Comprehensive Evaluation of the Geothermal Resource Potential within the Pyramid Lake Paiute Reservation

Donna Marie Noel (PI)
Greg Pohl (Presenter)
Pyramid Lake Paiute Tribe, Desert Research Institute, University of Nevada, Reno, Optim Software and Data Solutions, Ehni Enterprises

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Validation of Innovative Exploration Technologies

This presentation does not contain any proprietary confidential, or otherwise restricted information.
Relevance/Impact of Research

• Two overarching objectives of project:
  – Characterize geothermal reservoir at Astor Pass using innovative technologies
    • 3D geologic and reservoir model
    • SeisOpt® seismic data analysis to create fault-plane images
  – Exploration to locate blind geothermal reservoirs at other sites in Reservation
• Validate innovative characterization and simulation techniques
• Provide data for National Geothermal Database
• Expect results relating to efficacy of characterization activities to be applicable to other geothermal sites
• Recovery Act goal of 400MW by 2014
Scientific/Technical Approach

- Shallow temperature survey
- Seismic data collection and analysis
- Fracture stress modeling and slip tendency analysis
- Drill two wells (4000 ft)
- Borehole geophysics
- Well testing and geochemical analysis
- Three-dimensional geologic model
- Three-dimensional reservoir model
- Reservation wide geothermal potential assessment
  - Reservation-wide digital geologic map, including new mapping in northeastern portion of reservation, and better earthquake map
  - Shallow temperature surveys
  - Soil sampling at Sheep Pass and into San Emidio Valley, where Hg concentrations are over twice those in Astor Pass area
  - Re-processing of a previously collected COCORP seismic line
  - Temperature gradient wells in promising parts of the reservation
  - Geothermal potential map
<table>
<thead>
<tr>
<th>Original Planned Milestone/Technical Accomplishment</th>
<th>Actual Milestone/Technical Accomplishment</th>
<th>Date Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1 - Permitting</td>
<td>Drilling permits completed</td>
<td>11/10/2010</td>
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<tr>
<td>Task 2 – Shallow Temperature Survey</td>
<td>Astor Pass and Emerson Pass (prelim) completed</td>
<td>6/10/2010</td>
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<tr>
<td>Task 3 – Seismic Data Collection/Analysis</td>
<td>Astor Pass seismic data collected and analyzed</td>
<td>11/1/2012</td>
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<td>Task 4 – Fracture Stress Analysis</td>
<td>Borehole analysis completed; slip tend. analysis complete</td>
<td>11/1/2012</td>
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<td>Task 5 – Phase I Reporting</td>
<td>Phase I report completed</td>
<td>9/10/2010</td>
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<tr>
<td>Task 6 - Drilling</td>
<td>Two wells drilled to 4000 ft</td>
<td>3/1/2011</td>
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<td>Task 7 – Borehole Geophysics</td>
<td>Borehole data collected (APS-2/3)</td>
<td>3/1/2011</td>
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<td>Task 8 – Phase II Reporting</td>
<td>Phase II report completed</td>
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<td>Original Planned Milestone/Technical Accomplishment</td>
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<td>Task 9 – Well Testing/Geochemical Analysis</td>
<td>Reservoir parameters &amp; conceptual model complete</td>
<td>12/31/2012</td>
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<td>Task 10 – 3D Geologic Model</td>
<td>Digital model transferred to modeling team</td>
<td>Near completion</td>
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<tr>
<td>Task 11 – 3D Reservoir Model</td>
<td>Reservoir model currently being calibrated</td>
<td>Near completion</td>
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<tr>
<td>Task 12A- Shallow Temp PLPT</td>
<td>Detailed temp survey at Emerson Pass completed</td>
<td>3/14/2013</td>
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<td>Task 12B/C Geologic Mapping</td>
<td>Reservation wide geologic map in one GIS database</td>
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<td>Task 12D – Well site selection</td>
<td>Six pad locations selected for temp grad. wells</td>
<td>3/15/2013</td>
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<tr>
<td>Task 12E – Slip/dilation tendency analysis</td>
<td>Borehole analysis completed; slip tend. analysis complete</td>
<td>3/15/2013</td>
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<td>Task 12F – Reprocessing of COCORP lines</td>
<td>Anderson Bay seismic data processed</td>
<td>Near completion</td>
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</tbody>
</table>
Borehole Breakout Analysis – Astor Pass

- Breakout data from APS-2 and APS-3 wells (from McNamara).
- Stress orientation calculated
- Stress magnitudes being calculated.

**APS-2**

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<td>Well Median Orientation</td>
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<td>27</td>
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<tr>
<td>Well STD</td>
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<td>14</td>
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<tr>
<td>Above 3600 Average</td>
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<td>30</td>
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<tr>
<td>Above 3600 Median</td>
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<td>31</td>
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<tr>
<td>Above 3600 STD</td>
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<td>12</td>
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<tr>
<td>Below 3600 Average</td>
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<tr>
<td>Below 3600 Median</td>
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<tr>
<td>Below 3600 STD</td>
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**APS-3**

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<tr>
<td>Well Median Orientation</td>
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<td>9</td>
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<tr>
<td>Well STD</td>
<td>12</td>
<td>16</td>
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</table>
**Dilation Tendency – Astor Pass**

Preliminary *dilation tendency* on three faults at Astor Pass.

Preliminary *slip tendency* on three faults at Astor Pass.

**Fault Intersection Density**
Light blue – Intersection of two faults.
Warmer colors - Progressively more faults.
Astor Pass – Reservoir Modeling Structure

- Hydraulic modeling of reservoir test complete
- Results suggest max flow rate of 2,000 gpm which is ~ 2 MW
- Reservoir model is currently in calibration phase
Emerson Pass

- Area chosen due to broad step-over (or relay ramp) and terminating faults.
- ~204 km² mapped at 1:24,000.
- Possible high-temperature geothermal system defined.
- Fault kinematic data acquired.
- Stress field estimated.
- Cross sections constructed.

- Characterized by terminating east- and west-dipping faults that intersect and interact.
- Steeply dipping fault intersections plunging to the north and south.
- Several Quaternary faults younger than Lahontan sediments (~12,000 years B.P).
- Calcite and silica veins closely associated with fault intersections.
- Reworked Lahontan gravels cemented by calcite and silica, indicating a geothermal system that flowed to surface in recent past.
Emerson Pass – Structural Setting

- Cross sections were generated based on geologic mapping.
- Cross section through the thermal anomaly.
  - Reveals complex fault intersections.
  - Set of closely spaced faults where the Fox Range normal fault terminates southward.
Indicators of Geothermal Activity: Emerson Pass

- Blue polygons are anomalous illite/montmorillonite from hyspectral data (Kratt et al., 2010a)
- Circles are 2 m temperature probe points that show N-S thermal anomaly along range front.
- Polygon outlined in black is altered Tertiary and Mesozoic rocks.
- Polygons outlined in brown in the foreground are tufa mounds.
- Green line and ball show N striking, steeply dipping calcite and silica veins.
Anderson Bay

- Detailed magnetic survey, ap. 2.6 km² (1 mi²) area
- Large gradients suggest Lake Ra. fault splay to NE, or E?
Future Directions

The following tasks will be conducted during the remainder of the project which will be completed by September 30, 2013:

- Predictive simulations with reservoir model to determine long term viability of the Astor Pass geothermal reservoir
- Finalize reservation wide geologic map
- Finalize slip and dilation tendency analysis at Astor Pass
- Finalize seismic analysis at Anderson Bay
- Develop the geothermal potential map of the reservation
- Drill up to six temperature gradient wells at Emerson Pass
- Phase III report
• Preliminary results indicate that Astor Pass can maintain 2MW energy production
• Preliminary evidence suggests that Emerson Pass is located within a high temperature geothermal system
  – Favorable structural setting
  – Hyperspectral data indicates anomalous thermal alterations
  – Very high 2m temperatures (40 – 80 deg C)
  – Steeply dipping calcite and silica veins
• Combined, the two sites will likely become a valuable geothermal resource
Project Management

Timeline:

<table>
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<th>Planned Start Date</th>
<th>Planned End Date</th>
<th>Actual Start Date</th>
<th>Current End Date</th>
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Budget*:

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<th>Federal Share</th>
<th>Cost Share</th>
<th>Planned Expenses to Date</th>
<th>Actual Expenses to Date</th>
<th>Value of Work Completed to Date</th>
<th>Funding needed to Complete Work</th>
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<tbody>
<tr>
<td>4,800,000</td>
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<td>4,000,000</td>
<td>4,076,000</td>
<td>20%</td>
<td>769,000</td>
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- Leveraged the following projects to obtain additional characterization
  - Bureau of Indian Affairs
  - Two regional DOE projects
- Project is on time and on budget

*Budget Note: Budget assessment is current as of December 31, 2012.