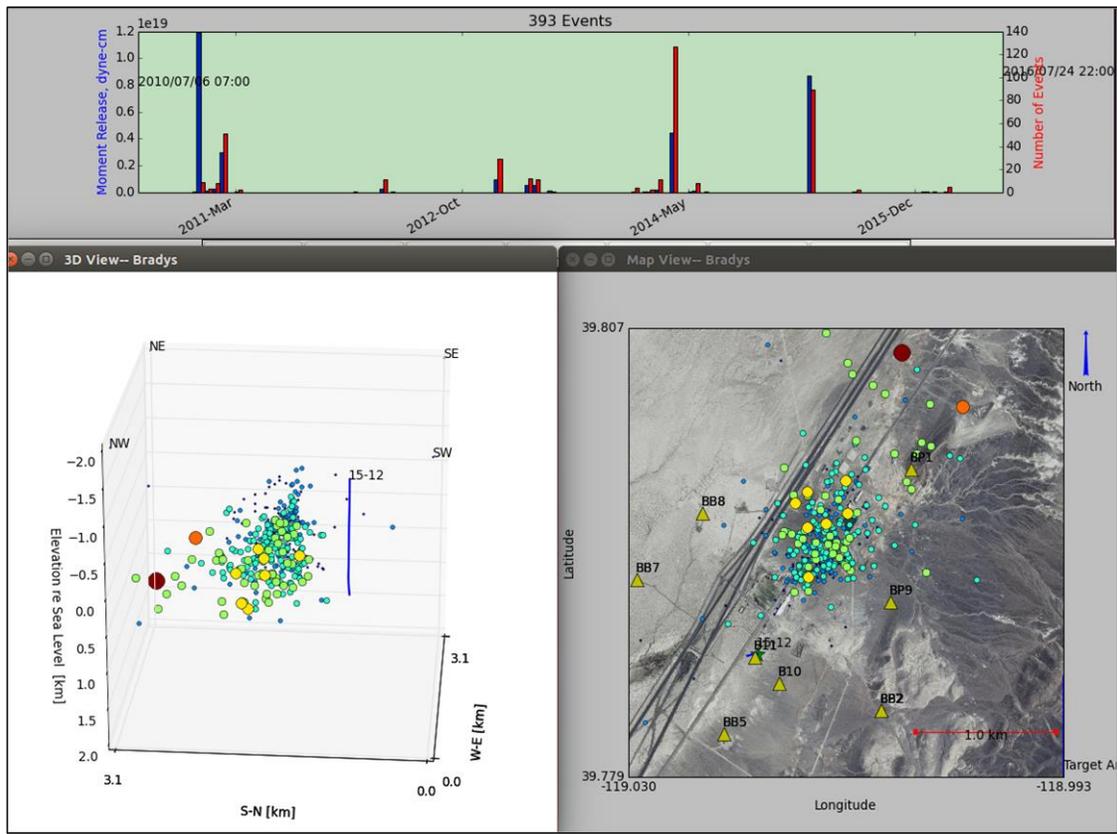
Figure 10 below shows the seismicity at the Desert Peak EGS project during a monitoring period of more than 5 years. The micro-seismic activity (2000 events) has been a function of injection at the EGS well and the other injection wells. There was a peak of seismicity (2011- 2013) during the main EGS activity in the target well 27-15; the largest event during the entire monitoring period was magnitude 1.7.



**Figure 10. Micro-seismicity and the seismic monitoring array at the Desert Peak EGS project.**

Figure 11, below, presents similar data for the Brady’s Hot Springs EGS project. A first examination of the seismicity reveals a correlation to particular sharp changes in injection/production activities (these data are not included in Figure 10), which is not unusual for geothermal fields. As shown in the lower left figure below, no seismicity has been associated with stimulation of EGS well (15-12); it has all been associated with the main production/injection activities north of the EGS site. The largest event has had a magnitude of 2.0. *No damage was caused by this small event, and no concern by the local population was reported.*

A comparison of seismicity with net volume injection shows only one small peak in early 2012 that correlates with seismicity. The events comprising this peak were part of a series of events that propagated northward out of the geothermal field, suggesting a natural (rather than induced) origin. *The magnitudes of induced seismic events at Brady’s are very small; other than the one event mentioned above, all are less than 2 and most are in the range of 0 to 1. This shows that very little seismicity is generated relative to the amount of water injected. Supporting this conclusion is the alignment of induced seismicity with the NNE-SSW trend of faults.*



**Figure 11. Micro-seismicity and the seismic monitoring array at the Brady's Hot Springs EGS project. Note the lack of seismicity around the stimulated well (15-12).**

Additional data from a combined chemical and high-pressure stimulation in Desert Peak EGS well 27-15 (between 6 February and 29 April 2011) are relevant when considering the design of the micro-seismic monitoring array at the Fallon FORGE project. During the period from 2-19 April 2011, a total of 42 events were located inside the monitoring volume at Desert Peak, as shown in Figure 12, the surface area of which defines the target area shown in Figure 13 and Figure 14. These results demonstrate that if seismic data are to be collected from relatively small injections like that into well 27-15, the detection threshold magnitude should be at least -1, and preferably as low as -2. This would require 300- to 500-foot-deep (~90-150 m) boreholes specifically drilled for downhole seismic monitoring in an optimal pattern around the injection well. Deeper wells with geophone arrays would further improve the ability to locate small events.

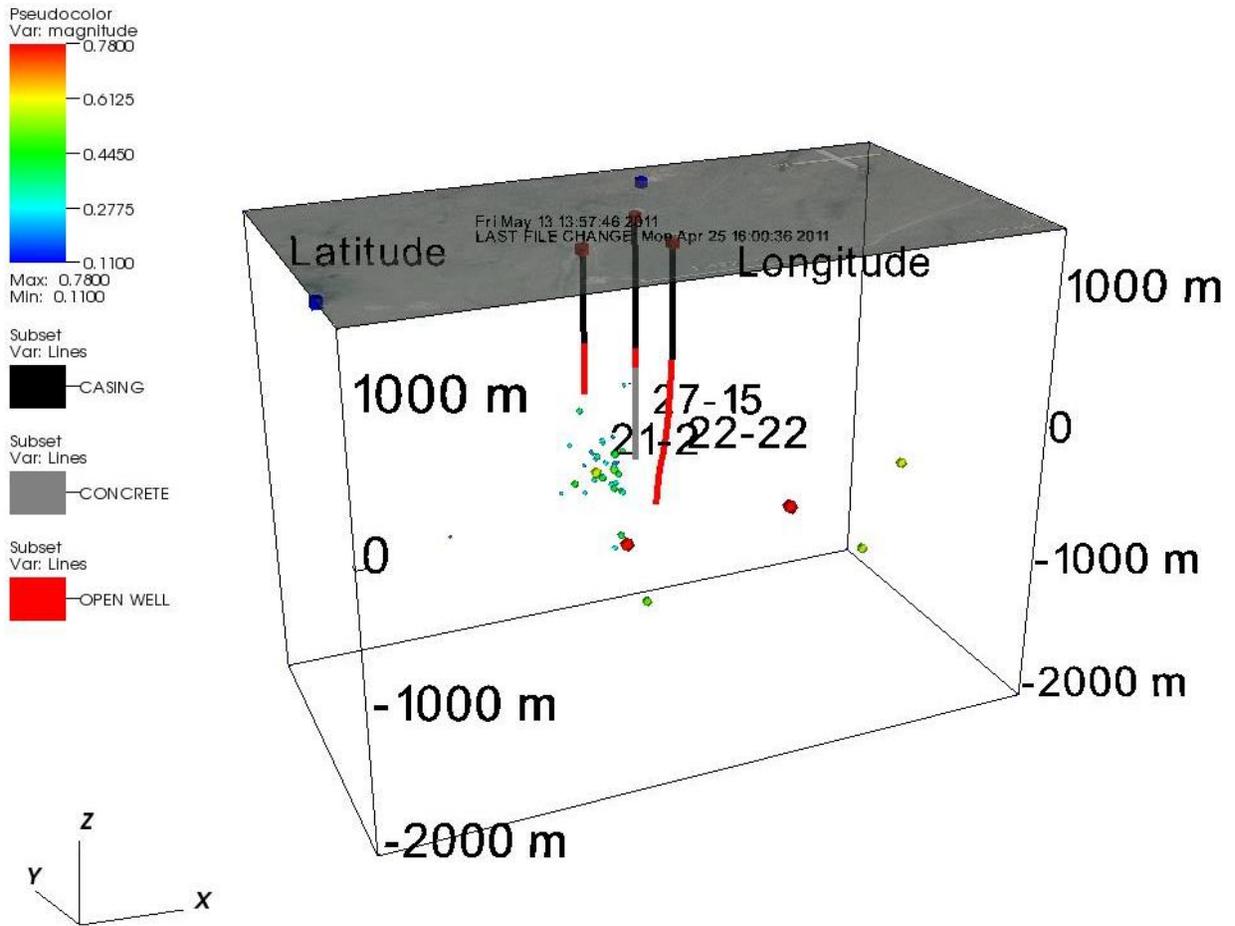


Figure 12. Seismic events recorded from 2 April to 13 May 2011 during a high-pressure stimulation of Desert Peak well 27-15.



Figure 13. The surface outline of the 12 km<sup>3</sup> Desert Peak EGS target area, which is centered on the target well (27-15).

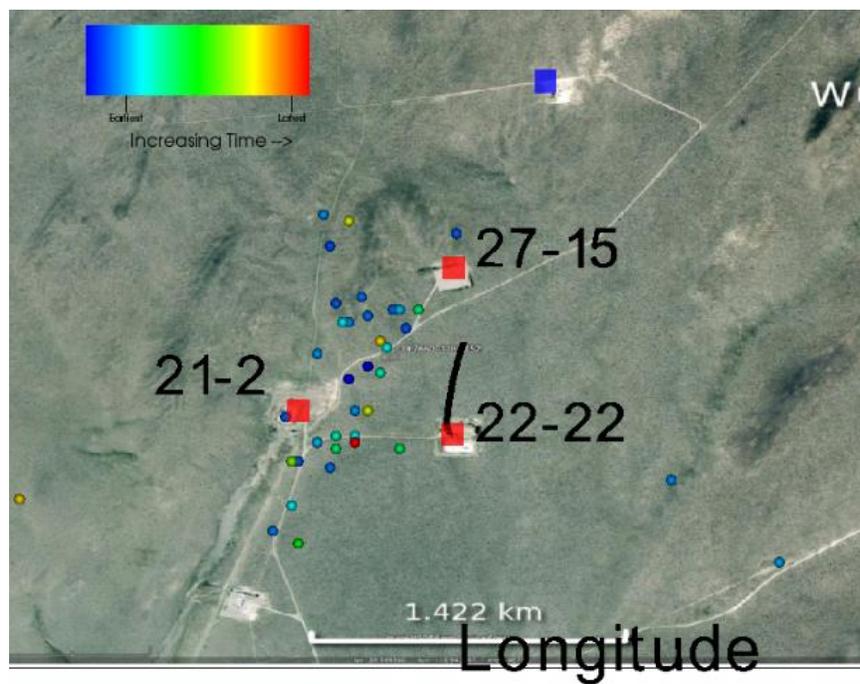


Figure 14. Plan view of seismicity as a function of time during the high-pressure stimulation of well 27-15 in 2011. Blue dots represent the earliest events, and red dots represent the latest events.

## 6.2 PHASE 2 HAZARD ASSESSMENT PLANS AT THE FALLON FORGE PROJECT

Probabilistic or deterministic seismic hazard analysis (PSHA and DSHA, respectively) are two methods commonly used to assess ground motions associated with seismicity. The former (PSHA) is more commonly used since it provides the probability that a specified level of ground motion (*i.e.*, one that could lead to damage) would be exceeded. The Protocol recommends performing a PSHA for a magnitude 4 event to consider the potential for damage, and a lower magnitude to consider “nuisance” (people being disturbed by induced micro-seismicity) and/or interference with highly sensitive activities. The hazard is expressed in terms of Peak Ground Acceleration (PGA), acceleration response spectra, and Peak Ground Velocity (PGV) or Peak Particle Velocity (PPV). However, because both the magnitude and duration of induced seismic events are low, there is a low probability of structural damage to buildings.

The overall process of the PSHA is to undertake it first for natural seismicity, and then superimpose the induced seismicity to evaluate the incremental addition to the pre-existing, natural hazard. Background seismicity in this area has been discussed in Step 1 above. Active faults are located and within the Carson Sink; for example, the Rainbow Mountain Fault Zone and the faults surrounding the Stillwater Range, which have had relatively large events in the last century. These events and others in the area provide useful information for a PSHA, including source fault orientation, event magnitudes and recurrence rates. It is noted that no known active faults pass through the proposed Fallon FORGE area.

In comparison to large, natural tectonic earthquakes, the hazard associated with induced seismicity is very low. Nevertheless, micro-seismicity is anticipated. Therefore, the Fallon FORGE team has developed a detailed geologic model, including faults in the project area, and analyzed the ambient stress field around the Fallon site (see section 1 of this preliminary ISMP). Based on planned injection and pore pressure increase scenarios, and by analogy with similar EGS projects (see above), the maximum magnitude of an induced event and the likely rates will be estimated. From this, the maximum ground motions will be calculated.

## 7 CHARACTERIZATION OF THE RISK FROM INDUCED SEISMIC EVENTS (PROTOCOL STEP 6)

### 7.1 PROBABILITY OF AFFECTING NEARBY COMMUNITIES

The project target area is defined as the effective area in which micro-seismic events are expected to occur. The Fallon FORGE target area will be defined taking the following in consideration:

- Geological and geophysical survey data
- Stress field orientation (particularly the direction of the maximum horizontal stress,  $S_{Hmax}$ ) as determined from recent fault trends and analyses of wellbore failures
- Previous records of the effective distribution of induced micro-seismic events in similar EGS projects (a radius of 500 m around the stimulated well is reasonable)
- The 3D geologic model, including mapped fracture and 3D reservoir analysis
- Preliminary interpretation of ground deformation (*e.g.*, from ground leveling surveys, high-resolution GPS data or InSAR interferometry)
- All known historical seismicity
- Known faults dimensions within the target FORGE volume

- Volume, rate and pressure of injections

The observations and assessment presented above suggest that the likelihood of generating large seismic events in the specific region around the proposed Fallon FORGE site is very low. For example:

- There are no recorded natural earthquakes greater than 2.7 in the area, indicating that residual strain energy within this environment is relatively low.
- The volumes to be injected during the proposed stimulations are unlikely to accommodate large amounts of strain, and thus are unlikely to generate large induced seismic events.
- The superficial material in this area is loose volcanic sand, which is likely to absorb the majority of the energy from either natural or induced events.

Additionally, it is noted that the nearest populated residential area is at least 12 km away from the FORGE site. Therefore, events generated during stimulation activities are unlikely to be noticed by residents some 12 km distant from the injection site.

The analysis described above indicates that it may not be necessary for this site to implement all aspects of the protocol. However, it will be reasonable and prudent to install strong motion seismometers in Fallon (the nearest population center to the project area) to record ground velocity and frequency. As noted above, the placement of these instruments will be determined in cooperation with local stakeholders to ensure they are placed in area of particular importance, demonstrating to the residents that all due care has been taken to protect their property and that accepted criteria for structural damage will be used.

## 7.2 POSSIBLE EFFECTS AT NAS FALLON

The nearest operating facility NAS Fallon, where the most critical facilities are the runways. The observations and anticipated magnitude of seismic events indicates in this area suggests that it is unlikely to have any adverse effect on the runways or facilities. Based on typical construction methods of major runways, it is estimated that the critical event would have to be a magnitude 4 or larger to be of concern.

## 8 RISK MITIGATION (PROTOCOL STEP 7)

The first six steps of the induced seismicity protocol suggest various activities to address the impact of induced seismicity. If the induced seismicity exceeds the design maximum from the injection parameters (yet to be determined) or if major deviations from assumed geologic and stress conditions are encountered during the operation of the FORGE, then it may be necessary to perform additional actions.

Two broad areas of measures could be used to mitigate any adverse or unwanted effects of induced seismicity (Majer *et al.*, 2014):

- **Direct mitigation** refers to those actions engineered either to reduce the seismicity directly or relieve the effects of the seismicity. Examples of this approach include modification of the injection or production rates, and a calibrated control system that has been dubbed the “traffic light” system. This is a system for real-time monitoring and management of the induced seismic vibrations, which relies on continuous measurements

of the ground motion (usually PGV) as a function of injection rates and time. The traffic light system may be appropriate for many FORGE operations in that it provides a clear set of procedures to be followed in the event that specific seismicity thresholds are reached (Majer *et al.*, 2007). The traffic light system and the thresholds that would trigger certain activities by the operator should be defined and explained in advance of any operations.

- **Indirect mitigation** refers to those actions that are not engineered, but involve such issues as public/regulatory acceptance or operator liability. The level and amount of any indirect mitigation will be specific to different activities conducted at the Fallon FORGE site. Seismic monitoring, information sharing, community support, and direct compensation to affected parties are among the types of indirect mitigation that will be considered. Early support from the developer to the community can improve the ability to respond effectively to a potentially impacted community in the event of problematic induced seismicity. This may come in the form of that may be tailored to the specific needs of the community.

In most instances at Fallon, from our present knowledge of seismicity hazard, community and Navy assets, little or no mitigation may be required to gain public acceptance. However, if there is any indication that induced micro-seismicity may affect critical facilities (such as facilities on the Navy base) or if structures are experiencing unacceptable ground motion, mitigation measures would be required. At Fallon it is anticipated that by properly carrying out the preceding six steps, mitigation will not be required in the majority of instances. However, in Phase 2, the Fallon FORGE team will develop a full set of options that can be implemented if and when needed.

## 9 CONCLUSION

In summary, the information gathered to date indicates a very low risk of any significant impact related to induced seismicity that would occur during operations at the Fallon FORGE site. Historical seismicity records for the past 100 years have shown that there has been no seismicity of magnitude 1 or greater within at least a 10 km radius of the proposed Fallon FORGE site. Expected micro-seismicity from EGS stimulations and other operations is also expected to be at a level well below that leading to potential damage or other risk at NAS Fallon and in the City of Fallon. Our examination of induced micro-seismicity at nearby EGS projects is consistent with the preliminary predictions of magnitudes for induced seismicity at Fallon. Should a higher level of induced seismicity occur, pre-determined mitigation measures can be implemented, based on accurate, real-time monitoring of seismicity during site operations. This is a critical element in making FORGE a success.

A world-class EGS observatory must have a world-class seismic monitoring system to fully understand subsurface mechanisms associated with the manipulation and control of fractures. Therefore, building on the existing GPO seismic monitoring installation, the Fallon FORGE team will design and implement a seismic array with the sensitivity to detect and accurately locate events with magnitudes less than -1.0 (ideally down to -2.0) and have a spatial coverage that is optimal for deriving accurate moment tensor solutions from the recorded micro-seismic data.

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## **APPENDIX K. ENVIRONMENTAL SAFETY AND HEALTH PLAN**

# ENVIRONMENTAL SAFETY AND HEALTH PLAN

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Fallon, NV

## NAS FALLON



*Geothermal Research  
Observatory*

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# ENVIRONMENTAL SAFETY AND HEALTH (ES&H) PLAN

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Fallon, NV

## 1 Introduction

Frontier Observatory for Research in Geothermal Energy (FORGE) is a dedicated site to enable scientists and engineers to develop, test, and accelerate breakthroughs in enhanced geothermal system (EGS) technologies and techniques. Fallon FORGE is a DOE operation with the associated prime contractor being Sandia National Laboratories (SNL). The Department of Energy (DOE) requires that all work performed by the Department and its contractors follow a broad set of requirements for Integrated Safety Management (ISM). The DOE ISM directive is the foundation for Sandia National Laboratories' Integrated Safety Management Systems (ISMS) and its approach to Environmental, Safety, and Health (ES&H); therefore, the Sandia ISMS is the basis for the FORGE ES&H Plan. Per DOE requirements, this ES&H plan and any revisions of this plan cover all Fallon team members and contractors working on this project. This plan and its attachments are subject to revisions throughout the project and will be updated as necessary. Revisions will include any new environmental safety and health requirements, new contact personnel, new training requirements, and new contractors.

The core functions of the Sandia ISMS, as applied to Fallon FORGE operations, provide the structure to mitigate risks and hazards to the public, the worker, and the environment, effectively integrating safety into all facets of work planning and execution. As illustrated in Figure 1, these functions include the following five elements:

- **Define Work Scope:** Translate the required activity into work, set expectation, identify and prioritize tasks, and allocate resources.
- **Analyze Hazards:** Identify, analyze, categorize, and communicate hazards and associated impacts associated with the work.
- **Control Hazards:** Identify controls to prevent or mitigate hazards and environmental impacts.
- **Perform Work:** Confirm readiness and then perform work safely and in an environmentally responsible manner.
- **Feedback and Improve:** Gather feedback information on the adequacy of controls, identify and implement opportunities for improving the definition and planning of work, and conduct line and independent oversight.



**Figure 1. Integrated Safety Management System Core Functions associated with FORGE**

These five core functions are not unique to the operations of FORGE but form the basis of any comprehensive effort to reduce project risk to personnel, the public, or the environment. As such, this plan is not a substitute for plans or requirements originating from other entities (e.g., Department of the Navy, R&D participants, vendors, FORGE Team Members, etc.). This ES&H plan, with its attachments, provides structure for participating organizations and describes how work will be carried out at Fallon FORGE.

Relative to site specific issues, Appendix A (Emergency Response Plan) provides detailed information regarding the requirements set forth by DOE regarding identification of contact personnel responsible for on-site safety, as well as provides for procedures and protocols for hazards communication, emergency evacuation and response, and any ES&H training requirements. As specific operational procedures are developed (e.g., earthwork, drilling, hoisting & rigging, elevated work ...) they will be developed within the guidelines of US Army Corps of Engineers EM-385-1-1; Safety and Health Requirements Manual <http://www.usace.army.mil/SafetyandOccupationalHealth/EM38511,2008BeingRevised.aspx>.

## **2 Participating Organizations**

All project participants engaged in on-site FORGE activities, either through competitively funded R&D, directly contracted work, or vendor services will be required to have an approved safety plan in place to perform specific work outlined in Phase 2. Those plans will be reviewed by the FORGE project manager or his/her delegate. Such plans will need to contain the fundamental elements associated with the broader FORGE ES&H plan, and will need to comply with the Navy installation ES&H requirements outlined in Attachment A.

### **3 Ownership**

The Fallon FORGE project manager is responsible for ensuring that the criteria in this document are implemented.

## **4 Overarching Criteria**

### **4.1 Safe-by-Design Intent**

Safety is an attribute of a system of interconnected elements—people, procedures, facilities, equipment, and the hazards inherent in them and that to which they are applied. If one element of the system changes, the system is changed and must be reexamined in the new context. All elements must remain seamlessly tied together from the design phase through the execution phase. As different organizations are integral to the system, particular attention must be paid to early involvement and reliable communication across the organizational interfaces during project execution. Poor communication of safety-related information across organizational interfaces is a frequent contributor to accidents.

Human performance is an integral part of the system and is often overlooked in planning because of trust and respect in each other's competence. However, human performance is a common source of error. Accident pathways resulting from human error must be identified upfront and removed or blocked by design intent. Further, robustness should be built into the design of the system to compensate for uncertainties in human performance.

Safety is most effectively and efficiently achieved by designing it into the system at the conceptual or initial planning stages. However, it should not be reflexively assumed that designing safety features into an existing system will be difficult, time-consuming, or expensive. Effort expended toward this aim should be proportional (graded) to the severity of potential accident consequences.

### **4.2 Understand Technical Basis**

It is vital to understand how a system design works to accomplish its performance objectives. From a safety perspective, it is vital to understand how the system design can fail and cause an accident. Formal hazard analysis appropriate to the technical complexity of the activity will inform decision-making on the number and type of controls necessary to reduce the probability of occurrence. While this analysis can be relatively straightforward for a new hazardous activity, it can be problematic for older facilities and operations. The technical basis of an existing hazardous activity must be reconstructed sufficiently to assure continued safe operations. The effort will be prioritized according to the severity of potential accident consequences.

### **4.3 Identify and Control Energy Sources**

Stored energy in all of its forms and guises must be identified and controlled with appropriate engineered and administrative controls designed to prevent or mitigate the consequences of accidental release. Kinetic, potential, electrical, electro-mechanical, thermal, pressure, and chemical energy sources all can be released directly, or released in another form of energy, as the result of an accident. In most cases, the concern will be stored energy in the system, but lack of energy could also pose a problem if continuously energized controls are necessary to assure safe operations.

The requirement to identify and control energy sources applies not only to complex technical activities, but it also can be applied to the simplest examples of work. For example, it may be stored energy in a steel band that compresses waste material for size reduction; a chemical reaction that starts a fire; or rupture of a pressure vessel that punctures a tank containing a toxin. In short, it will usually require some form of unplanned energy release to disturb a harmless equilibrium.

#### 4.4 Define Unacceptable Consequences

All personnel must focus on what they do not want to happen as a result of work activities. Unacceptable consequences should be identified in the context of the activity being performed. In addition to the harmful effects of accidents on people and the environment, other consequences, such as temporary or permanent loss of capability, impact on site operations, or serious damage to the reputation of FORGE, must be consciously considered and defined up front. The effects of exposure to known health hazards must also be considered in the definition of unacceptable consequences.

#### 4.5 Risk Assessment Approach

Standard practice in risk assessment requires one to judge the probability that a particular accident consequence will occur. While probability assessment is the basis of routine risk decisions, this practice is problematic for early decision-making on appropriate controls for hazardous work. If an estimate of low probability of occurrence dominates early decision-making, human nature and external pressures tend to minimize the use of an otherwise sensible set of controls based on the severity of accident consequences.

Many factors contribute to this thought pattern, such as:

- Often, there are little or no failure data to make a meaningful estimate of a specific accident probability; therefore, if the accident scenario has not occurred yet or it is not in a person's experience base, the probability must be low.
- Even when success and failure data enable a statistically valid estimate, the uncertainty bounds or confidence limits on the estimate tend to be overlooked.
- Skill of the worker or skill of craft, combined with judgments about complexity of the work, can contribute to low probability presumptions and lack of attention to the severity of accident consequences.
- A presumption of low probability can enable the belief that the accident is more likely to occur near the last trial than during the equally probable first trial, so "not on my watch."
- Project success, cost, and schedule pressures can influence the presumption of low probability; the need for controls may add to these pressures.

The foregoing is not an argument for dismissing consideration of the probability of accident scenarios in risk assessment, but rather a serious caution to avoid the natural pitfalls that can lead to premature dismissal of the need for appropriate controls. Credible accident scenarios should be based on credible failure-mode analyses and the professional judgment of subject matter experts.

A second risk-assessment caution is to avoid jumping directly to mitigating accident consequences without first giving due consideration to controls that would prevent the accident from happening. Prevention is the first line of defense. Mitigation is the second line of defense.

#### **4.6 Positive Verification**

Because safety is a system attribute, the elements should be kept connected not only during the design phase, but also verifiably connected during the execution phase. Accidents frequently occur as a result of poor communication during the execution phase, especially across organizational interfaces. A team of people is often relied upon to assure a safe operation. Positive verification means that team members must each affirm to the person in charge (PIC) that their part of the system is in the state intended for safe operation. Otherwise, it should be assumed by the person in charge that it is not safe to proceed. Positive verification is not a one-time activity, but a concept that should be applied across the system or activity as appropriate and performed in an iterative manner.

### **5 Define Scope**

The purpose of defining the scope of work is to help ensure that safety concerns are adequately considered early in the decision-making process to accept, reject, or continue work. While it is recognized that more detailed analysis in subsequent steps might change these initial determinations, appropriate discipline and formality is needed when making this decision.

#### **5.1 Identify Work Planner**

For work activities, a “work planner” is responsible for ensuring that all elements of this plan have been addressed, including the evaluation factors in Sections 4.3 and 4.4 and documentation of the evaluation in support of a FORGE management decision to accept, reject, or continue the work. The FORGE project manager must assign and or identify a work planner. The FORGE project manager is responsible for the quality of the work-planning effort regardless of who performs the work planner role.

#### **5.2 Establish a Work-Planning Team**

The FORGE project manager or delegate shall establish, or assist the work planner in establishing, an interdisciplinary team consisting of subject matter experts necessary to competently address all elements in this plan. The initial task of the work planner and team is to support a FORGE management decision on the scope of work.

#### **5.3 Role of the Work Planner**

The work planner, supported by an appropriate interdisciplinary team, shall address the following factors in support of a line-management decision on scope:

- Identify the hazards associated with the activity.
- Determine the highest potential unmitigated-accident-consequence.
- Determine if the work is within the operating envelope for the FORGE site.
- Identify and complete documentation that may be necessary to perform the work.
- Ensure and document that site, and equipment are in the condition to perform the work.
- Confirm and document current status of personnel qualifications to perform the work.

- Ensure that cost and schedule allotted for work have taken into account all activities associated with that work.

#### **5.4 Decision to Accept, Reject, or Continue Work**

The work planner shall document the evaluation of the key factors and shall submit the evaluation to the FORGE project management having approval authority.

## **6 Analyze Hazards**

### **6.1 Detailed Identification of Hazards**

While the major hazards are identified in the Define Scope core function, the hazards may be characterized somewhat generically or enveloped to see if they fit into facility safety and environmental envelope. Once the decision is made to proceed with the work, the specifics of the hazards need to be more clearly defined to support the development of a conceptual system design or reexamination of an existing design.

### **6.2 Identify Safety Themes, Standards, and Codes**

Once all the hazards have been identified in sufficient detail, a “safety theme” shall be developed if there is a set of dominant hazards—for example, high pressure or electrical hazards. A safety theme is an overarching technical strategy aimed at stimulating upfront critical thinking on the prevention or mitigation of accident consequences. Multiple safety themes may be necessary based on the diversity of hazards present. This does not have to be a very formal exercise. In fact, informality with the right set of subject matter experts can be helpful in quickly setting the best approach. Consider bringing in subject matter experts from outside the organization to brainstorm the approach for the higher-consequence accidents.

Awareness of all standards and codes that apply to working with the particular hazards should be part of the critical thinking that goes into the development of the safety theme(s). However, use of standards and codes alone will not automatically make work safe. If multiple hazards are present, there can be conflicts in applying standards and codes that can adversely affect the safety of the activity.

### **6.3 Perform Formal Hazard Analysis**

A failure-mode or hazard analysis shall be performed on the new or existing system design using recognized technical standards appropriate to the task. If needed, two references that describe graded approaches to failure-mode analysis are: 1) ANSI/ASSE Standard Z590.3, Prevention through Design: Guidelines for Addressing Occupational Risks in Design and Redesign Processes, and 2) the Center for Chemical Process Safety Guidelines for Hazard Evaluation Procedures. At a minimum, the analysis methodology selected must be capable of identifying the single-point failure modes in the system that can result in accidents having unacceptable consequences. The term “single-point failure mode” means that it only takes that one failure for the accident to happen, not multiple failures. Human failure can be the single-point failure and should never be automatically dismissed due to the perceived competence of the team members.

## 7 Control Hazards

While the criteria for the Analyze and Control Hazards core functions are described in a linear fashion, in reality, the system-design process is likely to be iterative. The number of iterations needed is likely to be a reflection of the complexity of the operation and the severity of potential accident consequences.

### 7.1 Eliminate Hazards and Single-Point Failures

The first priority is to eliminate a hazard rather than attempt to control it. When this is not feasible, the next priority is to eliminate single-point failures that can cause unacceptable consequences. Remove as many single-point failures as reasonable and practical. The remaining single-point failures that can cause unacceptable consequences dictate a natural priority for the development of engineered and administrative controls. Selection of personal protective equipment (PPE) is the last line of defense.

### 7.2 Apply Engineered and Administrative Controls

Engineered and administrative controls are described in broad context as follows:

Engineered controls are physical or engineered features that provide active or passive protection to prevent or mitigate accident consequences. Traditionally, these were hardware controls; however, software controls also play an important role in assuring safety and their role needs to be carefully considered and evaluated.

Administrative controls are processes and procedures utilized to control any exposure and assure appropriate safety discipline is used to conduct hazardous work. Based on potential accident consequences, a graded approach shall be used in regard to operating procedures, critical steps in procedures, team training and qualification, hazard analysis, readiness reviews, and so on.

It is important to focus on the desired performance characteristics of engineered controls and their use in the system design. Robust and reliable engineered controls should be placed in series to block accident pathways leading to unacceptable consequences. If the reliable performance of one control is independent of another control, then the probability of both failing and realizing the accident consequence will be greatly reduced.

#### *Engineered Control Characteristics*

<b>Reliable</b>	The calculated or data-based reliability of the engineered control should not have a failure rate greater than one in a thousand.
<b>Robust</b>	The engineered control should have a significant design margin relative to its failure point...the goal is factor of two or more.
<b>Independent</b>	The engineered control has no common mode of failure.

### 7.3 Approval of Safety Case

The safety case is a narrative explanation of how the Overarching Criteria outlined in in this document are addressed. The safety case does not have to meet a standard of rigorous proof, nor does it have to be long. However, the critical thinking and reasoning in regard to managing the safety risk must be clear and include the planning for off-normal events. In addition, evidence of technical “due diligence” should be apparent to others technically knowledgeable and reasonably familiar with the hazardous activities involved. Supporting documentation can and should be used to support the narrative addressing the criteria in this document.

In the end, it will always come down to a judgment as to whether the controls actually implemented are commensurate with the safety risk.

## 8 Prepare and Perform Work

The scope of work includes the preparation and troubleshooting phases of the activity. Accidents frequently occur during these phases but they are often overlooked during the planning phase.

### 8.1 Complete Technical Work Document

A technical work document (TWD) is a formally approved document that identifies activity-level work hazards along with their associated work-control measures and communicates them to the team—generally a “how to” document. TWDs clearly specify the work to be accomplished, expected outcome, and critical steps necessary for successful and safe completion of the activity. A critical step is a procedural step, series of steps or action that, if performed improperly, will significantly affect the safety of an activity. Preapproved TWDs associated with controlling specific hazards common to FORGE activities can be used if appropriate to the scope of the hazardous activity. Development of unique TWDs will usually begin in earlier phases when the system design is mature enough to make it worthwhile; however, TWDs shall be made final and placed under formal change control before the hazards are first introduced, even if the system is in set-up, shakedown, or troubleshooting mode.

#### Example Content of TWDs:

- Establish work scope boundaries or limits
- Identify hazards—highlight critical steps/controls
- Identify who is authorized to perform critical steps
- Provide sufficient step-by-step details
- Plan for anomalies and off-normal events
- Identify special requirements

### 8.2 Perform Job Safety Analysis

A job safety analysis (JSA) or equivalent should be performed in association with the development of TWDs and before the work is performed.

### **8.3 Confirm Team Training and Qualification**

While the identification of key positions associated with performing safety-critical steps would naturally occur earlier in the development of the system design, it is necessary to confirm and document that the personnel who will actually be performing these tasks have completed the necessary training before authorizing the work to begin. In some cases, there may be a formal qualification requirement that needs to be met.

### **8.4 Conduct Readiness Reviews or Assessments**

Formal readiness reviews or assessments shall be performed. If there are pre-start corrective actions from the readiness reviews or assessments, these actions must be completed.

### **8.5 Decision to Authorize Work**

Before work begins, FORGE management shall formally authorize the work and shall describe any limiting conditions placed on that authorization. FORGE management should ensure that the required PPE is provided and that personnel access is controlled when the hazards are present.

### **8.6 Perform Work**

After appropriate authorization has been received, the FORGE management is responsible for controlling the day-to-day work. This responsibility may be formally delegated to a PIC who is properly trained or qualified to perform the function. FORGE management or the delegated PIC shall do the following:

- Conduct a pre-job briefing prior to initial start-up of the work and repeat at appropriate intervals depending on the nature and frequency of the work.
- Use a “positive verification” approach to ensure that all elements of the interconnected system are as intended for performing the work.
- Define a periodic monitoring scheme using positive verification techniques
- Prepare for and manage emergencies
- Manage accountability for operational modes of facilities
- Implement conduct of operations

## **9 Feedback and Improvement**

A feedback and improvement process must be applied to all work performed in order to achieve the following:

- Identify and correct processes or deviations that lead to unsafe or undesired work outcomes
- Evaluate and mitigate risks associated with work processes
- Provide FORGE management and team members with information to improve the quality and safety of subsequent similar work

## Attachment A: Emergency Response Plan

### 1 PROJECT ORGANIZATION AND RESPONSIBILITIES

The personnel and organizations assigned to FORGE.

#### FORGE Personnel/Responsible personnel

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Michael Lazaro/alternate Work Planner  
Office: 760-939-0146  
Email: [Michael.lazaro@navy.mil](mailto:Michael.lazaro@navy.mil)

Kelly Blake/alternate Work Planner  
Office: 760-939-4056  
Email: [Kelly.blake@navy.mil](mailto:Kelly.blake@navy.mil)

## 2 EMERGENCY RESPONSE TELEPHONE NUMBERS

A list of Emergency Response Phone Numbers shall be posted in the following locations:

All Work Planners Offices

NAS Fallon Security

Fallon FORGE office, trailers, etc.

Navy Geothermal Program Office

**Work Planner will be the initial point of contact for all emergencies.**

Contact	Phone Number
Medical, Fire, Rescue Any time	911
NAS Fallon Any time	Police: 775-426-2803 Fire: 775-426-3411 Geothermal Program Office: Andy Tiedeman, o. 775-426-3605, c. 360-990-4881
Churchill County's Sheriff's Department Any time	775-423-3116 or 911
Hospitals	Banner Churchill Community Hospital: 775-423-3151  Saint Mary's Regional Medical Center: 775-770-3000  Renown Regional Medical Center: 775-982-4100
Fallon FORGE Team members	Project Manager, Doug Blankenship, c. 505-554-0956
	Work Planner (ES&H), Andy Tiedeman, o. 775-426-3605, c. 360-990-4881
	Navy Alternate POC, Michael Lazaro, o. 760-939-0146, c. 805-651-9256
	Navy Alternate POC, Dave Meade, o. 760-939-4057, c. 760-382-7705
	Navy Alternate POC, Andrew Sabin, 760-939-4061, c. 719-373-3531
Navy Alternate POC, Kelly Blake, o. 760-939-4056, c. 845-781-6685	

## 3 STATEMENT OF PURPOSE

The Emergency Response Plan covers procedures to be implemented in the event of an emergency at the Fallon FORGE Project site.

## 4 SCOPE

This procedure applies to all Fallon team members, contractors, and visitors.

## 5 RESPONSIBILITIES

**The Work Planner will be the initial point of contact for all emergencies.**

**Site Management** shall be responsible for;

The implementation and enforcement of this Plan at the Fallon project site;

Monitoring compliance with this plan by Fallon FORGE team members, and contractors working at the Fallon FORGE Project;

Being involved in every emergency;

Determining if or when it is necessary to involve outside specialist, such as the Fire Department or other emergency personnel;

Designating personnel to be trained and certified in First Aid and CPR and ensuring such training is provided as required by the certifying agency;

Ensuring all employees who may respond to an emergency will be involved in one drill or exercise per year.

Ensuring all personnel are informed of the requirements of this Plan and comply with its requirements; and Maintaining all documents and records as required by this Plan for inspection by:

Fallon FORGE personnel;

Navy personnel;

Regulatory and governmental agency representatives.

**The Fallon FORGE team, contractors, and visitors** shall be responsible for:

Following all directives and procedures associated with this plan.

## 6 PLAN LOCATION

Emergency Response Plans are located in the following locations:

On site - TBD

Location for Outside Emergency Responders

## **7 PRIORITIES**

People **ALWAYS** come first! Always protect employees first, regardless of the situation.

Priority number 1- Protecting our employees

Priority number 2- Protecting the environment

Priority number 4- Maintaining applicable compliances

Priority number 3- Protecting Operations

## **8 STATEMENT OF SAFETY AND HEALTH POLICY**

NAS Fallon FORGE project members shall institute and administer a comprehensive and continuous Environmental Safety and Health Plan during all FORGE related activities. Fallon FORGE members hold environmental safety and health as a first priority and are committed to providing a safe and healthful workplace for all involved. The health and safety of an individual employee, contractor, or third party takes precedence over all other concerns. In support of this commitment to environmental safety and health, NAS Fallon FORGE will provide measures to control workplace hazards on the site of the project through communications, periodic inspections, incident investigation, mitigation, compliance audits and personnel training. It is NAS Fallon FORGE's intent that all activities will follow the Safety and Health Requirements Manual EM-385-1-1; 15 JUL 14, and that the Manual serve as the guideline for the plan and its implementation. Furthermore, health and safety shall be interwoven into every phase of the project. All personnel shall observe the policies and procedures of each program. Each supervisor shall be held responsible for the safety performance of everyone involved under their supervision. Moreover, management shall assume ultimate responsibility for the implementation of this environmental safety and health plan for each activity of the project. The goal is to achieve a zero accident record, remain a good steward to the environment and provide an overall healthy work environment.

## **9 FALLON FORGE EM 385-1-1 SAFETY PLAN GUIDELINES**

For all FORGE related activities, a safety plan following the US Army Corps of Engineers EM-385-1-1; 15 JUL 14 Safety and Health Requirements Manual must be submitted and approved by the local or regional Safety Manager prior to any site specific activity moving forward. (See Appendix A attached). Following this requirement identifies and analyzes safety risks for existing and potential hazards or unsafe conditions associated with FORGE activities. In addition, the approved plan shall be available on each work site.

## **10 TRAINING**

All NAS Fallon FORGE members, construction superintendents/foremen, environmental managers, on-site project leads and quality control personnel must complete ECATTS training prior to any work being performed on all Navy land positions.

(<<https://environmentaltraining.ecatts.com/>>)

Additionally, depending on the activity (i.e. drilling, crane operation, OSHA), personnel/operators must be certified as applicable with state, county and regional requirements. All training and certifications must be up to date and provided upon request.

## **11 PROTECTION OF THE ENVIRONMENT**

All Fallon FORGE and contractor personnel will be informed of the Fallon FORGE policy regarding undue degradation of the environment. These measures are intended to prevent all unacceptable impacts from occurring as a result of operations.

### **A. Fire Prevention**

The sites and access roads will be cleared of all vegetation when necessary depending on activity. The cleared areas will be maintained during any applicable operations. Fire extinguishers will be available on the site. Water that is available for use during some activities will also be available for firefighting.

Personnel will be allowed to smoke only in designated areas. Any special permits required for fires, welding, and etc., will be obtained.

### **B. Prevention of Soil Erosion**

Minimal soil erosion problems are anticipated from this project. In addition, runoff will be channeled to energy dissipaters to minimize erosion when applicable.

### **C. Surface and Ground Water Quality Protection**

The location of the operations/activities has yet to be selected, but future efforts to minimize the potential for surface water pollution from runoff during operations, drilling, measuring or other related activities.

Surface water and ground water pollution from drilling and testing will be prevented by steel casing cemented to below these zones.

Only non-toxic, non-hazardous drilling mud constituents will be utilized during drilling operations. Waste drilling mud, drill cuttings, and any runoff from the well site will be discharged into the containment basin to prevent ground water quality degradation.

Any potential well will be cased and cemented to prevent interzonal migrations of fluids and reduce the possibility of blowouts. Based on the water levels observed at existing wells, no over-pressured or gas-rich zones are expected to be encountered.

### **D. Air Quality Protection**

Fugitive dust generation during operations and use of access roads and well site will be minimized by watering as necessary.

### **E. Prevention of Noise**

To abate noise pollution, mufflers will be utilized on engine-driven equipment when necessary.

## F. Protection of Public Health and Safety

In addition to the emergency contingency plans (See Emergency Response Procedures), public health and safety will be protected through instructions to work crews and contractors regarding compliance with regulations.

## G. Protection of Fish, Wildlife, and Botanical Resources

Direct impacts to wildlife habitat and botanical resources will be minimized. Fish habitats will be protected through prevention of erosion.

## H. Protection of Cultural Resources

Field survey for cultural resources will be performed and avoidance measures taken for all potential field operations.

## I. Waste Disposal

Solid waste materials (trash) will be deposited at an authorized dump by a disposal contractor.

Portable chemical sanitary facilities will be used by all personnel. These facilities will be maintained by a local contractor.

## J. Environmental Monitoring

A qualified cultural resource monitor may be on site for all operation activities. In addition, regular routine visual inspections of the project area and access roads will be conducted by the on-site operational personnel to quickly detect and correct any operational problems that could lead to environmental problems. Environmental specialists will monitor and inspect the operations, if necessary, during the course of the project.

## 12 EMERGENCY RESPONSE PROCEDURES

### 12.1 Organization

The procedures are organized and administered by the Fallon FORGE Team. The goal is to have an appropriate number of rescuers on site at all times.

### 12.2 Emergency Communications

Call 911

If a transport is necessary, provide emergency response directions to project area.

1. The caller is to provide the 911 operator with all the necessary information, and communicate that we will have an employee standing by at the entrance for escort purposes.
2. The caller should remain in contact with the in-route ambulance crew until they have arrived on scene.

## 13 ACCIDENTS AND INJURIES

### 13.1 First Response

Whenever personnel are injured pre-determined contact shall be notified immediately.

All personnel should become familiar with the location of first aid kits and AED's at the project.

### 13.2 MEDICAL EMERGENCY PROCEDURES

**Survey the scene**-Ensure the safety of the first responder;

**Primary Survey**-Survey the injured person(s) by checking the ABC's-Airway, Breathing, and Circulation. If not breathing start rescue breaths. If no pulse, start CPR, AED.

**Secondary Survey** – Take vital signs and do a head to toe exam.

**Check for bleeding** – If a person is bleeding, apply direct pressure and bandage. If the injury continues to bleed, elevate the wound. If still bleeding apply pressure to the closest pressure point to the wound.

**Treat injuries**

### 13.3 Medical Emergencies

1. Treat for Shock- When a person shows any signs of shock, maintain body temperature, and monitor vitals. All employees showing signs of shock will be seen by a physician prior to returning to work.
2. Transport – If the decision is made to transport the person, notify 911 for the ambulance. Secure the patient on the gurney and administer oxygen.
3. Air Ambulance – In the event an air ambulance is needed:
  - a. First ensure that the injury or illness meets the criteria for an airlift.
    - i. Air ambulance is a very limited commodity that is only to be used when:
      1. A life threatening condition exists; and
      2. When the reduction in overall transport time is expected to have an impact on the patient's outcome.
      3. If you cannot save a minimum of 15 minutes over an ambulance trip time, it is not necessary to request an air ambulance.
    - b. Make the request when calling 9-911. Communicate to them where the landing point is located. Always have the ground unit respond with the air unit in case the air unit runs into problems.
    - c. Never approach the helicopter when it lands. The crew will come out to meet you.

### **13.4 Post Incident Procedures**

After every emergency response the team will hold an evaluation session to go over the events to ensure that any problems that arise will be addressed and covered in the future. If the emergency involves death or serious trauma that could cause the responder emotional trauma, a debriefing or crisis management session will be held.

## **14 BLOWOUTS AND WELL DAMAGE**

The appropriate professional in charge will take the following steps for any wellhead blowout. These steps are only a recommendation. The exact response will depend on the severity of the blowout condition.

### **14.1 Initial Response**

1. Notify Project Manager;
2. Evacuate and provide care for any injured personnel;
3. Evaluate the extent of the damage and initiate the appropriate control measures with any emergency response agency or Fallon FORGE management, if possible;
4. Secure and maintain control of the access road to eliminate unauthorized personnel;
5. Mobilize earth-moving equipment to channel the flow of fluids into a sump or other containment area. Mobilize portable pumps to transfer fluids collected during the blowout or damaged wellhead;

### **14.2 Initiate Control and Containment Plans**

1. Kill the well consistent with safe operating practices prior to starting any repair work;
2. Take steps to expose the damaged portion of the well;
3. Repair the damaged area or replace the wells casing and or wellhead;
4. Inspect the surrounding areas for any erosion that occurred to the sump, pad, roads or other areas in the well field.
5. If the well cannot be contained, the manager shall initiate a program to kill, plug and abandon the well;
6. If there is a definite threat to human life, the manager will secure the area and make arrangements for outside contractors to secure the well.
7. Written reports and cleanup efforts associated with the incident will be a joint effort between Fallon team members and the Work Planner.

## 15 EARTHQUAKES

### 15.1 Earthquake Preparedness

All team members shall be trained in the earthquake procedure and evacuation plan;

The escape routes shall be posted in all work sites; and

Safety meetings shall be held on earthquake preparedness.

#### 15.1.1 ACTION - ONSET OF AN EARTHQUAKE

If inside a building, **DROP** to the floor, take **COVER** by getting under or next to a sturdy desk or table, and **HOLD ON** to it until the shaking stops.

If outside, find an area clear of falling objects and **DROP** to the ground;

Remain where you are until all movement has stopped.

#### 15.1.2 ACTION - ONCE THE EARTHQUAKE STOPS

Report to your designated check point;

Attend to any injured personnel, but **Do Not Move** them unless they are in an unsafe area;

Call 911 if emergency assistance is required.

Be aware that there may be aftershocks that may be large enough to do additional damage.

#### 15.1.3 ACTION – AFTER ALL TEAM MEMBERS/CONTRACTORS ARE ACCOUNTED FOR

Management or a designee will evaluate the extent of the damage and make the decision of whether or not to evacuate the facility.

Check water and electrical lines, buildings, pipelines, cooling towers, and tanks for damage. Barricade downed power lines, if applicable.

If evacuation is necessary, the work planner will give directions for the escape route to be used.

The work planner will contact appropriate management and provide a status report.

#### 15.1.4 ACTION – IF EVACUATION IS ORDERED

The project manager is responsible for making sure everyone is evacuated. He/she may designate this job to other personnel.

If transportation is a problem, the project manager will notify additional resources for assistance.

If injured personnel require special transportation, the project manager will make the necessary arrangements. All personnel will meet at the designated muster point upon evacuation of the facility. All employees must check in with the manager upon arrival.

If anyone is missing, the project manager is to be notified immediately so they can dispatch rescue personnel.

Once all personnel have been accounted for, the management will determine the personnel who must stay and who can leave the area.

## 16 EXPLOSIONS

An explosion is a sudden release of energy. The released energy may have originated from an exothermic chemical reaction or may have contained stored energy in the form of compressed air, steam, or high pressure liquid. Damage may result in shock wave radiating from the explosion or by flying debris.

### 16.1 Action - After the Explosion

Report to your designated check in station. If any personnel are missing, a search will be made to determine his/her location and condition, when it is safe to do so;

Attend to any injuries, but **Do Not Move** injured persons unless they are in an unsafe area;

### 16.2 Action - After All Team Members/Contractors Are Accounted For

The Work Planner will evaluate the extent of the damage and make the decision to evacuate the project.

The Work Planner will notify senior management of the incident and status of the project.

The Work Planner will station an employee at the projects entrance to direct incoming emergency equipment to the incident site.

If evacuation is necessary the Work Planner will give direction for the evacuation route.

## 17 FIRES

### 17.1 Action – Onset of Fire

Any person who discovers smells or sees smoke and believes there is a fire will immediately take the following actions:

1. Contact the Work Planner.
2. Verbally pass the word. Be sure to notify anyone in immediate area.

The onsite Work Planner will ensure the following actions take place:

1. Control vehicular traffic into, from and about the fire scene.
2. Keep spectators at a safe distance from the fire scene.
3. Establish a watch at the fire site to prevent unauthorized access pending completion of an investigation.

### 17.2 Action - After the Onset of Fire

Report to your designated check in station. If any personnel are missing, a search will be made to determine his/her location and condition, when it is safe to do so;

Attend to any injuries, but **Do Not Move** injured persons unless they are in an unsafe area;

The control room will be used by the IC to receive calls/reports of injuries;

Call the Navy 2 control room to report the fire and for emergency assistance.

### 17.3 Action - After All Employees/Contractors Are Accounted For

The Work Planner will evaluate the extent of the damage and make the decision to evacuate the project.

The Work Planner will notify senior management of the incident and status of the project.

The Work Planner will station an employee at the projects entrance to direct incoming emergency equipment to the incident site.

If evacuation is necessary the Work Planner will give direction for the evacuation route.

## 18 HYDROGEN SULFIDE HAZARDS

The Coso Operating Company H<sub>2</sub>S Program is designed to address the risk of H<sub>2</sub>S exposure for employees, contractors and visitors. The goal of the program is to deploy safety precautions on an “as needed” basis recognizing that not all areas of the project represent the same degree of H<sub>2</sub>S risk. The two key safety precautions are personal H<sub>2</sub>S monitors and fixed monitors.

In the event that an employee, contractor or visitor breathes in a large amount of H<sub>2</sub>S, and you can safely access them, move the person to fresh air at once. If the atmosphere is not safe, **do not attempt to rescue by holding your breath. If they went down, so will you.**

Notify the Navy 2 Control room Operator to dispatch the ER Team.

**Primary Survey** - Survey the injured person(s) by checking the ABC's-Airway, Breathing, and Circulation. If not breathing start rescue breaths. If no pulse, start CPR, AED.

**Transport** – If the decision is made to transport the person, call the Navy 2 CR Operator to notify 911 for the ambulance.

The IC will station an employee at the projects entrance to direct incoming emergency equipment to the incident site.

## 19 LIGHTNING

### 19.1 Action-At Onset of a Lightning Storm

If you are inside stay inside. Avoid contact with metallic objects. Stay clear of electric power sources.

If outside find shelter. Stay clear of all pipelines, tanks, wellheads and other equipment. Try to get to a building or a vehicle.

Be prepared to extinguish small fires.

## 20 SPILLS AND DISCHARGES

Although the detailed procedures will vary depending of the location and severity of the spill, in all situations the team member or Contractor who discovers the spill shall report it as described below. All reported spills must have an “Accidental Spill/Discharge Notification Form” filled out. The Contractor or his designee should fill out section 1 of the form. Section 2 will be filled out by the Public Works(PW) Environmental Department or his/her designee.

**Brine Spills** – Brine, condensate or any geothermal fluid release of 300 gallons or more must be reported to PW environmental immediately. If the release occurs after normal business hours, contact the Work Planner at home (See phone list on page 4 of this Plan). Releases of less than 300 gallons must be reported by the next business day.

**Hazardous Materials Spills** - Hazardous materials releases of more than 5 gallons must be reported immediately to Work Planner and PW Environmental. Releases of less than 5 gallons must be reported to the EC the next business day during normal office hours.

Never attempt to clean up the released material unless you have received specific HAZWOPER training. Isolate the area if it can be done safely with barrier tape or other barrier devices. Call the PW Environmental for further instructions if problems develop during the isolation of the area.

## 21 POST INCIDENT PROCEDURE

After every emergency response management will hold an evaluation session to go over events to ensure that any problems that arise will be covered and addressed. If the emergency involves a death or serious trauma that could cause the first responders emotional trauma, a debriefing and a crisis management session will be held.

### 21.1 Bodily Injuries Such as Breaks and Sprains

1. All of these injuries are treated the same way. If the person is to be moved, it is necessary to immobilize the injured area above and below the wound. If the injury is minor, apply ice and elevate to allow swelling to subside. If a back injury occurs, the employee will be seen by a physician before returning to work.
2. **Burns**
  - a. First aid for thermal burns is to cool with water and wrap in damp gauze. For a chemical burn, continue to flush for 10-20 minutes.
  - b. Full thickness burns (Third degree) should be wrapped in dry sterile gauze.

- c. Depending on the percentage of the body burned and the severity of the burn, treat for shock, monitor vital signs and transport.
- d. If the burn is an electrical burn, the major concern is breathing and heartbeat. Begin first aid for breathing and heart emergencies. All persons involved in electrical related injuries will be seen by a physician before returning to work.

### 3. Insect Bites

- a. Ask the person if they are allergic;
- b. If they respond affirmatively, and they are allergic, assist them in administering their medication, if available.
- c. If an allergic reaction starts, transport immediately.
- d. If the person is not allergic, if applicable, remove the stinger by scraping it off. Lower the sting area below the heart.
- e. Apply an ice pack wrapped in a protective barrier to prevent skin damage.

### 4. Eye Injuries

- a. For small foreign bodies, encourage the person to blink, then flush impacted eye with sterile eyewash solution.
- b. For chemical injuries, flush with sterile eyewash solution for 10-20 minutes.
- c. All employees with eye injuries will be seen by a physician before returning to work.

### 5. Deceleration Injuries

- a. Any time a person's body comes to an abrupt stop or is accelerated by force, **full spinal immobilization is required**. To achieve this one person will hold the head in the inline stabilization position and maintain until the cervical collar is in position and secured, the person is strapped to the backboard and the head restraints are secured.
- b. If the person is in full cardiac arrest, CPR is the priority.
- c. Ensure the person is on their back on a hard surface. Do your best to minimize movement of the spine.
- d. Use the chin lift or jaw thrust method for opening the airway.

### 6. Vehicle Incidents

- a. Vehicle incidents are to be approached with caution. Be sure the scene is safe. If the vehicle is unstable, do what is needed to stabilize it first, before attempting a rescue.

- b. Once you are able to reach the injured person, **begin inline stabilization and maintain it until total spinal immobilization has been achieved.** Do a secondary survey, start oxygen, and transport.

## 22 TRAINING

### 22.1 Requirements

Employees will receive training on this plan, the emergency response procedures, and their responsibilities under this plan, upon commencing employment with the company, whenever the plan is updated, or if the employee's responsibilities or designated actions under this plan are altered.

First responders will be re-certified every two years in basic First Aid/CPR/AED.

Each employee that may respond to an emergency will be involved in one drill or exercise per year. Participation in an actual rescue or emergency counts towards the one drill per year requirement.

Employees will receive HAZMAT training on the Awareness level. This will allow them to identify that a hazardous material incident has occurred and how to report the incident.

With this HAZMAT training, they will be able to recognize what the hazard is, know how to read the DOT Hazardous Materials handbook, how to read an SDS, learn when a rescue can be attempted and when it is not feasible, the proper use of PPE, and who to call when an incident occurs.

This training is **not** to be used for clean-up of hazardous spills.

## 23 INSPECTION AND OBSERVATION OF THIS PLAN

All Fallon FORGE team members and contractors with the training and capacity to identify violations or unauthorized deviations to this Plan that put at risk the health and safety of people shall report any such incident to facilitate immediate corrective action and/or investigation in accordance with the following notification priority list:

Immediate supervisor of the person involved;

The Work Planner; and

Fallon FORGE Environment, Health and Safety Lead, and;

All Fallon FORGE team members determined to have committed an intentional violation of this Plan, following an investigation, may be subject to disciplinary action up to and dismissal from the team.

## **24 DANGEROUS VIOLATION OF SAFETY POLICY OR PROCEDURE**

It is expected that most team members and contractors of the Fallon FORGE site are very good at following safety policies and procedures; however, an occasion may arise where an individual commits a serious safety violation, or refuses to follow necessary safety procedures. There are several situations where intervention would be required. Use the following process if this should occur:

Is there a general, but not an immediate threat to the individual's safety? If so, notify the employee or contractor. If the employee does not respond to the warning notify the Work Planner.

Is there an immediate and serious life threatening situation? Immediately intervene to stop the unsafe act, if possible, and then notify the Supervisor/ Manager;

If others are at risk, warn them to evacuate the area, if necessary;

Notify the Work Planner of the threat and take immediate action if it is required.

## Attachment B

### Emergency Evacuation Response Plan

Potential on-site emergencies are expected to be restricted to injuries to site personnel. On-site conditions are expected to be within the limits of measures, which can be taken by on-site personnel. During any on-site emergency, work activities will cease until the emergency is brought under control.

Address locations to nearby medical centers are attached at the back of this plan (see Attachments A, B, and C). The emergency contacts will be kept in each field vehicle. A list of the emergency telephone numbers is included in this Plan. All personnel working on site will be informed of these numbers and emergency routes, and will also be informed of evacuation routes, meeting places, and evacuation warning signals in case of the need for an evacuation. All field personnel will have cellular telephones.

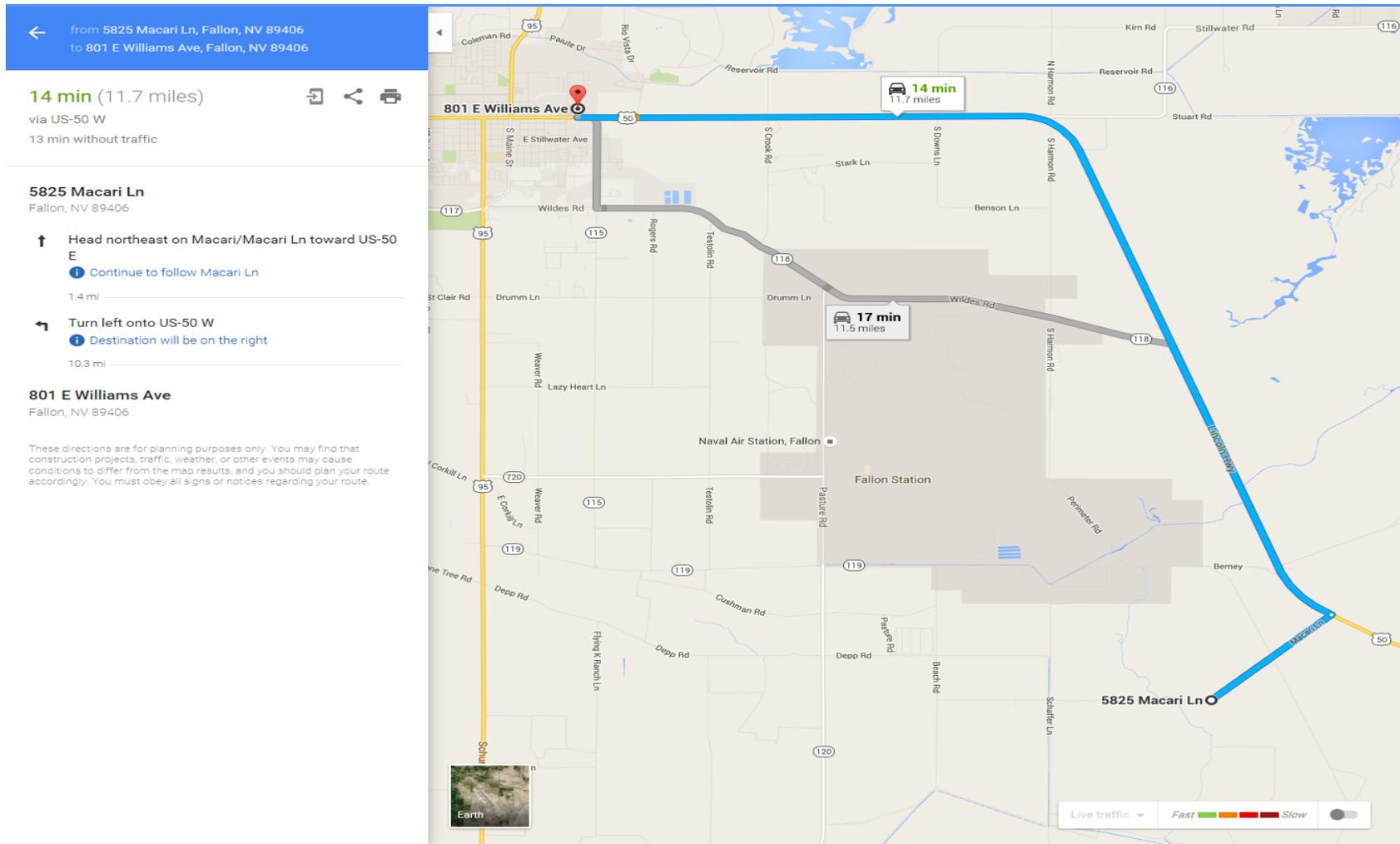
#### Emergency Contact Phone Numbers

Name/Place	Telephone Number
NAS Fallon – Andrew Tiedeman/GPO	775-426-3605
Emergency Response: Fire, Ambulance	911
Banner Churchill Community Hospital	775-423-3151
Saint Mary’s Regional Medical Center	775-770-3000
Renown Regional Medical Center	775-982-4100

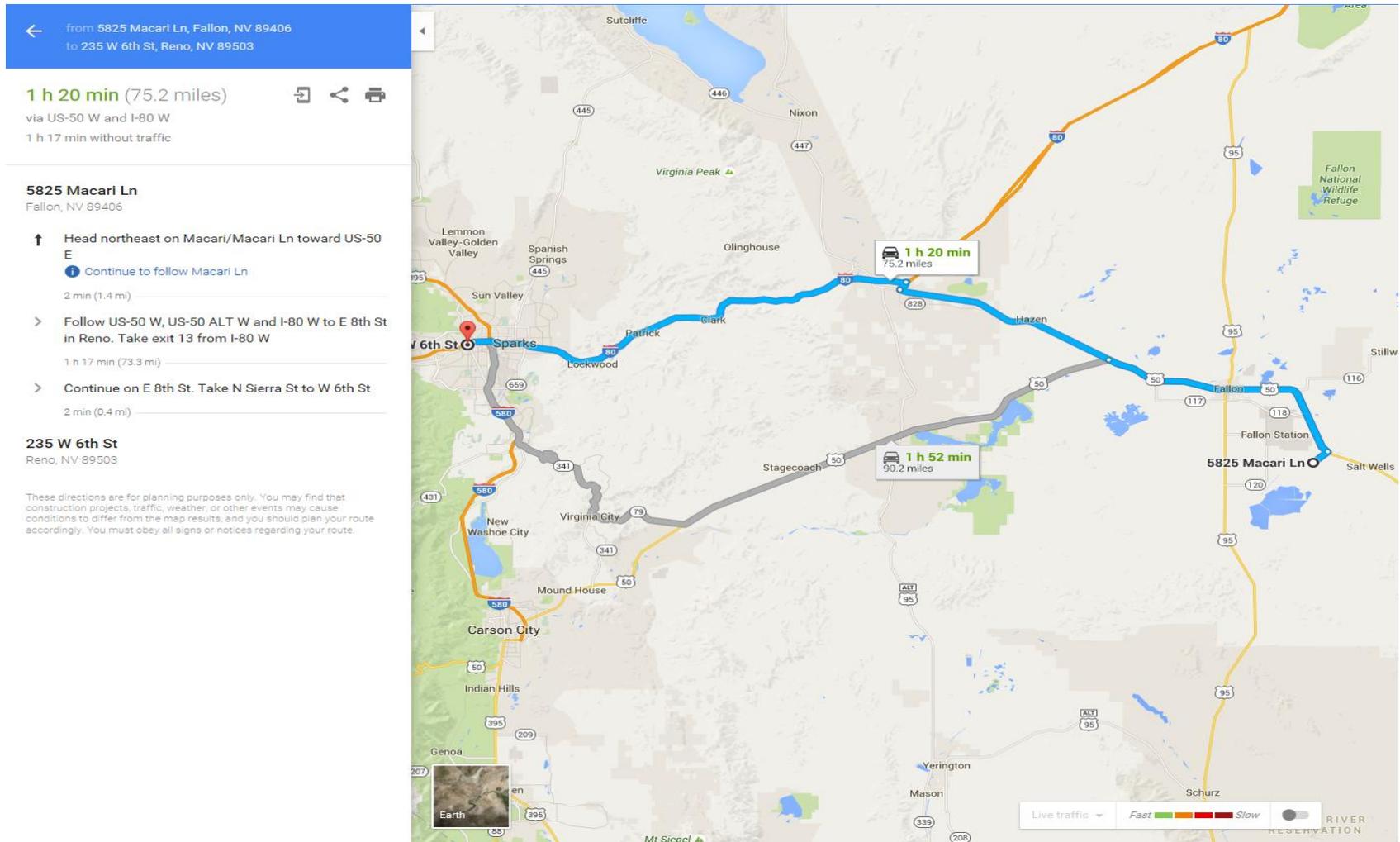
Banner Churchill Community Hospital  
801 E Williams Ave  
Fallon, NV 89406

Saint Mary’s Regional Medical Center  
235 W 6<sup>th</sup> St  
Reno, NV 89503

Renown Regional Medical Center  
1155 Mill St.  
Reno, NV 89502



Banner Churchill Community Hospital  
801 E Williams Ave  
Fallon, NV 8940



Saint Mary's Regional Medical Center  
235 W 6th St  
Reno, NV 89503

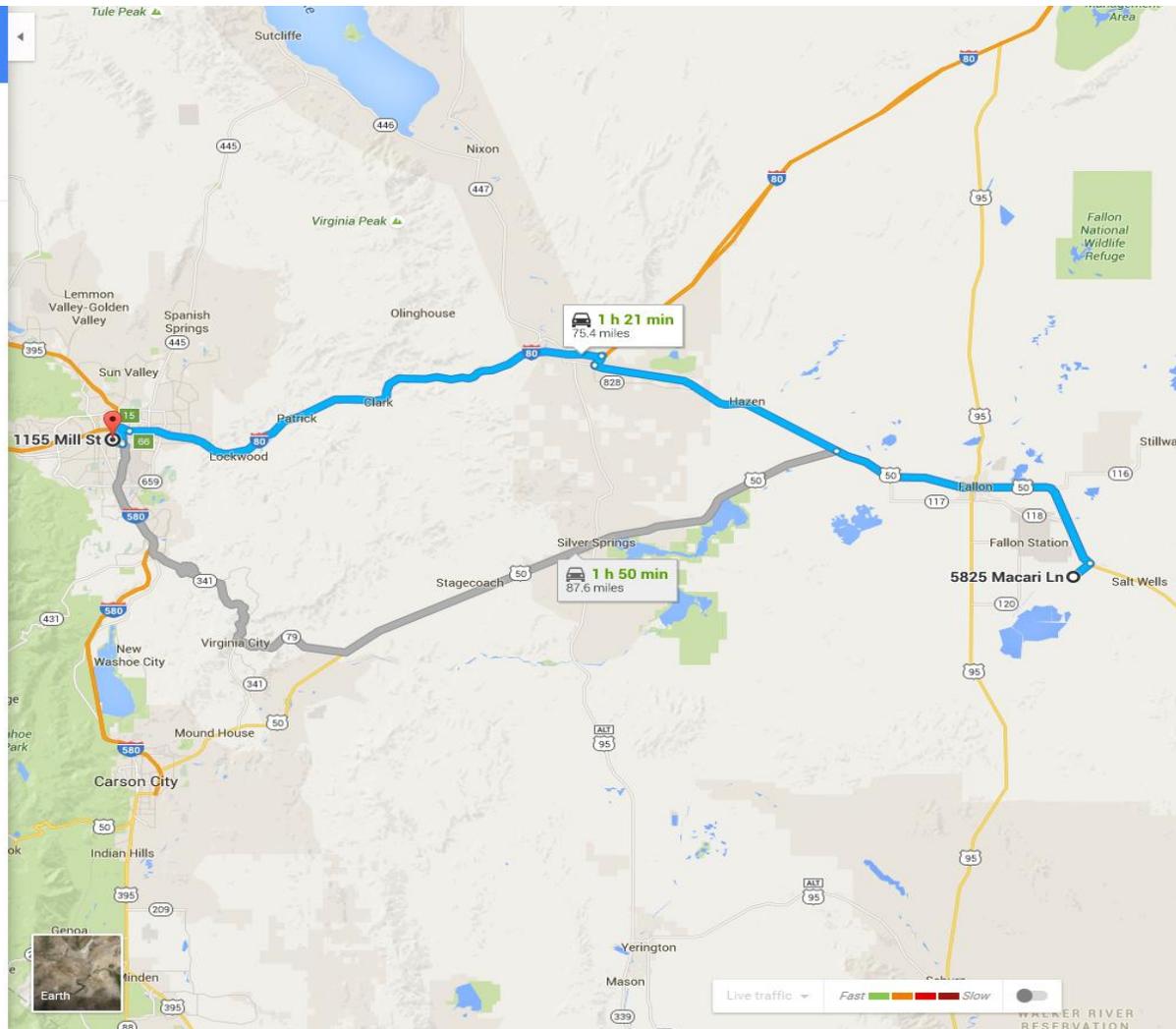
← from 5825 Macari Ln, Fallon, NV 89406  
to 1155 Mill St, Reno, NV 89502

**1 h 21 min** (75.4 miles)  
via US-50 W and I-80 W  
1 h 17 min without traffic

**5825 Macari Ln**  
Fallon, NV 89406

- ↑ Head northeast on Macari/Macari Ln toward US-50 E
  - 1 Continue to follow Macari Ln
  - 2 min (1.4 mi)
- > Follow US-50 W, US-50 ALT W and I-80 W to Mill St in Reno. Take exit 66 from I-580 S/US-395 S
  - 1 h 17 min (73.2 mi)
- ↘ Turn right onto Mill St
  - 1 Destination will be on the right
  - 3 min (0.8 mi)

**1155 Mill St**  
Reno, NV 89502



Renown Regional Medical Center  
1155 Mill St.  
Reno, NV 89502

**APPENDIX L. RESEARCH AND DEVELOPMENT IMPLEMENTATION  
PLAN**

# RESEARCH AND DEVELOPMENT IMPLEMENTATION PLAN

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Fallon, NV

## NAS FALLON



*Geothermal Research  
Observatory*

# RESEARCH AND DEVELOPMENT IMPLEMENTATION PLAN

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## INTRODUCTION

This Research and Development (R&D) Implementation Plan provides the technical vision of the Fallon FORGE team and describes how that vision aligns with the goals of the U.S. Department of Energy (DOE). The plan describes the approach for managing the Fallon, NV, project site and the approach to managing the details associated with the selection and execution of competitively funded R&D.

The plan details the Fallon FORGE Team's commitment to manage and coordinate all logistical, administrative, analytical, and technical support for the planning, solicitation, review, and selection of technologies to be tested and evaluated at the FORGE site. The team will implement formal procedures to ensure that technologies selected for testing and evaluation directly support the objectives of DOE's Geothermal Technologies Office (GTO). These procedures will ensure a fair, logical, and competitive technology procurement process consistent with DOE and Federal guidelines and regulations. (Such procurement regulations are currently followed by the Prime Recipient, Sandia National Laboratories.) The R&D plan outlines recurring cycles for planning, review, and selection of FORGE-related technologies for testing and evaluation. The proposed management structure for the Fallon FORGE site will ensure close collaboration with the proposed site management team and provide a process for establishing and maintaining technical expert teams (e.g., STAT membership) to meet the project's objectives and evolving technical needs. This process of expert engagement will address management of conflicts of interest for participating members.

## TECHNICAL VISION FOR FORGE AND ALIGNMENT WITH DOE GOALS

### EGS: FROM CONCEPT TO COMMERCIALIZATION

The vision for FORGE is a dedicated Enhanced Geothermal Systems (EGS) field laboratory and a complementary R&D program that focuses on the science and technology necessary to bring the EGS concept to fruition and ultimately lead to commercialization. The Fallon FORGE team envisions that FORGE will result in a rigorous and reproducible methodology that will enable development of on the order of 100+ GWe of cost-competitive EGS power, thus supporting the U.S. efforts to reduce our dependency on fossil fuels and safeguard the nation's military readiness, through collaboration with the U.S. Navy. Successful development of EGS requires a thorough and fundamental understanding of how to enhance and maintain subsurface permeability via fluid injection, thermal rock-fluid interaction, chemical stimulation, or other well-engineered stimulation processes that re-open pre-existing fractures and/or create new ones.

### OVERCOMING TECHNICAL BARRIERS

However, many technical barriers to commercialization have been identified. We need a multi-pronged approach to address these barriers, starting with a thorough understanding of techniques to effectively stimulate fractures in different rock types. We also need to develop techniques capable of imaging permeability enhancement and evolution from the reservoir scale to the

resolution of individual fractures; effective zonal isolation for multistage stimulations; directional drilling/stimulation technologies for non-vertical well configurations; and long-term reservoir sustainability and management techniques.

It is our team's goal to manage FORGE as a dedicated site where the eligible subsurface scientific and engineering community to develop, test, and improve new technologies and techniques in an ideal EGS environment that will address the barriers to commercialization. The FORGE site will allow the geothermal and other subsurface communities to gain a fundamental understanding of the key mechanisms controlling EGS success, in particular how to initiate and sustain fracture networks in the spectrum of basement rock formations using different stimulation technologies and techniques. This critical knowledge will be used to design and test a methodology for developing large-scale, economically sustainable heat exchange systems, thereby paving the way for a rigorous and reproducible approach that will reduce industry development risk. Essential to this process is a comprehensive instrumentation and data collection effort that will capture a higher-fidelity picture of EGS creation and evolution processes than any prior demonstration in the world. Finally, a dedicated FORGE allows for the highly integrated comparison of technologies and tools in a controlled and well-characterized environment, as well as the rapid dissemination of technical data to the research community, developers, and other interested parties.

#### **DEDICATED FIELD LABORATORY**

As a field laboratory for EGS research, additional site characterization to complement the Phase 1 efforts will be emphasized and conducted at the earliest opportunity (all in compliance with applicable permits) to further the understanding of the subsurface at the Fallon site. While the latter part of Phase 2 is designated for full site characterization, these activities will not artificially stop at the commencement of full FORGE operations in Phase 3. Refinement of the geological model will continue throughout the project as a result of continued site development activities and FORGE supported R&D efforts. While FORGE will be well characterized before full site implementation begins the geologic model will evolve throughout the project.

Previous EGS efforts have commonly been hampered because of limitations in site monitoring data. Throughout the operation of FORGE, the site will be continuously monitored, employing not only additions to the established seismic monitoring network but other relevant technologies as well, such as borehole strain and tilt meters, microgravity, electromagnetic sensors, downhole fluid pressure sensors and geochemical tracers. Particular emphasis will be made to ensure that the volumetric coverage of the site is optimized to provide the microseismic and other data needed to ensure a detailed understanding of the EGS stimulation efforts planned in Phase 3. This will include continued integration of site characterization, refinement of the velocity model of the site, as well as full areal and deep vertical coverage of the expected volume of stimulation. Permanent monitoring holes that will be constructed during the development of the site will be complemented with the construction of similar monitoring "holes of opportunity" to accommodate additional FORGE stimulation monitoring and associated FORGE R&D efforts. During the later portion of Phase 2 and throughout Phase 3 Multiple thermo-hydro-mechanical-chemical modeling tools will be used in concert with field and laboratory data from site characterization, downhole measurements/sampling and stimulation monitoring to make testable predictions of reservoir performance and inform decisions related to additional stimulation

operations and long-term flow testing. As with all Phase 3 activities, evolving requirements for stimulation monitoring, modeling and additional stimulations will be carried out through a combination of activities conducted by the broader Fallon FORGE Team and by scientists and engineers selected through the competitive Phase 3 R&D solicitations.

### **LOOKING AHEAD TO PHASE 3**

Full implementation of FORGE begins in Phase 3. Our team envisions at least two, and probably more, full-sized wells for EGS stimulation. The geologic environment will determine well placement and orientations. Wells for EGS stimulation will be drilled using advanced directional drilling technologies to most effectively exploit pre-existing geologic structures and the in-situ stress and rock hydrologic and geomechanical properties to create a pervasive, interconnected fracture network optimal for efficient and sustained geothermal heat extraction under low-pressure injection and production. Specific well designs will be developed as site characterization activities advance and defensible modeling efforts are completed in the latter part of Phase 2. These wells will be subjected to multiple stimulation technologies applied at multiple positions along the wellbore, followed by flow, tracer and other testing to quantify improvements in well connectivity and to evaluate the performance of the heat exchanger so created.

In addition to the drilling needed to develop and monitor the planned EGS circulation system, drilling to support defined monitoring needs and testing of innovative technologies (through the competitive R&D process) will be needed and implemented during the course of the project. The number of such wells and proximity to the primary EGS circulation test site will depend on the evolving need to support community R&D. For example, drilling required for an innovative monitoring technology will be performed in an area to accommodate the monitoring requirements. Wells will be developed for testing of technologies that could cause normally eschewed well damage or impact the primary circulation system or required monitoring if not vetted first. To the extent possible, all drilling will be performed using advanced drilling efficiency monitoring and advisory systems (such as monitoring and use of mechanical specific energy guide the drilling process) to advance these principles in the geothermal community and to reduce the cost of FORGE operations. Additionally, new and advanced drilling technologies will be afforded a location to test such systems while also supporting the need to develop an unprecedented level of subsurface access that FORGE requires.

### **ADDRESSING EGS PERFORMANCE**

While EGS development efforts have implemented methods to stimulate multiple zones of an existing wellbore (e.g., Cladouhos, et. al., 2015) critical technical and commercial limitations to EGS development remain. As illustrated by Doe, et.al. (2014), the inherent heterogeneity and fracture network complexity in natural systems concentrate flow in reduced portions of the available fracture system and tend to degrade EGS performance. In general, these observations have shown that it is vital to the success of EGS to have the capability to selectively and independently stimulate, inject, and produce along the intended production and injection sections of EGS wells. While R&D solicitations directed toward FORGE efforts to advance EGS technology will be developed in concert with the Science and Technology Analysis Team (STAT) and DOE, the Fallon FORGE Team envisions that efforts will be directed to address this critical need for selectively controlling zones of injection and production along respective

wellbores. Technology to isolate sections of wells and actively control flow from isolated zones exist today for the oil and gas industry but similar technologies do not exist for geothermal applications. Existing systems provided by service companies such as Schlumberger and Halliburton are plagued by operating temperature limitations and wellbore and tubing diameters that cannot be accommodated today. While it is envisioned that R&D solicitations will address exploration, development, operation, and monitoring for EGS development, the ability to control injection and production along EGS wells is believed to be critical and development and fielding of this capability must be central to the FORGE vision.<sup>i</sup>

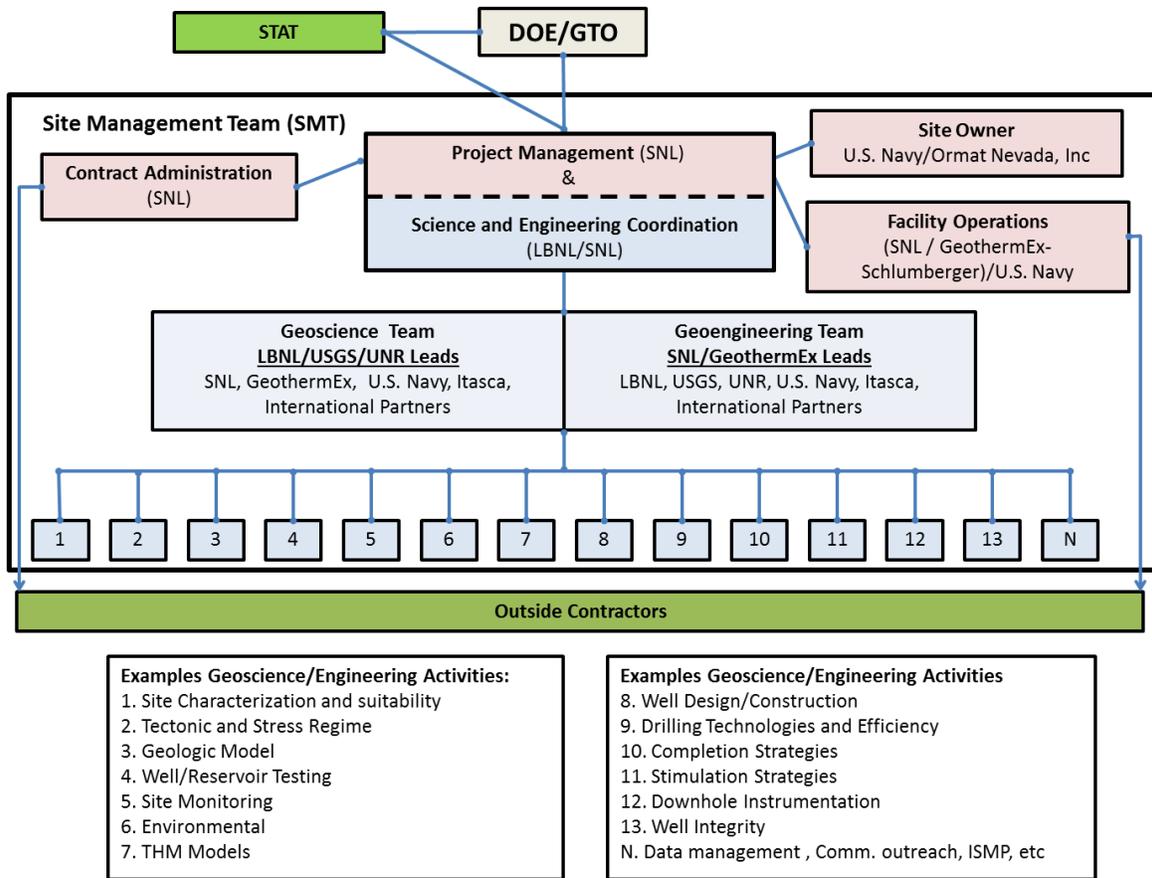
## **R&D PORTFOLIO**

At least 50% of annual Phase 3 FORGE funding will be directed toward competitive R&D solicitations, exclusive of funds dedicated to innovative drilling and flow testing. Competitive solicitations will be issued annually, which will require a robust institutional procurement system. This will result in a broad portfolio of R&D activities in support of FORGE, involving multiple research organizations (e.g., government research labs, universities, and private companies) within the broader national and international community. It is also expected that FORGE will be an international centerpiece of the subsurface research community and will complement the current SubTER initiative at DOE; thus, researchers not directly connected to EGS efforts will also have the opportunity to engage in FORGE-related research that can advance EGS. The operation of FORGE during Phase 3 will require thoughtful and purposeful integration of all activities, both at the field site and in laboratories and research institutions around the world involved in EGS research. Such coordination will require regular meetings of FORGE participants, organized by the Fallon FORGE Team, to discuss recent results and develop future plans and proposals for FORGE-related science and engineering.

## **MANAGING AND COORDINATING LOGISTICAL, ADMINISTRATIVE, ANALYTICAL AND TECHNICAL SUPPORT**

### **MANAGEMENT STRUCTURE**

Successful management of FORGE (including the planning, solicitation, review, and selection of technologies that will be tested at FORGE) will require a management structure that provides clear lines of communication, authority, responsibility and continuity of interests and mission between DOE, the Science and Technology Analysis Team (STAT) and the Site Management Team (SMT). The SMT will be responsible for site operations and support for R&D activities needed to facilitate and advance the goals of FORGE. The schematic diagram in Figure 1 shows the proposed management structure for the Fallon FORGE project.



**Figure 1. Fallon FORGE project management team and structure. Arrows indicate communication/interaction paths.**

The SMT, shown in Figure 1 within the large box outlined in black, will consist of two primary interactive components: Project Management (pale pink boxes) and the Geoscience and Geoengineering Teams (pale blue boxes). Project Management will be overseen by the Project Manager (SNL), who in turn will preside over the Contract Administrator (SNL) and the Facility Operator (SNL, GeothermEx, U.S. Navy). The Project Manager will work directly with the Site Owners (U.S. Navy and Ormat Nevada, Inc.) on all issues relevant to site operations and logistics. The Project Manager will also participate in the Science and Engineering Coordination (SEC), a team co-led by LBNL and SNL.

The SEC will work directly with the Geoscience and Geoengineering Teams to identify, conduct and report on site activities related to characterization, environmental impact, well design, downhole measurements/sampling, stimulation design, flow testing and monitoring, and any other issues as indicated by the small blue boxes (numbered 1-14, Figure 1). The Geoscience and Geoengineering Teams will report directly to the SEC and Project Manager. Within our project management structure we have placed the DOE/GTO, STAT, contractors needed for FORGE operations and independent researchers working under the Phase 3 R&D solicitation outside the SMT box. Recipients of competitive R&D solicitations will be contracted to the Prime Recipient (SNL).

The DOE/GTO has ultimate oversight of FORGE, utilizing advice and recommendations issued by the STAT, the Project Manager and the SEC. We have placed STAT outside the box (Figure 1) to ensure a degree of independence and autonomy with respect to the SMT. STAT will have a direct line to the FORGE Project Management and the SEC, as well as DOE/GTO. Contractors performing operational work at the FORGE site through contracts issued by the Contract Administrator also reside outside of the SMT box, and will be used if expertise or service is needed that does not reside inside the SMT. The roles, responsibilities, communication lines and team members for each box are described in more detail below. The organization and operation of STAT is described later in the plan.

## MANAGEMENT TEAM

### *Project Manager*

The project site will be managed by SNL. The manager will oversee contract administration, oversee site operations (with GeothermEx) and coordinate all activities with the Site Owners. Duties will include handling of site finances; deploying, managing and maintaining site facilities; developing adequate training protocols for environmental health and safety regulations; and permitting, issuing and administering R&D FOAs as prescribed by the STAT and DOE/GTO. Furthermore, as the single point of contact with DOE, the project manager will ensure that the site mission, as defined by the DOE GTO and SEC team, is carried out.

### *Contract Administration*

The project site will be managed by SNL. The manager will oversee contract administration, oversee site operations (with GeothermEx) and coordinate all activities with the Site Owners. Duties will include handling of site finances; deploying, managing and maintaining site facilities; developing adequate training protocols for environmental health and safety regulations; and permitting, issuing and administering R&D FOAs as prescribed by the STAT and DOE/GTO. Furthermore, as the single point of contact with DOE, the project manager will ensure that the site mission, as defined by the DOE GTO and SEC team, is carried out.

### *Facility Operations*

GeothermEx/Schlumberger, in collaboration with SNL, will be responsible for the operation of the facility, which will be conducted in collaboration with the Site Owners (U.S. Navy and Ormat Technologies). The operator will be responsible for all field logistics and coordinating site operations.

### *Science and Engineering Coordination (SEC)*

The SEC team will be co-led by LBNL and SNL. The roles of the SEC will be to (1) provide clear lines of communication within the SMT and to and from the STAT and DOE; (2) coordinate geosciences and geoenvironmental activities conducted at the site by SMT team members and non-Team R&D projects; (3) provide recommendations and guidance to STAT and DOE regarding R&D needs and potential FOA topics identified by the SMT as necessary to meet FORGE objectives and (4) report directly to DOE on project status, problems and future directions.

### ***Geoscience and Geoengineering Teams***

These groups will have multiple leads aligned along core capabilities of their institutions. Their role will be to identify, conduct and report on the necessary site activities related to reservoir characterization, well design, etc. Examples of specific activities are given in Figure 1. It is important to note that the Team responsibilities will depend on the project Phase. For instance, the Teams will focus on site characterization during Phases 1 and 2, but upon entering Phase 3 all site characterization and other R&D activities will be evaluated through independent FOA and proposal evaluation processes. The Geoscience and Geoengineering Team leads will report directly to the SEC team. The Geoscience Team will have three leads: Lawrence Berkeley National Laboratory (LBNL), U.S. Geological Survey (USGS) and the University of Nevada, Reno and Nevada Bureau of Mines and Geology (UNR). The UNR Team will develop the 3D model for the site in Phase 1 and continue to update the model as more data are acquired in subsequent phases. Additional participants will include Sandia National Laboratories (SNL), GeothermEx, Itasca, and international partners (presently we have a commitment of interest from Japan, through ASTI). The Geoengineering Team will be led by GeothermEx and SNL with additional participation from LBNL, USGS, UNR, Itasca, and participating international partners. GeothermEx, playing a dual role as a Facility Operator, will provide assistance with subsurface site characterization, field activities carried out by the Geoscience Team, development of the reservoir conceptual model, the induced seismicity protocol, supporting NEPA clearance, developing well stimulation plans in concert with the Geoengineering Team and overseeing stimulation activities. As needed, the Geoscience/Geoengineering Teams will engage outside collaborators to provide additional expertise.

## **ENSURING THAT TESTED AND EVALUATED TECHNOLOGIES SUPPORT GTO OBJECTIVES**

### **COMMUNICATION WITH SITE MANAGEMENT**

Our Project Management Plan is structured to ensure that DOE has a direct path of communication with site management (through the Project Manager), SEC, and STAT. Through these lines of communication, DOE will be substantially involved in project decisions, including participation in decisions related to the technical, programmatic, and/or financial aspects of the project and operation of the FORGE site. As noted above, to ensure adequate integration of DOE, the SEC team will report directly to DOE via regularly scheduled teleconferences, face-to-face meetings and quarterly and annual reports. Furthermore, the FORGE site will include office facilities for on-site DOE personnel.

### **COLLABORATIVE APPROACH**

To adequately address critical project or programmatic issues, all FORGE management and oversight activities will be conducted in collaboration with DOE, including recommendations of alternate approaches or delaying work or shifting emphasis, if needed. DOE will review ongoing technical performance to ensure that technical progress has been achieved within sub-phases before work can proceed to subsequent phases. Principally with the Project Manager, DOE will collaborate in the allocation of funds budgeted as work progresses and as funding needs may change among the different projects undertaken. DOE will be kept apprised and participate in

the reviews of contractor activities and reports related to project activities. As stated in the “Conflict of Interest” section, DOE will review and provide final resolution of actual and perceived conflicts of interest with the SMT, STAT and outside contractors. DOE will also serve as a scientific and technical liaison between FORGE team and other program or industry personnel and interests.

**RECURRING CYCLES: PLANNING & REVIEW, TESTING & EVALUATION**

Competitive R&D solicitations will be issued on an annual basis. To support the annual solicitations, the development of the areas of interest, development of the solicitations, issuance of the solicitations and review of the solicitation responses will be a continuous process throughout the life cycle of the project. Assuming annual awards are made on a fiscal year basis, the following timeline shown in Table 1 will be implemented.

**Table 1. Timeline for annual R&D solicitations**

Task Name	Start	Finish
Development of R&D Needs	Nov. 1	Mar. 1
Write Solicitation	Mar. 1	Apr. 1
Issue Solicitation	Apr. 1	Apr. 1
Proposals Due	June 1	June 1
Review Proposals	June 1	Aug. 1
Notification of Award	Aug. 1	Aug. 1
Negotiation of Award	Aug. 1	Sept. 1
Funds Distributed	Oct. 1	Oct. 1

During the course of the FOA funded R&D projects, project participants will be required to provide quarterly project reports to the FORGE Project Management Team—the reports will be provided to DOE and to the members of the STAT. In addition to the required quarterly reviews, monthly teleconferences between the FORGE Project Manager or delegate and the awardee will be established. DOE and selected members of the STAT will be invited to these calls.

Furthermore, all activities occurring within and conducted by the SMT will be reported on a recurring monthly basis to the STAT and GTO. The SMT along with the SEC and Project Management group (site owners, facility operations and contract administration) will hold weekly meetings to provide status updates for internal (SMT) and external (outside R&D) projects and identify potential logistical issues, site characterization/monitoring needs and data dissemination. As noted, activities related to FOA-funded R&D projects will be reported quarterly by the funded recipients to the SMT. The reports will be used to facilitate R&D activities at FORGE, coordinate future operations, insure completion of R&D projects in a

timely manner as defined by project milestones and the reports will be compiled in condensed form for presentation to the STAT and the GTO. Using appropriate scientific/trade meeting (e.g., GRC, Stanford Workshop, ARMA, AGU, etc.) as a forum, FORGE progress and status reports will be presented to the general public on a regular basis (semi-annually at a minimum). As outlined under Outreach and Communications, regular meetings with the local communities and stakeholders describing FORGE operations, progress and plans will be conducted.

## **R&D IMPLEMENTATION INVOLVES CLOSE COLLABORATION WITH THE SMT**

All R&D projects conducted at FORGE will have access to logistical support that can be provided by the SMT (e.g., development and/or access to monitoring and testing wells), including any necessary support from outside contractors. Data acquired by the SMT, particularly data relevant to site characterization will be made available to all R&D projects in near real time (see the Data Dissemination plan). It will be encouraged that potential responders to FOA funded R&D projects work closely with the SMT during conceptual stages to facilitate project design, including logistical support, site data, etc. R&D project scientists will have site access, within the guidelines outlined by the U.S. Navy Command, and access to site facilities needed for project support.

## **ESTABLISHING AND MAINTAINING STAT**

The role of the Science and Technology Analysis Team is defined by the GTO and consists of a group of best-in-class technical experts who will provide technical guidance needed to ensure that GTO objectives are fully considered and incorporated into the execution of FORGE, including associated Phase 3 R&D projects. The STAT will play a critical role in assessing R&D needs in accordance with GTO roadmaps and goals, establishing technical baseline information and performance specifications, guiding ongoing site characterization and monitoring efforts, developing topics for Phase 3 FORGE R&D solicitations, and providing guidance for review and selection of these R&D projects. Since it is likely that institutions represented within the SMT and STAT will be involved in responding to R&D solicitations, STAT will create an independent review panel consisting of external people and unconflicted STAT members to assess and rate R&D proposals. To mitigate possible conflict of interest issues, final R&D award decisions will be made by the GPO with the help of STAT recommendations.

The STAT will also assess the progress and results of the work carried out by the SMT at FORGE as well as independent scientific and engineering R&D implemented at FORGE under the Phase 3 solicitations and provide input to the SEC team for the development of annual Topical Reports. As noted above, we have placed STAT outside of the SMT box. By remaining outside the box, and therefore maintaining a degree of independence from the SMT, STAT will be afforded a better opportunity to evaluate operations, assess needs and recommend appropriate R&D topics. The STAT will communicate directly with DOE/GTO and the SEC team. In turn, the SEC team will gather and synthesize information and recommendations from the Geosciences and Geoenvironmental Teams and Facility Operations that will be passed onto STAT for further independent evaluation.

In consultation with the GTO, ten members of STAT will be selected from the geosciences and geoengineering community. Members will be drawn from the GTO, National Laboratories, academia and the private sector and will, if appropriate, be paid a stipend for their services on the committee. The Navy will also provide a Naval Facilities Engineering Command employee to participate in STAT. A lead spokesperson will be selected, preferably a member of the GTO. The STAT will be charged to develop an internal process for evaluating potential conflict of interest cases that affect the STAT members associated with potential responses to R&D solicitations. DOE will review and provide final resolution of actual and perceived conflicts of interest with the STAT.

### **ADDRESSING CONFLICTS OF INTEREST AMONG SMT AND STAT**

The R&D needs and associated solicitation topics will be developed by the STAT with guidance and assistance from the SEC and DOE. Given that individuals and/or institutions that make up the SMT, SEC and STAT may wish to propose R&D at the Fallon FORGE site during Phase 3, it is required that potential real or perceived conflicts of interest are mitigated. In our structure, the STAT is purposefully outside the SMT structure and as such acts independently of the SEC and SMT. Since the role for STAT includes developing topics for recurring FORGE R&D solicitations, providing guidance for review and selection of R&D projects, and developing out-year R&D strategies, we are confident that the STAT—operating as an entity outside of the SMT—can assist in the development of solicitations with autonomy; this is one aspect of our mitigation strategy. The FORGE Project Manager will not propose R&D during the course of the project to allow effective firewalling of his activities from his parent institution and to allow unfettered assistance to the R&D procurement process.

Another aspect of our conflict of interest mitigation strategy involves the manner in which independent Phase 3 R&D proposals will be evaluated. Proposal responses to this R&D solicitation will be reviewed and ranked by an outside, independent Proposal Review Panel convened by STAT and the DOE/GTO. This Proposal Evaluation Panel will review proposals submitted in response to the Phase 3 R&D solicitations, which will be developed and issued by the Prime Recipient. This Review Panel will be composed of people who are experts in fields relevant to the Phase 3 solicitations, but who are not actively involved in FORGE R&D activities. Furthermore, with respect to final selections of R&D proposals, it is envisioned (with concurrence from DOE/GTO) that the Proposal Review Panel will only provide their recommendations to DOE and that the source selection officer will reside within the DOE/GTO.

Within the SMT, potential conflicts of interest relative to pursuing R&D solicitations will be evaluated on a case-by-case basis by the STAT. Since the STAT committee resides outside of the SMT box and acts independently of SMT, the STAT committee, with DOE and SEC participation will evaluate potential conflict of interest cases that affect the STAT members associated with potential responses to R&D solicitations. There will be an emphasis to recruit outside qualified STAT members who do not have or anticipate potential conflicts. However, if STAT members are deemed conflicted they will recuse themselves from the development of solicitation topics. DOE will review and provide final resolution of actual and perceived conflicts of interest with the SMT, STAT, as well as outside contractors. DOE's option to appoint at least 30% of the STAT will offer an additional mitigating step. In addition, we

propose that no more than 50% of the STAT be from organizations that make up the SMT. As an additional mitigation, it is envisioned that those engaged in the issuance of the solicitation from the SMT (primarily select individuals from the Prime Recipient) will be suitably firewalled from the potential responders and will not be eligible to participate in responses to R&D solicitations.

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Doe, T., McLaren, R., Dershowitz, W., Weston, R., Discrete Fracture Network Stimulations of Enhanced Geothermal Systems, *Proceedings*, 39<sup>th</sup> Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2014).

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