THERMAL ENERGY EXTRACTION FROM A GEOTHERMAL RESERVOIR: NUMERICAL AND ANALYTICAL MODELING ANALYSIS

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ACKNOWLEDGEMENTS

Collaborators (PoroTomo Team):

- Lawrence Berkeley National Laboratory
- University of Nevada, Reno
- Colorado School of Mines
- Temple University
- ORMAT Technologies, Inc.

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Cardiff: EAR-1654649 “CAREER: Understanding transport processes in fractured sedimentary rock through multi-frequency and multi-method investigations”
• PoroTomo Overview
• Study Area
• Thermal Characterization
• Hydraulic Characterization
• Conclusions
• Future Work
Big Picture Question:
• Can we constrain the thermal sustainability of a geothermal reservoir?

First Order Questions:
• Can we estimate the relevant thermal and hydraulic reservoir properties?
• How does fluid move through the reservoir?
Poroelastic Tomography by Adjoint Inverse Modeling of Data from Seismology, Geodesy, and Hydrology

• Project Objective
  • “…assess an integrated technology for characterizing and monitoring changes in the rock mechanical properties of an EGS reservoir in three dimensions with a spatial resolution better than 50 meters.”
  (http://geoscience.wisc.edu/feigl/porotomo/)
Brady Geothermal Field
• 75 km NE of Reno
• NE-SW trending high angle normal faults
• Shallow sedimentary units
• Deeper volcanic units
Borehole DTS

- Sampling interval
  - Spatial – 0.12 [m]
  - Temporal – 60 [s]
- Borehole temperature recovery
- Inverted geotherm below 260 m

Adapted from Patterson et al., [2017]
**Thermal Characterization**

**Borehole schematic**
- Vertical temperature profile along borehole
- Radial heat diffusion into borehole
- Fluid filled and cased portion of borehole (~125 – 300 m depth)
- Conceptual model for numerical heat transfer model

*Patterson et al., [2017]*
Parameter estimation results:

- Thermal diffusivity depth profile
- Major changes correlated with lithologic changes
- Estimated diffusivity lower than lab reported values

Patterson et al., [2017]
Adapted from Feigl and Team, [2018]
Evidence for fault-driven groundwater flow:
• Borehole advection

Adapted from Patterson et al., [2017]
Evidence for fault-driven groundwater flow:
• Borehole advection
• Ground subsidence

Adapted from Reinisch et al., [In Review]
Evidence for fault-driven groundwater flow:
• Borehole advection
• Ground subsidence
• Hydrothermal Deposits

Adapted from Miller et al., [2018]
Hydraulic Characterization

Groundwater Flow Model
- 7 km x 13 km x 6 km
- Discretization
- 3 Hydraulic Property Zones
- Zoned Parameter Estimation
HYDRAULIC CHARACTERIZATION

Drawdown [m] vs. Date [UTC]

- Drawdown [m]
  - Mar 14
  - Mar 15
  - Mar 16
  - Mar 17
  - Mar 18

- Date [UTC]
  - Mar 2016

A

B

C

2018 GSA - NORTH CENTRAL SECTION
## Hydraulic Characterization

<table>
<thead>
<tr>
<th>Lithology</th>
<th>K [m/s]</th>
<th>$S_z$ [m$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedimentary</td>
<td>$4.1 \times 10^{-2}$</td>
<td>$7.0 \times 10^{-8}$</td>
</tr>
<tr>
<td>Volcanic</td>
<td>$2.7 \times 10^{-4}$</td>
<td>$3.5 \times 10^{-8}$</td>
</tr>
<tr>
<td>Fault</td>
<td>$1.7 \times 10^{-8}$</td>
<td>$1.8 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

Parameter estimates indicate:

- Specific storage estimates indicate confined behavior.
- Faults may act as barrier to flow.
HYDRAULIC CHARACTERIZATION

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<th>Lithology</th>
<th>K [m/s]</th>
<th>S_z [m⁻¹]</th>
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</thead>
<tbody>
<tr>
<td>Sedimentary</td>
<td>4.1 x 10⁻²</td>
<td>7.0 x 10⁻⁸</td>
</tr>
<tr>
<td>Volcanic</td>
<td>2.7 x 10⁻⁴</td>
<td>3.5 x 10⁻⁸</td>
</tr>
<tr>
<td>Fault</td>
<td>1.7 x 10⁻⁸</td>
<td>1.8 x 10⁻⁶</td>
</tr>
</tbody>
</table>

Two component fault zone
- Low permeability fault core
- Higher permeability damage zone

Adapted from Bense et al., [2013]
Plan View (100 m depth)

- Advective transport from injection well
- Flow paths show planar flow following fault traces
FLOW CHARACTERIZATION

Elevation [masl]

1035 1055 1075 1095 1115 1135 1155

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PoroTomo Y [m]

1000 m
• Thermal characterization determines thermal diffusivity estimates which are consistent with expected values based on rock types.

• Hydraulic characterization implies individual faults act as barriers to groundwater flow

• Geophysical, visual observations, and advective transport simulations indicate fault-driven groundwater flow system.
FUTURE WORK

Analytical Modeling
- Energy consumed vs energy produced?
- Hydraulically active faults?
- Parameter sensitivity?
Questions?