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Conrad

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Geochemistry Sampling for Traditional and Multicomponent Equilibrium Geothermometry in Southeast Idaho

Cody Cannon^{1,2}, Thomas Wood^{1,2}, Ghanashyam Neupane^{2,3}, Travis McLing^{2,3},
Earl Mattson³, Patrick Dobson⁴, and Mark Conrad⁴

¹University of Idaho-Idaho Falls, Idaho Falls ID

²Center for Advanced Energy Studies, Idaho Falls ID

³Idaho National Laboratory, Idaho Falls ID

⁴Lawrence Berkeley National Laboratory, Berkeley CA

cann8218@vandals.uidaho.edu

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ABSTRACT

The Eastern Snake River Plain (ESRP) is an area of high regional heat flux due to the movement of the North American Plate over the Yellowstone Hotspot beginning ca. 16 Ma. Temperature gradients between 45–60 °C/km (up to double the global average) have been calculated from deep wells that penetrate the upper aquifer system (Blackwell 1989). Despite the high geothermal potential, thermal signatures from hot springs and wells are effectively masked by the rapid flow of cold groundwater through the highly permeable basalts of the Eastern Snake River Plain aquifer (ESRPA) (up to 500+ m thick). This preliminary study is part of an effort to more accurately predict temperatures of the ESRP deep thermal reservoir while accounting for the effects of the prolific cold water aquifer system above. This study combines the use of traditional geothermometry, mixing models, and a multicomponent equilibrium geothermometry (MEG) tool to investigate the geothermal potential of the ESRP. In March, 2014, a collaborative team including members of the University of Idaho, the Idaho National Laboratory, and the Lawrence Berkeley National Laboratory collected 14 thermal water samples from and adjacent to the Eastern Snake River Plain. The preliminary results of chemical analyses and geothermometry applied to these samples are presented herein.

1. Introduction

High thermal fluxes in the ESRP were first documented in the early 1970's (Brott et al., 1976). Heat flow values of 110 mW/m² have been calculated below the ESRPA and values over 150 mW/m² have been projected for depths to 6 km (Blackwell and Richards, 2004). Yet, to date, geothermal exploration in the area has had little success due to the masking of the geothermal systems by a huge volume of cold groundwater moving through

the ESRPA, which originates as snowmelt from the Yellowstone Plateau and surrounding mountain basins through the overlying the prolific ESRPA. The Idaho National Laboratory (INL), the University of Idaho – Idaho Falls (UI-IF), and Lawrence Berkeley National Laboratory (LBNL) are partnering on a project that will improve upon conventional geothermometry and help identify hidden geothermal reservoirs beneath the ESRPA. This project is aimed at applying traditional (cation and silica), isotopic, and multicomponent equilibrium geothermometry coupled with mixing models to waters throughout the ESRP and southern Idaho.

Although there have been several reported water compositions (e.g., Ross, 1971; Young and Mitchell, 1973; Ralston et al., 1981; Lewis and Young, 1982; Wood and Low, 1988; Parlman and Young, 1992; Mariner et al., 1991, 1997; McLing et al., 2002) for many ESRP springs/wells, the reported chemical analyses often do not provide complete chemical compositions. The current sampling campaign is aimed at measuring aluminum as well as several isotope compositions in spring and well waters. Here we describe the first sampling campaign conducted over five days in March of 2014 and present the preliminary results.

2. Geology and Geothermal Setting

The ESRP (Figure 1) is formed by crustal down-warping, faulting, and successive caldera formation that is linked to the middle Miocene to recent volcanic activities associated with the relative movement of the Yellowstone Hot Spot (Pierce and Morgan, 1992; Hughes et al., 1999; Rodgers et al., 2002). The ESRP consists of thick rhyolitic ash-flow tuffs, which are overlain by >1 km of Quaternary basaltic flows. The rhyolitic volcanic rocks at depth are the product of super volcanic eruptions associated with the Yellowstone Hotspot. These rocks progressively become younger to the northeast towards the Yellowstone Plateau (Pierce and Morgan, 1992; Hughes et al., 1999). The younger basalt layers are the result of many low-volume, monogenetic shield-forming eruptions of short-duration that emanated from northwest trending volcanic rifts in the wake of the Yellowstone Hot Spot (Hughes et al., 1999). The thick sequences of coalescing basalt flows with interlayered fluvial and eolian sediments in the ESRP constitute a

very productive aquifer system above the rhyolitic ash-flow tuffs (Whitehead, 1992; Neilson et al., 2012; Shervais et al., 2013).

Recent volcanic activity, a high heat flux, and the occurrence of numerous peripheral hot springs suggest the presence of undiscovered geothermal resources in the ESRP (e.g., Nielson and Shervais, 2014). As a consequence of these geologic indicators, we hypothesize that the ESRP at depth hosts a large geothermal resource with the potential for one or more viable conventional or enhanced geothermal reservoirs. In particular, we consider the lower welded rhyolite ash-flow tuff zone (Figure 2) to have exploitable heat sources that can be tapped by Enhanced Geothermal System (EGS) development. However, the regionally extensive and cold-water ESRPA coupled with interactions of the upwelling thermal waters with basalt at the base of the aquifer (Morse and McCurry, 2002) is likely masking the expression of the deep thermal resource (Figure 2).

3. Sampling Method

Sampling of thermal waters in southeast Idaho is driven by the need to analyze for parameters required for the MEG analysis, which were usually not analyzed in previous geothermal sampling efforts. For example, many reported geothermal waters do not have measured aluminum concentrations (Pang and Reed, 1998). In addition to collecting water samples for MEG, this sampling event served as an opportunity to establish procedures and assemble the sampling equipment required for the remainder of the project. To this end, our selection of sampling sites included a range of field conditions, including improved and unimproved thermal springs and thermal wells spread over a 500 km circuit in southeast Idaho (Figure 1 sampling locations). The different conditions allowed us to test and evaluate our methods and equipment to ensure that our sampling team was prepared for the extensive

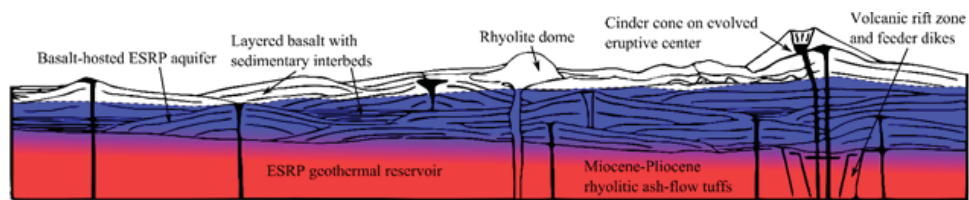


Figure 2. Schematic cross-section across the ESRP (Neupane et. al., 2014) showing underlying rhyolitic ash-flow tuffs and overlying basalt flows with few sedimentary layers. The rhyolite ash-flow tuffs underlying the basalt aquifer system are assumed to be the ESRP geothermal reservoir.

sampling campaign planned for the summer of 2014. Health and safety documentation and standard procedures were approved by cognizant personnel at the Center for Advanced Energy Studies (CAES), Idaho Falls, ID. A mobile field sampling trailer was constructed to protect equipment and staff from harsh environmental conditions often present in southeast Idaho.

Field parameters were measured in a flow through cell (YSI® 6850) including: pH, oxidation-reduction potential, dissolved oxygen, temperature, and conductivity. Water was filtered through a 0.45 micron filter prior to storage in acid-cleaned sample bottles (cation and trace metal samples) and water (nanopure)-cleaned bottles (anion samples). Cation and trace metal samples were acidified in the field to a pH ≤ 2 and alkalinity titration was conducted in the field immediately after collection of sample. He isotope samples (either dissolved gas in water or gas) were collected using Cu tubing and refrigerator clamps. Water samples were transported to the laboratory at 4–6 °C, and stored in a refrigerator at 4 °C until chemical analysis. Chemical analyses of sampled waters were performed in the Analytical Chemistry Laboratory located in the CAES building. Major cations (Ca, K, Mg, Na, and SiO₂ (aq)), major anions (F, Cl, SO₄, and NO₃), and trace elements (Al, B, Li, and Sr) were analyzed with ICP-OES, Ion chromatography, and ICP-MS, respectively. Samples with low concentration of Mg were also analyzed with ICP-MS for this constituent. Bicarbonate concentration in water samples was calculated from field-alkalinity data using Geochemist's Workbench (Bethke and Yeakel, 2012).

4. Results

4.1 Chemistry of ESRP waters

Locations, field temperatures, and chemistries of water samples collected from 14 springs/wells in the ESRP and surrounding areas are presented in Table 1. Major cations and anionic species in these waters are also presented in Figure 3. All the springs/wells visited in the March sampling campaign represent the expression of the geothermal system (field T > 20 °C) in the ESRP. The highest field temperature is recorded at Miracle Hot Springs (58.4°C). With the exception of Heise Hot Spring (pH 6.34), all other springs/wells are issuing neutral to slightly basic waters (Table 1). Heise Hot Springs is also different from all other waters because of its high total dissolved solids (TDS). Classification (type) of water based on dominant aqueous species in the sampled waters is also given in Table 1. Validation of our sampling and analytical methods was achieved from a comparison between the chemical concentrations of some of our March samples (Condie HS, Green Canyon HS, Heise HS, Lidy

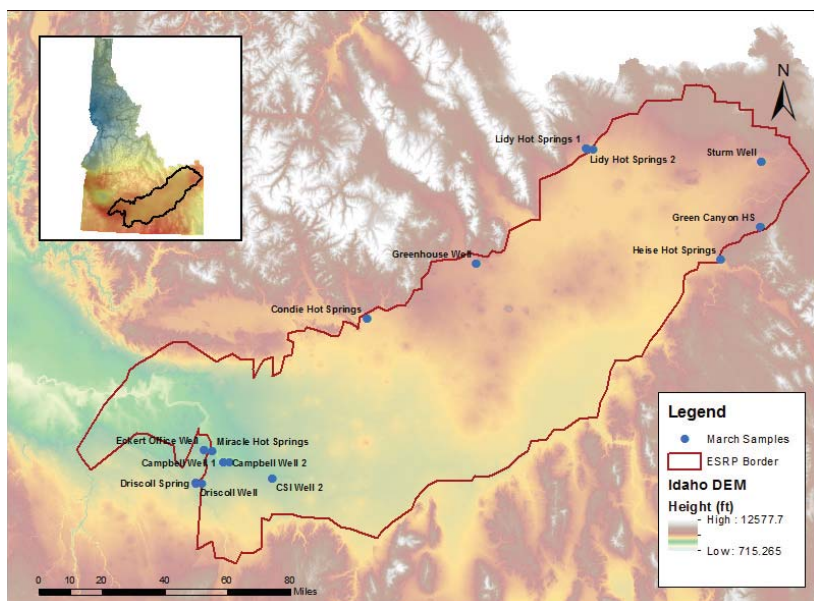


Figure 1. Digital Elevation Map of the ESRP showing locations of March 2014 Samples.

Table 1. Chemistry of ESRP spring & well waters (in mg/L unless noted otherwise).

Springs/Wells	Latitude	Longitude	T (°C) ¹	pH	Ca	K	Mg	Na	SiO ₂ (aq)	Li ²
Heise HS	43.64283	-111.68768	48.2	6.32	488	206	94	1540	33.6	2478
Lidy HS 1	44.14558	-112.55494	56.1	7.17	66.2	13.2	15.6	25.4	37.8	45.3
Lidy HS 2	44.14166	-112.5524	52.3	7.21	64.2	13.5	16.3	27.6	34.2	46.8
Green Canyon HS	43.79211	-111.44009	44	7.2	144	4.5	33.8	5	27	14.8
Sturm Well	44.09325	-111.43534	31.4	8.73	3.2	0.89	0.05	33.2	63.1	49.8
Condie HS	43.33278	-113.9179	50.5	7.03	61.1	22.5	11.5	62.4	29.5	89.3
Greenhouse Well	43.60234	-113.24214	36.3	7.09	77.8	9.4	27.7	33.8	31.6	39.9
Eckert Well	42.6994	-114.9104	24.7	9.47	5.7	4.2	0.74	112.8	52	9.3
Campbell Well 1	42.64497	-114.78706	34.5	7.98	23.5	7.7	3	57.5	71.9	56.9
Campbell Well 2	42.64432	-114.78294	34.4	7.96	26.7	8	3.5	55.9	69.4	56.3
Miracle HS	42.69457	-114.85592	58.4	9.53	0.8	1.9	0	128.2	99.5	46.2
Driscoll Well	42.54479	-114.94855	37.5	8.59	11.2	1.4	0.4	149.4	45.5	188.1
Driscoll Spring	42.54348	-114.94897	36.2	8.65	11.1	1.9	0.8	146.6	48.4	189.6
CSI Well 2	42.58318	-114.47496	38.1	8.79	4.5	3.3	0.2	94.9	64.2	10.7

Springs/Wells	Al ²	Sr	B	F	Cl	SO ₄	NO ₃	HCO ₃	Type
Heise HS	15.9	5.5	4.5	4	2268	712	< LOD ³	923	Na-Cl
Lidy HS 1	1.1	0.6	0.09	4.6	7.3	101.9	< LOD ³	127	Ca-HCO ₃
Lidy HS 2	0.9	0.61	0.09	4.7	6.9	98.3	< LOD ³	158	Ca-HCO ₃
Green Canyon HS	0.62	1.2	0.02	1.5	0.94	314.2	2.1	131	Ca-SO ₄
Sturm Well	5.2	0.005	0.04	2.1	3.3	5.8	0.63	62	Na-HCO ₃
Condie HS	0.81	0.93	0.26	1.6	14	33.5	2.7	306	Ca-HCO ₃
Greenhouse Well	0.63	0.72	0.15	0.74	22.2	57.5	6.6	279	Ca-HCO ₃
Eckert Well	4.5	0.02	0.19	12.2	46.5	90.9	1.2	60	Na-SO ₄
Campbell Well 1	0.48	0.16	0.11	2.2	23.1	40.5	5.4	141	Na-HCO ₃
Campbell Well 2	0.68	0.18	0.11	2.5	20	31.8	4.7	124	Na-HCO ₃
Miracle HS	15.9	0	0.33	22.4	31.7	33.7	< LOD ³	59	Na-F
Driscoll Well	3.3	0.06	0.12	2.4	53.3	188	1.4	89	Na-SO ₄
Driscoll Spring	11.5	0.07	0.11	2.4	53.6	186.6	< LOD ³	91	Na-SO ₄
CSI Well 2	1.1	0.02	0.15	9.6	26.4	46.8	4.9	117	Na-HCO ₃

¹ Field temperature (°C)² Concentration in µg/L³ Below limits of detection

HS, Miracle HS, and Sturm Well) with available data from other sources (McLing et. al, 2002; Young and Mitchell 1973; Ralston et. al, 1981).

4.2 Traditional Geothermometry

After processing the results from chemical analyses, certain chemical constituents (SiO₂, Na, K, Ca, and Mg) are run through a series of traditional geothermometers based on temperature dependent chemical equilibria and the assumption of an unaltered chemical composition from source to surface expression. These include the silica geothermometers based on the increased

solubility of silica with increasing temperature (Fournier 1977, Fournier and Potter 1982, and Arnórsson et. al 1983). Sodium-potassium geothermometers based on the retrograde relationship between the Na/K ratio and temperature are also used (Truesdell 1976; Fournier and Potter 1979; Giggenbach 1988; and Arnórsson et. al 1983). However, these geothermometers give anomalously high temperature prediction values due to the high amount of calcium in waters that have mixed with the ESRPA waters which are predominately Ca-Mg-HCO₃ in composition (McLing et. al, 2002). For this reason, the empirical Na-K-Ca geothermometer (Fournier and Truesdell 1973) is utilized. These values are then subsequently corrected for high magnesium concentrations which yield temperature overestimations using the Mg correction provided by Fournier and Potter (1979). Selected predicted reservoir temperatures for the March ESRP samples are presented in Table 2.

The sample compositions are also plotted on a Giggenbach ternary diagram (Figure 4) to determine evidence of equilibration and/or mixing. The Giggenbach ternary diagram is used to classify waters into fully equilibrated (mature) waters, partially equilibrated, and immature waters. The latter two categories show evidence of mixing with cool meteoric waters. The diagram uses the full range of equilibrium relationships between Na, K, and Mg to determine the degree of equilibration between the water and the rock of thermal influence

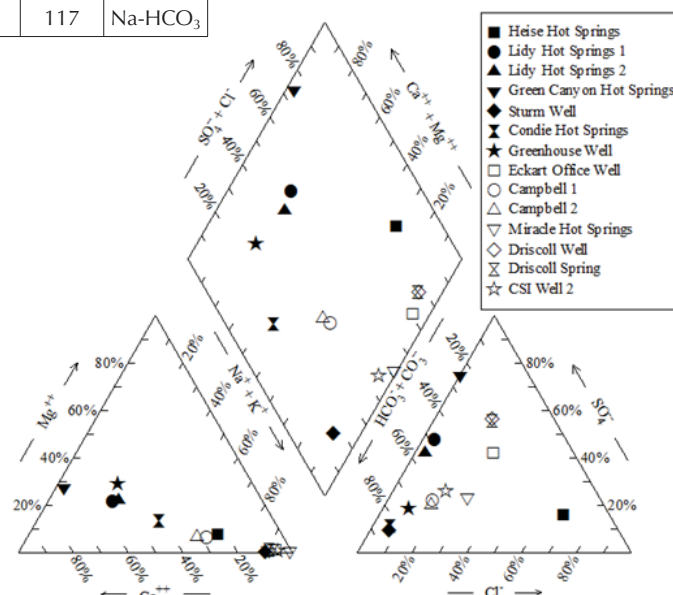


Figure 3. Piper Diagram showing water chemistries of the March 2014 ESRP samples. Twin Falls area samples are denoted by open markers.

Table 2. Selected geothermometry temperature values for March ESRP sampling.

Name	Fournier 1977		Fournier and Potter (1982)	Truesdell (1976)	Fournier (1979)	Giggenbach (1988), t>180	Arnorsson (1983) 25-280	Fournier and Truesdell 1973; Fournier, 1977	
	Qtz (no steam loss)	Qtz (steam loss)	Quartz	Na-K			Na-K-Ca	Na-K-Ca	Na-K-Ca (Mg Corrected)
Heise Hot Springs	85	88	85	221	243	257	227	209	92
Lidy Hot Springs 1	89	92	90	477	416	410	457	229	74
Lidy Hot Springs 2	85	88	85	466	409	405	448	229	73
Green Canyon HS	75	79	76	675	523	501	625	221	69
Sturm Well	113	112	113	80	126	146	92	110	110
Condie Hot Springs	79	83	80	392	363	364	382	228	95
Greenhouse Well	82	85	83	332	323	329	328	195	42
Eckert Office Well	104	104	104	101	145	164	112	136	110
Campbell Well 1	120	118	120	221	243	256	226	175	109
Campbell Well 2	117	116	118	230	250	262	234	177	106
Miracle Hot Springs	137	133	137	46	94	115	58	113	113
Driscoll Well	98	99	98	24	74	95	36	82	82
Driscoll Spring	100	101	100	39	88	109	51	93	93
CSI Well 2	114	113	114	96	140	160	107	132	132

at depth. The grouping of the results of the March 2014 samples from southern Idaho suggest that the majority of the waters are mixed (partially equilibrated and immature) and reinforces the legitimacy of the careful use of the Na-K-Mg geothermometers as well as the adjustments made by the use of mixing models.

4.3 Mixing Models

Because of the large influence of cold water mixing from the ESRPA and partial-equilibrium conditions (the results from the Giggenbach ternary diagram), temperature predictions cannot be taken at face value until appropriate mixing models have been applied to the data. The silica-enthalpy mixing

model (Figure 5) is based on the positive relationship between silica solubility and increasing temperatures. However, in this model, respective enthalpies of sample waters calculated from field temperatures are used as plot coordinates rather than temperature because enthalpy is conserved as waters mix and boil whereas temperature is not (e.g., Fournier, 1977). This model can be applied with two separate scenarios. A straight line is drawn from the point representing the non-thermal component of the mixed water (lowest silica and enthalpy), through the mixed water warm springs. The intersection of this line with the quartz solubility

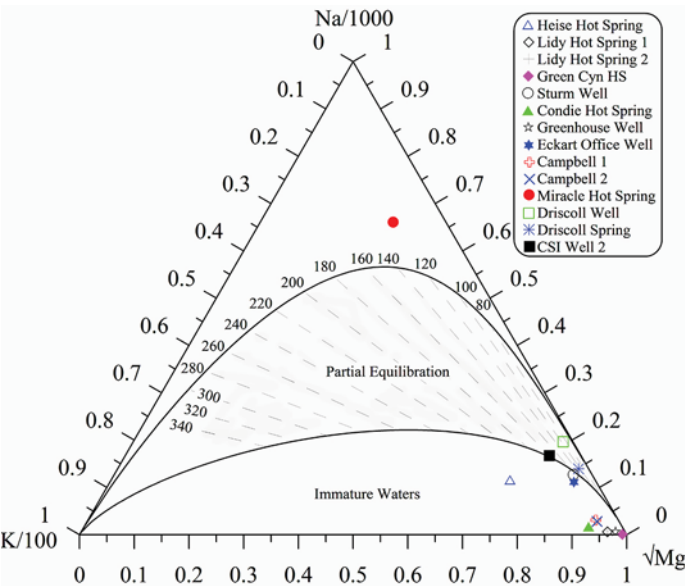


Figure 4. Giggenbach ternary diagram of March ESRP thermal samples.

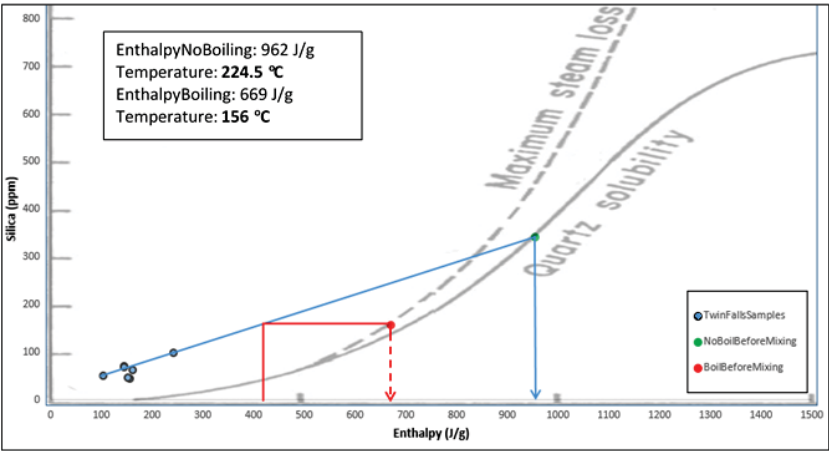


Figure 5. Silica enthalpy mixing model applied to Twin Falls, ID area thermal samples.

curve gives the enthalpy of the hot-water component at reservoir conditions if there was no boiling prior to mixing. The enthalpy at the boiling temperature (100°C) which is 419 J/g is intersected with the projected trend line. From this intersection, a horizontal line is drawn to the quartz maximum steam loss line. This new enthalpy value can be used to calculate the reservoir temperature if boiling occurred prior to mixing (Fournier, 1977).

Another mixing model used in adjusting temperature predictions for the possibility for boiling and mixing is the silica-carbonate mixing model (Figure 6). Because, there exists a positive relationship between CO₂ concentrations and temperature and the majority of CO₂ is in the form of dissolved carbonate, the relationship between total carbonate and silica can be used as a mixing model for thermal waters. The model is particularly useful in separating boiled waters from mixed waters because boiling will result in a drastic reduction in carbonate content while increasing the saturation of silica. Mixing without boiling however, will result in waters with high carbonate/silica ratios.

The relationship between silica and carbonate is plotted as a power curve. Those points falling below the curve represent mixed and non-boiled waters while those above the curve represent boiled waters. Once plotted a trend line can be applied to the data and projected to the silica-carbonate relationship curve (Arnósson, 1985). The newly determined silica value can then be applied with a quartz geothermometer to produce an adjusted reservoir temperature. The major advantage to the silica-carbonate model is that it eliminates the choice between boiling before mixing or not that has to be made with the silica-enthalpy model. The waters plotted on the silica-carbonate model as mixed non-boiled waters and the temperature adjustments were in fact very similar between the silica-enthalpy (no boiling before mixing).

The silica-enthalpy and silica-carbonate mixing models were applied to data from the 14 ESRP samples taken in March. However, these points did not show a strong trend and yielded a wide range of possible reservoir temperatures. Samples taken from the Twin Falls, ID area give a much tighter fit and correlation when other samples are excluded. Chemical concentrations and calculated temperatures show that the many samples taken from the Twin Falls, ID area suggest they need to be evaluated as a separate and distinct reservoir. When the silica-enthalpy and silica-carbonate mixing models are

applied to only the Twin Falls samples, they generate temperature values of 224 °C and 217 °C respectively.

4.4 Multicomponent Equilibrium Geothermometry

A newly developed MEG tool known as Reservoir Temperature Estimator (RTEst) (Neupane et al., 2014) is also used to estimate reservoir temperatures. The RTEst is an inverse geochemical tool that implements MEG with a capability of process optimization for secondary processes such as boiling, mixing, and gas loss. More detailed description about RTEst can be found elsewhere (e.g., Palmer et al., 2014; Neupane et al., 2014).

In MEG, the reservoir temperature is estimated by first selecting a reservoir mineral assemblage (RMA) with which the reservoir fluid likely equilibrated. For a water sample from a spring or shallow well, the activities of the chemical species in solution are determined and the saturation indices are calculated using the field measured temperature of the sample. Saturation index (SI) is defined as $\log Q/K_T$, where Q is the ion activity product and K_T is the temperature dependent mineral-water equilibrium constant. The SI calculation is repeated as a function of temperature. The likely reservoir temperature is predicted by the point at which all minerals in an assemblage are in equilibrium with the reservoir

fluid as indicated by near zero $\log Q/K_T$ values of these minerals on a $\log Q/K_T$ versus temperature plot ($\log Q/K_T$ plot) (Reed and Spycher, 1984; Spycher et al., 2014). If $\log Q/K_T$ curves of minerals in a reservoir do not show a common temperature convergence at $\log Q/K_T = 0$, then it suggests that there are errors in the analytical data, the selected mineral assemblage does not represent the actual mineral assemblage in the reservoir, or the sampled water must have been subjected to composition altering physical and chemical processes during its ascent from the reservoir to the sampling point.

Figure 7a shows $\log Q/K_T$ curves of the RMA (calcite, chalcedony, beidellite, mordenite-K, and paragonite) used for the Miracle Hot Spring water composition. The $\log Q/K_T$ curves of these minerals intersect the $\log Q/K_T = 0$ at a wide range of temperatures, making the $\log Q/K_T$ curves derived from the reported water chemistry minimally useful for estimating temperature. The range of equilibration temperature for the assemblage minerals is a reflection of physical and chemical processes that may have modified the Miracle Hot Spring water composition during its ascent to the sampling point.

Two common composition altering processes are the loss of CO_2 due to degassing and the gain/loss of water due to mixing/boiling. Particularly, the loss of CO_2 from geothermal water has direct consequence on pH of the water, and it is often indicated by the oversaturation of calcite (Palandri and Reed, 2001). Similarly, dilution of thermal water by mixing with cooler water or enrichment of constituents (chemical components) by boiling is indicated by lack of convergence of $\log Q/K_T$ curves over a small temperature range at $\log Q/K_T = 0$. Although, in principle, these composition-altering processes can

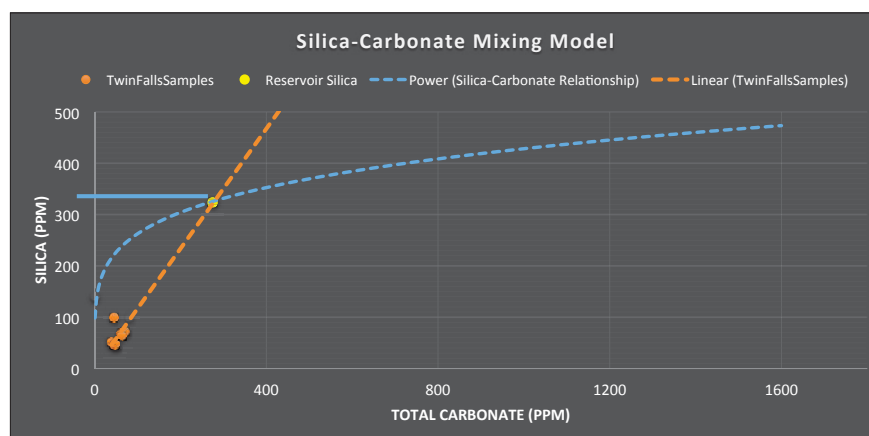


Figure 6. Silica-carbonate mixing model applied to Twin Falls, ID area samples.

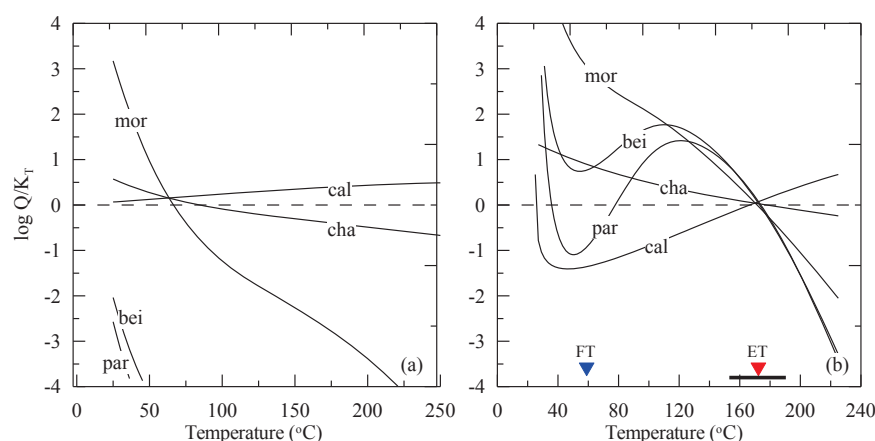


Figure 7. Temperature estimation for Miracle Hot Spring near Twin Falls, Idaho. (a) The $\log Q/K_T$ curves for minerals calculated using original water chemistry, (b) optimized $\log Q/K_T$ curves [FT: field temperature (58.4°C); ET: estimated temperature (172 °C), the dark horizontal bar below ET represents the \pm standard error for the estimated temperature (± 19 °C); bei: beidellite-K, cal: calcite, cha: chalcedony, mor: mordenite-K, and par: paragonite).

be taken into account by simply adding them into the measured water composition and looking for convergence of the saturation indices of the chosen mineral assemblage, a graphical approach becomes cumbersome even for two parameters (e.g., temperature and CO₂).

To account for possible composition altering processes, RT-Test was used to simultaneously estimate a reservoir temperature and optimize the amount of H₂O and the fugacity of CO₂. The optimized results for Miracle Hot Spring are shown in Figure 6b. Compared to the log Q/K_T curves calculated using the reported water compositions (Figure 7a), the optimized curves (Figure 7b) converge to log Q/K_T = 0 within a narrow temperature range (i.e., 172±19 °C).

The preliminary temperature estimates and composition parameters for the other Southeast Idaho waters reported in Table 1 were similarly estimated using RT-Test. The estimated reservoir temperatures, mass of water lost due to boiling or gained due to mixing, and fugacity of CO₂ along with the associated standard errors are presented in Table 3.

Table 3. RT-Test temperature estimates.⁰

Springs/Wells	T ^a ± σ ^b	M _{H₂O} ^c ± σ ^b	log f _{CO₂} ± σ ^b
Heise Hot Spring	61±8	-0.11±0.25	-0.28±0.26
Lidy Hot Spring 1	87±18	0.44±0.24	-0.65±0.72
Lidy Hot Spring 2 ^d	98±10	0.54±0.08	-0.01±0.34
Green Cyn HS ^d	87±14	0.55±0.13	-0.24±0.51
Sturm Well	153±16	0.70±0.05	0.01±0.45
Condie Hot Spring ^d	85±29	0.35±1.2	-0.28±1.24
Greenhouse Well ^d	67±15	-0.08±0.58	-1.18±0.74
Eckart Office Well ^d	112±9	0.47±0.12	-1.29±0.38
Campbell 1	125±26	0.53±0.24	0.16±0.88
Campbell 2	125±22	0.54±0.2	0.13±0.75
Miracle Hot Spring	172±19	0.60±0.09	-0.30±0.51
Driscoll Well ^d	140±13	0.70±0.05	0.08±0.35
Driscoll Spring	140±18	0.72±0.1	0.25±0.54
CSI Well 2 ^d	154±9	0.65±0.04	0.27±0.23

^a RT-Test estimated temperature;

^b σ is standard error in each RT-Test optimized parameter (temperature, mass of water, and fugacity of CO₂);

^c Positive and negative numbers indicate the fraction of cold water present and steam-loss per kilogram of sampled water, respectively;

^d for these samples, K-feldspar equilibrium was utilized to fix Al content instead of using measured Al during RT-Test modeling.

5. Limitations

While the mixing models and multi-component equilibrium geothermometry provide reservoir temperature values for the Twin Falls area that are as high as 224 and 172 °C respectively, previous studies involving cation and isotope geothermometry in the Twin Falls, ID area suggest reservoir temperatures on the order

of 90-100 °C (Lewis and Young, 1982; Mariner *et al.*, 1997). Additionally, reports from the Kimberly Well (Hot Spot Project) show that lower temperature waters (57.4 °C) can prevail to considerable depths (nearly 2 km) (Neilson *et al.*, 2012). The mixing models applied to the Twin Falls area samples make the assumption that all samples are a part of the same thermal system which is not likely the case. The MEG assumes that the RMA is accurate and applicable to all sample sites. Also, there are simply too few data points in this preliminary study to say anything definitive about the reservoir temperature using these analytical methods. However, with a larger cluster of data points and the analysis of smaller regions within the Twin Falls area, the trend lines projected in the mixing models as well as the selected RMAs will yield more definitive results. We will obtain the necessary data points in the coming summer of 2014.

6. Conclusion

Heat flux values, surface thermal expressions, and regional geology suggest the presence of a deep thermal reservoir beneath the ESRP groundwater system. However, the thermal signatures in the region may have been masked by mixing of overlying cold groundwater. Furthermore, potential re-equilibration of water in the basaltic zone may have obscured the higher temperature in the deeper rhyolite sections. A comparison between predicted reservoir temperature values from traditional and multicomponent geothermometers shows this to be the case in most instances. The use of mixing models in this preliminary analysis suggests that geographic areas within or adjacent to the ESRP may be separate and distance subsets of the larger ESRP geothermal system. The results of the silica-enthalpy mixing model and the silica-carbonate mixing model suggest a much higher reservoir temperature (154-224 °C) in the Twin Falls, ID area. Results from the multicomponent equilibrium geothermometer RT-Test also show higher reservoir temperatures (112-172 °C) for Na-HCO₃ and Na-SO₄ type waters that are present in this area. These waters exhibit an absence of ESRP cold water influence in their low Mg and Ca concentrations and are also more similar in composition to waters of the deep thermal system as seen in deep waters from the INEL-1 well (McLing *et al.*, 2002). Moving forward, we plan to continue implementing our sampling procedure across the entirety of the ESRP and southern Idaho in an effort to produce a reliable and comprehensive geothermometry derived temperature map of the region. He isotopic results may also provide insights as to the amount of mantle input (via magmatic sourced fluids) in geothermal fluids within this region.

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