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Geothermal Play Fairway Analysis of Potential Geothermal Resources in NE California, NW Nevada, and Southern Oregon: A Transition between Extension-Hosted and Volcanically-Hosted Geothermal Fields

Project Officer: Michael Weathers

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University of California , Davis

In collaboration with the
Lawrence Berkeley National Laboratory
Patrick Dobson, Principal Investigator

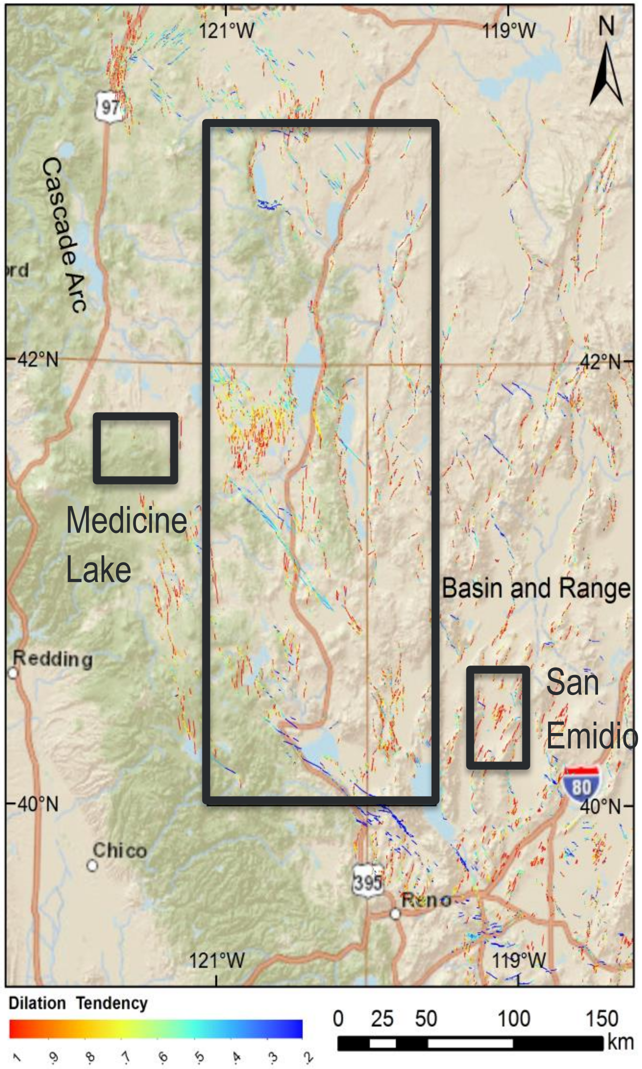
Project Objectives

The goal of this project is to apply the “Play Fairway” approach to regions where geothermal resources are transitional between volcanically hosted and extensionally hosted systems.

- In the fossil fuel industry, Play Fairway exploits models for depositional systems on entire basins to predict risk and chances of success. For geothermal systems similar approaches are being used and refined for systems that are volcanically hosted OR extensionally hosted. It should be noted that the important characteristics for these two types of systems are weighted differently in the analysis of risks associated with exploration and exploitation.
- The premise of this project is that in regions that display a transition between the two types of systems must exploit a different weighting scheme, one that is itself transitional between schemes used in the two end member cases.

Objectives (part 2)

- We have chosen the Modoc Plateau region of northeastern California, with a long history of volcanic activity to the west (and known volcanically hosted geothermal systems), and Basin and Range extension to the east.
- For the short term this project will result in an enhanced exploration capability in the region, where geothermal resources are underexploited and drilling risks are high.
- For the long term, our project will develop and test the Play Fairway approach for transitional regions that are common across many parts in the world.



Relevance/Impact of Research

- Objectives (part 3)

- Our project complements ongoing efforts by U.C. Davis to explore and understand the geothermal system in the Surprise Valley in Modoc County. We are collaborating with the county and private companies to develop small scale power generation systems in the valley (funded by the California Energy Commission).

Scientific/Technical Approach

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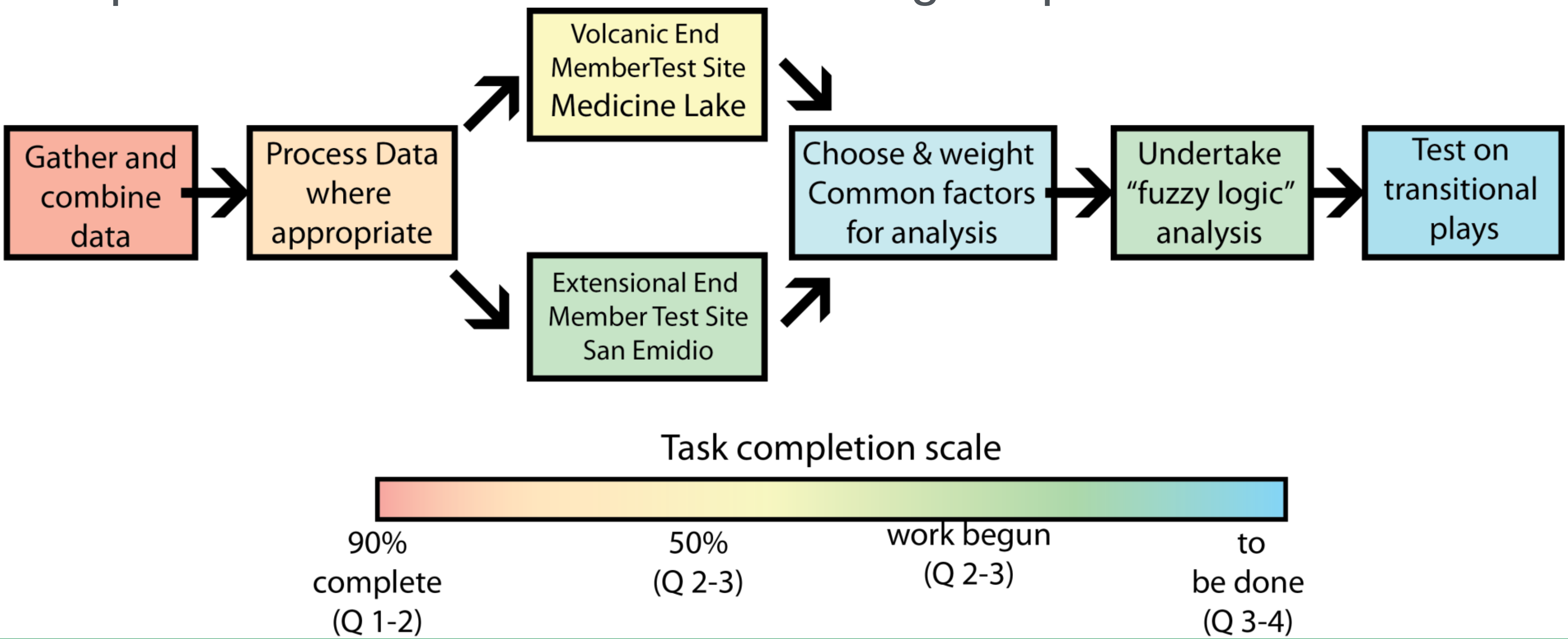
Our overall approach is to examine the important characteristics for known and adjacent *end-member* sites (volcanic and extensional), and to use those sites to find common (overlapping) characteristics to define traits that can be used to predict risk and success for drilling in specific transitional sites.



Scientific/Technical Approach

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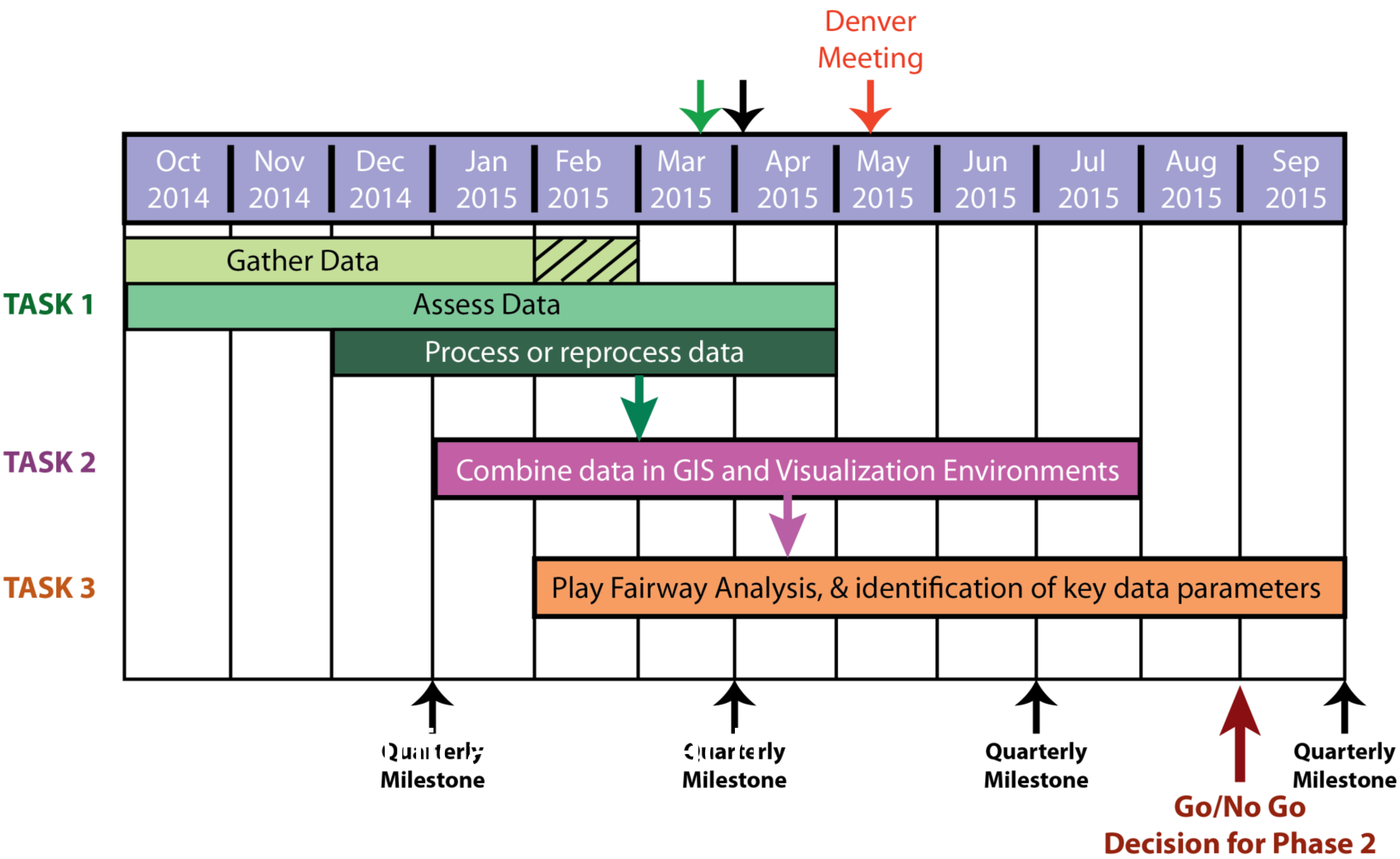
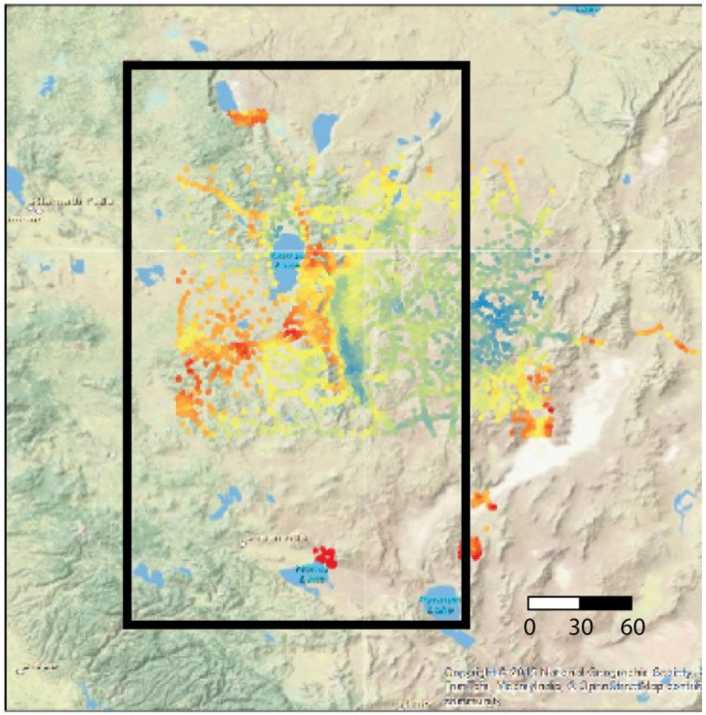




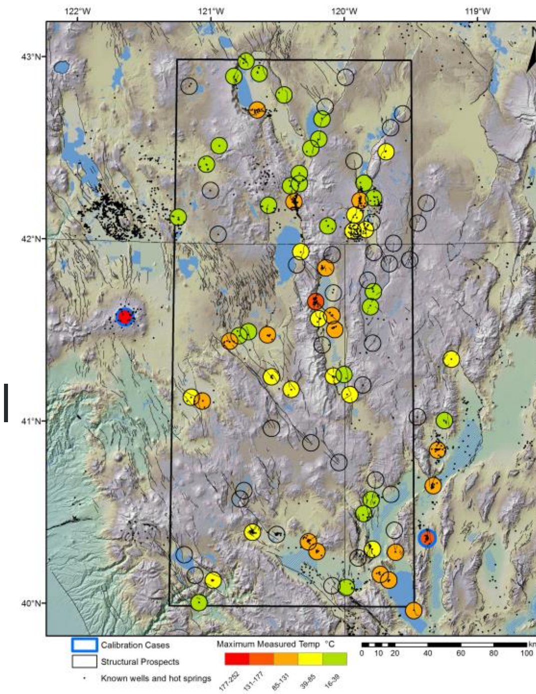
Gravity data points overlaid on topography

Tasks 1A & 1B, Gather and Assess Data

Geophysical data: Gravity, magnetic, heat flow, surveys. Seismic and E-M surveys.

Geological data

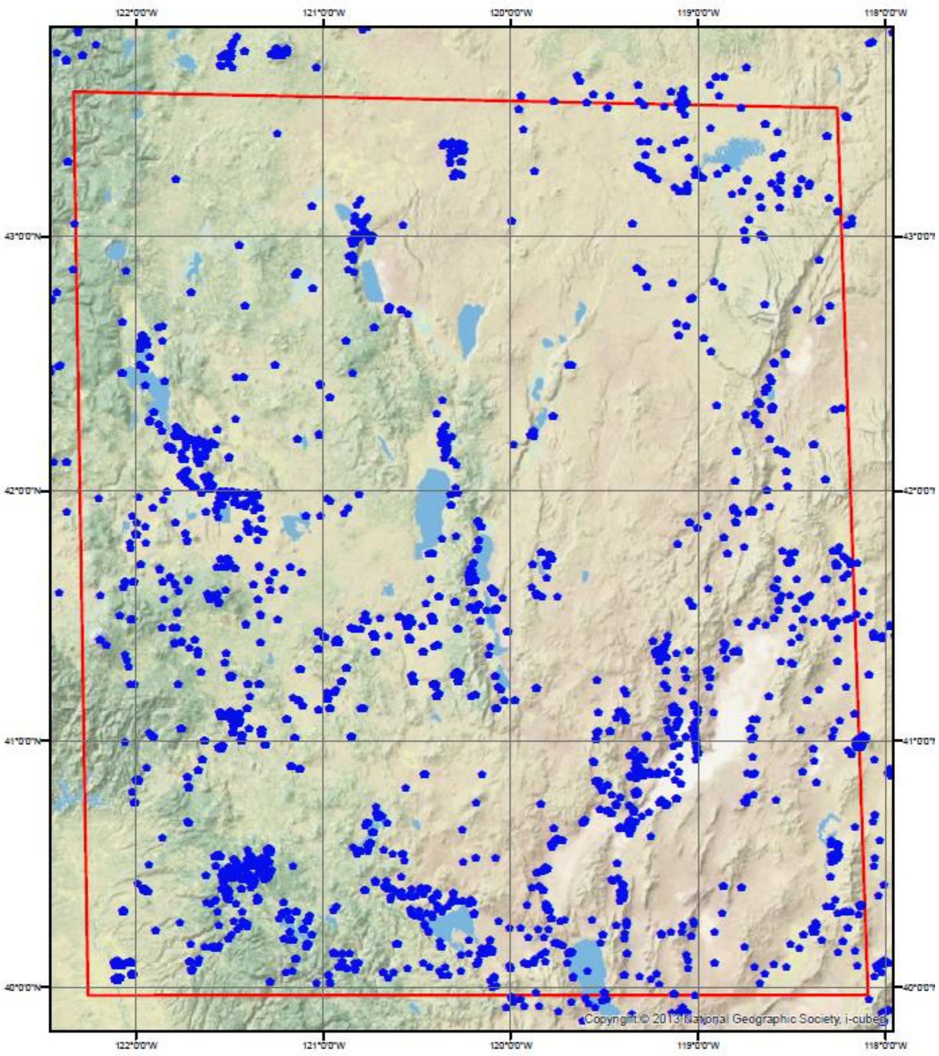
Volcanic, thermal, hydrological and fault features.



Borehole temperatures

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Gather and assess data	Heat flow data remains	May 1, 2015

Fluid Chemical Data Locations



Tasks 1A & 1B, Gather and Assess Data (part 2)

Geochemical data:

Shown at left are sites where thermal and nor-thermal waters in our project area available for chemical analyses and inference. These will include.

- Chemical tracers
- Chemical geothermometers

Student participation:

Part of the mission of the University of California is to provide learning experiences for students. During the Fall and Winter quarters we conducted special topics classes in geothermal problems. In the Winter quarter the group grew to an nearly unmanageable 15 students.

Accomplishments, Results and Progress

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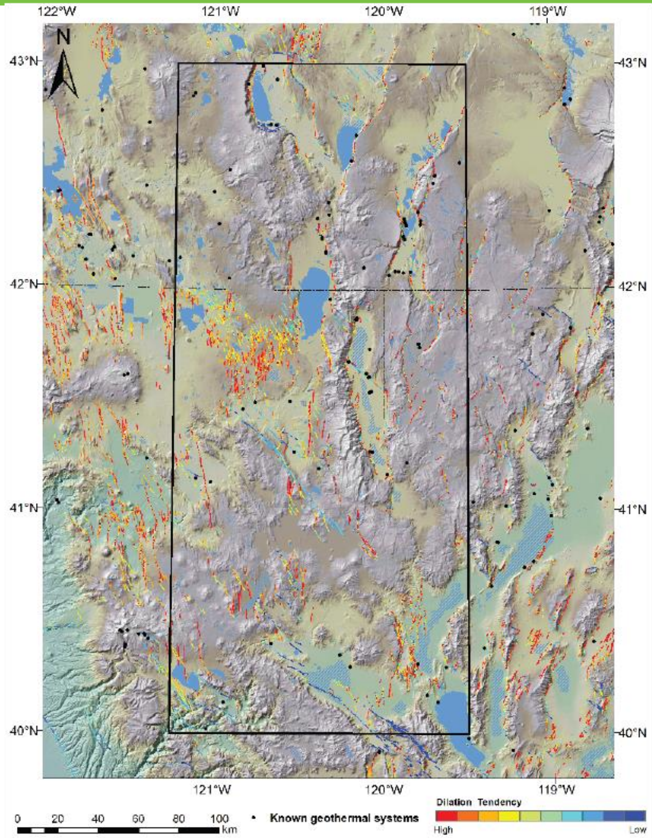
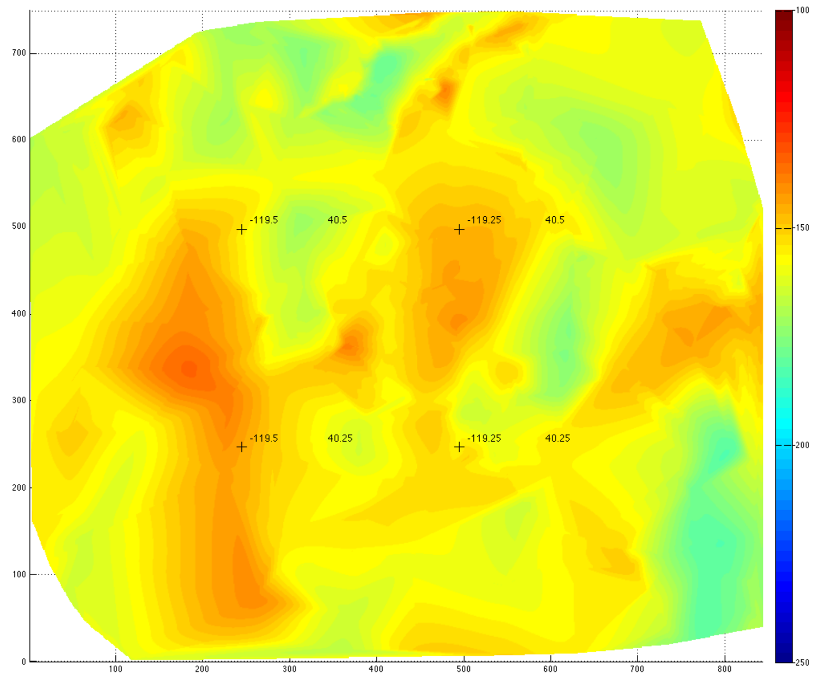


Tasks 1C, Process or Reprocess Data

1) Calculated fault dilantency tendency from regional stress and known fault orientations (example at left Siler [LBL]).
2) Identified lava types and distributions.
3) Data included in shape files for GIS (e.g. examples in presentation figures).
4) We have identified on the order of 10^3 well locations where chemical and/or temperature data are available

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Process or reprocess data sets.	Data processed & entered into GIS	May 1, 2015

Tasks 1C, Process or Reprocess Data (part 2)



5) Interpolated gravity and magnetic maps for region.
6) We have developed interpolated subsets of data for our end-member sites. (example at left for San Emidio).
7) We have identified many of the key characteristics for end-member sites.
8) We have computed potential field gradients for the end-member sites.

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Process or reprocess data sets.	End member sites characterized	May 1, 2015

Accomplishments, Results and Progress

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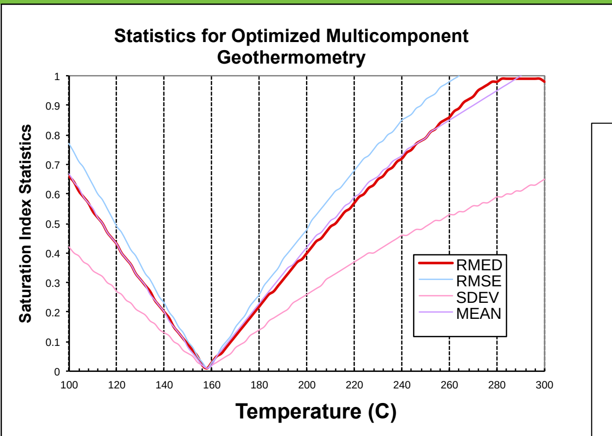
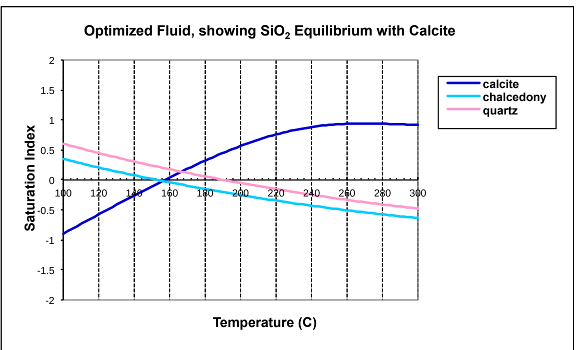
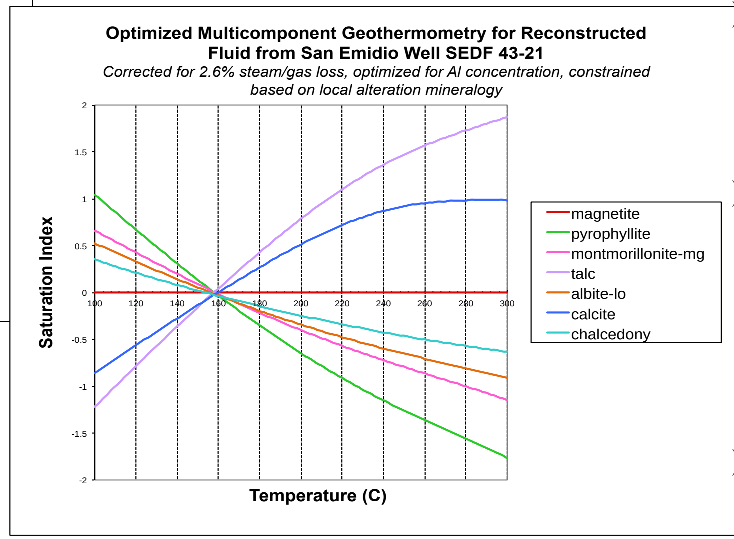
1C, Process or Reprocess Data (part 3)



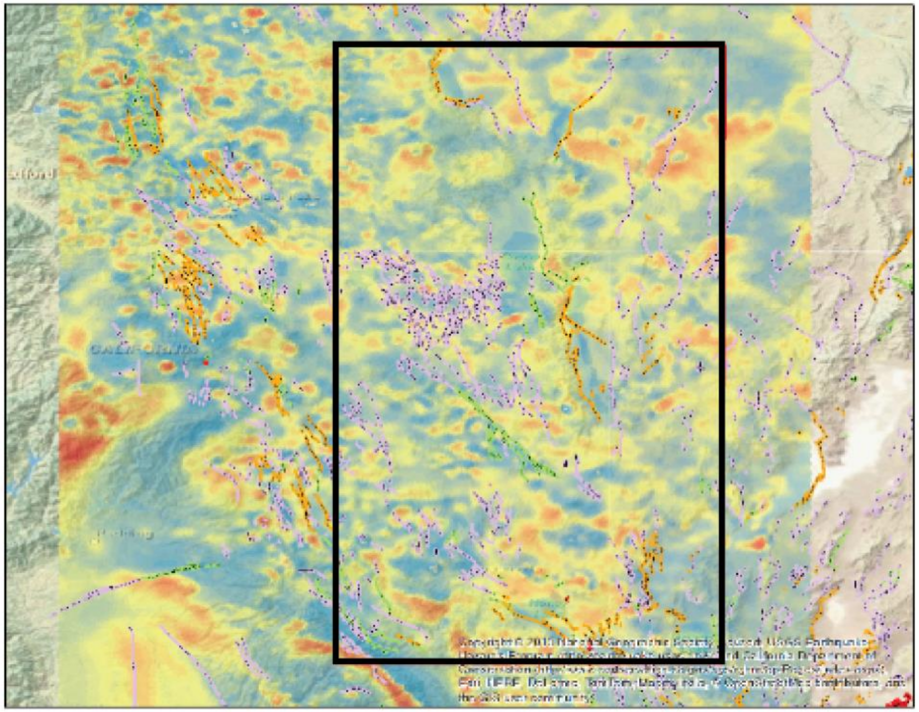




San Emidio end-member example

- **Optimized multicomponent geothermometry using GeoT and iTOUGH2-PEST software.**
- **Determination of deep fluid temperature at control points →calibration of broadly applicable chemical proxies for fluid temperature**
- **Ideal for complex transitional systems where fluid dilution and mixing may obscure more traditional geothermometry**

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Process or reprocess data sets.	Spycher et. al., 2015 (Stanford Geothermal Workshop)	Jan 22, 2015



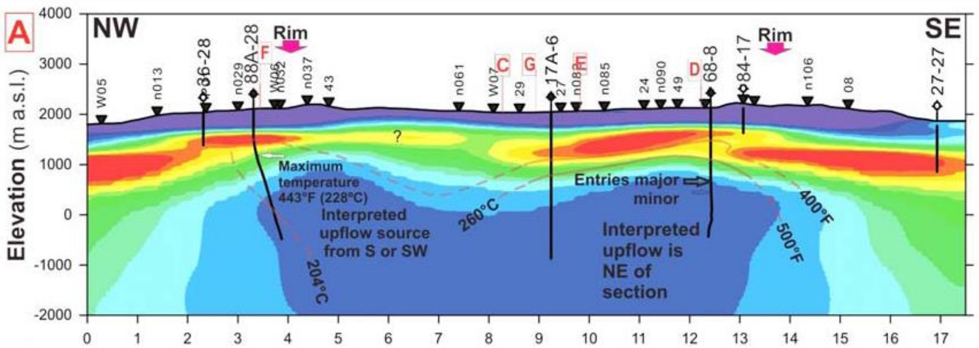
Task 2. Combine data in GIS and 3-D visualization

Shape files:
Faults, geothermal features, well locations, lava flows, combined gravity and magnetic data, geochemical data sites. (Example at left is combined magnetic and fault locations and ages.)

3-D visualization:
To be completed.

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
GIS and 3-D visualization	On schedule as planned	July 31, 2015

Task 3: Play Fairway Analysis & Identification of key data parameters



Conceptual model for Medicine Lake (Cumming and Mackie, 2007)

1) We have identified key parameters for Medicine Lake (volcanically hosted end-member): active volcanic source, temperature gradients, argillaceous impermeable cap, complex faulting.
2) We have begun identifying key parameters San Emidio (tectonically hosted end-member): hot springs, complex faulting.
3) We have begun developing "fuzzy logic" approach to Play Fairway analysis.

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Identify and weight key parameters	Unchanged	July 31, 2015
Apply fuzzy logic GPFA to test areas	Unchanged	

Future Directions

FOR REMAINDER OF FY 2015 WE WILL:

1) Determine subsurface temperature field from raw downhole temperature measurements using USGS temperature gradient measurements and new geothermometers.
2) Continue to process data from the end-member sites, including developing potential field gradients.
3) Develop a 3-D model for both surface and subsurface data for use in an immersive visualization environment at U.C. Davis (Keck CAVE facility)
4) Continue to identify faults and complex fault zones using LIDAR measurements and potential field gradients (gravity and magnetics).
5) Complete weighting schemes for the characteristics critical to each end-member site.
6) Develop weighting for transitional sites.

Future Directions

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FOR REMAINDER OF FY 2015

WE WILL: (continued)

7) Use the weighting schemes with a "fuzzy logic" approach to evaluate the geothermal plays in transitional sites
8) Create critical element risk maps for the study area

Milestone or Go/No-Go	Status & Expected Completion Date
Complete Tasks 1A and 1B (data gathering and assessment)	90% complete, awaiting additional temperature information, (complete 5/1/2015)
Complete Task 1C (process data).	50% complete. (complete 5/31/2015)
Complete Task 2 (place data in GIS and 3D).	40% complete (complete 7/31/2015)
Complete Task 3 (develop and apply Play Fairway analysis)	20% complete (complete 7/31/2015)
Complete Task 3 (test approach on known [Surprise Valley] and blind site [Modoc])	Not started (complete 8/31/2015)
Evaluate applicability of approach to transitional systems and write final report	Not started (complete 9/30/2015)

Conclusions

All geothermal systems require the presence of ground water, the presence of a heat source (magma or hot rock), and the presence of the permeability structure (both aquitards and aquifers). Key observations (e.g. fault characteristics, borehole temperatures) are all related to these parameters. Geothermal Play Fairway Analysis is one way to improve the identification and viability of these systems.

Our approach is to take optimal solutions from known end-member geothermal systems and learn how to weight those solutions to apply the Play Fairway approach to transitional systems.

Our approach will be applied to the northeastern California, southern Oregon, and northwestern Nevada, an area of low economic resources, but potentially high (and underexploited) geothermal resources. We would hope to make our results useful to geothermal companies that have or will explore the region.

The results of this project will be to create an approach to transitional (and sometimes blind) systems throughout the western U.S. and the world.