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

Project Officer: Mark Ziegenbein .

Total Project Funding: $4.8 Million

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Donna Marie Noel (PI))

Greg Pohll (Presenter)

Pyramid Lake Paiute Tribe, Desert Research Institute, University of Nevada, Reno, Optim Software and Data Solutions, Ehni Enterprises

Validation of Innovative Exploration Technologies

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

Accomplishments

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Task 1 - Permitting	Drilling permits completed	11/10/2010
Task 2 – Shallow Temperature Survey	Astor Pass and Emerson Pass (prelim) completed	6/10/2010
Task 3 – Seismic Data Collection/Analysis	Astor Pass seismic data collected and analyzed	11/1/2012
Task 4 – Fracture Stress Analysis	Borehole analysis completed; slip tend. analysis complete	11/1/2012
Task 5 – Phase I Reporting	Phase I report completed	9/10/2010
Task 6 - Drilling	Two wells drilled to 4000 ft	3/1/2011
Task 7 – Borehole Geophysics	Borehole data collected (APS-2/3)	3/1/2011
Task 8 – Phase II Reporting	Phase II report completed	6/1/2011

Accomplishments

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Task 9 – Well Testing/Geochemical Analysis	Reservoir parameters & conceptual model complete	12/31/2012
Task 10 – 3D Geologic Model	Digital model transferred to modeling team	Near completion
Task 11 – 3D Reservoir Model	Reservoir model currently being calibrated	Near completion
Task 12A- Shallow Temp PLPT	Detailed temp survey at Emerson Pass completed	3/14/2013
Task 12B/C Geologic Mapping	Reservation wide geologic map in one GIS database	Near completion
Task 12D – Well site selection	Six pad locations selected for temp grad. wells	3/15/2013
Task 12E – Slip/dilation tendency analysis	Borehole analysis completed; slip tend. analysis complete	3/15/2013
Task 12F – Reprocessing of COCORP lines	Anderson Bay seismic data processed	Near completion

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

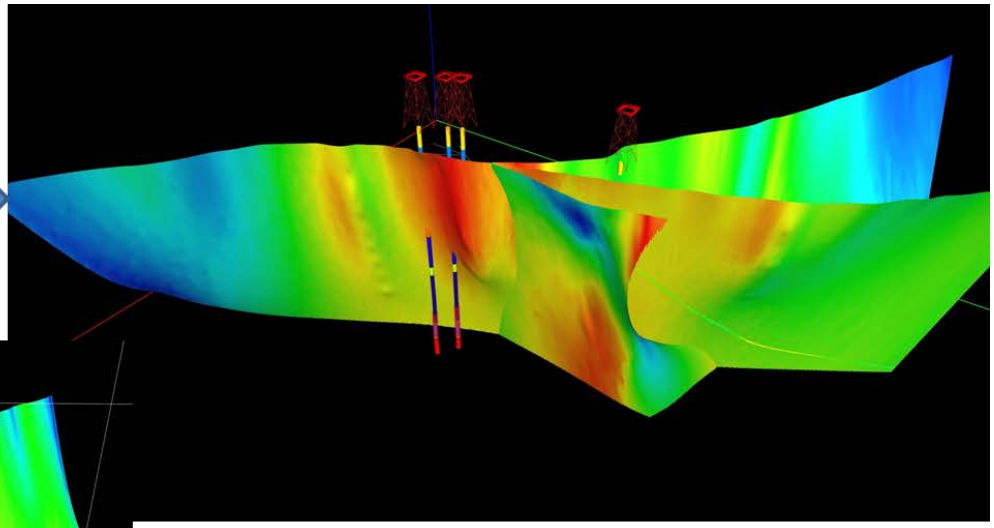
	Shmin	SHmax
Well Average Orientation	102	26
Well Median Orientation	99	27
Well STD	16	14
Above 3600 Average	122	30
Above 3600 Median	121	31
Above 3600 STD	11	12
Below 3600 Average	94	14
Below 3600 Median	95	18
Below 3600 STD	10	14

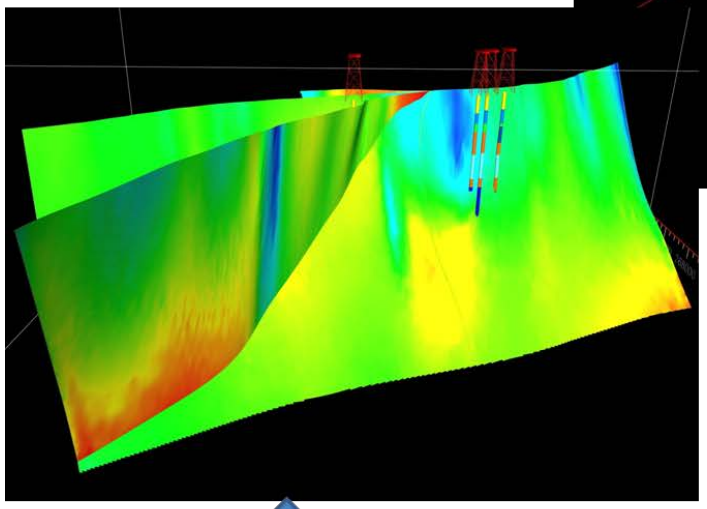
APS-3

	Shmin	SHmax
Well Average Orientation	93	4
Well Median Orientation	92	9
Well STD	12	16

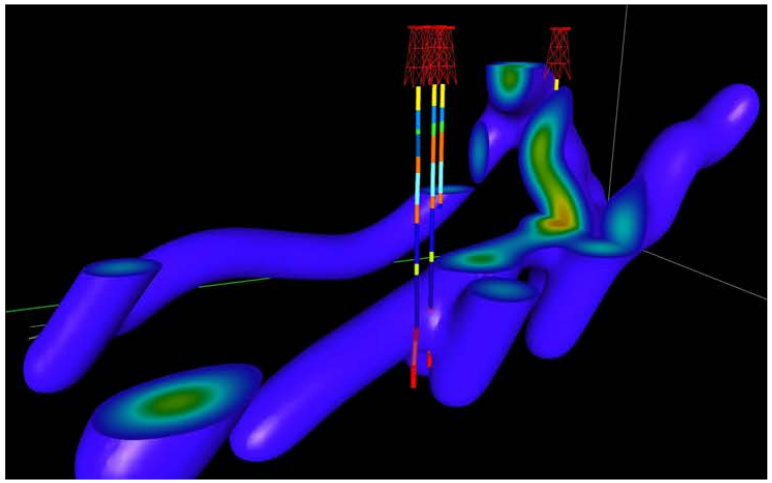
Dilation Tendency – Astor Pass

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





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

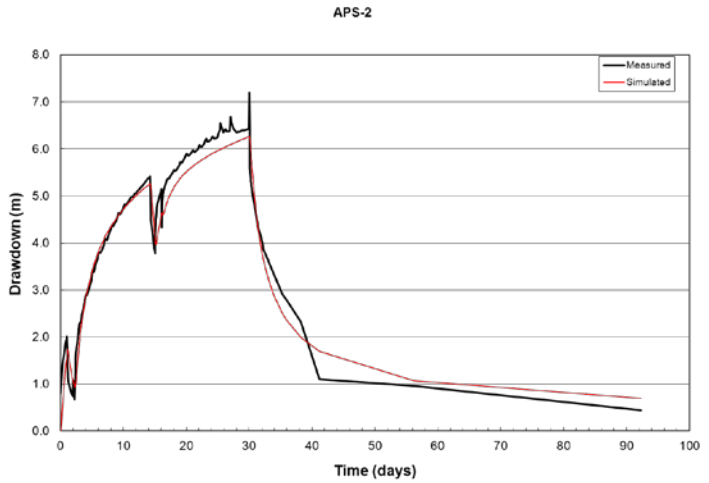


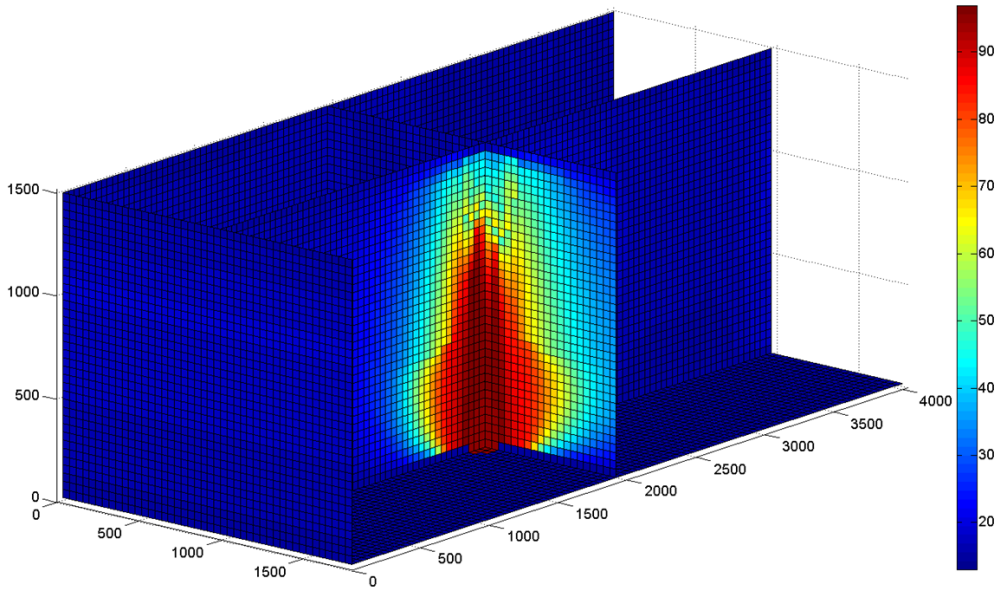
Fault Intersection Density

Light blue – Intersection of two faults.
Warmer colors - Progressively more faults.

Astor Pass – Reservoir Modeling Structure

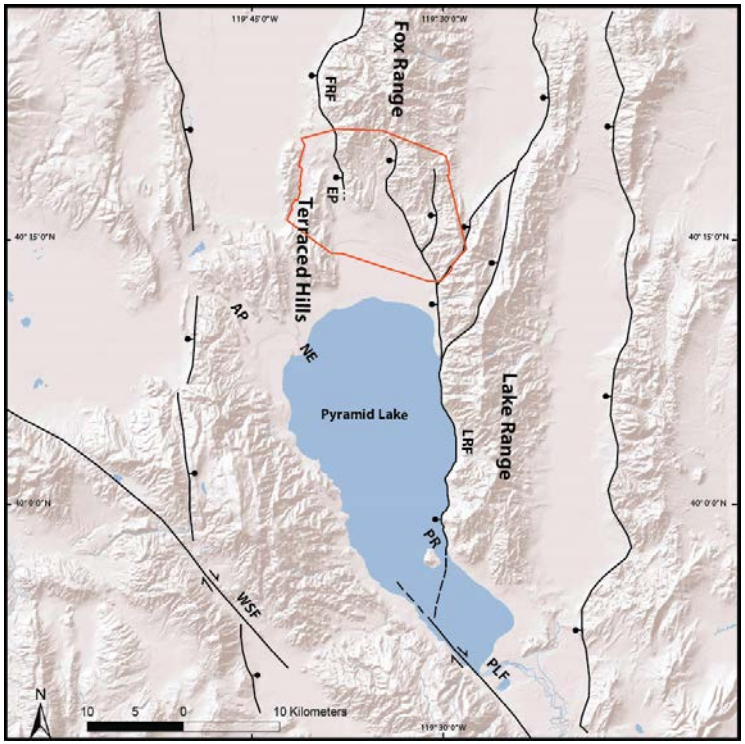
- Hydraulic modeling of reservoir test complete
- Results suggest max flow rate of 2,000 gpm which is ~ 2 MW
- Reservoir model is currently in calibration phase

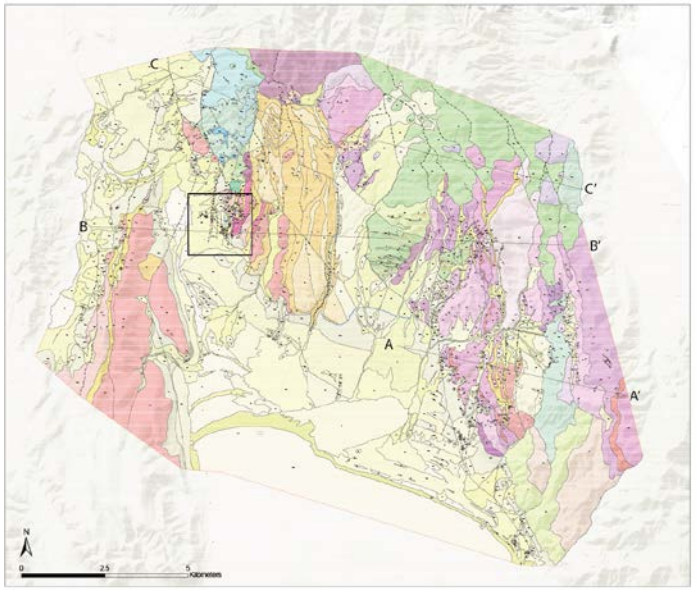




Emerson Pass

- Area chosen due to broad step-over (or relay ramp) and terminating faults.
- ~204 km^2 mapped at 1:24,000.
- Possible high-temperature geothermal system defined.
- Fault kinematic data acquired.
- Stress field estimated.
- Cross sections constructed.

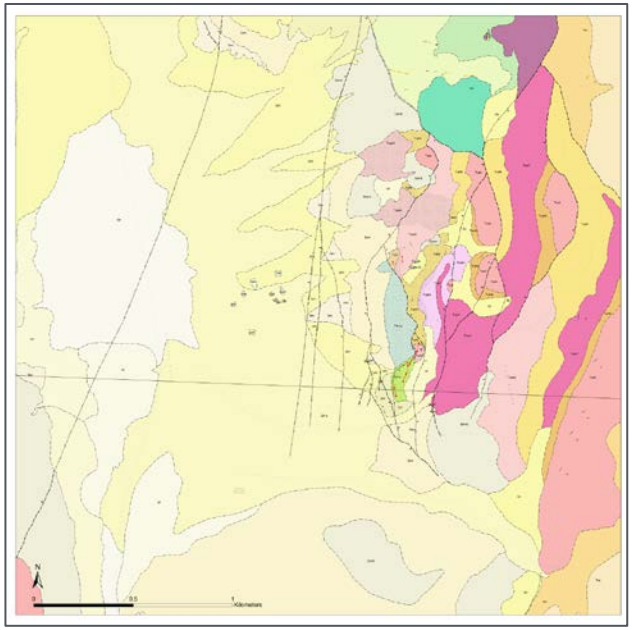


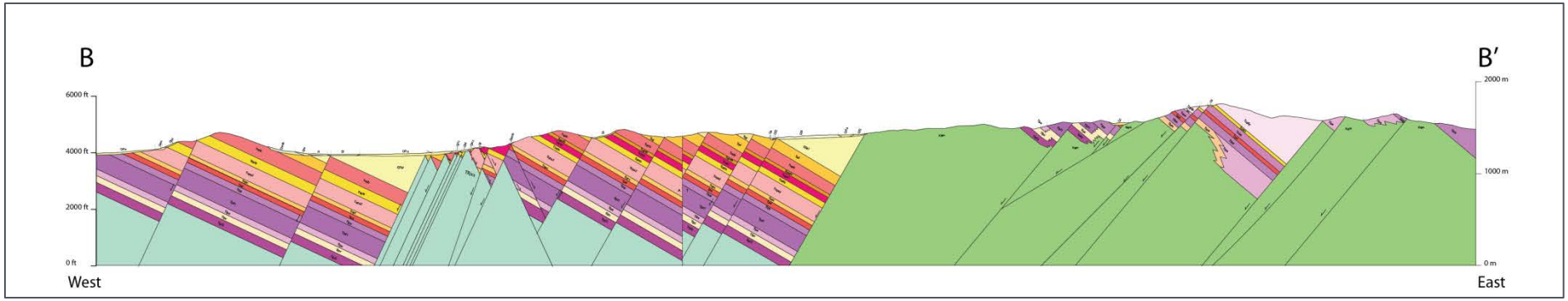


- Characterized by terminating east - and west-dipping faults that intersect and interact .
- Steeply dipping fault intersections plunging to the north and south.
- Several Quaternary faults younger than Lahontan sediments (~12,000 years B.P).
- Calcite and silica veins closely associated with fault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

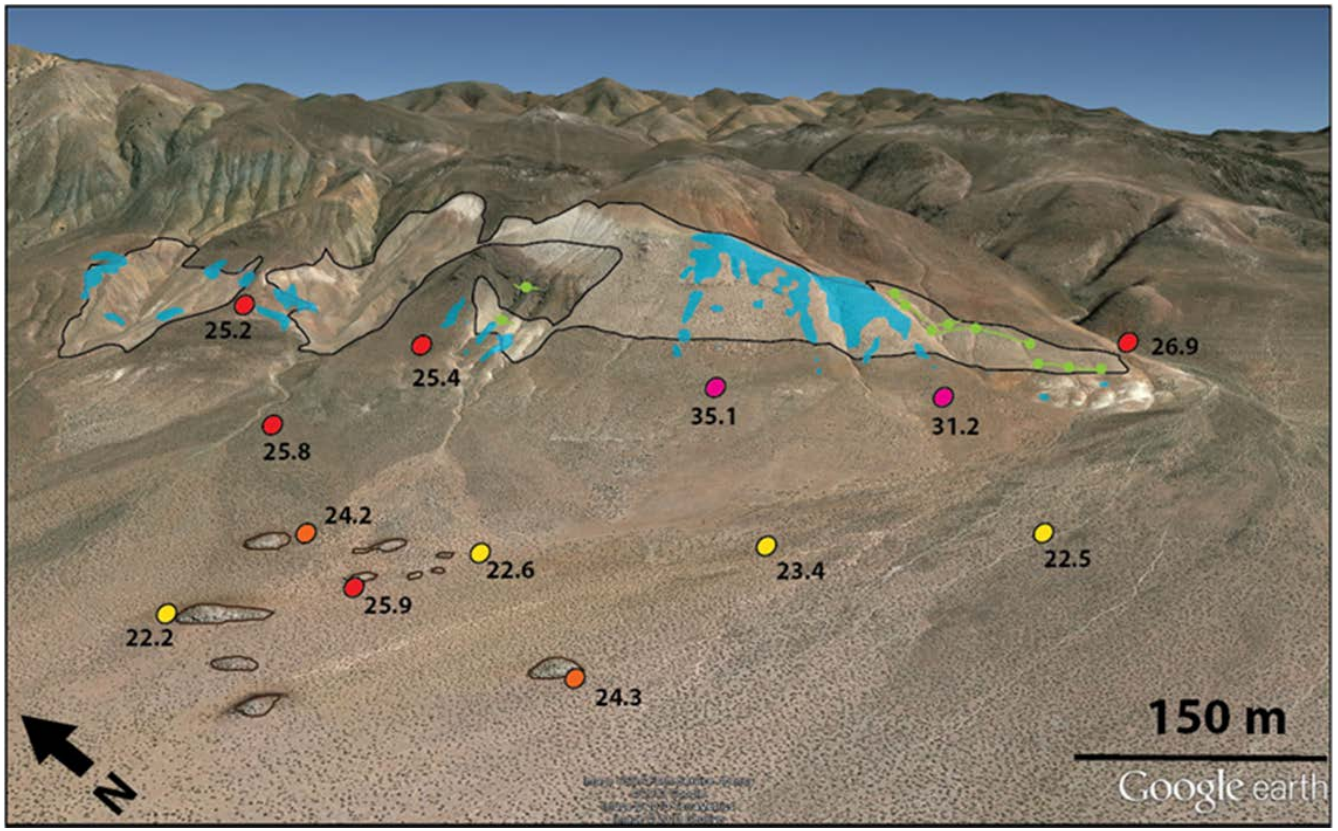
Emerson Pass – Structural Setting

- 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.





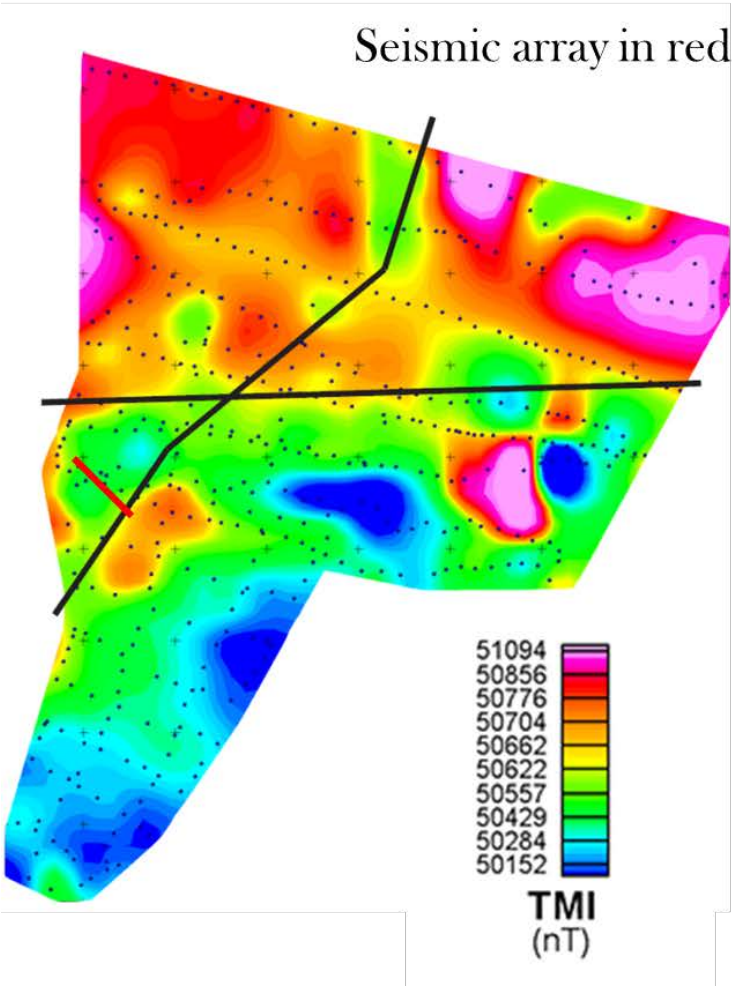
Indicators of Geothermal Activity: Emerson Pass



- 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 km^2 (1 mi^2) 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

Summary

- Preliminary results indicate that Astor Pass cab 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:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
1/29/2010	5/30/2013	1/29/2010	9/30/2013

Budget*:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
4,800,000	0	4,000,000	4,076,000	20%	769,000

- 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.*