U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Hydrogeochemical Indicators for Great Basin Geothermal Resources

Project Officer: Eric Hass

Total Project Funding: $1.2 million

April 24, 2013

Principal Investigator
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Relevance/Impact of Research

- Determine fundamental controls on fluid-mineral equilibria in six geothermal systems across the Great Basin to develop and calibrate chemical geothermometers
- Model reactive transport processes affecting reservoir fluids as they ascend and quantify changes in compositions due to boiling, mixing, cooling, mineral precipitation and dissolution starting at Desert Peak.
- Formulate and advance geochemical exploration tools for the cost effective discovery and sustainable management of geothermal resources in the Great Basin, USA.
- Help to discover and sustainably manage geothermal reservoirs, advancing hydrothermal resource confirmation
- First application to Great Basin geothermal resources

Scientific/Technical Approach

- Use field/analytical data for thermal waters and minerals to determine states of fluid-mineral equilibria that underpin chemical geothermometry
- Use numerical modeling to quantify the effects that potentially modify an equilibrated reservoir water as it rises to the surface
- Showed that fluid-mineral equilibria is partially to fully developed in six Great Basin geothermal systems showing the promise of conventional chemical geothermometry, with some modifications.
- Key issues deal with geological characterization of reservoirs including P-T-X structure, poro-perm distribution, mineralogy, & fluid chemistry data

Scientific/Technical Approach

Field/lab data for evaluation of fluid-mineral equilibria/chemical geothermometers

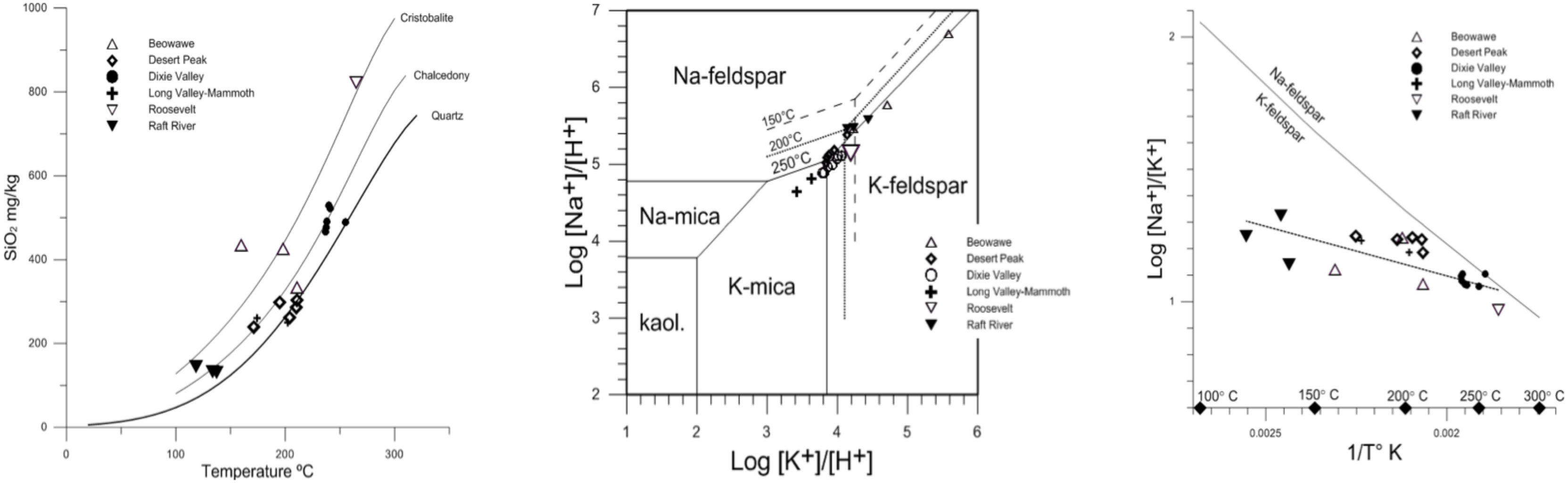
System/well	Res/Max T°C	pH (lab)	Li	Na	K	Ca	Mg	Cl	F	SO4	HCO3	B	SiO2	Source
Beowawe														
Rossi 21-19	198	8.10	0.90	143	14.0	24.0	7.10	25	2.8	28	145	0.9	427	Cole & Ravinsky, 1984
Ginn 1-13	211	8.40	1.40	203	30.0	11.0	0.30	59	7.9	47	260	1.7	335	Cole & Ravinsky, 1984
85-18	160	9.10	1.90	277	35.0	2.5	0.30	31	18	76	267	2.0	436	Cole & Ravinsky, 1984
Desert Peak														
21-1	204	8.29	4.00	2500	251.0	114.0	0.11	4350	nd	104	38	18.2	296	BM Kennedy (unpublished LBNL data)
67-21	210	8.17	nd	3040	312.0	183.0	0.12	5350	nd	128	33	20.0	336	BM Kennedy (unpublished LBNL data)
77-21	195	8.33	nd	2990	306.0	149.0	0.13	5080	nd	121	44	23.7	337	BM Kennedy (unpublished LBNL data)
86-21	211	8.18	nd	2830	324.0	148.0	0.08	5030	nd	97	32	22.6	357	BM Kennedy (unpublished LBNL data)
74-21	171	8.36	nd	3180	316.0	227.0	1.18	5670	nd	189	55	21.2	252	BM Kennedy (unpublished LBNL data)
Dixie Valley														
76-7 DV96-8	255	9.09	2.29	474	69.5	8.5	0.03	524	13.4	201	121	11.6	599	Goff et al., 2002
74-7 DV97 14+15	238	9.06	2.43	500	72.2	9.2	0.01	584	13.5	204	71	11.8	586	Goff et al., 2002
82a-7 DV97 20+21	237	9.05	2.22	495	72.6	9.6	0.01	575	14.5	212	125	11.7	556	Goff et al., 2002
73b-7 DV97 22-23	238	9.07	2.34	499	76.4	9.1	0.01	571	13.7	212	128	11.7	569	Goff et al., 2002
27-33 DV97 25+27	240	9.03	2.22	423	66.8	7.7	0.01	443	14.7	183	184	9.2	627	Goff et al., 2002
37-33 DV97 28+29	241	9.16	2.26	431	68.8	7.2	0.02	475	16.1	191	165	9.5	621	Goff et al., 2002
27-33 Reed '89	250	9.70	2.98	438	69.7	1.0	0.01	352	15.2	139	454	11.9	710	Reed, 1989
Mammoth-Long Valley														
Shady Rest	202	5.90	2.80	369	43.0	7.4	0.20	280	12	159	375	12.0	250	Tempel et al., 2011
Casa Diablo MBP-4	174	6.00	nd	350	36.0	6.9	0.24	230	10	110	440	10.0	260	Tempel et al., 2011
Roosevelt														
14-2	265	6.20	2.26	2200	410.0	6.9	0.08	3650	4.8	60	170	28.0	1002	Capuano & Cole, 1982
Raft River														
RRG-1	137	7.19	1.89	670	83.2	56.2	0.11	1181	7.07	62.1	40	0.5	132	B Ayling & J Moore (unpublished EGI data)
RRG-4	134	7.50	1.92	537	43.5	50.8	0.15	833	7.3	59.2	66	0.5	134	B Ayling & J Moore (unpublished EGI data)
RRG-7	119	7.00	4.44	1610	158.0	217.0	0.90	3000	4.74	59.3	33	0.6	145	B Ayling & J Moore (unpublished EGI data)

Accomplishments, Results and Progress

- Task 1: Compute states of fluid-mineral equilibria in geothermal reservoirs & test chemical geothermometers
  - Showed that full to partial equilibrium exists in 6 geothermal systems across the Great Basin
  - Demonstrated that the equilibrium mineral assemblage is made of quartz, chalcedony, Na-feldspar, K-feldspar, K-mica, Mg-chlorite, and calcite
  - Used thin section and XRD analyses (50 rock samples) to prove that the equilibrium assemblage is widespread
  - Showed that the most reliable geothermometers are based on aqueous silica and quartz/chalcedony solubility
  - Showed that Na/K ratios represent equilibration temperatures (~250°C), but that these overestimate reservoir temperature and possibly reflect much deeper, hotter conditions
  - Showed that a linear trend in Na/K vs reservoir T°C could be formulated into a new provisional geothermometer
  - Showed that there is moderate to low confidence in the application of the K/Mg geothermometer

Accomplishments, Results and Progress

- Task 1: Compute states of fluid-mineral equilibria in geothermal reservoirs & test chemical geothermometers (continued)



Examples of phase diagrams plotted with concentrations of aqueous components; the dashed linear correlation of Log [Na^+]/[K^+] vs 1/T ° K (far right graph) is used to write a new Na/K geothermometer (below):

$$t^{\circ}\mathrm{C} = \frac{373}{\log\left[\frac{Na}{K}\right] - 0.351} - 273$$

Accomplishments, Results and Progress

- Task 1: Compute states of fluid-mineral equilibria in geothermal reservoirs & test chemical geothermometers (continued)
  - the reliability of old analytical data for geothermal fluids is questionable & new fluid analyses need to be obtained (Beowawe & Roosevelt)
  - no measurable fluid inclusions were found to test for modern thermal equilibria, and instead we initiated a study of fractured crystalline rocks from Coso and Steamboat Springs to evaluate microscopic hydrothermal alteration effects as a proxy for an EGS resource

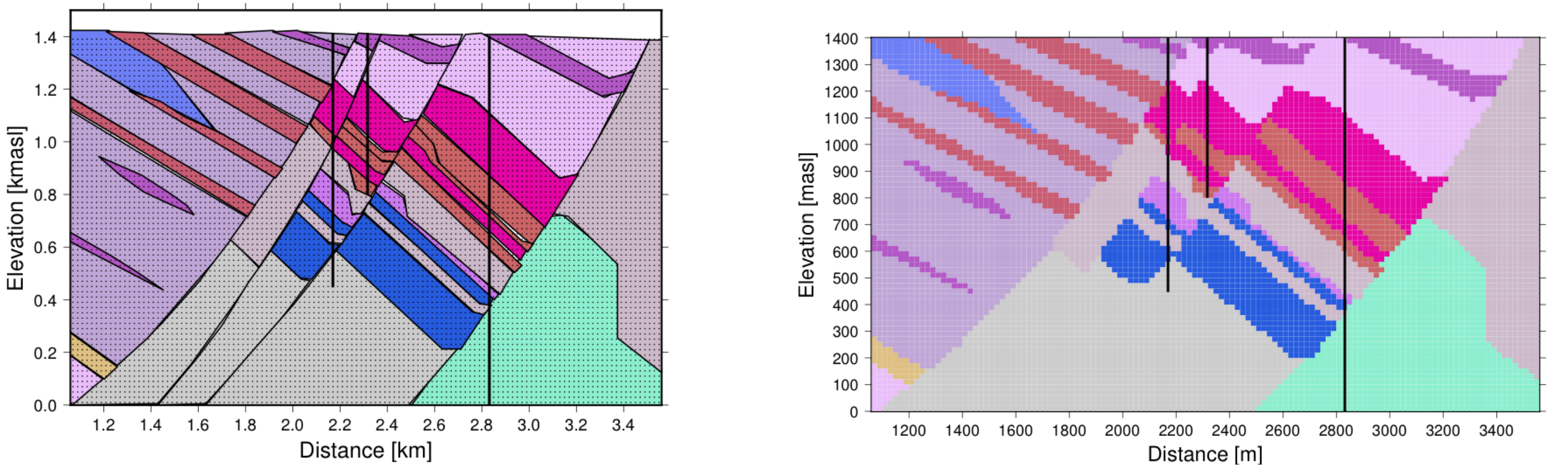
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Compute states of fluid-mineral equilibria, analyze minerals in rocks, test for existence of fluid inclusions, formulate a chemical geothermometer	Computed states of fluid-mineral equilibria, analyze minerals in rocks, tested for existence of fluid inclusions, formulated a chemical geothermometer	12/31/2012

Accomplishments, Results and Progress

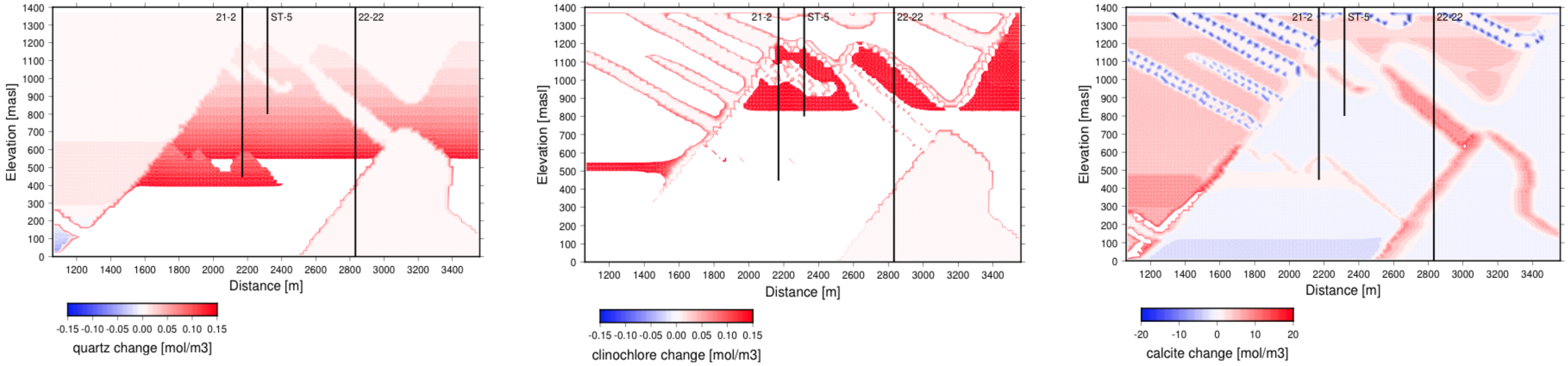
- Task 2: Develop a state-of-the art 2-D numerical thermal-hydrological-chemical model of the Desert Peak geothermal area
  - Created a mesh for a 2-D cross-section 2.5 km long & 1.4 km deep, subdivided into 20 x 20 m grid blocks,
  - Developed preliminary data set for hydrological, mineralogical, & thermal properties with detailed lithology from Faulds et al., 2012
  - Utilized a dual permeability model for reactive transport to capture the effects of fluid flow through fractured rock, and fracture-matrix interaction effects
  - Ran preliminary simulations for 2300 years (2 days computational time) but reservoir temperatures had still only reached ~80°C, less the Tres ~ 210°C
  - Showed that the application of multi-component chemical geothermometers on modeled thermal waters closely match the model temperatures
  - Mapped out changes in the dissolution-precipitation of key hydrothermal minerals to show how fluid-mineral equilibria was being established during early stages of hydrothermal fluid flow
  - Proved the viability of TOUGHREACT numerical modeling for assessing time-dependent changes in fluid-mineral equilibria and their effects on the evolving compositions of hydrothermal fluids and the distributions of secondary minerals

Accomplishments, Results and Progress

- Task 2: Create a 2-D numerical thermal-chemical-hydrological model of Desert Peak (continued)



The Desert Peak cross section (left) showing stratigraphy and structure, and the corresponding mesh of 20x20 m grid blocks (right)



Change in mineral abundances (moles mineral/m^3 of rock) over 1000 years. Wells are plotted as black lines. Spotty regions of dissolution/precipitation are contouring artifacts.

Accomplishments, Results and Progress

- Task 2: Create a 2-D numerical thermal-hydrological-chemical model of Desert Peak (continued)
  - longer simulation times are required to bring the thermal structure of the system to a modern state
  - once deeper units are added to the geological model and the associated fault zone properties are incorporated, then hotter fluids can be assessed
  - shallow level effects yet to be studied and evaluated

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Create 2D thermal-chemical-hydrological model, determine flow paths and thermal structure, incorporate themodynamics & reaction kinetics, assess shallow level effects	Create 2D thermal-chemical-hydrological model, determine flow paths and thermal structure, incorporate themodynamics & reaction kinetics, obtained preliminary model	3/15/2013

Future Directions

- Investigate in detail the effects of fluid-mineral equilibria and prove chemical geothermometers for resource evaluation in geothermal systems across the Great Basin
  - Acquire new fluid analyses and analyze for major, minor and trace components
  - Incorporate at least four additional geothermal systems
  - Advance study of microscopic effects of hydrothermal alteration on young fractures in crystalline rocks as a proxy for EGS water-rock interaction effects

Milestone	Status/Expected Completion Date
fluid-min equilibria; ≥10 systems total	Proposed 12/31/2014
acquire ~30 thermal fluid analyses	Proposed 12/31/2014
acquire new mineralogical data: occurrence & compositions	Proposed 12/31/2014
identify incipient hydrothermal phases in fractures	Proposed 12/31/2014
identify hydrogeochemical indicators for geothermal resources	Proposed 12/31/2014

Future Directions

- Finalize 2D thermal-chemical-hydrological model of Desert Peak
  - Evaluate spatial patterns in fluid-mineral equilibria
  - Quantify shallow changes to fluid chemistry due to boiling, mixing, cooling, mineral dissolution-precipitation
- Evaluate performance of GeoT on Great Basin geothermal resources

Milestone	**Status/Expected Completion Date**
refine model by deepening section & improving permeability structure	Proposed 12/31/2014
incorporate new mineralogical/hydrological data, including data based on simulations of high-T experiments	Proposed 12/31/2014
run model simulation out for geologically realistic period, and compare to samples collected from production and groundwater wells	Proposed 12/31/2014
evaluate geothermometers on simulated fluid compositions	Proposed 12/31/2014

Mandatory Summary Slide

- Phase I objectives mostly achieved.
- Demonstrated fluid-mineral equilibria are an important control on deep thermal water compositions and that these provide the basis for geothermometers.
- Discovered unexpected Na/K vs temp trend which is formulated into an empirical chemical geothermometer.
- Demonstrated the viability of TOUGHREACT numerical simulation involving coupled chemical, thermal, and hydrological modeling.
- Showed that the modeling provides a test bed for assessing time dependent changes in hydrothermal fluid compositions.

Project Management

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
10/1/2011	12/31/2014	1/1/2012	12/31/2014

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$1,038,000	$168,000	$368,000	$368,000	$368,000	$838,000

- Phase I (2012, no cost share)
  - Funds spent on salaries, meetings, and lab analyses
  - Synergistic with Dixie Valley thermal-chemical-hydrological modeling & chemical signatures of fracture stimulation at Desert Peak
  - Preliminary outcomes presented at Stanford Geothermal Workshop
- Phase II (2013-14, 20% cost share)
  - Funds to be spent on salaries, field work, meetings, and lab analyses
  - Cost share U Utah and industry (Newmont)
  - 4 Industry partners identified