Laboratory Analysis Results for Sampling of Wells in the Northwest Territories

Report for SR-2022-001

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1. Introduction

The South Slave region is located in the southeast of the northern extension of the Western Canadian Sedimentary Basin. This area encompasses the main communities of Fort-Providence, Kakisa, Hay River and Enterprise, and has a high geothermal gradient whose geothermal potential is being evaluated. Hence, the Northwest Territories Geological Survey in collaboration with the Institut national de la recherche scientifique (INRS) has completed the first phase of a research project on the geothermal resource potential where the first step comprised the measurement of thermophysical properties of split core samples collected from oil and gas wells in the South Slave region. This allowed estimation of heat transfer mechanisms prevailing at depth. This first part of the project will be used as a basis for multi-year studies in the South Slave Region. Selection of sampling intervals of cores was based on the Geothermal Database Compilation of Petrel Robertson Consulting Ltd. (2022), which includes 109 former oil and gas exploration wells in the Northwest Territories. The sampling is targeted at the cored intervals of 33 wells (see Figure. 1 for well locations and Appendix 1 for the list of samples).

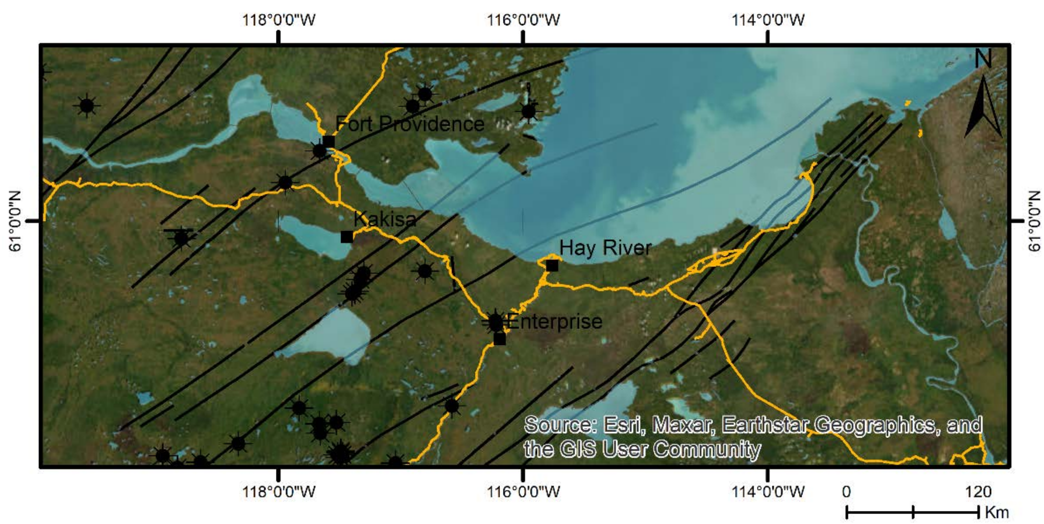

Figure 1: Locations of wells sampled in this study area

2. A summary of the testing / analysis procedures

Core sampling was authorized and approved by the Office of the Regulator of Oil and Gas Operations (OROGO) in June of 2022 for SR 2022-001, and sampling at the Geological Survey of Canada's Core Repository in Calgary was conducted from June 13-20, 2022. Based on availability of core intervals and permeability data analysis, a total of 33 wells were identified in which two intervals per geologic formation were selected for sampling (Table 1).

Table 1: Core samples collected from wells.

Well	Depth	Formation	Lithology	Well	Depth	Formation	Lithology
A-52	1 379,0	Sulphur Point	Dolostone	H-28	687,6	Horn Plateau	Limestone
A-52	1 383,9	Sulphur Point	Anhydrite	H-28	689,3	Horn Plateau	Limestone
A-52	1 479,4	Keg River	Limestone	H-64	1 514,3	Slave Point	Limestone
A-52	1 491,1	Keg River	Limestone	H-64	1 528,3	Slave Point	Limestone
A-70	462,5	Nahanni	Dolostone	I-57	655,4	Nahanni	Dolostone
A-70	465,1	Nahanni	Anhydrite	I-57	656,3	Nahanni	Dolostone
A-77	421,0	Slave Point	Limestone	I-74	1 425,9	Muskeg	Dolostone
A-77	423,2	Slave Point	Limestone	I-74	1 429,9	Muskeg	Dolostone
C-19(1)	431,2	Nahanni	Dolostone	J-04	1 417,4	Sulphur Point	Limestone
C-19(1)	438,6	Nahanni	Dolostone	J-04	1 422,3	Sulphur Point	Limestone
C-19(1)	479,0	Slave Point	Limestone	J-12	766,4	Slave Point	Limestone
C-19(1)	479,6	Slave Point	Limestone	J-12	776,1	Slave Point	Limestone
C-19(2)	109,0	Slave Point	Limestone	J-26	725,4	Muskeg	Dolostone
C-19(2)	114,1	Slave Point	Limestone	J-26	760,6	Muskeg	Dolostone
C-22	1 490,6	Muskeg	Dolostone	J-42	1 467,0	Slave Point	Limestone
C-22	1 491,4	Muskeg	Dolostone	J-42	1 472,1	Slave Point	Limestone
C-27	655,7	Watt Mountain	Limestone	J-53	766,3	Sulphur Point	Dolostone
C-27	656,5	Watt Mountain	Limestone	J-53	766,9	Sulphur Point	Dolostone
C-27	661,7	Sulphur Point	Dolostone	K-18	619,6	Watt Mountain	Limestone
C-27	667,7	Sulphur Point	Limestone	K-18	622,5	Watt Mountain	Limestone
C-75	1 420,7	Sulphur Point	Dolostone	K-18	626,1	Sulphur Point	Limestone
C-75	1 430,6	Sulphur Point	Dolostone	K-18	629,8	Sulphur Point	Limestone
D-06	762,3	Keg River	Dolostone	K-18	742,5	Keg River	Dolostone
D-06	763,6	Keg River	Dolostone	K-18	746,8	Keg River	Dolostone
D-34	762,4	Keg River	Dolostone	K-24	884,0	Slave Point	Limestone
D-34	765,0	Keg River	Dolostone	K-24	886,1	Slave Point	Limestone
D-47	147,7	Slave Point	Limestone	K-74	1 422,1	Sulphur Point	Limestone
D-47	166,1	Slave Point	Limestone	K-74	1 431,8	Sulphur Point	Dolostone
D-47	189,6	Watt Mountain	Limestone	L-69	913,2	Slave Point	Limestone
D-47	195,5	Sulphur Point	Limestone	L-69	923,0	Slave Point	Limestone
D-47	197,6	Sulphur Point	Limestone	M-49	1 463,1	Keg River	Dolostone
D-47	400,2	Chinchaga	Anhydrite	M-49	1 467,6	Keg River	Dolostone
D-47	401,6	Chinchaga	Anhydrite	M-73	1 350,6	Slave Point	Dolostone
D-66(01)	500,4	Horn Plateau	Limestone	M-73	1 368,6	Slave Point	Dolostone
D-66(01)	506,0	Horn Plateau	Limestone	M-73	1 405,0	Sulphur Point	Limestone
D-66(2)	402,2	Slave Point	Limestone	M-73	1 411,7	Sulphur Point	Limestone
D-66(2)	417,8	Slave Point	Limestone	O-16	726,8	Slave Point	Limestone
E-02	1 380,5	Slave Point	Limestone	O-16	741,7	Slave Point	Limestone
E-02	1 383,8	Slave Point	Limestone	O-16	783,6	Watt Mountain	Limestone
F-75	1 420,7	Sulphur Point	Limestone	O-66	31,4	Sulphur Point	Limestone
F-75	1 428,2	Sulphur Point	Limestone	O-66	38,4	Sulphur Point	Dolostone
G-21	1 498,5	Slave Point	Limestone				
G-21	1 510,9	Slave Point	Limestone				

The targets were selected to include a low and a high permeability interval in order to cover possible variation within lithologic units that can influence the thermal parameters during analysis. To have enough sample material, only intervals with core samples of at least 20 cm in length were considered.

To preserve as much as possible of the original core material, the selected full-size core samples were sawed on site along their drill axis (Appendix 1). A total of 84 split core samples from 33 wells including 8 formations were collected, packed, and shipped to the INRS in Quebec City for laboratory analysis.

Depending on the state of the sample, the total number of samples used for each type of analysis is different (Table 2).

Table 2: Number of samples used by type of analysis and by geological formation.

Formation	**Permeability Porosity**	**Thermal Properties**		**Geochemistry**	
		Optical scanning	**Thermal dependence**	**U, Th, K concentration**	**XRD Mineralogy**
Slave Point	19	28	28	28	19
Watt Mountain	4	6	6	6	6
Sulphur Point	15	22	15	22	15
Muskeg	6	6	6	6	5
Keg River	10	10	2	10	9
Horn Plateau	2	4	-	4	4
Nahanni	5	6	-	5	5
Chinchaga	-	2	-	2	2
Total	**61**	**84**	**49**	**84**	**65**

Porosity, permeability, grain density, was measured on the 61 core plugs with a diameter of 2.54 cm and a length between 2.54 cm and 10 cm with a grain volume chamber using the AP-608 combined gas permeameter and porosimeter at the Laboratoire ouvert de géothermie (LOG) at INRS.

Thermal conductivity and diffusivity were measured on 84 split cores with length between 10 cm and 20 cm with an optical scanning instrument. Then, the volumetric heat capacity was calculated from the measured values of thermal conductivity and diffusivity. The FOX50 Heat Flow Meter from Laser Comp TA-Instruments were used to evaluate the effect of the temperature on the thermal conductivity at the Laboratoire ouvert de géothermie (LOG) at INRS.

The geochemical analysis by inductively coupled plasma (ICP) techniques, more precisely, optical emission spectrometry (OES) and mass spectrometry (MS) of rock samples was also completed at INRS geochemical laboratories on 84 sample powders. Mineralogical analyses were conducted by AGAT Laboratories in Calgary, AB on 65 sample powders.

3. A Summary and Interpreted Results

A summary of interpretation of the analytical results are listed below. Full results will be disseminated in an NTGS Open Report to be published in 2023.

3.1.1 Porosity under atmospheric and confining pressure and permeability

The results of porosity and permeability analysis are presented in Appendix 2. At atmospheric pressure, the porosity of the samples is 0.09 % to 14.13 %, with a mean of 2.57 %. The highest value is found in the Sulphur Point dolostone samples with a mean of 6.9 % ±3.6 .These values of porosity decrease to <0.1 % to 13.98 % with the mean of 2.61 % under a confining pressure of 3.4 MPa. The measured range indicates that the majority of samples have negligible to poor matrix porosity. The permeability of the samples varies from less than 1.0×10^{-19} m^2 to 1.9×10^{-14} m^2 (<0.001 mD to 18.8 mD), with a mean of 4.8×10^{-14} m^2 (0.47 mD). The Sulphur Point dolostone samples is also the most permeable formation with an average value of 0.40 mD ±0.49. Considering the measured range, the majority of samples have a matrix that is impermeable to low permeability.

3.1.2 Thermal conductivity, thermal diffusivity and heat capacity at room temperature

The full result is in Appendix 3. The thermal conductivity of the samples ranges from 2.4 $Wm^{-1}K^{-1}$ to 5.6 $Wm^{-1}K^{-1}$, with an average of 3.7 $Wm^{-1}K^{-1.}$ The Sulphur Point Formation is the most important heat conductor with an average value of 5.2 $Wm^{-1}K^{-1}$. When using a cut-off value of 3.5 $Wm^{-1}K^{-1}$, the majority of the rocks analyzed act as an intermediate between insulator and conductor to heat conductor. The thermal diffusivity ranges from 1.2 10^{-6} m^2/s to 2.1 0^{-6} m^2/s with mean of 1.5 and the volumetric heat capacity ranges between 2.4 $MJ/m^3/K$ to 3.0 $MJ/m^3/K$ with mean of 2.6 $MJ/m^3/K$.

3.1.3 Thermal conductivity under temperature variation

The full result is in Appendix 3. The average thermal conductivity varies from 3.4 $Wm^{-1}K^{-1}$ to 1.7 $Wm^{-1}K^{-1}$ in the limestone samples whereas it varies from 4.6 $Wm^{-1}K^{-1}$ to 2.3 $Wm^{-1}K^{-1}$ in the dolostone samples, over the experimental temperature range of -5 to 180 °C. We found that as temperature the thermal conductivity decreases around 50 %.

3.1.4 Radiogenic elements and heat production

The full results of the ICPMS-AES analyses are in Appendix 4. The results of the analysis provide specific information on the concentration of radiogenic elements K, U, Th. The values of K range from to 0.01 % to 0.12 %, Th from 0.1 µg/g to 1.5 µg/g, U from 0.1 µg/g to 0.5 µg/g. The heat generation rate is 0.02 μWm^{-3} to 0.25 μWm^{-3}. The highest value is in the limestone of the Slave Point Formation and the minimum value is in the anhydrite of the Sulphur Point Formation.

3.1.5 Mineralogy

The full results of the XRD analyses are in Appendix 5. The main minerals in the samples are calcite (0 % to 98.8%), dolomite (0 % to 99.0 %), and anhydrite (0 % to 99.5 %). The dominance of calcite and dolomite allow classifying the carbonates rock samples into magnesian dolomite, dolomitic limestone and calcium limestone with high-calcium and magnesium contents. These results are confirmed by the major elements in oxide form contents analysed by the ICPMS-AES.

4. Appendix

1. List of samples and sample description; includes sample ID, well ID, coordinates, depth, and geological formation, link of photographs of each sample before undergoing destructive testing. (.xlsx file).

2. Permeability and Porosity analysis results (.xlsx file).

3. Thermal properties of each sample including one sheet with the thermal dependence result (.xlsx file).

4. Whole rock major oxide and trace element geochemistry (.xlsx file).
5. Whole rock major minerals XRD analysis (.xlsx file).