Analysis of downhole data from USU-1 well

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Technical Report

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Introduction

The Snake River Plain (SRP) Geothermal Play Fairway Analysis team identified two regions of interest during Phase 2 studies: the western SRP near Mountain Home, Idaho and Camas Prairie, Idaho (Shervais et al., 2018). The project team decided to focus on Camas Prairie for validation during Phase 3. Camas Prairie is an EW-trending half-graben bounded on the north by the Idaho Batholith and on the south by the Mount Bennett Hills. Camas Prairie is bisected by a major NW-trending fault system (The Pothole fault) that separates NW-trending faults to east from ENE-trending faults to the west. Evidence of a geothermal system in Camas Prairie is provided by various geological and geophysical observations including warm springs and wells, buried faults and basins, mapped faults, and young basalt vents and lava flows along the range front. Permeability is suggested by the confluence of intersecting faults, including the range front system and the Pothole fault system, the presence of springs along mapped structural features, and dilatational stress along major NW-trending fault systems. In order to confirm an economically viable low-temperature resource, the project team decided to drill a 700 m (~2000 ft) test well into an inferred permeable structure along the Pothole fault system near the range front of the Mount Bennett Hills. It was also planned to perform a suite of reservoir tests and down-hole geophysical logs to characterize the system and document reservoir characteristics.

The test well USU-1 was spudded on September 15, 2018, and completed on October 19, 2018 to a total depth of 1608 ft (~490. 12 m). The well was completed with a 6 inch cemented casing to a depth of 1141 ft (~347.78 m); below the latter depth, a 5 5/8 inch open hole is present. Following well completion, brief discharge and injection tests were performed. The test sequence and data are described in the Appendix authored by Colin Goranson. In the following sections, test data are analyzed to infer formation properties in the vicinity of USU-1. A comparison of temperatures recorded in USU-1 with the reported temperatures in other nearby wells is also presented.

Pressure and temperature surveys and Permeable zone

Available temperature and pressure surveys in the shut-in well are displayed in Figures 1 and 2 respectively. Partial temperature survey of October 19, 2018 was taken just after well completion and prior to discharge and injection activities. The only other temperature survey was run on October 24, 2018 some 14 hours after cold water injection into the well. It is unlikely that the temperatures had equilibrated in the well at the time of the latter survey. Presence of a cold zone centered at ~357.5 m most likely indicates the permeable zone that accepted cold injection water. A maximum temperature of 77.2 ^{o}C was recorded at the bottom of the well (~490 m) on October 24, 2018; considering that the well was shut-in only for 14 hours after cold water injection, it is likely that the stable formation temperature at 490 m is considerably higher than 77.2 ^{o}C. By comparison between the temperature profiles of October 19 and 24, 2018, the feedzone temperature (~357.5 m) is estimated to be at least 70 ^{o}C. A pressure of 34.84 bars was measured at 357.5 m on October 24, 2018.

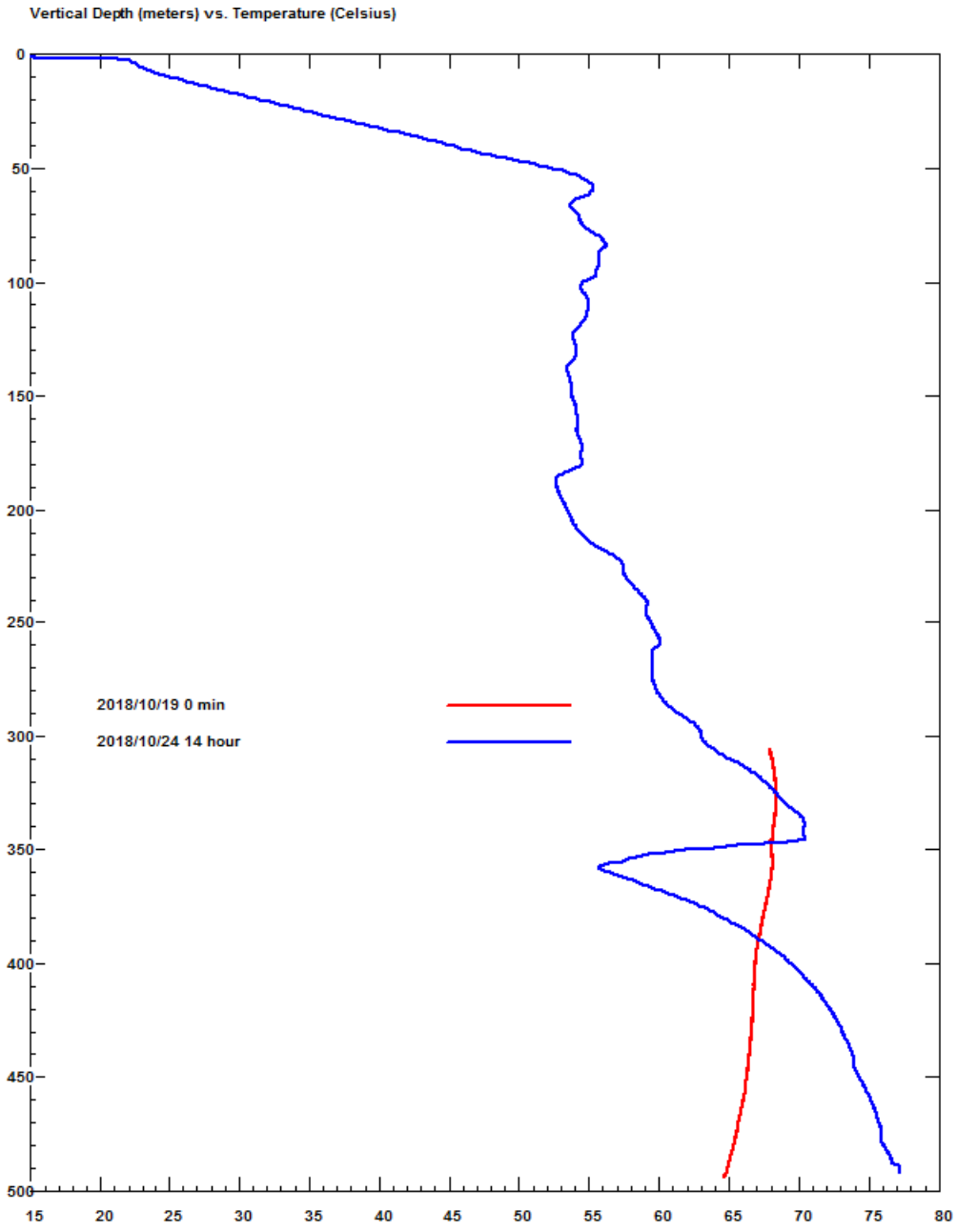


Figure 1: Temperature surveys under shut-in conditions in well USU-1

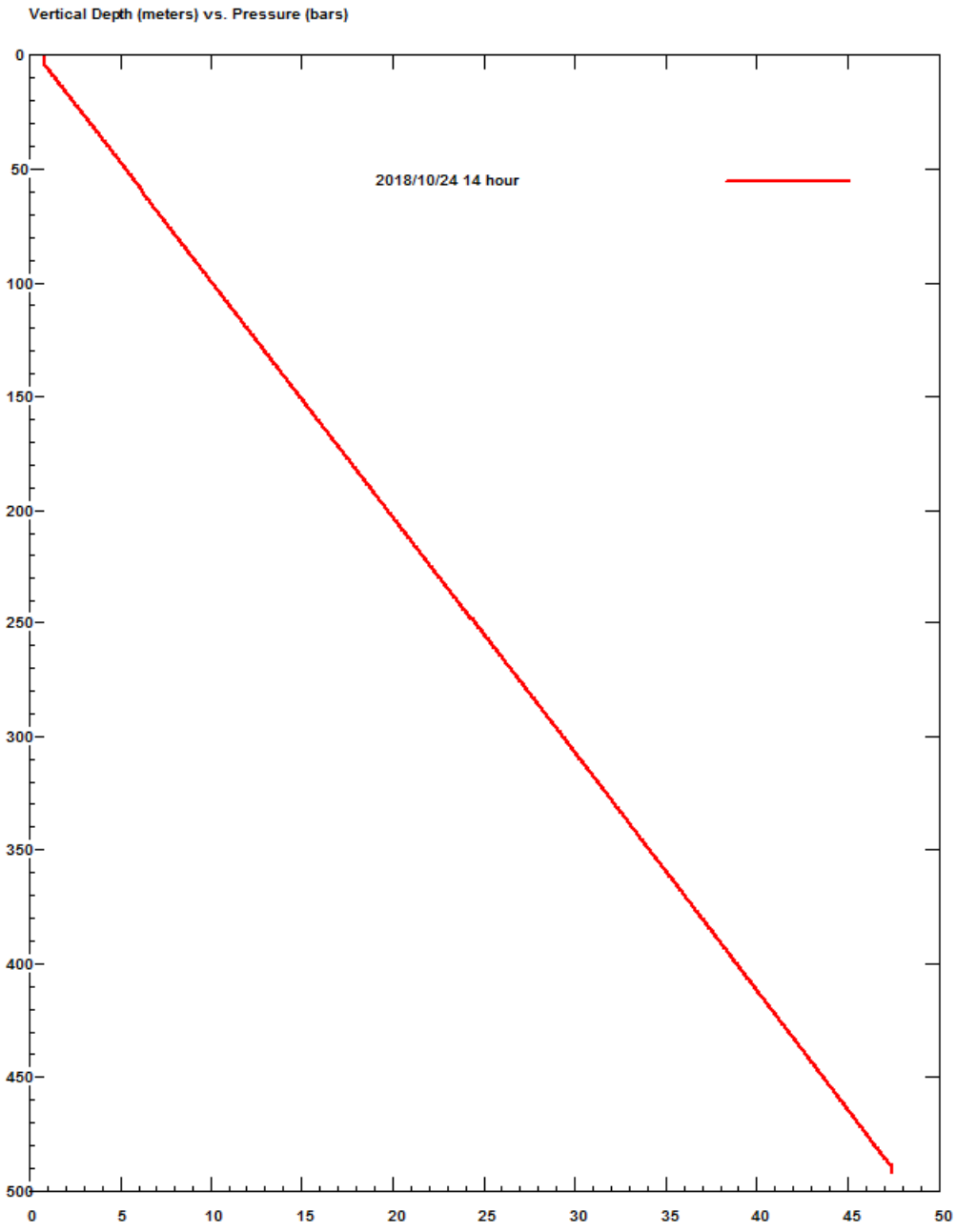


Figure 2: A pressure survey recorded under shut-in conditions in well USU-1

Discharge test

The well was discharged for about 4 hours (10:38 LT to 14:33 LT) on October 20, 2018 by air lift through drill pipe (DP) lowered to 735 ft (224.0 m). The average discharge rate was about 60 gpm (~3.79 l/s = 3.71 kg/s) at a maximum surface temperature of 67.8 ^{o}C. During the discharge

test, the pressure was steady at 155 psig (~11.53 bar) at 224 m. The static pressure at 224 m was ~22.03 bar on October 24, 2018 (Figure 2). Therefore, the productivity index (PI) is given by:

PI = 3.71/ (22.03 – 11.53) = 0.35 kg/s-bar

The computed productivity index (PI) is relatively low. Continued injection (or discharge) is often found to lead to an improvement in the PI as a result of hole clean up.

Injection tests

Two injection tests were performed on October 21, 2018 (11:19 LT to 18:10 LT) and October 23, 2018 (09:26 LT to 17:16 LT). The injection rates had to be kept low (~22 gpm on October 21, 2018 and ~16 gpm on October 23) due to leakage of the surface packer. During both the injection tests, a PT (pressure and temperature) tool was installed at 1225 ft to record changes in downhole pressure and temperature. Unfortunately, the tool failed to record properly on October 21, 2018; thus, downhole pressure data are only available for the second injection test performed on October 23, 2018. The injected water temperature was ~11.1 ^{o}C on October 24.

It was not possible to record the early injection rate on October 23, and the corresponding pressure record contains large oscillations (see Appendix). The pressure record was processed to remove the latter oscillations and resampled using a time interval of 0.005 hours; the resampled data were then filtered using a low pass filter (corner frequency = 10) to remove high frequency oscillations. Finally the filtered data were resampled (decimated) using a minimum pressure interval of 0.0015 bar (~0.02 psi). The resampled and filtered pressure data are displayed in Figure 3.

The pressure data in Figure 3 display an anomalous response. Normally, one would expect pressure to increase monotonically with continued injection; however, in this case, the pressure decreases. A decrease in pressure indicates an improvement in injectivity with continued injection. The final injection pressure just prior to shut-in at 17:19 LT on October 23, 2018 was ~35.90 bar (g). By the end of the downhole recording (about 8:20 LT on October 24, 2018), the pressure had declined to about 35.24 bar (g). With an injection rate of 16 gpm (~1.01 l/s = 1.01 kg/s), the injectivity index (II) is given by:

II = 1.01 / (35.90 – 35.24) = 1.53 kg/s-bar

The above injectivity index is more than 4 times the productivity index obtained from the brief discharge test on October 20, 2018. As noted earlier, the injectivity improved during the injection test.

Because of anomalous pressure response during the injection phase, the pressure data for this part of the test cannot be analyzed to obtain formation and well properties. Consequently, it was decided to focus on the fall-off pressure data. The latter data were at first analyzed using the standard Horner plot (see e.g. Streltsova, 1988) shown in Figure 4.

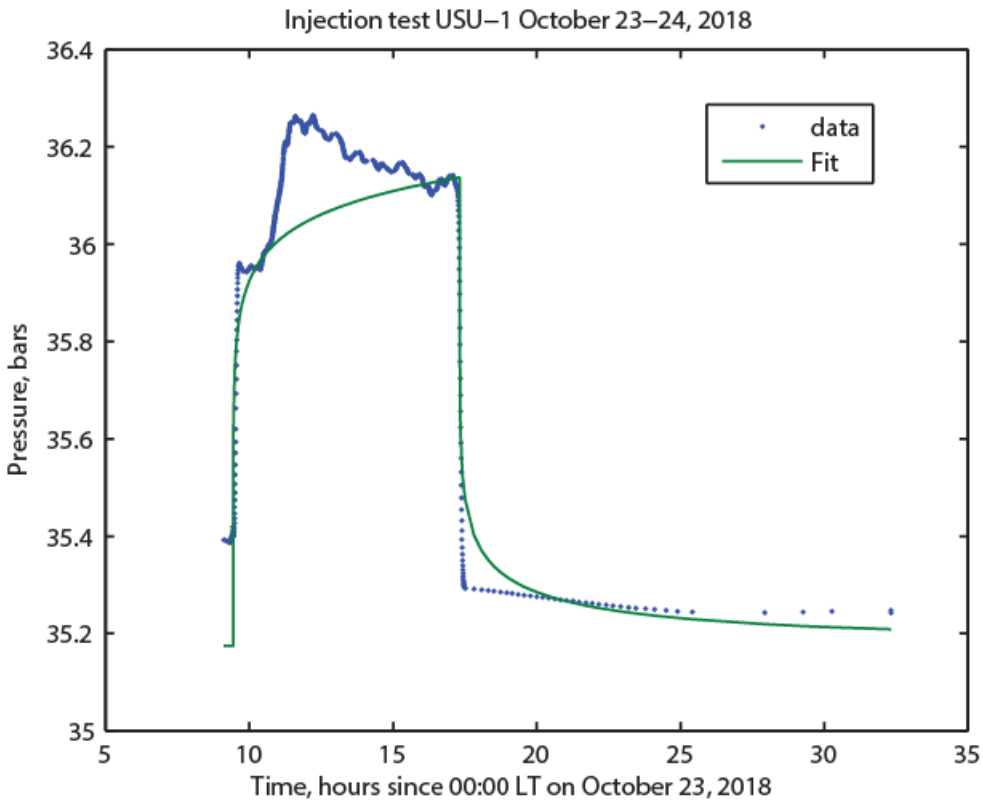


Figure 3: Comparison between pressure data recorded the injection test on October 23-24, 2018, and mathematical fit (see text).

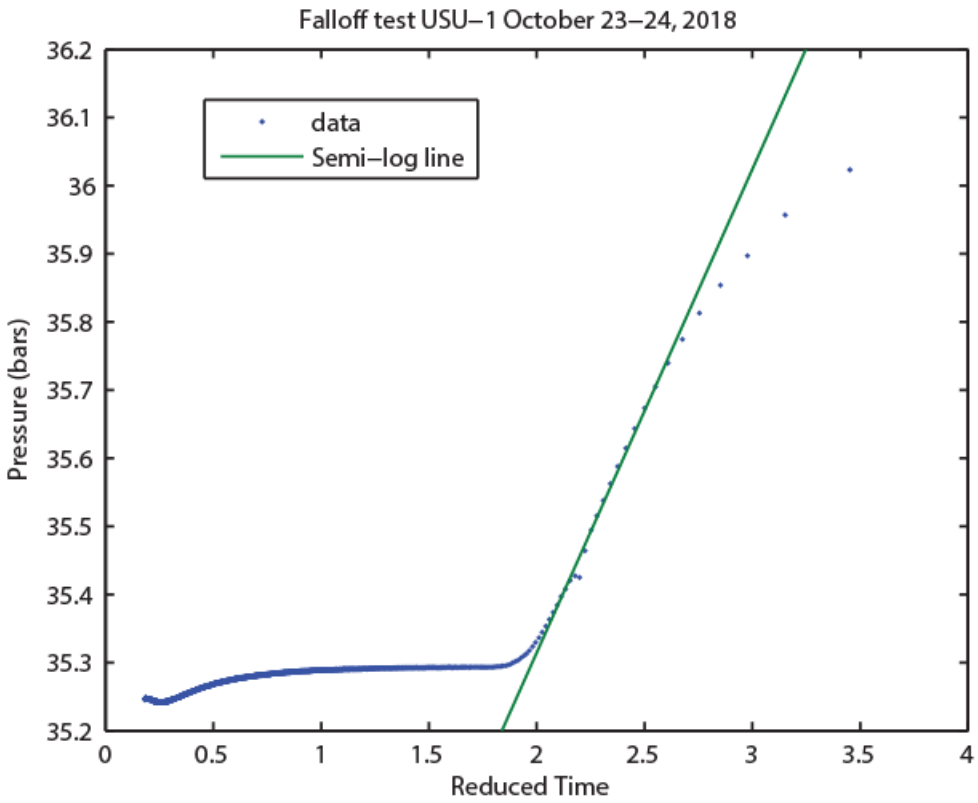


Figure 4: Horner plot of the pressure fall-off data recorded in well USU-1 on October 23-24, 2018. The semi-log straight-line has a slope of 0.709 bar/cycle.

With a discharge rate of 1.01 kg/s, a fluid density of 977.7 ^{o}C and viscosity of 404 microPa-s (corresponding to a temperature of 70 ^{o}C), the formation permeability-thickness (kh) is given by:

kh = 1.15 * (mass flow rate/density)*viscosity/ (2*pi*slope of semi-log line) ~1.09 darcy-meter.

The fall-off data were also analyzed using an automatic inversion program DIAGNS (Garg et al., 2002); inversion was performed using the classical finite cylindrical source solution (Streltsova, 1988; Garg et al, 2002). Results of analysis are shown in Figure 3 and Table 1. Agreement between the data and the mathematical fit is only fair (Figure 3). Mathematical fit (Table 1) yields a permeability-thickness of about 4.17 darcy-meter, which is about 4 times that inferred from the Horner plot. In any event, it appears that the formation intercepted by USU-1 has a modest transmissivity (1 to 4 darcy-meter).

Table 1: Formation parameters inferred from inversion of injection rate and pressure fall-off data for well USU-1, October 23-24, 2018.

Parameter	Value
Initial pressure, bars	35.17
Transmissivity, Darcy-meters	4.17
Storage coefficient, meters/Pa	4.52e-9*
Skin factor, dimensionless	-2.61
Wellbore storage, cubic meters/Pa	1.12e-10
Pressure range, bars	1.02
Standard error/Pressure range, dimensionless	0.071

*Kept fixed at 4.52e-10 (compressibility of water at 70 ^{o}C) x 10 m

Formation Temperatures near well USU-1

Temperature data are available for several wells near well USU-1 (see Figure 5 for well locations). These data are summarized in Table 2.

Figure 5: Google earth map of well locations and faults (red lines). Several of the wells (Barron Big H.S., USU-1, Gonsales, and Barron) are located close to the NW trending Pothole fault.

Table 2: Temperature data for wells near USU-1. Wells are arranged in the table from south to north.

Well	Latitude	Longitude	UTM north, m	UTM east, m	Date	Depth, m	Temp., degrees C	Comments
Barron Big H.S.	43.29194	-114.911	4795354	669455	07/23/2010	61	63	67 C at 46 m
USU-1	43.29889	-114.909	4796129	669594	10/24/2018	492	77	After 14 hours shut-in
Gonsales	43.30167	-114.909	4796437	669586	07/23/2010	121	74	
Barron	43.3025	-114.909	4796530	669584	07/22/2010 08/08/2016	168 160	82 85	91 C at 91 m (7/22/2010)
SRV2	43.3205	-114.92	4798507	668640	12/11/2017	56	12	
1A	43.33532	-114.92	4800152	668583	06/06/2018	106	18	
3A	43.3351	-114.901	4800168	670181	06/06/2018	74	15	

It appears that the thermal reservoir does not extend as far north as wells SRV2, 1A, and 3A. Little is known about the well conditions (e.g. time since shut-in) at the time of the temperature surveys. All four of the southern wells (Barron Big H.S., USU-1, Barron, and Gonsales) are close to the Pothole fault and appear to have similar temperatures (75 +/- 15 ^{o}C). It is possible that all of these wells are supplied by hot water upwelling along the Pothole fault. Well USU≥-1 is considerably deeper than the other wells. The temperature survey recorded on October 24, 2018 in USU-1 exhibits a conductive gradient of ~7 ^{o}C / 100 m below a depth of 420 m; it is thus possible that temperatures ≥ 100 ^{o}C may be encountered at depths of 700 to 800 m in the area.

References

Garg, S.K., Alexander, J., Ellis, M., Kelly, C., Kuharski, R., Patnaik, P. (2002), Well testing for hydrological properties: geothermal pressure transient analysis software DIAGNS (FY 2001), Report, Science Applications International Corporation (now Leidos, Inc.), San Diego, California, February.

Shervais, J.W., Glen, J.M., Siler, D., DeAngelo, J., Liberty, L.M, Nielson, D.L., Garg, S., Neupane, G., Dobson, P., Gasperikova, E., Sonnenthal, E., Newell, D.L., Evans, J., Snyder, N. (2018), Provisional Conceptual Model of the Camas Prairie(ID) Geothermal System from Play Fairway Analysis, Proceedings Stanford Geothermal Workshop, February.

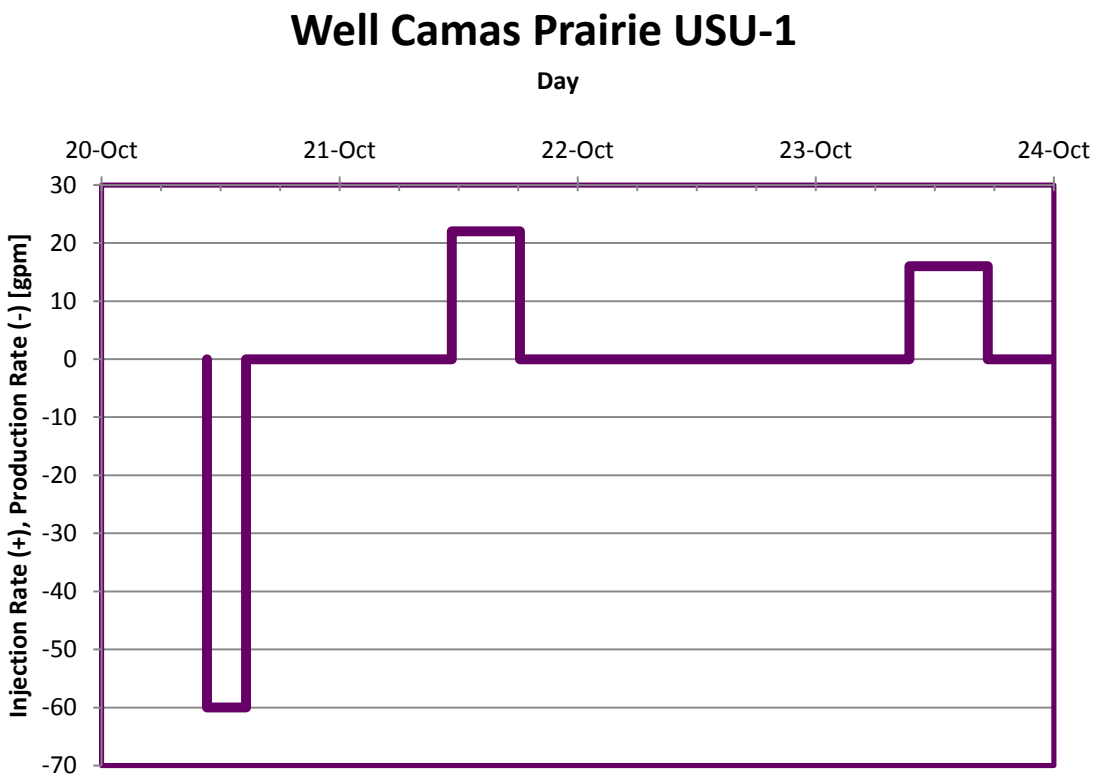
Streltsova, T.D. (1988), Well testing in Heterogeneous formations, John Wiley & Sons, New York, N.Y.

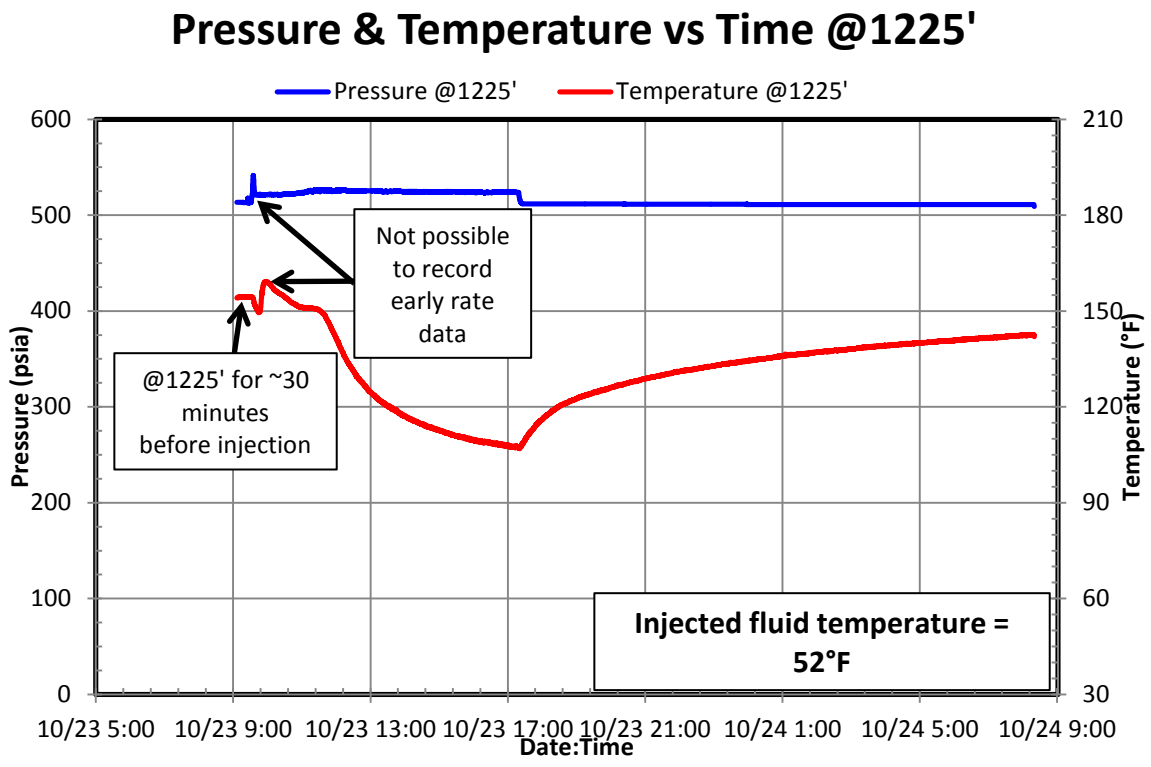
Appendix: USU-1 Well Testing Operations

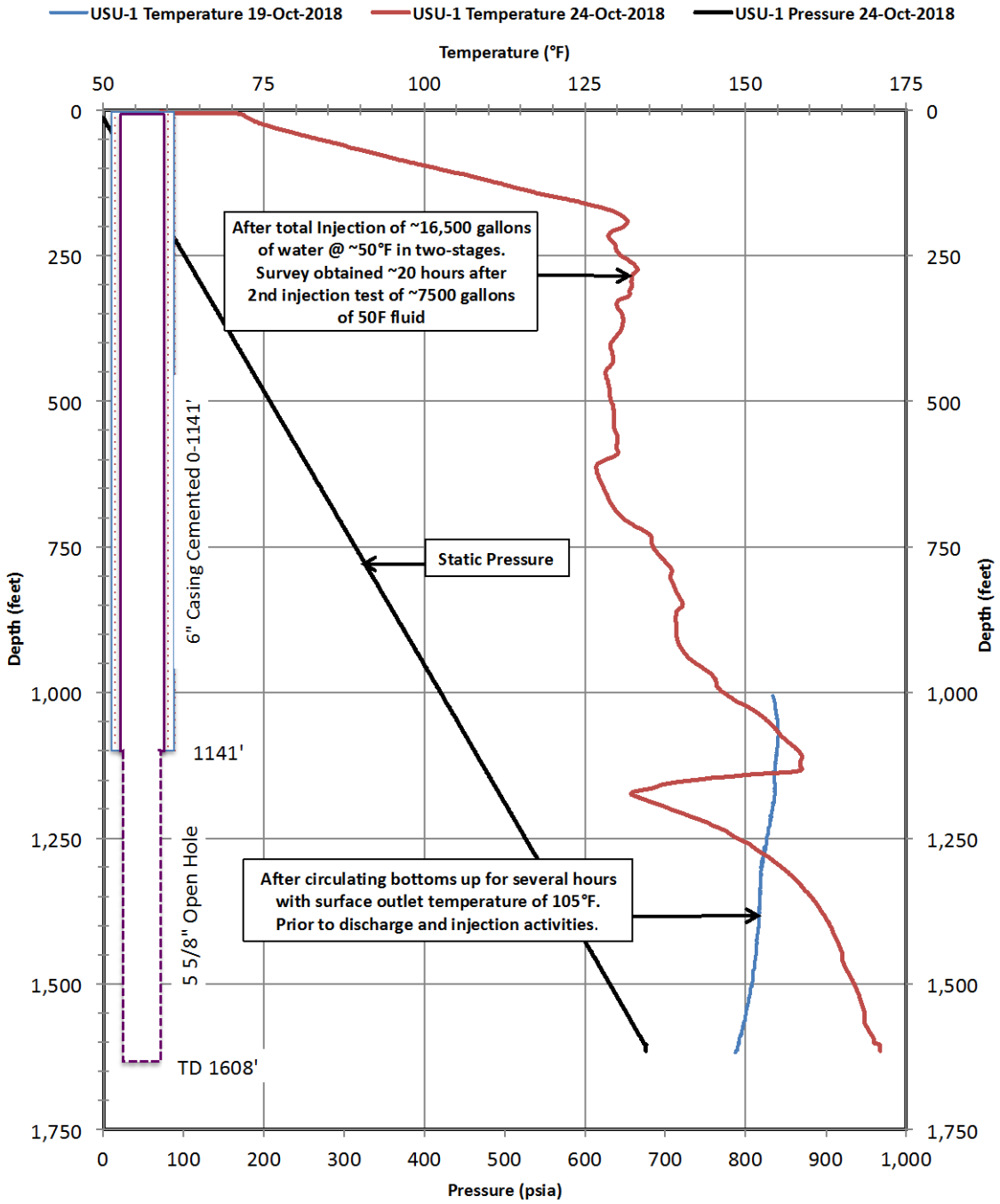
(Prepared by Colin Goranson)

Date	Camas Prairie USU-1 Well Testing Operations
18-Oct-18	Lv for Fairfield, Idaho Camas Prairie-1 (USU-1) Well site.
18-Oct-18	Ar Fairfield 17:30 hrs
19-Oct-18	Rig working 7AM-7PM, 07:30 hrs at USU-1. Circulating Hole (41°C Outlet). USGS Logger shows up at 11AM. Kuster equipment brand new never used. Run Geo Logs, caliper and Temp Log.
20-Oct-18	Run Temp survey, tool died @~400'. Rig up to air lift well for fluid samples. RIH with DP to 735'. Start Air compressor (350 psi, 1000 cfm), 10:38 fluid out, max pressure (Breakover pressure) 300 psi. Use bucket for flow measurement at 4-5 secs for 5-gallons ~60 gpm. Steady pressure @735' = 155 psi during discharge. This implies, for a static water level of 46' (measured during logging), a pressure drop at 755' of 300-155=145 psi at 60 gpm of discharge, or ~0.41 gpm/psi . Take gas and water samples (Hari from INEL). Max Temp out to surface 67.8C (154F). 14:33 Hrs shut off air and well discharge. Total produced volume ~14,100 gallons (~8 wellbore volumes based on production zone at ~1200'). Pull drill pipe out of hole. Run Kuster PT Log, recovered data but depth encoder not working.
21-Oct-18	Kuster depth encoder not working properly. No wellhead packer available to seal around cable when injecting fluids. Make up rubber packer assembly but will have to inject at low rates. However, downhole pressure changes should be large enough with ~20 gpm injection rate based on air-assisted discharge data. Run PT tool to 1225' (depths measured using winch counter). 11:19 hrs start injection. Injected fluid temperature 41°F. Use Frac tank measurement (Tank is 41' long by 8' wide for 80.5 gallons per cm). Take periodic Frac Tank water level measurements. Positive displacement Mud Pump on rig being used for injection, howver, pump never calibrated and driller not clear on what size liners and pistons are in the pump so will be using Frac Tank water level measurements versus time for rate estimates. Average injection rate ~22 gpm. Stop injection @18:10 hrs. ~9000 gallons injected.
22-Oct-18	Out to site. Pull Kuster PT tool out of well. Data looks OK, downhole pressure ~500 psi, but several additional pressure changes noted in data. Leave for Home. Drive to Battle Mountain, Nevada. Call from USGS operator indicates Kuster pressure data may be bad. He had filled the Kuster pressure tool with oil, as per manual, but instead of screwing Filter into oil fill hole (pressure tool inlet) he screwed plug back in. Kuster says data may be good or bad. Talk with John Shervais and decide to redo injection test. Head to Bellevue, Idaho (Fairfield Hotel closed). Rig hands filling water tank.
23-Oct-18	Out to site for repeat of injection test (raining). 08:51 hrs downhole Kuster PT tool set at 1225'. 09:26 hrs start injection. Injected water temperature 52°F. Injection rate ~16 gpm (higher rate caused surface packer to leak badly).Will inject at reduced rate. Not possible to get early time flow rates (using 20,000 gallon Frac Tank for Injection Rate estimates). 17:19 hrs shut-off injection. ~7500 gallons of fluid injected.
24-Oct-18	Out to site. 08:36 hrs Kuster tools out of hole. Data looks good. Head for home. 19:30 hrs home

Camas Prairie Well USU-1 Fairfield, Idaho October 18-24, 2018	
Date	**Average Discharge (-)/Injection (+) Rate (gpm)**
10/20/18 10:38	0
10/20/18 10:38	-60
10/20/18 14:33	-60
10/20/18 14:33	0
10/21/18 11:19	0
10/21/18 11:19	22
10/21/18 18:10	22
10/21/18 18:10	0
10/23/18 09:26	0
10/23/18 09:26	16
10/23/18 17:19	16
10/23/18 17:19	0
10/24/18 00:00	0


Well Camas Prairie USU-1
Day
20-Oct
21-Oct
22-Oct
23-Oct
24-Oct
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Injection Rate (+), Production Rate (-) [gpm]


Pressure & Temperature vs Time @1225'
Pressure @1225'
Temperature @1225'
600
500
400
300
200
100
0
210
180
150
120
90
60
30
Pressure (psia)
Temperature (°F)
Not possible to record early rate data
@1225' for ~30 minutes before injection
Injected fluid temperature = 52°F
10/23 5:00
10/23 9:00
10/23 13:00
10/23 17:00
10/23 21:00
10/24 1:00
10/24 5:00
10/24 9:00
Date:Time


USU-1 Temperature 19-Oct-2018
USU-1 Temperature 24-Oct-2018
USU-1 Pressure 24-Oct-2018
Temperature (°F)
50
75
100
125
150
175
0
250
500
750
1,000
1,250
1,500
1,750
Depth (feet)
After total Injection of ~16,500 gallons of water @ ~50°F in two-stages. Survey obtained ~20 hours after 2nd injection test of ~7500 gallons of 50F fluid
Static Pressure
6" Casing Cemented 0-1141'
1141'
5 5/8" Open Hole
TD 1608'
After circulating bottoms up for several hours with surface outlet temperature of 105°F. Prior to discharge and injection activities.
0
100
200
300
400
500
600
700
800
900
1,000
Pressure (psia)