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Newberry Volcano 2014 EGS Flowback Sampling

Evaluation of Stimulation at Newberry Volcano EGS Demo Site Through Natural Isotopic Reactive Tracers and Geochemical Investigation

Project Officer: Lauren Boyd

Total Project Funding: $250,000.

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Lawrence Berkeley National Lab

Track 4: EGS2

Relevance/Impact of Research

Team Members: Nicolas Spycher, John Christensen, Shaun Brown, Mark Conrad, Mack Kennedy, Li Yang (all at LBNL), AltaRock Energy (Grasso, Cladouhos)

Objectives: To constrain THMC models of the Newberry Volcano EGS stimulation using geochemical and isotopic data, combined with modeling and multicomponent geothermometry

- Principal barriers to EGS commercialization: Creating, sustaining and reducing the cost of reservoirs
  - *Evaluation of chemical and isotopic changes associated with mechanical effects (e.g., shear failure) on fracture permeability will allow for better techniques to reduce costs*
- Benefits: Improved characterization of fracture surface area generated during stimulation. Improve predictions of fracture permeability changes from mineral precipitation/dissolution to optimize production.
- Relevance: EGS require fracture generation as well as fluid injection to extract energy. Continued fluid injection, coupled to changes in the stress regime owing to temperature and pressure changes, leads to permeability changes via mechanical, chemical, and mechano-chemical processes. This project is directly tied to the Newberry EGS Demonstration Project, collecting and using geochemical/isotpic data to constrain THMC models of stimulation

Impacts to following Geothermal Technologies Programs' goals:

EGS: Improved characterization of fracture surface area generated during stimulation. Improved predictions of fracture permeability changes from mineral precipitation to optimize production.

Goal: Provide independent constraints on model of reservoir conductivity at an EGS system demonstration project, using novel isotopic systems and modeling/analysis methodologies

Relevance/Impact of Research

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Project Innovations:

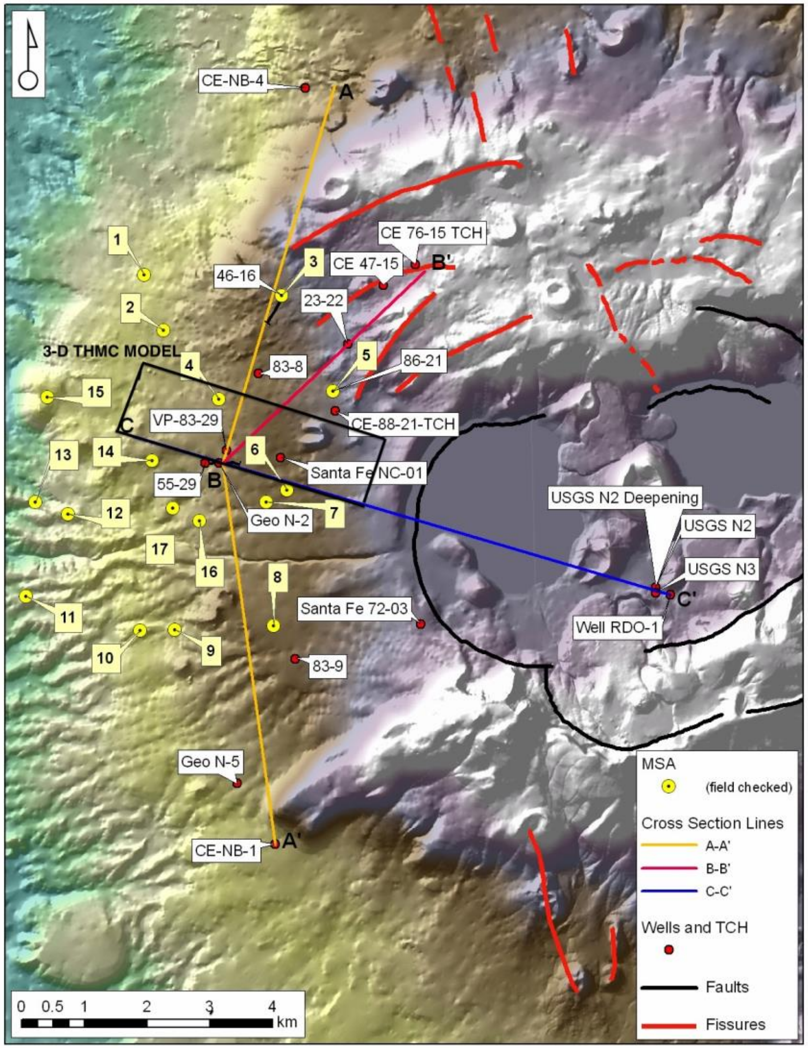
- Ca, Sr, and Li are commonly analyzed in geothermal waters for tracing water sources, mixing processes, and in geothermometry. Nontraditional isotopic systems (e.g. Li, Ca) can add to this range of processes. Ca and Sr isotopes were measured in stimulation flowback waters from Newberry Volcano (Ca for the first time measured at an EGS site) and are providing valuable information on rates and types of mineral-water reactions. Li isotopes are planned to be analyzed, which will also be new for EGS, and can yield rates of clay or other phyllosilicate mineral formation in fractures.
- A new geothermometry technique using oxygen isotopes in sulfate and water was used to determine simulated fracture zone temperatures
- A new multicomponent geothermometry code (GeoT) was used to determine stimulated fracture zone temperatures and constrain important mineral-water-gas reactions
- He isotopic measurements along with geochemical and isotopic data on waters and gases will help constrain the effective fracture porosity, based on mixing of injected groundwater and in-situ magmatic/geothermal water
- Quantitative incorporation of geochemical and isotopic systems into THMC models using the new TOUGHREACT-ROCMECH code and a novel solid-solution approach for isotopic modeling, with comparison to hydrological, thermal, geophysical, geochemical and isotopic data sets is providing unique constraints on reservoir properties and stimulation processes

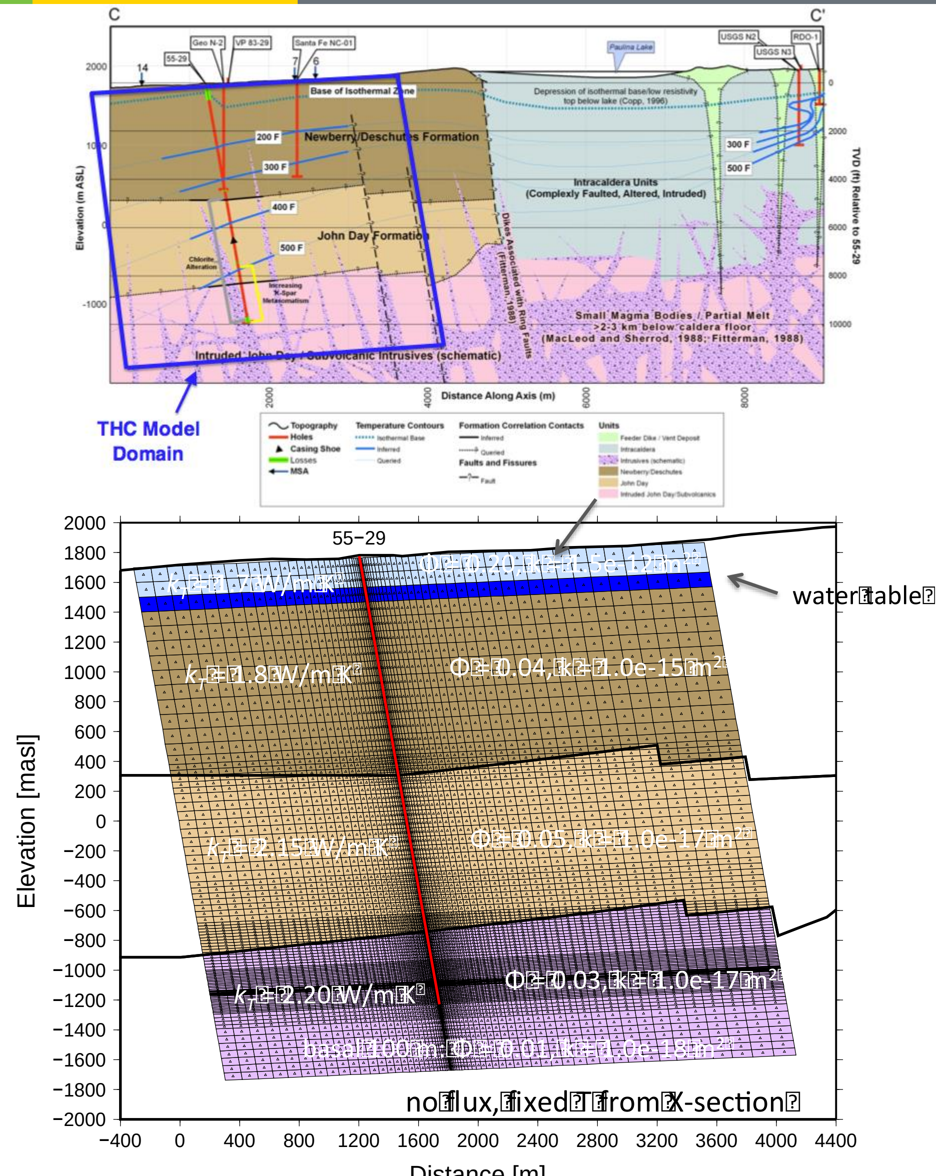
Scientific/Technical Approach

1. Sample fluids and gases during flowback after injection (Sonnenthal, Grasso at AltaRock)
2. Filtered samples for anions. 2. Filtered/acidified samples for cations, Sr, Ca, and Li isotopes. 3. Evacuated bottles for gases. 4. Copper tubes for He isotopes and noble gases. 5. Specially filtered and prepared samples for oxygen (in water and sulfate), hydrogen and sulfur isotopes
3. Perform ICP-MS, ICP-OES for cations, anions, trace metals (Yang)
4. Gas analyses (Thermochem)
5. Mass spectrometry for He and other noble gas isotopes (Kennedy)
6. Mass spectrometry for Ca, Sr, Li isotopes (Brown, Christensen)
7. Mass spectrometry for stable O, H, S isotopes (Conrad)
8. Multicomponent geothermometry using GeoT code, and empirical geothermometery on waters, gases (Spycher, Sonnenthal)
9. Use measured groundwater and injected water chemistry as inputs to THMC modeling using TOUGHREACT V3-OMP and TOUGHREACT-ROCMECH (3-D modeling primarily done as part of other projects)

Flowback samples and filter papers collected from Oct. 23-24 flowback

Newberry Volcano EGS 3-D THMC Model





Flowback Water Chemistry
Oct. 23-24, 2014

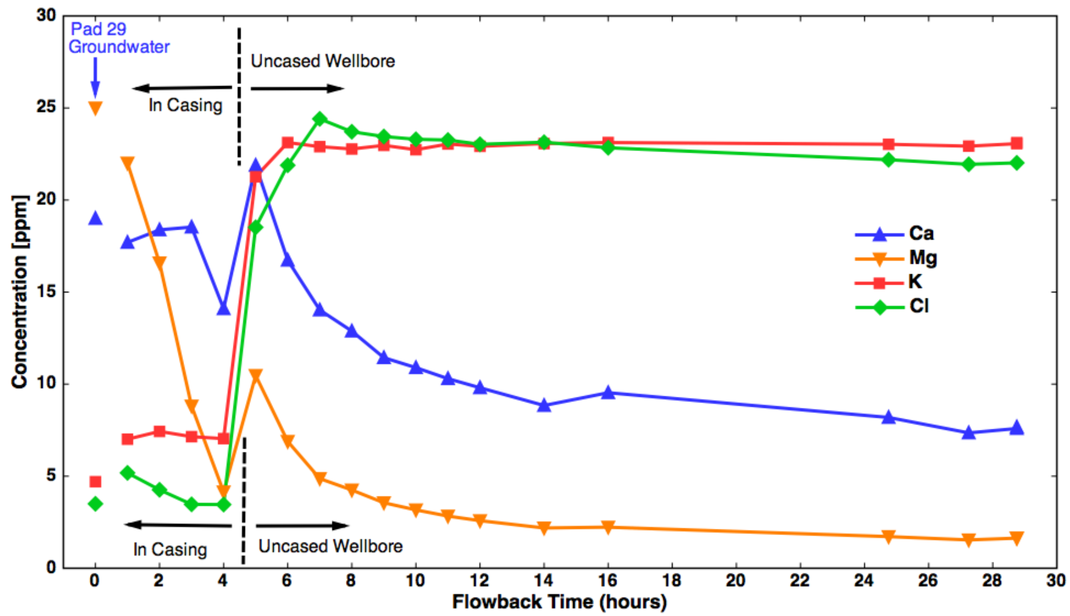
> Flowback waters show systematic trends over time from heated groundwater in the cased interval to water-rock reaction and mixing with in-situ water in the open well

> Sharp increase in Cl indicates mixing of injected groundwater with a small amount of more saline *in-situ* geothermal/magmatic fluid (with He R/Ra ~ 8)

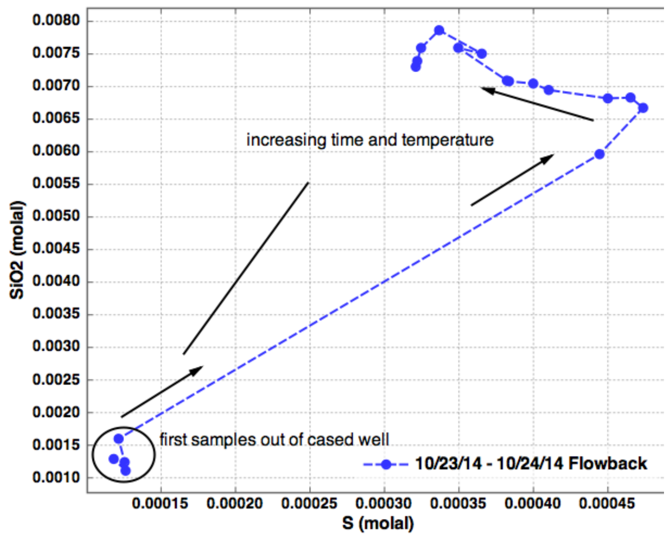
> Sharp increase in K indicates reactions with feldspars

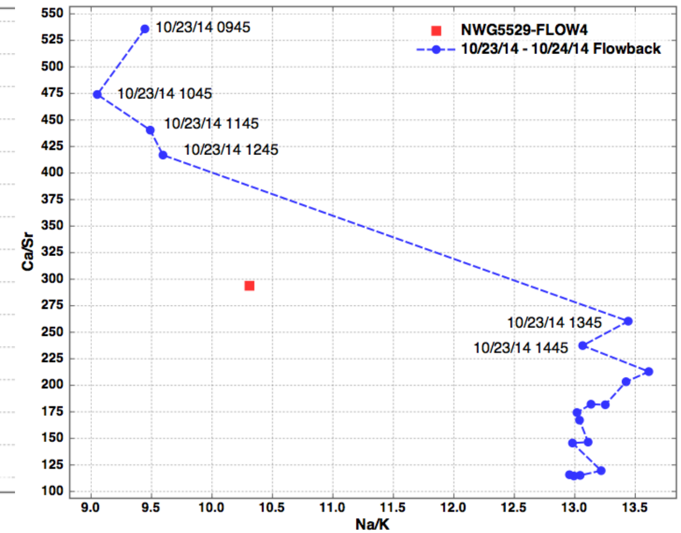
> Increases in Ca, followed by a sharp decline reflect calcite dissolution and precipitation at higher temperatures

> Mg declines likely a result of amorphous Mg-silicate precipitation during groundwater heating in casing, precipitatation of chlorite in rock, followed by redissolution in casing during flowback

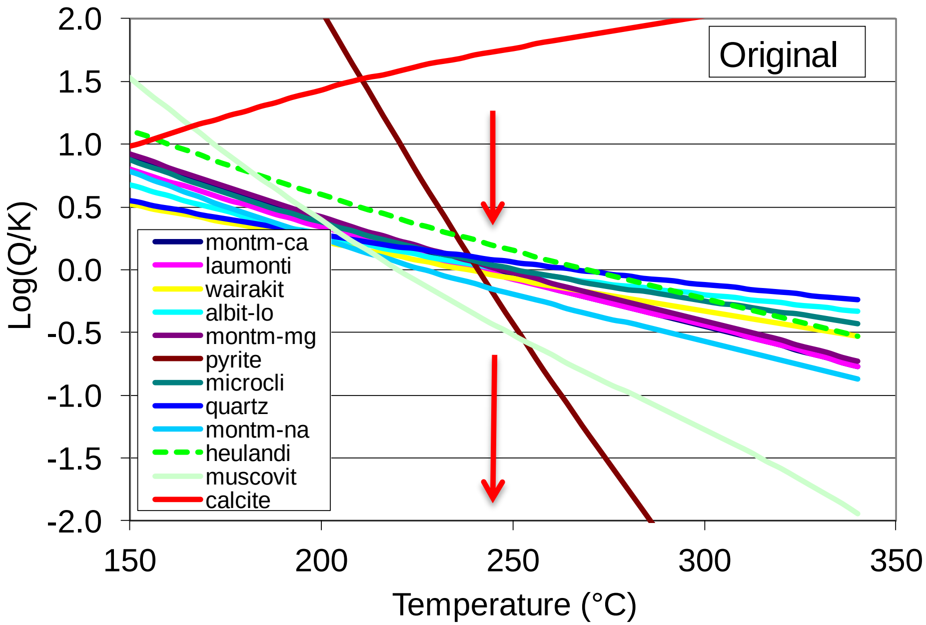


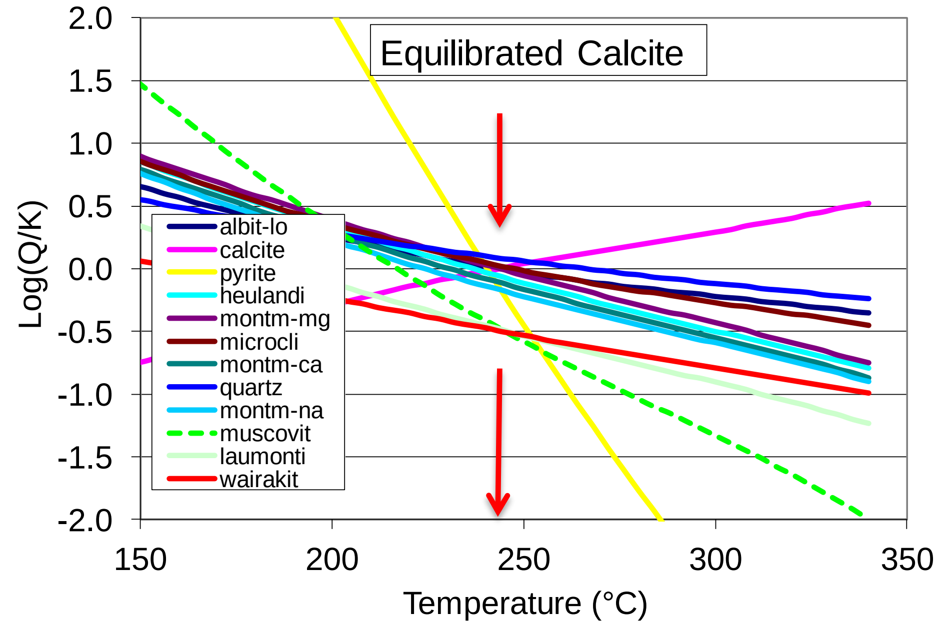
- **Silica and sulfur are low and similar to groundwater in the first 4 samples out of the cased interval in the well**
- **Silica in the open well sharply increases owing to reactions wih quartz and feldspars**
- **Total sulfur increases sharply due to reactions with pyrite & sulfides but then decreases, possibly because deeper rocks have less pyrite**
- **Ca/Sr vs Na/K show trends due to calcite dissolution/precipitation and feldspar reactions in the rock**





Multicomponent Geothermometry using GeoT on Flowback Waters





- Use 2nd before last collected water (near end of first flowback)
- Estimated T around 240-250° C using realistic minerals - *where curves cross log (Q/K) = 0.0*
  - HS- taken as difference between total S and SO_4^{-2} (~56 uM)
  - Minor correction to HCO_3^- for charge balance (~7.5 vs 7.2 mM)
  - Assume Al from equilibration with albite (~15 vs 0.66 uM)
- Large supersaturation wrt calcite (chlorite also hugely above saturation)
  - Adjust Ca for calcite saturation (~39 vs 20 uM) and HCO_3^- for charge balance (~7.1 vs 7.2 mM)
  - Adding CO_2 without changing Ca yields unrealistically high HCO_3^-

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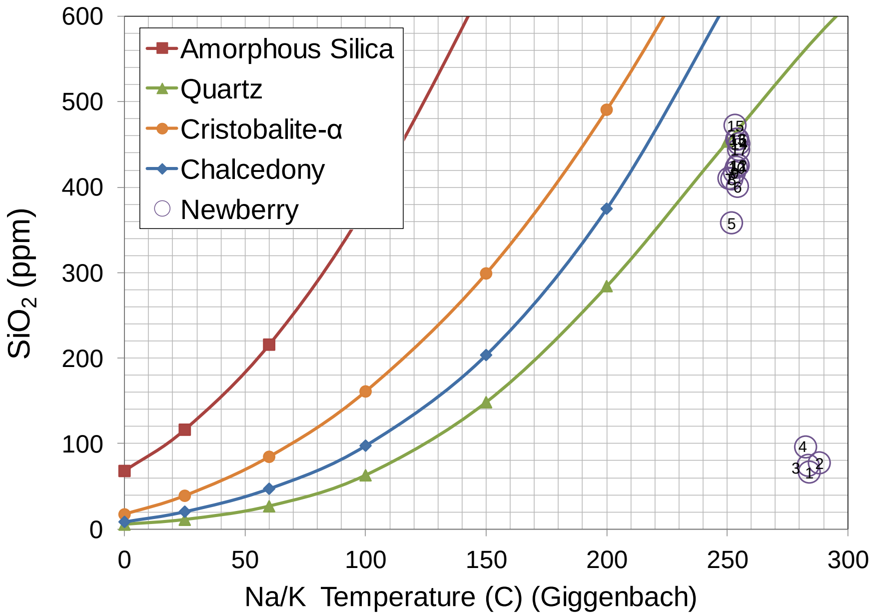
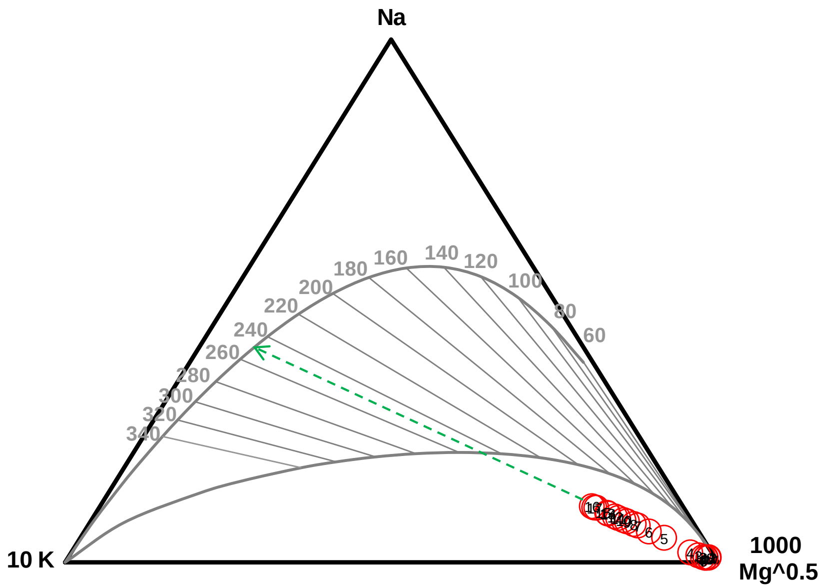
Empirical Geothermometry on Flowback Waters





- Later samples show consistent Na/K and quartz temperatures around 250 C (left plot)
- Early waters (lower right in plot at left) are far from equilibrium (injection water from cased hole)
- Giggenbach Na-K-Mg geothermometer (right plot) shows “immature” waters evolving with time towards equilibrium temperature ~250 C
- Remarkably constant Na/K ratio in flowback waters indicating strong control of feldspar reactions in stimulated fractures

Accomplishments, Results and Progress

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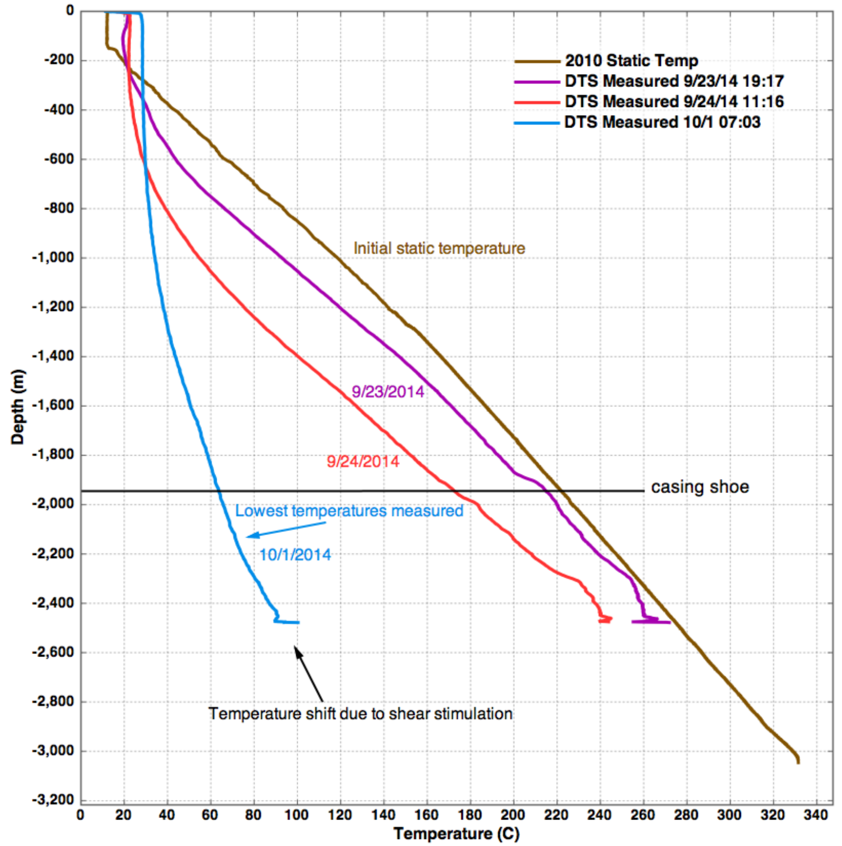
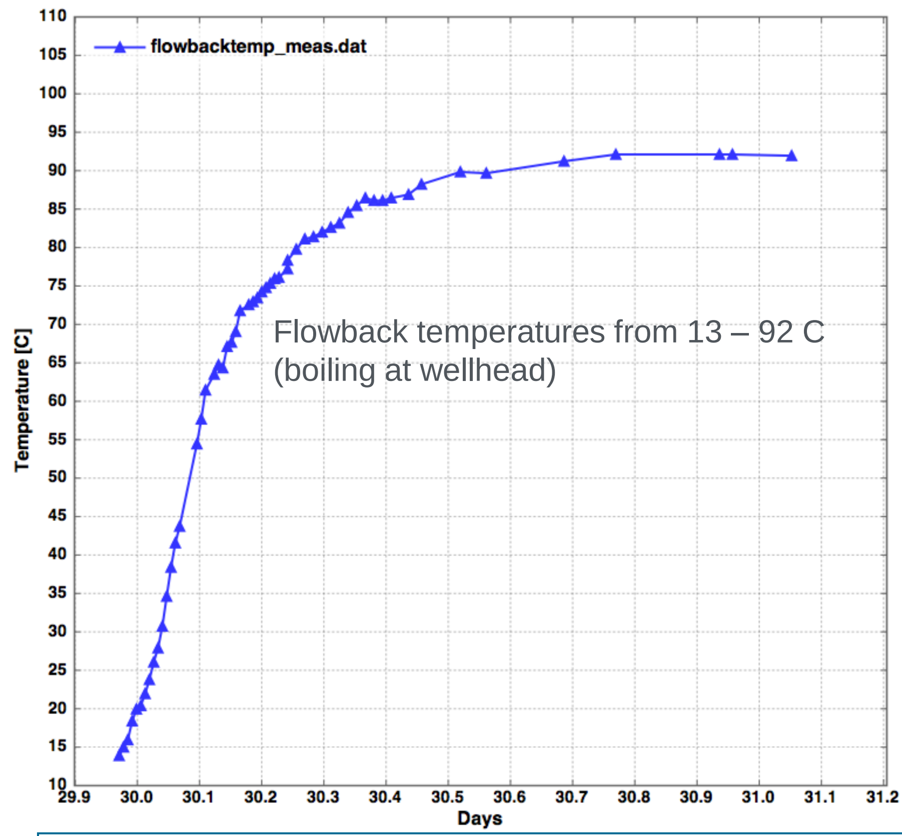
Measured Wellbore (DTS) and Flowback Temperatures



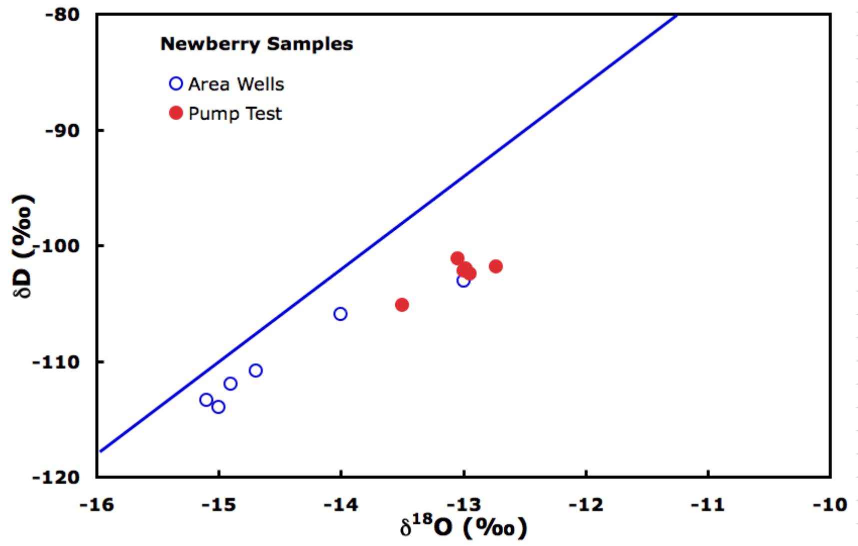


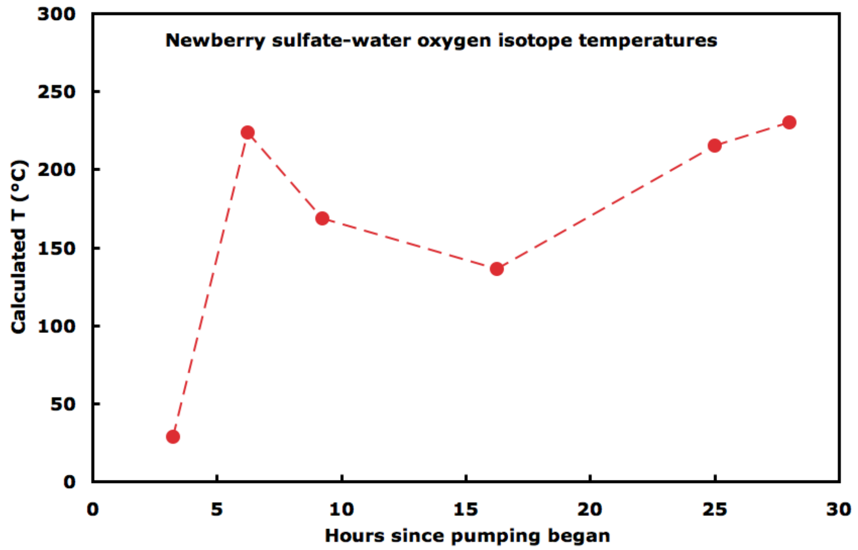
- Temperature range of open hole from 220 – 330 C
- Wellbore temperatures at maximum flow rates are depressed by at least 200 C in the reservoir center (2400 m below surface) during stimulation

- Geothermometry of flowback water much higher than flowback temperatures indicating water-rock equilibration at slightly less (~240-250 C) than the mean open hole (~ 275 C)
- Also higher than wellbore temperatures during injection (left plot) indicating water-rock interaction in stimulated rock fractures outside the wellbore in deeper zones

Oxygen and Hydrogen Isotopes in Water and Sulfate

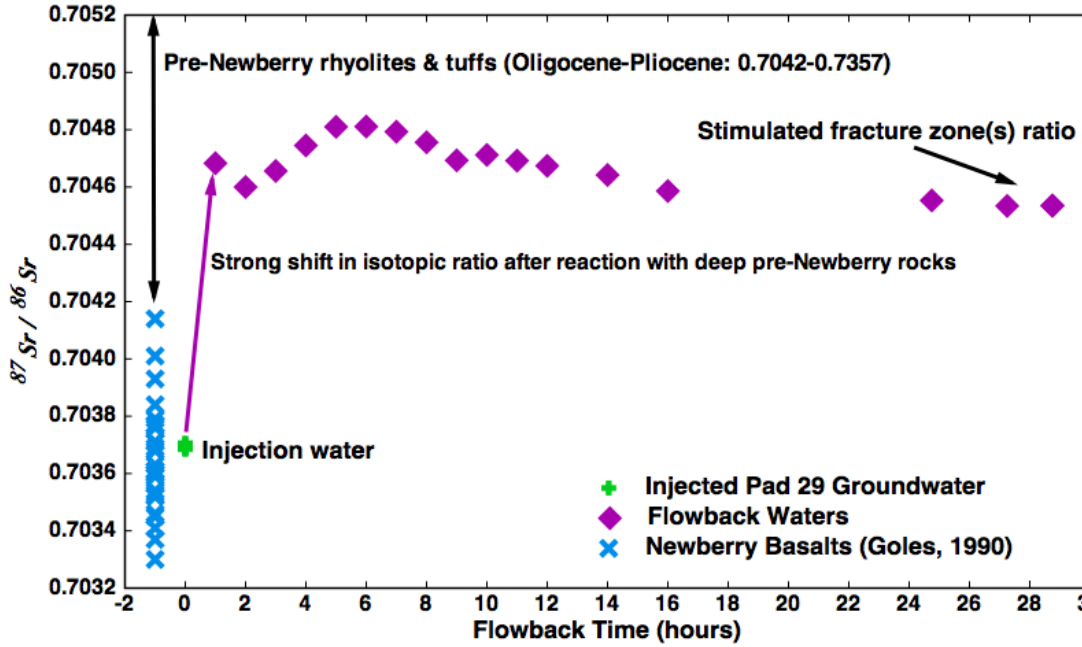
- $\delta^{18}O$ and δD on flowback water samples (red) compared to groundwaters (blue) in plot at upper right
- Red data point furthest to the left is the early sample (before return of water from below the casing). Other samples are all shifted to the right, away from the meteoric water line, likely indicating some vapor loss due to boiling or a shift due to water-rock interaction, but shift in in δD suggests vapor loss
- Calculated sulfate-water oxygen isotope temperatures plotted versus time (lower right)
- Calculated temperature starts from sample in casing at low temperature, then jumps up ~220° C, drops down to <150° C then increase up to 230° C in the last sample
- High temperature of last sample consistent with multicomponent and Na-K geothermometers (240-250 C)

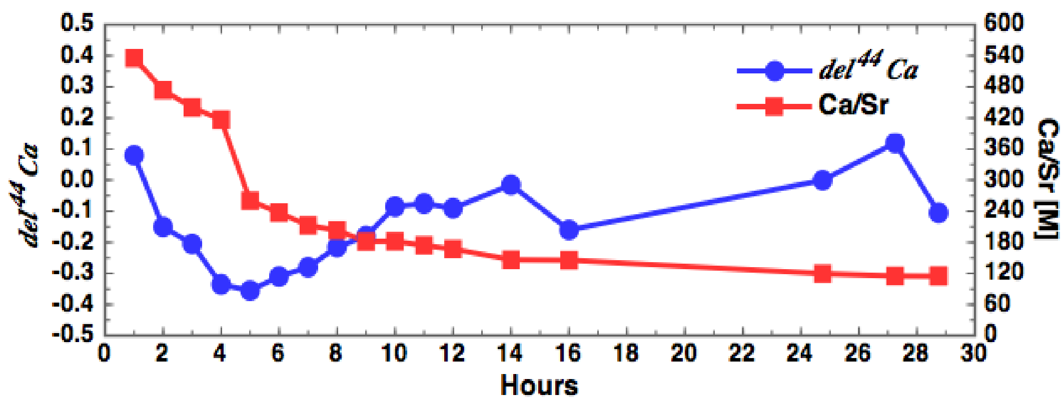




Newberry Volcano EGS Sr & Ca Isotopes

- $^{87}Sr/^{86}Sr$ and $^{44}Ca/^{40}Ca$ measured on 1st set of flowback waters (after 3 week injection and 1 week shut-in period)
- Injected groundwater has $^{87}Sr/^{86}Sr$ ratio close to mean of all surface rocks
- Flowback waters show sharp increase to higher ratios only seen in much older pre-Newberry silicic rocks (e.g., Smith Rocks, Rattlesnake tuff)
- $\delta^{44}Ca$ values show trends related to calcite dissolution/precipitation
- Ca/Sr concentration ratios show a similar early drop suggesting calcite and silicate dissolution/precipitation
- *Isotopic ratios at later times should reflect rocks with higher Sr concentrations and reactivity in main stimulated fracture zones*
- Models are not well-constrained yet owing to unknown deep rock Sr and Ca isotopic ratios
- Will need to measure isotopic ratios in chip samples from deep volcanic and intrusive rocks





Accomplishments, Results and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
1.1 Collection of samples from 2012 Stimulation	No waters were flowed back in 2012, so only groundwaters were analyzed	Completed for Sr isotopes 5/2013; $\delta^{44}Ca$ underway
1.2 Collection of samples from 2014 Stimulation	Collected water and gas samples for all measurements Oct – Nov 2014	11/2014
1.3 Analyze water samples for major cations, anions, trace metals	90% of samples complete	3/2015
1.4 He isotopes and noble gases	Completed	1/2015
1.5 Sr isotopes	Completed on first set	1/2015
1.6 Ca isotopes	Completed on first set	3/2015
1.7 O, H isotopes on sulfate and water	Completed	3/2015
1.8 Gas samples (from evacuated glass bottles)	Completed	3/2015
1.9 Li isotopes on water samples	Underway	not completed
2.0 Multicomponent Geothermometry	Completed on first set	3/2015
2.1 Develop inputs for THMC Models	Just started since samples are still being analyzed	not completed

Future Directions

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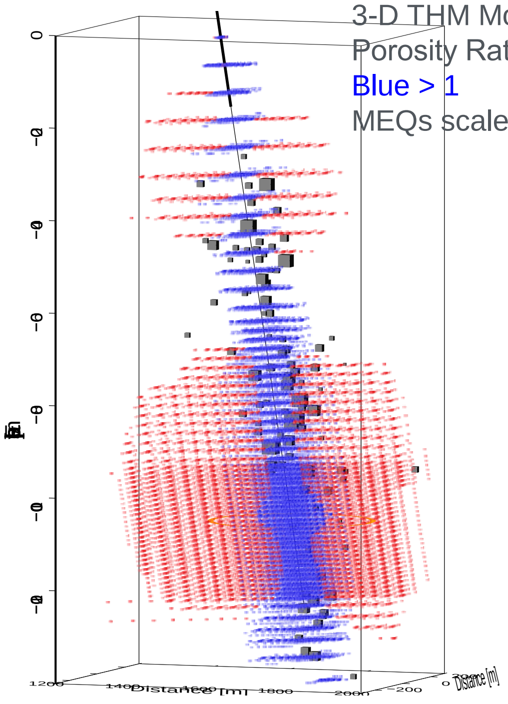
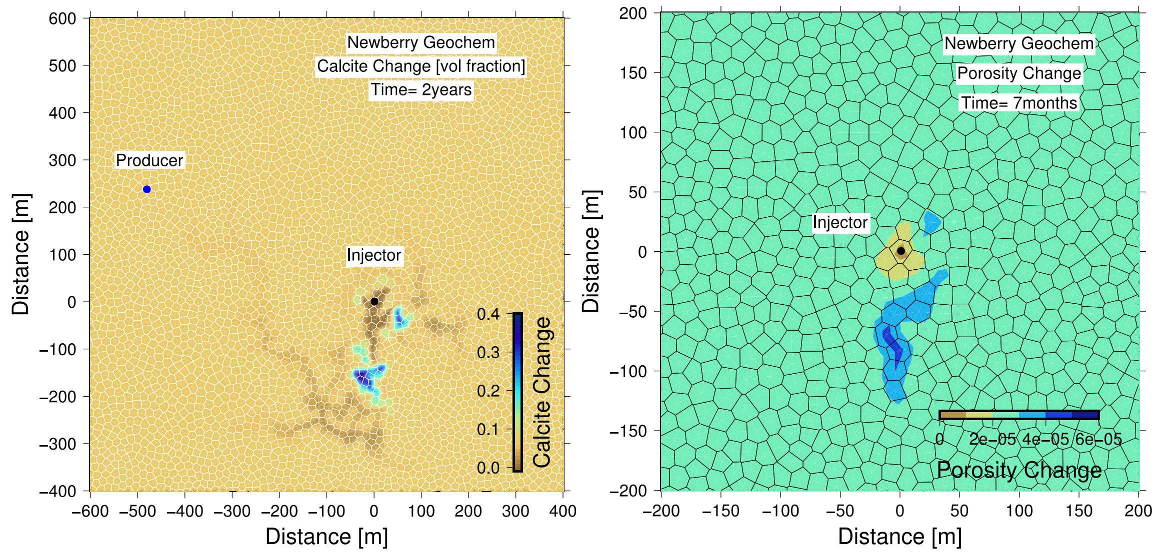
- Outcome of this work will be a set of high quality geochemical and isotopic data that forms the basis for the coupled THMC models (figures below) being applied to Newberry EGS analyses and predictions with improved decision-making for well locations, stimulation strategies, production rates, and sustainability
- Research in FY2015 will include the following, plus considerations for future work having the most impact on EGS goals:
- Complete geochemical and isotopic analyses on all remaining flowback samples
- XRD of filter papers to look at mineral precipitates
- GeoT analyses of November flowback data, and set-up of geochemical inputs for THMC models
- Future work should be aimed at doing flow-through experiments at reservoir temperatures on rock chips from potential stimulated zones to compare to sampled waters in order to pinpoint highest permeability zones and spatial extent of stimulation



3-D THM Model at 9 Days
Porosity Ratio (ϕ/ϕ_0)
Blue > 1 Red < 1
MEQs scaled by mag.

2-D THC heterogeneous permeability model of Newberry EGS with Injector-Producer showing regions of calcite precipitation and dissolution after 2 years injection/production and induced porosity changes (after 7 months)



Future Directions (Cont.)

- Future work should be aimed at:
- Flow-through experiments at reservoir temperatures on rock chips from potential stimulated zones to compare to sampled waters in order to pinpoint highest permeability zones and spatial extent of stimulation
- If a production well is drilled and stimulation takes place in 2015, efforts should be focused on planning and sampling to best evaluate the injector-producer connectivity, stimulated volume, and potentially chemical stimulation methods

Milestone or Go/No-Go	Status & Expected Completion Date
1. Flow-through experiments at reservoir temperatures on rock chips from potential stimulated zones to compare to sampled waters in order to pinpoint highest permeability zones and spatial extent of stimulation. Go/No-Go. Depends on availability of funding for new experiments. If no new funding, then continue focusing on developing inputs for THMC models	Have some experimental equipment from experiments on Desert Peak tuffs, but no expected start or completion date for this new work
2. Submit data to GDR	Collection of all data about 75% complete. 9/30/2015
3. Submit paper on Newberry stimulation geochemistry and modeling	THMC Model inputs about 60% complete. 9/30/2015
4. Collect and analyze samples from production well. Go/No-Go. Depends on outcome of Stage-Gate Review and funding for new sampling and analyses.	No decision yet of drilling. No project yet for for continued sampling/analyses.

Summary

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- Flowback waters from the Newberry Volcano EGS were collected in Oct. 2014 and analyzed for water and gas chemistry, O, H, He, Sr and Ca isotopes (Li isotopes planned)
- First flowback shows a systemic trend from heated groundwater to waters showing significant water-rock reaction and mixing with in-situ “magmatic-hydrothermal” water
- Multicomponent, empirical and isotopic ($\delta^{18}O$ in SO_4-H_2O) geothermometers all indicate water-rock equilibration at temperatures in the range of 230–250° C
- This is much higher than the maximum temperatures of flowback waters (~ 90° C), and possibly higher than the highest temperatures in the wellbore during the periods of maximum sustained injection, suggesting water-rock interaction outside the wellbore in stimulated fracture zones
- $^{87}Sr/^{86}Sr$ isotopes of groundwaters in center of range of surface basalts
- Strong shifts in the flowback $^{87}Sr/^{86}Sr$ ratios to more radiogenic values than the groundwater or any rocks from Newberry Volcano, indicate reactions with pre-Newberry (Oligocene-Pliocene) silicic volcanics that outcrop in central-eastern Oregon
- Observed shifts in Ca & Sr isotopic ratios, and water/gas chemistry indicate calcite dissolution/precipitation in the wellbore and in the rock mass
- Sulfide (mostly pyrite) reactions with injected groundwater led to increased S and transition metals
- Drops in Mg due to chlorite and potentially amorphous Mg-silicate precipitation
- $^3He/^4He$ of R/Ra > 8 shows significant interaction with magmatic fluids, which will help constrain stimulated fracture porosity
- THMC models under development to include new geochemical and isotope data
- Geochemical and isotopic data will provide strong constraints on the extent of fracture surface area contacted by fluids, reservoir properties, and help pinpoint stimulated zones

Additional Information

Publications:

Cladouhos, T., Petty, S. Swyer, M.W., Uddenberg, M.E., Grasso, K. Nordin, Y., Sonnenthal, E.L., Smith, J.T., Kim, J. *Newberry Volcano EGS Demonstration Results 2011-2015*. (submitted to Geothermics).

Smith, J.T., Sonnenthal, E.L., Cladouhos, T. *Thermal-Hydrological-Mechanical Modelling of Shear Stimulation at Newberry Volcano, Oregon*. (ARMA, accepted).

Kim J., Sonnenthal, E., and Rutqvist, J., 2015. *A sequential implicit algorithm of chemo-thermo-poro-mechanics for fractured geothermal reservoirs*, Computers & Geosciences, 76, 59-71.

Spycher, N., Peiffer, L., Sonnenthal, E.L., Saldi, G., Reed, M.H., Kennedy, B.M., 2014. *Integrated multicomponent solute geothermometry*. Geothermics 51, 113–123.

Keynote and Invited Presentations:

Sonnenthal, E.L., 2014. *TOUGHREACT: A Numerical Laboratory for Investigating Multiphase Flow and Reactive Transport in Geothermal Systems*. Keynote Presentation, New Zealand Geothermal Workshop, November, 2014.

Sonnenthal, E.L., 2013. *Multicontinuum approach for modeling multiphase reactive geochemical and isotopic transport in geothermal systems*, in: AGU Fall Meeting Abstracts. p. 5. Invited.

Conference Presentations:

Sonnenthal, E.L., J.T. Smith, T. Cladouhos, J. Kim and L. Yang, 2015. *Thermal-Hydrological-Mechanical-Chemical Modeling of the 2014 EGS Stimulation Experiment at Newberry Volcano, Oregon*. PROCEEDINGS, Fourtieth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 26-28, 2015, SGP-TR-204.

Sonnenthal, E.L., S. Nakagawa, J. Christensen, C. Wanner, and S. Nakashima, 2015. *Geochemical and Isotopic Constraints on Fracture Surface Area: Experiments and Reactive Transport Modeling*. PROCEEDINGS, Fourtieth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 26-28, 2015, SGP-TR-204.

Wanner, C. E. Sonnenthal, S. Nakagawa, S. Brown, J. Christensen, J. Icenhower, 2014b. *Tracking geothermal reservoir stimulation by Li isotope fractionation*. Goldschmidt 2014, Sacramento, CA.