Stanley Geothermal Feasibility Study

Task 1 Report

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1. Introduction

The purpose of this report is to give a general geological background of the Stanley area for the feasibility of direct use heating, potential low power generation, and other economical uses of geothermal energy. The content of this report was obtained from background literature research and from in-kind contributions from students at Idaho State University and is aimed at providing a starting place for future research on the current project.

2. Geographic Location

Stanley resides in the central part of Idaho and is situated at the intersection of State Highways 21 and 75 (Figure 1). The study area for this project covers nearly 450 km^2 and extends from 44.07° to 44.83°N and -114.73° to -115°W (Figure 2). The area around Stanley is characterized by tall mountains and deep glacial valleys. Two rivers run near the Stanley area, the Main Salmon River and also the South Fork of the Payette River. Numerous thermal springs are reported to exist along the Salmon River near Lower Stanley.

Figure 1. Image showing geographic location of Stanley, Idaho. Taken from Google Earth on August 14, 2011.

According to the 2000 census, the population of Stanley is 100 people. There were 45 households, 23 families and 77 housing units. The median age was 39 years and the median household income in the city was $37,813. The median income for a family was $45,625 and the per capita income for the city was $23,303. Historically the area was supported by ranching and mining activities. Currently, the area is more dependent on recreation.

Stanley has a cold climate. Frosts occur an average of 290 days in the year, 10 of them in July. Sixty days are below zero degrees Fahrenheit. (Wikipedia, October 2011)

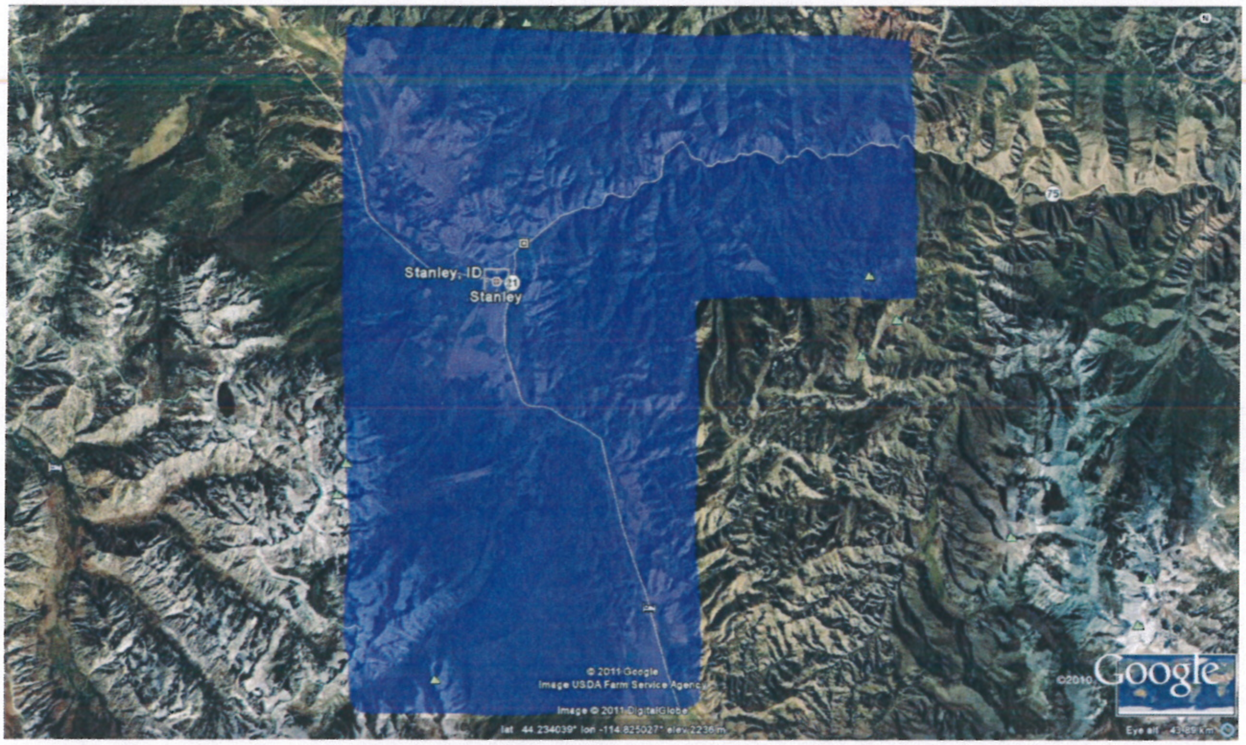


Figure 2. Blue Polygon shows approximate spatial extent of current project. Area covers approximately 450 km^2. Image taken from Google Earth on August 14, 2011.

3. Geology

The geology of the area consists mainly of igneous rocks of the Idaho Batholith and more specifically of the Atlanta Lobe of the Idaho Batholith (Figure 4), all of which are either Cretaceous (~80 Ma) or Tertiary (~50-7 Ma) in age (van Middlesworth and Wood, 1998). The Tertiary volcanic rocks in this area are associated with the Challis Volcanic terrane (van Middlesworth and Wood, 1998). These different ages define two distinct episodes of granitic intrusion. Emplacement of these plutons is thought to have been caused by the subduction of the Farallon plate. As oceanic crust is forced into the aesthenosphere, it is hydrated and melts to form magmas of tonalitic composition. These types of rocks can be seen on the western margin of the Idaho batholith (Criss and Taylor, 1983). Crustal contamination can also occur during the rise of these magmas, which often creates more felsic magmas in which the resulting rocks are more granitic in composition. In the Stanley area, these are characterized by granodiorites. Students from Idaho State University (ISU) have identified that these are titanite bearing granodiorites, contain large (~2 cm) phenocrysts of plagioclase, and also contain biotite, hornblende and quartz. Porphyritic dikes containing pyrite and epidote have also been identified by students at ISU. These dikes are very important in the hydrology of local geothermal systems. Many other minerals created by hydrothermal alteration can be seen in these dikes (Criss and Taylor, 1983; Druschel and Rosenberg, 2001). The composition of these granites is quite variable and is most noticeable between units that are of different ages (van Middlesworth and Wood 1998). In a report done by Chapman (1986), two wells were drilled in the Stanley area to identify lithologic units, temperature gradients, and flow rates. The author describes encountering rocks of granitic, dioritic, and granodioritic composition just below Quaternary deposits (Chapman, 1986).

Above the igneous rocks of the Idaho batholith lay glacial deposits of Pleistocene age (Williams, 1961). Most of these deposits are in the form of glacial till, outwash, and moraines (Williams, 1961). These deposits do not play a major role for geothermal resource exploration but have been important in placer gold deposits (Williams, 1961).

Faults play an important role in geothermal systems, allowing for the upwelling of hot water. The Trans-Challis Fault System (TCFS) of Bennett (1986) consists of a belt of northeast trending normal faults that are related extension (Figures 3 and 4). These faults are thought to be coeval with the onset of Tertiary (Eocene) volcanism (Bennett, 1986). The northwest trend of faults associated with Basin and Range extension as seen in the Lost River, Lemhi, and Beaverhead Ranges of eastern Idaho terminate at the TCFS (Bennett, 1986). Many springs in Lower Stanley seem to lie on the lineament of the TCFS but will require additional field observations for proof.

Fractures are the most important local structure controlling fluid transport (Druschel and Rosenburg, 2001). Igneous rocks (locally granites, granodiorites, and rhyolites) are generally impermeable to water movement, therefore fractures act as the main control on water permeability. There are several reasons fractures can form in igneous rocks but the two most important to this study include cooling fractures and fractures created by tectonics. Cooling fractures arise from when the melt, or magma, was cooling to form the crystalline rocks we see today. These generally occur in dike rocks that are intruded into cooler country (surrounding) rocks and form perpendicular to the cooling surface. These fractures operate on a smaller scale and only affect the younger rock that intruded into the older rock. Fractures from tectonism most likely play a more significant role in fluid transport than do cooling fractures because they may be laterally and vertically continuous over large (~km's) areas. Students from ISU have measured these fractures and are listed in a table below. There are several orientations to these fractures, all of which are the result of the orientation of the stress field at the time they were created. A possible explanation to the change in the stress field could be related to the shift from Basin and Range extension (recall NW-SE trending faults discussed above) to the tectonic process which created the Trans-Challis Fault System (NE-SW trending faults).

Fracture Number	Strike	Dip	Dip Direction
1	199	78	NW
2	009	45	NE
3	137	58	SW
4	170	24	SW
5	350	64	NE
6	268	41	SE
7	326	34	NE
8*	090	67	S
9*	350	57	SW
10*	290	85	SW

Table 1. Strike and Dip data acquired from ISU Students. * Indicates measurements taken by author.

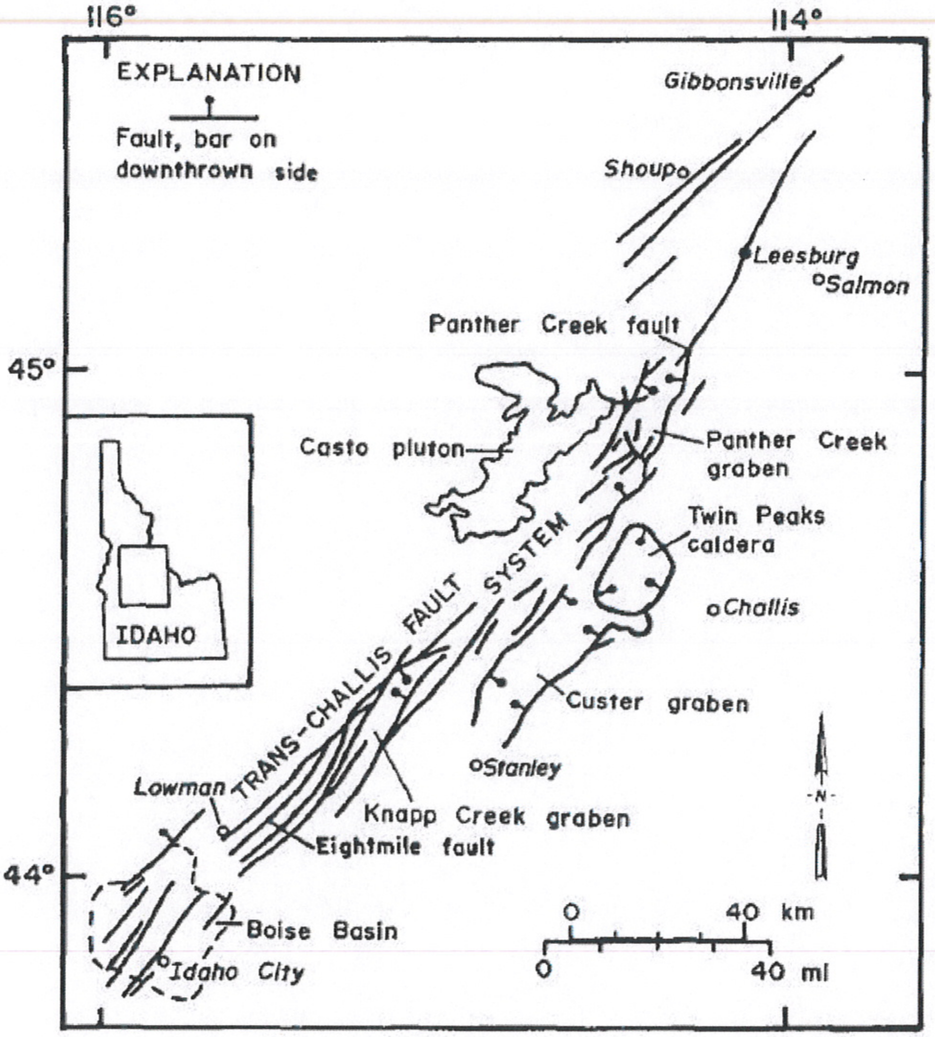


Figure 3. Location and orientation of the Trans-Challis Fault System. Notice northeast trend in fault orientation. These structures are most likely controlling the spatial distribution of hydrothermal springs in the Stanley area. Figure taken from Bennett (1986).

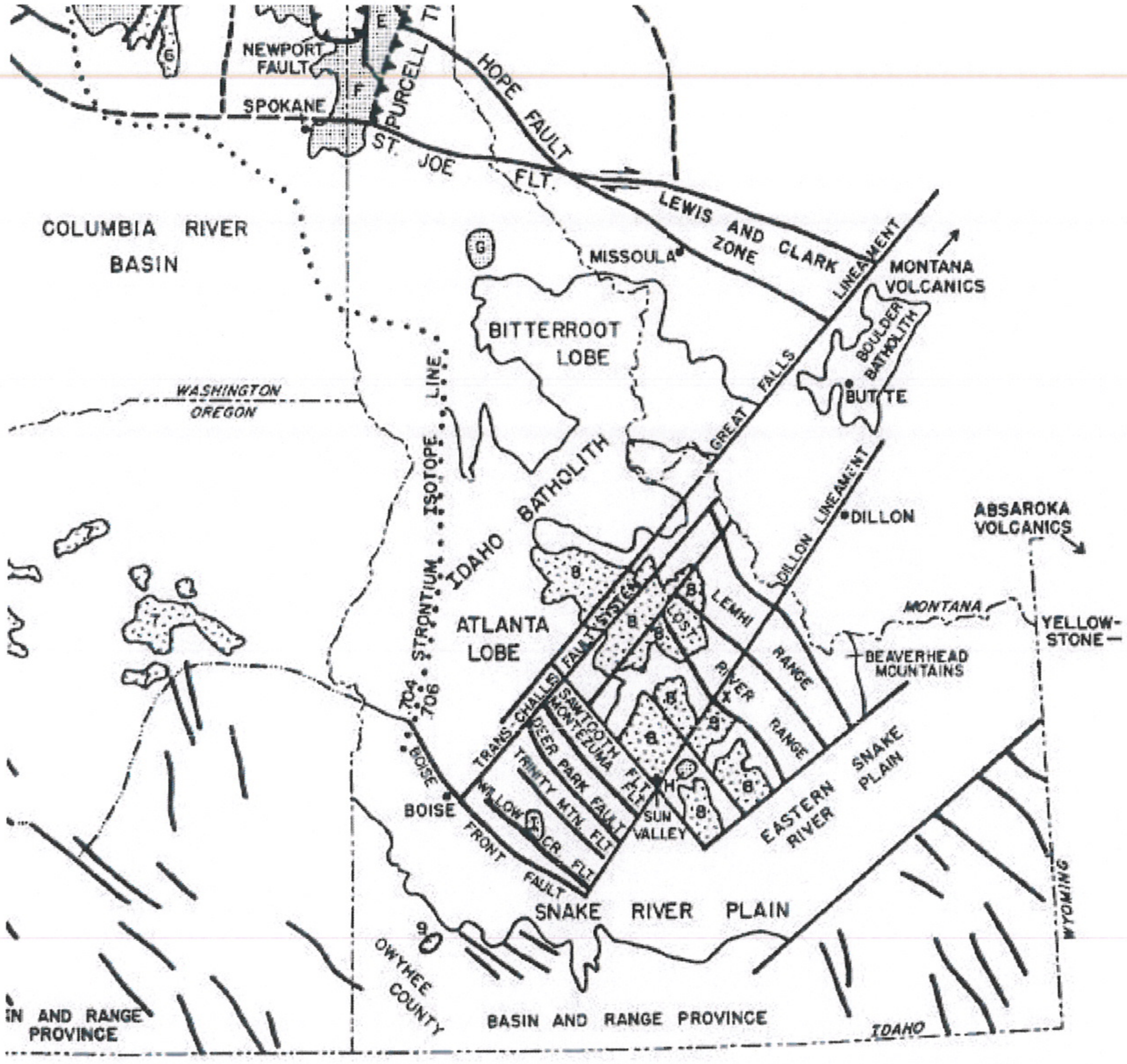
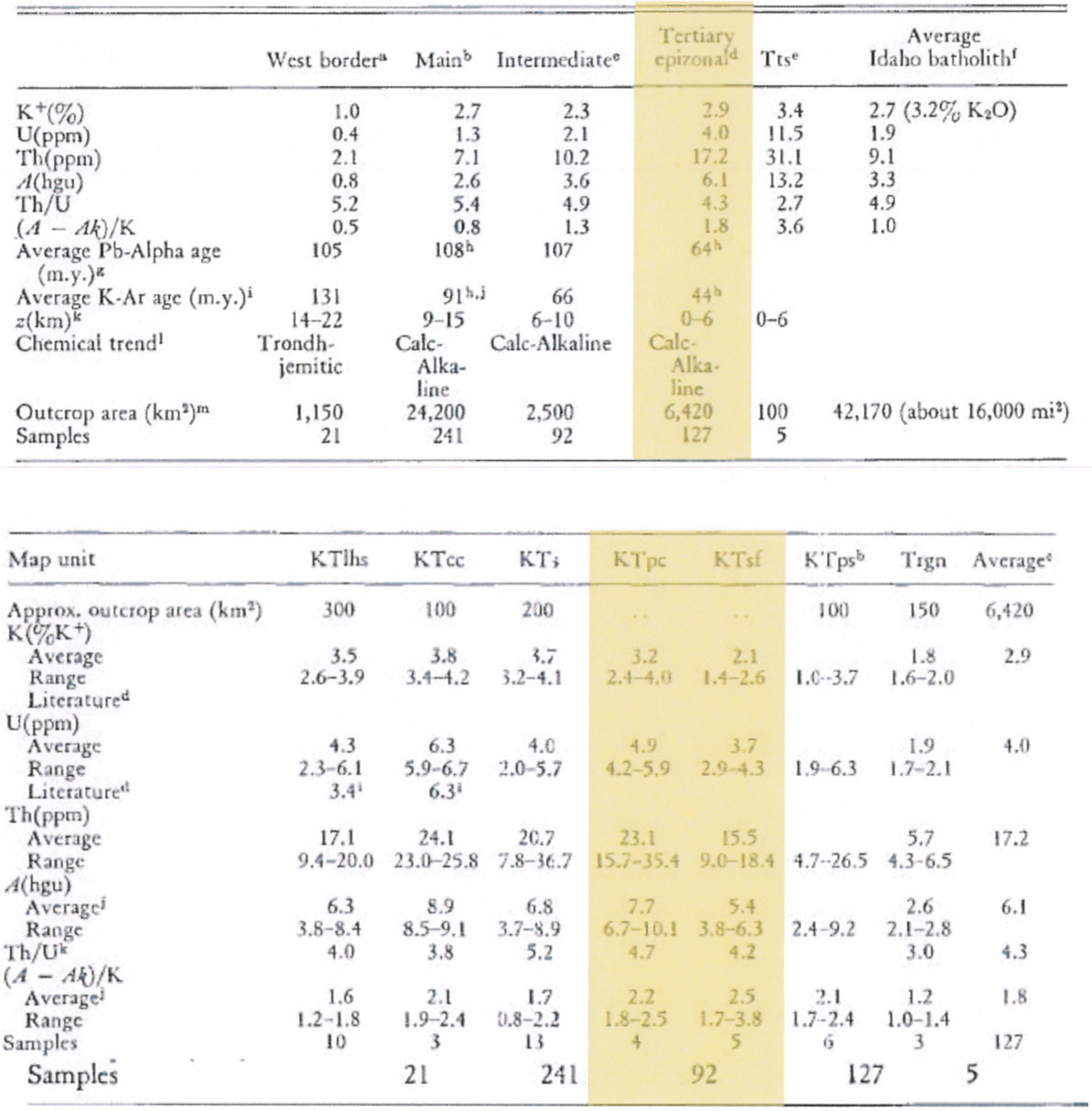


Figure 4. Overview map of the major trends in fault orientation throughout central Idaho. Two major trends can be seen, one NE-SW and one NW-SE. Faults trending northeast are associated with Early Eocene extension and volcanism (Bennett, 1986). Faults trending northwest are related to mid Eocene to recent extension of the Basin and Range Province (Bennett, 1986). Figure taken from Bennett (1986).

Heat Generation in the Idaho batholith is mostly the product of radioactive decay of three main elements: U, Th, and K (Swanberg and Blackwell, 1973; van Middlesworth and Wood, 1998). The generation of heat from these elements can be calculated with the equation (Swanberg and Blackwell, 1973; Birch et al 1968; Roy et al 1968):

$$Q = Q_o + Ab$$

"Where Q is surface heat flow in 10^{-6} cal/cm^{2}sec and A is surface heat generation in 10^{-13} cal/cm^{3}sec and *b* and Q_o are constant within a heat flow province" (Swanberg and Blackwell, 1973). The degree of heat produced and ultimately exchanged with through-flowing waters is a function of the sum of the original amount of each radioactive element. Figure 5 is taken from Swanberg and Blackwell (1973) showing the concentrations in parts per million (ppm) of each of these elements. Rocks of Tertiary age are in general more radioactive due to their increased U, Th, and K concentrations (Swanberg and Blackwell, 1973). Geothermal gradients are also affected because of this and vary from 25°C/Km in Cretaceous age rocks of the Idaho Batholith to 32°C/Km in Tertiary age rocks (Druschel and Rosenberg, 2001). Chapman (1986) reports rocks with compositions most resembling those of Tertiary age volcanic rocks coming from two test wells in the immediate Stanley area; therefore, one can deduce that if drilling into these rocks a geothermal gradient of near 32°C/Km could be expected. Several small bodies of Cascade Granodiorite have been described as having high K radioactivity (Swanberg and Blackwell, 1973), most likely due to their large phenocrysts of microcline microperthite (Larson and Schmidt, 1958), in which K is a major chemical constituent.



	West border[a]	Main[b]	Intermediate[c]	Tertiary epizonal[d]	Tts[e]	Average Idaho batholith[f]
K^+(%)	1.0	2.7	2.3	2.9	3.4	2.7 (3.2% K_2O)
U(ppm)	0.4	1.3	2.1	4.0	11.5	1.9
Th(ppm)	2.1	7.1	10.2	17.2	31.1	9.1
A(hgu)	0.8	2.6	3.6	6.1	13.2	3.3
Th/U	5.2	5.4	4.9	4.3	2.7	4.9
$(A - Ak)/K$	0.5	0.8	1.3	1.8	3.6	1.0
Average Pb-Alpha age (m.y.)[g]	105	108[h]	107	64[h]		
Average K-Ar age (m.y.)[i]	131	91[h,j]	66	44[h]		
z(km)[k]	14–22	9–15	6–10	0–6	0–6	
Chemical trend[l]	Trondhjemitic	Calc-Alkaline	Calc-Alkaline	Calc-Alkaline		
Outcrop area (km^2)[m]	1,150	24,200	2,500	6,420	100	42,170 (about 16,000 mi^2)
Samples	21	241	92	127	5	

Map unit	KTlhs	KTcc	KTs	KTpc	KTsf	KTps[b]	Trgn	Average[c]
Approx. outcrop area (km^2)	300	100	200	..	..	100	150	6,420
K(%K^+)								
Average	3.5	3.8	3.7	3.2	2.1		1.8	2.9
Range	2.6–3.9	3.4–4.2	3.2–4.1	2.4–4.0	1.4–2.6	1.0–3.7	1.6–2.0	
Literature[d]								
U(ppm)								
Average	4.3	6.3	4.0	4.9	3.7		1.9	4.0
Range	2.3–6.1	5.9–6.7	2.0–5.7	4.2–5.9	2.9–4.3	1.9–6.3	1.7–2.1	
Literature[d]	3.4[i]	6.3[i]						
Th(ppm)								
Average	17.1	24.1	20.7	23.1	15.5		5.7	17.2
Range	9.4–20.0	23.0–25.8	7.8–36.7	15.7–35.4	9.0–18.4	4.7–26.5	4.3–6.5	
A(hgu)								
Average[j]	6.3	8.9	6.8	7.7	5.4		2.6	6.1
Range	3.8–8.4	8.5–9.1	3.7–8.9	6.7–10.1	3.8–6.3	2.4–9.2	2.1–2.8	
Th/U[k]	4.0	3.8	5.2	4.7	4.2		3.0	4.3
$(A - Ak)/K$								
Average[j]	1.6	2.1	1.7	2.2	2.5	2.1	1.2	1.8
Range	1.2–1.8	1.9–2.4	0.8–2.2	1.8–2.5	1.7–3.8	1.7–2.4	1.0–1.4	
Samples	10	3	13	4	5	6	3	127
Samples		21	241		92	127	5	

Figure 5. Highlighted area in top table shows average U, Th, and K values for Tertiary volcanic rocks. Highlighted area in bottom table shows U, Th, and K values for two granodiorites near Stanley, Idaho. Note that unit KTpc has higher than average values. Tables taken from Swanberg and Blackwell (1973).

Geothermometers are an important tool used by geoscientists to determine potential aquifer temperatures based on concentration of certain chemical species. Temperatures calculated by these methods are often referred to as the "temperatures of last equilibrium" because they represent rock-fluid equilibrium at depth (van Middlesworth and Wood, 1998). Several geothermometers are available to the geoscientist and most of them only require running major analyte analysis. Table 2a is a compilation of major cation and anion concentrations obtained by literature review for springs and wells near the Stanley area. Table 2b contains additional pertinent information from the same wells.

Well	Na	K	Ca	Si	SiO_2	Mg	HCO_3	CO_3^{2+}	SO_4	NO_3	Cl	F	P
8N 17E 32bca1S[a]	100	13	21	43	NA	5.5	234	0	94	0.06	26	8.4	0.02
14N 19E 34daa1[a]	45	7.6	55	23		21	226	0	130	0.1	4	1.1	0.01
Sunbeam HS 11N 15E 19c1S[a]	85	2.4	1.5	91		0	119	0	54	0.06	12	13	0.02
Sullivan HS 11N 17E 27bdd1S[a]	170	15	49	38		11	554	0	26	0.06	57	1.8	0.02
Baracy HS 11N 25E 23cab1S[a]	9	1.5	37	18		20	181	0	35	0.25	4	0.5	0.03
Stanley HS 10N 13E 3cab1S[a]	60	0.3	2.2	55		0.1	30	28	31	0.05	5	14	0.01
Slate Creek HS 10N 16E 30a1S[a]	83	4.5	8.1	86		0.1	110	0	110	0.03	7	8.7	0.02
Sunbeam[b]	64	1.3	1.9		70	0.01	90		26	0.1	5	14	
Campground[b]	74	1.5	1.6		82	0.04	106		30		6	14	
Cape Horn[b]	82	0.3	1.4		61	0.1	103		39	0.01	8.7	22	
Rozalays[b]	57	0.7	2.7		54	0.1	90		34	0.13	6.5	11	
Russian John[b]	71	0.8	2		47		81		41		11	16	
Warfield[b]	66	1.8	2.4		87	0.01	99		40		6	14	
Stanley[c]	42.68	0.69	1.64		69.9	0.05	69.36		18.95		1.63	0.25	18.95
Sunbeam[c]							111.44		40.92		11.39	15.85	40.92
Bonneville[d]	92.8	2.7	1.2		98.2	0.009	90.2	0.9	45	3.5	6	16.4	2.4
Sacajawea[d]	89.8	2.6	1.2		85.1	0.009	108.5	5.9	41.9	1.9	8.6	14.5	2.3

Table 2a. Major cation and anion concentrations for springs in the Stanley Area. Units are all in mg/L. Well location from Young and Mitchell (1973) refer to quarter section in which the well is located.

[a] Data taken from Young and Mitchell (1973).

[b] Data taken from Mariner et al (2006).

[c] Data taken from van Middlesworth and Wood (1998).

[d] Data taken from Druschel and Rosenberg (2001).

Well	Cond. (µmhos)	TDS	Disch. (gpm)	Temp (°C)	pH	Alka. (CaCO$_3$)	Lat	Long
8N 17E 32bca1S[a]	651	425	25	51	6.7	192		
14N 19E 34daa1[a]	625	398	50	40	7.3	185		
Sunbeam HS 11N 15E 19c1S[a]	413	320	444	76	8.5	98		
Sullivan HS 11N 17E 27bdd1S[a]	1070	640	70	41	7	454		
Baracy HS 11N 25E 23cab1S[a]	364	215	170	28.5	7.8	148		
Stanley HS 10N 13E 3cab1S[a]	293	211	110	41	8.8	71		
Slate Creek HS 10N 16E 30a1S[a]	437	362	185	50	8	90		
Sunbeam[b]		227		62	9.18		44 16.1'	114 44.9'
Campground[b]		261		56	9.39		44 15.9’	114 48.6’
Cape Horn[b]		265		37	9.6		44 23.9'	115 8.9'
Rozalays[b]		210		47	9.4		44 6.1'	114 51.9'
Russian John[b]		229		34	9.7		43 48.3’	114 35.1’
Warfield[b]		266		52	9.1		43 38.5'	114 29.2'
Stanley[c]	320		29.85	48.1	9.15	67.5		
Sunbeam[c]	850		299.88	75	8.26	94		
Bonneville[d]	975			83.9	9.1	74		
Sacajawea[d]	600			65.1	9.2	89		

Table 2b. Additional information taken from literature research that is pertinent to current study. TDS units are in mg/L.

[a]Data taken from Young and Mitchell (1973).

[b]Data taken from Mariner et al (2006).

[c]Data taken from van Middlesworth and Wood (1998).

[d]Data taken from Druschel and Rosenberg (2001).

The values from tables 2a and 2b were used in conjunction with a spreadsheet developed by Powell and Cumming (2010) to calculate possible aquifer temperatures based on concentrations of select chemical species. Temperatures range from 0-114 °C using the Na-K-Ca geothermometer of Fournier and Truesdell (1973). Temperatures calculated from the Na/K method of Fournier (1979) indicate possible temperature of 0-266 °C. Table 3 summarizes the entire range of temperatures calculated from all methods but the two mentioned above tend to give the best results given the geologic environment in which these springs exist.

Sample Name	Amorphous Silica	Chalcedony cond	Quartz cond	Quartz adiabatic	Na-K-Ca	Na-K-Ca Mg corr	Na/K Fournier	Na/K Truesdell	Na/K (Giggenbach)	K/Mg (Giggenbach)
G-1					40	40	104	55	124	79
UHS1	-20	64	95	97	108	-38	241	218	254	81
UHS2	-42	37	69	74	60	-104	266	252	278	53
Sunbeam	12	105	132	128	109	109	128	82	148	#DIV/0!
Sullivan	-25	59	90	92	99	-33	206	174	223	76
Baracy	-49	27	60	65	12	-134	265	250	277	23
Stanley	-10	77	107	106	33	33	48	-2	70	42
Slate Creek	10	101	129	126	90	90	170	130	188	106
Sunbeam2	0	90	118	117	78	78	110	62	131	103
Campground	7	99	127	124	89	89	110	62	131	88
Cape Horn	-6	82	112	111	44	44	37	-13	59	42
Rozalays	-11	76	106	106	51	51	85	36	107	59
Russian John	-16	69	99	100	63	63	82	32	103	#DIV/0!
Warfield	10	102	130	126	84	84	126	80	146	112
Stanley2	0	90	118	117	58	58	99	50	119	67
Sunbeam2	16	109	136	132						
Bonnevile	16	109	136	132	134	-391	130	84	150	41
Sacajawea	9	101	129	125	145	-393	155	112	174	40

Table 3. Calculated aquifer temperatures based on data gathered from literature review. All temperatures are in Celcius.

4. Conclusions

The Stanley area is host to many hydrothermal springs, the heat source for these springs is due to the radioactive decay of U, Th, and K (Swanberg and Blackwell, 1973; van Middlesworth and Wood, 1998) unlike Basin and Range type geothermal systems where large scale normal faulting and the resulting thinning of the crust is the source of heat. The Trans-Challis Fault System undoubtedly plays a role in the hydrology of the Stanley area but is not as significant as Basin and Range type geothermal systems. Two main trends in regional faults exist, those of the TCFS trending NE-SW and others trending NW-SE. Detailed field mapping will be needed to identify the significance of these local faults on the movement of hydrothermal water. Fractures are also very important to the local movement of water through the granitic rocks of the Idaho Batholith. The goal of any exploration well that might be drilled should be to find the intersection of these fracture/fault planes.

Geothermometer data has shown that possible aquifer temperatures could reach 266 °C in some of the aquifers near the Stanley area. From background literature review, only two samples have been taken from the immediate area, those being Stanley Hot Springs and the Campground Hot Spring. To properly identify local thermal conditions, temperature profiles and water samples from existing wells must be obtained.

5. Acknowledgements

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