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Subsurface Characterization Methods for Multilateral Closed Loop Geothermal Systems. Case Study of Field Scale Technology Demonstration Project in Alberta, Canada

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ABSTRACT

The production of heat and electricity from geothermal energy is an old concept and has been around since the early 1900's. However, many geothermal projects are plagued by high up-front exploration costs, financing difficulties and geological risk of low permeability reservoirs which limits development past the exploration phase. Historically geothermal energy is produced from high capacity hydrothermal resources. Recently the concept of production from enhanced geothermal systems through hydro shearing tighter aquifers or production from hot dry rock is growing in popularity. Hydro shearing is often met with uncertainty by local stakeholders because it is perceived as hydraulic fracking on the scale of that of the oil industry. Drilling into hot dry rock involves drilling deep and costly wells into plutonic rocks and has, in some instances, caused induced seismicity.

The concept of producing geothermal energy from true multilateral closed loop systems, whereby there is zero fluid interaction with the formation, seeks to solve the problem of permeability risk, avoids the negative association of hydraulic fracking and does not necessarily involve ultra deep drilling into plutonic rocks.

Closed loop systems extract heat through the process of conduction which has challenges such as limited conductive heat transfer through rock and high drilling costs of multilateral wells. Eavor has designed a system to address these issues through the drilling of long, closed loop multilateral wells without the use of casing in sedimentary basins. This system can produce heat and power at temperatures greater than 100 degrees Celsius.

This paper demonstrates standard geological and geophysical workflows for oil and gas prospecting can be applied in closed loop geothermal settings for the determination of geothermal gradient, permeability and rock type, validates the predicted rock conductivity with the thermal output from a closed loop system and shows the potential for scalability in sedimentary basins across the globe.

1. INTRODUCTION

Subsurface characterization involves a multidisciplinary approach of stratigraphic correlation, structural mapping, determination of heat gradient and rock petrophysics. Many sedimentary basins are highly explored for oil and gas, CO_2 sequestration, geothermal and mining applications. Therefore, data is readily available for analysis. Figure 1 illustrates a typical workflow when prospecting.

Figure 1: Workflow for geothermal prospecting of closed loop geothermal systems.

The Eavor-Loop^{TM} Technology Demonstration Project (TDP) is in the Western Canadian Sedimentary Basin (WCSB) and has hundreds of thousands of well bores and seismic surveys available for analysis. Analysis relied heavily on regional data analysis of temperatures, porosity/permeability and lithostratigraphy. All wellbore bottom hole temperatures (BHT), drill stem tests (DST) and absolute open hole flowing pressure (AOFP) data was collected and used to determine the relationship between the borehole temperatures and the dynamic data to create regional gradient maps and temperature at formation maps to validate published literature on the thermal regimes.

Following the gradient mapping the search for a suitable rock type through desktop studies begins and is validated through core data and rock petrophysics. The TDP was chosen based on this workflow.

The required geological characteristics for Hot Sedimentary Aquifers (HSA's) exploited using open geothermal systems and Eavor-Loop^{TM} are fundamentally different. Traditional convective geothermal plays involve producing water from HSA's and rely heavily on the presence of high-permeability aquifers. For this reason, "traditional" geothermal prospecting in Alberta has focused on the presence of "Sweet Spots" (Banks, 2017). This is a direct parallel to prospecting for conventional oil and gas plays, as they require a costly exploration and delineation phase to confirm adequate reservoir properties.

With Eavor-Loop^{TM}, any rock, even that with less than 50 mD permeability, is suitable for development. In fact, lower porosity and permeability rock is better due to increased thermal conductivity.

Thermodynamic modelling of the Eavor-Loop™ system has revealed a strong dependence of system performance on rock conductivity. However, the economics are relatively insensitive to conductivity as the drilling Rate-of-Penetration (ROP), and in turn lateral wellbore cost, is generally inversely related. For example, certain siltstone and shales can be drilled at 70-100 meters per hour, greatly decreasing the drilling cost but the estimated thermal conductivity is about 2 W/mK versus 3-4.6 W/mK in sandstone.

The Eavor-Loop™ forms a closed system, meaning geological and geophysical characterization requirements are minimized, though not removed altogether. Geological and geophysical inputs are required for drilling plans, horizontal trajectory planning, the identification of drilling hazards, and the refinement of geothermics. Fundamentally, Eavor-Loop™ is dependent on temperature, rock conductivity, and drilling Rate-of-Penetration. It is important to emphasize that Eavor-Loop™ will work in any formation, regardless of mineralogy or conductivity, but some formations are superior than others due to either high ROP or high conductivity. Thus, the following factors are influential for prospecting; stratigraphic architecture, rock thermal conductivity, mineralogy, porosity and permeability, and geomechanical considerations such as fracture/fault characterization. Figure 2 is an illustration of an Eavor-Loop™ closed loop system.

The TDP, is a full-scale prototype of the technology intended to de-risk the key technical components. The closed-loop system consists of a large U-tube shaped well at 2.4km depth, with two parallel approximately 2000m multilateral horizontal wellbores, and a pipeline connecting the sites on surface. Two drilling rigs are operated simultaneously from both sites and used to intersect the multilateral wellbores at depth. A water-based working fluid is circulated in the inlet well, through the parallel wellbores to recover heat by conductive heat transfer with the rock and rises in the outlet wellbore at a higher temperature. The density difference between the inlet well and outlet well creates a thermosiphon which completely drives the flow, without any pumping power. A test facility on surface is designed to measure and remove solids, measure all relevant performance data, and cool the water for re-circulation into the inlet well (Toews et al., 2019).

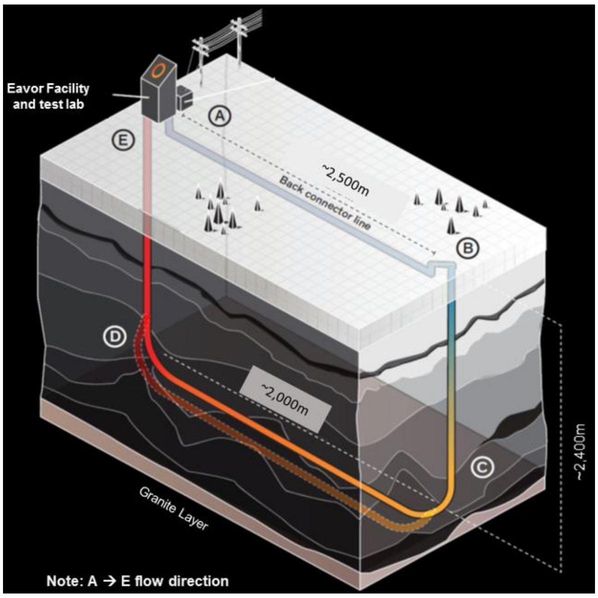

Figure 2: Eavor-Loop™ Geothermal TDP Configuration

The technical objectives for the TDP include: drilling and connecting multilateral horizontal wells, wellbore sealing while drilling to create a pseudo casing and a field scale measurement of thermal output using a conductive heat transfer mechanism in sedimentary rock within a closed loop multilateral system.

2. GEOLOGICAL SETTING

2.1 TDP Location

The TDP is in the Western Canadian Sedimentary Basin (WCSB), a massive wedge of sedimentary rocks that is bounded by the Rocky Mountains in the West and the Canadian Shield in the east (Figure 3). The WCSB has long been home to a vast oil and gas industry since the 1940's. The primary location for the TDP was selected in Township 38-05W5, 18 KM southwest of the town of Eckville, Alberta (Figure 4). This site was selected because it has an ideal depth, geological formation, existing surface locations, conductive sediments with low porosity and permeability, excellent well control and available 3D seismic for drilling and operational risk management.

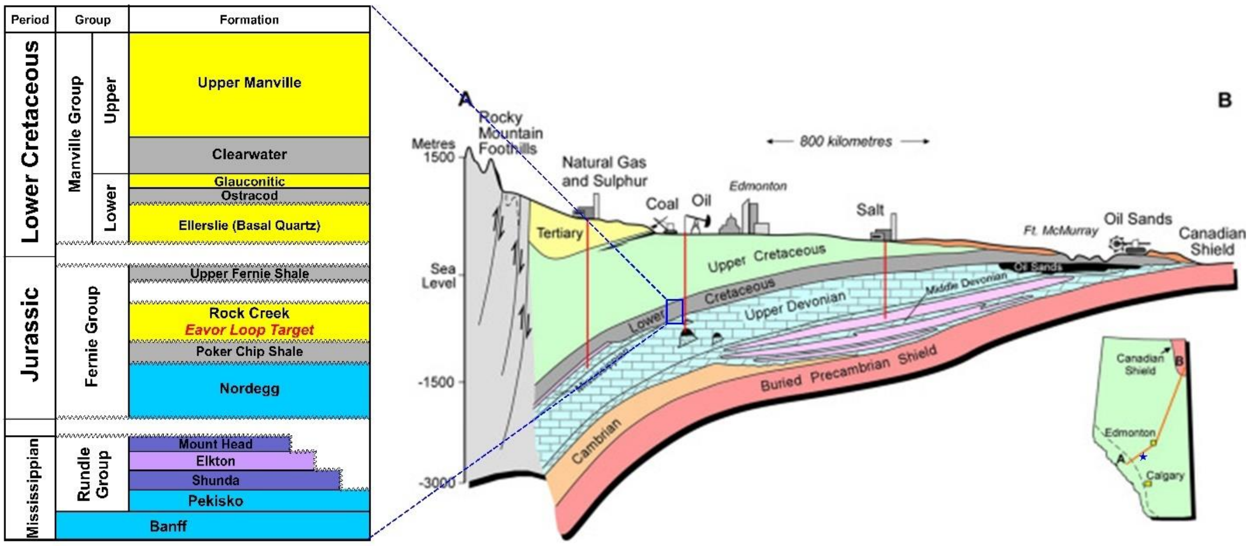

Figure 3: Stratigraphic table of formations and schematic cross section of the Western Canadian Sedimentary Basin. Modified from (Hein, 2017 and Alberta Geological Survey, 2015)

Figure 4: Eavor-Loop Demonstration Project Location Map, Alberta, Canada (red star)

2.2 Stratigraphy

The Cretaceous-Jurassic boundary is notoriously hard to correlate throughout Alberta because it hosts many hydrocarbon plays. It is essential to understand the stratigraphy both for land tenure purposes and reservoir characterization. The Jurassic Fernie Group sediments rest unconformably on carbonate rocks of the Mississippian Rundle Group (Figure 3), representing a hiatus of approximately 145 million years. Similarly, the overlying Cretaceous/Jurassic boundary can have a hiatus between 20-40 million years leading to multiple erosion events and difficulty correlating the channel and marine sands.

This prompted the 1993 Alberta Research Council Open File Report 1993-23 Jurassic Boundary Study (Strobl et al., 1993), a study that incorporated greater than 100 core descriptions, 200 palynology samples and associated wireline logs. The TDP is located inside the boundary study. A second, more recent, report on the Rock Creek was presented at the Canadian Society of Petroleum Geologists (CSPG) Core Conference in May 2019 (Aukes et al., 2019). This study covers 54 townships, includes 1500 well log correlations, 30 core studies and is located about 10 km northwest of the TDP.

The Jurassic sands of the Rock Creek member of the Fernie Group (Figure 3) were targeted for the purpose of heat harvesting through a closed loop geothermal system. At the TDP location, the Rock Creek member sits conformably on the Poker Chip shale in the study area and is a generally accepted as a widespread marginal marine sand throughout Alberta (Mosspo & Shetsen, 1994 & Losert 1986). Aukes et al. (2019) illustrates the abundant nearshore facies that exist at the margins of the sheet sands. The TDP is targeting the older Bajocian stage sands of the Lower Rock Creek (Figures 7&8).

The Rock Creek Member of the Fernie formation is considered a nearshore marine sand as evidenced by the trace fossils found therein (Losert, 1986). Typical log signatures have a blocky signature and sharp base and exhibit slightly coarsening upward signatures typical of sheet sands (Figures 7&8). Geological mapping shows the average gross thickness across the horizontal wells is 15 m and the structure ranges between -1407 m subsea to -1389.2 m subsea (Figures 5A & 5B respectively).

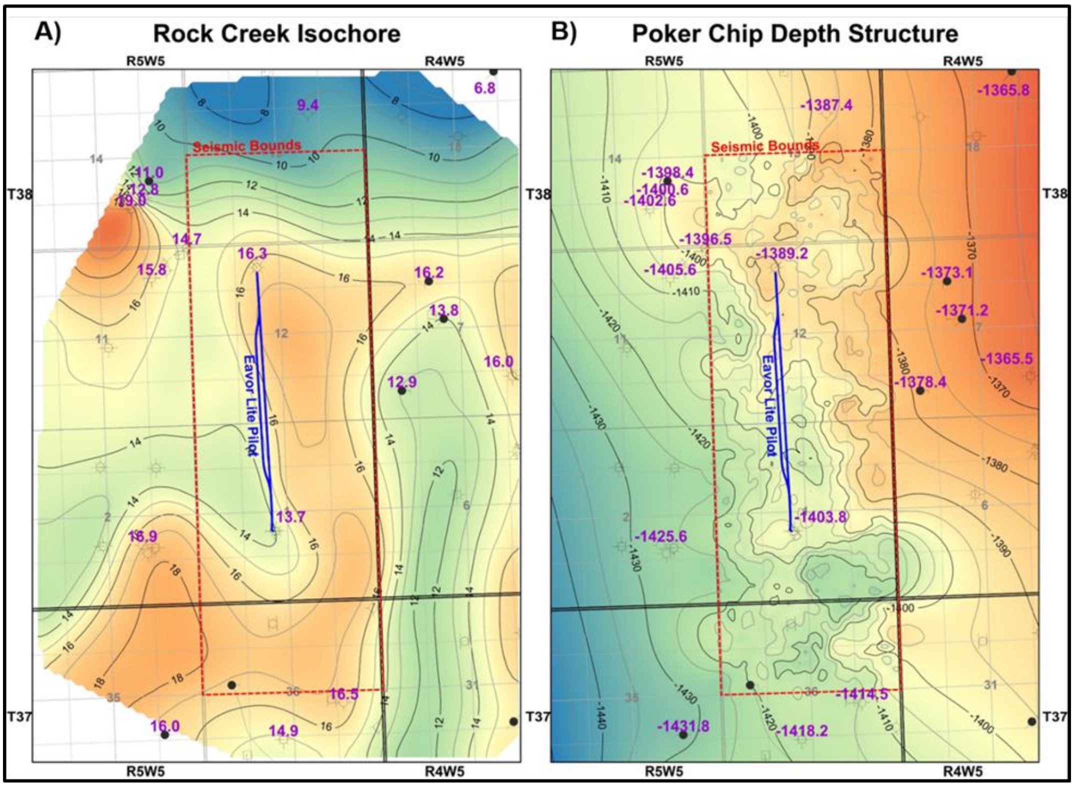

Figure 5: A) Rock Creek gross sand isochore and B) depth structure map on the top of the Poker Chip Formation (base of Rock Creek formation). The TDP is indicated in blue and the 3D seismic is dashed in red.

The geothermal gradient in the area is 30 degrees Celsius per km therefore the expected temperature in the Rock Creek using an ambient temperature of 6 degrees Celsius is approximately 75 degrees Celsius.

2.3 Rock Characterization

2.3.1 Data and methods

As the TDP is in an area of active hydrocarbon development there is abundant raw data and literature to draw from. Once the TDP location was selected it was important to further characterize the Rock Creek for Eavor-Loop™ implementation and to establish a baseline for thermodynamic results. Therefore, a series of core tests for further rock characterization was completed including; thin sections, X-Ray diffraction (XRD) and unconfined compressive strength. The two wells on the TDP site, 100/14-12-038-05W5/00 and 100/06-01-038-05W5/00 did not have core over the zone of interest. Two cores were chosen for sampling, 100/11-28-038-05W5/00 and 100/08-30-037-03W5/00, located approximately 6 km NW of the TDP and approximately 11 km ESE of the TDP respectively. The following sampling program was undertaken:

Table 1: Objectives of the rock characterization core study for the TDP.

Test Type	Measurement	Objectives
Triaxial testing	Measure the stress state of the rock creek and determine the maximum compressive strength of the rock	Ground truth Eavor Lite geomechanical hypothesis prior to drilling to validate mud weights
Thermal conductivity	Determine the thermal conductivity of the Rock Creek	Populate Eavor Lite thermodynamic model prior to drilling, calibrate Eavor Lite model post drilling by comparing to actual thermal output
XRD	Detailed mineralogical analysis	To back calculate thermal conductivity and determine if mineralogy could substitute thermal conductivity measurement in the future
Thin sections	Petrographic Study	Determine cementation to aid rate of penetration modelling, understand controls on porosity and permeability

2.3.2 Petrophysical Characterization of the Rock Creek Target Zone Regionally

To understand the regional trends in porosity and permeability all publicly available core analyses (774 cores) from T 37 R37 to T54 R18W5 was gathered. A purely statistical approach using lognormal probability distribution plots (probit plots) was used to analyse the data to find regional trends. Probit plots help to visually assess data by comparing it to an empirical distribution. Data points are sorted from low to high, and a fractile is assigned for each data point. The fractiles are plotted on the Y axis which is on probability scale. The data points are plotted on the X axis. A lognormal regression line of the data is plotted through the data to illustrate how well data fits to lognormality. If the data points plot in a straight line the data is lognormal, but if the data curves, the data may be trending to normal, exponential or another distribution.

The regional results of the core data for porosity and permeability are summarized on probit plots (Figure 6). The core porosity from the regional probit plot (Figure 6A) suggests a P50 of 7 % for the Rock Creek, and a range in data from 2% to 28% porosity. Core permeability from the regional probit plot (Figure 6B) shows a P50 of 0.57 mD and range in data from 0.01 to 108 mD. Typically, in oil and gas and in traditional geothermal, net reservoir is calculated based on a set of cut-offs, and subsequently porosity and permeability distribution are determined for those zones. This analysis does not discriminate between sand or shale, all core samples were included which does not represent aquifer characteristics but zonal characteristics of the Rock Creek.

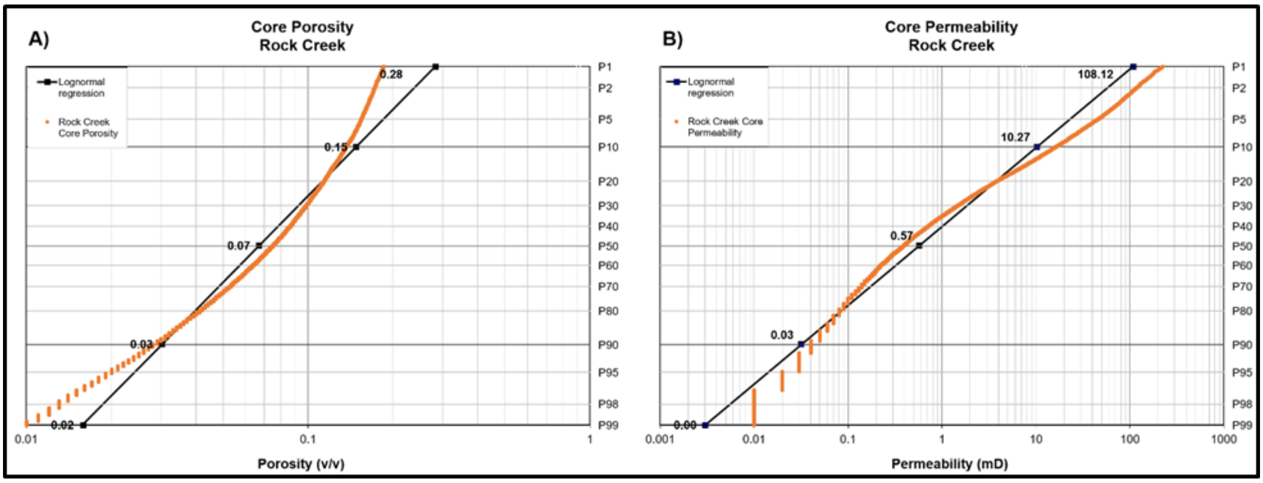

Figure 6: A) Regional Porosity Probit Plot of Rock Creek core analyses showing a P50 of 0.08 and a range between 0.02 and 0.28 in Central Alberta. B) Regional Permeability Probit Plot of Rock Creek Core Analyses showing a P50 range of 0.57 mD and a range in data from 0.01 to 108mD

Two vertical wells penetrate the Rock Creek and are the control wells for the planned TDP; 100/14-12-038-05W5 and 100/06-01-038-05W5. The 100/06-01-038-05W5/00 well (Figure 6) has a full curve suite including gamma ray, neutron/density porosity, sonic and resistivity and the 100/14-12-038-05W5/00 (Figure 7) has gamma ray, sonic and resistivity enabling a robust petrophysical analysis to be completed in both wells.

The porosity for the 100/06-01-038-05W5/00 well was calculated using a neutron-density cross plot. The porosity in the 100/14-12-038-05W5/00 well was calculated using the sonic log and the Wyllie time average equation. Total porosities were corrected for shale using a volume of shale calculated from gamma ray log with a linear conversion to obtain an effective porosity. Water saturations were calculated using the simandoux equation with A, M and N constants of 0.62, 2.15 and 2.0 respectively, and a water resistivity of 0.14 ohm*m at 25^{o}C which was obtained from nearby water analysis. A porosity cut off of 3% was applied to the Rock Creek to obtain an average porosity.

The average porosity for 100/06-01-038-05W5/00 and 100/14-12-038-05W5/00 is 8.1% and 6.4% respectively.

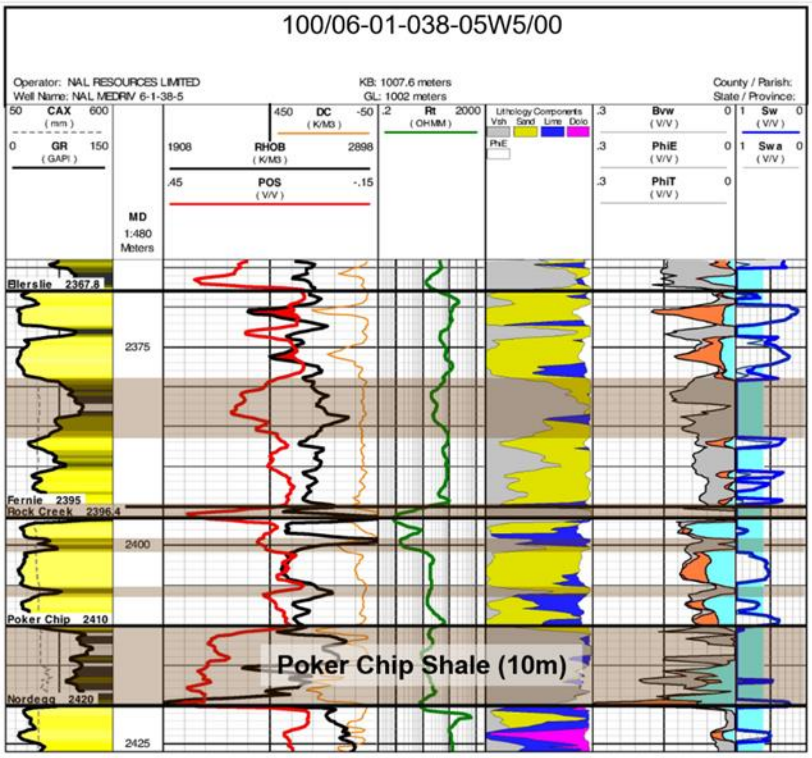

Figure 6: 100/06-01-038-05W5/00 Type Log with petrophysical interpretation

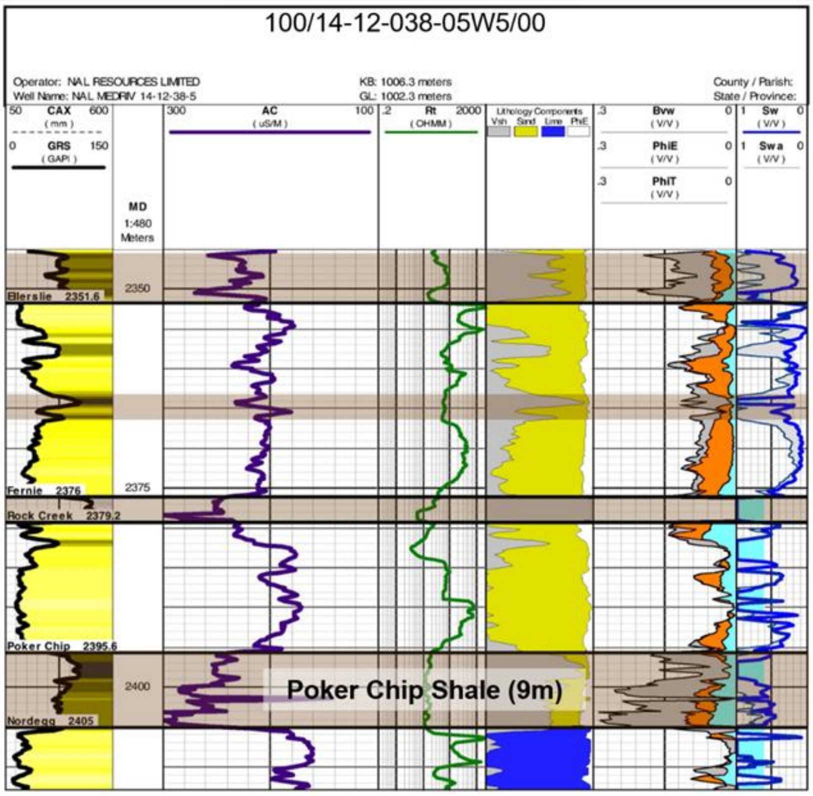

Figure 7: 100/14-12-038-05W5/00 Type Log with petrophysical interpretation.

<u>2.3.3 X Ray Diffraction</u>

The results of the bulk XRD reveal both cores are quartz based with percentages ranging between 31.4% to 94%. Three of the 4 samples have samples with > 70% quartz. The XRD agreed with the general interpretation that the Rock Creek Member is a quartzarenite sandstone, however bulk mineralogy shows that samples in the 100/11-28-038-04W5/00 well are remarkably different in that the quartz percentage is 31.4% compared to 72.2% in the shallower sample. Calcite makes up most of the bulk sample with percentages ranging between 0.3% to 62.1% (Table 2).

Table 2: XRD Bulk Mineralogical Results

UWI	Sample (m)	Quartz	Feldspar		Carbonates		Clays	Sulphide
			Albite	K-Feldspar	Calcite	Fe-Dolomite	Illite/Mica	Pyrite
100/08-30-037-03W5/00	2242.5	93.3	1.8	1.5	0.7	0.4	1.9	0.3
100/08-30-037-03W5/00	2249.3	94.0	1.3	0.9	0.3	0.0	2.0	1.4
100/11-28-038-05W5/00	2423.1	72.2	1.6	2.2	19.0	0.3	3.8	1.0
100/11-28-038-05W5/00	2428.7	31.4	0.9	1.2	62.1	0.5	2.1	1.8

2.3.4 Petrography/Mineralogy

Petrographic analyses of four core samples taken from proximal wells was performed to characterize texture, composition and cementation of the Rock Creek. Two samples were taken from 100/08-30-037-03W5/00 and 100/11-28-038-05W5/00 at approximately the depths shown in Table 2.

Samples from the 100/08-30-037-03W5/00 well are classified as massive, well sorted, subangular to sub-rounded, very fine to medium grained quartzarenite sandstones. The rock framework composition is mainly quartz with minor amounts of feldspar and chert. Sample 2249.3 is coarser grained with higher pore space. In both samples clays tend to present in patchy concentrations and as rims on grain boundaries. Pyrite occurs in trace amounts and is present in the sample 2242.5 only. Cementation is predominantly a function of quart overgrowths and residual pyro-bitumen, both occluding pore space and blocking pore throats. Porosity is mainly intergranular primary porosity with occasional secondary porosity created by the dissolution/degradation. Porosity is estimated at 15-20% in sample 2249.3 and 5-8% in sample 2242.5 and is controlled by cementation. (Figure 8 A&B).

Samples from the 100/11-28-038-05W5/00 well are classified as massive, well cemented, well sorted, subangular to subrounded, very fine to fine grained quartzarenite sandstones. The rock framework composition is noticeably different, sample 2428.7 is fossiliferous and borders on the limestone classification due to the abundance of shells, shell fragments and calcite cement, whereas sample 2423.1 is predominantly quartz. Minor feldspar, chert, pyro bitumen and rare glauconite, rare mica clay rims and scattered pyrite framboids and clusters are also observed (Figure 8 B&C). Cementation is predominantly sparry calcite and rare quartz overgrowths. Visual porosity is <1% and microcrystalline calcite cement is considered the dominant control on porosity and permeability.

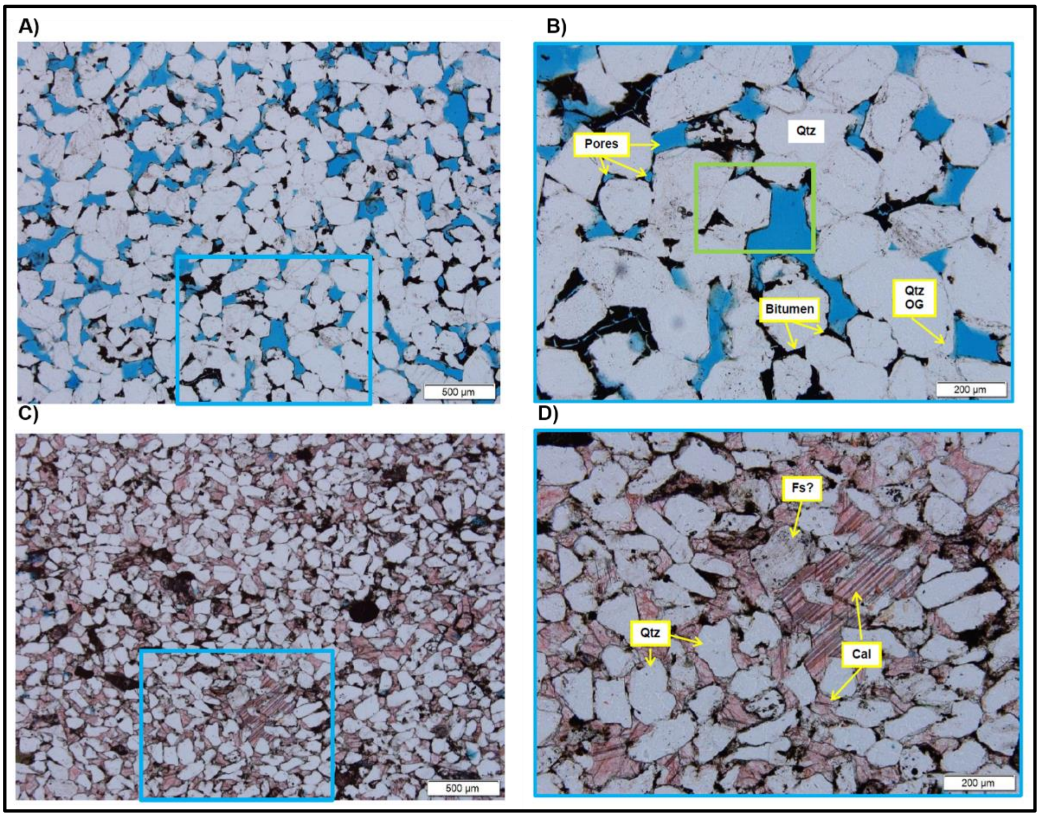

Figure 8: Thin sections. A & B are sampled from 100/08-30-038-03W5 at 2249.2 m tvd. C & D are sampled from 100/11-28-038-55/00 at 2423.1 m tvd.

2.3.5 Thermal Conductivity Modelling from XRD

In order to estimate thermal conductivity from mineralogy a simple analytical model was adopted from Jorand et al. (2015). The model used XRD and petrophysical data to calculate volume percentage of minerals and total porosity of the rock. The thermal conductivity was calculated by weight averaging the thermal conductivity of the fluid and the matrix, which was determined with a power equation weighting the volume fractions of the minerals present. The thermal conductivity was corrected to temperature by scaling the temperature dependant results presented in Jorand et al., 2015 and Robertson, 1988. Further factors were added accounting for large scale heterogeneity of the rock such as lithology changes, shale plugs, small scale fractures with different mineralogy, organic matter etc., and small-scale errors such as grain to grain contacts, cementation and grain size distribution. Using an average reservoir temperature of 75 degrees Celsius, the model calculated an average thermal conductivity for all 4 samples to be 3.52 W/mK. The predicated average rock thermal conductivity for the 100/08-30-037-03W5/00 and 100/11-28-038-05W5/00 is 3.7 and 3.4 W/mK respectively. Quartz has a very high thermal conductivity, approximately 7 W/mK at reservoir temperature (Robertson 1988). Although, the quartz percentage drops to 31% at 100/11-28-038-055/00 well, the predicted average thermal conductivity is relatively unchanged (3.4 W/mK compared to 3.7 W/mK). This is due to the decrease in porosity, which has an inverse relationship to conductivity. Therefore, although porosity degrades from south to north along the TDP horizontals, the thermal conductivity is expected to remain relatively stable.

2.3.6 Geomechanics

A geomechanical study was completed in order to determine borehole stability and natural fracture stability. A local stress model for Eavor Lite was built using publicly available data from the Alberta Energy Regulator and quantified the following parameters; vertical stress, minimum horizontal stress, pore pressure, rock properties and maximum horizontal stress. Four core tests were used to ground truth the model. Overburden stress (vertical stress) is 23-24 kPa/m at depth which is consistent with regional data. Minimum horizontal stress was estimated between 16-18 kPa/m and maximum horizontal stress ranges between 28-30 kPa/m. The azimuth of maximum horizontal stress is 30-60 degrees, also consistent with regional observations.

In order to predict the drilling rate of penetration and required mud weights for drilling, triaxial testing was performed on 4 rock samples. Unconfined compressive strength (UCS) ranges between 32,100 and 53,800 kPa for all samples. The 100/08-30-038-03W5/00 samples averaged 42,950 kPa, and the 100/11-28-038-05W5/00 samples averaged 38,000 kPa. A calibrated calculation of UCS from sonic logs determined a wide range from about 33,100 to 100,000 kPa. These results are lower than a previous, uncalibrated model based on the sonic log which provided UCS values around 145,000 kPa.

It is likely that cementation type and intensity is a control on the UCS. Unfortunately, sample points are too sparse for direct correlation. However, an oil and gas operator in the Rock Creek to the north west of the TDP reported that poorly cemented facies had a UCS of approximately 30,000 kPa and well cemented facies had UCS of approximately 100,000 kPa (Fox, A., 2019, Pers. Commun.), in agreement with the range from the calibrated sonic-based calculations. Triaxial testing was utilized in this study to determine UCS whereas Aukes et al. (2019) used an indentation hardness along core to determine UCS (Fox, A., 2019, Pers. Commun.). The Aukes et al. (2019) sampled 4 distinct facies and found no correlation to mineralogy and the positive correlation was determined to be the degree of cementation. In other words, diagenetic processes are the controlling factor for UCS determination.

Borehole stability and fracture/fault slip risk are both closely tied to formation pore pressure. Measured pressures in the area range from about 8.5 (normal pressure) to about 10 kPa/m, depending on formation. Pressure in the target Rock Creek is expected to be normal at the drilling location. Fractures and faults are expected to be stable (i.e., not critically stressed) given the wellbore fluid pressures that are expected to be used for both drilling and geothermal energy production.

3.0 GEOPHYSICAL INTERPRETATION

Three square miles of good quality 3D data was purchased for the TDP. The technical objectives of the seismic analysis were three fold; to confirm or eliminate the presence of faulting along the well path, to determine the structure of the Rock Creek along the well path and to determine whether or not any shale plugs might exist along the well path that could impact the predicted thermal conductivity.

The 3D seismic cube was tied to the 100/06-01-038-05W5/00 well. A good correlation to the underlying Pokerchip shale was used as the basis for seismic mapping because of a high amplitude trough.

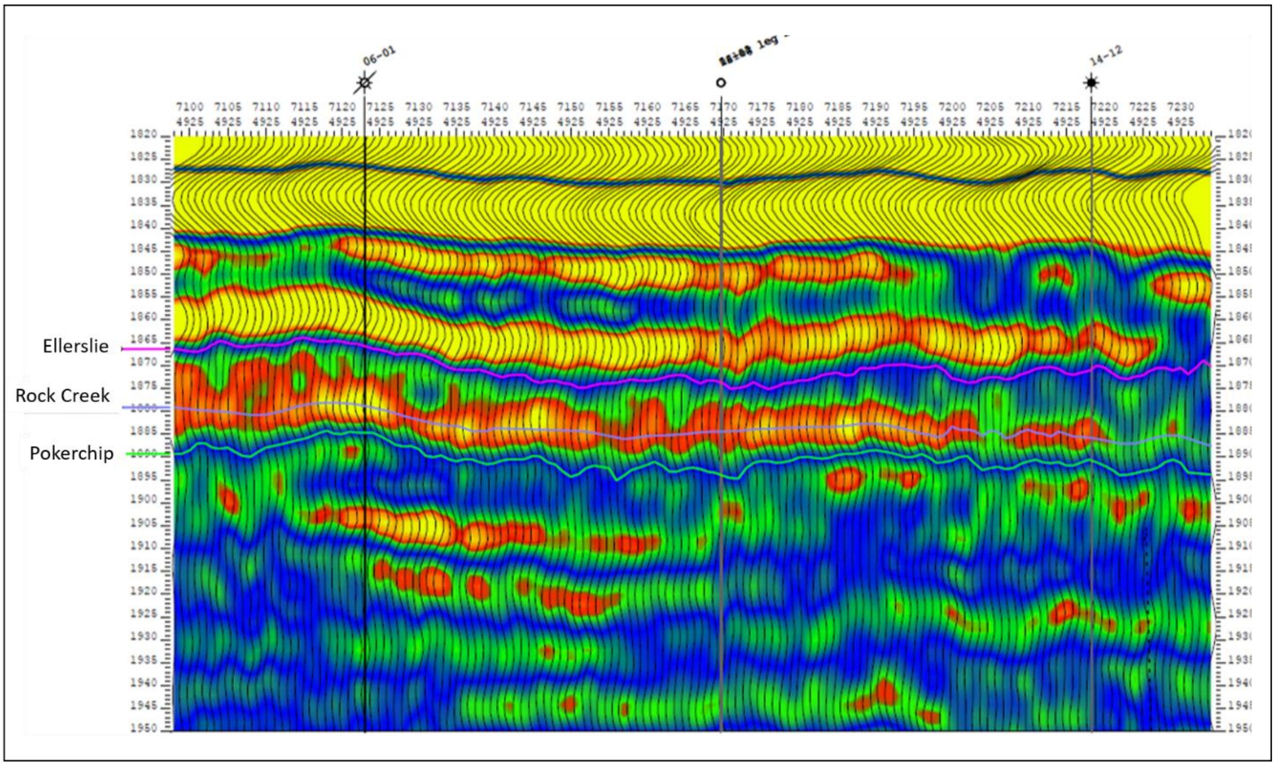

Figure 9: South North seismic cross section along the well path illustrating the Pokerchip trough pick and change of Rock Creek character

The amplitude variability in the Rock Creek may be due to the degradation of porosity observed between the 100/06-01-038-05W5/00 higher porosity well to the 100/14-12-038-05W5/00 lower porosity well. It is likely that cementation is controlling the porosity based on the results noted in the petrographic section.

The Pokerchip depth conversion used a four-layer approach, using four regionally correlatable surfaces and four separate interval velocity models to calculate the final depth at the Pokerchip. The depth conversion revealed a structural low due north of the 100/06-01-038-05W5/00 wells. The Rock Creek isochron averages 6 ms in thickness along the projected well path and the average thickness along the well path is between 14-16 m, showing good correlation with geological mapping.

In order to discern whether faulting was present in the area, a similarity map was constructed. It is likely there is a small displacement north of the 100/14-12-038-05W5/00 well at the Leduc level that potentially propagates to the Pokerchip level. Further fault mapping was not undertaken because faulting is not present along the well path. Early fault initiation is pre-Leduc time and is coincident with the north end of Leduc reef build up.

The 3D seismic analysis was useful in mapping the Pokerchip structure, Rock Creek thicknesses and eliminated the possibility of faulting along the well path. Amplitude mapping suggests changes in the Rock Creek may be the result of porosity degradation observed in the wireline logs and has been confirmed with petrography.

4.0 DRILLING PROFILE AND EXPERIENCE

The execution of the TDP involved the drilling of 4 multi-lateral wellbores that are mechanically intersected halfway between the vertical wells. The joining of the wells effectively created two multilateral wells for the closed loop test (Figure 10).

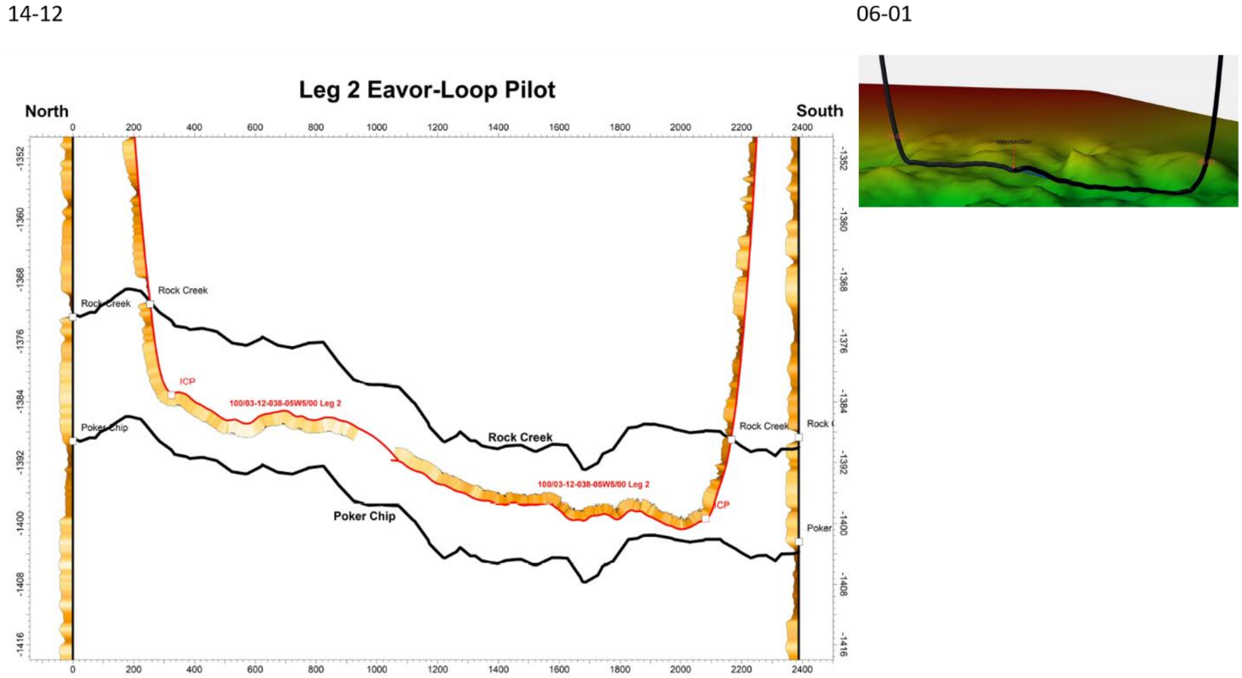

Figure 10: TDP as drilled Leg 2

5.0 CONCLUSIONS

Recall, the thermal conductivity was calculated by weight averaging the thermal conductivity of the fluid and the matrix and was corrected to temperature by scaling the temperature dependant results presented in Jorand et al., 2015 and Robertson, 1988. Further factors were added accounting for large scale heterogeneity of the rock to arrive at a 3.52 w/mK. Prior to applying a large-scale heterogeneity factor, the predicted thermal conductivity was 4.5 w/mK using an average reservoir temperature of 75 degrees Celsius. The history match of the field scale transient numerical model predicts the rock thermal conductivity is 4.5 w/mK at 78 degrees Celsius reservoir temperature. Therefore, rock mineralogy is a good tool for predicting thermal conductivity in quartz dominated rocks. The laterally continuity of the Rock Creek shoreface sands in the TDP as demonstrated from logs and core, coupled with the information of 5 m samples along the wellbore shows a consistent rock type through the lateral legs with exception of the calcite cementation.

The TDP confirmed formation temperature of 78 degrees C, rock conductivity of 4.6 W/mK and an annualized thermal output of 800 KWth. Therefore; standard oil and gas workflows are highly applicable for the generation of prospects underscoring that Eavor Loop^{TM} can be characterized with mineralogical data and seismic and potentially forgo the costly exploration phase.

The success of the TDP unlocks vast untapped geothermal resources because it does not require the use of an aquifer and therefore reduces or eliminates exploration costs and the overall bankability of early stage geothermal projects in many sedimentary basins around the globe.

REFERENCES

Alberta Geological Survey, 2015. Alberta Table of Formations; *Alberta Energy Regulator*.

Aukes, P., Reinson, G., Collins, T., Hammel, C., (2019) The Jurassic Rock Creek member in West-Central Alberta – a Conundrum of Sequence Stratigraphic Complexity, Depositional Facies Variability, Reservoir Predictability and Productivity. *Abstract, CSPG Geoconvention 2019*

Banks, J., (2017). Deep Dive Analysis of the Best Geothermal Reservoirs for Commercial Development in AB: Final Report. *University of Alberta, Earth and Atmospheric Sciences & Alberta Innovates.*

Hein, F.J., (2017), Geology of bitumen and heavy oil: An overview, Journal of Petroleum Science and Engineering, Volume 154, Pages 551-563,

Jorand, R., Clauser, C., Marquart, G., Pechnig, R., (2015) Statistically reliable petrophysical properties of potential reservoir rocks for geothermal energy use and their relation to lithostratigraphy and rock composition: The NE Rhenish Massif and the Lower Rhine Embayment (Germany), Geothermics, Volume 53, Pages 413-428

Losert, J., (1986). Jurassic Rock Creek Member in the Subsurface Edson Area (West-Central Alberta), Alberta Research Council Open File Report 1986-3, 39 p.

Mossop, G.D., Shetsen, I., (1994) Geological atlas of the Western Canada Sedimentary Basin; Canadian Society of Petroleum Geologists and Alberta Research Council

Mottaghy, D., Vosteen, H.-D., Schellschmidt, R., 2008. Temperature dependence of the relationship of thermal diffusivity versus thermal conductivity for crystalline rocks. Int. J. Earth Sci. 97, 435–442, http://dx.doi.org/10.1007/ s00531-007-0238-3.

Robertson., E.C., (1988) Thermal Properties of Rocks, United States Department of the Interior Geological Survey, Open-File Report 88-441, 110 p.

Strobl, R., S., Kramers, J.W. & Dolby. G., (1993) Jurassic Boundary Study: Medicine River/Sylvan Lake. Alberta Research Council Open File Report 1993-23, 142 p.

Toews, M., Riddell, D., Vany, J., Schwarz, B.: Case Study of a Multilateral Closed-Loop Geothermal System (2019), Proceedings World Geothermal Congress 2020, Reykjavik, Iceland, April 26 – May 2, 2020

William,. S., Krause., F.F., Knopp, S.T., Poulton, T.P., DeBuhr, C.L., (2013) A High Resolution Sedimentological Assessment: Niton Member of the Fernie Formation, West-Central Alberta. *Abstract, CSPG Geoconvention 2013*