UTAH FORGE INDUCED SEISMICITY MITIGATION PLAN

Enhanced Geothermal System Testing and Development at the Milford, Utah FORGE Site

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Prepared for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Contract DE-EE0007080

December 30, 2020

This induced seismicity mitigation plan (ISMP) follows the best practices established by Majer et al. (2016). Information that was collected in Phases 1 and 2 of the Utah FORGE project has been incorporated, as have literature searches and risk assessments. As required, the ISMP and the PSHA (Attachment 1) will be updated and will incorporate new data and new mitigation strategies that may be developed.

December 30, 2020

EXECUTIVE SUMMARY

Enhanced Geothermal Systems (EGS) require the creation of sustainable rock permeability in the subsurface reservoir in order to extract heat. This is carried out by water injection stimulation to create or enhance fractures along favorably oriented trends of weakness in the rock. Seismicity induced by such stimulation must be monitored both to map EGS reservoir growth and to alleviate possible damage to infrastructure and surrounding development. While most EGS induced events are too small to be felt (M <2), some larger ones may be and may cause limited damage. It is thus essential to implement an appropriate and effective induced seismicity mitigation plan (ISMP) that references the natural background geological structures, the state of stress, and the potential impacts of EGS operations upon infrastructure and people.

The Utah FORGE ISMP follows the best practices outlined in Majer et al. (2016) to describe the seismic hazard, seismic risk, plans for seismic monitoring and mitigation, and plans for communicating with stakeholders and the public. Utah FORGE has completed NEPA compliance, all drilling plans have been approved by the Utah State Engineer, and Beaver County has issued needed conditional use permits. There is a great deal of support for the Utah FORGE project at the local, county, and State levels and by the Utah federal congressional delegation. No issues regarding induced seismicity were raised by local stakeholders following presentations specific to the possibility of induced seismicity or in other communications directed to the Utah FORGE team. The seismic monitoring is being done by the University of Utah Seismograph Stations (UUSS), a State funded organization housed at the University of Utah, charged with monitoring seismic (both natural and induced) activity within the State of Utah. UUSS is also the Advanced National Seismic System (ANSS) authoritative agency for monitoring seismic activity in Utah.

Seismic risk is the product of seismic hazard, vulnerability, and cost. We start by describing the hazard. There are no mapped faults under the FORGE footprint. The seismicity surrounding the Utah FORGE site is characterized by low magnitude earthquakes occurring at low rates. The largest earthquake within 20 km was the 1908 M 4 earthquake located near Milford, Utah. Most natural earthquakes in the area occur under the Mineral Mountains to the east of the FORGE site or in a localized area near the Milford airport. Before the borehole injection experiment in April 2019, there was no seismicity recorded within the Utah FORGE footprint. Using deep borehole receivers, only microseismic events (M < -0.5) were detected during the experimental injection activity. In addition to the tectonic earthquakes and induced seismicity pertaining to FORGE, there are seismic events related to quarries to the northwest of Milford and perhaps induced seismicity associated with the Blundell geothermal power plant located east of the Utah FORGE site.

The U.S. Geological Survey National Seismic Hazard Maps (Peterson et al., 2020) characterize the location of Utah FORGE to be low hazard. This is supported by a site specific probabilistic seismic hazard assessment (PSHA) performed by Wood Environmental & Infrastructure Solutions, Inc. The recurrence interval for earthquakes within 50 km of Utah FORGE is ~10 years for M > 4 and ~1000 years for M > 6. Based on the local PSHA there is a 10% probability that peak ground acceleration will exceed 10 to 13% g in the next 50 years. For ground motion frequencies greater than 1 Hz, the 10% in 50-year hazard is largely a function of small to moderate sized earthquakes located within 5 to 10 km of the Utah FORGE site. Using relations developed from other induced seismicity studies that include geothermal, fluid disposal, and hydraulic stimulation data sets, together with estimated fluid injection volumes currently proposed for Utah FORGE operations, we calculate a maximum magnitude for an induced earthquake at the Utah FORGE project of M 3 to M 4. While larger earthquakes are possible, they are much lower probability events, and in a seismic risk calculation would be weighted accordingly.

Moving to vulnerability, the Utah FORGE project is located in remote south-central Utah. The immediate region surrounding FORGE is uninhabited. The closest town, Milford, Utah, (pop. ~1400) is ~16 km to the southwest. Within ~5 km of Utah FORGE there is a geothermal power plant, a wind farm, and scattered pig farms. Based on distance and ground motion prediction equations, earthquakes below M 3 would not likely be felt in Milford, and if felt would be hard to distinguish from background levels of ground motion due to e.g. vehicle traffic including a railroad. Ground motion associated with the calculated maximum magnitude (M 4) will be felt throughout the region (as was experienced by a recent M 3.9 occurring south of Milford), but is unlikely to cause damage even at distances within 5 km of FORGE.

For magnitudes approaching M 5, the potential for moderate damage within 5 km and light damage out to 10 to 15 km increases. To decrease the exposure to the potentially more damaging earthquakes, the mitigation plan (a traffic light system) has been developed in an effort to keep events below M 4. This is accomplished by stopping activities at the FORGE site if an M > 3 earthquake occurs, and by slowing and re-evaluating operations if an M > 2 occurs or if 10 or more M > 1 events occur within a 24-hour period. While we acknowledge that we cannot strictly control seismicity, these mitigation activities will decrease the probability of an M 4 or larger earthquake being induced and thus decrease the overall vulnerability from induced earthquakes at the Utah FORGE site.

The final component of the risk calculation is cost. Given the overall rural nature of the region surrounding Utah FORGE, the low seismic hazard, and the highest probability induced earthquakes being M 4 or smaller, together with the support of the project from local and regional stakeholders, it is difficult to associate a significant cost with induced seismicity.

An operation with the scale of Utah FORGE is obligated to keep its many stakeholders informed. We have had regular interactions with stakeholders and the community. We provide information about the project on the Utah FORGE website and social media channels, plus real-time seismic information, including seismograms, on the UUSS FORGE website.

Majer, E., Nelson, J., Robertson-Tait, A., Savy, J., & Wong, I. (2016). Best practices for addressing induced seismicity associated with enhanced geothermal systems (EGS), Topical report, Lawrence Berkeley National Laboratory, prepared at the direction of the Dept. Of Energy Geothermal Technologies Program, April 8, 115 pp. Petersen, M. D., Shumway, A. M., Powers, P.

M., Mueller, C. S., Moschetti, M. P., Frankel, A. D., Rezaeian, S., McNamara, D. E., Luco, N., Boyd, O. S., Rukstales, K. S., Jaiswal, K. S., Thompson, E. M., Hoover, S. M., Clayton, B. S., Field, E. H., & Zeng, Y. (2020). The 2018 update of the US National Seismic Hazard Model: Overview of model and implications. Earthquake Spectra, 36(1), 5–41. https://doi.org/10.1177/8755293019878199.

Table of Contents

ACRONYMS

∑: Seismogenic index
3C: Three-component
ANSS: Advanced National Seismic System
AQMS: ANSS Quake Monitoring System
BLM: Bureau of Land Management
DAS: Distributed Acoustic Sensor
DOE: Department of Energy
DFIT: Diagnostic Fracture Injection Tests
EGI: Energy & Geoscience Institute at the University of Utah
EGS: Enhanced Geothermal System(s)
FORGE: Frontier Observatory for Research in Geothermal Energy
GMPE: Ground Motion Prediction Equation
GPS: Global Positioning System
GRID: Geothermal Risk of Induced seismicity Diagnosis
ISB: Intermountain Seismic Belt
M: Magnitude
M_{comp}: Magnitude of Completeness
MMI: Modified Mercalli Intensity
NGA: National Geospatial-intelligence Agency
NSHM: U.S. Geological Survey National Seismic Hazard Maps
PGA: Peak Ground Acceleration
PGV: Peak Ground Velocity
PSHA: Probabilistic Seismic Hazard Analysis
SAT: Seismic Advisory Team
SPAC: Spatial Autocorrelation
SMP: Seismic Monitoring Plan
TLS: Traffic Light System
UUSS: University of Utah Seismograph Stations
Vs30: average shear velocity in the upper 30 m

FIGURES

INTRODUCTION

Seismicity induced by industrial activities has been known and studied for many years (e.g. Hsieh and Bredehoeft, 1981; Raleigh et al., 1976). With both increased and changing activity in energy sectors and the migration of some of these activities toward more populated areas, reporting and concern about induced seismicity has dramatically increased (e.g. Petersen et al., 2017). Often cited examples of more frequent induced seismicity and its resulting societal impacts include the rapid increase of M > 3 earthquakes in Oklahoma beginning in 2001 (Ellsworth, 2013), the 2006 Basel, Switzerland M_L 3.4 earthquake (Bachmann et al., 2011; Deichmann and Giardini, 2009) and more recently the 2017 Pohang, South Korea M_W 5.5 earthquake (Ellsworth et al., 2019; Grigoli et al, 2018; Lee et al., 2019; Woo et al., 2019). With an increase of induced seismicity worldwide (Foulger et al., 2017), it is important to assess and make plans to mitigate the risk of induced seismicity prior to activities that might lead to these earthquakes (e.g. Majer et al., 2012; Trutnevyte and Wiemer, 2017; Walters et al., 2015).

As a result of increased levels of induced seismicity, much has been learned about how and when induced seismicity is likely to occur and different methods and procedures have been proposed to mitigate the risk. In one such method, Zoback (2012) proposes a five-point checklist: (1) avoid active faults, (2) install seismic monitoring, (3) minimize pore pressure changes at depth, (4) establish modification protocols, and (5) be ready to change plans. In another method, GRID (Trutnevyte and Wiemer, 2017), a relation between seismic hazard, secondary hazards and exposure, and social concerns is developed, and specific mitigation steps are suggested. In yet another method, nuisance events (earthquakes that might be felt but cause no damage) versus damaging events are used to establish protocols (Schultz et al., 2020).

Herein we present an induced seismicity mitigation plan (ISMP) for the Utah Frontier Observatory for Research in Geothermal Energy (FORGE) project that follows the seven-step best practices described in Majer et al. (2016). The resulting plan describes the likelihood of occurrence of, and potential ground motions resulting from, induced seismicity and presents a clear set of procedures in the event that certain seismicity thresholds are reached. The protocol steps are: (1) preliminary screening, (2) outreach and communications, (3) criteria for ground vibration and noise, (4) collection of seismicity data, (5) hazard evaluation of natural and induced seismic events, (6) risk informed decision analysis and tools for design and operation of Enhanced Geothermal Systems (EGS), and (7) risk-based mitigation plan.

PRIMARY ISMP STEPS

Our implementation of the seven steps or procedures particular to defining an ISMP appropriate to the Utah FORGE project is laid out below. The implementation incorporates project area characteristics pertinent to each step, existing institutional infrastructure to process earthquake and site properties information, description of augmented induced seismicity monitoring capability, and action protocols in the event of a significant possible induced earthquake.

1. PRELIMINARY SCREENING EVALUATION

As advised by Majer et al. (2016), "The screening evaluation in Step 1 is not meant to provide a definitive estimate of risk. It is meant to identify the sites that would, most likely, be inappropriate, based on risk of exceeding acceptability criteria of ground shaking". Preliminary screening of the Utah FORGE project was carried out in Phase 2. As part of this screening, an initial version of the ISMP was submitted to DOE. That version included all the aspects of the current ISMP including evaluation of seismic hazard and risk and communication with stakeholders. Based on this work and other aspects of the Utah FORGE project, Utah FORGE was selected by DOE from five candidate project sites as the FORGE project to proceed.

Following Phase 2, the Utah FORGE project has completed NEPA compliance, and all drilling plans have been approved by the Utah State Engineer and Beaver County has issued a Conditional Use Permit for proceeding. Recently (September 15, 2020), stakeholders were re-engaged through public meetings with the Beaver County Commissioners and at open meetings in Milford with the town council. The prospect of induced seismicity was presented. There were no concerns regarding induced seismicity voiced during these public meetings. The potential for induced seismicity at the FORGE site and the mitigation plan were also presented to the Utah Seismic Safety Commission (October 29, 2020). Again, there were no concerns voiced. There is strong support for the Utah FORGE project to proceed at the local, county and State levels.

Since the Utah FORGE project is now in Phase 3, in this section we present an overview of the area, background seismicity, and an initial assessment of the seismic hazard and risk. Specific and more detailed aspects of hazard and risk will be presented in greater detail in the following steps of this plan. The discussion of hazard and risk developed throughout the document will lead into plans for mitigation, which is one of the main goals of this document.

The Utah FORGE site is located in rural Beaver County, Utah. The nearest population center is the town of Milford, located 16 km to the southwest of the FORGE site, with a population of ~1400 persons. Critical facilities include a hospital, an airport, and schools. Based on 2010 Census Bureau data, there are ~2500 households and a total population of 6,629 in Beaver County, with the majority of the population located in the town of Beaver, 32 km southeast of the deep drilling location. The majority of the built environment is residential. Based on the population density and the built environment, the current assessment is that this is a low seismic risk area — "Can proceed with planning but may require additional analysis to confirm" (Majer et al., 2012). A more complete discussion of risk is in Section 6.

The University of Utah Seismograph Stations (UUSS), a partner in the Utah FORGE team responsible for seismic monitoring, has been doing so throughout Utah and the surrounding region for over 50 years. UUSS is a core agency within the Utah Earthquake Program (https://ussc.utah.gov/pages/help.php?section=Utah+Earthquake+Program) funded by the State of Utah for monitoring seismicity within the State. UUSS is also a funded Advanced National Seismic System (ANSS) network and is the authoritative agency for monitoring seismicity in the Utah region and Yellowstone National Park.

The Utah region has several types of seismic sources (Pankow et al., 2019b). Tectonic earthquakes tend to be located in the Intermountain Seismic Belt (ISB; Smith and Arabasz, 1981), a band of seismicity running from Montana to Arizona. There are also prominent sources of induced seismicity, most notably mining induced seismicity associated with coal mining in the Wasatch Plateau and Book Cliffs in central Utah (Arabasz et al., 1997) and fluid injection seismicity in the Paradox Basin on the Utah Colorado border (Ake et al., 2005; Block et al., 2014). Other cases of induced seismicity have been associated with the Blundell Power Plant (Pankow et al., 2019a) and along the eastern edge of the Wasatch Plateau (Stein, 2016). Other seismic sources in the region include surface and underground blasting associated with mining activity (e.g. Linville et al., 2019; Tibi et al., 2019; Voyles et al. 2020) and explosions related to munitions at military facilities located within the State (e.g. Stump et al., 2009). While there are State regulations related to ground motions and surface air fronts from blasting, induced seismicity is not currently subject to State regulation.

To provide one view of seismic hazard, UUSS has compiled an earthquake catalog going back to 1850 (Arabasz et al., 2015, 2017; Figure 1). This catalog composes one part of a more detailed seismic hazard analysis that will be expanded upon in Section 5. In this historical record, there has been only one M > 4 earthquake in the greater Milford, FORGE study area (yellow box, Figure 1). This was the 1908 M 4.1 Milford earthquake. Within ~50 km of the proposed FORGE site, there have been other earthquakes with M < 4.9, but there is only one earthquake M ≥ 4.9; the 1901 M 6.6 Tushar Mountain earthquake (labeled 'T', Figure 1) located ~50 km to the east within the seismically active ISB. Based on both the UUSS catalog and an early study by Zandt et al. (1982), natural seismicity in the Utah FORGE study area is characterized by small magnitude earthquakes and a low seismicity rate. This will be further discussed in Section 4.

As across much of Utah, there are other known seismic sources near the Utah FORGE site in addition to the earthquake hazard. There is a large quarry operation northwest of Milford producing infrequent seismic events of similar magnitude (M < 2) and ground shaking to the majority of cataloged earthquakes (Pankow et al., 2019a; Potter, 2017). Additionally, there is the possibility of small ground motions associated with railway traffic in the town of Milford, and noise sources related to the railroad and air traffic.

To get an alternate overview of seismic hazard, the 2014 U.S. Geological Survey National Seismic Hazard Maps (NSHM; Petersen et al., 2014) showed the Utah FORGE study area is in a region of low to moderate seismic hazard. The peak ground acceleration (PGA) with a 10% probability of exceedance in 50-years (475-yr return interval) was cited as 10% g. These maps were recently updated and replaced with the 2018 NSHM (Petersen et al., 2020). In the revised maps, PGA with a 10% probability of exceedance in 50 years is reduced to < 10% g (Figure 2a). The new maps also look at the chance of experiencing a Modified Mercalli Intensity VI (the level of shaking that starts to produce damage, such as cracks to weak plaster and masonry; Wald, 1999) from earthquake shaking in the next 100 years (Figure 2b). For the Utah FORGE area, this probability is ~30%.

Based on: (1) the rural nature of the proposed site, (2) the expectation that induced seismicity will be smaller or equal in magnitude to background tectonic earthquakes (van der Elst et al., 2016), (3) the overall low hazard as found in the NSHM, and (4) the on-going nuisance-level ground motion and noise related to the quarry, railway, and airport; our analysis classifies the overall risk as very low (I) to low (II). This assessment will be further developed and expanded upon in the following best practice steps.

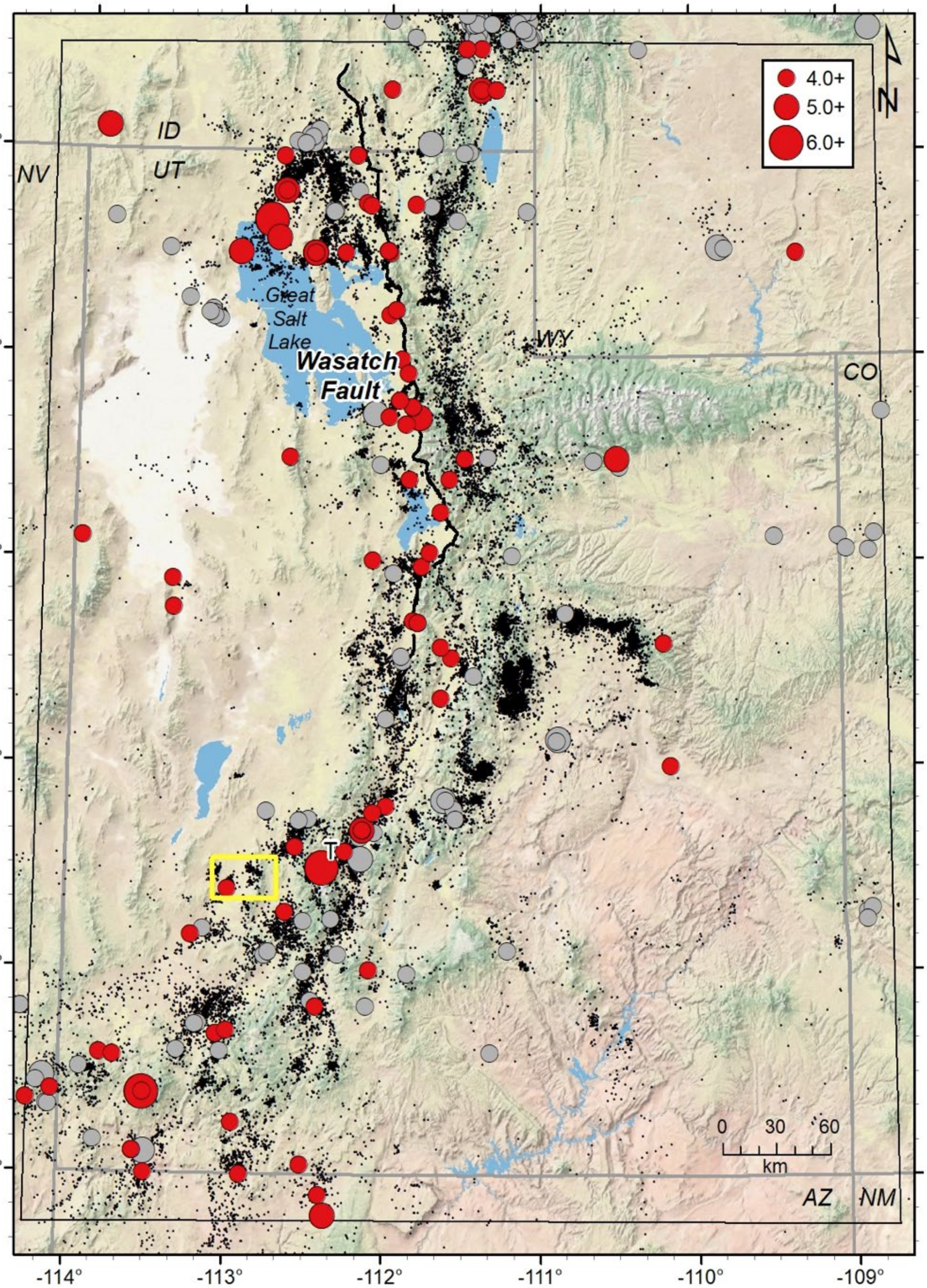


Figure 1. *Epicenter map of mainshocks of moment magnitude, M > 4.0 in the Utah Region, 1850 through September 2012 (red circles, scaled by magnitude; Arabasz et al., 2015, 2017); M > 4.0 2012 through January 2020 (grey circles scaled by magnitude; UUSS catalog). The small black dots show all earthquake epicenters in the UUSS earthquake catalog, July 1962 through January 2020. The yellow box contains the FORGE study area.*

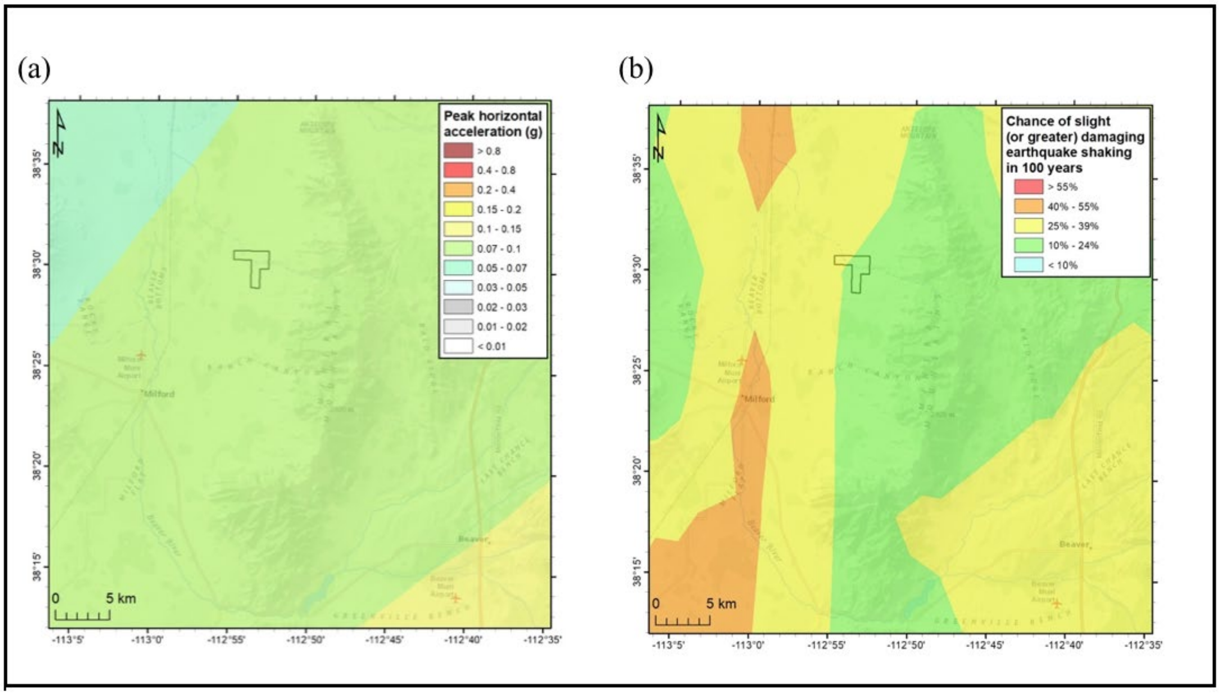


Figure 2. *Probabilistic seismic hazard at the FORGE site from the 2018 National Seismic Hazard map (data from Rukstalis and Petersen, 2019). (a) 10% g in 50 yrs PGA hazard (475 yr return period). (b) Chance of slight to damaging ground motions in the next 100 years.*

2. OUTREACH AND COMMUNICATION PROGRAM

2.1. Program Purpose

As with any EGS project, outreach and communication (O&C) are essential for ensuring the project's success and acceptance. In order to achieve this success, the identification and proactive engagement of various stakeholders is paramount. Specifically, multidirectional communication is needed to foster acceptance, trust, and involvement by these stakeholders.

It is important to recognize that "one size" does not fit all – this communications and outreach plan is designed particularly to address the Utah FORGE project being conducted approximately 16 km northeast of the town of Milford in Beaver County, Utah, an area designated as a rural community.

2.2. Main Elements of Outreach & Communication Approach

Utah FORGE is implementing a "best practices" approach to its outreach and communication efforts following Majer et al. (2016). Four main requirements, and their essential components, have been identified and are listed below.

1. Identify key stakeholders early in the process. Significant effort and time were invested in identifying stakeholders and engaging them from the beginning of the FORGE project, starting in 2015, which has allowed for effective and targeted outreach (Appendix A). The Utah FORGE Outreach and Communication program has always been designed to encourage multi-fronted communication between a variety of stakeholders, with transparency and community participation at its core.

   Forming an early, transparent, and ongoing dialogue with Utah FORGE's myriad stakeholders established a level of trust and understanding around safety and environmental issues, including induced seismicity. The Utah FORGE Outreach and Communication plan facilitates communication and maintains positive relationships with all of its identified stakeholders including the local community, partners, elected officials, regulators, and landowners. Utah FORGE has implemented the means for stakeholders to provide feedback, ask questions and make comments through its website, public meetings and social media platforms.

2. Establish an appropriate Outreach and Communication team. Utah FORGE has clearly defined the processes for both internal and external communication for the project (refer to the Project Management Plan). Since the outreach team serves as the "face" of the project, a diverse group has been assembled, ensuring the right message is delivered to the appropriately-identified audience by the most suitable team member or "proxy." Therefore, along with the core team responsible for the planning and implementation of day-to-day O&C efforts, additional experts and proponents of the project are tapped as appropriate. These additional outreach team members include – but are not limited to – scientists, engineers, seismologists, and on-site staff. At times, depending on the message, Utah FORGE may elicit assistance from community leaders, public safety officials and regulators as well.

3. Provide the community with complete and credible information. The ongoing success of the Utah FORGE EGS project depends on the acceptance and support of the community, which encompasses a large group of stakeholders. In turn, this community cannot continue to offer its acceptance and support without having up-to-date information available that reflects their interests, which for residents of the area can include potentially contentious issues such as induced seismicity. The plan for directly communicating about induced seismicity follows below.

   Utah FORGE began this process of providing credible information regarding the history and potential for induced seismicity to stakeholders even before the site was chosen by the Department of Energy. Beginning in September of 2015, outreach began to ensure acceptance, advocacy and cooperation in fulfilling the overall mission of the project. This outreach, which is catalogued in Appendix B, has continued without interruption since. During this time, support and excitement from stakeholders and the local community has grown. Recent meetings, which included a presentation on seismic activity, seismic monitoring and the traffic light system (https://www.youtube.com/watch?v=USGysyFKuUU), held in August and September in

Milford and Beaver with local officials, showed strong support expressed for the project. In another example, enthusiasm can be seen through social media (Figure 3) posting by one of Utah FORGE's partners, the Utah School and Institutional Trust Lands Administration (SITLA), which is the owner of the land Utah FORGE sits on.

Figure 3. *SITLA Tweet of Utah FORGE information*

Moreover, through its Outreach and Communications Plan, Utah FORGE has worked diligently to establish mutually-respectful working relationships with communities and interested members of the public, local groups, government agencies, regulators, and individuals (refer to the Outreach and Communications Plan). Outreach tools have included:

- An interactive website to provide up-to-date information about Utah FORGE, EGS, and geothermal energy. The site also includes several avenues for stakeholders to contact the project with any concerns, comments or questions.
- A newsletter, which includes sections highlighting the latest developments at the project, scientific information, data, and other announcements. The newsletter is available on the website and is proactively emailed to subscribed stakeholders.
- A data dashboard to afford the research community "one stop" access to data.
- In person meetings with elected officials, civil servants, and area partners to provide updates, answer questions, receive input and suggestions.
- Community presentations to apprise stakeholders of the project's progress.
- Frequent calls and emails to elected officials, administrators and regulators in response to questions, to solicit for concerns and provide updates.
- Social media posts to promote information about geothermal energy, EGS technologies, and to spotlight Utah FORGE activities.

- Media relations to educate audiences about the project, its goals, possible effects – both positive and negative – and its progress.
- Educational materials, including lectures, podcasts, videos, informal presentations, articles in general media publications, that raise awareness about Utah FORGE, EGS, and geothermal energy in general.

With a new round of drilling commencing, Utah FORGE will be increasing its presence in Beaver County and the nearby communities of Milford and Minersville. Specific outreach related to induced seismicity is discussed below. We plan to hold quarterly meetings, have a booth at the 2021 county fair, provide additional community updates in the local paper, collaborate with local towns for social media postings, and host activities on the Fourth of July and on Pioneer Day (an especially important local Utah holiday). Quarterly updates are planned whenever opportunities to meet with various stakeholders (e.g. elected officials, community leaders, school groups, etc.) present themselves. For example, a booth has been booked at the Beaver County Fair (August 26-28), which attracts 1500-2500 people. Otherwise, we will proactively schedule meetings for around the 15th of each quarter's second month (e.g. Aug. 15, Nov. 15, Feb. 15, May 15).

Other possible engagements are being investigated. Two new informational kiosks have been produced and installed. Both virtual and in-person tours of the site are being planned as is practical and safe to do so.

<u>Gain a community perspective as a pathway for gaining public trust.</u> Utah FORGE believes understanding the diverse concerns of the community has better equipped the project to demonstrate both its commitment to, and support of, the community. Therefore, stakeholder involvement in the process was initiated early in the project. A broad coalition of stakeholders – including those living closest to the site – has been defined, and the needs of the community have been identified. For example, after meeting with the elected officials, it was determined that computers be provided to the Milford, Beaver and Minersville libraries to allow interested parties to view project progress and real-time seismicity. Efforts have also been made to continue expanding the positive economic impact that the project is having on the area.

During recent in-person meetings, various elected officials expressed enthusiastic support for the project, viewing it as a vital part of their vision to develop rural areas in general and the Milford area in particular. Because of the potential positive role geothermal energy may play in the nation's energy portfolio, and since the project is funded by the Department of Energy, all of Utah's Congressional delegation are kept abreast of the project's progress. Representatives from Senator Mike Lee's office toured the site on August 12, 2020.

To ensure that Utah FORGE continues to enjoy the public trust it has garnered, members of the community have been encouraged to express their views and concerns throughout the life of the project. Along with frequent in-person meetings and presentations, the Utah FORGE website will always serve as a venue and method for bilateral communication to permit proactive and constructive discussion.

2.3. Outreach and Communication Around Induced Seismicity

Building on Utah FORGE's ongoing and successful O&C activities over the past several years, a specific plan has been developed by UUSS, the State agency charged with monitoring seismic activity within the State. While following the UUSS guidelines, Utah FORGE will also provide additional proactive O&C to the local community and all other stakeholders beyond the requirements of the State.

2.4. The Location of the Utah FORGE Project

Outreach and communication to local stakeholders is tailored to reflect the demographic makeup of the area. For example, the Utah FORGE project is located approximately 16 km northeast from the town of Milford, which has a population of ~1400 residents. Milford is in Beaver County, which ranks 24th out of 29 counties in the state for population density and is designated as a rural region by the State. Milford sits in the center of Utah's Renewable Energy Corridor that includes conventional geothermal plants, solar and wind fields, and a biogas facility. The importance of Utah FORGE as a center of EGS research and development has not gone unnoticed by the local residents and state officials.

The communities of Beaver County are experienced with naturally-occurring seismicity. Most recently, on January 17, 2020, the 3.9 magnitude Minersville Earthquake, a naturally occurring event unrelated to Utah FORGE, occurred 12 km southeast of Milford. No damage was reported. Following the January earthquake, 189 individuals (mostly from the area) proactively logged onto the USGS website's Did You Feel It? page to contribute data to its "Felt Report" (Figure 4). Despite the locals' familiarity with seismicity, it is still paramount to openly discuss the possibility of triggered or induced seismicity frequently.

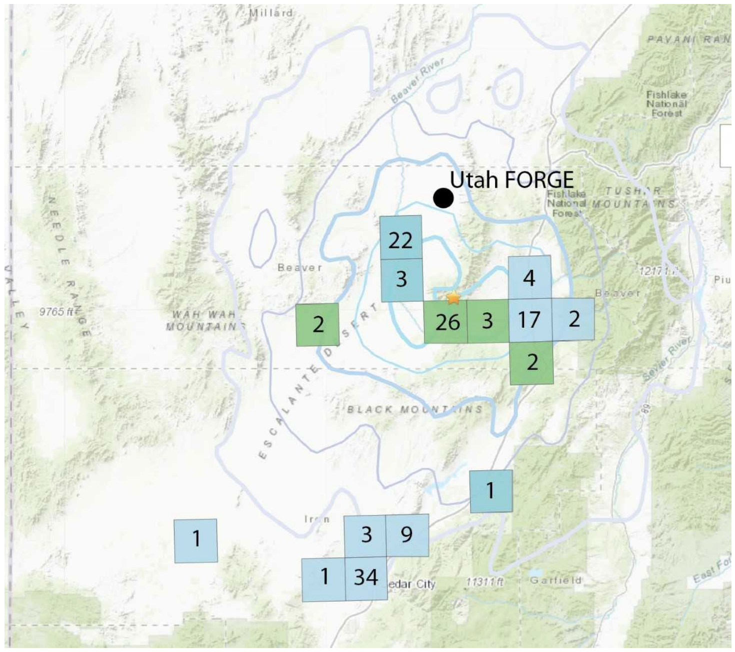


Figure 4. *Number of reports and intensity levels logged on USGS 'Did You Feel It?' website following the M 3.9 Minersville earthquake (https://earthquake.usgs.gov/earthquakes/eventpage/uu60356907/dyfi/intensity)*

2.5. Seismic Mitigation Plan

Continued outreach, education, and communication are the key elements to helping residents understand the meaning of induced seismicity and microseismicity, how it is monitored and what ramifications are associated with it. Transparent and open, multilateral interaction with stakeholders is the cornerstone to Utah FORGE's induced seismicity communication strategy.

An Outreach & Communication Implementation Program is in place to communicate information regarding injection stimulations operations that may or may not induced seismicity. Communication will occur pre-stimulation, during stimulation and post-stimulation to inform various stakeholders of operations and activities (Table 1). The program provides an overview of activities, the intended audience(s) for each action, and the expected timeframe for each.

Table 1. *Communication and Outreach Implementation Program*

Phase	Type	Audience	Timing
Pre-stimulation	Public outreach, professional meetings, and discussions	Public, media, regulators, elected officials, landowners, other stakeholders	Ongoing since 2014
Pre-stimulation	Social media and website updates	Public	Weekly

Pre-stimulation	Local newspaper / newsletter / social media notices	Public	2-3 weeks prior to stimulation
Pre-stimulation	Informational kiosks on Antelope Point Road near Utah FORGE site	Public	Fall 2020
Pre-stimulation	Public outreach meetings	Elected officials, public	2-4 weeks prior to stimulation
Stimulation	Public outreach meetings	Elected officials, public	Quarterly and as needed
Stimulation	Social media and website updates	Public	Weekly
Stimulation	Daily stimulation and seismicity reports	DOE	Daily
Stimulation	Exception Reports	DOE	As required by triggers
Post-stimulation	Public outreach meetings	Public, local media, elected officials	Following stimulation and ongoing quarterly

Pre-stimulation

Since its inception, Utah FORGE has laid the groundwork to inform the community and various stakeholders to better understand geothermal energy, EGS, and seismicity. Public meetings and discussions with a variety of stakeholders, including the community, members of the media, elected officials, regulators, and landowners began in 2015. This outreach has included:

1. Open access and communication with all stake holders on a routine basis
2. Up-to-date information on various aspects of the project
3. Regular meetings with all stakeholders
4. Opportunities for the public to ask questions and/or express concerns – both in person and electronically
5. Field trips and visual media

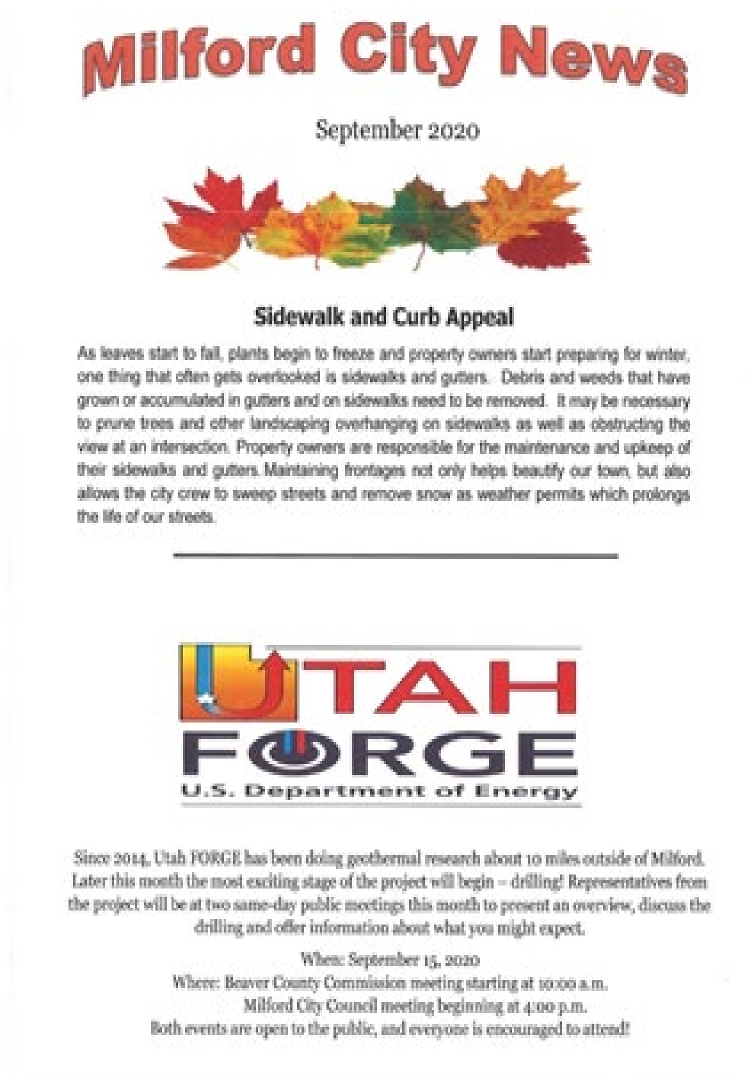
As part of that outreach, the Utah FORGE website (UtahForge.com) has been updated consistently with new content and information. To ensure stakeholders are aware of any new information, as well as to promote other content, the O&C Team proactively posts regularly on its social media platforms. These include:

- Facebook (https://www.facebook.com/utahforge)
- Twitter (https://twitter.com/utahforge)

- LinkedIn (https://www.linkedin.com/company/utah-forge)

To help inform the local community about scheduled drilling and related activities, Utah FORGE collaborates with local media and the area towns to help generate interest in attending public meetings and to educate the community about seismicity.

Advertorials –articles Utah FORGE wrote and paid to have published – appeared in the *Beaver County Journal*, the area's local weekly paper on September 2, 2020 and February 3, 2021. Additionally, a reminder advertisement appeared on September 9, 2020, one week prior to the public meetings. Local municipalities help promote meetings through their monthly newsletters and social media platforms (Figure 5 and 6).



Milford City News

September 2020

Sidewalk and Curb Appeal

As leaves start to fall, plants begin to freeze and property owners start preparing for winter, one thing that often gets overlooked is sidewalks and gutters. Debris and weeds that have grown or accumulated in gutters and on sidewalks need to be removed. It may be necessary to prune trees and other landscaping overhanging on sidewalks as well as obstructing the view at an intersection. Property owners are responsible for the maintenance and upkeep of their sidewalks and gutters. Maintaining frontages not only helps beautify our town, but also allows the city crew to sweep streets and remove snow as weather permits which prolongs the life of our streets.

UTAH FORGE
U.S. Department of Energy

Since 2014, Utah FORGE has been doing geothermal research about 10 miles outside of Milford. Later this month the most exciting stage of the project will begin – drilling! Representatives from the project will be at two same-day public meetings this month to present an overview, discuss the drilling and offer information about what you might expect.

When: September 15, 2020
Where: Beaver County Commission meeting starting at 10:00 a.m.
Milford City Council meeting beginning at 4:00 p.m.
Both events are open to the public, and everyone is encouraged to attend!

Figure 5. *Milford City Newsletter announcing Utah Forge public meeting.*

Figure 6. *Social Media post by Milford City.*

To continue educating the community about geothermal energy and the Utah FORGE project, public kiosks have been produced and are installed. These kiosks are located on Antelope Point Road near the Utah FORGE site and will complement existing kiosks that highlight the area's history, geology, and other renewable energy resources (Figure 7).

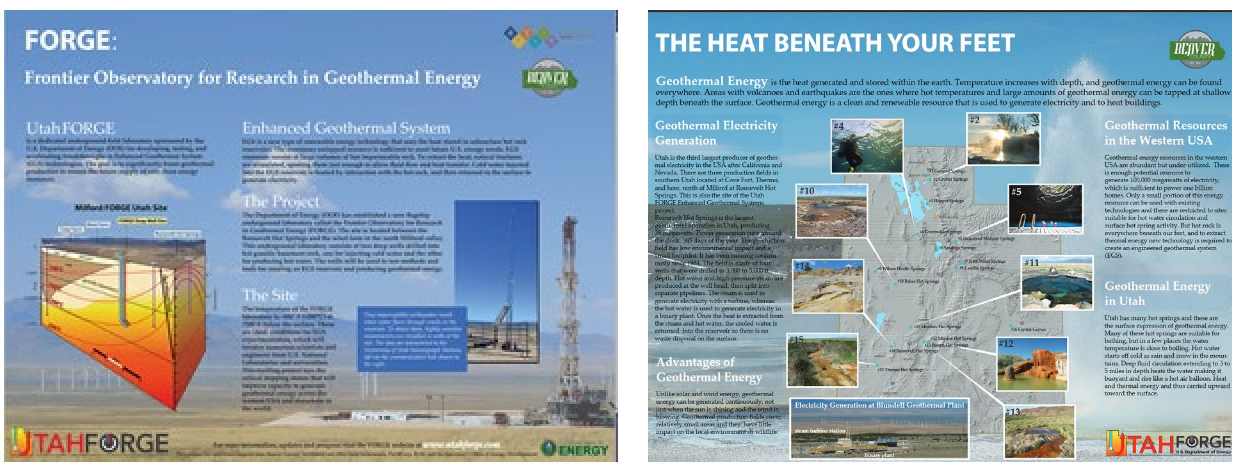


Figure 7. *New kiosks installed on Antelope Point Road.*

To prepare the community for stimulation, outreach includes focused education about EGS and induced seismicity during meetings with the Beaver County Commission, Milford City Council and Beaver County Planning and Zoning Commission. All the meetings are open to the public. Topics in the presentations include:

- <u>Why is seismicity associated with EGS activities:</u> The formation of an EGS reservoir involves the release of energy (stored strain) in the form of microseismicity (very small earthquakes). Since these earthquakes are the result of industrial (manmade) activities, these earthquakes are referred to as induced seismicity.

- The cause of induced seismicity: The fundamental causes of induced seismicity are generally well understood. They include changes in pore pressure, thermal stress, volume change, and chemical alteration of rock slip surfaces.
- Monitoring for Induced seismicity: All drilling and stimulation activities will be monitored using an extensive network of very sensitive seismic monitoring instruments. The instruments can monitor microseismicity long before it reaches a level that can be felt. A detailed plan, referred to as a Traffic Light System (TLS) has been developed to mitigate against the generation of larger earthquakes. The plan defines mitigation measures. These measures may include ramping-down or stopping activities associated with the EGS operations entirely.
- How the public can follow the seismic monitoring: Microseismicity can be followed in real time on the Utah FORGE website (quake.utah.edu/forge-map)

Public meetings, local media coverage, newsletters, stakeholder social media and one-on-one discussions with influencers and partners facilitates this successful outreach.

Stimulation

Stimulation is the process of creating the fractured EGS reservoir through high-pressure water injection. Microseismicity is typically generated during these injection periods. Felt seismicity, while still a low probability, is more likely to be generated during these injections. To ensure the community is proactively kept updated during simulation, Utah FORGE will continue to provide complete and credible information on the project's activities and progress, and address potentially all issues such as the possibility of a seismic event.

To encourage the discussion throughout the stimulations, Utah FORGE will hold quarterly meetings, publish additional information in the local media, post on its social media platforms (and collaborate with local stakeholders such as the town of Milford to repost or produce their own social media postings), and update the website regularly.

The prior content and outreach will focus on the status of the project, progress being made, any issues, and learnings. A virtual tour of the site will be made available to schools, with possible in-person presentations specifically for students to discuss geothermal energy, EGS, and seismicity (dependent on safety guidelines). A webpage will be created on the Utah FORGE website to serve as a compendium of seismic information, including helpful downloadable information for students and their family (https://utahforge.com/seismic-monitoring/).

Continuing to foster an open dialogue, the local community and all other interested parties will have the opportunity to express any concerns and raise questions both at these public meetings, as well as by contacting Utah FORGE directly.

While meetings are a beneficial way to share overall plans and information, when the public feels unexpected ground motion, they will be able to obtain rapid confirmation and details regarding the seismic event. Seismic monitoring is conducted by UUSS. This agency is charged with monitoring seismic activity in Utah and maintains a public website (https://quake.utah.edu/) to disseminate information regarding Utah earthquakes. A link to this site is available on the Utah FORGE website, along with real-time, interactive information about monitored seismicity at the FORGE site (https://quake.utah.edu/forge-map). To facilitate access to digital information, like these and the Utah FORGE website (utahforge.com), computers will be provided to libraries in Milford, Beaver, and Minersville.

For the Utah FORGE immediate area, the plan is to issue alarms to key project personnel and emergency managers and post information to the UUSS, U.S. Geological Survey, and Utah FORGE websites about earthquakes with M ≥ 2 and generate ShakeMaps for earthquakes M ≥ 2.5 within approximately one hour. The information will also be automatically shared through social media. For widely-felt events or those with M ≥ 3.5 UUSS will issue a press release. The press release will be shared on the UUSS and the Utah FORGE websites and through social media channels. Since all earthquakes are contributed to the USGS comprehensive catalog (Comcat), others desiring automatic alarms are recommended to sign up for the USGS ENS service (https://earthquake.usgs.gov/ens/).

For M < 2 events, routine location and magnitude determination is conducted during business hours and posted to the web at that time. These events will not be felt. Waveform seismic data are also available in near-real-time via webicorders (quake.utah.edu/forge-map). The Project Manager's contact information and the contact information for UUSS are on the FORGE website, and available from local first responder officials.

Finally, a "calling tree" has been established in order for FORGE management to be notified of M ≥ 2 events located within the immediate FORGE area or for M ≥ 3 in the larger FORGE region.

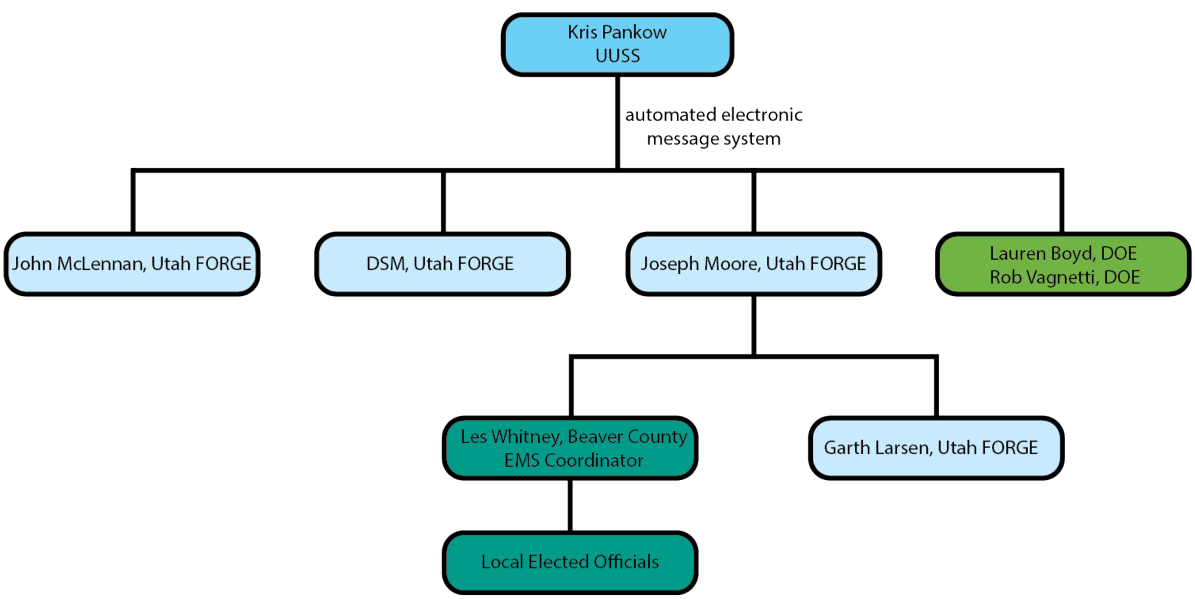


***Figure 8**. "Calling tree" protocol for seismic events M≥2.*

The Utah FORGE Principal Investigator will also contact the O&C Team to ensure information is shared on the website and through social media channels in a timely manner, and to help prepare for any potential media requests.

During the stimulation period, daily stimulation and seismicity reports will be sent to the Department of Energy. Exception reports will be sent to the DOE as warranted.

Post stimulation

Following stimulation, representatives from Utah FORGE will hold a public meeting in the area to provide an overview of the stimulation, report findings, and discuss future activities. Going forward, additional quarterly update meetings will serve as a vehicle for continued community reporting.

Finally, to continually grow its presence within the community, Utah FORGE will have a presence at local events such as the Beaver County Fair and local holiday events, as noted above. Also, as discussed previously, a visitor center will be developed with the collaboration of stakeholders to provide information on the project.

2.6. Conclusion

Utah FORGE is committed to being a good neighbor. The O&C Seismic Mitigation Plan is designed to showcase this commitment. The groundwork has been laid. Utah FORGE is a known entity and a trusted partner to its various stakeholders. By clear, open communication provided through myriad vehicles, the project endeavors to continue earning the trust and cooperation of the community.

3. CRITERIA FOR GROUND VIBRATION AND NOISE

“This section provides guidelines for selecting criteria for vibration and ground-borne noise to assess the potential impact of EGS-induced seismicity on the built environment and human activity.” (Majer et al., 2016). While it seems that the intent of the best practices is more general, in this document we want to establish the criteria for ground vibration and noise specific to the Utah FORGE site. This is the information that is needed in the subsequent sections to assess risk and to design for mitigation.

Following from Schultz et al. (2020), we consider the Utah FORGE area to be uninhabited transitioning to rural. While there are scattered farms, the region surrounding FORGE is largely uninhabited. The town of Milford, 16 km to the south, would be considered rural given a total population of ~1400. Apart from population considerations, there are three nearby industry-related facilities. The Blundell geothermal power plant, scattered industrial pig farms, and a wind farm within ~5 km of the Utah FORGE site (Figure 9).

Based on the rural nature (see overview in Figure 9) and the distance to these facilities. We review ground shaking thresholds from different studies. Richter (1958) proposed thresholds in terms of acceleration—10% g for damage to weak structures and 0.1% g as a lower limit for the felt threshold. Siskind et al. (1980) argue that particle velocity is the best ground motion predictor and proposed a threshold of 0.1 – 0.2 cm/s for cosmetic damage, 12.5 – 25 cm/s for structural damage, and 0.12 cm/s as a felt threshold. Schultz et al. (2020) take a more conservative approach and propose thresholds for ground motions that would be considered a nuisance versus those that might cause damage (0.03 to 0.4 cm/s). Worden et al. (2012) map various ground motion levels both PGA and peak ground velocity (PGV) to intensity, which is a measure of perceived ground shaking and impact of the ground motion (Figure 10). Based on this analysis, the felt threshold is at 0.3% g or 0.1 cm/s, levels of shaking that may produce very light damage start at 6.2%g or 4.7 cm/s, and moderate damage is consistent with 22% g or 20 cm/s. We summarize these values in Table 2.

Other threshold considerations relate directly to the industrial activities. Vibration is actively monitored at the Blundell power plant (Michael Saunders, personal communication 2018) and plant operators have not voiced any concern regarding potential induced seismicity from Utah FORGE. They have also agreed to host a seismic station on their property. Seismic analysis of wind turbines has been performed in various studies. Factors that influence how ground motion translates into the structure include resonance frequencies, the operational status of the windmill, and soil effects (Katsanos et al., 2016). Kjørlaug et al. (2014) looked at the effect of both vertical and horizontal ground motions and found that small to moderate (moderate is typically defined to be M 5.0 to 5.9) earthquakes will not govern the design for windmills located in stiff soils. The average shear velocity in the upper 30 m in the area near the Utah FORGE operations site and the wind farms is 422 m/s (Zhang and Pankow, 2020), classifying as a stiff soil. It is also relevant that, per Utah building codes, windmills need to meet material design limits as well as structure design requirements for earthquakes and wind (Barry Welliver, structural engineer and former Chair of the Utah Seismic Safety Commission, personal communication, August, 2020).

Table 2. *Summary of ground motion thresholds.*

	Felt	Very Light Damage	Moderate Damage
PGA %g	0.1 to 0.3	6.2 to 10	> 22
PGV cm/s	0.1 to 0.12	0.1 to 4.7	12.5 to 20

Having established felt and damaging ground motion criteria, we next look at background ground motion levels in the Utah FORGE area. As pointed out in Majer et al. (2016), it is unreasonable to require "that EGS-induced ground motion never exceed a certain magnitude in areas where that magnitude is often exceeded by natural seismicity." Here we extrapolate from magnitude to ground motion and find that it is unreasonable for EGS induced ground motions to have lower ground motion thresholds than background ground shaking that may come from other seismic sources (e.g. earthquakes, explosions, trains, airplanes) provided local background shaking is not considered a nuisance. To establish the background ground motion levels for the town of Milford and near the FORGE site, we calculated PGV for each hour from September 2017 through January 2018, using data collected by a strong-motion instrument located in Milford and station FOR3 located at the FORGE site, and for the Blundell power plant for each hour from January 2019 through May 2019 using data collected at station FORB. Figure 11 shows that other than a few outliers, PGV tends to be < 0.1 cm/s in Milford and < 0.05 cm/s at the Utah FORGE site and power plant. We use this background analysis to help bound the nuisance threshold. There were no reports of shaking to UUSS during these time periods, so we conclude the nuisance threshold is above what has been measured. For Milford, this means that nuisance ground motions are > 0.15 cm/s. Seismic events with M > 3 at the Utah FORGE site would be needed to produce this level of ground motion (Figure 12).

To bring this information together, we plot PGV versus epicentral distance for a M 3, 4, and 5 earthquakes with a depth of 1 km using the Chiou et al. (2010) ground motion relation for small earthquakes. (Figure 12). The Chiou et al. (2010) relation was shown to fit ground motions recorded from 163 Utah earthquakes (3 < M < 5.5) at distances from 4 to 200 km with little to no bias (Pankow, 2012). In conclusion, for the M 4 or smaller events typical of induced seismicity, we do not anticipate ground vibration and noise to be an issue. Risk is further discussed in Section 6.

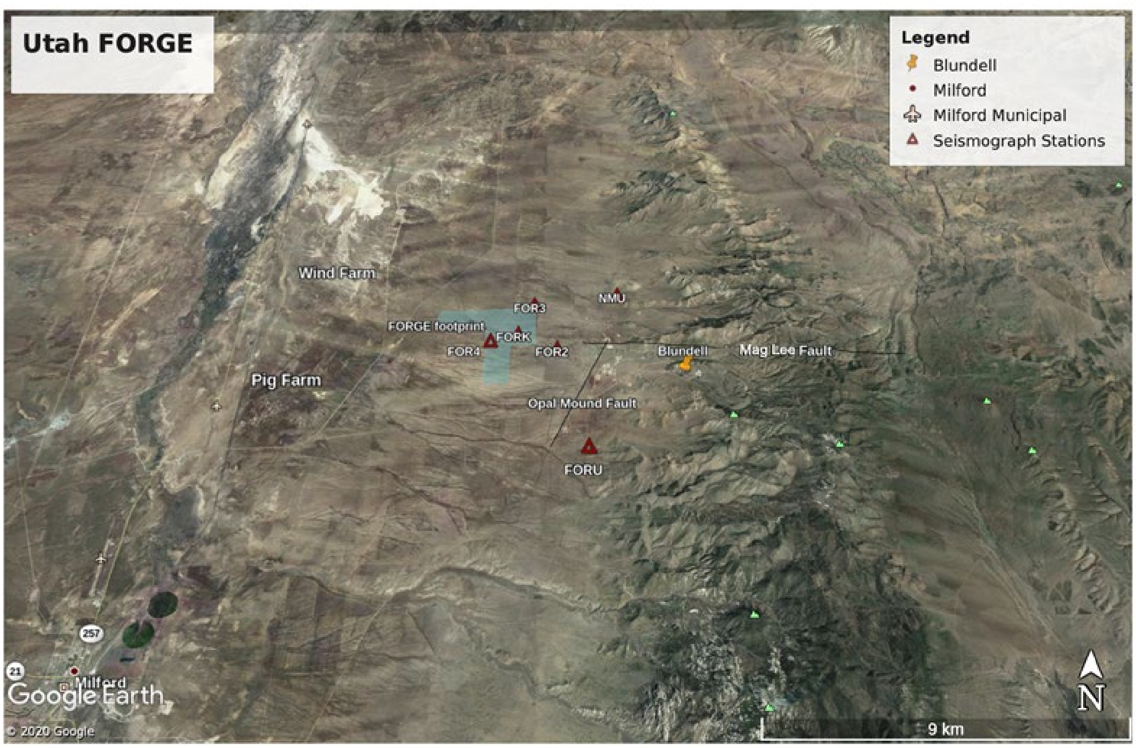


Figure 9. *Map from Google Earth showing the rural nature of the area and the relative distances between the FORGE site and the limited structures.*

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

Figure 10. *Mapping of ground motion to intensity that is used in generating ShakeMaps (Wald et al., 2001; Worden et al., 2012).*

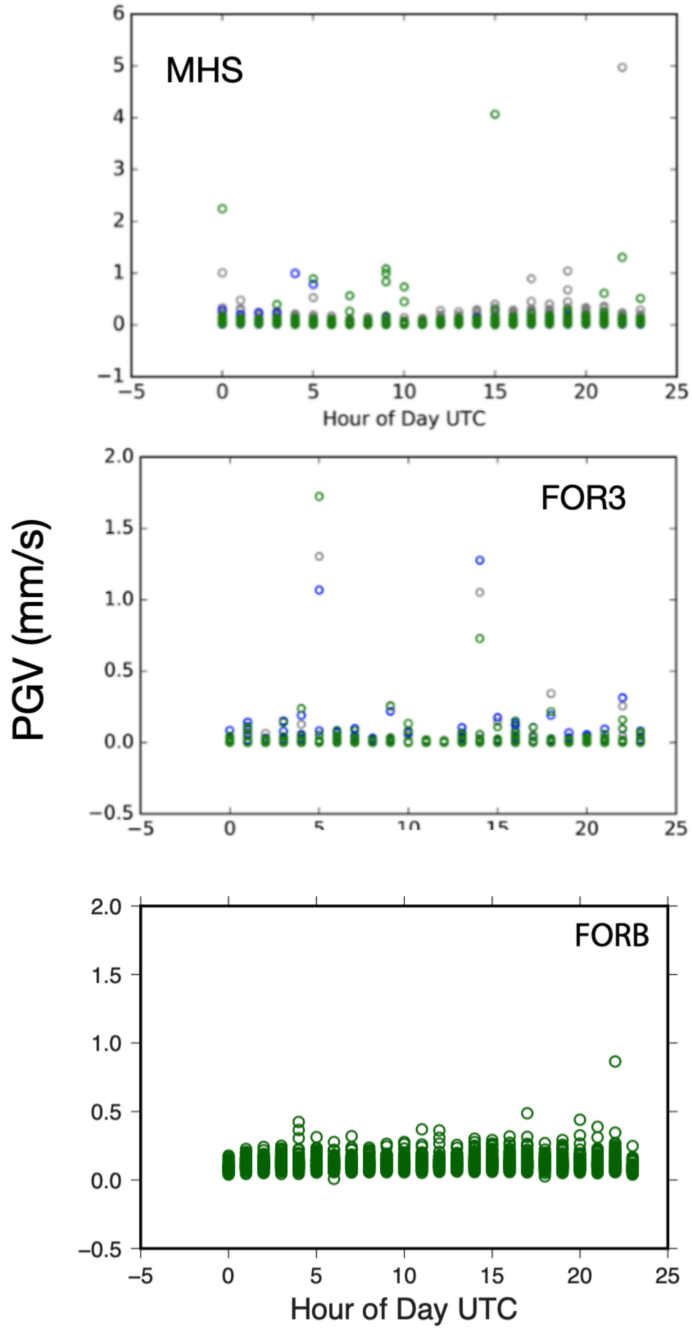


Figure 11. *Background peak ground velocity levels for each hour September 2017 through January 2018 for seismic stations MHS located in the town of Milford and station FOR3 located within the Utah FORGE polygon (right). Colors indicate components: east (green), north (blue), and vertical (gray). Background maximum horizontal peak ground velocity levels for each hour January 2019 through May 2019 for seismic stations FORB located near the Blundell power plant. Time is plotted by hour to show the diurnal cycle.*

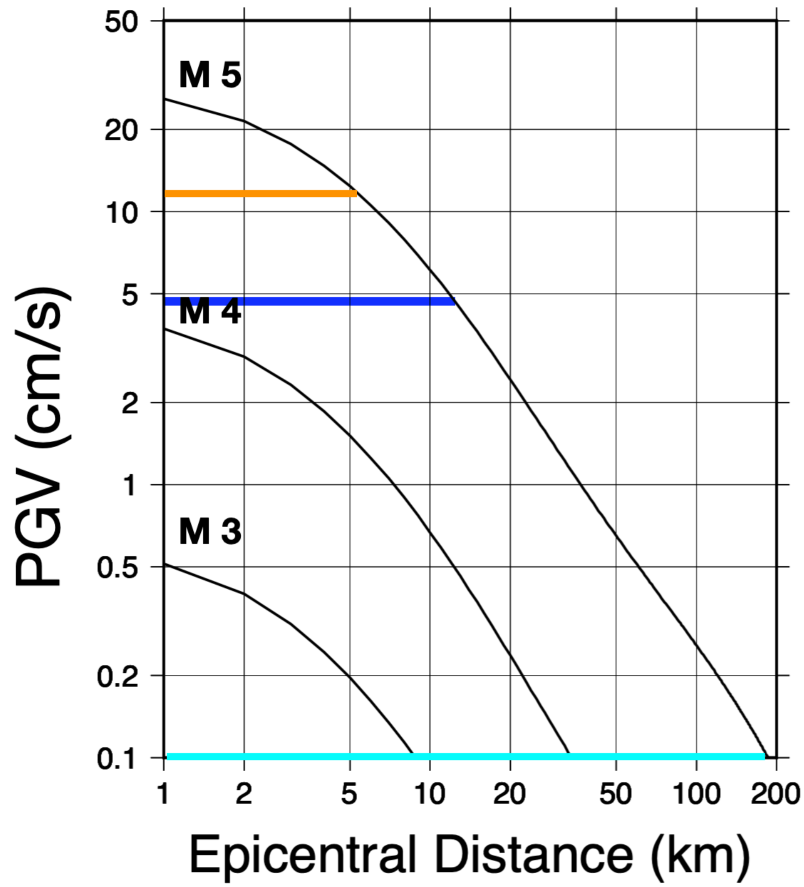


Figure 12. *PGV curves (Chiou et al., 2010) for M 3, 4, and 5 earthquakes (depth 1km). Colored lines indicate threshold levels for felt (cyan), very light potential damage (blue), and moderate damage (orange) following Figure 10 (Worden et al., 2012).*

4. COLLECTION OF SEISMICITY DATA

"The purpose of this step is to gather the data on seismicity that will be needed to accomplish the objectives of the EGS/Geothermal project" (Majer et al., 2016). Local seismic monitoring involves two main aspects. First, we need to know characteristic natural seismicity levels as a standard for comparing seismic activity during FORGE project operations. Second, we wish to establish a permanent seismic network for capturing seismicity that may be related to FORGE such as induced events or reservoir development events occurring outside of deep borehole monitoring volumes or times.

4.1 Collect unbiased (in time and space) local seismic data prior to Utah FORGE operation

Seismic activity in the area surrounding the Utah FORGE site has been steadily monitored by UUSS since 1981. Event locations and magnitudes are captured in the UUSS catalog. To evaluate the historical seismicity, we review four relevant earthquake catalogs: (1) a uniform moment magnitude catalog (1850–September 2012; Arabasz et al., 2015, 2017) (Figure 1); (2) the microseismic catalog (August 1979–August 1981) collected by Zandt et al. (1982) (Figure 13); (3) the UUSS earthquake catalog, 1981–2016 (Figure 13); and (4) the catalog collected as part of the FORGE project (November, 2016–September 15, 2020) (Figure 14). For all four catalogs, seismicity near the Utah FORGE site is characterized by low-magnitudes (M < 2.5) occurring at low rates (on average ~5 earthquakes/yr with the regional seismic network and ~170 earthquakes/yr with the more dense and, hence, more sensitive Utah FORGE network). Only 10 earthquakes with M > 2.5, the largest being M 3.8, occurred in the almost 40 years between 1981 and 2020.

Using the Arabasz et al. (2015) catalog of tectonic earthquakes, we observe that the largest event in the study area (M_W 4.05) occurred in 1908 and was located near the town of Milford (Figures 1 and 13). The closest significant earthquake (M > 6) occurred in 1901 in the Tushar Mountains north of Beaver ~50 km to the northeast of the Utah FORGE site (Figure 1). The largest recent tectonic event in the general vicinity to Utah FORGE was the January 2020 M_L 3.9 earthquake that occurred under the Mineral Mountains 12 km southeast of Milford (outside of the FORGE study area). This recent event is a good proxy for what might be expected from an M 4 induced earthquake at FORGE, given the comparable distance to Milford. Figure 15 shows the PGA map generated by ShakeMap for this event. The peak ground motion is 2.19% g (0.87 cm/s) near the source and for the town of Milford it is 1.1% g (0.4 cm/s). One hundred fifty-six people reported to the U. S. Geological Survey “Did You Feel It?” web site (Figure 4). The maximum shaking was a Modified Mercalli Intensity (MMI) of V corresponding to moderate shaking and perhaps very light damage. The majority of reports were less than MMI IV.

Before geothermal production at Roosevelt Hot Springs[1], Zandt et al. (1982) installed a local seismic array to detail the background seismicity. During the approximate 2-year deployment, they concluded that there are few earthquakes M > 2. They did capture one energetic seismic swarm (1044 earthquakes M ≤ 1.5) during June through August 1981. This swarm occurred east of the present borehole field at the Blundell power plant, primarily in the Mineral Mountains (Figure 16). The seismicity trend was mostly east-west. There is a clear depth separation for events locating on the east side of the swarm zone versus the west side. We interpret the deeper events to be tectonic in origin. The smearing of events to the west is a function of the asymmetric seismic network geometry, where all seismic stations are located to the west of the source zone. Zandt concluded that the swarm was primarily naturally occurring and was consistent with either (or both) seismicity occurring along the projection of the east-west trending Mag Lee fault or along northwest-trending faults mapped by Nielson et al. (1978). A few of the earthquakes located at shallow depths on the west end of the swarm zone and Zandt

[1] This is the Blundell power plant./

et al. (1982) speculated that these may have occurred along the Opal Mound Fault or were the result of seismicity induced by the development activities associated with the power plant.

In support of the Utah FORGE project, events in the UUSS catalog (1981–2016) were relocated using *HYPOINVERSE-2000* (Klein, 2001) configured with 14 velocity models for the entire Utah region. The main change was to calculate hypocentral depth relative to sea level (Figure 13). The relocation of the events caused slight changes in location, and overall provided tighter spatial clustering. No earthquakes in this time period locate within the proposed FORGE footprint (Figure 13). Earthquakes occurring outside the Utah FORGE footprint during this time period range in magnitude from M -0.09 to 3.91. The average horizontal and vertical 90% confidence errors for these earthquakes are 0.879 km and 4.863 km, respectively. Spatially, there are three distinct clusters: (1) north northwest of Milford, (2) northeast of Milford, and (3) scattered seismicity including the swarm zone found by Zandt in the Mineral Mountains (Figure 13 and 14).

Waveform analysis and event timing indicates that events to the northwest of Milford (labeled Quarry, Figure 13) are quarry blasts, not tectonic earthquakes (Pankow et al. 2019a). Evidence for this conclusion includes their epicentral proximity to quarries (conspicuous on Google maps), small magnitudes (M 0.49 to 2.05), shallow depths, restricted timing (all events occur during daylight hours), and highly correlated waveforms implying a similar location and source mechanism. The second cluster is located northeast of Milford near the Milford airport and not far from the M_W 4.05 1908 Milford earthquake (Figure 13). The magnitudes in this cluster range from M 0.46 to 3.91, and the events occur throughout the day and night (random timing). This cluster is interpreted as tectonic in origin. Of the remaining seismicity located in the Mineral Mountains, most locates east of the Opal Mound Fault with a second cluster to the south of station FORU (Figure 13). Regarding the Zandt swarm zone, Pankow et al. (2019a) shows that the events form two distinct clusters. The first cluster appears related to activities associated with the Blundell power plant. The events are shallow (< 2km) and epicentrally dispersed. The second cluster locates at greater depths and further to the east. Many of the larger events in the Zandt catalog from 1981 were also detected and located by UUSS using the regional network. These events all locate in the cluster to the east of the Blundell swarm (Figure 16). Depths for these events range from 0 to 8 km relative to sea level.

To ensure that we detect seismicity down to magnitude 0, in November 2016 (under Phase 2A of the FORGE project) a five-station surface seismic network was installed. This array has remained operational to date and was augmented in 2019 to include a borehole sensor and three strong-motion accelerometers: (1) near the Blundell power plant (FORB); (2) in the wind farm (FORW); and (3) upgraded FOR3 to include an accelerometer (Figure 17). Data from this network were combined with data from the regional seismic network to locate and determine magnitudes for new seismic events (Figure 14). The improved monitoring network with stations closer to the source zone also improved location accuracy. The 90% confidence location errors decreased to 0.68 and 2.98 km horizontal and vertical, respectively. Spatially, most of the seismic events locate east of the Opal Mound Fault primarily in or near to the Zandt swarm region (Figure 14). There is also a small cluster in the southern Mineral Mountain source zone.

Of importance, no events are located in the FORGE footprint. The network was further updated in October 2020 to include three shallow (~80') boreholes instrumented with three-component broadband and three-component accelerometer sensors (BOR1, BOR2, and BOR3, Figure 17b).

Additional seismic instrumentation in the area includes, an accelerometer at Milford High School, which was re-installed in December 2020. Seismic instrumentation for this site was provided by the State of Utah. This seismic station provides background monitoring of ground motions for Milford, the closest town to FORGE. UUSS also operates accelerometers located in Beaver, the next closest town to FORGE. To further augment seismic monitoring, four stand-alone, dense, short-period digital Fairfield Nodal temporary seismic arrays were installed within and/or adjacent to the proposed Utah FORGE site for approximately one-month duration per deployment (data available at https://constantine.seis.utah.edu/datasets.html). Trow et al. (2018) used data from two of the Nodal deployments to detect 42 events (M –0.7 to 0.5). These events locate in previously identified source areas (Figure 13).

Analysis of the Utah regional catalog for the period 1 January 2000 to 30 June 2003 found a minimum magnitude of completeness (M_{comp}) for the Utah FORGE site of 1.5 (Pankow et al., 2004). Potter (2017) using only UUSS catalog data local to Utah FORGE determined an M_{comp} for the Utah FORGE site of 1.7 and when using the Utah FORGE catalog for events occurring in 2017 an M_{comp} of ~0.5. Most detections after the installation in the FORGE catalog (Figure 14) are well-below the regional network M_{comp} of 1.5 to 1.7 and tend to be M < 1 with several events M < 0.

In conclusion, based on the multiple-levels of seismic monitoring: (1) no naturally occurring seismic events locate within the Utah FORGE footprint; (2) natural seismicity over the FORGE region occurs at low rates and with low magnitudes, typically M < 1.5; and (3) most seismic events in this area occur under the Mineral Mountains to the east of the Opal Mound Fault with a less pronounced source zone near the Milford airport.

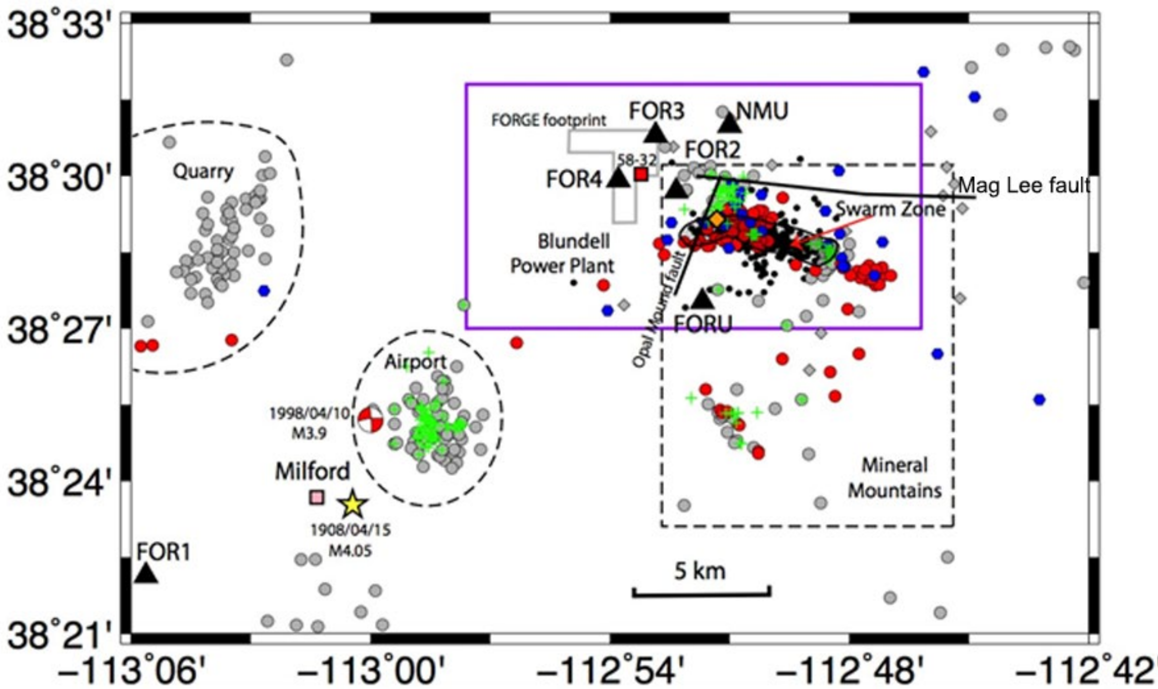


Figure 13. *Utah FORGE earthquake catalog. Grey circles, earthquakes from the UUSS catalog 1981–2016 relocated with an updated velocity model. Black dots, earthquakes from Zandt et al. (1982). Red circles, earthquakes located after installation of the broadband network. Green crosses, events detected by Potter (2017). Blue hexagons, events found from Nodal geophone deployment (Trow et al., 2018). Dashed polygons denote the three source zones discussed in the text. Black triangles, locations of seismic sensors. Grey shaded polygon labeled Swarm Zone, boundaries for earthquake swarm identified in Zandt et al. (1982).*

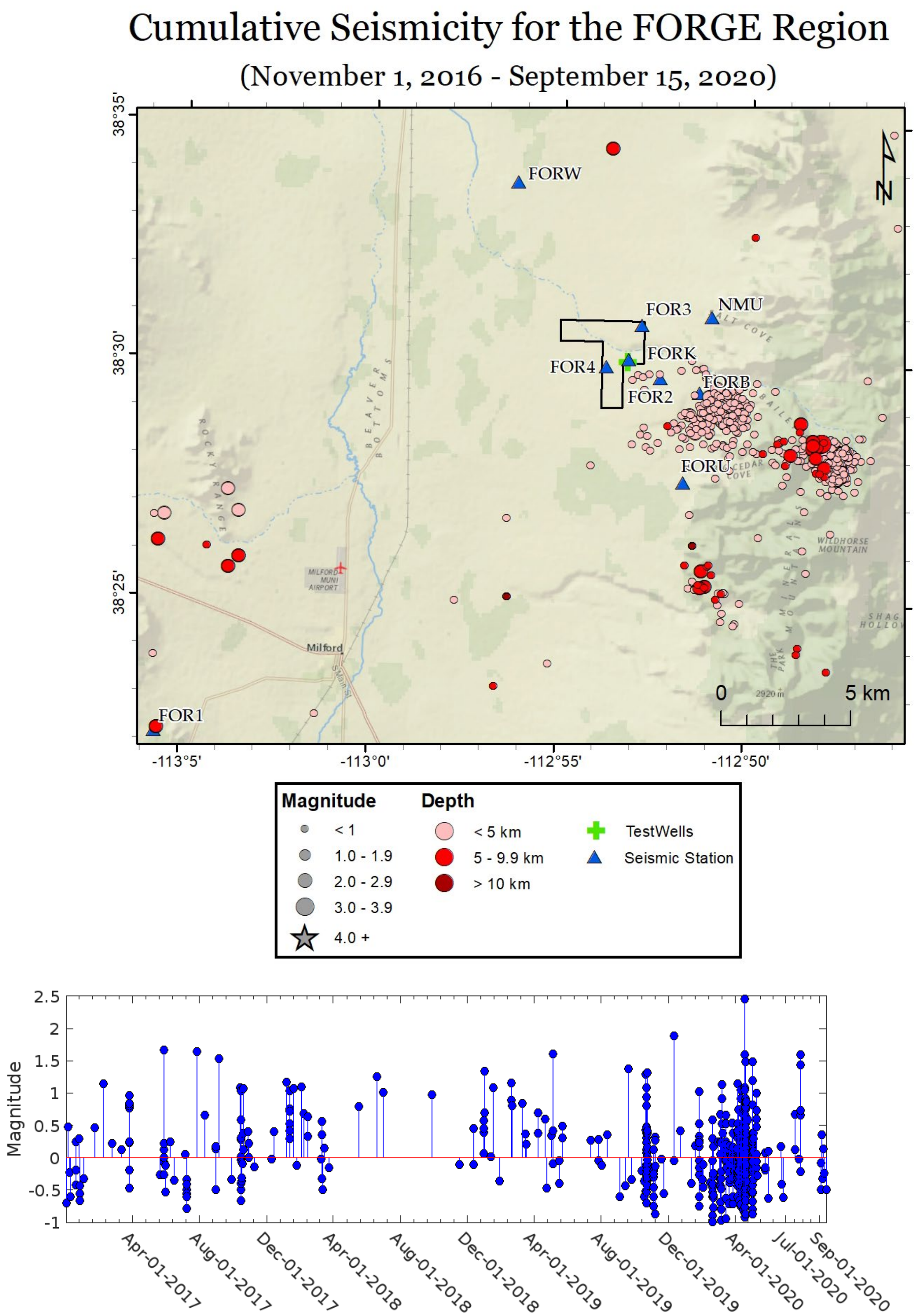


Figure 14. *Map and magnitude time history of earthquakes recorded using the Utah FORGE seismic network.*

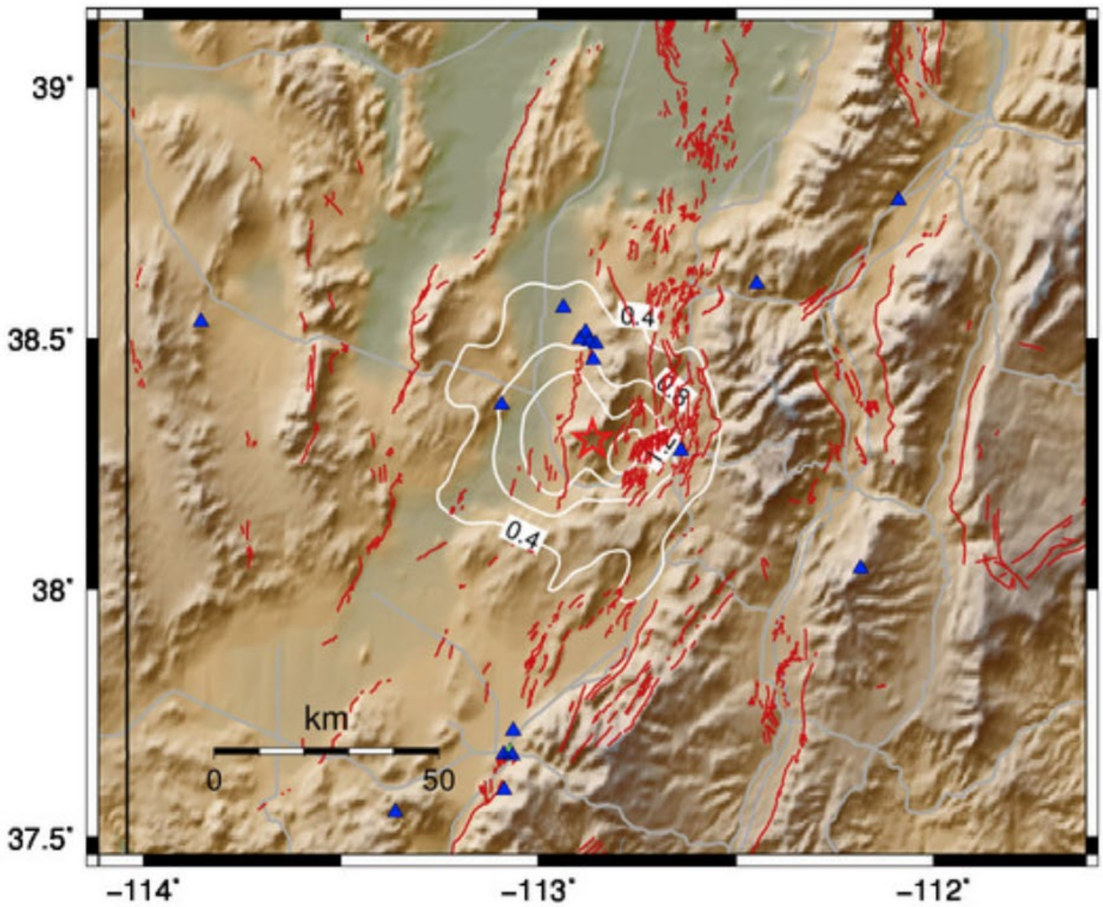


Figure 15. *PGA contours (% g) generated by ShakeMap for the January 2020 M 3.9 earthquake located in the Mineral Mountains south of Milford (red star). Ground motion values are constrained by recordings at the nearby seismic stations. Red lines show the Quaternary faults. Blue triangles are seismic stations.*

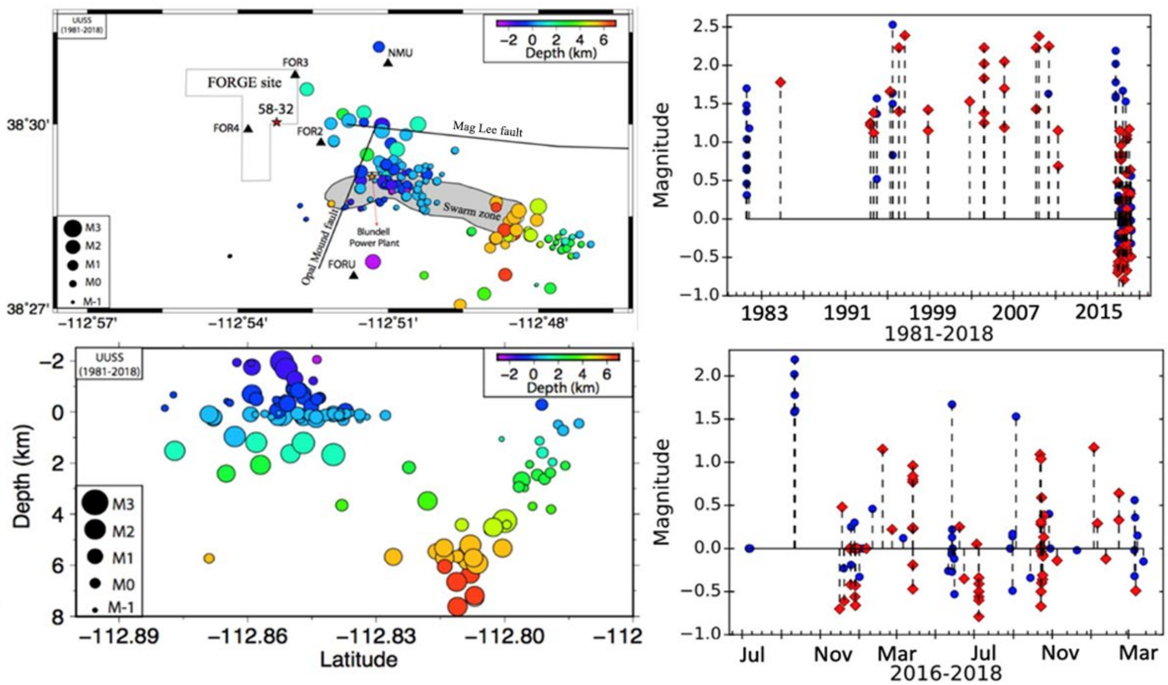


Figure 16. *Seismicity from the UUSS catalog surrounding the swarm zone first identified by Zandt et al. (1982). Left column: epicenters and hypocenters (color signifies depth). Note the two well separated clusters, shallow west and deeper east. Right column: magnitude time history. Blue symbols, events that locate in the east cluster and red symbols, events to the west that are typically shallower than 2 km.*

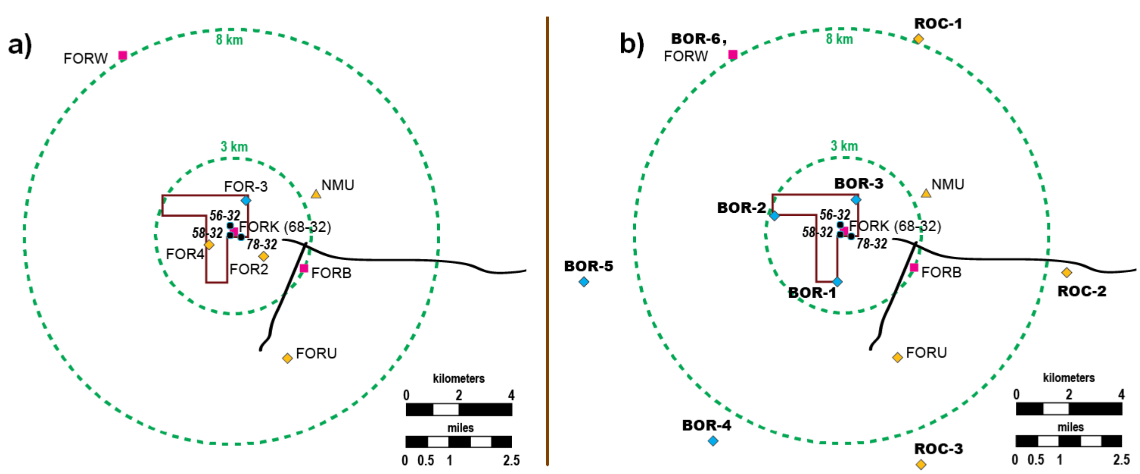


Figure 17. *a) The current Utah FORGE microseismic monitoring network. For reference, the FORGE footprint (brown outline), the Opal Mound Fault (northeast-trending line east of the FORGE footprint) and the Mag Lee Fault (east - trending line east of the FORGE footprint), black lines. The green rings are located approximately 2 miles (3 km) and 5 miles (8 km) from the center of the injection well, 16A(78)-32. b) Plan for permanent microseismic monitoring network. Triangles denote short-period sensors, diamonds denote broadband sensors, squares denote strong motion sensors.*

4.2 Network array design to capture all aspects of seismicity

For seismic monitoring at the Utah FORGE site, there are two main goals: (1), capturing events at an M_{comp} level of 0 (Majer et al., 2012) in order to monitor seismic hazard and inform risk decision metrics, such as a TLS for risk mitigation; and (2), monitoring fracture growth in the reservoir during all injection or production activities to an M_{comp} -2. The infrastructure-related Seismic Monitoring Plan (SMP) (Rutledge et al., 2020), a separate but companion document, was recently approved by DOE/GTO and describes the seismic monitoring for the drilling of 16A and the first injection. The SMP will be revisited with iterations to stimulation plans to determine if more seismic stations are needed or if current stations should be moved.

To inform the SMP, microseismic data from a hydraulic injection experiment conducted in April and May, 2019, in well 58-32 were processed and presented with requirements for FORGE monitoring to a Seismic Advisory Team (SAT) in November, 2019. The experiment consisted of low-volume (1 – 15 bbl/min) water injection at three depth levels below 6500 ft in the well. For the experiment, the local Phase 2A FORGE seismic network (diamonds and triangles, Figure 17a) was augmented with instrumentation (a 3C geophone and 3C accelerometer) in a shallow (925') borehole 68-32 (sensor FORK). Separately, a deeper borehole 78-32 was drilled into the granite to a depth of ~3300 ft and was instrumented with a DAS cable cemented in the annulus. Also, during the 2019 injection phases, a 12-level 3C geophone string with 100' spacing was lowered to near the bottom of 78-32. The DAS and string instrumentation were monitored and processed by contractors, Silixa and Schlumberger, respectively. Also, 151 3C Nodal geophones were installed in concentric rings centered on borehole 58-32 where the injection tests were being conducted.

Figure 18 summarizes the detections from the various systems. The geophone string recorded the smallest events and had the most complete detection levels (435 events, M_W -2.0 to -0.5). The detection level from the DAS processing by Silixa found 40 events (Schlumberger determined magnitudes M_W -1.7 to -0.5), and 19 events were identified in the shallow borehole instrumentation (M_W -0.5 to 0.8). Subsequent reprocessing of the DAS data detected 113 events in a highly active 24-hr period with M_{comp} -1.4 (Lellouch et al., 2020). The Schlumberger catalog for the same 24-hour period produced 299 detected events. In the initial processing of the Nodal array data, only 5 events (M_W -0.9 to -0.5) were identified. Reprocessing of the Nodal array data identified 23 events in common with the geophone string catalog (M_W -1.7 to -0.5) (Mesimeri and Pankow, 2020). While it was hoped that the injection testing might help to establish the b-value for the localized FORGE site, there were relatively few events (< 1000) and the events spanned a narrow magnitude range (M_W -2.0 to -0.5) making the calculation of a robust and reliable b-value difficult to obtain.

Based upon the event population and detection thresholds, and the desire to have monitoring capability in place at the commencement of the drilling of an extended reach well 16A(78)-32[2],

[2] Current plans are for well 16A(78)-32 to be drilled to a depth of 10,938 ft MD, 8540 ft TVD, at an inclination of 65° to the vertical.

an augmented seismic monitoring instrument array was defined and described in detail including a time-line for installation in the SMP document (Rutledge et al., 2020) (Figure 17b). Combined broadband and strong-motions sensors will be emplaced in shallow boreholes BOR-1, 2, and 3 before drilling well 16A (78)-32. Together with existing sites FORK, NMU, FORB, and FORU, these constitute a well-sampled, 3 km radius inner ring of sensors that can monitor drilling events. Based upon the experience described above, these will achieve the desired M_{comp} 0 or lower beneath the entire FORGE footprint.

Subsequently, and before experiments on fluid injection and production occur in the lower reaches of well 16A(78)-32, a second ring of broadband sensors in shallow boreholes (BOR) or on bedrock (ROC) will be established with a diameter of 8 km relative to well 16A(78)-32 (Figure 17). Complementing the good event depth (hypocentral) control of the 3 km ring, the outer ring provides good event horizontal location (epicentral) control. The rings will also allow for tracking seismicity that migrates away from the injection zone. The primary monitoring goal of the ring arrays is for induced or natural earthquakes occurring near and below the FORGE footprint. Seismicity associated with reservoir development will also be monitored with deployments of short-term string arrays at depths of several thousand feet in boreholes 58-32, 78-32, a planned well 56-32, and possibly an additional deep monitoring well of opportunity.

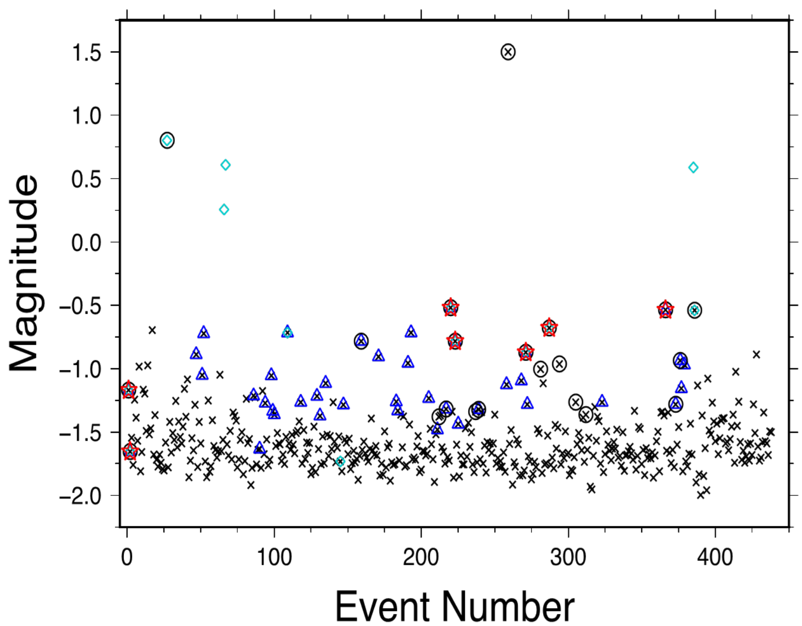


Figure 18. *Initial event detection of seismic events during the mini-stimulation experiment at the Utah FORGE site in April 2019. The first two events are check shots detected by all networks. Black crosses, detections from the geophone string; Blue triangles, detections from the DAS; Black circles, detections on shallow borehole 68-32 instrumentation; Red stars, detections on the Nodal array; and Cyan diamonds, detections by local array. All magnitudes were determined by Schlumberger using data from the geophone string.*

5. HAZARD FROM NATURAL AND INDUCED SEISMIC EVENTS

Quoting Majer et al. (2016), “The purpose of Step 5 is to estimate the ground shaking hazard at a proposed EGS site due to natural (tectonic) seismicity and induced seismicity.”. The hazard from natural seismicity is determined following a Probabilistic Seismic Hazard Analysis (PSHA) approach. Full details of this analysis, including all the model inputs, are available in the report provided by Wood Environment & Infrastructure Solutions, Inc. (Attachment 1). This PSHA followed an initial PSHA performed by Amec Foster Wheeler (2018), and used new information and model parameters including updated earthquake catalogs, new research on fault parameters, and the availability of more detailed local shallow velocity information.

To address hazard from earthquakes that could possibly be induced by FORGE operations, we conducted a literature review of other induced seismic events and methods for estimating the potential maximum magnitude. Based on information available in the peer-reviewed literature, we calculate a range of potential maximum magnitudes for the Utah FORGE project. We then use these magnitudes to calculate deterministic ground motions.

It is important to remember that this section, and PSHA in general, addresses seismic hazard. The purpose is to assess the potential for strong/damaging ground motions and the expected maximum magnitudes for earthquakes in the study area. A PSHA or hazard assessment in general does not evaluate the effect of the hazard on the built environment and population. The consequences of the ground motion are the topic of seismic risk, which is addressed in Section 6 using the criteria established in Section 3.

5.1 Seismic hazard analysis from natural seismicity

There are three key data inputs to the PSHA for natural seismicity. First, a uniform magnitude seismic catalog is needed to determine earthquake recurrence intervals and the spatial distribution of earthquakes. Second, details on nearby faults are needed to constrain potential source zones for larger earthquakes. Third, estimates of site-specific ground motion are needed to constrain the shaking hazard.

5.1.1 Evaluate historical catalog

The earthquake catalog used in the PSHA calculations is a combination of the Utah uniform magnitude catalog (Arabasz et al., 2017) and the catalog used in the 2014 NSHM (Petersen et al., 2014). These catalogs were chosen because a PSHA requires uniform magnitude calculations and must cover an area that encompasses all earthquakes that might cause damaging ground motions in the study area. Great care was taken in combining these catalogs (refer to Attachment 1). Based on these catalogs, the PSHA recurrence modeling indicates an annual frequency for a $M > 4$ earthquake within 50 km of the Utah FORGE site to be once every 10 years and for $M > 6$ once every 1000 years approximately (Figure 19).

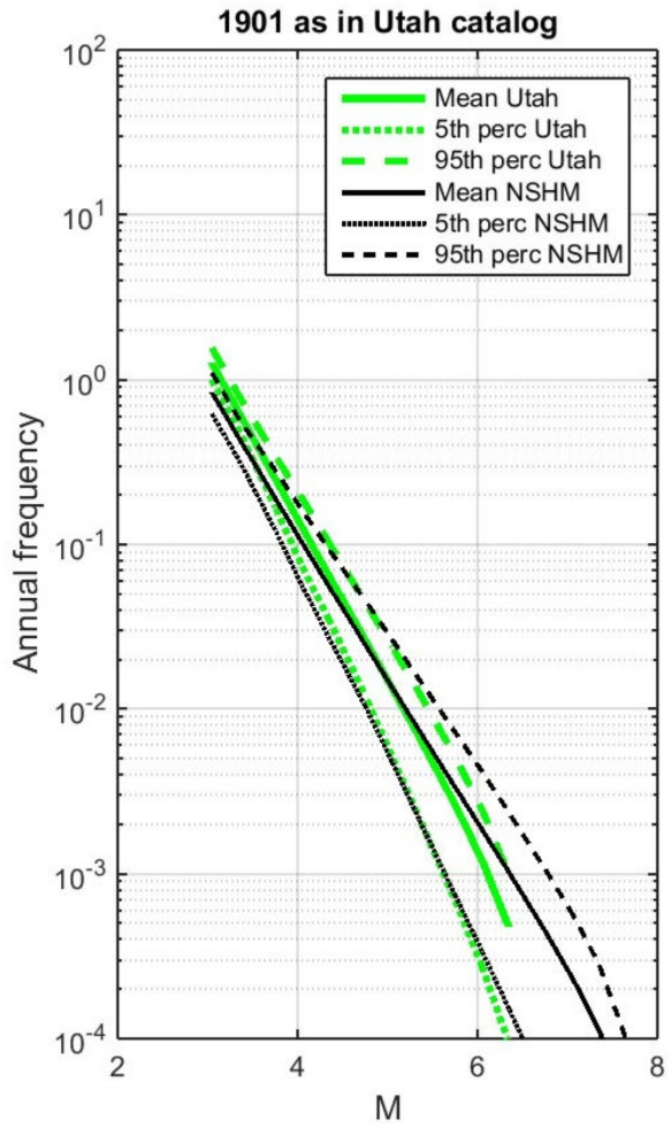


Figure 19. *Earthquake recurrence curves for a region within a 50 km radius of the FORGE site from the PSHA.*

5.1.2 Characterize any active or potentially active fault and estimate source parameters

Details regarding the seismic sources, areal fault sources and both local and regional faults are available in the PSHA (Attachment 1). One aspect of a PSHA is to try and account for seismicity from potential unknown faults. This is done with an areal source where distributed seismicity is modeled with varying weights for the probability calculation. Regarding the mapped fault sources (Table 3.2, Attachment 1), an important observation is that the larger mapped faults in the analysis tend to be regional in nature (at larger distances from FORGE), so are not likely to be directly impacted from activities at FORGE (Figure 3.3, Attachment 1). There are four faults local to the FORGE area that we discuss in more detail in this section (Figure 20).

First, the Opal Mound fault (OMF) extends ~7 km in a north-northeast direction, branching in the northernmost part. Displacement is down to the east, and most researchers infer a steep eastward dip (e.g. Nielson et al., 1986). The majority of recent movement is late Pleistocene (12 – 126 ka) with cumulative alluvial offsets up to 18 m (Knudsen et al., 2019). The OMF marks the western boundary of the Roosevelt Hot Springs hydrothermal system and, importantly, forms a hydrological barrier to westward hydrothermal flow as revealed by pressure profiles from wells either side of the fault (Allis and Larsen, 2012; Allis et al., 2016).

Second, the Mag Lee fault (MLF) is an east-west striking structure that dips to the north and extends ~10 kilometers eastward from the north-south trending Opal Mound fault. The MLF can be traced on the surface over a distance of ~1 km where it pierces an old alluvial fan deposit, creating an east-west ridge or scarp in the middle of Mag Lee wash. Siliceous sinter of the OMF near its north end is not deflected by the MLF implying that the MLF is older, and furthermore it is not favorably aligned for slip in the current stress field (Knudsen et al., 2019). A paleoseismic analysis of this structure concluded the fault is pre-Quaternary in age and the scarp is the result of differential erosion of a geological unit contact rather than faulting (Knudsen et al., 2019).

Third, the Mineral Mountains West fault system represents a corridor of north-south trending fault scarps that are mappable in fan deposits south of the FORGE site (Figure 20). The system is up to 3 km wide, and runs for at least 30 km, west of and parallel to the range front along the southern part of the Mineral Mountains, south of the FORGE footprint. Individual strands are marked by scarps that extend continuously for several km, having heights <5m. At the surface, these faults do not enter the FORGE footprint. The faults have not been detected in legacy seismic reflection profiles (Smith and Bruhn, 1984; Smith et al. 1989) or in the modern vibroseis reflection surveying performed in Phase 2B of the Utah FORGE project (Miller et al., 2019). There is also no evidence of structural offsetting along the alluvium-granite interface to within the vibroseis seismic resolution of 25 m (Miller et al., 2019; Wannamaker et al., 2020). The most recent movement on these also is late Pleistocene (Knudsen et al., 2019).

Fourth, perhaps the most significant of the four fault structures is that comprising the unconformable contact between overlying basin fill and the underlying crystalline basement rock. This structure has been penetrated by wells west of the Opal Mound fault, including well 58-32 within the FORGE footprint. These well data and the notably strong reflector in seismic reflection profiles strongly suggest the top of basement contact forms an inclined ramp, which dips ~20° west and intersects the surface near the Opal Mound fault. However, direct evidence of fault offset across the contact is lacking. Large scale down-dip detachment displacement along the interface of >10 km is deduced from seismic reflection profiles, regional outcrop patterns, the uniform eastward dip of stratified rocks in the Mineral Mountains, the uniform westward dip of late Miocene dikes in the Mineral Mountains, paleomagnetic data, and cooling patterns interpreted from thermochronology (Smith and Bruhn, 1984; Nielson et al., 1986; Smith et al., 1989; Coleman and Walker, 1992, 1994; Coleman et al., 1997, 2001; Bartley, 2019).

From these studies, it appears that most of the large-scale extension occurred during a spasm of accelerated displacement in the late Miocene (~8 Ma), and this caused uplift, exhumation, and tilting of the Mineral Mountains (Coleman and Walker, 1994; Coleman et al., 2001; Bartley, 2019).

The prior detachment faulting probably initiated as a moderate to steeply dipping plane(s) that rotated with extension in response to a rolling hinge associated with isostatic rebound of the footwall block (Wernicke and Axen, 1988; Buck, 1988; Coleman and Walker, 1994; Bartley, 2019). After acquiring low angle orientations, however, slip along these structures greatly diminished or ceased after ~8 Ma based, for example, upon the horizontal disposition of alluvial sediments as resolved by the seismic reflection survey (Wannamaker et al., 2020) and in spatial autocorrelation (SPAC) imaging (Zhang and Pankow, 2020). Given that the reflection survey resolved that slip offset across the bedrock interface is <25m over this long time period, natural seismic rupture potential on existing faults is concluded to be low. In fact, from interpretation of both the reflection survey (Miller et al., 2019; Wannamaker et al., 2020) and the SPAC velocity model (Zhang and Pankow, 2020), topography on the alluvium-granite interface is consistent with an erosional surface rather than faulting.

In summary, the Opal Mound and Mag Lee faults are relatively short length structures that intersect orthogonally to form the boundaries of the Roosevelt Hot Springs reservoir. The Mineral Mountains West fault system comprises a series of parallel north-south trending, discontinuous normal fault segments with small offsets. These probably sole into the unnamed low angle detachment fault comprising the bedrock interface, which appears to have accommodated most of the extension (>10 km) in the late Miocene to form the North Milford valley. Recent movement on the detachment appears to be minimal, as reflected in the basin profile, and the absence of significant fault scarps and faceted spurs along the Mineral Mountains range front.

The lengths of the mapped/projected traces of the Opal Mound fault and the Mag Lee fault (Figure 20) are ~7 km and ~10 km, respectively. Assuming the entire length ruptures in a normal faulting event, the maximum magnitude for these faults is calculated to be M 5.9 (Wells and Coppersmith, 1994). This moderate magnitude is consistent with the lack of well-defined scarps. The mapped length of the Mineral Mountains West Fault is 38 km (Lund, 2014), which is long enough to generate an M 7.0 earthquake. However, as described, given the lack of geophysical evidence for basement displacement and the discontinuous nature of the mapped fault trace (Kleber et al., 2017), it is unlikely that this fault is capable of generating large magnitude events. Based on these observations, the seismogenic potential of the Mineral Mountains West Fault system is doubtful, and we assume a maximum magnitude of 6.5, which is the approximate magnitude threshold for surface faulting in the Basin and Range Province (dePolo, 1994).

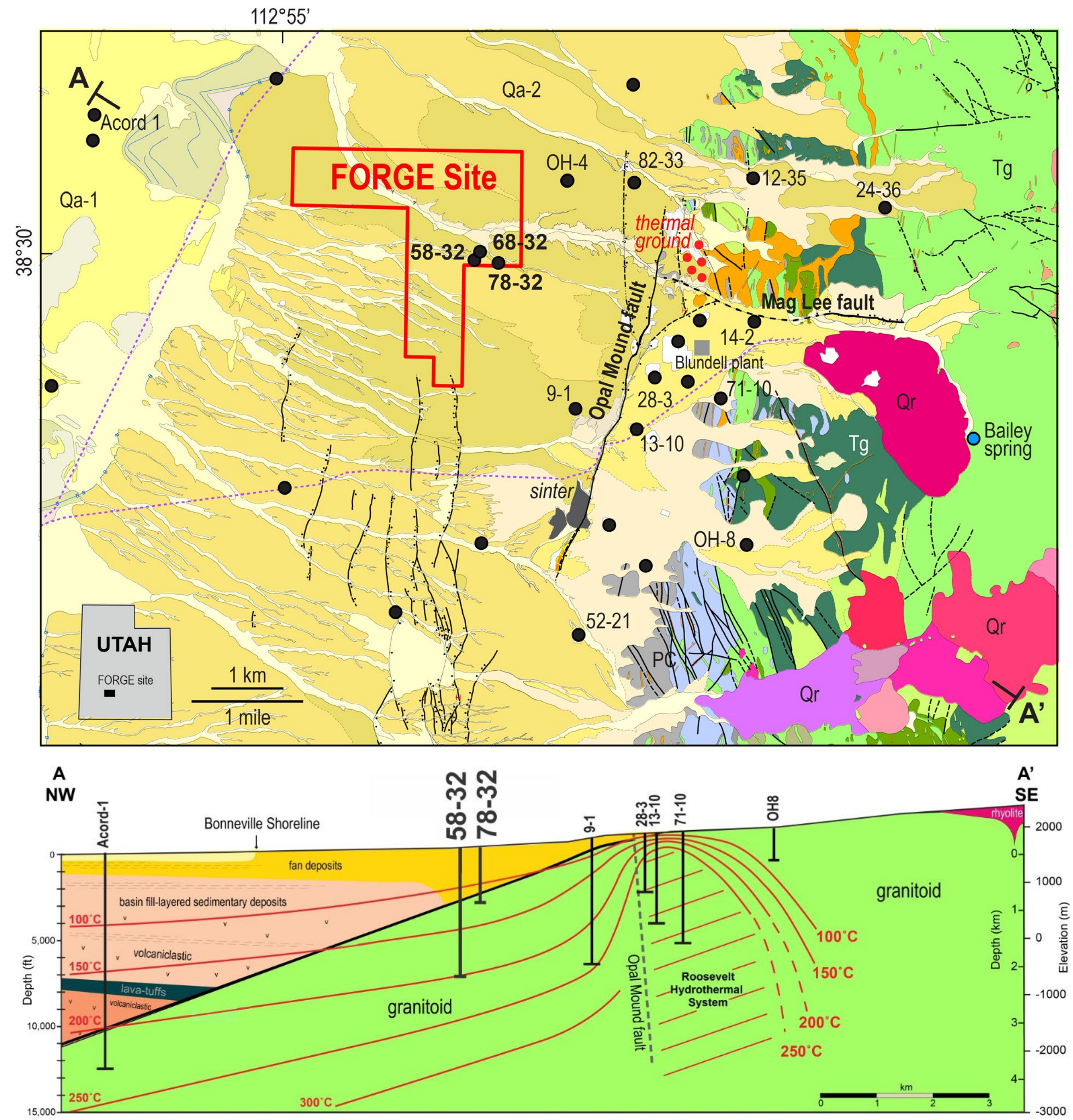


Figure 20. *Geological map and cross-section for the Utah FORGE site. Shown are locations of mapped faults relative to the FORGE footprint and locations of earthquakes located with seismometers installed for the FORGE project December 2016 through January 2018). Also shown on the cross-section are geotherms and location of nearby wells.*

5.1.3 Geological site conditions and shallow shear-wave velocity

The shallow shear-wave velocity structure, often described using the average velocity in the upper 30 m (Vs30), is a key parameter used for estimating ground motions. For the FORGE project, we conducted spatial autocorrelation (SPAC) surveys to measure shear-wave velocity profiles that could be used for Vs30 calculations at three locations: (1) within the FORGE footprint, (2) near the Blundell Power Plant, and (3) in the town of Milford. For these three locations, the measured Vs30 was 400, 408, and 333 m/s (Zhang et al., 2019). More recently, we expanded the SPAC methodology to create a three-dimensional shear-wave velocity model of the upper 2 km for the region directly above the FORGE footprint (Zhang and Pankow, 2020). The advantage of the expanded SPAC methodology is that we recover the velocity profile to greater depths. With the velocity profile, other parameters (depth to 1.0 and 2.5 km/s) important for ground motion calculations can also be recovered. The full velocity profile was used in the PSHA modeling.

For calculations in ShakeMap, UUSS uses a generalized shear-wave velocity map based mainly on mapped geologic units *(*http://quake.utah.edu/monitoring-research/uuss-urban-strong-motion-network/geological-site-conditions*)*. Vs30 values for each unit are based on Vs30 measurements collected for the Wasatch Front in northern Utah (McDonald and Ashland, 2008). The default Quaternary Vs30 for Utah is 230 m/s. Because the soils near FORGE are stiffer (have larger measured Vs30 values) compared to the default values used in generating ShakeMap scenarios, ground motions estimated for deterministic scenarios presented later are slightly over-predicted and hence conservative.

5.1.4 Select appropriate ground-motion prediction models

For earthquakes with magnitudes greater than M 5, UUSS currently uses the Chiou and Youngs (2008) ground motion prediction equation (GMPE) to generate deterministic scenarios with ShakeMap. Data from normal faulting earthquakes are scarce for Basin and Range earthquakes. However, ground motion modeling exercises can be used to provide some validation of GMPEs. For models developed for the Salt Lake Valley (Roten et al, 2012) reasonable agreement was found between the modeling results and older GMPEs, like Chiou and Youngs (2008). For the PSHA, a suite of ground motion models was used including the NGA West 2 GMPEs (Abrahamson et al., 2014; Boore et al., 2014, Bozorgnia et al., 2014; Chiou and Youngs, 2014).

5.1.5 Perform a PSHA and produce hazard curves

An updated site-specific PSHA analysis for the Utah FORGE site down to M 4 was performed by Wood Environment & Infrastructure Solutions, Inc. (full report, Attachment 1). Figure 21 summarizes the 10% probability that a level of ground motion will be exceeded in the next 50 years. These curves can also be interpreted as 2% probability in 10 years (more appropriate for the lifetime of FORGE). For the four locations (FORGE site, Blundell Power Plant, wind farm, and Milford), we see that there is a 2% chance of exceeding a PGA (highest frequencies, Figure 21) of 10 to 13% g in the next 10 years. For building types four-stories or less resonant frequencies tend to be between ~2 (four story building) and ~10 Hz (one story building), for these frequencies there is a 2% chance of exceeding ~15 to 30%g in the next 10 years. Overall, this is a low hazard and represents a 30 - 50% decrease from the Amec Foster Wheeler (2018) calculations. The deaggregation of the hazard shows that the largest contribution to the 10% in 50 years hazard for frequencies ≥ 1 Hz is controlled by relatively small background events not associated with specific faults. The decrease in hazard can be attributed to a correction in how M_{comp} was propagated in the Amec Foster Wheeler (2018) calculations and the incorporation of new information from fault studies, specifically new information on the Wasatch and Mag Lee faults.

We compare the expected ground motions from the PSHA to deterministic scenarios generated using ShakeMap (Wald et al. 1999; Worden and Wald 2016) for an M 5.4 Opal Mound fault earthquake and an M 5.9 Mag Lee earthquake (Figure 22). Based on the recurrence modeling, these earthquakes represent 100 to 1000-year events (Figure 19). The scenarios were generated using the Chiou and Youngs (2008) GMPE and site amplification factors from the statewide Vs30 database (McDonald and Ashland, 2008). The Vs30 clearly dominates the pattern of ground motions, as seen by the significantly larger amplitudes in the basin. The difference in amplification between the measured and assumed Vs30 is a function of magnitude, but the ShakeMap values for these magnitudes will be slightly larger because of the lower default Vs30.

The maximum PGA for the Opal Mound earthquake scenario is ~28% g over the rupture area (close to the Utah FORGE site) and falls off to ~10% g in Milford. PGV values are ~30 cm/s and 8 cm/s for the same two areas. Based on ShakeMap relations, this translates to the potential for moderate damage at the epicenter, but light potential for any damage in Milford. For the Mag Lee scenario PGA near the Utah FORGE site is ~35% g (PGV ~35 cm/s) and for Milford PGA is ~12% g (PGV 12 cm/sec). For the area near the Utah FORGE site, potential damage could be moderate. Structures in this area include the well-site, wind farm, and the Blundell power plant. Based on the limits for cosmetic and structural damage discussed in Section 3, the Opal Mound and Mag Lee scenarios would be felt in Milford and possibly Beaver. There could be limited damage to weak structures (near the epicenter) and some cosmetic damage (at distances of ~10 km or ~30 km, respectively).

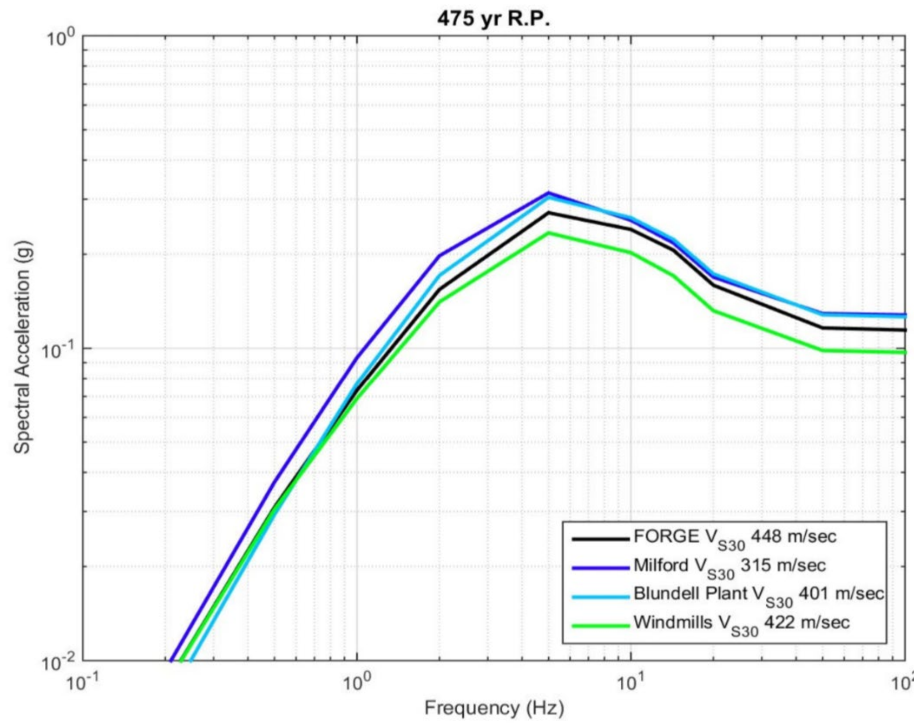


Figure 21. *Comparison of the 475 years return period uniform hazard response spectra for the four sites denoted in the legend. This return period corresponds to 10% probability in 50 years.*

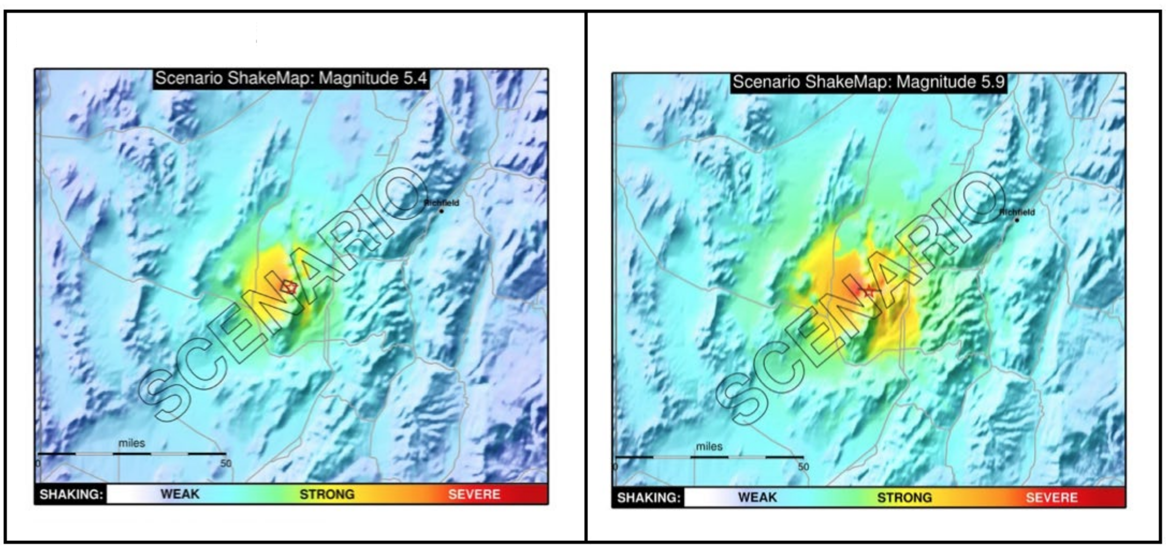


Figure 22. *Deterministic intensity maps for two potential scenario earthquakes near the Utah FORGE site: Left, Opal Mound M 5.4 and right, Mag Lee M 5.9. Maps were generated using ShakeMap (Wald et al., 2005; Worden and Wald, 2016). Maximum magnitude (ground motions) based on fault dimension for the Opal Mound and Mag Lee scenarios (gray box surface projection of fault trace).*

5.2 Estimate hazard from induced seismicity

With natural seismicity hazard quantified above in Section 5.1, we proceed to define factors that control the generation and magnitude of induced seismicity. Steps in determining the factors include reviewing cases of) induced seismicity during creation of Enhanced Geothermal System (EGS reservoirs, reviewing models for maximum magnitude of induced seismicity, and evaluating the characteristics of pre-existing faults and the geologic framework.

5.2.1 Review known cases of induced seismicity and compare tectonic framework

Fluid related induced seismicity has been associated with several types of energy production, including oil and gas, unconventional oil and gas, carbon capture and storage, and geothermal. Induced seismicity results from the injection of fluids when the net pore pressure change exceeds a critical value (National Research Council, 2013). The volume change appears to correlate with the maximum magnitude induced earthquake (McGarr, 2014). Therefore, the largest magnitude induced events are expected when large volumes of fluid are injected or withdrawn from a reservoir or from the cumulative effect of wastewater disposal or carbon capture (National Research Council, 2013). Unlike some of these other industries, the goal in geothermal is a net zero fluid balance with extraction roughly equaling injection. In addition to an increase in pore pressure for fluid induced seismicity, there must also be a fault or faults of substantial size optimally oriented for failure in the current stress field close to the point of fluid injection (National Research Council, 2013) or a fluid pathway to basement faults of substantial size (e.g. BC Oil and Gas Commission, 2012; Skuomal et al., 2017; Zhang et al., 2013).

is an artificial underground heat exchanger designed to extract geothermal energy by circulating fluid between an injection well and a production well through n engineered or enhanced volume of fractures in the subsurface. In geothermal environments, induced seismicity can result from multiple factors, including fluid induced pore-pressure increases that result in effective stress reduction, temperature decreases that result in the contraction of fracture surfaces, volumetric changes from poroelastic and thermoelastic stress effects driven by pore-pressure and temperature changes associated with fluid withdrawal and injection, and chemical alteration of fracture surfaces that change the coefficient of friction (Majer et al., 2007). The extent and degree to which these subsurface phenomena are active is contingent on the orientation and magnitude of the deviatoric stress field relative to existing faults, the extent of faults and fractures, and the area of fault slippage and stress drop across a fault (Majer et al., 2007).

Natural geothermal systems have sufficient permeability for fluid convection and heat extraction to occur. Although hot rock is abundant in the subsurface, few areas have the permeability required for fluid circulation. Permeabilities can be enhanced by opening existing fractures or creating new fractures by injection of fluid into the rocks. p Most often EGS development has been attempted in areas where there is hot impermeable rock near the Earth's surface, either on the periphery of natural geothermal systems or in areas where a preexisting geothermal resource did not exist, but temperature gradients were sufficient to provide hot rock at depths that could be accessed practically by drilling. Techniques that have been investigated to increase the permeability of these rocks include high-pressure and high-rate hydraulic stimulations, low-rate, low-pressure hydraulic shearing, long-term injection/circulation of cool fluids, high rate gas fracturing or deflagration, and acidization. EGS projects have been ongoing since 1974 when the first EGS research was undertaken at Fenton Hill, New Mexico. Subsequently, EGS projects have been conducted in North and Central America, Europe, Japan, and Australia (Breede et al., 2013).

Factors that influence geothermal induced seismicity include the depth at which the stimulation is carried out, initial stress state of the formation, formation temperature, and rock type, as well as stimulation types (hydraulic, long-term circulation, and chemical/acidizing). Other factors include stimulation parameters such as injected fluid volume, wellhead pressure, injection rate, and duration of injection/circulation. Summaries of EGS systems and the induced seismicity have been presented by Tester et al. (2006), Majer et al. (2007), Ghasemi et al. (2010), Bromely and Majer, (2012) and Breede et al. (2013). Maximum magnitudes are typically M < 4.

Two high profile EGS induced seismicity cases include the 2006 Basel, Switzerland M 3 earthquakes (Deichmann and Giardini, 2009) and the 2017 Mw 5.5 Pohang, Korea earthquake. In both cases the induced events were located near urban areas and both cases highlight the need for both seismic mitigation plans (like this one) and the need for additional research located in areas of low seismic hazard and risk (like at Utah FORGE). For Basel, there was a Traffic Light System (TLS) in place. When a M_L 2.6 earthquake occurred during injection, activities were stopped. However, the largest event M_L 3.4 occurred later in the day leading the operator to open the well and allow flow back to more rapidly dissipate the pore pressure at depth. Three additional $M_L > 3$ events occurred over the next couple of months. The mainshock was widely felt in the area leading to concerns from the public. Damage was non-structural in nature (e. g. Bachmann et al., 2011; Deichmann and Giardini, 2009). The maximum magnitude (M_L 3.4) is consistent with estimates based on the injected volume (McGarr, 2014) and the number of seismic events decayed following cessation of injection operations (Bachmann et al., 2011). A high-quality seismic data set was collected during this experiment and enhanced detection algorithms have further refined the available catalog (Hermann et al., 2019). This catalogue will assist in understanding the evolution of the seismic sequence with the hope of providing better tools for forecasting and development of improved TLSs.

Unlike the Basel earthquake, which occurred during stimulation, the Pohang earthquake occurred during the drilling of one of the geothermal wells and was consistent in time with the loss of a significant volume of drilling mud Ellsworth et al. 2019). This event was larger than what would have been expected for an induced earthquake given the injected volume (McGarr, 2014) or when considering the Gutenberg-Richter relation for tectonic earthquakes (van der Elst et al., 2016), and initially it was unclear if it was induced. After careful review, it was concluded by an advisory committee formed by the Korean government that earthquakes induced by high-pressure fluid injection triggered this Mw 5.5 earthquake on a previously unmapped fault (Ellsworth et al., 2019). However, in the preceding year there was an M 5.5 earthquake 40 km south of the Pohang sequence in September 2016 (Grigoli et al., 2018;

McGarr et al., 2018). So, while the Pohang earthquake was likely triggered by activities related to EGS, a careful PSHA analysis would have identified and included the recent increased seismicity in the area and adjusted the hazard and perhaps the stimulation and monitoring accordingly. Lessons learned from the Pohang earthquake regarding monitoring induced seismicity at geothermal locations are detailed in Ellsworth et al. (2019).

While not an EGS project, a potential analog for investigating induced events at the Utah FORGE site is the adjacent Roosevelt Hot Springs geothermal system and operations at the Blundell power plant. This plant has been in operation since 1984. Electricity is produced by binary and flash plants. Over 1.57 x 10^8 m^3 (4.16 x 10^{10} gallons) of water have been injected and recovered for power generation. Associated seismic activity is minimal, with $M < 2$ occurring at average rates of a few events/month.

Lessons that we should heed from the literature review include that induced seismicity from EGS can result from pore fluid pressures changes, temperature differences, or chemical changes. For the events related to pore fluid pressure changes, instances of induced seismicity are related to the volume and rate of injected fluids, fluid pathways to larger faults, and the orientation of the background stress field. Most earthquakes are $M < 2$ (called microseisms) and are below the felt threshold. This is true for both natural and induced earthquakes and is described by the Gutenberg-Richter relation (Gutenberg and Richter, 1956), which is a log-based relation between the number and magnitude of earthquakes. Thus, most EGS induced earthquakes will go unnoticed. The maximum induced earthquake for many fluid related earthquakes has been shown to be bounded by the volume of injected fluid (McGarr, 2014), to the size and shape of the injection-influenced reservoir volume (Shapiro et al., 2011) and/or to the distribution of tectonic earthquakes following the Gutenberg-Richter relation (van der Elst et al., 2016). However, if there is a fluid pathway to pre-existing faults, the maximum magnitude is a function of the tectonic environment versus the reservoir development. These lessons seem to hold for seismic activity associated with the Blundell Power Plant, where the rates and magnitudes are low, consistent with a net fluid balance.

Other lessons that should be considered in devising mitigation plans include: that the largest earthquake often occurs after shut-in (perhaps several years later) and away from the injection well (potentially several tens of kilometers) often near the edge of the seismic cloud (Baisch et al., 2010); Rock failure associated with fluid injection can be tensile (Hubbert and Willis, 1957) or by shear failure of pre-existing joint or fracture sets (Hubbert and Rubey, 1961) or both; and Seismicity tends to migrate away from the injection well, and the source types as well as b-values also can also change as the seismicity migrates to larger distances from the well (e.g. Zang et al., 2014, and references therein).

5.2.2 Review models for induced seismicity that estimate the maximum magnitude

In early work, McGarr (1976) used the volume of injection (fluids) or extraction (mining environments) to determine the maximum magnitude of induced earthquakes. This work was updated for fluid injection-induced earthquakes (McGarr, 2014). The new relation limits the maximum seismic moment to the product of the injected volume and the modulus of rigidity. In comparing this relation to many examples where volume and magnitude are known, the relation does an impressive job of bounding the maximum observed magnitude. However, van der Elst et al. (2016) concluded that the number of induced earthquakes is proportional to the injection volume and that the magnitude limit is the same as for tectonic earthquakes. In other studies, Shapiro et al. (2011) showed that the magnitudes of induced earthquakes are controlled by the interactions between preexisting faults and the crustal volume influenced by the pore pressure increase. Gishig (2015) showed that the maximum magnitude depends on fault properties, the orientation of the natural faults, and the stress field.

To estimate an upper bound on the maximum induced earthquake for the Utah FORGE site, we use two different relations, McGarr (2014) and van der Elst et al. (2016). In the 2021 stimulation phase for the Utah FORGE site, we anticipate the total fluid injection volume for the three stages of stimulation to be less than 1200 m^3. We assume a modulus of rigidity of 2.85 x 10^{10} Pa. Using these values and the McGarr relation, we get a maximum moment of 3.42 x 10^{13} N m. This moment is equivalent to an M_W 3.0 earthquake. This moment is less than those for the EGS sites analyzed in the McGarr (2014) study but consistent with the lower anticipated injected volumes. If instead we use the relation developed by van der Elst et al. (2016), and a range of possible b-values and values for seismogenic index (∑), the maximum magnitude ranges from less than 1 to almost 4 (Table 3). To reach a magnitude 5 with this range of b and ∑, the injected volume would have to be at least ~10^5 m^3 (or about 630,000 barrels).

Table 3. *Maximum Magnitude for injection volume of 1200 m3 (van der Elst et al., 2016)*

	b = 0.8	b = 1.0	b = 1.2
Σ = -2	M 1.4	M 1.1	M 0.92
Σ = -1	M 2.6	M 2.1	M 1.8
Σ = 0	M 3.9	M 3.1	M 2.6

5.3 Evaluate geologic framework, characteristics and distribution of pre-existing faults

There are four requirements to evaluating the geologic framework of induced seismicity, as follows:

1. Characterize the local stress field: The FORGE site is located in the Basin and Range physiographic province, an area known for east-west extension and primarily north-south striking faults. The basin fill stratigraphy is dominated by volcaniclastic and alluvial material overlying basement granitoid. As previously discussed there are four known fault structures in the FORGE area. The Mineral Mountains West fault system and the unconformable contact between basement and basin strike mostly north-south. The Opal Mound Fault strikes northeast-southwest, while the Mag Lee fault strikes east-west. Seismic activity does not correlate with these structures (Figure 12). Importantly, no additional faults have been imaged

in 3D seismic surveying. Based on both seismic data and the core from test well 58-32, the basement rock is granitoid with no significant faulting.

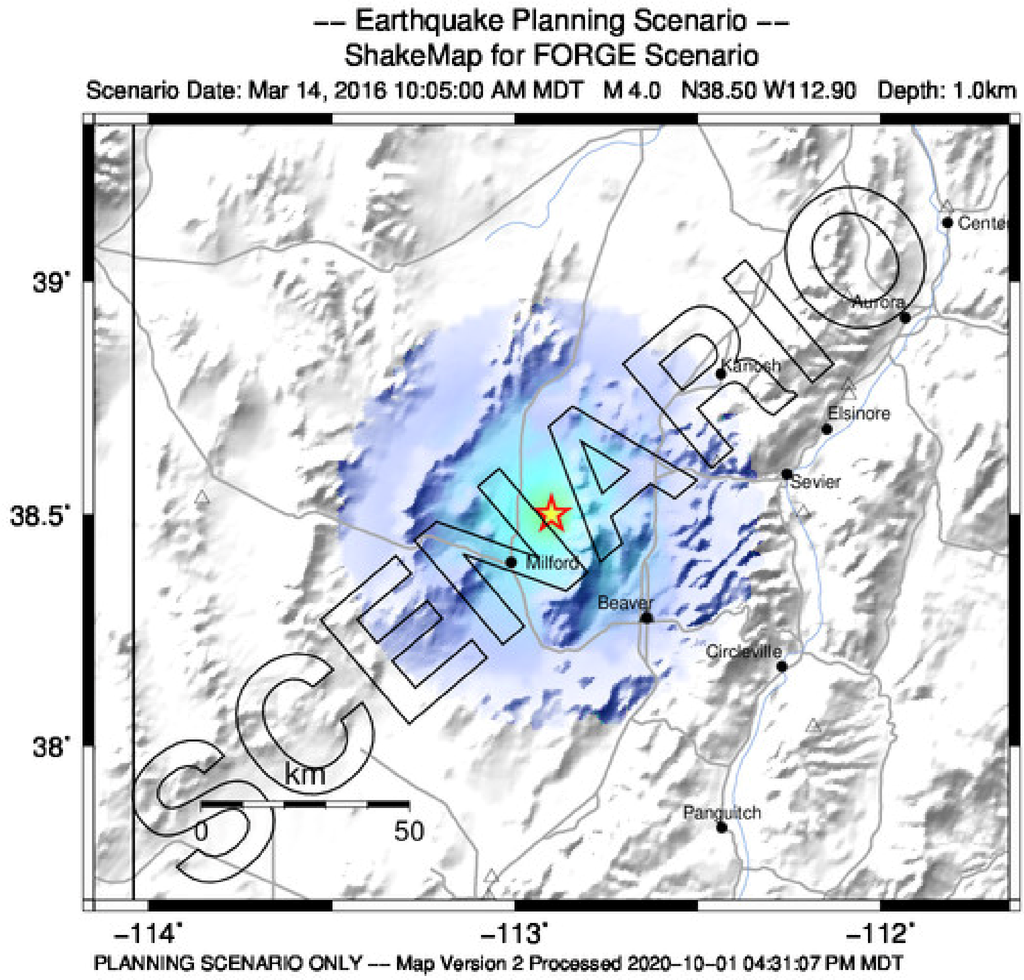
Regarding fractures, an FMI log for the deeper granitic section of test well 58-32 identified ~2000 apparent fractures. The north-south fracture population has moderate dips (<70°) to the west, and the east-west population has dips that cluster between 50–90° to the south. The northeast-southwest population has dips that are scattered, ranging from moderate to steep dips to the southeast and northwest. These patterns strongly resemble the spacings and orientations of fractures in granitic rocks in the Mineral Mountains, especially those occurring east of Roosevelt Hot Springs (Bartley, 2019). They are also different from the fractures and joint patterns occurring in young rhyolite flows, suggesting that most of the fractures in granitic rocks formed before 0.5–0.8 Ma (Bartley, 2019).

For comparison, induced fractures produced during drilling show a narrow range of orientations, predominantly NNE-SSW with near vertical dips. This direction is taken to represent the maximum total horizontal stress, σ_{Hmax}, and is consistent with the orientation of σ_{Hmax} determined from geological observations to the east. Well testing suggests permeabilities of the granite near the bottom of the hole are small, at approximately 30 microdarcies, consistent with a measurement of 6 microdarcies that was acquired on core plugs at EGI. These values indicate that the proposed EGS reservoir has very low natural permeability. The apparent lack of basement faulting and the low permeability reduce the likelihood of significant induced seismicity.

<u>2. Characterize maximum dimensions of pre-existing faults:</u> Details on each of the faults is available in section 5.1.2. Notably, 3D seismic reflection (Miller et al., 2019) and quasi-3-D Vs models (Zhang and Pankow, 2021) do not show displacement across the sediment bedrock interface from which deeper basement faulting would be inferred. The three mapped faults in the study area include the Opal Mound fault, the Mag Lee fault, and the Mineral Mountains West fault system. The lengths of the mapped traces are 5 km, 10 km, and 38 km, respectively. Assuming the entire length ruptures in a normal faulting event, the maximum magnitude for the Opal Mound and Mag Lee faults are calculated to be M 5.4 and M 5.9, respectively (Wells and Coppersmith, 1994). These moderate magnitudes are consistent with the lack of well-defined scarps. For the Mineral Mountains Fault, we assume a maximum M of 6.5. This is consistent with surface scarp amplitudes, but is considered unlikely given no resolvable displacement observed across the basement interface.

<u>3. Review and select empirical relations appropriate for small magnitude events:</u> Pankow (2012) compiled ground motion data for all M 3 to M 5 earthquakes recorded by the state-wide seismic network in Utah. Using PGA and PGV, she compared the data to three ground motion prediction equations developed for M<5 earthquakes: Chiou et al. (2010), Atkinson and Boore (2011), and TriNet (Wald et al., 2005). The Chiou et al. (2010) predictive equations for Southern California fit the Utah data quite well. There was a large distance bias in the Atkinson and Boore (2011) relation for both PGA and PGV and a distance bias for PGV for the TriNet relation.

4. Calculate scenario ground motions from the maximum induced seismic event: Given the distance from the mapped faults to the FORGE site and the low permeabilities, it appears unlikely that earthquakes will be induced on these structures. We therefore use a conservative estimate of M 4 and 1 km depth to generate an induced seismic scenario. The deterministic scenario was generated using ShakeMap (Wald et al. 1999; Worden and Wald, 2016) for an M 4 induced earthquake located at the proposed Utah FORGE site (Figure 23). The scenario was generated using the Chiou et al. (2010) Southern California GMPE, and the statewide Vs30 database (McDonald and Ashland, 2008). The default Vs30 values used in this analysis are based on Vs30 measurements from northern Utah, which are low compared to Vs30 measured at the FORGE site, power plant, and town of Milford. The difference in amplification between the measured and assumed Vs30 is a function of magnitude, but the ShakeMap values for these magnitudes will be slightly larger because of the lower Vs30. The maximum PGA is ~10% g at the epicenter, which based on ShakeMap relates to light perceived shaking and no potential for structural damage. The maximum PGV is ~7 cm/s.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

Figure 23. *Deterministic intensity map for an induced scenario earthquake located near the Utah FORGE site (depth 1 km). Map was generated using ShakeMap (Wald et al., 1999; Worden and Wald, 2016). A point source is assumed because of the small magnitude.*

5.4 Summary of Induced Seismicity Hazard Analysis

Based on all the information in this section, the literature review, the absence of imaged basement faults near the FORGE site, low permeabilities (limited fluid pathways), and low injection volumes coupled with recovery of the fluid, the hazard related to induced seismicity from the Utah FORGE site is concluded to be constrained by the tectonic stresses (as modeled in the PSHA). However, the hazard is more likely to be lower, as constrained by the maximum magnitude calculations following van der Elst et al. (2016).

6. RISK FROM INDUCED SEISMIC EVENTS

Risk is the product of vulnerability, hazard, and cost or the product of probability and consequence. In the first definition, risk has monetary implications. The second definition acknowledges that consequences can relate aspects beyond direct monetary issues. These other costs might relate to the societal effects of increased exposure to felt ground motions or to perceptions around safety of technologies. As will be detailed in this section, the rural location of the Utah FORGE site combined with low seismic hazard results in low monetary risk. The distance to populations centers results in a lower risk from exposure to ground shaking.

To address vulnerability, we return to a description of the Utah FORGE area. The Utah FORGE site is located in an uninhabited area in southcentral Utah. The closest town, Milford, Utah is located 16 km to the southwest and has a population of ~1400. Within ~5 km of the Utah FORGE site, there is a power plant, a wind farm, and barns associated with pig farms. Based on the ground motion threshold criteria discussed in Section 3 and the estimates of ground motion presented in that section, for earthquakes to be felt in Milford (present a nuisance) the magnitudes will have to be at least M 3, the threshold for light damage for the distance of 16 km is M 5 and for distances < 5 km is at least M 4. The threshold for moderate damage at distances < 5 km requires a magnitude approaching 5 (Figure 12).

To address hazard, we note that we have not identified, through 3D geophysical surveys or planar alignments of seismic events, faults within the FORGE footprint where injection will occur. The closest fault, the Opal Mound fault, is also not defined by seismic sequences (Figure 16). Previously we calculated the maximum magnitude expected for an induced earthquake to be M 4 using the relation from van der Elst et al. (2016) that incorporates tectonic earthquakes. Based on this assessment together with the results of the Utah FORGE specific PSHA and the 2018 NSHM, the seismic hazard in the Utah FORGE area is low.

The last parameter is cost. Given the distance to the population center and the felt threshold being M 3, the cost associated with producing nuisance events is minimal. Regarding cost associated with the industrial facilities, there is a chance of light damage if magnitudes exceed 4 and more extreme damage if magnitudes exceed 5. As seen from the hazard assessment these are low probability events. Moreover, the Blundell power plant has vibration monitors to mitigate damage (cost) to the turbines. Windmills should remain undamaged if located in stiff soil for moderate earthquakes as required by state code, thus addressing their potential vulnerability to earthquakes. Finally, the pig farms are relatively new, with simple rectangular construction which will limit damage. So, while there could be some cost associated with a low probability M > 5 earthquake, the cost should be minimal.

In another approach to estimate seismic risk from induced earthquakes, a recent study (Trutnevyte and Wiemer, 2017) provided tools (GRID) for estimating to what extent induced seismicity is a concern to a specific project and then provides a suggested framework for risk governance. GRID provides a mechanism for relating seismic hazard, secondary hazards and exposure, and social concerns, The Utah FORGE project is in GRID Category I (damaging events are unlikely, no significant social concerns). Recommendations from GRID include active seismic monitoring, assessing the hazard and potential ground motions, development of a TLS, and developing a seismic events communications plan. All recommendations have been addressed as part of this ISMP.

In summary, based on (1) the rural nature of the location of Utah FORGE and the distance to a population center, the associated vulnerability to felt induced seismic events (M < 4) is low; (2) the seismic history of low rates, low magnitudes and the local faults present, the seismic hazard is low; and (3) the existing infrastructure, potential cost is low. Following Majer et al. (2016) best practices and GRID (Trutnevyte and Wiemer, 2017), risk assessments developed for induced earthquakes, the overall local risk from the Utah FORGE project is low. This makes the Utah FORGE site an ideal laboratory for developing EGS. That is not only can we develop new engineering technologies, but we can develop these technologies in an environment with low societal risk, and thereby improve and develop seismic risk-based mitigation techniques that can be applied in future projects closer to higher-risk, urbanized areas.

7. RISK-BASED MITIGATION PLAN

The purpose of a seismic risk-based mitigation system is to provide metrics for responding to changes in seismic activity in a way that reduces the risk from a potential, damaging earthquake. A TLS is a common means for organizing and communicating the strategy (Bommer et al., 2006), with amber defining when operational changes are required and red defining when operational activities must cease.

In the TLS, a series of observations controls the alert level and is associated with specific actions. Two metrics often used in a seismic TLS are (1) measured ground motions and (2) earthquake magnitudes. Ground motions have the advantage that they are more easily interpreted in terms of consequences (Siskind et al., 1980). Magnitude thresholds have the advantage that they are quick to calculate and can be used to monitor changes in background hazard including the potential for runaway earthquakes, i.e. earthquakes triggered by operational activities that grow and release tectonic strain (e.g. van der Elst et al., 2016). At Utah FORGE, given the rural nature, we are more concerned with triggering a large earthquake than ground motions following induced events and will thus use magnitudes to define the alert levels. In defining magnitude thresholds, it is important to set the amber level threshold low enough that there is time to change operations before reaching red levels. We elaborate upon threshold criteria below.

The first determination to be made is what defines red, when operations cease. In states with higher population densities (e.g., Kansas, Ohio, Oklahoma), M ≥ 2 is used to initiate action plans and may lead to ceasing operational activities. Based on the hazard and risk assessment performed in this report, we set the red level as M ≥ 3. This level is below where we expect damage at the wind farms and power plant, but it will be felt and might cause concern among nearby residents. Ellsworth et al. (2019) suggest that amber level magnitude thresholds be two units below the red level in order to have time for operational mitigations to lower the seismic hazard. The goal is to never reach red. For Utah FORGE, the monitoring threshold for amber will be ten M ≥ 1 earthquakes in 24 hours within 3 km of the FORGE footprint and/or an M ≥ 2 within 3 km of the FORGE footprint. These levels are set to be consistent with the Gutenberg-Richter relation (Gutenberg and Richter, 1956), which is a log-based relationship between magnitude M and the log of the number of events N(M) of magnitude M and larger. This relation implies that if you get 10 M > 1 events you should start to expect an M ≥ 2 and the chance for an M ≥ 3 is also increased. Our real-time detection limits using the augmented seismic monitoring array discussed in Section 4 and elaborated in the Seismic Monitoring Plan (SMP) are at least as low as M_{comp} 0, and so easily meet the TLS detection requirements.

In addition to the magnitude-based thresholds, we include two additional criteria for the TLS. First, leveraging what was learned from the Pohang earthquake, if while drilling excessive mud losses are encountered, the TLS will move to amber, until the losses are cured. Second, high precision relative relocations will be performed daily for events M ≥ 0 to monitor if seismic activity is illuminating a fault plane. This will only be possible if enough events (n > 20) occur to perform a stable inversion. M ≥ 0 is chosen to separate events associated with small fractures and reservoir development from events occurring on larger fault surfaces.

Table 4 shows observations and actions for the Utah FORGE TLS. The observational thresholds are independent of well pad activities. However, actions are dependent on whether stimulation/injection activities are current or impending.

Automatic alarms are established to alert UUSS duty seismologists for any M ≥ 2 earthquake within ~15 km of the FORGE footprint and ShakeMaps are automatically generated for M ≥ 2.5 earthquakes within 3 km of the FORGE footprint. Alarming events are reviewed by a duty seismologist within approximately one hour to verify location and magnitude. In addition, a cron job will check reviewed triggers and detections and if 10 M ≥ 1 events occurred within 24 hours an additional alarm will be emailed to both UUSS personnel and the FORGE group. Reviewed events will also initiate the communication tree (Figure 9). Increased scrutiny of events in the region will take place for a minimum of two weeks and until background seismic levels are restored. For the case of a red alert during injection into a well, the Project Manager will communicate instructions to the field supervisor to cease pumping and immediately begin flowback.

Regarding education and outreach, the seismic alert level will be displayed on the webpage so that residents and stakeholders are informed of increased seismic activity. For prolonged periods of orange or red alert stages, a public meeting will be convened to provide updates and to answer questions.

Table 4. *Traffic Light System. If any of the events in the first column occur, the steps of the second or third column are activated.*

Observations	Actions: Stimulation	Actions: Non-Stimulation
• No anomalous seismic events	• No actions. Follow good engineering and safety practices.	• No actions. Follow good engineering and safety practices.
• M ≥ 2 within 3 km • 10 M ≥ 1 in 24 hr within 3 km • Events propagating along imaged fault plane • Total loss of drilling mud that cannot be cured in 30 minutes.	• The Drilling Site Manager (DSM), the Operations Superintendent and the Project Manager must be immediately notified, and the DSM will coordinate appropriate activities on location. • Assemble all personnel at designated muster point and hold an offsite safety meeting • DSM will immediately terminate pumping • DSM will initiate controlled flow back with first occurrence of orange. If the well is shut-in, the well will be also be flowed back. Do this in an orderly, controlled manner. Ensure that this is done in a safe fashion for personnel, the rig and surface peripherals, integrity of the well and downhole equipment (if feasible). This is done under the authority of the Drilling Site Manager and the Operations Manager, unless directed otherwise by the project manager. • Wait for instructions to resume injection. • Notify all personnel on the FORGE footprint including FORGE staff, contractors, service personnel and visitors. • All unnecessary personnel are to move away from the wellhead. • Ensure the safety of personnel first and the integrity of the rig and peripheral equipment if that can be safely done.	• The Drilling Site Manager (DSM), the Operations Superintendent and the Project Manager must be immediately notified, and the DSM will coordinate appropriate activities on location. • Assemble all personnel at designated muster point and hold an offsite safety meeting • If Orange is triggered because of losses, rig crew and DSM will continue to work on curing the losses. • It may be possible that drilling is resumed with or without returns AFTER consultation with FORGE management, and possibly the DOE and key STAT representatives. • Regardless of the trigger, ensure the safety of all personnel on location, the rig (if present), the integrity of downhole equipment if feasible and safe. • Notify all personnel on the FORGE footprint including FORGE staff, contractors, service personnel and visitors. • All unnecessary personnel are to move away from the wellhead. • Ensure the safety of personnel first and the integrity of the rig and peripheral equipment if that

	• **Operations will cease until a plan to continue is approved by DOE and the STAT.** • **Resumption of injection could include continuation of pumping at a lower rate or with modified protocols**	can be safely done. • If drilling is ongoing and conditions are stabilized, POOH or pull into a cased section of the hole. • *If the issue is loss of circulation, cure the losses without shutting down until the losses are cured.* • *If cementing is ongoing, and it is deemed safe to do so, continue until the plug has bumped and secure the well.* • *If logging is ongoing, pull out of the hole.* • *If activities such as setting packers are ongoing, stabilize the well and wait for instructions.* • *Wait for instructions to resume operations.* • ***Operations will cease until a plan to continue is approved by DOE and the STAT.***
• M ≥ 3 within ~15 km	• The Drilling Site Manager (DSM), the Operations Superintendent and the Project Manager **must be immediately notified.** • **Contact information is available in Section III, page 7 of this document.** • Assemble all personnel at designated muster point and hold an offsite safety meeting • DSM will immediately terminate pumping and flow back with first occurrence of red. If the well is shut-in, the well will be flowed back. Do this in an orderly, controlled manner. Ensure that this is done in a safe fashion for personnel, the rig and surface peripherals, integrity of the well and downhole equipment (if	• The Drilling Site Manager (DSM), the Operations Superintendent and the Project Manager must be immediately notified, and the DSM will coordinate appropriate activities on location. • The Drilling Site Manager (DSM), the Operations Superintendent and the Project Manager must be immediately notified. • Contact information is available in Section III, page 7 of this document. • Assemble all personnel at designated muster point and hold an offsite safety meeting

	feasible). This is done under the authority of the Drilling Site Manager and the Operations Superintendent, unless directed otherwise by the Project Manager. ● All unnecessary personnel are to leave the location. ● Ensure the safety of personnel and the integrity of the rig and peripheral equipment. ● **Secure the well. When it is established to be safe to do so, POOH, and rig down service company.** ● **Operations will cease until a plan to continue is approved by DOE and the STAT**	● Ensure the safety of all personnel on location, the rig (if present), the integrity of downhole equipment if feasible and safe ● Notify all personnel on the FORGE footprint including FORGE staff, contractors, service personnel and visitors, ● All unnecessary personnel are to leave the location. ● Ensure the safety of personnel and the integrity of the rig and peripheral equipment. ● **Secure the well.** ● **Operations will cease until a plan to continue is approved by DOE and the STAT.**

SUMMARY AND CONCLUSIONS

The risk of damaging induced earthquakes from the Utah FORGE EGS research project is low. This was determined based on the rural area, low seismic rates and magnitudes, no earthquakes located within the FORGE footprint, no mapped faults within the FORGE footprint, and low proposed injection volumes. The hazard and risk from background tectonic earthquakes located within 50 km of the FORGE project are low to moderate. Because of the distance to known faults, it is unlikely that injection related to FORGE will trigger an earthquake on one of these faults. UUSS operates a well-established earthquake information center, which includes maintaining and operating the seismic center, recording and processing of recorded data, and communicating earthquake activity to the public and researchers. For the Utah region, UUSS is the authoritative network for seismic monitoring of both tectonic and induced earthquakes. To guide monitoring at the Utah FORGE site, a TLS has been developed to identify potential changes in the hazard level (facilitated with automated alarming) and to guide operational activities for mitigating the effects of these changes. A key element of the plan is clear communication with stakeholders and the public through timely information on websites.

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APPENDIX A:

STAKEHOLDERS

Property Owners

- Smithfield
- Utah School and Institutional Trust Land Administration (SITLA)
- Bureau of Land Management
- Unitarian Universalist Service Committee
- Toni and Pat Rule
- Ft. Churchill Corp.

Interested Public

- City of Milford
- Milford High School
- Beaver County Commissioners
- Paiute Indian Tribe of Utah
- Residents of Beaver County

Private Power Developers

- Cyrq Energy
- PacifiCorp (Blundell geothermal plant)
- Milford Solar Project (solar)
- Milford Wind Farm
- Blue Mountain Biogas
- Rocky Mountain Power
- ENEL

Federal and State Organizations

- Idaho National Laboratory
- U.S. Geological Survey
- Utah Geological Survey

Federal and Utah State Government Agencies

- U.S. Bureau of Land Management
- Utah School and Institutional Trust Land Administration (SITLA)
- Utah Department of Environmental Quality (DEQ)
- Utah Underground Injection Control Program
- Utah Division of Water Rights / State Engineer
- State Historic Preservation Office (SHPO)

- U.S. Fish and Wildlife Service Natural Resources, Agriculture, and Environmental Quality Appropriations Sub-committee
- Utah Governor's Office of Economic Development
- Utah Governor's Office of Management and Budget
- Utah Governor's Office of Energy Development
- University of Utah
    - Dept. of Chemical Engineering
    - Dept. of Geology and Geophysics
    - Univ. of Utah Seismograph Stations (UUSS)
    - Office of Sponsored Projects
    - Vice President of Research
    - Department of Communications
    - College of Education

APPENDIX B:

COMMUNICATIONS AND OUTREACH HISTORY

Year 2015

April 27, 2015
A press release was issued by the University of Utah announcing the Phase 1 grant awarded to EGI.

September 2015
Article in September issue of UGS' "Survey Notes" on the FORGE project and the Milford, Utah site selected as one of five possibilities for the field laboratory. Written by Rick Allis.

November 18 – 25, 2015
Project contacts David Cluff, Principal of Milford High School, about setting up a seismometer on the school grounds. A strong-motion instrument will be installed in small out-building on the school property.

December 3, 2015:
Rick Allis and Stuart Simmons conducted a site visit for landowners, regulators and interested stakeholders, including the BLM, Beaver County representative, DEQ, PacifiCorp, Murphy Brown, SITLA and SunEdison. The locations of the deep drill holes, the potential access routes, and the main groundwater collection facility were visited.

December 15, 2015:
Joseph Moore gave an invited presentation at the 6th Annual Program on Energy and Sustainable Development (PESD) convened by the Stanford Precourt Institute for Energy. The theme of the conference was Building Risky Energy. Joseph Moore discussed the role geothermal energy can play in today's energy mix. He discussed challenges facing conventional geothermal development and the potential of EGS. He stressed the importance of the FORGE laboratory where new techniques for EGS development could be developed and tested.

Year 2016

January 15, 2016

Joseph Moore met with D. Hollett, S. Hamm and L. Boyd at DOE headquarters to review our vision of the FORGE project. Meetings were also held with the BLM, who are familiar with the area because of other infrastructure development, and representatives of Senator Hatch and Representative Stewart. The BLM considered potential environmental or archeological risks posed by the project to be low.

January 27, 2016:
Joseph Moore presented an invited talk to a class in NUCLEAR ENGINEERING at the University of Utah. The presentation covered the basics of geothermal energy and the need for EGS development and a national FORGE laboratory, where new technologies can be tested.

February 2-4, 2016:
STEM Fest (Science-Technology-Engineering-Mathematics) is a unique gathering of Utah educational and business leaders engaged in science and technology. The event offers students in 7th through 10th grades the opportunity to learn exciting and innovative career opportunities in Utah. EGI hosted a booth in conjunction with the Utah Governor's Office of Energy Development that highlighted the Utah FORGE project.

February 8, 2016
FORGE Utah website goes live. The website address is http://www.forgeutah.com/outreach/

February 9, 2016
Rick Allis presents FORGE summary to Natural Resources Appropriations sub-committee of the Utah Legislature.

February 18, 2016
The University of Utah has signed an MOU with Southwest Petroleum University (SPU) of China to exchange information on EGS development. SPU has been working on an EGS project in granite in Korea. The graduate student working on the project will spend a year at EGI beginning in early summer.

February 22 - 25, 2016
Three papers on the Utah FORGE site presented at Stanford Geothermal Workshop.

March 3, 2016
Facebook page published. The Facebook address is https://www.facebook.com/forgeutah/

March 4, 2016

Email to David Cluff, Principal, offering a talk to Milford High School about Utah earthquakes and the FORGE project. Offer not followed up.

March 2016
Utah FORGE Team collaborated with Utah Office of Energy Development on a video about geothermal energy in Utah, including the FORGE project: https://www.youtube.com/watch?v=4-6UgHq_Xe4

March 23, 2016
Joseph Moore presented an invited talk to a class in Sustainable Energy (Dept. of Geography at the University of Utah. The presentation covered the basics of geothermal energy and the need for EGS development and a national FORGE laboratory, where new technologies can be tested.

March 30, 2016
Rick Allis met with Utah Division of Wildlife to discuss biological clearances at FORGE site.

April 4, 2016
Joseph Moore and Rick Allis give presentation concerning the status of the FORGE project to Utah School and Institutional Trust Lands Administration.

April 19, 2016
Representatives of the BLM and Paiute Indian Tribe of Utah met to discuss the FORGE project. The tribe had no objections to the project moving forward. They only requested to be kept informed of changes or updates.

May 6, 2016
Manuscript on the revised thermal regime of the Milford FORGE site submitted to Geothermal Resources Council for their October 2016 meeting in Sacramento, California.

October 11 – 15, 2016
Joseph Moore presented invited lectures at the International Seminar on Exploration and Development of Hot Dry Rock Resources, sponsored by the College of Environment and Resources, Jilin University, Changchun, China, and the Institute of Hydrogeology and Environmental Geology, China Geological Survey Beijing, China.
October 18, 2016
Discussions with Bill Dent (Manager) at SunEdison wind farm maintenance facility and Scott Albrecht (Beaver County Commission) and Jim Webb (Smithfield), followed by presentations to

PacifiCorp staff at Blundell Geothermal Power Plant and the monthly meeting of Milford City Council about FORGE project.

October 22, 2016
Joseph Moore presented an invited talk entitled "Overview of the Utah FORGE site at the GRC Workshop on Reservoir Stimulation: Recent Field Practices, Monitoring Techniques and Theoretical/Laboratory Investigations."
October 28, 2016
Phone call from reporter Linda Peterson of Beaver County Journal. Interviewed about FORGE project as a result of the Milford City Council presentation. Article prepared for Beaver County Journal.

November 30, 2016
Email exchange between University of Utah and Principal of Milford High School about a suitable backyard in the City for a nodal seismometer for the one month of the survey planned for December-January time period. The Principal, David Cluff offered his own backyard for the nodal seismometer.

December 6, 2016
Meeting with Scott Albrecht, Beaver County, to discuss ownership of roads around the FORGE site and activities planned for 2017. Discussion of County requirements for Conditional Use Permit (CUP).
December 7, 2016
Meeting with Rocky Mountain Power in Cedar City and Kent Sorensen from Richfield office who was connected by phone. Discussed power requirements for FORGE. Rocky Mountain Power to prepare assessment of issues and cost.

December 12, 2016
Joseph Moore presented an invited talk entitled "Overview of the Utah FORGE Site" to the Utah Geological Association, Salt Lake City, Utah.

Year 2017

January 4, 2017
Feedback from Beaver County that they are applying to BLM for an easement to allow power to be run in the corridor adjacent to Antelope Point Road. They expect this to be relatively quick approval because of past paperwork and activities on and beside the road.
January 5, 2017

Jim Webb, Smithfield, reaffirms support for the FORGE project in an email.

January 10, 2017
Email letters sent to the two landowners in Section 32 updating them on the project and plans for 2017 which could involve crossing their land.

January 2017
School and Institutional Trust Lands updated on project progress (email correspondence).
January 11, 2017
An article featuring the FORGE project in Milford, Utah as well as its partnership with Smithfield was published in the October issue of the Beaver County Journal.

March 16, 2017
Christian Hardwick gave a presentation on Utah FORGE developments at the meeting of the Association of Environmental and Engineering Geologists, Utah Chapter.

March 21, 2017
Joseph Moore and Mark Gwynn presented to the Beaver County Planning Commission, which unanimously approved the project and recommended review by the County Commission.

April 4, 2017
A presentation by Rick Allis was provided to the Beaver County Commission as the final phase of the Conditional Use Permit.

April 13, 2017
Rick Allis gave the Distinguished Lecture to the Department of Geology and Geophysics at the University of Utah and included material about Utah FORGE.

April 17, 2017
Stephen Potter presented a poster on the seismicity in the Milford – Mineral Mountains region at the annual meeting of the Seismological Society of America.

April 2017
A Peltier teaching module and head exchanger module were both completed.

May 2017
A seismometer module was completed, which uses an accelerometer to detect small vibrations in a classroom.

July 10, 2017
Dr. Tony Butterfield and his team validated the above-mentioned modules by demonstrating them at the Utah Energy Career Expo.

August 2017
Four field trips were conducted. The tours were held for DOE Managers, interested local stakeholder and regulatory administrators, students from the Dept. of Chemical Engineering at the University of Utah taking a course in drilling, and a contingent from the Chinese Geological Survey tasked with developing an Enhanced Geothermal System program. The tours included discussions of the FORGE project, visits to the FORGE site and tours of the drilling rig, the mud system and the logging facilities, and a tour of PacifiCorp's Blundell geothermal plant.

September 7, 2017
ThinkGeoEnergy published photos and a wrap up of the test well.

September 2017
Clay Jones presented a lecture to students in Chemical Engineering on geothermal energy and development.

October 4, 2017
Dr. Tony Butterfield demonstrated the Peltier module and his students developed at the Utah FORGE booth during the Annual Meeting of the Geothermal Resources Council, which was held in Salt Lake City.

October 23-24, 2017
During STEM Fest, over 150 participating students grades 7 through 10 learned about geothermal energy and the Utah FORGE project from Dr. Tony Butterfield and other team members.

October 2017
Approximately 20 individuals attended a field trip to the Utah FORGE site.

December 19, 2017
Dr. Tony Butterfield, several graduate students from the Department of Chemical Engineering, and Clay Jones of EGI, visited Milford High School's Career Day.

December 2017

Visitors from SINOPEC toured the Utah FORGE site and the surrounding geothermal features and power plant.

<u>Year 2018</u>

January 2018
The Utah FORGE project was featured in Survey Notes, published by the Utah Geological Survey.

June 14, 2018
The Salt Lake Tribune carried a story announcing the selection of the Utah FORGE site, as did the University of Utah's UNews. ThinkGeoEnergy and Energy Central News both also ran the story.

June 15, 2018
Story about Utah FORGE selection appeared in The Spectrum.

June 18, 2018
A story about the selection of the Milford site ran in Kallanish Energy e-newsletter.

June 26, 2018
A question-and-answer piece was carried by CleanTechnica following the selection of the Utah FORGE site.

June 2018
Prof. Butterfield's undergraduate outreach mentors from the University of Utah's Chemical Engineering department presented two different STEM modules demonstrating concepts applicable to geothermal energy at the Explore Engineering Summer Camp for STEM focused high school students and Hi-GEAR Summer Camp (exclusively for high school girls).
July 25, 2018
ThinkGeoEnergy had a story about Utah FORGE receiving an Office of Energy grant for powerline construction.

July 2018
Two teaching modules titled 'Thermoelectric Human Power' and 'Turbine Electric Generator' were created and made available.

August 4, 2018

An article providing an overview of Utah FORGE ran in The Deseret News.

October 22-23, 2018
Utah FORGE participated in the annual STEM FEST during which the team interacted with school children from elementary to high school age from all over Utah, as well as parents and educators. In addition to the kids, the team interacted with other exhibitors including Utah division of oil and gas, various departments within the U of U, Salt Lake Community College, Utah Valley University, Kennecott/Rio Tinto, and Governor's office of Energy development.

Year 2019

January 31, 2019
Dr. Anthony Butterfield and the outreach team attended Family Night at the Leonardo Gallery from 5 PM to 8 PM. This three-hour tabling event included the Turbine and the Thermoelectric Power modules and the 3D printed site map of the FORGE project.

February 2, 2019
A short article announcing a forum featuring Dr. John McLennan to discuss geothermal energy at Utah FORGE appeared in The St. George News.

February 25, 2019
ThinkGeoEnergy included a story about the U.S. Department of Energy's Geothermal Technology Office's webinar updating listeners about the roadmap for Utah FORGE.

March 12, 2019
Dr. Anthony Butterfield and the outreach team spoke at the Taylorsville Library's Teen Homeschool Program. During the energy portion of the talk the team introduced the FORGE project, and Dr. Butterfield and the team had the kids attending conduct the turbine module, in which they generate electricity from their blowing into a small turbine to illustrate how steam from geothermal energy is used to create electricity. They also conducted the Thermoelectric Power module, in which the children use the heat from their hands to create a temperature gradient with ice water to create electricity. This module was related back to the geothermal project to illustrate the need to have both a heat source and sink in order to create useful work.

March 18, 2019
A Serbian delegation representing various ministries and agencies visited the Milford site to learn about the geothermal research program. The trip was led by Joseph Moore and sponsored by the Open World Leadership Program. The site visit included stops at the

geothermal power plant, and solar and wind farms to learn about Beaver County's renewable energy resources. The structure seen through the winder is the Ormat binary power plant at the Bundell geothermal facility.

April 5, 2019
The Utah FORGE team participated in the University of Utah's Geology and Geophysics Department's Open House attended by the students and the general public. The team held a booth with posters and handouts about the FORGE project and geothermal energy in Utah.

April 18, 2019
Following the first STAT meeting held in Salt Lake City April 15-17, a field trip to the FORGE site and surrounding area on held.

April 25, 2019 – At Latinos in Action, a 1-hour presentation on chemical engineering at the University of Utah was provided. This event brings high school students from the Latino community to campus for college information and recruitment. We used the FORGE turbine and Peltier hands-on projects with students during this event.

May 7-8, 2019
A two-day event at Cyprus High School was by outreach student mentors and team members. Six physics and mathematics classes were visited in which the OED FORGE teaching modules were conducted.

May 13, 2019
ThinkGeoEnergy carried a story about Seequent's collaboration with Utah FORGE.

May 20, 2019
The team visited Hunter High School. The event lasted the entire school day, with the team visiting different chemistry classes. In each, we conducted the OED FORGE modules with the students.

May 30, 2019
The Governor's Energy Development Symposium was attended with example outreach modules. We received multiple requests for information on conducting the modules and we gave out the link to the online material.

June 14, 2019

The outreach team participated at Hi-GEAR Summer Camp which is STEM-focused and intended exclusively for girls. The team offered a chemical engineering presentation and then conducted the OED FORGE outreach hands-on activities. We concluded the event having all the students combine and light as many lights as they could.

June 20, 2019
Dr. Tony Butterfield's outreach team attended the Explore Engineering Summer Camp which is for STEM-focused high school students in which they visit each department in the College of Engineering. The approximately 40 students spent two hours with our outreach team in which we gave a chemical engineering presentation and then conducted the OED FORGE outreach hands-on activities. We concluded the event having all the students combine and light as many lights as they could.

July 18, 2019
A brief announcement about the Utah Governor's Office of Energy releasing the fourth in a series of videos about the Utah FORGE project.

August 31, 2019
Joseph Moore led a field for faculty members from the China University of Geosciences in Chendu, China and EGI students to the site.

September 2019
Joseph Moore gave several invited presentations at the annual meeting of the Geothermal Research Society of Japan.

October 7-8, 2019
Hosted Utah FORGE display at Salt Lake City STEM fest, which included demonstration of the geothermal energy modules and talking about geothermal energy. This is an annual event attended by upwards 20,000 4th through 10th grade students.

October 9-10, 2019
Joseph Moore attended the European Geothermal Workshop in Insheim, Germany.

October 19, 2019
Hosted Utah FORGE display at the Geology and Geophysics, University of Utah, open house, which included demonstration of the geothermal energy modules and talking about geothermal energy.

November 8-11, 2019
Chemical Engineering, University of Utah, undergraduate students participated in outreach competition sponsored by the American Institute of Chemical Engineers (AIChE) Annual Meeting and Student Conference including demonstration of Peltier engine module; the students won the 2nd place prize. The student competition is an annual event attended by over 10,000 participants.

November 23, 2019
Hosted Utah FORGE display at the Engineering Day, University of Utah, which included demonstration of the geothermal energy modules and talking about geothermal energy.

November 25-27, 2019
Stuart Simmons represented the Utah FORGE team at the NZ Geothermal Workshop in Auckland and presented a paper entitled “Overview of the Geoscientific Understanding of the EGS Utah FORGE Site, Utah, USA.”

November 2019
John McLennan delivered an invited presentation on Utah FORGE to the Grand Junction Chamber of Commerce, Colorado.
Rob Podgorney delivered an invited presentation on Utah FORGE to Jackson Hole Geologists at INL.

December 5, 2019
Rob Podgorney was the core speaker at the CODEBREAKER’s day at the Center for Advanced Energy Studies highlighting opportunities to use earth as source of energy.

December 9-13, 2019
Kris Pankow and Phil Wannamaker represented the Utah FORGE team at the AGU Fall Meeting in San Francisco.

December 12, 2019
Rob Podgorney gave a presentation to the DOE-Idaho operations office about INL’s support to the Utah FORGE project.

Year 2020

January 8-9, 2020

Joseph Moore participated at the ICDP workshop at Cornell University providing expert opinion about geothermal projects and Utah FORGE experience.

February 11, 2019
Spring 2020 STEM Career and Internship Fair, Union Bldg., University of Utah. Several of the Chem E students associated with the Utah FORGE project attended the fair.

February 12, 2020
Renewable Energy Press Event/Open House, Architecture Bldg, University of Utah – ad hoc invitation to host a table showcasing the FORGE project on the heels of U of U's recently signed partnership with Cyrq energy. The EGI team and ChemE student team representative attended the event to distribute fliers, show Peltier modules and talk about geothermal energy. The event was attended by about 30 people. https://sustainability.utah.edu/5291-2/

February 10-12, 2020
Seven presentations focusing on Utah FORGE were made by the Utah team members at the Stanford Geothermal Workshop.

February 19, 2020
Science Night at Oquirrh Elementary, West Jordan, UT. The ChemE student team participated in the event bringing some of the FORGE modules. It is estimated that their table saw over 250 visitors and the event had over 400 participants in attendance.

February 2020
General overview presentation about geothermal energy and about the FORGE project at the Reid School in Millcreek, UT. The team of ChemE students brought along several mini turbine and Peltier modules to show to a class of 46 students.

March 2020
University of Utah hosts activities for the refugee program in March. The ChemE. students presented an overview of FORGE, attended by about 10 people.

March 2020
In the first Utah Robotics competition, the ChemE. student team set up a table with FORGE modules and gave a presentation. This event was attended by hundreds of students, mentors and parents. https://www.utfrc.utah.edu/

March 2020

The homepage https://utahforge.com has been expanded to house the "Did You Know" feature, the "Share a Scientific Paper" and the Data Dashboard.

April 28, 2020
The first quarterly newsletter, *At the Core*, was launched and distributed to nearly 200 contacts, and published on the website. https://utahforge.com/at-the-core/

April 30, 2020
The Utah FORGE team released first Solicitation 2020-1 and the website serves as the gate to general information and to the InfoReady site that operates the mechanics of the application processes. https://utahforge.com/rd/solicitations/

May 6, 2020
A pre-recorded, 20-minute webinar on the Geoscientific Overview of Utah FORGE coinciding with the release of Solicitation 2020-1 was created and distributed.

May 14, 2020
The core curation web page has been launched to facilitate core and water sample requests https://utahforge.com/laboratory/sample-curation/.

May 2020
The Data Dashboard was created, allowing those seeking information to access it in a "one stop" location, providing a user-friendly experience. The Data Dashboard can be accessed here.

May 2020
A visual representation of the FORGE project in a short animation was created to summarize in a nutshell the concept of the project https://utahforge.com/outreach/education/education-for-students/

June 8, 2020
The outreach team expanded the social media footprint by launching a LinkedIn profile. LinkedIn allows for professional interaction for the project and those interested in geothermal, while also fostering cross marketing efforts.

June 9, 2020
Utah FORGE worked closely with Professor Sara K. Yeo in the University of Utah's Department of Communications to develop the syllabus for an upcoming Capstone course in the fall. The

students will develop a survey instrument to collect data about public opinion, awareness and knowledge of geothermal energy.

June 17, 2020
The June edition featured Pengju Xing and John McLennan, both of the University of Utah, presenting on “Injection Testing and Stress Measurements.”

June 25, 2020
Pengju Xing gave a talk at this year’s ARMA (American Rocks Mechanics Association) ROBE Talk. The talk’s focus was “Using Flowback and Temperature for Closure Stress Diagnosis.”

June 2020
A contact lists for email communications of newsletter, news, and announcements was created. In addition, a subscription form was added to the website. The number of subscribers at the end Q3 is 240.

July 1, 2020
Utah FORGE team members met with Jesse Puckett, a representative of the ENEL/Cove Fort geothermal plant, provided an update on Utah FORGE activities, discussed potential future collaboration, and scouted possible locations for additional geothermal-related roadside kiosks. Utah FORGE team members introduced Utah FORGE to Robert Pyles, the new Beaver County Economic Development Director and County Administrator. Provided an overview of Utah FORGE, discussed continuing cooperation opportunities.

July 14, 2020
The second edition of the quarterly newsletter, *At the Core* was published on the Utah FORGE website and promoted to our email distribution list and through our social media platforms.

August 12, 2020
Members of the Utah FORGE team met with representatives from Senator Mike Lee’s office. Heath Hansen, Southern Utah Director; Cole LaCroix, Legislative Correspondent / Policy Analyst Environmental Affairs; and Carolyn Phippen, Area Director were provided with an overview of the Utah FORGE project, toured the site, and the existing kiosks.
Members of the Utah FORGE team provided updates on upcoming activities to Beaver County Commissioner Mark Whitney, Beaver County Administrator Robert Pyles, Milford Mayor Nolan Davis, Milford City Councilmen Les Whitney and Scott Symond, Milford City Administrator Makayla Bealer, and Beaver City Mayor Matt Robinson.

August 18, 2020
A university-level lecture / presentation on conventional geothermal resources by Stuart Simmons was produced and promoted to our email distribution list and through our social media platforms. The presentation is the first in a series of two aimed at educating students on geothermal energy.

August 26, 2020
The first episode in a series of podcasts titled *FORGEing Ahead with Geothermal Energy* was released.

August 24, 2020
A Capstone class in the University of Utah Department of Communications was commenced. The Capstone is taught by Professor Sara Yeo. The class theme is focused on better scientific communications and students developed a survey to judge overall understanding of geothermal energy.

August 28, 2020
A short piece announcing the upcoming drilling and inviting the community to attend the planned presentations appeared in the Milford City Newsletter.

August 2020
An overview of Utah FORGE bylined by Joseph Moore appeared in *The Explorer*, the publication of AAPG.

September 2, 2020
An advertorial article appeared in *The Beaver County Journal* announcing drilling would be commencing and inviting the public to attend public meetings to learn more.

September 9, 2020
A reminder advertisement inviting the public to attend public hearings to learn more about the upcoming Utah FORGE drilling appeared in *The Beaver County Journal.*

September 15, 2020
Members of the Utah FORGE team presented to the Beaver County Commission. There were approximately 25 people in attendance. Dr. Joseph Moore provided an overview of the project and outlined upcoming drilling activities. Dr. Kristine Pankow joined the meeting virtually and discussed seismicity. Questions from the public focused on water usage, County investment in the project and what benefits would stem from the project for the people living in the County.

September 15, 2020
The Utah FORGE team met with Adam Snow, Southern Utah Director for U.S. Representative Chris Stewart. Dr. Moore provided him with an update about the project.
A presentation was made to the Milford City Council in advance of planned drilling activities. There were approximately 20 people in attendance. Dr. Joseph Moore provided an overview of the project and outlined upcoming drilling activities. Dr. Kristine Pankow joined the meeting virtually and discussed seismicity.
Joseph Moore presented to the Beaver County Planning and Zoning Commission to secure the required Conditional Use Permit.

September 2020
A member of the Utah FORGE team attended all of the classes in the Capstone course at the University of Utah's Department of Communications, answering questions and providing insights when appropriate. The 15+ students are building a survey tool to gauge the public's understanding about geothermal energy. Both Joe Moore and Stuart Simmons presented overviews to the class.
The final kiosk panels were installed on Antelope Point Road. The panels highlight geothermal energy in Utah and the Utah FORGE project specifically.

ATTACHMENT 1:

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SEPARATE FILE