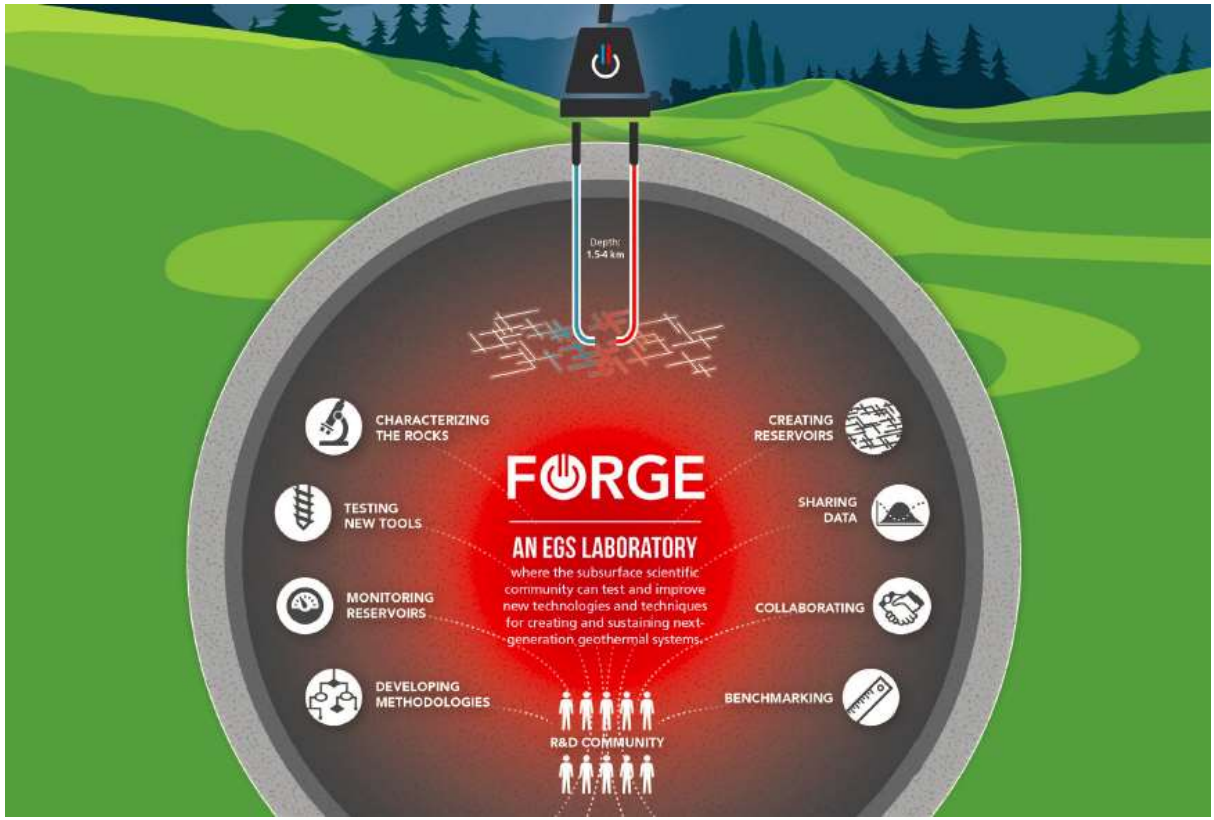
FALLON

Geothermal Research Observatory



Frontier Observatory for Research in Geothermal Energy - Fallon, NV

FORGE Manager: Lauren Boyd

Project Officer: Steve Henry (NETL)

Project Monitor: Elisabet Metcalf

Total Project Funding: $9,899,708

November 13, 2017

Douglas Blankenship

Sandia National Laboratories

General Session

Relevance to Industry Needs and GTO Objectives

The objective of this project is *to establish and manage FORGE as a dedicated site where the subsurface scientific and engineering community will be eligible to develop, test and improve new technologies and techniques in an ideal EGS environment.*

- EGS offers the promise of a vast, renewable energy source..
- Many technical barriers to commercialization have been identified.
  - Techniques to effectively stimulate fractures in different rock types.
  - Techniques capable of imaging permeability enhancement and evolution
  - Effective zonal isolation for multistage stimulations
  - Directional drilling/stimulation technologies for non-vertical well configurations
  - Long-term reservoir sustainability and management techniques.
- FORGE is intended to enable the R&D that will address these barriers.
- Fallon was proposed because it is an outstanding location to design and test a methodology for developing large-scale, economically sustainable heat exchange systems.

FALLON

FORGE

Geothermal Research Observatory

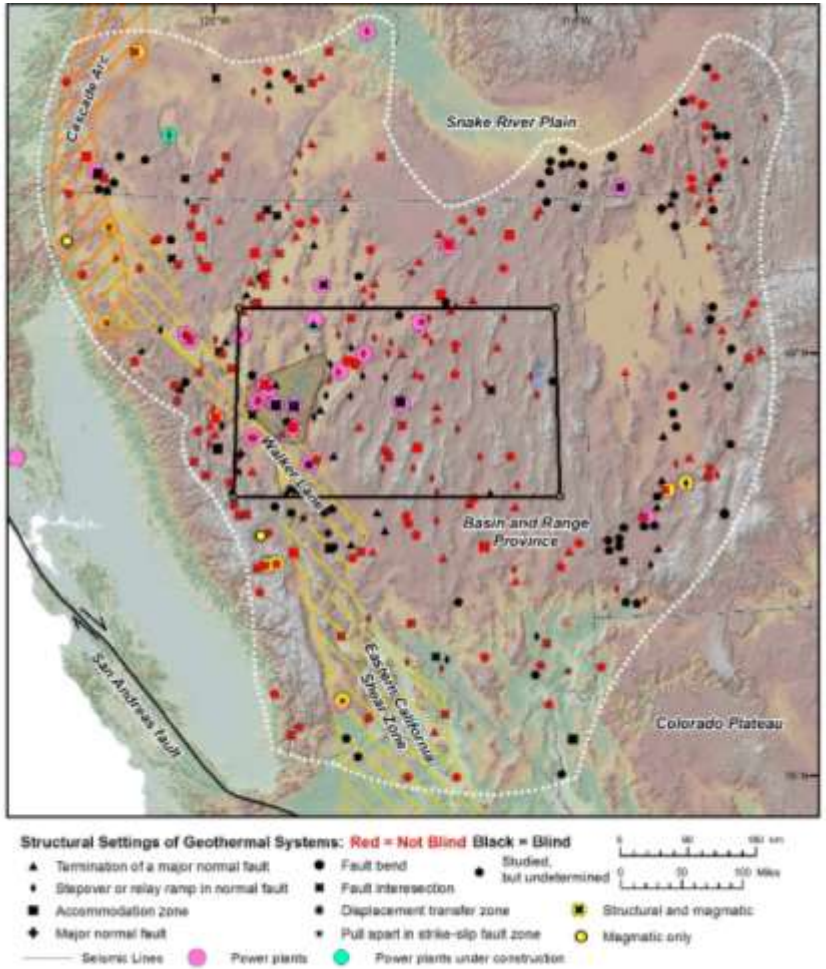
Methods/Approach

- Assembled a talented multidisciplinary team and reviewed available candidate sites on Ormat and Navy controlled lands
- Reviewed several geothermal systems across a wide swath of the Great Basin
- Review built on many previous and ongoing studies by team members

Sandia National Laboratories
BERKELEY LAB
University of Nevada, Reno
nbmq
USGS science for a changing world
ITASCA
GeothermEx A Schlumberger Company
ORMAT
Innovate Geothermal
EMPS inc.
Hi-Q Geophysical Inc.

Methods/Approach

Candidate Site Selection

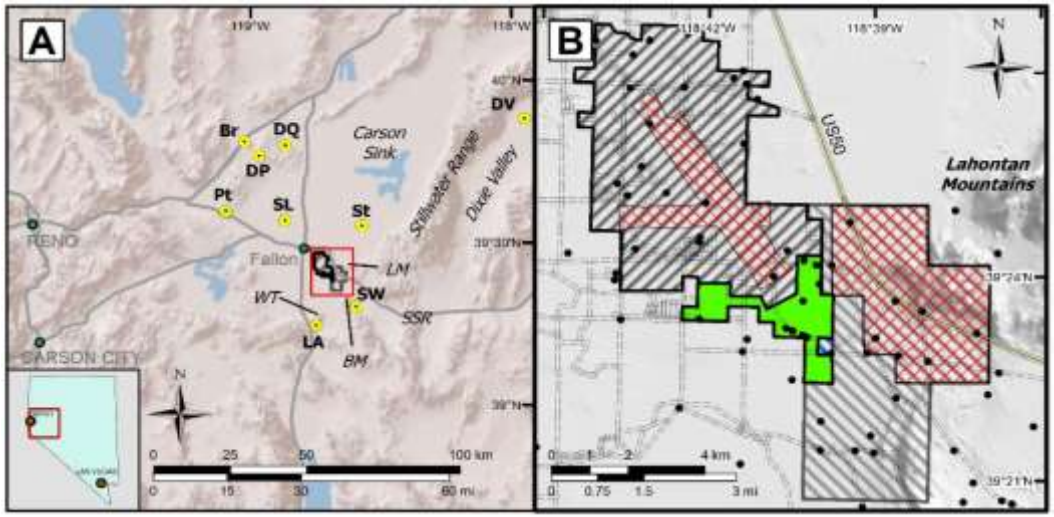


- Carefully considered several key parameters:
  - No hydrothermal system
  - Temperature (175-225^{o}C)
  - Depth (1.5- 4 km)
  - Low permeability (~10^{-16} m^2)
  - Crystalline basement rocks
  - Favorable stress regime
  - Favorable land status
  - Favorable infrastructure
  - Willing partners / land owners

Methods/Approach

- Land status secure
  - Naval Air Station Fallon (NASF)
  - Ormat leased and owned land
  - 4.5 km^2 FORGE site
  - 40 km^2 monitoring area
- Existing infrastructure
- Regional geologic setting
- Abundant available data
  - Geologic
  - Geochemical
  - Geophysical
- Temperatures
- Permeability
- Potential crystalline targets and reservoirs
- No hydrothermal system – attempts to develop have failed

Why Fallon?



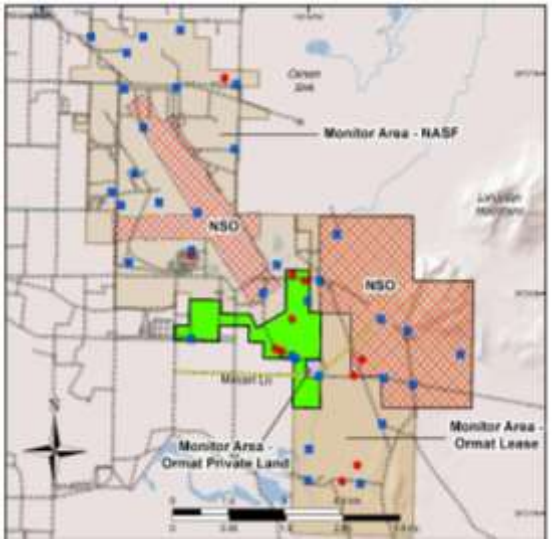
Technical Accomplishments and Progress

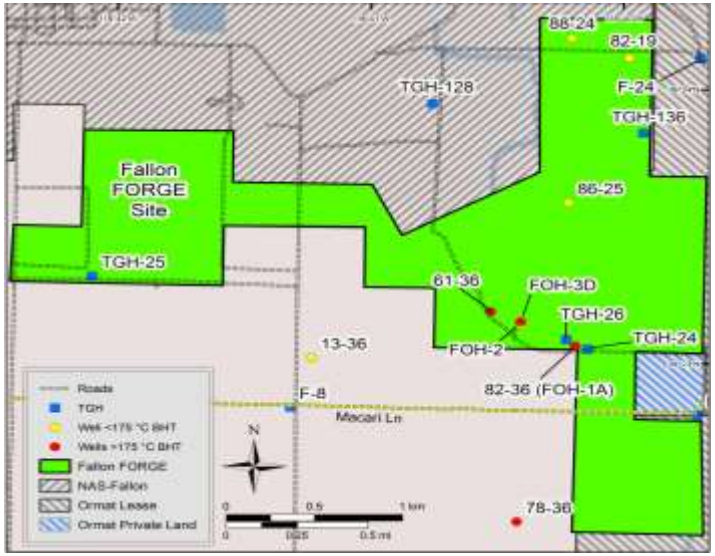
- Synthesize extensive site specific data from many wells, geophysical data and regional geologic and seismic data.
- Developed a robust geologic model for the FORGE project area.
- Completed a Preliminary ISMP, upgraded an existing network, initiated the Final ISMP.
- Completed plans for Fallon FORGE activities (ES&H, R&D, Data Dissemination, ...)
- Developed strategy and initiated the process for obtaining NEPA approval through Phase 3.
- Detailed assessment of the site and surrounding infrastructure.
- Developed well design and plan for Phase 2B well; permitting underway, drilled this year
- Performed ground magnetic survey of the Fallon FORGE site and surrounding area.
- Reprocessed existing seismic lines for improved resolution.
- Initiated additional gravity surveys.
- Integrate high-precision geodetic data with InSAR for background information.
- Continued refinement of the geologic model as new data become available.
- Development of the geomechanical model of the site and initiation of analyses to support well placement, stimulation scenarios and micro-seismicity predictions.
- Extensive outreach activities.
- Presentation of important results at GRC, SGW, ...

Technical Accomplishments and Progress

Analyzed Existing Well Data

- 46 Geothermal and TG wells
  - 12 geothermal wells
  - 34 temperature-gradient wells
  - 7 geothermal wells, 4 TG holes on FORGE site
  - 5 geothermal wells, 30 TG holes on NASF and Ormat monitoring areas

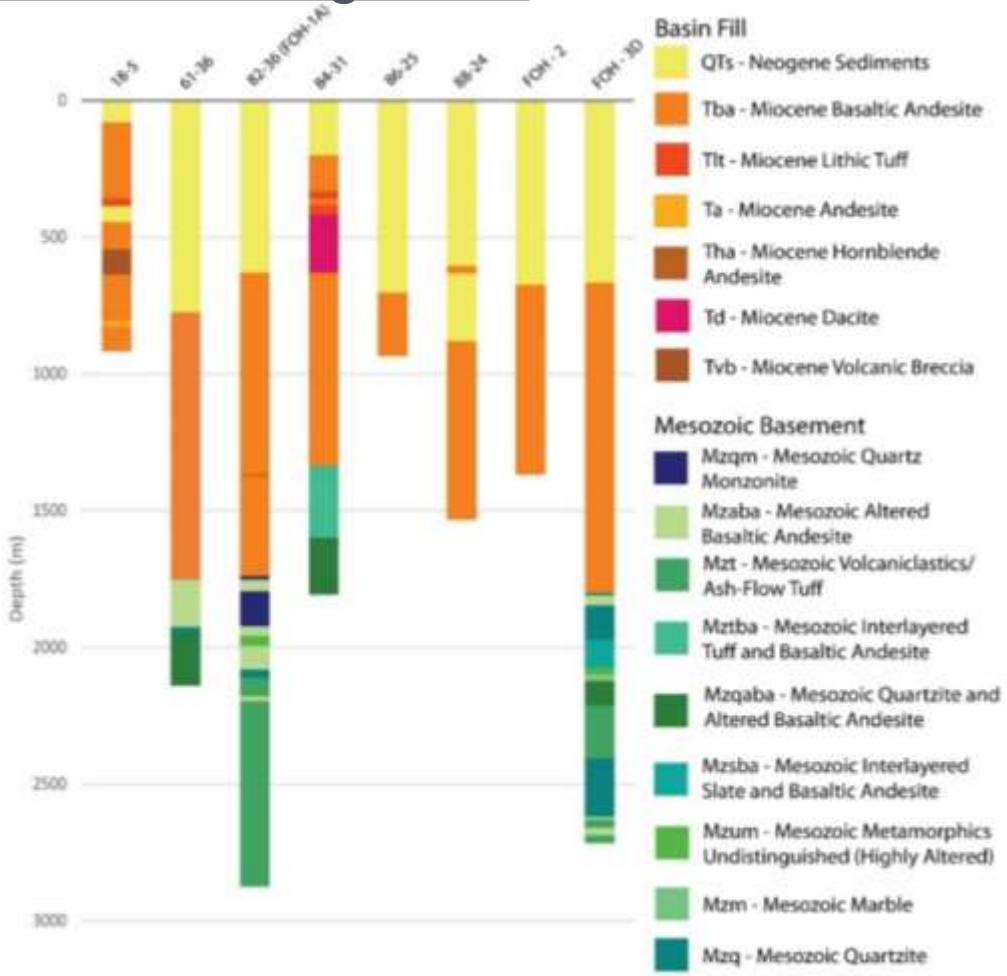




- Reviewed 14,135 m of core and cuttings, and thin sections of core and cutting samples from 6 wells on the FORGE site and 2 wells on the monitor area
- Reviewed an additional ~20,000 m of core and cuttings from another 8 wells in the surrounding area
- Assessed lithology and degree and type of alteration

Stratigraphic Interpretation From Existing Wells

- 8 Wells, FORGE site and monitor areas
- QTs – Late Miocene to Quaternary basin fill, 0.1 to 1.4 km thick
- Tvs – Miocene volcanic rocks, 0.7 to 1.1 km thick
- Mesozoic Basement, top at 1.3 to 1.8 km depth below ground surface, includes:
  - Meta-tuffs
  - Quartzite
  - Meta-basalt
  - Granite
  - Slate
  - Marble

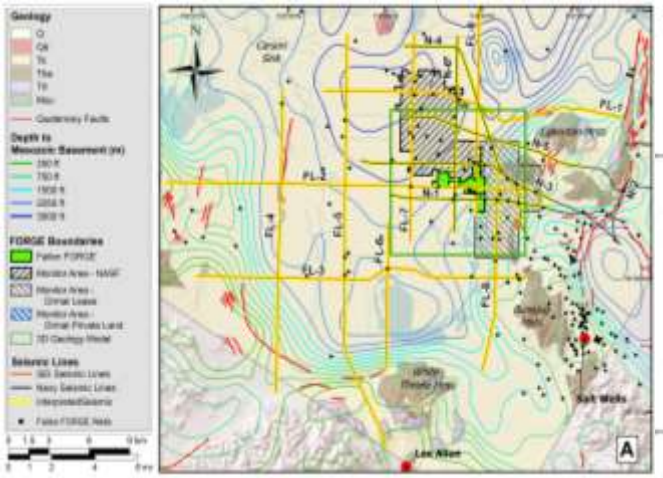


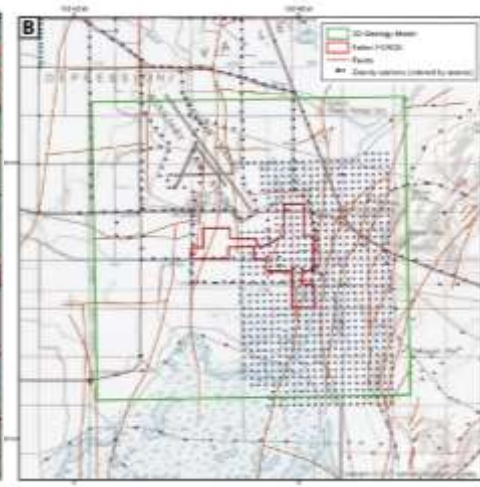
3 WELLS ABOVE IN BASEMENT WITHIN FORGE BOUNDARY

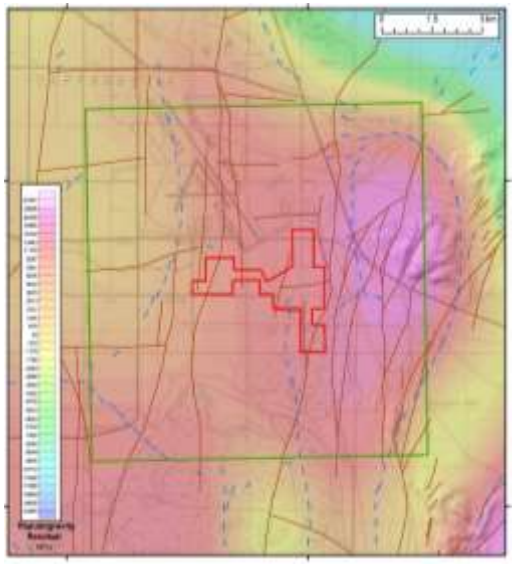
Technical Accomplishments and Progress

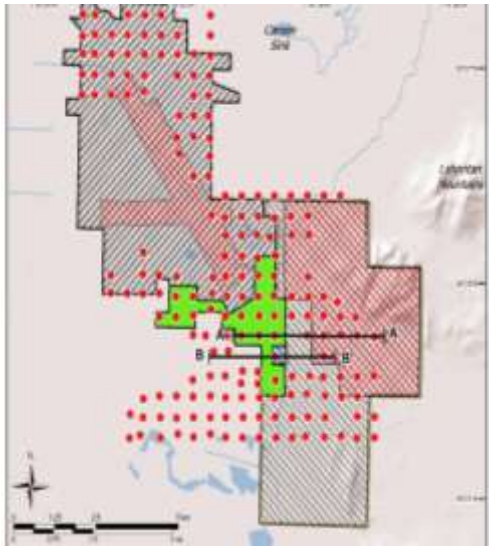
Interpretation of Existing Geophysical Data

- 2D Seismic reflection analysis
  - 270 km, 14 profiles from Navy (1994) and Seismic Exchange (70's-80's)
- Fallon area/site gravity
  - Carson Sink at 400, 800, and 1600 m intervals (2013), eastern part of FORGE site at 200 m (2007)
- Aeromag (1970s)
  - Regional
- Detailed MT (2013)
  - Fugro – contract to Navy GPO





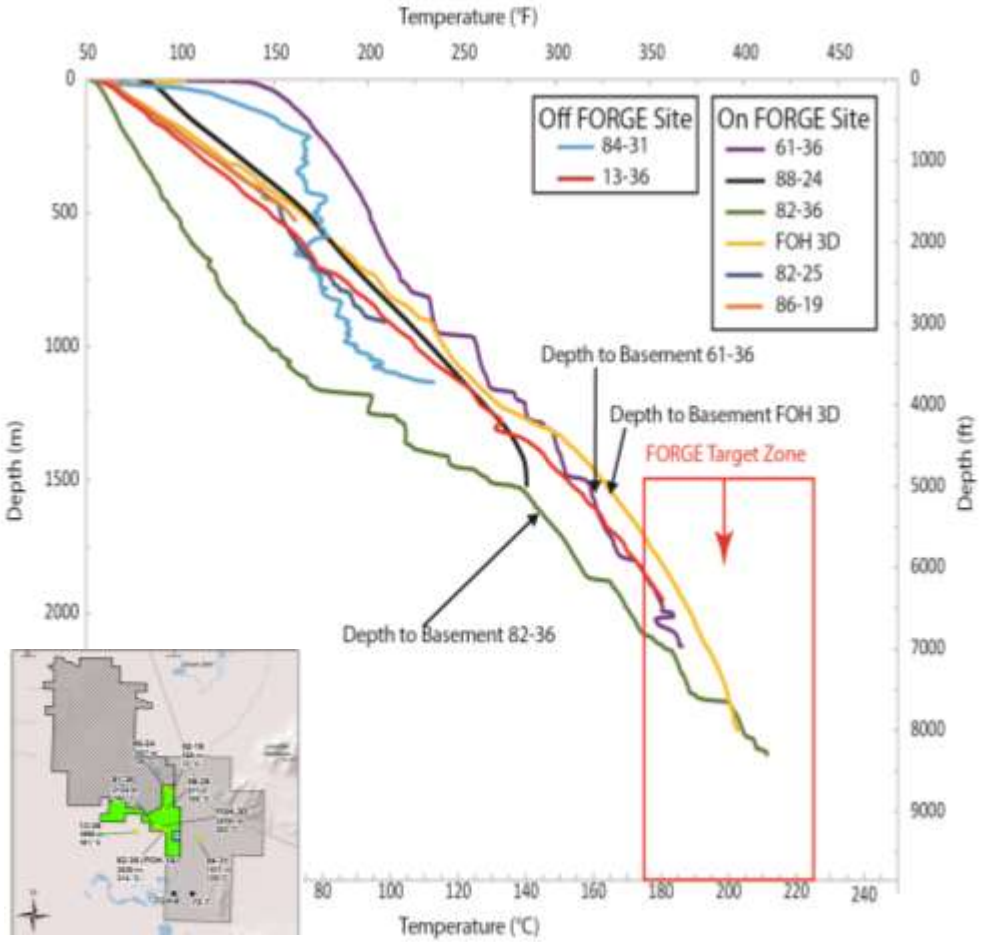




Technical Accomplishments and Progress

Temperature Gradient Review

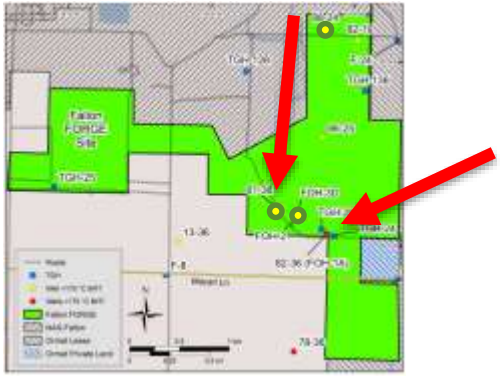
- Deeper levels (>1500 m) – similar linear paths indicate conductive thermal regime
- Gradient ~75-80^{o}C/km
- Steps in Miocene-Pliocene sections suggest some fluid flow at shallow depths
- FORGE depth and temperature criteria met at Fallon site



Technical Accomplishments and Progress

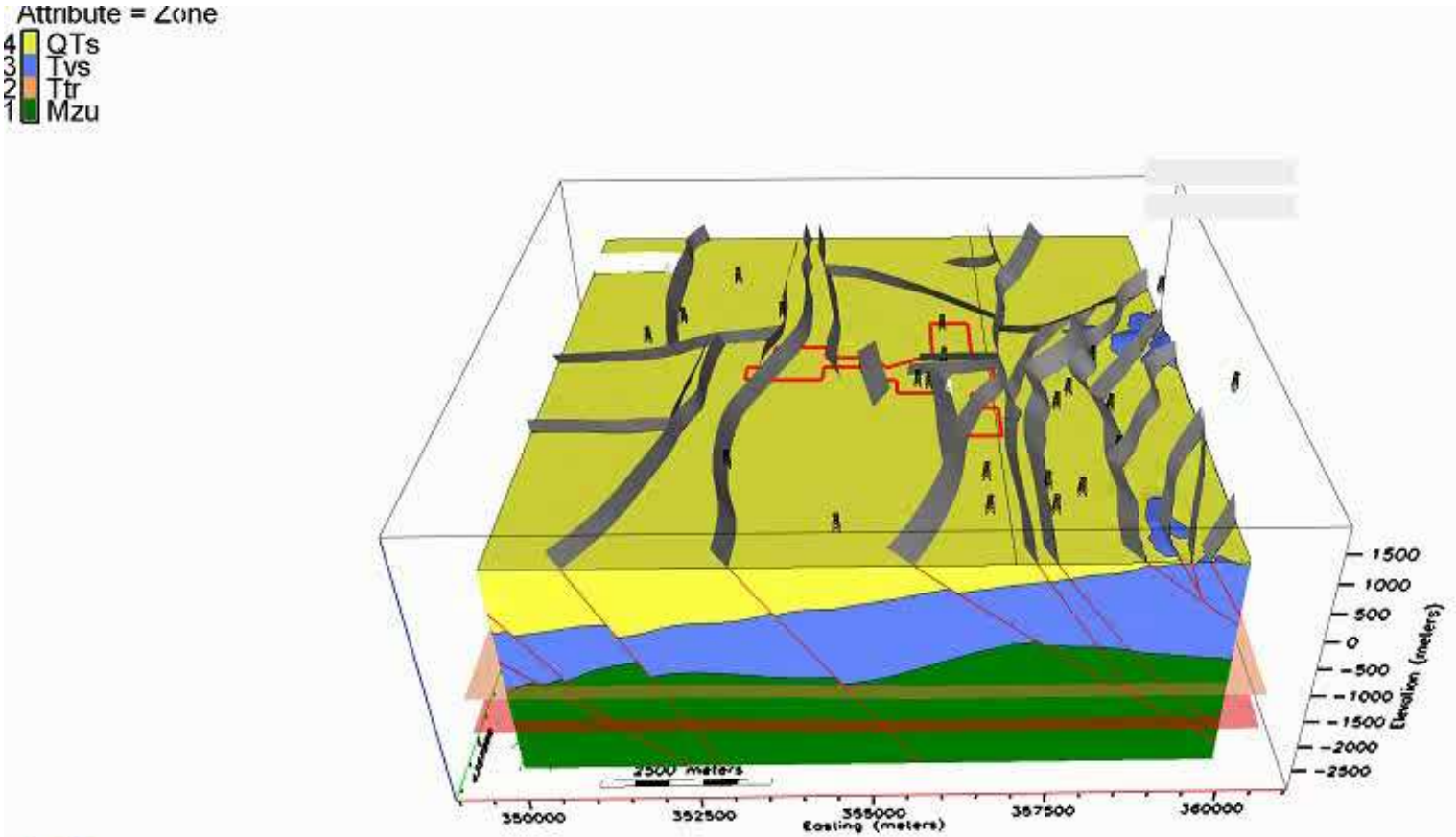
Well Test Review

- Results – low injectivity (<1 gpm/psi)
- Insufficient permeability for production flow rates
- Low permeability FORGE criteria met within Fallon site



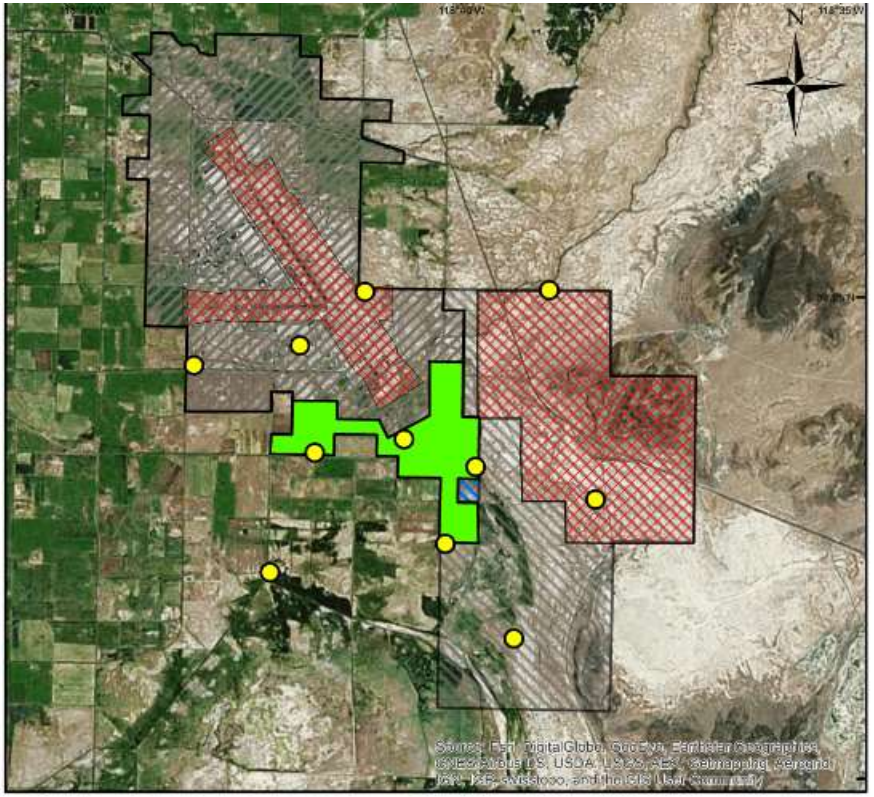
Exploration Hole		82-36	61-36	88-24	86-25	82-19
Depth (ft) Depth (m)		8301.0 2530	6970.9 2125	5000 1530	3000 930	1735 529
Injection Test	gpm/psi	0.27	0.62	9.50	1	1-9.5
	lpm/kPa	0.14	0.34	5.22	0.55	0.55-5.22
Artesian	Temp (°F/°C)	231/110.6	195/90.6	170/76.7	n/a	n/a
	Max Flow (gpm/lpm)	30/113.6	30/113.6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

Technical Accomplishments and Progress



Seismic Monitoring & ISMP

- Upgraded 10 borehole array operating since 11/1 /16
  - 300-foot holes / 3-component geophones
  - Sensitivity down to Magnitude -1
  - 500 samples/sec, 24 bit resolution
  - New Nanometrics electronics
  - Telemetered to Berkeley
- Preliminary ISMP completed
- Full ISMP in development
  - Following “Protocol” and “Best Practices”



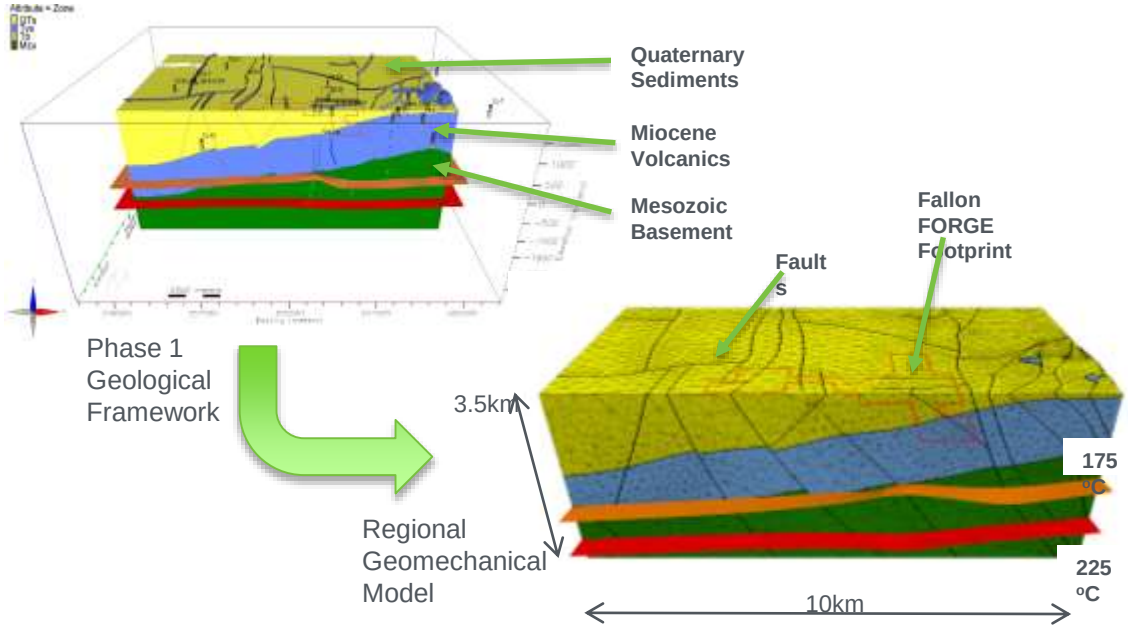
https://www.fallonforge.org/

or

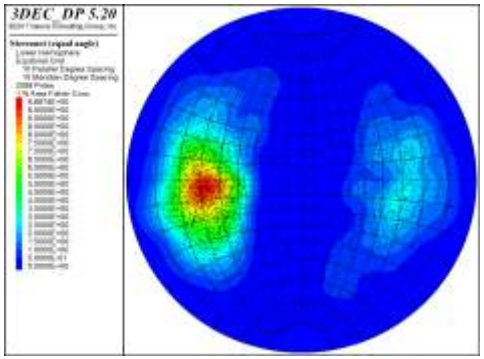
http://esd1.lbl.gov/research/projects/induced_seismicity/egs/

Technical Accomplishments and Progress

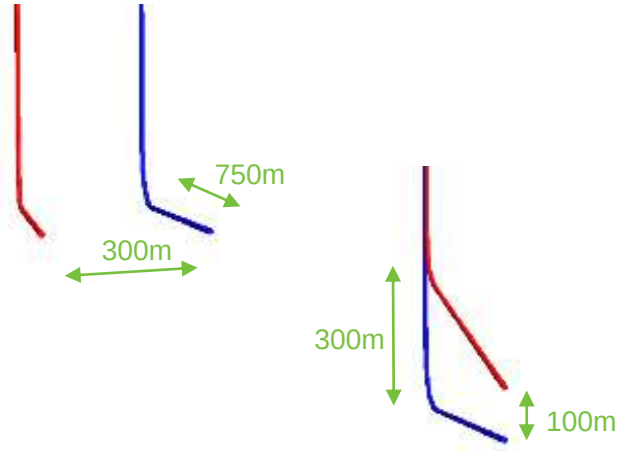
Geomechanical Model Development



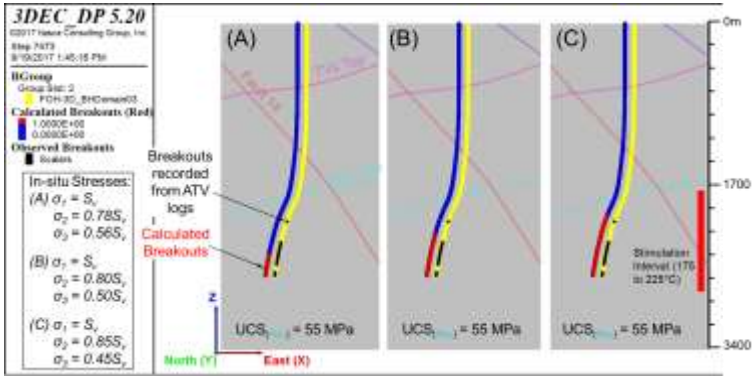
Hydro-Shearing Capability



Well Alignment



Stress magnitude assessment



Research Collaboration and Technology Transfer

- Papers and presentations at 2015/16/17 GRC Annual Meetings & 2016/17 Stanford Geothermal Workshops
- Continued interactions with AIST (Japan) / ETH (Switzerland) / BGRM (France) / broader community
- Expansion of team as project progressed
- State of Nevada highly engaged – Office of Energy is contributing funds to the Phase 2B exploration hole.
- Extensive interactions with DOD & NAS Fallon and FORGE operational agreements have been established.

Research Collaboration and Technology Transfer

Established strong relationships with and garnered enthusiastic support from community, local, state, and federal leaders, including:

- Mayor, City of Fallon; City Engineer/Director of Public Works
- County Manager, Churchill County
- Superintendent, Churchill County School District
- Executive Director, Churchill County Economic Development Authority
- Tribal Chairman and Council, Fallon Paiute-Shoshone Tribe
- Nevada State Assemblymember Robin Titus; Nevada State Senators James Settelmeyer and Pat Spearman
- Nevada Governor's Office of Energy; Nevada Governor's Office of Economic Development; Nevada Division of Minerals
- Offices of U.S. Senators Dean Heller and Catherine Cortez Masto; Rep. Mark Amodei (District and DC staff)

Participated in events to raise awareness about the benefits of the Fallon FORGE initiative:

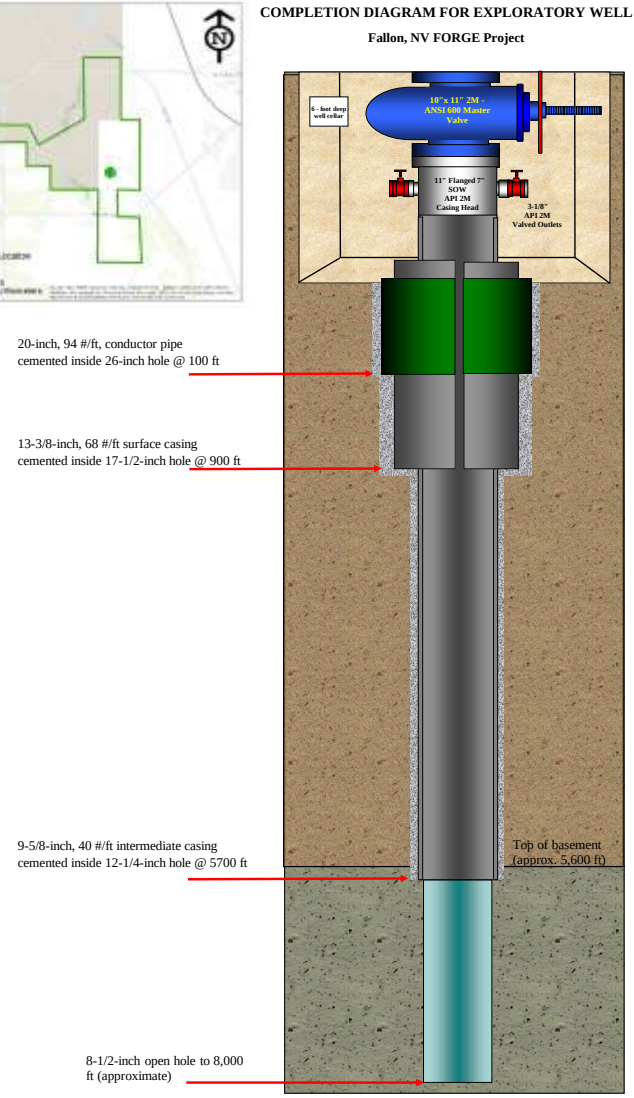
- Tabled at Geothermal Day at the Nevada State Capitol – spoke with policymakers about importance of EGS
- Tabled at Fallon Cantaloupe Festival – spoke with hundreds of community members about the initiative
- At her request, provided tour of Fallon FORGE site to Senator Catherine Cortez Masto

Developed connections to support education and outreach programs in the community:

- Churchill County Museum and Archives – interested in partnering to develop exhibits around EGS, including access to research information (i.e., data monitoring stations, adult learning and project update presentations)
- Lawrence Hall of Science – world-renowned science education experts will help develop afterschool STEM and in-classroom learning curricula
- William N. Pennington Life Center – interested in serving as resource for community to learn about Fallon FORGE

Future Directions

- Complete Phase 2B activities
  - Complete ISMP
  - Move NEPA approval forward
  - Complete Additional Exploration Well and conduct testing
  - Continue refinement of geologic and geomechanics models
- Phase 2C
  - Establish to STAT
  - Ready the site for Phase 3 (Drill monitoring wells)
  - Continue Characterization
  - Establish high resolution microseismic systems in monitoring holes
  - Continue geologic / geomechanical model development
  - Implement FORGE node to NGDS
- Phase 3
  - Operate the site and work with DOE to coordinate research for the benefit of the Nation



Mandatory Summary Slide

FORGE is being developed by DOE for the community to do the scientific and engineering R&D needed to enable EGS development.

- The Fallon FORGE project has assembled a strong, multi-disciplinary team to execute the requirements of the project.
- The selection of the Fallon FORGE site was a natural evolution of more than a decade of geothermal exploration work conducted by the Navy GPO and Ormat.
- Abundant existing data has been reviewed and synthesized and new data is being obtained to supplement the geologic and geomechanics models.
- Communications and outreach is more important than many of us as researchers may appreciate.
- Will complete Phase 2B work and look forward to the opportunity to move into later Phases.