Geothermal Technologies Office 2017 Peer Review

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New Exploration Methods Applied to Previously Studied "Known Geothermal Resource Areas" in Southern Idaho and Eastern Oregon

Project Officer: Eric Hass

Total Project Funding: $599K (LBNL), ~$550K (INL)

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LBNL & INL

Track 1: Hydrothermal

Relevance to Industry Needs and GTO Objectives

The primary objective of our project is to take a fresh look at previously explored KGRAs in southern Idaho and eastern Oregon using new exploration tools and techniques to reevaluate these systems.

Our project utilizes new multicomponent geothermometers (GeoT and RTEst) that can unravel mixed thermal fluids and better assess reservoir temperatures

Our team also applied cluster and principal component analysis methods to compare these areas with known commercial geothermal resources

This project addresses two key GTO and industry goals:

- Improving processes of identifying, accessing, and developing geothermal resources
- Identifying and accelerating near term conventional and/or blind hydrothermal resource growth

Methods/Approach

- Review of past exploration studies of KGRAs and other prominent identified geothermal resources (IGRAs) in southern Idaho and eastern Oregon
- Conduct geochemical sampling and analysis of thermal waters from wells and springs in the region
  - More detailed field studies conducted at Preston, Bruneau, and Camas Prairie
  - Apply multicomponent geothermometers to estimate reservoir temperatures for these areas
- Compile comprehensive geochemical database (268 sample locations from 14 geothermal areas and one non-thermal control area) within region
- Perform PCA and cluster analysis using reference data set to identify most prospective areas for additional study

Study Area – KGRAs and Sample Locations

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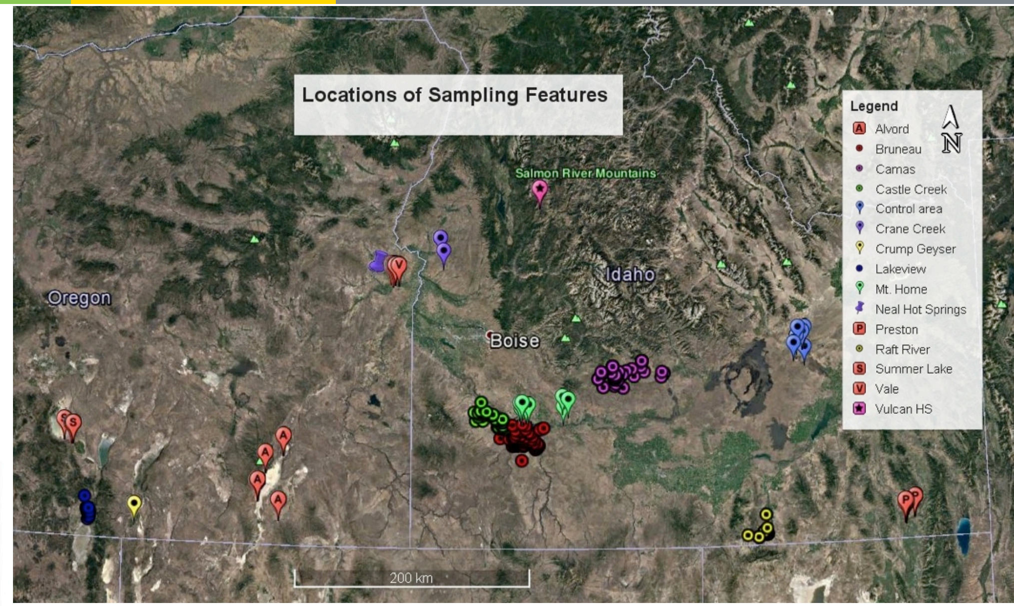
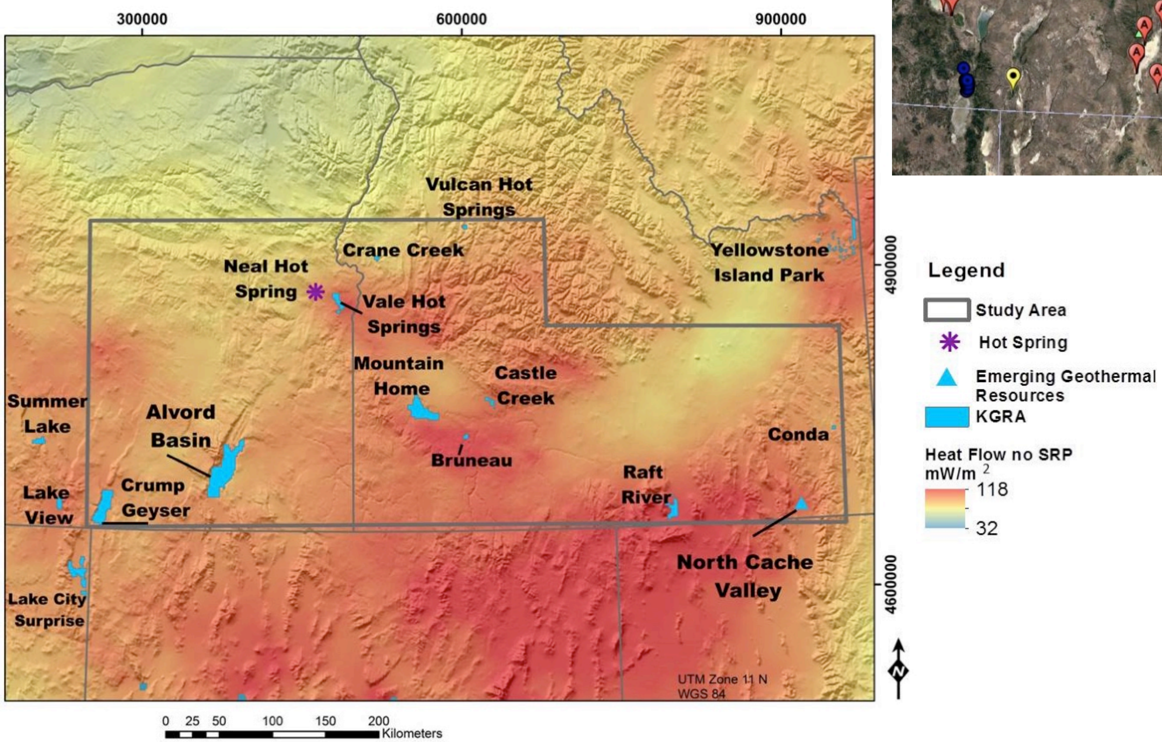
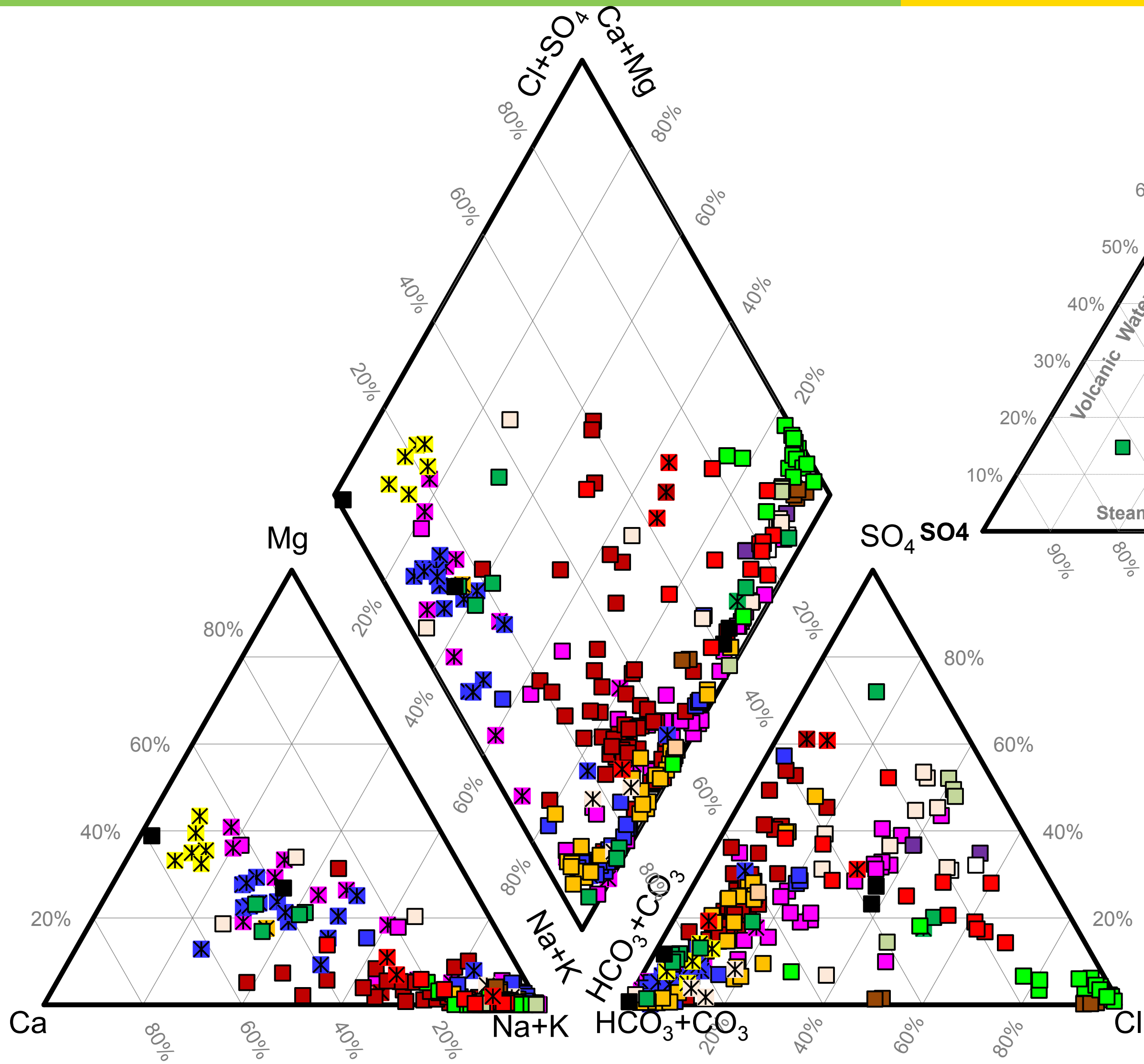
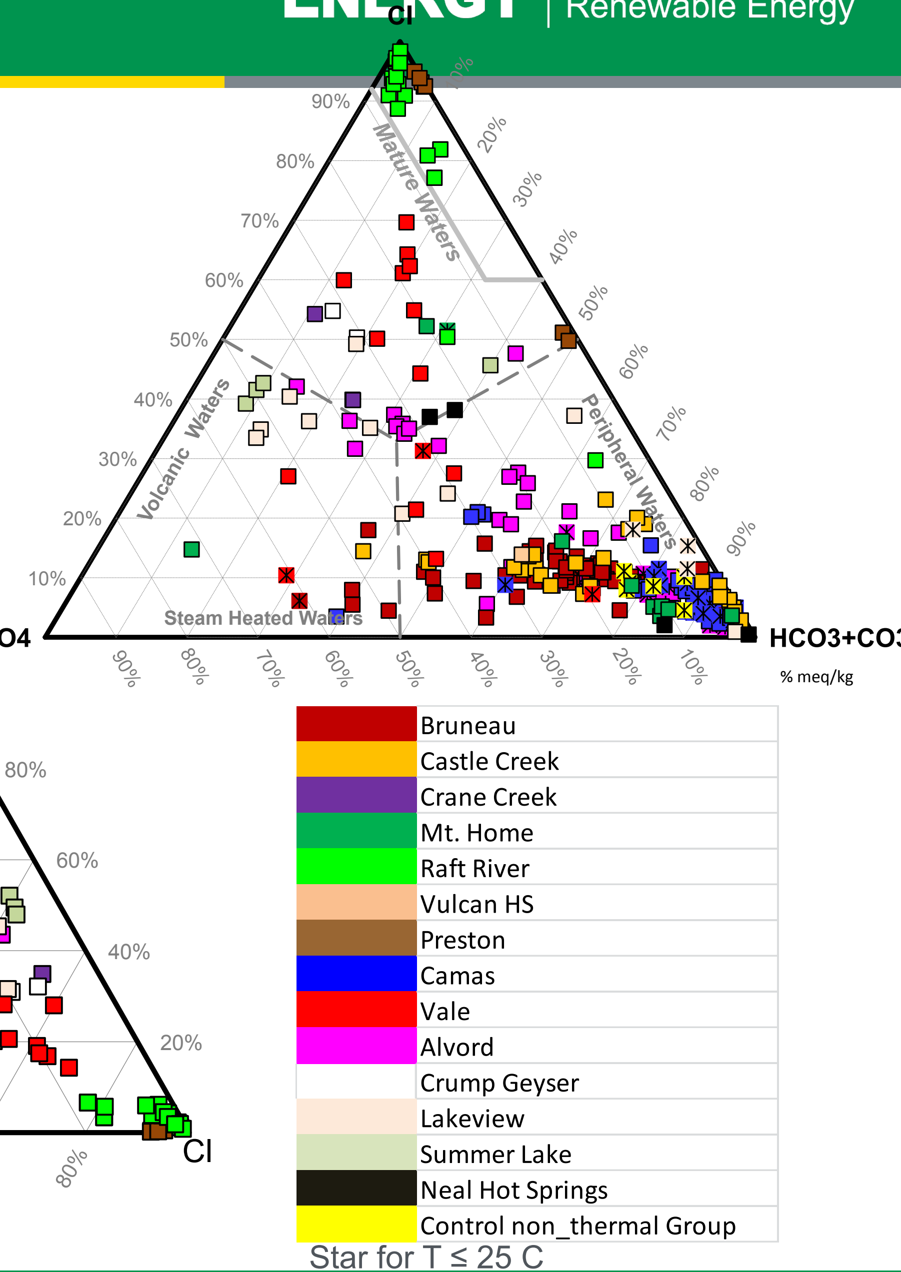


Heat flow map from Williams and DeAngelo (2011)



All KGRAs – Water Chemistry





Multicomponent Geothermometry Tool - GeoT

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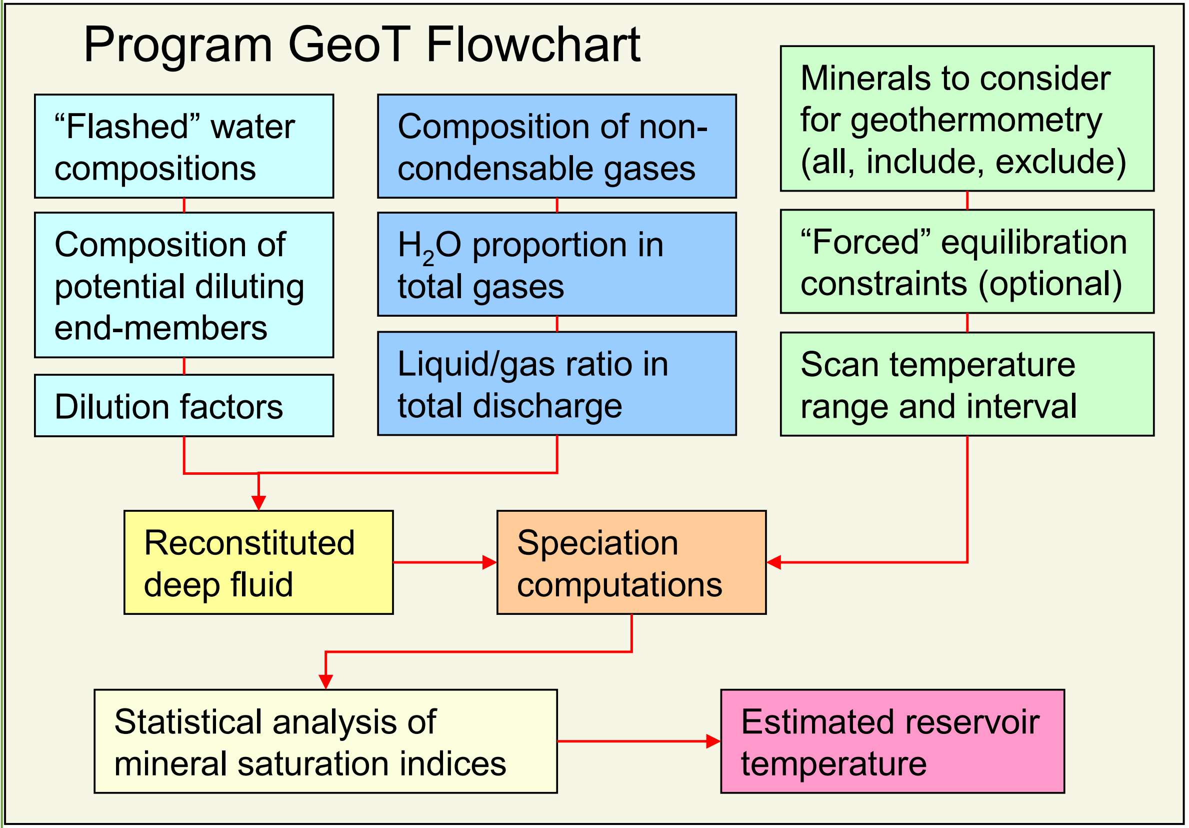
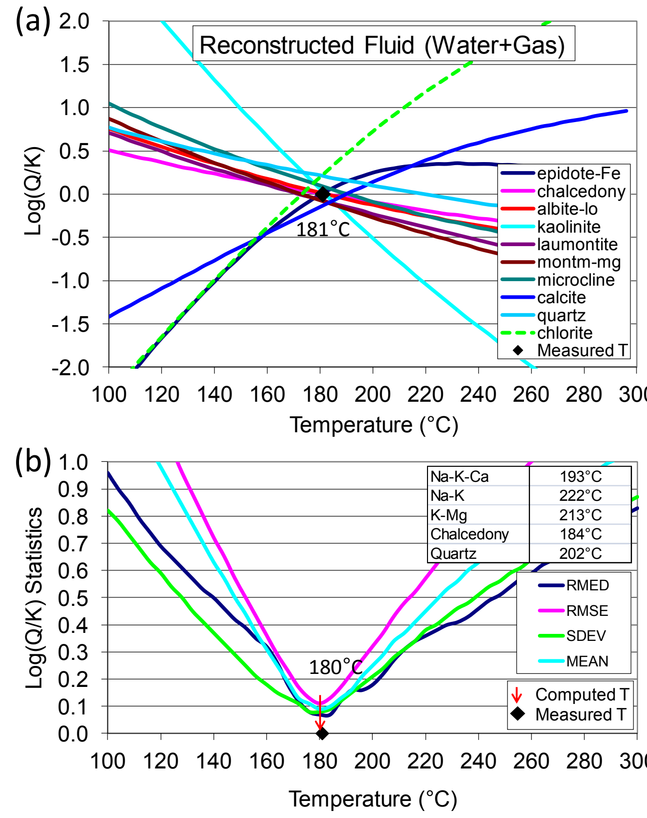
- Automatic reconstitution of deep fluid compositions
- Simultaneous regression of multiple waters
- Reservoir temperature is automatically computed from the clustering of mineral saturation indices
- Traditional geothermometers are also computed with reconstructed fluids





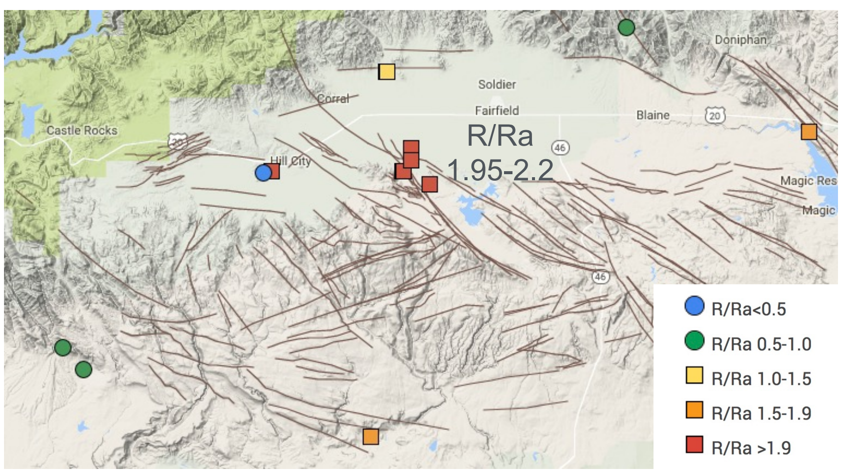
(Spycher et al., 2011 GRC; 2014 Geothermics)

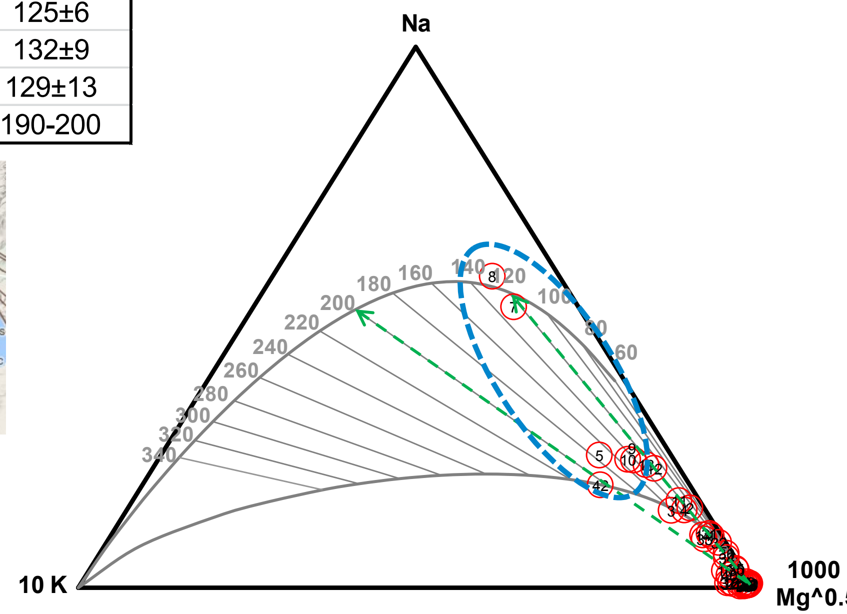
Camas Area Multicomponent Geothermometry & He Isotopes

- Selected samples for multicomponent geothermometry
  - Highest spring temperatures and SiO_2
  - Most “mature” and highest temperature on Giggenbach Na-K-Mg plot

Index	Sample Name	Temp (°C)	pH	SiO_2 (mg/L)	T SiO_2 (°C)	T Na/K (°C)	T GeoT (°C)
1	Wardrop Hot Spring	68	9.00	76.8	123	118	160-186
2	Hot Spring Ranch 1	60	9.2	81	126	113	160-186
3	Hot Spring Ranch 2	67	9.2	78	124	162	160-186
4	Hot Spring Ranch 3	64	9.2	78	124	134	160-186
5	Wolf Hot Spring	50	9.48	64	114	173	140-183
7	Elk Creek Hot Spring 1	50	9.12	65.0	115	126	125±6
8	Elk Creek Hot Spring 2	56	9.05	65.3	115	122	125±6
9	Barron's Hot Spring 1	49	8.30	84	128	143	132±9
10	Barron's Hot Springs 2	73	8.20	84	128	149	129±13
42	Magic HS Landing Well	72	6.90	105	140	205	190-200

He isotope results

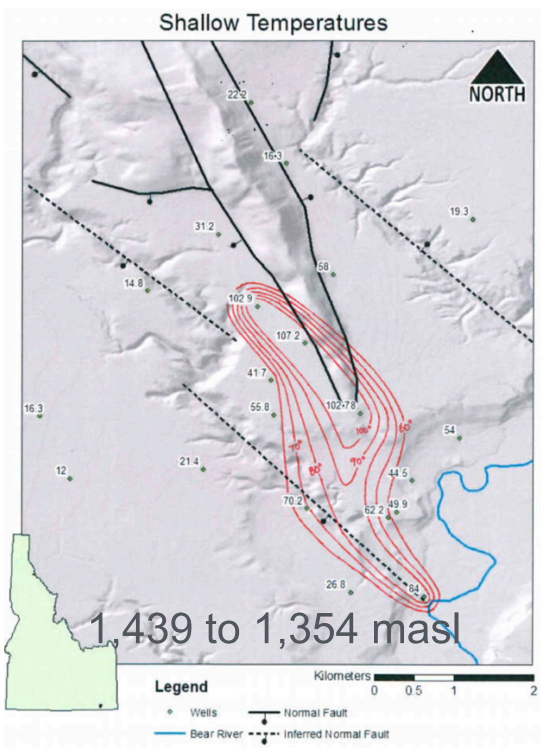


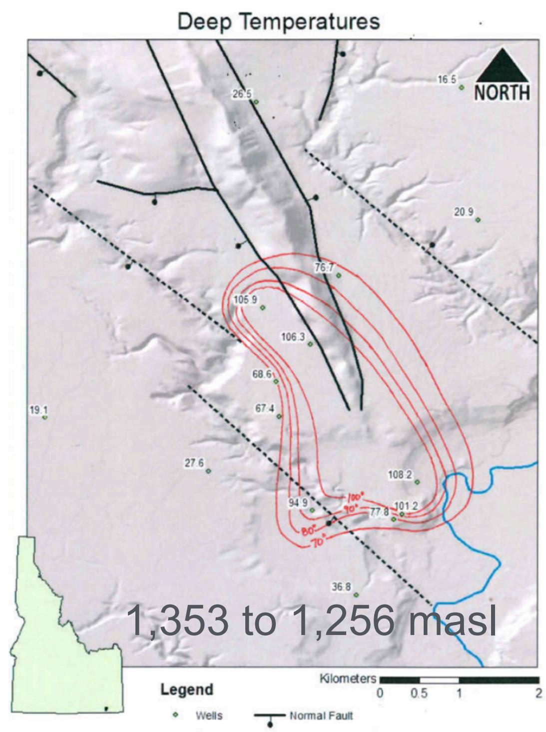


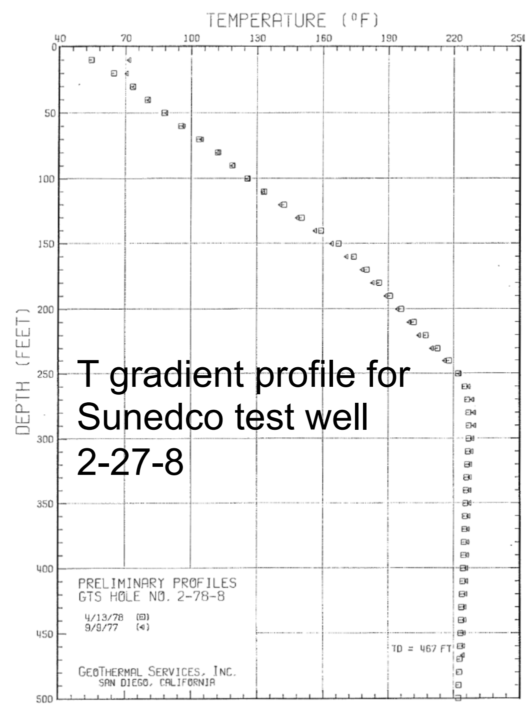
Methods/Approach: Preston Structural and Temperature Maps

Structural and temperature maps delineate thermal anomaly

Worthing, 2016







Methods/Approach: Database

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- Quality and integrity of existing and new data were checked by acquiring original publications, testing charge balance errors, and evaluating completeness of chemical components
- For structural classification, a scheme based on Faulds et al. (2011) for Basin and Range geothermal systems was adopted
- Finally, sequentially refined dataset based on multiple PCA analyses conducted to select appropriate parameters that capture the overall variance was used for final principal component and cluster analyses

Water composition (mg/L), location, and structural ratings for thermal/non-thermal features of several southern Idaho and southeastern Oregon KGRAs and IHRAs

KGRA/ IHRA	Feature Name	Latitude	Longitude	Depth (ft)	T (°C)	pH	Conduct. (uS/cm)	TDS (mg/L)	Ca	Mg	Na	K	SiO_2	Li	B	HCO_3 + CO_3	F	Cl	SO4	Fault Rating	Refs.
Alvord	Alvord Hot Spring	42.544333	-118.527667	NA	76	6.73	4590	3411	13	2.2	960	69	120	2.10	30	1197	10	780	220	62	1,2,3
	Hot Borax Lake	42.326667	-118.602833	NA	36	7.28	2410	1842	16	0.30	500	31	190	0.65	17	421	9	300	350	36	1,2,3
	Mickey Springs	42.676667	-118.345000	NA	73	8.05	2490	2073	0.9	0.10	550	35	200	1.10	11	785	16	240	230	56	1,2,3

Ref. 1: This study; 2: Mariner et al. (1974); 3: Mariner et al. (1980); 4: Benoit (1976); 5: Young et al. (1975); 6: INL unpub data; 7: LBNL unpub data; 8: Rightmire et al. (1976); 9: Young and Lewis (1982); 10: Mitchell (1976a); 11: Mattson et al. (2016); 12: NWIS; 13: Young and Mitchell (1973); 14: Mitchel et al. (1980); 15: Bartholomay and Twining (2010); 16: Young and Whitehead (1975); 17: Neupane et al. (2015); 18: Black et al. (1994); 19: Brown et al. (1980); 20: Lewis and Stone (1988); 21: Freeman (2013); 22: Young (1977); 23: Mitchell (1976b); 24: Dolenc et al. (1981); 25: Crosthwaite (1976); 26: Culp et al. (2015); 27: Ricker and Niewendorp (2012); 28: Gannett (1988); 29: Dellechaie (1975).

A portion of a screenshot of database table used for statistical analysis – uploaded to GDR

Principal Component Analyses

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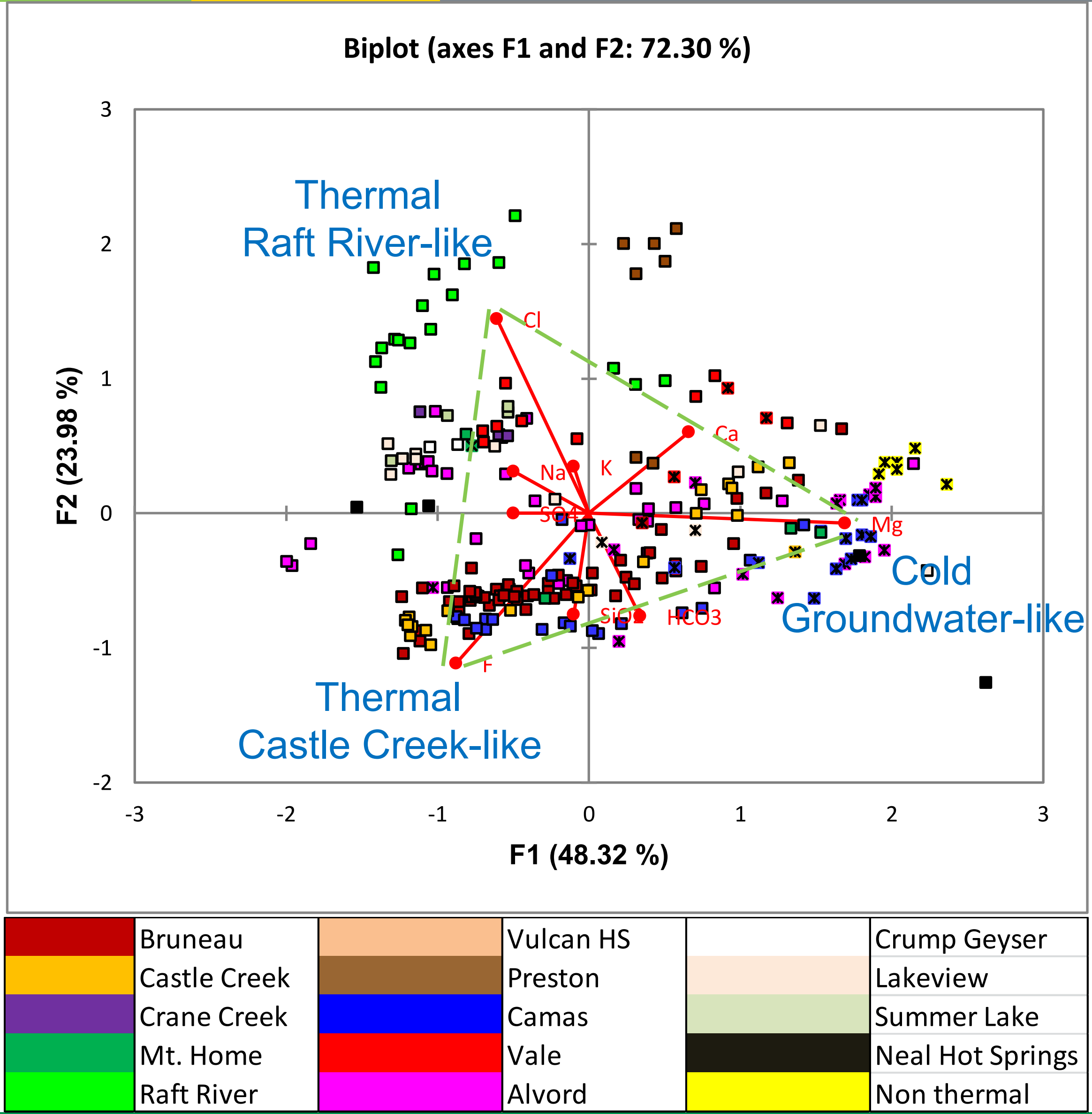
- Start with full data set:
  - Chemistry, T, location, structure
- Nine chemistry variables capture the variability as well as, and possibly more clearly, than the full dataset
  - Na, K, Ca, Mg, SiO_2, Cl, HCO_3, SO_4, and F
- Three main signatures
  - Raft River-like (Na,K,Cl)
  - Castle-Creek-like (F)
  - Groundwater-like (Ca, Mg)
- Sites most "like" Raft River
  - Vale, Alvord, Mt Home, Summer Lake, Crane Creek, Lakeview, Crump Geyser
- Wide range sites (cold & hot)
  - Bruneau, Camas, Castle Ck.

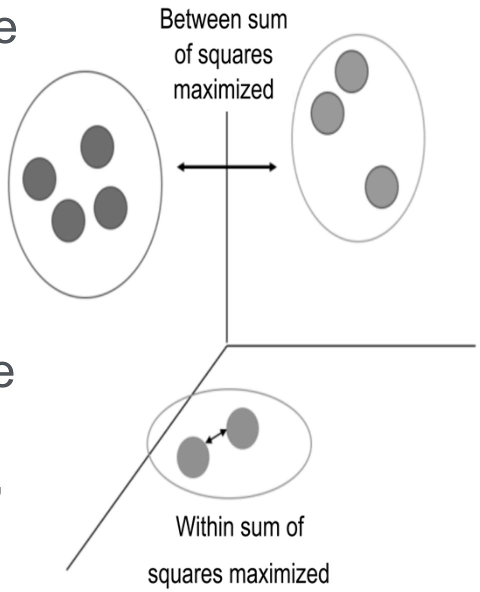


Two Primary Methods

- Hierarchal Cluster Analysis
  - Helps define optimum cluster number for the K-means analysis
- K-means Cluster Analysis

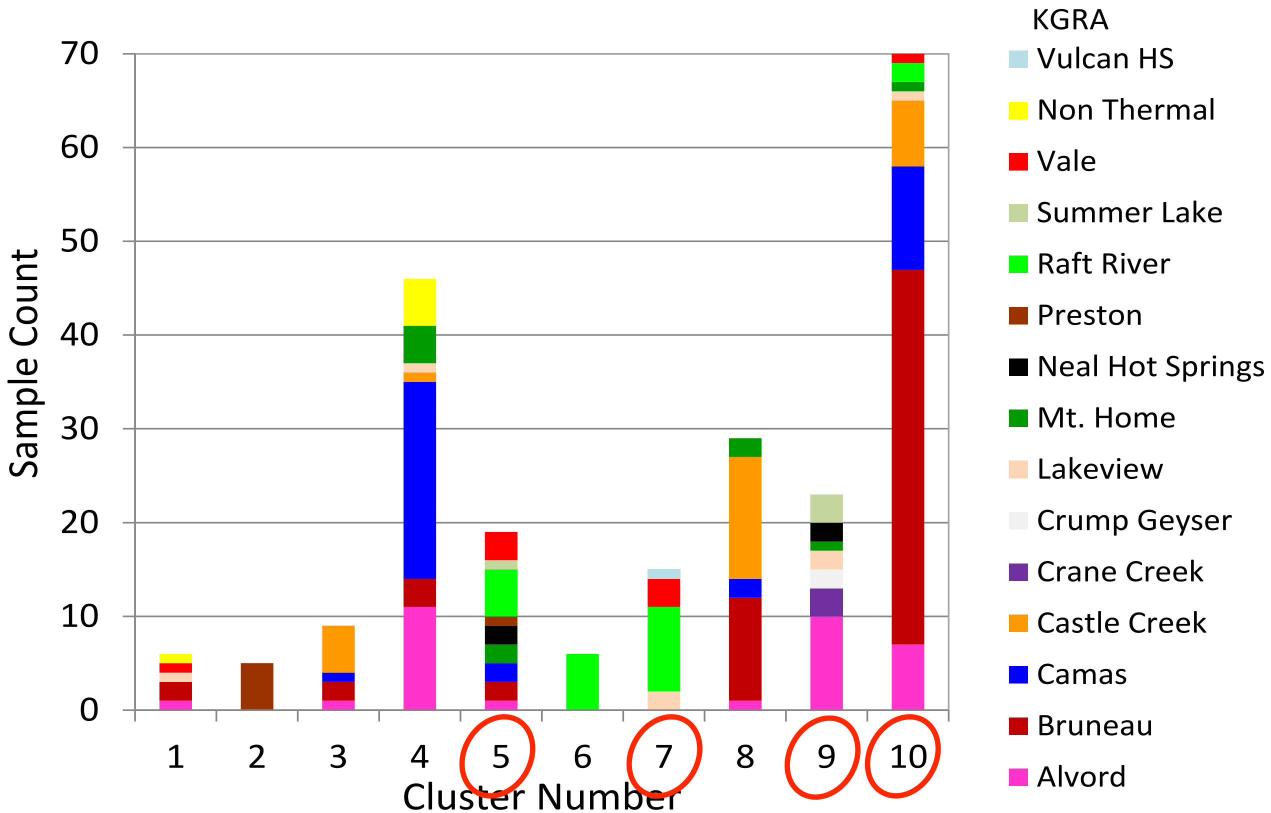
Final Cluster Analysis

1) A number of clusters, k, is chosen by the investigator (from hierarchal).
2) K objects are chosen and placed into the K clusters, one object per cluster. The distances between all other, yet-to-be classified objects and the initial set of k classified objects are calculated, and each object is placed in the cluster to which it is the closest. Once all the objects have been binned, the sum of squares is recalculated for the entire dataset.
3) Objects are moved from one cluster to another cluster, and the sum of squares is evaluated for the new groupings.
4) If the sum of squares decreases for the new groupings, the groupings are retained. Otherwise, replace the objects in the original groups.
5) Repeat steps 2, 3, and 4 until convergence is achieved (i.e., until further reductions in the sum of squares are small enough to be considered)



Cluster Analysis Results

- Use the data set constrained by PCA analyses: Na, K, Ca, Mg, SiO_2, Cl, HCO_3, SO_4, F
- K-means clustering; 10 to 12 clusters determined optimal for analyses
- High-potential clusters (#5, #7, #9 and #10) defined by samples from producing geothermal fields (Raft River, Neal H.S. and Summer Lake/Paisley)
  - ➔ Alvord, Bruneau, and Castle Creek fall in the high-potential clusters



Technical Accomplishments and Progress

- Comprehensive literature review of previous studies of KGRAs and other identified geothermal resource areas in southern Idaho and eastern Oregon
- Extensive geochemical sampling of thermal features in southern Idaho, with focused sampling of Preston, Bruneau, and Camas Prairie areas
- Analysis and publication of geochemical results using multicomponent geothermometry and isotope geochemistry techniques
- Developed geochemical database of 14 resource areas and one non-thermal control area and conducted cluster and PCA analysis to identify most prospective areas
- The identification of three prospective areas (Alvord, Bruneau, and Castle Creek KGRAs) meets our original project objective – these areas will be reassessed
- Major funding changes resulted in changes in scope and schedule of project

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Conduct comprehensive literature review	Conduct comprehensive literature review	Jan. 2015
Conduct field sampling and analysis for selected regions to fill data gaps	Conduct field sampling and analysis for selected regions to fill data gaps	Aug. 2016
Develop criteria and ranked list to identify overlooked KGRAs	Develop PCA/cluster analysis of KGRAs and IGRAs and identify most prospective areas for future study	July 2017

Research Collaboration and Technology Transfer

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- Our project has a key partner – The **University of Idaho**. We have worked closely with Profs. Tom Wood and Jerry Fairley, and their students have worked on this project. Wade Worthing conducted his MS thesis work on the Preston geothermal system, and Cary Lindsey performed a cluster analysis of the KGRAs in our study area.
- We have interacted with members of the geothermal industry (Dick Benoit, Jim Munoa, and Roy Mink) to obtain unpublished data for the Preston, Camas Prairie and Alford areas.
- We have collaborated closely with the **Snake River Plain Play Fairway Analysis team** on the Camas Prairie area – our geochemical work forms a key part of their conceptual model of the system
- We have presented and published four papers on our work at the Stanford Geothermal Workshop and submitted a manuscript on our cluster/PCA study to Geothermics
- The **comprehensive geochemical data set** used for our cluster/PCA analysis was **submitted to the GDR**

Future Directions

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- Our recent cluster and PCA analysis of the comprehensive database developed from the KGRAs and selected identified geothermal resource areas has identified three KGRAs (Alvord, Bruneau, and Castle Creek) that merit additional study. We will identify potential data gaps for these areas and conduct field work in FY18 to develop updated models for these systems.
- Our team will also monitor developments with the Snake River Plain play fairway Phase 3 study of the Camas Prairie – this was one of our focus areas in 2016.
- Following our planned field work, we will write up a final report summarizing our key findings

Milestone or Go/No-Go	Status & Expected Completion Date
Identify critical exploratory components missing from high-graded KGRAs	December 2017
Collect and analyze additional samples to fill data gaps and update model	June 2018
Write up final report and submit remaining data to GDR	September 2018

Mandatory Summary Slide

- The USGS identified significant identified hydrothermal resources in Idaho and Oregon – however, very little resource deployment has occurred in these states
- Using new geochemical and statistical analysis techniques and new data obtained from field sampling, our team has identified three KGRAs (Alvord, Bruneau, and Castle Creek) as meriting additional examination
- Our team developed key geochemical data for the Camas Prairie area shared with the Snake River Plain Play Fairway Analysis team that helped identify a potential drilling target for their Phase 3 model validation activities

Field Photos

University of Idaho

CAES
Center for Advanced Energy Studies

INL
Idaho National Laboratory

BERKELEY LAB
Lawrence Berkeley National Laboratory