Characterizing Fractures in the Geysers Geothermal Field by Micro-seismic Data, Using Soft Computing, Fractals, and Shear Wave Anisotropy

Fred Aminzadeh
University of Southern California
DOE Grant DE-FOA-0000075-23

May, 2010

This presentation does not contain any proprietary confidential, or otherwise restricted information.
Project Team

USC
Fred Aminzadeh (PI)
Mo Sahimi (Petroleum Engineering)
Charles Sammis (Earth Sciences)

LBNL
Ernie Majer
Leon Thomsen

Calpine
Mark Walters
### Project Timeline and Budget

#### Budget

<table>
<thead>
<tr>
<th>DOE Funding</th>
<th>$1,500K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matching and other External Funding</td>
<td></td>
</tr>
<tr>
<td>USC</td>
<td>$200K</td>
</tr>
<tr>
<td>Calpine</td>
<td>$300K</td>
</tr>
<tr>
<td>Total</td>
<td>$2,000K</td>
</tr>
</tbody>
</table>

#### Project Timeline

<table>
<thead>
<tr>
<th>Time</th>
<th>Q1-2010</th>
<th>Q2-2010</th>
<th>Q3-2010</th>
<th>Q4-2010</th>
<th>Q1-2011</th>
<th>Q2-2011</th>
<th>Q3-2011</th>
<th>Q4-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Evaluation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anisotropy (i)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fractal (ii)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neurofuzzy (iii)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neurofuzzy (iiib)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neurofuzzy (iiic)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Project Starts
- Decision Point
- Project Completes
The Geysers, California

- Low permeability

- Determine if fracturing could be used to enhance permeability, and whether dilution of existing fluids with injected water would lower corrosivity enough to allow economic production of power

- Municipal wastewater

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Location</th>
<th>Technology Description</th>
<th>Well Depth (meters)</th>
<th>Temperature (Celsius)</th>
<th>Resource Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Geysers Geothermal Area</td>
<td>North of San Francisco, California</td>
<td>The world’s largest dry-steam geothermal steam field hosts 22 power plants with capacities ranging from 20 to 120 MWe, producing a net total of over 750 MWe.</td>
<td>650-3350</td>
<td>240°-250°</td>
<td>Hydrothermal Dry Steam</td>
</tr>
</tbody>
</table>
More subtle faults and fractures will require application of our soft computing-based techniques, exploiting their anisotropic and fractal behavior that will help their identification and mapping.
Northwest-southeast cross-section through the Geysers geothermal field

2002 MEQ hypocenters, injection wells, power plants, and top of the high temperature zone (HTZ) (Stark, 2003)

Noticeable distribution of the seismicity below and around the injection wells
Develop Neuro-Fuzzy Process for Picking MEQ Events

Create Reservoir Image (Velocity Field / Faults)

Create Fractures Spatial Distribution Map

Develop An Understanding of Anisotropy

Monitor Changes Created by the Injection of Cold Water into Hot Water, already Fractured Rock.
Use of Soft Computing to analyze passive seismic data

Neuro-Fuzzy Auto-Picker

Pick the Subtle MEQs Events

Improve the Efficiency of the Process

Compressional velocity fields

Simultaneous analysis of shear wave and P-wave data

fuzzy relationships between the shear wave velocities for different rock types

Z_P = 5, Z_s = 2.75

sand,immature = 0.13, \mu_{sand,mature}=0.5, \mu_{conglomerate}=0.37
MEQs events overlaid on the velocity model for the 38.843 latitude section

MEQ location overlaid on velocity model

DEPTH

LONGITUDE

-122.85 -122.84 -122.83 -122.82 -122.81 -122.8 -122.79 -122.78

0 1 2 3 4 5 6 7 8 9

6.5 6 5.5 5 4.5 4 3.5 3 2.5 2

U.S. DEPARTMENT OF
ENERGY
Energy Efficiency & Renewable Energy

eere.energy.gov
Using microseismicity to map the fractal structure of the fracture network

Injection-induced seismicity at the Geysers geothermal field is the result of shear failure on critically stressed fractures caused by the reduction of normal stress associated with thermal contraction.

Field Observation

Geomechanical Modeling

Injection-induced seismicity at the Geysers geothermal field is the result of shear failure on critically stressed fractures caused by the reduction of normal stress associated with thermal contraction.

spatial analysis

Locations of induced events
Sizes of induced events
source mechanism of induced events

Structure of the fracture network in the Geysers reservoir
Anisotropic Velocity Tomography

- Form initial isotropic P-velocity field, MEQs locations are determined.
- The error-ellipsoids for each location are calculated.
- Refinements to the velocity field are driven by these error-ellipsoids.
- Refined error-ellipsoids for each location are calculated.
- A lower symmetry of anisotropy is selected (e.g., Tilted orthorhombic).
- Refinements to the anisotropic velocity field (i.e., distributions of anisotropic parameters) are driven by the error-ellipsoids.
- Refined error-ellipsoids for each location are calculated.
- Steps 5-8 are repeated until no significant further precision in the locations is achieved.

If data quality permits, the distribution of S-wave anisotropic parameters will be estimated, following a similar program but also taking advantage of the special phenomena of shear-wave splitting.
Number of micro-seismic events in each year at the Geyser
Distribution of MEQ events at the Geyser for the years 2006 - 2009

MEQ location data within specified depth, location & time frame

- Cap
- Normal Temperature Reservoir ~240°C
- High Temperature Zone (HTZ) ~350°C
Cluster centers for all the years at the HTZ zone.

Fuzzy Cluster Centers for 5 chosen zones

- Cap
- Normal Temperature Reservoir
- High Temperature Zone (HTZ)

- ~240°C
- ~350°C
Cluster center movement from 2006 to 2009

Direction of fuzzy cluster centers movement (2006 to 2009)

- **Cap**
- **Normal Temperature Reservoir** ~240°C
- **High Temperature Zone (HTZ)** ~350°C