Geothermal Exploration Case Studies on OpenEI

Stanford Geothermal Workshop
Palo Alto, California

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**OVERVIEW**

**Project Goal**
Assemble information in a way that allows experts to:
- Explore and analyze data and information
- Identify correlations among successful exploration programs
- Guide efficient exploration of new systems.

**Presentation Outline**
Project History
Case Study Template
  - Narratives
  - Data Tables
  - Exploration Activity Catalog
  - NEPA Analysis Collection
Example Case Studies
Geothermal Case Studies Challenge
Potential Future Directions
  - Navigation and Usability
  - Adding New Concepts/Content
  - Analysis and Analytical Features

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**OpenEI**
Open Energy Information
- Public collaborative, knowledge-sharing platform
- Provides free and open access to energy-related data, models, tools, and information
- Sponsored by the DOE in support of the White House’s Open Government Initiative

**Wiki Platform**
- Utilizes same underlying technology as Wikipedia
- Enables users to view, edit, add and download data
- Allows the assignment of queryable properties via semantic links
- Creates relationships automatically between pages
- Permits querying and exporting of data, similar to a database, in universal formats such as RDF and CSV
- Includes a variety of data display formats including maps, charts, graphs, and timelines

**Data Quality**
- Text and properties (data) allow citations
- Pages can be “watched” for changes, updates
- User community can help expand the data and increase accuracy

**OpenEI Statistics**
- Content Pages: 55,674
- Downloadable Datasets: 798
- Languages Used: English, Spanish
- Registered Users: 3,231
- Unique Visitors/Week: over 8,000
- Visits Last Year: 359,195
- Countries Visiting Site: 212

*per Google Analytics as of January 25, 2012*
GEOTHERMAL OPENEI - PROJECT HISTORY

2012
- Exploration Best Practices created on OpenEI
- Development of Case Studies Template
- First two case studies: Coso, Raft River

2013
- Addition of occurrence model types and data
- Development of NEPA Database, Regulatory Roadmap
- Improvements to Case Studies Template
- Complete ten additional example case studies

2014
- Develop reusable templates, review rubrics, etc. for future case studies
- Addition of Case Studies via Geothermal Case Studies Challenge
**CASE STUDY TEMPLATE**

**Narratives**
- General, Technical, Geological

**Data Tables**
- Power production, Well fields, Geology, Reservoirs, and Geochemistry

**Exploration Activity Catalog**
Catalog of exploration activities conducted in the area, including
- techniques applied
- date of the activity
- notes/comments
- reference(s)

**NEPA Analysis Collection**
Query of NEPA analyses conducted in the area (that have been catalogued in the OpenEI NEPA database), including:
- metadata (e.g., dates, offices, timelines),
- relevant documents (e.g., applications, reports, decision documents)
- potential impacts and mitigations (both industry proposed and agency imposed).
# NARRATIVES

<table>
<thead>
<tr>
<th>General</th>
<th>Technical</th>
<th>Geological</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Area Overview</td>
<td>5 Exploration History</td>
<td>9 Geology of the Area</td>
</tr>
<tr>
<td>2 History and Infrastructure</td>
<td>6 Well Field Description</td>
<td>9.1 Regional Setting</td>
</tr>
<tr>
<td>2.1 DOE Involvement</td>
<td>7 Research and Development Activities</td>
<td>9.2 Stratigraphy</td>
</tr>
<tr>
<td>2.2 Time Line</td>
<td>8 Technical Problems and Solutions</td>
<td>9.3 Structure</td>
</tr>
<tr>
<td>3 Regulatory and Environmental Issues</td>
<td></td>
<td>10 Hydrothermal System</td>
</tr>
<tr>
<td>4 Future Plans</td>
<td></td>
<td>11 Heat Source</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12 Geofluid Geochemistry</td>
</tr>
</tbody>
</table>
### Geothermal Area Profile
- Location
- Exploration Region
- GEA Development Phase
- Coordinates

### USGS Resource Estimate
- Mean Reservoir Temperature
- Estimated Reservoir Volume
- Mean Estimated Capacity

### Well Field Information
- Number of Production Wells
- Number of Injection Wells
- Number of Replacement Wells
- Average Temp of Geofluid
- Reservoir Temperature (Geothermometry-Indicated)
- Sanyal Temp Classification
- Depth to Top of Reservoir
- Depth to Bottom of Reservoir
- Average Depth to Reservoir

### Geologic Setting
- Tectonic Setting
- Controlling Structure
- Topographic Features
- Brophy Model
- Moeck-Beardsmore Play Type

### Geologic Features
- Modern Geothermal Features
- Relict Geothermal Features
- Volcanic Age
- Host Rock Age
- Host Rock Lithology
- Cap Rock Age
- Cap Rock Lithology

### Geochemistry Fields
- Salinity (low) in ppm
- Salinity (high) in ppm
- Salinity (average) in ppm
- Brine Constituents
- Water Resistivity

### Power Production Profile
- Gross Production Capacity
- Net Production Capacity
- Number of Operating Plants
- Owners
- Power Purchasers
- Other Uses
Geothermal Exploration Case Studies on OpenEI

DATA TABLE FEATURES

Geologic Features

- **Modern Geothermal Features:**
  - Fumarole

- **Relict Geothermal Features:**
  - Hydrothermal Alteration

- **Volcanic Age:**
  - Pleistocene

- **Host Rock Age:**
  - Mesozoic

- **Host Rock Lithology:**
  - Granitic

REFERENCES


CONVERSIONS

Quantity conversions on mouse-over of property values.

DESCRIPTIONS

Descriptions of properties on mouse over of blue “+”

Power Production Profile

- **Gross Production Capacity:**
  - 167.7 MW

- **Net Production Capacity:**
  - 229.3 MW

- **Owners:**
  - CoE

- **Power Purchasers:**

- **Other Uses:**

- **Depth to Top of Reservoir:**
  - 500 m

- **Depth to Bottom of Reservoir:**
  - 3500 m

- **Average Depth to Reservoir:**
  - 2000 m

Average Annual Net production [MW] delivered to the grid

- **Quantity:**
  - 2 km
  - 1.243 mi
  - 6,561.68 ft
  - 2,187.22 yd
# EXPLORATION ACTIVITY CATALOG

## Partial list from Blue Mountain Geothermal Area

<table>
<thead>
<tr>
<th>Technique</th>
<th>Exploration Basis</th>
<th>Start</th>
<th>End</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aeromagnetic Survey</strong></td>
<td>This survey was originally done as part of a mineral exploration effort. The information gained from the study was also useful when geothermal prospecting began in the area.</td>
<td>1988</td>
<td>1988</td>
<td>This aeromagnetic survey was conducted in conjunction with a very low frequency electromagnetic survey. The survey was along the western flank of Blue Mountain and covered most of the geothermal area. The magnetic contours interpreted from the data corresponded well with the major fault structures and hydrothermal alterations in the area.</td>
</tr>
<tr>
<td><strong>Dipole-Dipole Resistivity</strong></td>
<td>This survey was originally done as part of a mineral exploration effort. The information gained from the study was also useful when geothermal prospecting began in the area.</td>
<td>1988</td>
<td>1988</td>
<td>This survey was conducted by Chester Lide and Associates as part of a mineral exploration program. A dipole-dipole array with 150 m dipoles and recorded separations of N=1-7 was used.</td>
</tr>
<tr>
<td><strong>Core Holes</strong></td>
<td>Cores were taken during the drilling of Deep Blue No. 1 and 2 in order to learn about the lithology of the rocks at depth in the geothermal system.</td>
<td>2002</td>
<td>2004</td>
<td>During the drilling of the Deep Blue No. 1 and 2 (DB1 and DB2), observation wells, core drillings were made. Continuous cores were retrieved from between 176.5 to 672.1 m depth in Deep Blue No. 1. This core sample provided the first detailed geologic stratigraphy of the geothermal resource at depth. Core samples were collected roughly every 15 m in DB1 and about every 30 m in DB2.</td>
</tr>
<tr>
<td><strong>Core Analysis</strong></td>
<td>Core sample from the observation wells Deep Blue No. 1 &amp; 2 were analyzed as part of an effort to conceptualize the geology of the geothermal system.</td>
<td>2008</td>
<td>2008</td>
<td>The U.S. Geological Survey analyzed 36 core samples from Deep Blue No. 1 and 46 samples from Deep Blue No. 2. The diameter of the core samples are 6.4 cm. Density, porosity, and rock type information was recorded. The samples contain Jurassic and Triassic metasedimentary rocks consisting mainly of mudstone, sandstone, and argillite. There are also Tertiary diorite and gabbro, and Tertiary felsic dikes.</td>
</tr>
<tr>
<td><strong>Aeromagnetic Survey</strong></td>
<td>The USGS collected geophysical data near Blue Mountain and Pumpernickel Valley to study regional crustal structures to help understand the geologic framework of Blue Mountain and help in mineral and geothermal reconnaissance.</td>
<td>2008</td>
<td>2009</td>
<td>This aeromagnetic survey was part of a statewide survey. Flight lines over Blue Mountain were at a barometric elevation of 2700 m, oriented east-west, and spaced 1.6 to 3.2 km apart. The aeromagnetic data from Blue mountain was poor to fair resolution and shallow magnetic sources are not be well resolved.</td>
</tr>
<tr>
<td><strong>Conceptual Model</strong></td>
<td>This conceptual model was put together to help visualize the geology and hydrothermal system.</td>
<td>2010</td>
<td>2010</td>
<td>A conceptual model based on drilling results, fluid characteristics, lithology, and 3D permeability mapping has been created. This model has very little geophysical data to work from because of a relatively small amount of studies that have been done prior to the model. The model establishes that permeability is controlled by a fault and fracture network with the majority of fluid flow being along the range front fault.</td>
</tr>
</tbody>
</table>
# NEPA ANALYSIS COLLECTION

Example query of NEPA Analyses conducted at New York Canyon Geothermal Area

<table>
<thead>
<tr>
<th>Document #</th>
<th>Analysis Type</th>
<th>Applicant</th>
<th>Application Date</th>
<th>Decision Date</th>
<th># of Days</th>
<th>Lead Agency</th>
<th>Development Phase(s)</th>
<th>Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>NVN-087791</td>
<td>Casual Use</td>
<td>TGP Dixie Development Company</td>
<td>23-Jun-09</td>
<td>21-Jul-09</td>
<td>28</td>
<td>BLM</td>
<td>Exploration</td>
<td>Magnetotellurics</td>
</tr>
<tr>
<td>NVN-087812</td>
<td>Casual Use</td>
<td>TGP Dixie Development Company</td>
<td>30-Jun-09</td>
<td>21-Jul-09</td>
<td>21</td>
<td>BLM</td>
<td>Exploration</td>
<td>Electrical Techniques</td>
</tr>
<tr>
<td>NVN-087811</td>
<td>Casual Use</td>
<td>TGP Dixie Development Company</td>
<td>30-Jun-09</td>
<td>21-Jul-09</td>
<td>21</td>
<td>BLM</td>
<td>Exploration</td>
<td>Magnetotellurics</td>
</tr>
</tbody>
</table>

**LIST OF EXAMPLE CASE STUDIES**

- Areas with a relatively recent development history
- Non-operational site was selected for variety
- Diverse set of geothermal regions and occurrence models,
- Well-studied areas with a significant number of publications

<table>
<thead>
<tr>
<th>Geothermal Area</th>
<th>Type</th>
<th>Geothermal Region</th>
<th>Power Plants</th>
<th>Startup Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Coso</em></td>
<td><em>E</em></td>
<td><em>Walker Lane Transition Zone</em></td>
<td><em>BLM, Navy I, Navy II</em></td>
<td>1987</td>
</tr>
<tr>
<td><em>Raft River</em></td>
<td><em>E</em></td>
<td><em>Northern Basin &amp; Range</em></td>
<td><em>Raft River</em></td>
<td>2008</td>
</tr>
<tr>
<td><em>Neal Hot Springs</em></td>
<td><em>B</em></td>
<td><em>Northwest Basin &amp; Range</em></td>
<td><em>Neal Hot Springs Facility</em></td>
<td>2012-2013</td>
</tr>
<tr>
<td><em>Valles Caldera (Fenton Hill, Sulphur Springs, Redondo)</em></td>
<td><em>C</em></td>
<td><em>Rio Grande Rift</em></td>
<td><em>none</em></td>
<td>None</td>
</tr>
<tr>
<td><em>Long Valley Caldera</em></td>
<td><em>C</em></td>
<td><em>Walker Lane Transition Zone</em></td>
<td><em>Mammoth Pacific I &amp; II (Casa Diablo)</em></td>
<td>1984</td>
</tr>
<tr>
<td><em>North Brawley</em></td>
<td><em>D</em></td>
<td><em>Gulf of California Rift Zone</em></td>
<td><em>North Brawley Facility</em></td>
<td>2009</td>
</tr>
<tr>
<td><em>Dixie Valley</em></td>
<td><em>E</em></td>
<td><em>Central Nevada Seismic Zone</em></td>
<td><em>Dixie Valley Facility</em></td>
<td>1988</td>
</tr>
<tr>
<td><em>Roosevelt Hot Springs</em></td>
<td><em>E</em></td>
<td><em>Northern Basin &amp; Range</em></td>
<td><em>Blundell I &amp; II Facilities</em></td>
<td>1984</td>
</tr>
<tr>
<td><em>Blue Mountain</em></td>
<td><em>E</em></td>
<td><em>Northwest Basin &amp; Range</em></td>
<td><em>Blue Mountain - Faulkner</em></td>
<td>2009</td>
</tr>
<tr>
<td><em>Salt Wells</em></td>
<td><em>E</em></td>
<td><em>Northwest Basin &amp; Range</em></td>
<td><em>ENEL Salt Wells Facility</em></td>
<td>2009</td>
</tr>
<tr>
<td><em>Chena</em></td>
<td><em>E</em></td>
<td><em>Alaska</em></td>
<td><em>Chena Hot Springs Facility</em></td>
<td>2006</td>
</tr>
<tr>
<td><em>Kilauea East Rift</em></td>
<td><em>F</em></td>
<td><em>Hawaii</em></td>
<td><em>Puna Geothermal Facility</em></td>
<td>1993</td>
</tr>
</tbody>
</table>

1 Type refers to the Brophy Occurrence Model Types ([http://en.openei.org/wiki/Brophy_Occurrence_Models](http://en.openei.org/wiki/Brophy_Occurrence_Models)). Type A: Magma-heated, Dry Steam Resource; Type B: Andesitic Volcanic Resource; Type C: Caldera Resource; Type D: Sedimentary-hosted, Volcanic-related Resource; Type E: Extensional Tectonic, Fault-Controlled Resource; Type F: Oceanic-ridge, Basaltic Resource (Williams et al., 2011).

2 For a list of regions, see [http://en.openei.org/wiki/Geothermal_Regions](http://en.openei.org/wiki/Geothermal_Regions)
Conducting a student challenge that contributes to these case studies has many benefits:

- Allows students to participate in a project that directly contributes to industry’s body of knowledge;
- Connects students with industry members for potential internship and job opportunities;
- Exposes students to the benefits of contributing to and utilizing crowd-sourced information;
- Allows the database to continue to grow, providing detailed information about a growing number of geothermal areas.

This effort can save geothermal companies time and money – the type of information contained in the case studies are synonymous with the preliminary analysis conducted by most as a first step in reconnaissance of an area.
POTENTIAL FUTURE DIRECTIONS: Navigation and Usability

We’ve amassed a lot of data – what next?

User Task Analysis
• What tasks do users most want to accomplish with the data and information?
• Can users accomplish their tasks and goals when they come to the site?
• Can they do so in the best and most efficient way possible?
• Can they access the data and queries in the way most useful to their needs?

Readability
• Is the information readable so as to perform tasks efficiently and accurately?
• Readability hinges on: Ease of Comprehension, Legibility, Reading Enjoyment

Site Navigability
• Can users easily move through multiple webpages?
• Are navigability components appropriate? e.g. navigation menus, search boxes, links within text, sidebar widgets that display recent or top content

User Experience
• Largely subjective; can vary greatly from one user to the next
• Evaluate user perception: how pleasant a website is it to use?
• Does the user feel he’s obtained value from the website?
### Moeck–Beardsmore Play Types

Moeck and Beardsmore define a Geothermal Play as a model of a geothermal system consisting of the combination of structural position and geologic setting that create a recoverable geothermal resource. Geologic factors considered include the Reservoir, Rock Unit representing the primary reservoir for thermal fluids and/or geothermal heat; the Heat Charge System, consisting of the Heat Source and Heat Transport mechanism sustaining the system; a possible Regional Topseal or Caprock acting as a trap for heat and/or thermal fluids in the system that allow commercial exploitation (not present in all play types); the Timing of the above three factors that generates a recoverable geothermal resource; and the Play Fairway, which considers the expected geographic extent of the play.

Other definitions: [Wikipedia Reegle](#)

<table>
<thead>
<tr>
<th>Type</th>
<th>Geologic Setting</th>
<th>Heat Source/Storage Properties of Reservoir</th>
<th>Dominant Heat Transport Mechanism</th>
<th>Regional Topseal or Caprock</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV-1: Extrusive</td>
<td>CV-1a: Magmatic</td>
<td>Magmatic Arcs, Mid Oceanic Ridges, Hot Spots</td>
<td>Active Volcanism, Shallow Magma Chamber</td>
<td>Magmatic–hydrothermal Circulation</td>
<td>Extensive Low Permeability Clay-rich Layers</td>
</tr>
<tr>
<td>CV-1b: Intrusive</td>
<td>Magmatic Arcs, Mid Oceanic Ridges, Hot Spots</td>
<td>Active Volcanism, Shallow Magma Chamber</td>
<td>Magmatic–hydrothermal Circulation, Fault Controlled</td>
<td>---</td>
<td>Taupo Volcanic Zone</td>
</tr>
<tr>
<td>CV-2: Plutonic</td>
<td>CV-2a: Recent or Active Volcanism</td>
<td>Convergent Margins with Recent Plutonism (&lt; 3 Ma), Young Orogens, Post-orogenic Phase</td>
<td>Young Intrusion+Extension, Felsic Pluton</td>
<td>Magmatic–hydrothermal Circulation, Fault Controlled</td>
<td>---</td>
</tr>
<tr>
<td>CV-2b: Inactive Volcanism</td>
<td>Convergent Margins with Recent Plutonism (&lt; 3 Ma), Young Orogens, Post-orogenic Phase</td>
<td>Young Intrusion+Extension, Felsic Pluton, Heat Producing Element Rock</td>
<td>Hydrothermal Circulation, Fault Controlled</td>
<td>Low Permeability Caprock</td>
<td>The Geysers</td>
</tr>
<tr>
<td>CV-3: Extensional Domain</td>
<td>Metamorphic Core Complexes, Back-arc Extension, Pull-apart Basins, Intracontinental Riffs</td>
<td>Thinned Crust+Elevated Heatflow, Recent Extensional Domains</td>
<td>Fault Controlled, Hydrothermal Circulation</td>
<td>---</td>
<td>Basin and Range</td>
</tr>
<tr>
<td>CD-1: Intracratonic Basin</td>
<td>Intracratonic/Rift Basins, Passive Margin Basins</td>
<td>High Porosity/Low Permeability Sedimentary Aquifers</td>
<td>Litho/Biofacies Controlled</td>
<td>---</td>
<td>North German Basin</td>
</tr>
<tr>
<td>CD-2: Orogenic Belt</td>
<td>Fold-and-thrust Belts, Foreland Basins</td>
<td>High Porosity/High Permeability or High Porosity/Low Permeability Sedimentary Aquifers</td>
<td>Fault/Fracture Controlled, Litho/Biofacies Controlled</td>
<td>---</td>
<td>Southern Canadian Cordillera, Molasse Basin</td>
</tr>
<tr>
<td>CD-3: Crystalline Rock – Basement</td>
<td>Intrusion in Flat Terrain</td>
<td>Heat Producing Element Rock, Low Porosity/Low Permeability Hot Intrusive Rock (Granite)</td>
<td>Hot Dry Rock, Fault/Fracture Controlled</td>
<td>---</td>
<td>Saultz-sous-Forêts</td>
</tr>
</tbody>
</table>
**POTENTIAL FUTURE DIRECTIONS: Analytical Features**

Adding analytical features, conducting analyses of completed case studies – what has worked? What hasn’t worked? What trends do we see? how do we find blind systems?

- Example of correlation that can be drawn from OpenEI data.
- Data points are categorized according to Brophy’s occurrence models and show that, as expected, geothermal regions with magmatic input (types B and F) tend to have higher geothermal gradients than extensional regions (type E).
- The red line shows the lower bound of most electrically productive geothermal areas, showing that a temperature gradient of at least 70°C/km is necessary for an electric-grade geothermal resource.

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**Temperature of geothermal fluid vs. depth of producing reservoir**

| A – Magma-related, dry-steam resources |
| B – Andesitic volcanic resources |
| C – Caldera resources |
| D – Sedimentary-hosted, volcanic related resources |
| E – Extensions, fault-controlled resources |
| F – Ocean ridge, basaltic resources |
Thank You!

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