Stanley Geothermal Feasibility Study

Task 5 Report: Final Report

Kyle Makovsky
Boise State University
Department of Geosciences
1910 University Drive
Boise, ID 83725
KyleMakovsky@u.boisestate.edu
Phone: 208-473-8633

Leland "Roy" Mink
Mink GeoHydro Inc
H2oguy@copper.net
Phone: 208-699-4396

Robert Beckwith
2260 Dicky Ct.
Eagle, ID 83616
bobbeckwith@qwest.net
Phone: 208-939-8936

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1. Introduction

The purpose of this task is to summarize the data accumulated from previous sections of this study. From this, a discussion of the potential locations for an exploratory well(s) will be discussed. The well(s) will establish depth, temperature, and flow rates for the geothermal system near Stanley. So far four sub-studies have been discussed. They include a general geologic background to the Stanley area, creation of relevant geologic maps, hydrochemistry and geothermometry, and geologic and geophysical surveys. A brief discussion of each of these reports will be followed by placing them into a broader context of what they mean for the Stanley project. After this has been done, a location(s) for the test well(s) will be proposed.

2. General Geologic Background

Stanley resides in central Idaho along the confluence of Valley Creek and the Salmon River near State Highways 21 and 75. Three distinct rock types exist in the Stanley area: granitic and granodioritic rocks of the Idaho Batholith, volcanic rocks of the Challis Volcanic Group, and Quaternary glacial and fluvial sediments. The most important rocks to the Stanley geothermal system with respect to heat generation are most likely the volcanic rocks of the Challis Volcanic Group, as they have high reported concentrations of the radioactive elements U, Th, and K (Swanberg and Blackwell, 1973; van Middlesworth and Wood, 1998).

Understanding the role of faults and fractures in the movement of hydrothermal waters is paramount to properly characterize any geothermal system. In Stanley, two directions of fault orientations dominate: those trending NE-SW related to the Trans-Challis Fault System and those trending NW-SE related to regional extension of the Basin and Range geologic province. The creation of these faults allows for deep circulation of meteoric water, which over time will produce thermal water because of interaction with rocks with high heat generation and also from normal geothermal gradients. Fractures are important locally to the Stanley geothermal system because fractures also allow for rapid transport of fluids over great distances. Many warm seeps and hot springs within the Stanley area, specifically along the Salmon River, lie along the Mormon Bend Fault (Krahmer, 1995).

Glacial sediments are also important to the Stanley geothermal system because in the area southwest of the Historical Museum there are numerous warm seeps that discharge from these sediments. The glacial and alluvial sediments also contain significant colder ground water which can interact and dilute the upwelling thermal water. The locations of these seeps are no doubt controlled by geologic structures that affect the basement rocks (granites of the Idaho Batholith) and the overlying stratigraphy of the glacial and fluvial sediments.

3. Digital Geologic Data

The purpose of gathering pre-existing geologic maps is to minimize time spent on reproducing already published information. There were several geologic maps available for the Stanley area that were used for this study. The United States Geological Survey (USGS) has compiled and digitized several maps of the western states at a scale of 1:500,000. At this scale, it is easy to identify regional structural trends and also regional trends in major rock types. For a more detailed look at the Stanley area, a digitized map created by the USGS of the Challis 1° x 2° Quadrangle was used (1:250,000). This map allowed for a more detailed look at local rock types and fault density. Aerial photographs and satellite images were also used for a vast majority of maps created for this project. These photos were downloaded from the Inside Idaho website along with statewide coverage of highways. Statewide coverage of geothermal springs and wells, and statewide coverage of cities were obtained from the Idaho Department of Water Resources website. Digital Elevation Models or DEM's were obtained from the National Seamless Server operated by the USGS as part of their National Elevation Dataset (NED) program. The DEM's were important in creating and interpreting linear features near the Stanley area. All of these different datasets were imported into ESRI's ArcGIS software for manipulation. All subsequent maps created for this project were made in this program.

4. Hydrochemistry/Geothermometry and Thermal Gradients

The chemistry of regional thermal waters was obtained from background literature review. Several studies have been done in the Stanley area, reporting waters of non-magmatic sources (Druschel and Rosenburg, 2001; Krahmer, 1995; Criss and Taylor, 1983; Young, 1985; Young and Lewis, 1982). For our local study of the Stanley geothermal system, we obtained 8 samples for analysis. From this analysis, we have concluded that the waters in the Stanley geothermal system are also of non-magmatic affinity. Water quality is an important factor when considering use of geothermal water. In the Stanley area, the quality of thermal waters is quite good, with total dissolved solid (TDS) values ranging from 158-300 mg/L. Fluoride is the only chemical constituent of the thermal spring waters that exceeds water quality standards. The high concentration of Fluoride is most likely related to the volcanic rocks in which these waters interact.

Geothermometers were used to calculate potential reservoir temperatures based on measured concentrations of chemical constituents. The maximum calculated temperature is 142° C at Sunbeam Hot Springs, using the Giggenbach Na/K geothermometer. Reservoir temperatures for the Stanley Bathing Pool (Stanley Hot Springs) range from 60° to 83° C (John Welhan, written communication, 2011, Table 2). The quartz geothermometer predicted temperature of 112°C on table 2 is below the recommended threshold of 140°C for that geo-thermometer. The chalcedony geo-thermometer temperature of 83°C may be a more reliable predictor of reservoir temperature in the Stanley Hot Springs area, (Table2). The difference in predicted subsurface temperatures in springs near the Stanley Bathing Pool probably reflects the degree of mixing with cooler ground waters prior to discharging at the surface. The high predicted temperature for Sunbeam Hot Springs reflects minimal, if any mixing of shallow groundwater. This is supported by data collected from this study in which higher concentrations of the elements Na, K, Ca, and Si were found (Table 1). Sunbeam Hot Springs issues directly from a fracture network within exposed bedrock above the Salmon River; whereas the Stanley Hot Springs discharge out of unconsolidated alluvial sediments. It also should be noted the predicted temperatures of springs decrease westerly along the Mormon Bend Fault as evidenced by the Elkhorn and Boat Box Hot Springs (Table 2).

To further support the idea of non-thermal and thermal water mixing, mixing models using Boron were created. Preliminary work by John Welhan has shown that there is indeed mixing between thermal and non-thermal waters (John Welhan, written communication, 2011). This was obtained through regression analysis of Boron concentrations taken from the literature. Appendix 1 of Task 4 Report contains the values from this analysis. Stanley's thermal water chemistry is complex, and requires a substantial bit of knowledge regarding the effect of high pH on silica solubility (John Welhan, written communication, 2011). Because the Na-K-Mg-Ca, Na/K and K^2/Mg geothermometers are in agreement, it is reasonably safe to take calculated temperatures with significant confidence (John Welhan, written communication, 2011).

Local temperature gradients were also produced by temperature logging 6 wells in the Stanley area. The highest gradient observed during this study (Table 3) was that of Well #2 (this study), or Well G-2 of Chapman (1986). It is important to note that most wells with the highest gradient lie north of Stanley and west of the Historical Museum.

5. Geologic and Geophysical Surveys

A 2 meter or shallow probe survey consisting of 24 stations was conducted in the Stanley area to try and locate areas of high temperature, possibly caused by upflow of thermal waters along geologic structures (i.e. faults/fractures). An area north of Stanley and west of Highway 75, near the public bathing pool (formerly Stanley Hot Springs) has been identified as an area of high temperatures, ranging from 12.6°C to 15°C. Other areas near Lower Stanley may have geothermal potential but this remains to be confirmed because shallow ground water may have masked any thermal potential in these areas.

Three geophysical surveys (gravity, magnetic, and resistivity) were also conducted in the Stanley area to locate local structural features. A gravity profile was established along a transect that crosses both the Stanley Basin and potential geologic structures identified in previous tasks of this project. The gravity data suggests that there are up to 3 faults that are controlling the movement of fluid flow through the Stanley geothermal system. Gravity values range from -213.82 mGals to -211.92 mGals.

6. Proposed Location for Test Well(s)

Based on data gathered from this study and data gathered from background literature research, it has been determined that the best location for successful geothermal resource extraction lies near the

Well/Spring	pH	Temp (C)	As	B	Ca	Fe	Li	Mg	Mn	K	SiO2	Na	HCO3	F	Cl	SO4	Cond. (µhmos)	TDS
Rocky Mountain Ranch (S)	7.5	43.8	<0.003	<0.10	2.69	<0.05	0.06	<0.50	<0.05	0.6	54.7	57.9	61.6	10.9	NA	29	276	188
Bathing Pool (Stanley H.S.) (S)	8	39.4	<0.003	<0.10	**1.85**	<0.05	0.08	<0.50	<0.05	**0.7**	**62.1**	**64.5**	57.3	14.5	7	25	297	158
Harrah's #3 (W)	7.5	NA	<0.003	<0.10	1.79	<0.05	0.08	<0.50	<0.05	<0.5	59.8	62.1	55.9	13.8	7	22	293	188
Boat Box (S)	8.2	57.2	<0.003	<0.10	1.5	<0.05	0.13	<0.50	<0.05	0.9	72.6	70.4	64.7	15.8	7	25	332	226
Beckwith's Pool (S)	8.5	57.2	<0.003	<0.10	1.49	<0.05	0.13	<0.50	<0.05	1	75.2	69.8	65.5	17	NA	27	337	248
Elk Creek (S)	8.25	51.6	<0.003	<0.10	1.49	<0.05	0.14	<0.50	<0.05	1	75.5	69.4	68.7	17.9	NA	28	337	254
Cove (S)	8.75	56.1	<0.003	<0.10	1.73	<0.05	0.08	<0.50	<0.05	1.4	85.4	71.7	65.9	14.3	NA	38	347	260
Sunbeam (S)	9	76.6	<0.003	0.16	**1.44**	<0.05	0.07	<0.50	<0.05	**2.2**	**87.6**	**86.4**	93.5	15.5	NA	42	417	300

Table 1. Results of chemical analysis of water samples collected for this study. All concentrations are in mg/L. This table is identical to Table 2 in Task 3 Report. Refer to Figure 2 in Task 3 for locations of samples. As mentioned in the text of Task 3 the elements, As, B, Fe, Mg, and Mn were all below analytical detection limits.

Sample Name	Chalcedony cond	Quartz cond	Quartz adiabatic	Na-K-Ca	Na/K Fournier	Na/K Truesdell	Na/K (Giggenbach)
Rocky Mountain Ranch	76.44	106.41	106.21	47.45	77.82	27.92	99.05
Bathing Pool (Stanley H.S.)	**83.09**	**112.50**	**111.49**	**59.82**	**79.86**	30.06	**101.06**
Harrah's #3	81.09	110.67	109.91	50.53	67.07	16.74	88.44
Boat Box H.S.	89.92	118.72	116.86	72.58	87.30	37.91	108.37
Beckwith Pool	93.62	122.08	119.75	75.98	92.66	43.60	113.62
Elk Creek	93.84	122.28	119.92	75.92	92.94	43.90	113.89
Cove	100.96	128.73	125.43	84.07	108.07	60.20	128.65
Sunbeam Hot Springs	**102.46**	**130.09**	**126.59**	**125.49**	**122.35**	**75.88**	**142.51**

Table 2. Results of geothermometer analysis from concentration of select chemical species in degrees Celsius. Values were calculated in a spreadsheet by Powell and Cumming (2010). This table is identical to Table 3 in Task 3. Refer to Figure 2 in Task 3 for locations of samples.

Locations of Wells Logged for Temperature Gradient

Figure 1. Locations of Wells near the Stanley Area.

Well Name	Source	Northing (UTM 11N)	Easting (UTM 11N)	Surface Temp (°C)	BHT (°C)	TD (m)	Gradient (°C/km)
#2	This Study	4898404	665241	14.22	46.48	91	387.12
#3	This Study	4898511	665277	38.75	44.02	53	115.94
Neider's	This Study	4897256	665821	6.34	20.1	212	69.86
G-1	Chapman (1986)	4898512	665278	35	43	65	130.0
G-2	Chapman (1986)	4898405	665242	16	40	91	293.33
City Well	This Study	4898104	664888	9.8	10	45	5.28
Ken Smith's	This Study	4898665	665779	8.6	13.7	38	168.3
Harrah's Capped	This Study	4898573	665333	18.9	20.1	8	198.0

Table 3. Calculated temperature gradients from wells in the Stanley area. Refer to Figure 1 for well locations.

current location of the Stanley Hot Springs (Figure 2). Geologic structures, specifically faults, have been identified by previous investigators (i.e. Chapman, 1986; Krahmer, 1995) and by the work done in this study with the gravity survey near this location. One reason why thermal water reaches the surface at this location could be because of the intersection of 2 different faults (Figure 2), which would undoubtedly increase the fracture density and therefore increase permeability within this zone. Higher thermal gradients measured in wells and in the 2 meter survey indicate this is a good area for a test well.

From the study of the geothermal system near Stanley, two main trends in faults have been identified that control the geothermal fluid flows, those trending NE-SW related to the Trans-Challis Fault System and those trending NW-SE related to regional extension of the Basin and Range geologic province. The chemical qualities of the geothermal water at the surface and calculated potential reservoir temperatures based on hydrochemistry have been determined. Reservoir temperatures for the system of interest range from 60°-83° C. The decrease in temperature moving SW from Sunbeam Hot Springs to the Stanley Hot Springs is due to the increased mixing of meteoric waters (Table 2). The gravity survey indicates that there is a fault oriented N-S that is locally controlling fluid movement in the area of the Stanley Hot Springs.

A conceptual structural model was created by Kathleen Autenreith from Idaho State University based on data that was collected from background literature research and data collected from this investigation. This model takes two faults identified by Krahmer (1995) and projects them into the ground using Vulcan3D modeling software. The result of this modeling is shown in Figure 3.

In order to increase the probability of success of any new test wells drilled, it would be reasonable to target areas affected by the intersection of major faults where higher fracture density and permeability would be expected. Figure 2 shows a trend line (blue) that represents the vertical projection to the surface of the predicted below ground fault plane intersection. By calculating the plunge of a line that defines the intersection of the two planes, the depth of that intersection can be estimated for any point along the trend line. The trend line is based on the faults identified by Fisher et al (1992) and this study. An average dip of 55° was calculated from Krahmer (1995) to determine the trend and plunge of 357° and 45°. The dips of faults in this area range from 45°-60° (Krahmer 1995).

The shallower depth of 61 meters is essentially the same depth as wells previously drilled in the area and were found to have only moderate temperature due to mixing with shallow groundwater. It is estimated a depth greater than 152 meters would be needed to minimize the ground water mixing and cooling of the resource. Based on gradients in the area, depths of 389-750 meters may be required to obtain adequate temperatures for potential power production. As mentioned in the above, calculated reservoir temperatures based on geothermometers are in the range of 60°-83°C near the Stanley Bathing Pool and as high as 140°C at Sunbeam Hot Springs indicating a potential increase in reservoir temperatures to the north end east along the fault system.

Temperatures over 80°C could be used for low temperature binary power production with the effluent from the power plant used for direct heat uses prior to re-injection. Chena Hot Springs in Alaska is successfully using water at 74°C for power production (Lund, 2006). Geothermal fluids at temperatures above 50°C are viable for space heating and even lower temperatures are acceptable for aquaculture (Geo-Heat Center, 2012).

Based on intended use and the goal to achieve the highest potential temperature and flow, two potential drilling locations are proposed. Site A is the preferred location for drilling of an exploration well along the fault intersection trace used by Autenreith (ISU, written communication, 2011) to develop the conceptual structural model and is in an area acceptable for drilling. If the faults dip at 55°, then Site A has a predicted depth to fault intersection of 481 meters. This depth would place it below the active surface ground water system, minimizing mixing and cooling of the resource. Depending on the dip of the faults in this area the depth of the targeted fault intersection could range from 389 meters to 662 meters. The coordinates for Site A are 665291, 4898891 (UTM Zone 11N).

Site B is located north of Site A near the Cemetery access road. This location has the advantage of being located closer to the road thereby requiring less road construction for a drilling pad. The predicted depth to the fault intersection (with a 55° dip) at this location is estimated to be 545 meters but could range from 442 meters to 750 meters. The coordinates for Site B are 665289, 4898955 (UTM Zone 11N).

By drilling small diameter exploration holes, referred to as slim holes, several important characteristics can be identified, such as: a stratigraphic section; reservoir characteristics (i.e. permeability and porosity); thermal gradients; chemistry of the fluids; and potential flow rates. Another option for a test well would be to drill a larger diameter, deeper gradient hole. If adequate temperatures and flows were encountered this gradient hole could be developed and used as the production well of geothermal water for the City of Stanley.

The resource within the Stanley area may be suitable for different uses depending on the results from a successful test well. It would be suitable for space heating either through individual buildings in the shallower thermal systems or a district heating system in the deeper higher temperature portions of the reservoir. The hot water could also be used for greenhouse operations and recreational purposes. At the high end of the potential range of estimated temperatures and flow possibilities, it may also be suitable for power generation. Several companies have developed low temperature binary cycle, power generation units in modular form which can range from a few 10's of KWe to 100's of KWe. The low annual temperature in the Stanley area would be ideal for the cooling cycle resulting in efficient operation of such a unit.

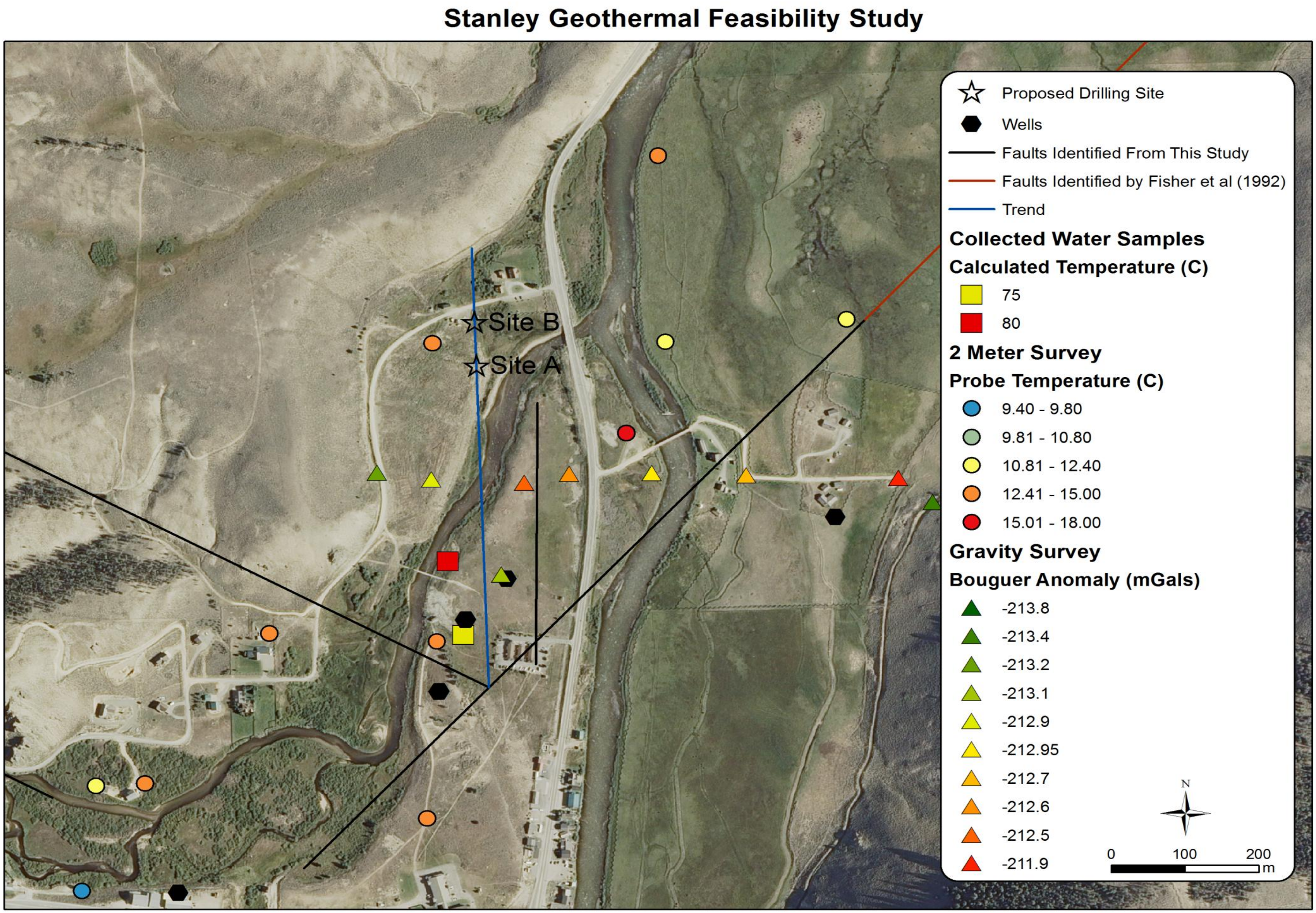

Figure 2. Data obtained during this study and how it has been use to determine location of the drilling area. See section 6 for further details.

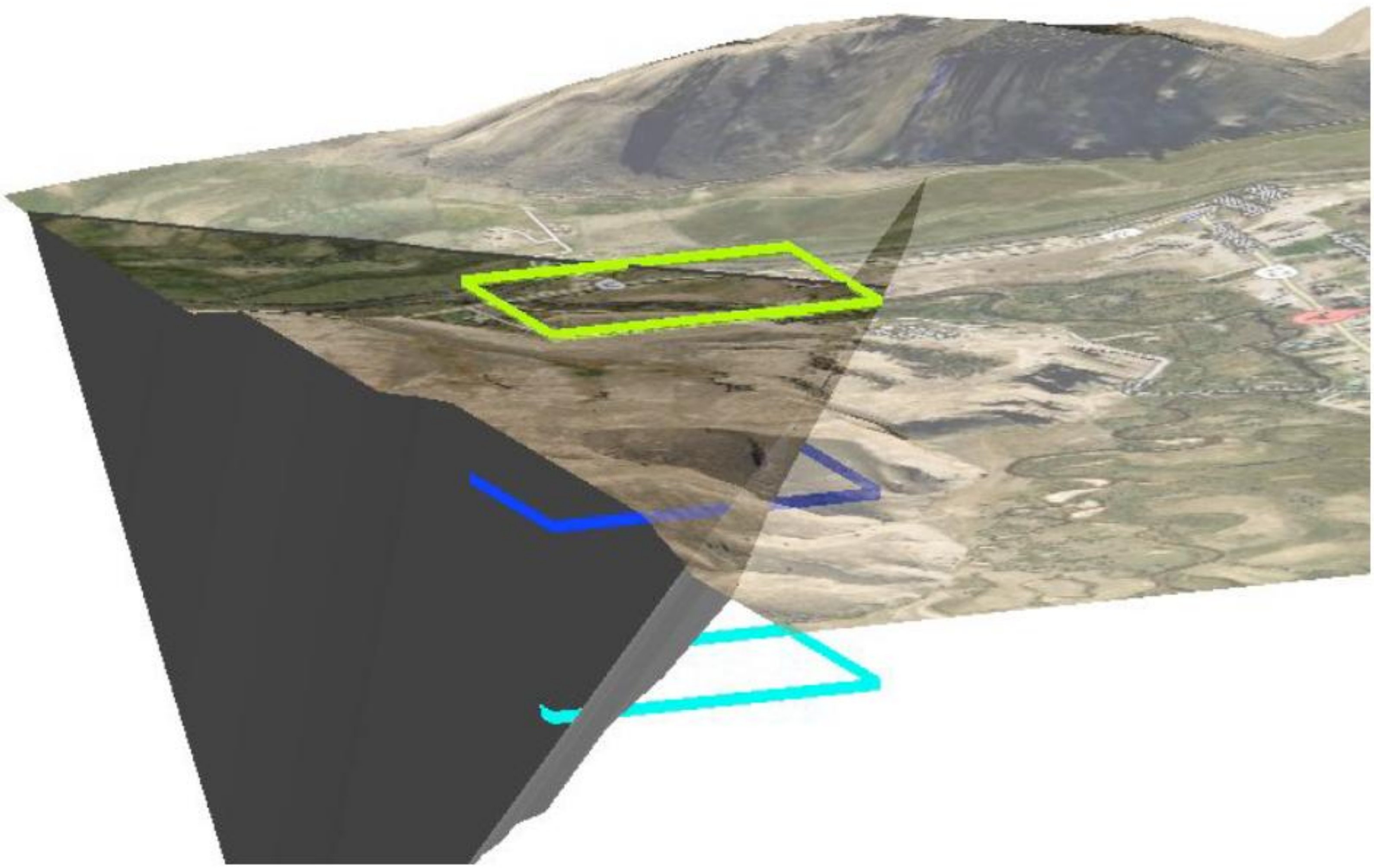

Figure 3. Conceptual structural model of 2 faults located north of Stanley. A dip of 55° was used for both faults, which is the average dip of faults in this area (ISU, written communication, 2011; Krahmer 1995). Rectangles represent depths of 0, 500, and 1000 meters (ISU, written communication, 2011). View is to the southeast.

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This project represents a major accomplishment for the City of Stanley and the surrounding community. Without the far reaching partnership, cooperation, and teamwork that occurred this project would never have reached fruition.

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