

Summary of Hydraulic Conductivity Values for the Paskapoo Formation in West-Central Alberta

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Abstract

As part of the Alberta Geological Survey project “Hydrogeological Characterization of the Fox Creek Area, West-Central Alberta,” the hydraulic conductivity of the Paskapoo Formation was evaluated for west-central Alberta. Hydraulic conductivity values were determined along the length of nine drill cores from the area between Hinton and Fox Creek using an air permeameter. Additionally, pumping test records from the Alberta Water Well Information Database were analyzed to estimate transmissivity and hydraulic conductivity. The resultant horizontal hydraulic conductivity values vary from 1.1×10^{-10} to 1.0×10^{-3} m/s, supporting previous findings that the Paskapoo Formation is a highly heterogeneous system. Whereas previous studies have focused mainly on the lower portions of the Paskapoo Formation (i.e., basal sandstone), this study focuses on the middle siltstone/mudstone unit (1.1×10^{-10} m/s to 4.9×10^{-8} m/s) and upper sandstone unit (1.1×10^{-9} m/s to 1.0×10^{-3} m/s) for the northwestern portion of the Paskapoo Formation.

1 Introduction

The Paskapoo Formation is the most important nonsaline groundwater source in the Canadian Prairies, covering 10% of Alberta and supporting over 60 000 water wells (Grasby et al., 2008). Although widely used and vital to Albertans, the Paskapoo Formation remains poorly understood in terms of the spatial variability of its potential as an aquifer system (Lyster and Andriashek, 2012; Grasby et al., 2008). Increasing development of shale gas plays in west-central Alberta requires large volumes of water, which could be sourced from the Paskapoo Formation to minimize reliance on surface water. In an effort to better understand the hydrogeological conditions of the area, the Alberta Geological Survey (AGS) has initiated a regional-scale characterization project in the vicinity of the Town of Fox Creek, Alberta (Figure 1).

The hydraulic properties of the Paskapoo Formation are essential for quantifying rates of groundwater movement and determining aquifer response to groundwater use. The objective of this study was to characterize the hydraulic conductivity of the Paskapoo Formation for a region centred on the Town of Fox Creek using both air permeametry (Hurst and Goggin, 1995) and pumping test data from the Alberta Water Well Information Database (Alberta Environment and Parks, 2015).

2 The Paskapoo Formation

2.1 Geological Overview

The Paskapoo Formation is a Paleogene to earliest Eocene fluvial deposit (Hamblin, 2004; Leberkmo et al., 2008) dominated by siltstone and mudstone and interbedded with high-permeability, coarse-grained channel sands (Grasby et al., 2008). It covers over 65 000 km² of southwestern Alberta and represents the uppermost bedrock unit over its area of occurrence (Chen et al., 2007; Hamblin, 2004). The Paskapoo Formation was deposited unconformably over the Upper Cretaceous– to lower Paleocene-aged Scollard Formation (Jerzykiewicz, 1997) as high-energy alluvial fan and floodplain deposits sourced from the eroding Rocky Mountains to the west (Hamblin, 2004). Its deposition into the subsiding foreland basin formed an asymmetrical clastic wedge with a present-day maximum thickness of up to 850 m in the foothills, pinching out to a few tens of metres towards the plains (Hamblin, 2004).

The Paskapoo Formation has been divided into three members by Demchuk and Hills (1991): the Haynes, Lacombe, and Dalehurst members. The lowermost Haynes Member is dominated by thick, massive, coarse-grained sandstones that are characteristic of the Paskapoo Formation (Demchuk and Hills, 1991). Outcrops of the Paskapoo Formation are often biased towards these massive, cliff-forming, basal sandstones, leading early interpretations to suggest a sandstone-dominated system (Lyster and Andriashek, 2012). The Lacombe Member consists of interbedded siltstone, mudstone, shale, and coal with minor fine- to medium-grained sandstone and conglomeratic lag-deposits (Demchuk and Hills, 1991). It is rarely exposed in outcrop due to its recessive nature, despite being the dominant component of the middle Paskapoo Formation (Lyster and Andriashek, 2012). The overlying Dalehurst Member is present only in the foothills of Alberta and displays interbedded sandstone, siltstone, mudstone, and shale with at least five thick (1.3 m to 6.1 m) coal seams (Demchuk and Hills, 1991).

2.2 Hydrogeological Characteristics

Sandstone in the Paskapoo Formation occurs as isolated, high-permeability channels that interconnect locally to form semicontinuous sandstone horizons (Grasby et al., 2007; Atkinson and Glombick, 2015). Further division of the Paskapoo Formation has been based on the occurrence of these sandstones, resulting in three informal hydrostratigraphic units suggested by Lyster and Andriashek (2012): the

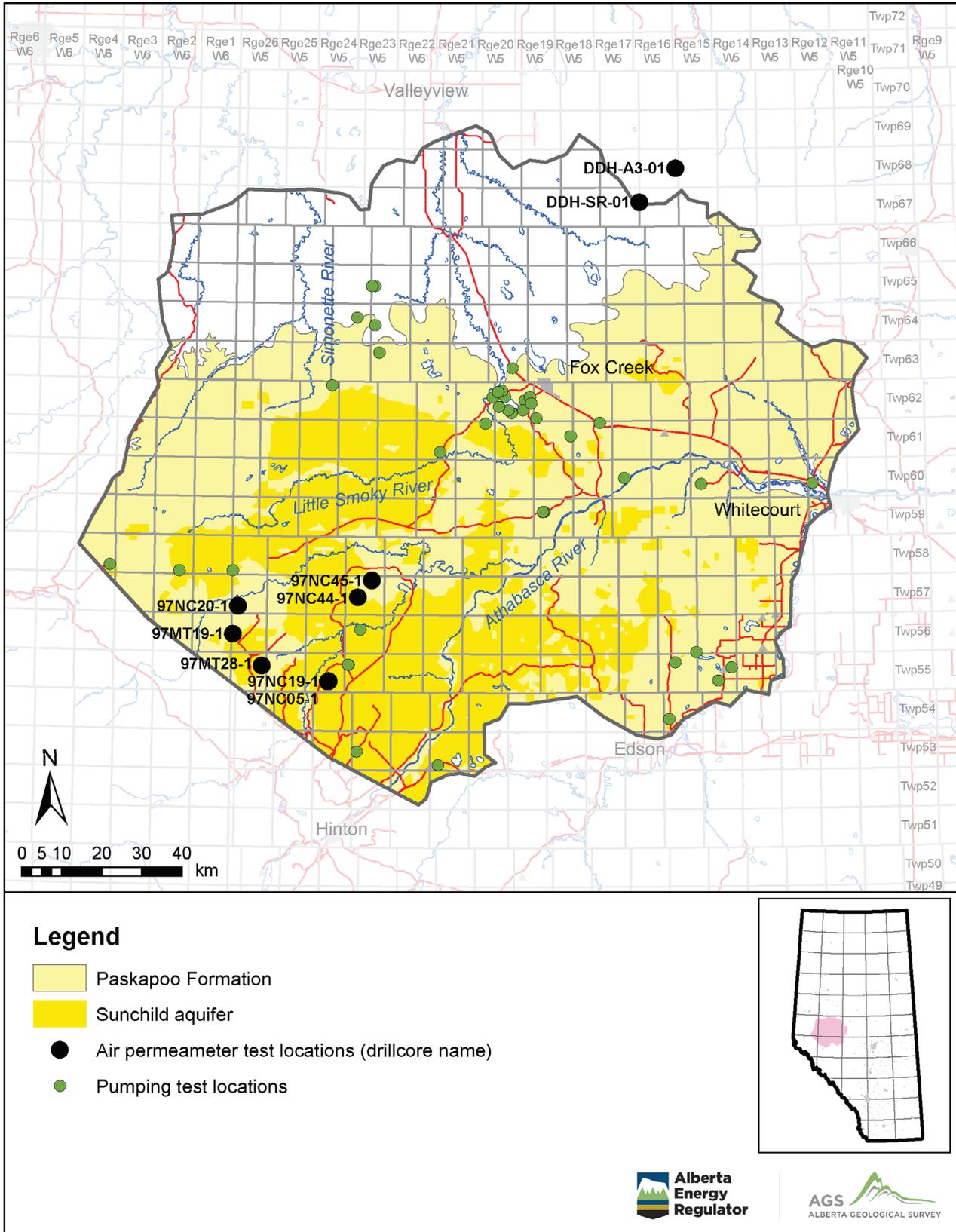


Figure 1. Location of the study area, drillcores tested with an air permeameter, and pumping test analyses. The extent of the Paskapoo Formation is shown with the Sunchild aquifer as proposed by Lyster and Andriashek (2012).

Haynes and Sunchild aquifers and the Lacombe aquitard. The Haynes aquifer and Lacombe aquitard units are roughly equivalent to the Haynes and Lacombe members, respectively, as proposed by Demchuk and Hills (1991). The Sunchild aquifer is suggested as an alternative unit to the Dalehurst Member and is characterized by permeable sandstone bodies that display variable interconnectivity due to incision by present-day streams (Lyster and Andriashek, 2012).

Previously reported measurements of the hydraulic conductivity of the Paskapoo Formation primarily include Grasby et al. (2007) and Riddell et al. (2009), both of which used the air-permeametry method. For six drillcores in the Red Deer and Calgary region, Grasby et al. (2007) obtained a bimodal permeability distribution, with a mean value of $2.8 \times 10^{-11} \text{ m}^2$ (corresponding to a hydraulic conductivity of $2.7 \times 10^{-4} \text{ m/s}$). High permeability values were interpreted as being either coarse-grained basal sandstones or sandstones from the upper weathered zone where surface weathering processes are thought to locally enhance near-surface permeability; low permeability values were interpreted as being fine-grained sandstones or mudstones (Grasby et al., 2007). As part of groundwater mapping in the Edmonton-Calgary corridor, Riddell et al. (2009) obtained a mean hydraulic conductivity of $5.3 \times 10^{-6} \text{ m/s}$ for drillcores intersecting the Paskapoo Formation. Low-permeability lithologies such as siltstone and mudstone were found to have little variation in hydraulic conductivity (from 1.0×10^{-9} to $9.5 \times 10^{-9} \text{ m/s}$), whereas sandstone intervals showed a range of conductivities spanning several orders of magnitude (from 4.5×10^{-9} to $4.9 \times 10^{-5} \text{ m/s}$). Such large variation in sandstone conductivity was attributed to grain size distribution and degree of cementation (Riddell et al., 2009).

2.3 Study Area

The region of interest covers roughly 22 000 km² of west-central Alberta in the vicinity of Fox Creek, approximately 260 km northwest of Edmonton (Figure 1). The study area is bounded to the southwest by the Cordilleran deformation belt and by sub-basin drainage boundaries along all other borders. The area is forested, and outcrops of Paskapoo Formation are scarce except along major rivers and road cuts, making subsurface data invaluable when characterizing properties at a regional scale. The Paskapoo Formation varies in thickness from zero to more than 400 m in the study area.

3 Methods

3.1 Air Permeameter Testing

Nine drillcores from within and around the study area were tested using a Temco MP-401 air permeameter at the Mineral Core Research Facility in Edmonton. The majority of drillcores were collected in 1997 for mineralogical exploration by Kennecott Canada Exploration Inc. and are 47.6 mm diameter (NQ size). All cores intersect the Paskapoo Formation (Figure 1) with the exception of DDH-A3-01, which is located where the thickness of the Paskapoo Formation is zero metres. This core is thought to be representative of the Scollard Formation and is included in the study due to its role as an invaluable, high-quality data source and its proximity to the study area. Each core was subject to between 25 and 30 spot measurements using a 3 mm diameter probe placed perpendicular to the core axis to obtain horizontal permeability. Test locations were chosen such that a range of depths and lithologies were represented; locations that were poorly consolidated or displayed a high fracture volume were excluded. A total of 215 permeability measurements were made at regular depth intervals along each core. Resultant permeability data was used to obtain hydraulic conductivity using Equation 1.

$$K = \frac{k\rho g}{\mu} \quad (1)$$

where K = hydraulic conductivity of sample (m/s); k = permeability of sample (m^2); ρ = density of water (assumed to be 999.9 kg/m^3); g = gravitational constant (9.81 m/s^2); and μ = dynamic viscosity of water ($8.9 \times 10^{-4} \text{ kg/m}\cdot\text{s}$).

3.2 Pumping Test Analysis

In addition to air permeameter testing, pumping test records were extracted for analysis from the Alberta Water Well Information Database. Only data from wells that had been subject to greater than 120 minutes of pumping were considered because surrounding aquifer properties are assumed to be reasonably well represented after this duration. In total, data from 50 water wells from within the study area (Figure 1) was extracted for use based on the following criteria:

- 1) The wells did not display artesian flow.
- 2) The well reports contained a sufficient litholog.
- 3) The well reports contained sufficient pumping test information—including a volumetric flowrate, no duplicate or missing drawdown values, and sufficient recovery data (i.e., after 120 minutes)—to be useful.

The resulting datasets were analyzed using the Cooper-Jacob straight-line approximation (Cooper and Jacob, 1946) for which drawdown is plotted against time using a semilogarithmic scale. A linear trend line was fit to the data recorded after 120 minutes and its slope was calculated. An example of a typical plotted dataset and corresponding trend line is given in Figure 2. The transmissivity of the surrounding aquifer horizons can then be calculated using Equation 2.

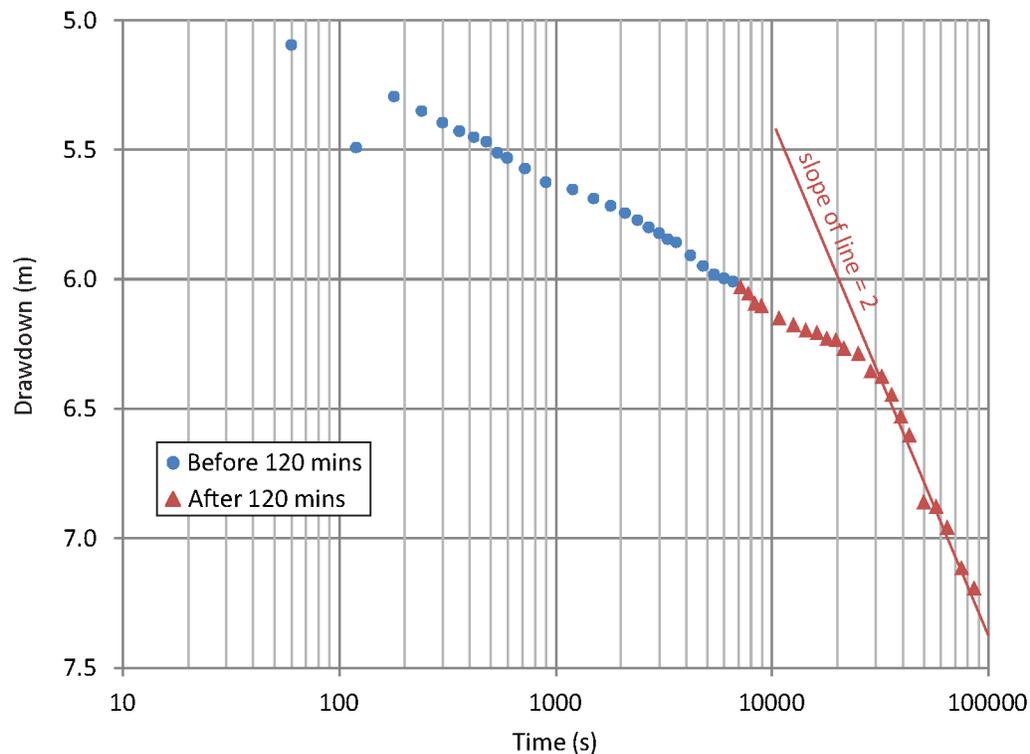


Figure 2. Example drawdown vs. time plotted using Jacob's straight-line method for pumping tests.

$$T = \frac{2.3Q}{4\pi m} \quad (2)$$

where T = transmissivity of the aquifer (m^2/s), Q = volumetric discharge of the well (m^3/s), m = difference in drawdown over one logarithmic cycle (slope). Resulting transmissivity values were used to obtain hydraulic conductivity using Equation 3.

$$K = \frac{T}{b} \quad (3)$$

where K = hydraulic conductivity of the aquifer (m/s), T = transmissivity of the aquifer (m^2/s), and b = thickness of saturated interval from which water is being pumped (m). Saturated thickness (b) for each well was obtained using well report lithologs along with recorded perforation intervals and the following hierarchy of required criteria:

- 1) b = the perforation interval given on the well report, or sum of perforation intervals if more than one interval exists.
- 2) b = the sandstone portions of the perforated interval if the perforation interval intersects multiple lithologies.
- 3) b = the intervals described as “aquifer” in the litholog if 1 and 2 do not apply.
- 4) b = the intervals described as “water-bearing” or “water-bearing sandstone” in the litholog if neither 1, 2 nor 3 apply.
- 5) b = the intervals described as “sandstone” or “clean sandstone” in the litholog if neither 1, 2, 3 nor 4 apply.

Because the resultant hydraulic conductivity values are representative of an interval (i.e., b), each conductivity was then assigned to a depth corresponding to the midpoint of the uppermost and lowermost depths of the saturated intervals.

4 Results

Air permeameter test results show hydraulic conductivity values that are generally lower than those from pumping test analyses (Figure 3). Values range from 1.1×10^{-10} to 3.0×10^{-5} m/s , with a weak bimodal distribution about an arithmetic mean of 7.4×10^{-7} m/s (Table 1; Figure 3a). Note that all mean values stated in this report are arithmetic means. An average hydraulic conductivity of 1.3×10^{-6} m/s was obtained for sandstone intervals, whereas the combined average for mudstones, siltstones, and shales is 4.4×10^{-9} m/s (Figure 4). Permeability values range from 9.9×10^{-18} m^2 to 2.7×10^{-12} m^2 , with an average permeability of 6.8×10^{-14} m^2 (Table 1). Summary results from individual core are located in Appendices 1 and 2.

Pumping test analyses show a broad range in hydraulic conductivities for the study area, from 2.5×10^{-6} to 1.0×10^{-3} m/s with a unimodal distribution about an average of 2.3×10^{-4} m/s (Table 1; Figure 3a). Values are randomly distributed across the study area with no significant regions of high or low hydraulic conductivity (Figure 5). Transmissivity results are located in Table 1, with a mean value of 2.3×10^{-3} m^2/s .

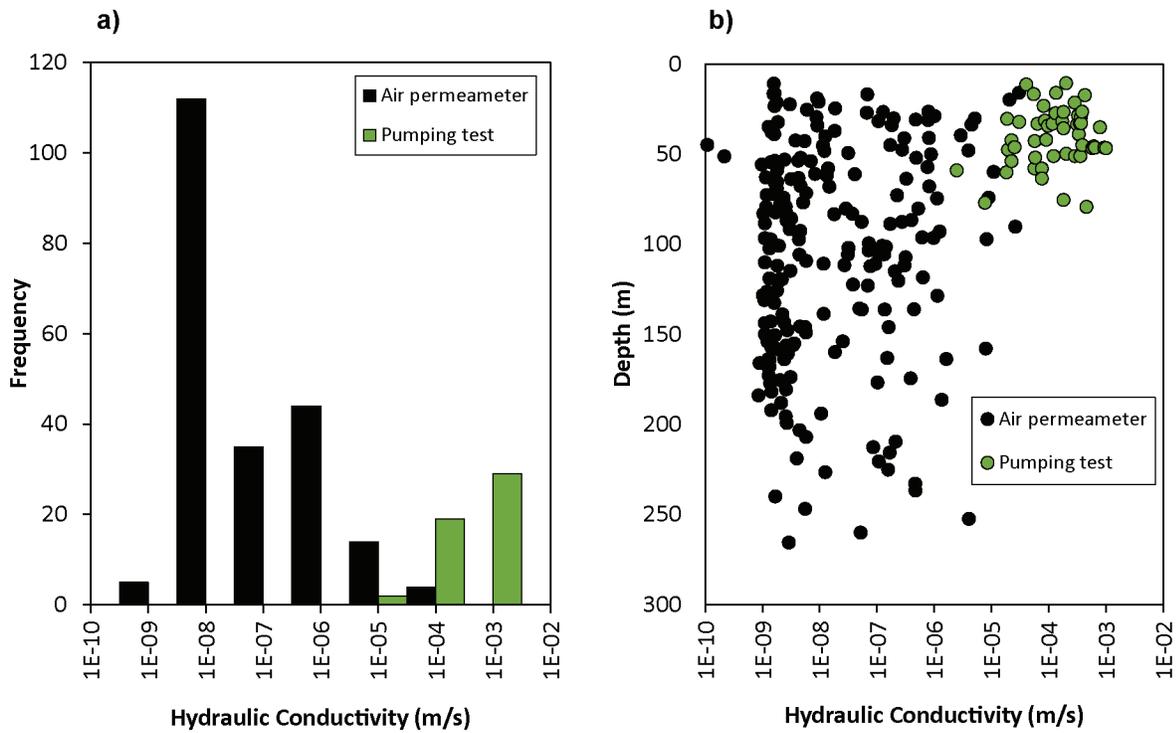


Figure 3. Summary of hydraulic conductivity values obtained during air permeameter testing and pumping test analyses. a) Distribution of hydraulic conductivities among both types of analyses. b) Hydraulic conductivity vs. depth plot demonstrates no relationship between the two variables. Pumping test values are several orders of magnitude higher than air permeameter results.

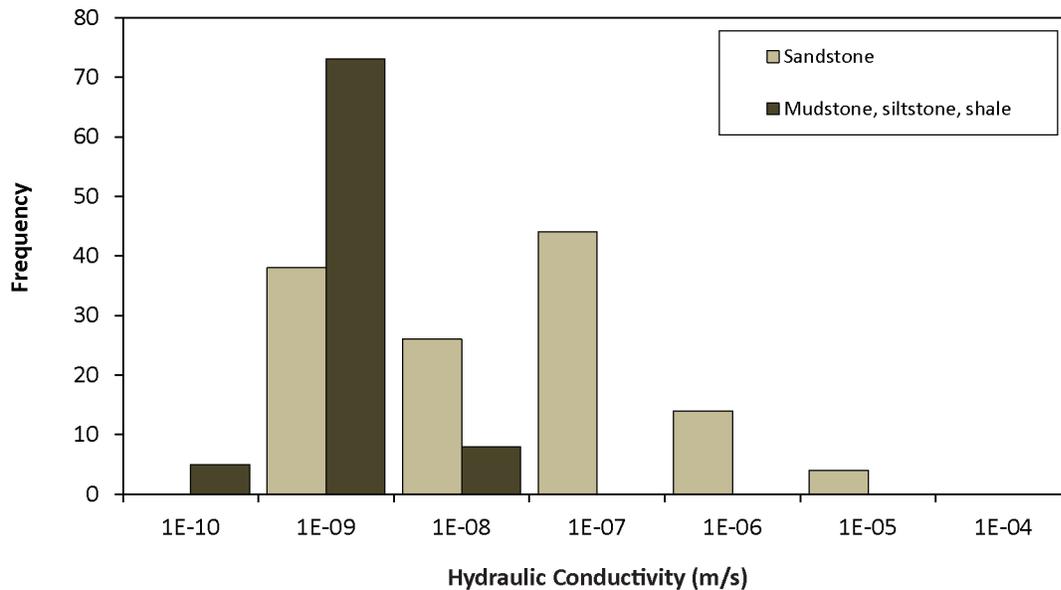
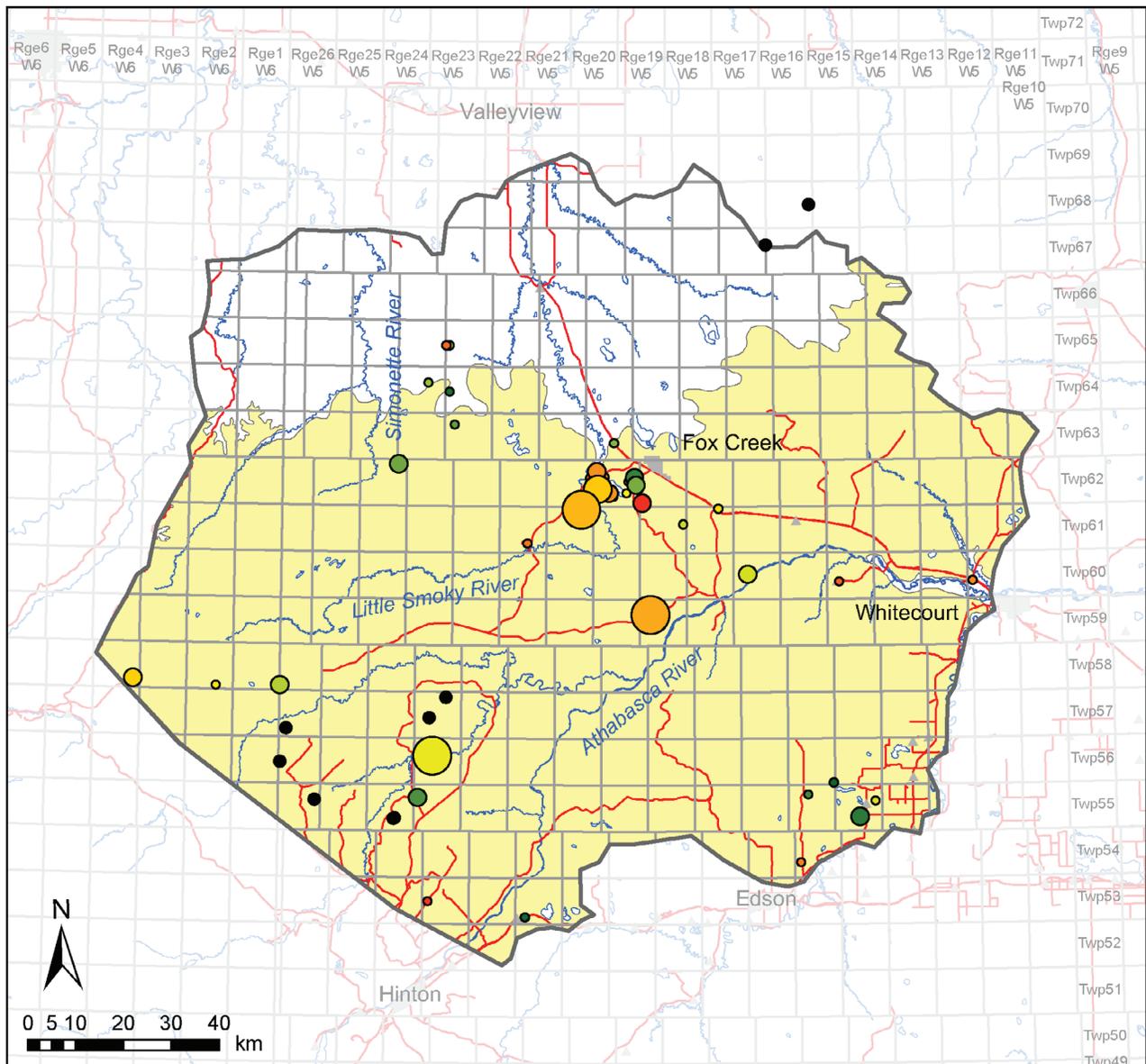


Figure 4. Distribution of hydraulic conductivities among sandstones and mudstones, siltstones, and shales obtained using an air permeameter. Sandstones show a wide range with bimodal distribution, while fine-grained lithologies show a narrow range with unimodal distribution.



Legend

- Paskapoo Formation
- Air permeameter test locations
- Pumping test location

<u>K (m/s)</u>	<u>Depth (m)</u>
○ 2E-04 - 3E-04	● 10-20
○ 3E-04 - 5E-04	● 20-30
○ 5E-04 - 8E-04	● 30-35
○ 8E-04 - 1E-04	● 35-40
	● 40-60
	● 60-80

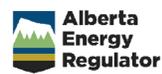
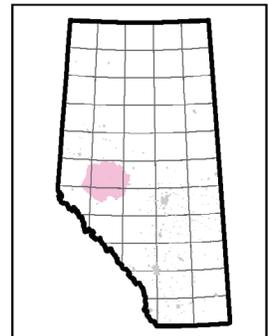


Figure 5. Results of pumping test analysis. Symbol size represents relative hydraulic conductivity obtained from pumping test analyses; colour represents depth of measurement below surface.

Table 1. Summary statistics showing hydraulic conductivity, transmissivity, and permeability results from air permeameter testing and pumping test analyses.

Dataset	Parameter	Min	Max	Mean	Std. Deviation	n
Air permeameter	k (m ²)	9.9×10^{-18}	2.7×10^{-12}	6.8×10^{-14}	3.0×10^{-13}	214
Air permeameter	K (m/s)	1.1×10^{-10}	3.0×10^{-5}	7.4×10^{-7}	3.3×10^{-6}	214
Pumping test	T (m ² /s)	4.7×10^{-5}	1.2×10^{-2}	2.3×10^{-3}	2.5×10^{-3}	59
Pumping test	K (m/s)	2.5×10^{-6}	1.0×10^{-3}	2.4×10^{-4}	2.4×10^{-4}	50

5 Discussion

The results from this study suggest that the Paskapoo Formation is an extremely heterogeneous system, with hydraulic conductivity values that vary over several orders of magnitude. This large variation is consistent with previous studies of the Paskapoo Formation and can be attributed to (a) methodological differences in measurement technique and (b) differences in physical properties.

One methodological factor that may contribute to a variation in results is differences in the volume and depth of porous media tested. Considering that production from water wells is primarily sourced from high-permeability horizons, it can be expected that pumping test data will be generally representative of sandstones and typically limited to a maximum of 80 m depth. Thus we can compare the average hydraulic conductivity obtained from pumping test analyses (2.3×10^{-4} m/s) to the average sandstone conductivity from the air permeameter results (1.3×10^{-6} m/s). The discrepancy between the two is due in part to scale: values obtained in situ are often found to be several orders of magnitude higher than those determined in laboratory settings (Ingebritsen et al., 2006; Schulze-Makuch and Cherkauer, 1998). The air permeameter analyzes a very small volume of rock (approximately 1 cm³) that is virtually homogeneous. Data obtained using pumping test analyses will be representative of several cubic metres of rock surrounding the screened interval and may include fractures and other heterogeneities that increase permeability. Furthermore, well-consolidated, highly cemented sandstones analyzed by air permeameter would be excluded from pumping test data due to low hydraulic conductivity. The resultant differences between measurement scale and sample selection are shown by the unimodal and bimodal distributions of pumping test and air permeameter data, respectively (Figure 4a).

Spatial differences in physical properties will also lead to a wide variation in hydraulic conductivity values. Weathering processes have the potential to enhance near-surface permeability (Grasby et al., 2007) and could also affect pumping test estimations of hydraulic conductivity. Although no apparent trends exist between hydraulic conductivity and depth (Figure 3b), measurements often show a distinct transition from high to low conductivity with depth when considering data from an individual core. This pattern can be interpreted as the transition from Sunchild aquifer sandstones into the underlying siltstones and mudstones of the Lacombe aquitard. An example of the transition can be seen in Figure 6, which shows the hydraulic conductivity profile for drillcore 97NC05-1. The upper two-thirds of measurements (1020–1130 m asl) range from 1.4×10^{-9} to 1.1×10^{-6} m/s, representing sandstones of the Sunchild aquifer, whereas the deeper, low conductivity values are interpreted as the siltstones and mudstones of the Lacombe aquitard. Similar lithologies for each core can be found in Appendix 3.

Measurements made in this study represent the upper portion of the Paskapoo Formation in west-central Alberta, which corresponds to the Sunchild aquifer and Lacombe aquitard. Neither the cores available for air permeameter testing nor the pumping test data were deep enough to reach the basal sandstones of the Haynes aquifer / Haynes Member. The sparsity of data and inherent bias of pumping test data towards high-permeability values demonstrates the importance of obtaining multiple data sources for regional-scale studies.

6 Summary

The Paskapoo Formation contains the most important nonsaline aquifer system in the Canadian Prairies, although not much is known about the hydrogeological regime. This study determined hydraulic conductivity values of the Paskapoo Formation in west-central Alberta using air permeameter measurements on nine drillcores from the Fox Creek area and pumping test data from the Alberta Water Well Information Database. Findings suggest that the variability in hydraulic conductivity of the Paskapoo Formation found previously is also true for the Fox Creek region. Results suggest that lithology alone is not a sufficient indicator of potential hydrogeological properties in the Paskapoo Formation due the wide range of values determined for sandstones. To explore the sandstone units further, suggested future work includes investigating the type and amount of cementation in Paskapoo Formation sandstones in the Fox Creek region as well as an evaluation of porosity using thin-section analysis. Additionally, vertical hydraulic conductivity measurements should be made using the air permeameter in order to quantify the degree of anisotropy in the region.

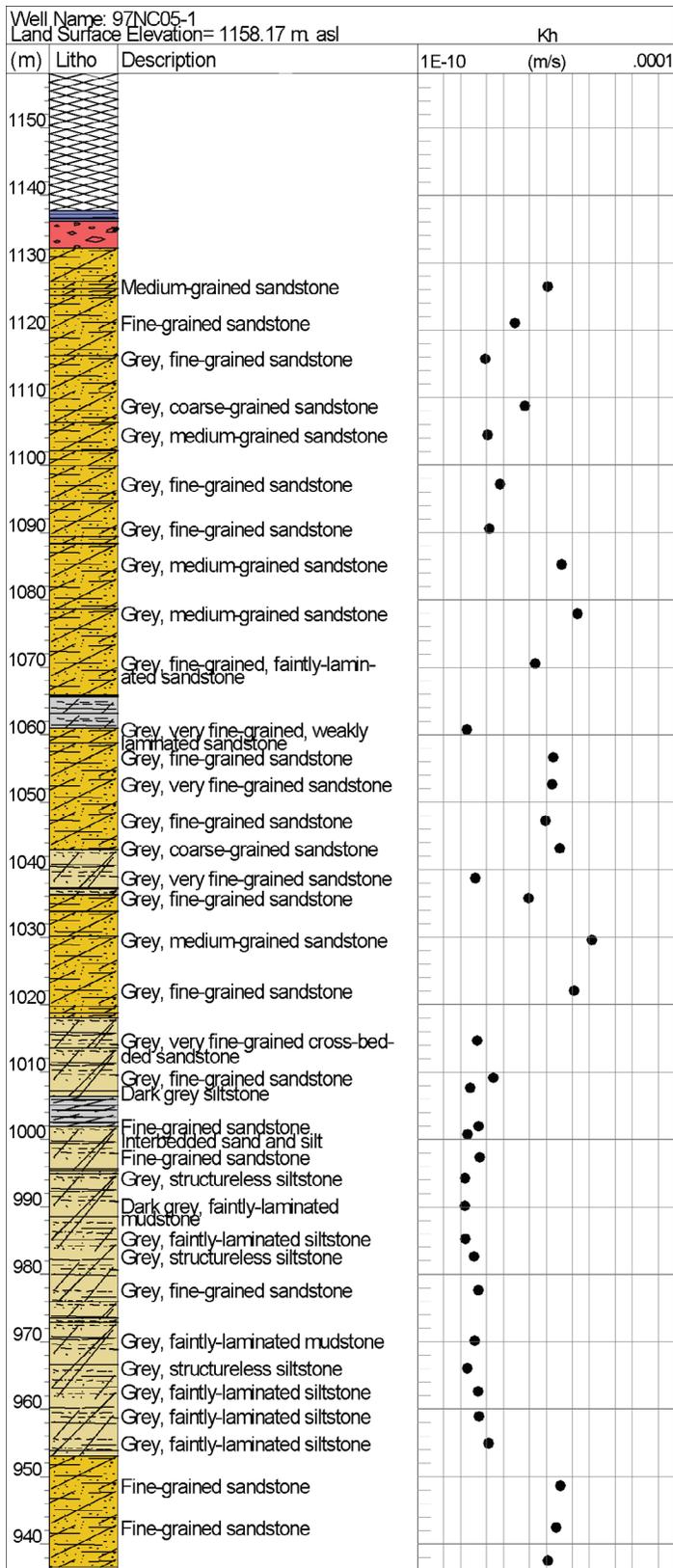


Figure 6. Strip log with hydraulic conductivity of drillcore 97NC05-1.

7 References

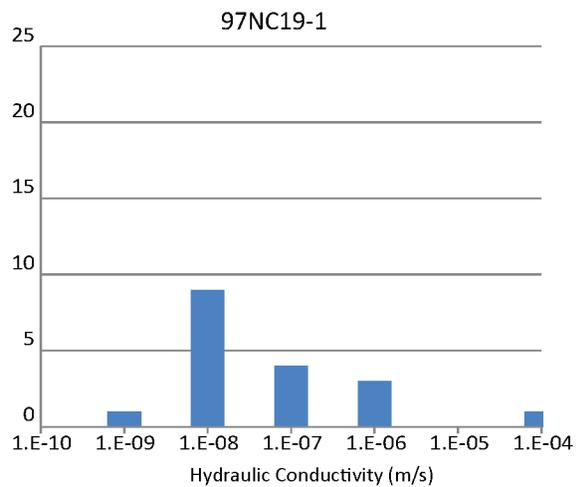
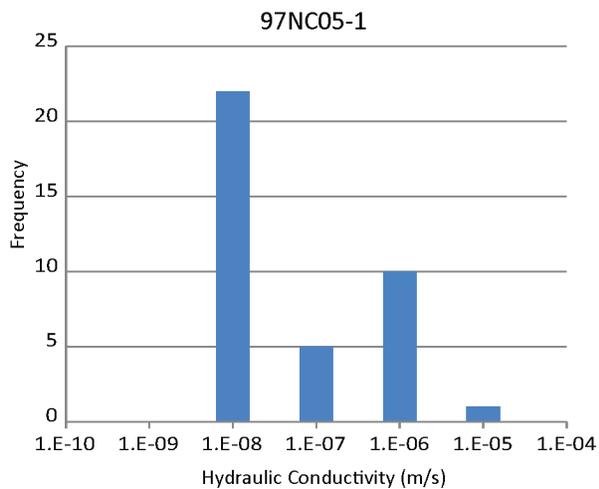
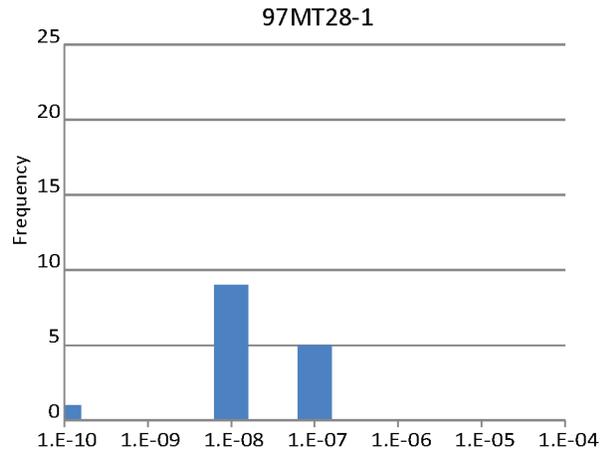
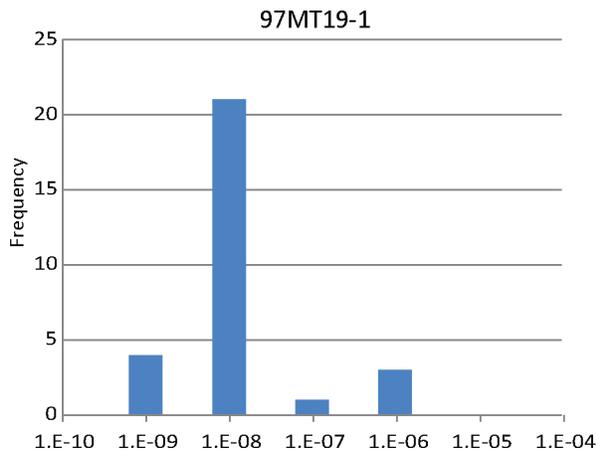
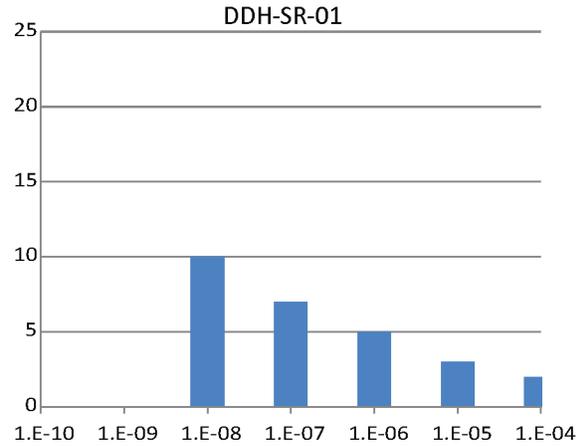
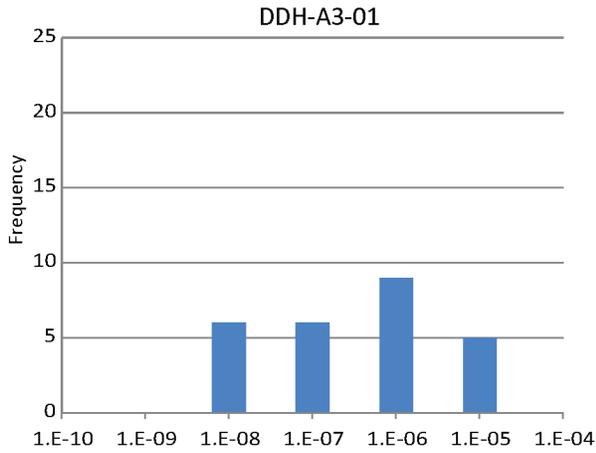
- Alberta Environment and Parks (AEP) (2015): Alberta water well information database; Government of Alberta, URL <<http://groundwater.alberta.ca/WaterWells>> [September 2016].
- Atkinson, L.A. and Glombick, P.M. (2015): Three-dimensional hydrostratigraphic modelling of the Sylvan Lake sub-basin in the Edmonton-Calgary Corridor, central Alberta; Alberta Energy Regulator, AER/AGS Open File Report 2014-10, 58 p., URL <http://ags.aer.ca/publications/OFR_2014_10.html> [September 2016].
- Chen, Z., Grasby, S.E. and Wozniak, P.R.J. (2007): Paskapoo groundwater study part VI: aquifer transmissivity estimation and a preliminary data analysis of the Paskapoo Formation, Alberta; Geological Survey of Canada, Open File 5444, 31 p., [doi:10.4095/224035](https://doi.org/10.4095/224035).
- Cooper, H. H. and Jacob, C. E. (1946): A generalized graphical method for evaluating formation constants and summarizing well-field history; *Eos, Transactions American Geophysical Union*, v. 27, no. 4, p. 526–534, [doi:10.1029/TR027i004p00526](https://doi.org/10.1029/TR027i004p00526).
- Demchuk, T.D. and Hills, L.V. (1991): A re-examination of the Paskapoo Formation in the central Alberta Plains: the designation of three new members; *Bulletin of Canadian Petroleum Geology*, v. 39, p. 270–282, URL <<http://archives.datapages.com/data/cspg/data/039/039003/0270.htm>> [September 2016].
- Grasby, S., Tan, W., Chen, Z. and Hamblin, A.P. (2007): Paskapoo groundwater study part I: hydrogeological properties of the Paskapoo Formation determined from six continuous cores; Geological Survey of Canada, Open File 5392, 6 p., [doi:10.4095/223756](https://doi.org/10.4095/223756).
- Grasby, S.E., Chen, Z., Hamblin, A.P., Wozniak, P.R.J. and Sweet, A.R. (2008): Regional characterization of the Paskapoo bedrock aquifer system, southern Alberta; *Canadian Journal of Earth Sciences*, v. 45, no. 12, p. 1501–1516, [doi:10.1139/E08-069](https://doi.org/10.1139/E08-069).
- Hamblin, A.P. (2004): Paskapoo-Porcupine Hills Formations in western Alberta: synthesis of regional geology and resource potential; Geological Survey of Canada, Open File 4679, 30 p., [doi:10.4095/215631](https://doi.org/10.4095/215631).
- Hurst, A. and Goggin, D. (1995): Probe permeametry: an overview and bibliography; *American Association of Petroleum Geologists Bulletin*, v. 79, p. 463–473. URL <<http://archives.datapages.com/data/bulletns/1994-96/data/pg/0079/0003/0450/0463.htm>> [September 2016].
- Ingebritsen, S.E., Sanford, W.E. and Neuzil, C. E. (2006): *Groundwater in geologic processes* (2nd edition); Cambridge University Press.
- Jerzykiewicz, T. (1997): Stratigraphic framework of the uppermost Cretaceous to Paleocene strata of the Alberta Basin; Geological Survey of Canada, Bulletin 510, 121 p. URL <<http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/6bd77380-f580-5f48-b441-151301bc923d.html>> [September 2016].
- Leberkmo, J.F., Heaman, L.M., Baadsgaard, H., Muehlenbachs, K., Evans, M.E. and Sweet, A.R. (2008): Normal polarity magnetosubchrons in 24r and the age of the Paleocene-Eocene boundary; *Canadian Journal of Earth Sciences*, v. 45, no. 7, p. 781-793, [doi:10.1139/E08-025](https://doi.org/10.1139/E08-025).
- Lyster, S. and Andriashek, L.D. (2012): Geostatistical rendering of the architecture of hydrostratigraphic units within the Paskapoo Formation, central Alberta; Energy Resources Conservation Board, ERCB/AGS Bulletin 66, 103 p. URL <http://ags.aer.ca/publications/BUL_066.html> [September 2016].

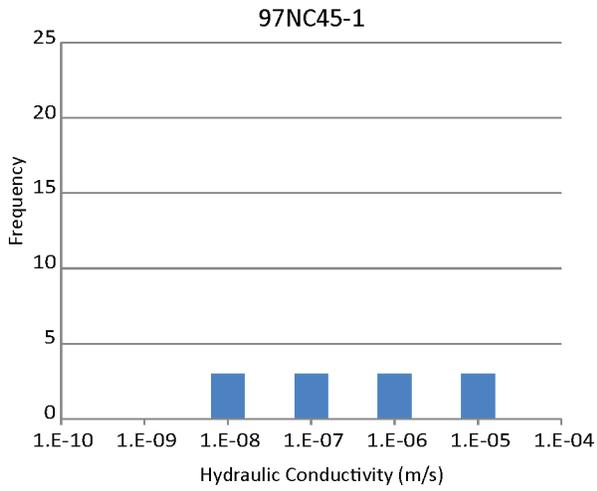
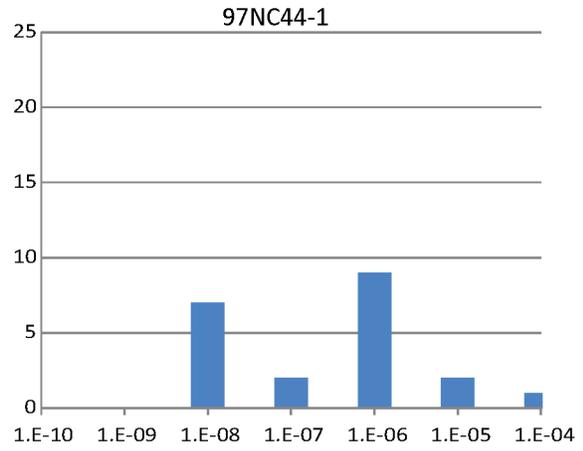
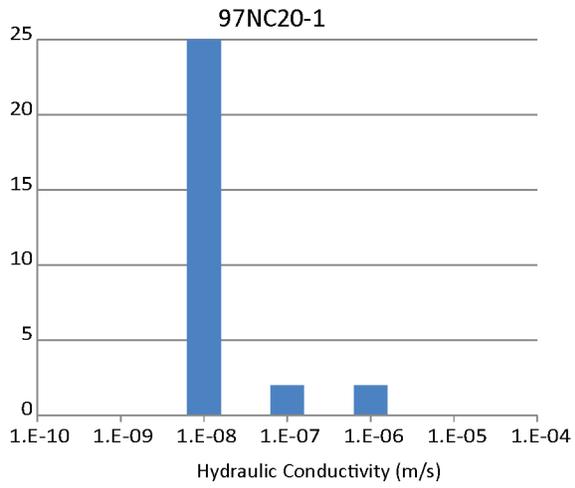
- Riddell, J.T.F., Andriashek, L.D., Jean, G. and Slattery, S.R. (2009): Preliminary results of sediment and bedrock coring in the Edmonton-Calgary Corridor, central Alberta; Energy Resources Conservation Board, ERCB/AGS Open File Report 2009-17, 81 p. URL <http://ags.aer.ca/publications/OFR_2009_17.html> [September 2016].
- Schulze-Makuch, D. and Cherkauer, D. S. (1998): Variations in hydraulic conductivity with scale of measurement during aquifer tests in heterogeneous, porous carbonate rocks; Hydrogeology Journal, v. 6, no. 2, p. 204–215, [doi:10.1007/s100400050145](https://doi.org/10.1007/s100400050145).

Appendix 1 – Summary Table of Air Permeameter Results

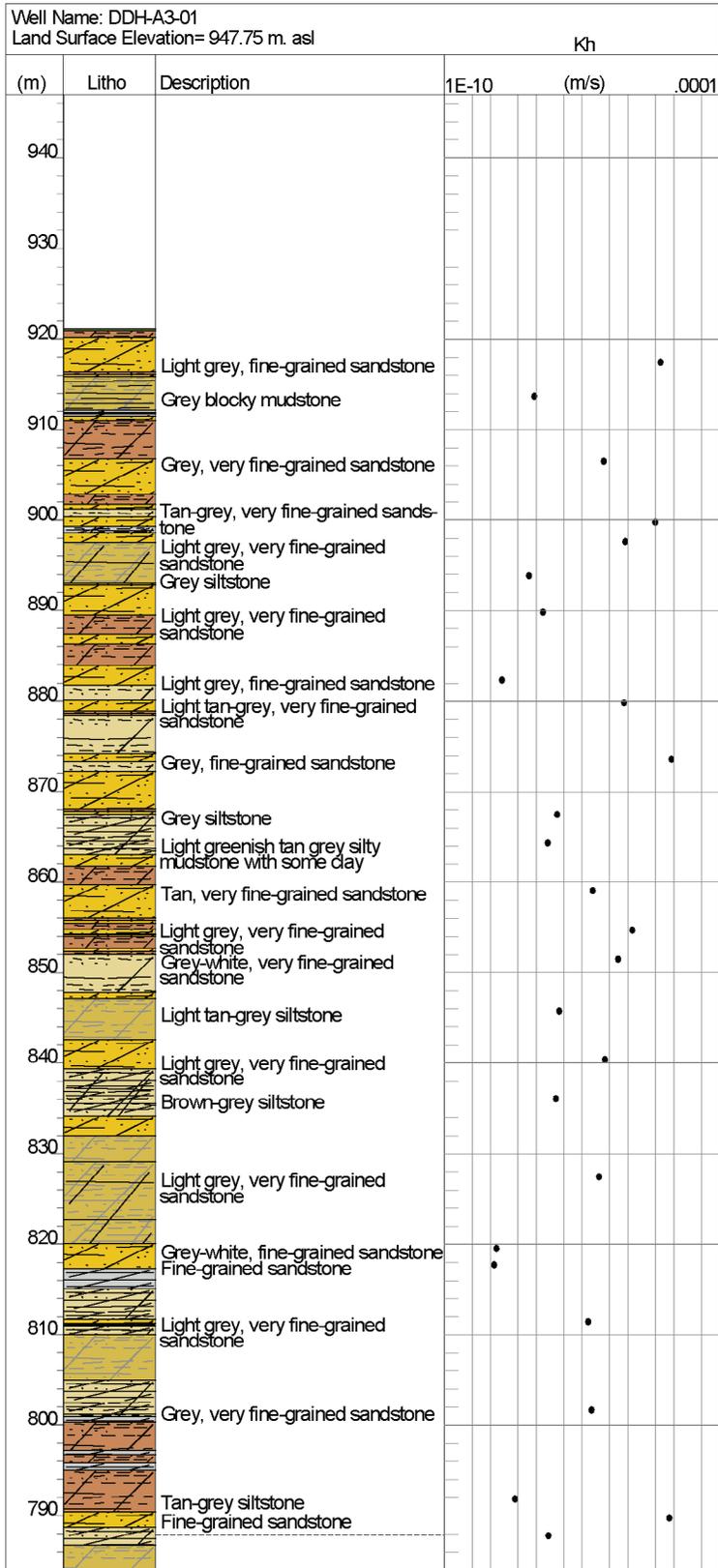
Drillcore name	Minimum (m/s)	Maximum (m/s)	Mean (m/s)	Std. Dev (m/s)	# Test points
DDH-A3-01	1.2×10^{-09}	8.9×10^{-06}	1.2×10^{-06}	2.5×10^{-06}	26
DDH-SR-01	1.2×10^{-09}	3.0×10^{-05}	2.2×10^{-06}	6.9×10^{-06}	27
97MT19-1	1.1×10^{-10}	2.0×10^{-07}	2.0×10^{-08}	5.0×10^{-08}	29
97MT28-1	1.1×10^{-09}	7.7×10^{-08}	1.5×10^{-08}	2.5×10^{-08}	15
97NC05-1	1.3×10^{-09}	1.1×10^{-06}	9.8×10^{-08}	2.1×10^{-07}	38
97NC19-1	8.6×10^{-10}	2.6×10^{-05}	1.5×10^{-06}	6.2×10^{-06}	18
97NC20-1	1.1×10^{-09}	8.1×10^{-07}	4.1×10^{-08}	1.6×10^{-07}	29
97NC44-1	1.6×10^{-09}	1.1×10^{-05}	1.1×10^{-06}	2.5×10^{-06}	21
97NC45-1	6.8×10^{-08}	1.2×10^{-08}	9.9×10^{-07}	2.3×10^{-06}	12

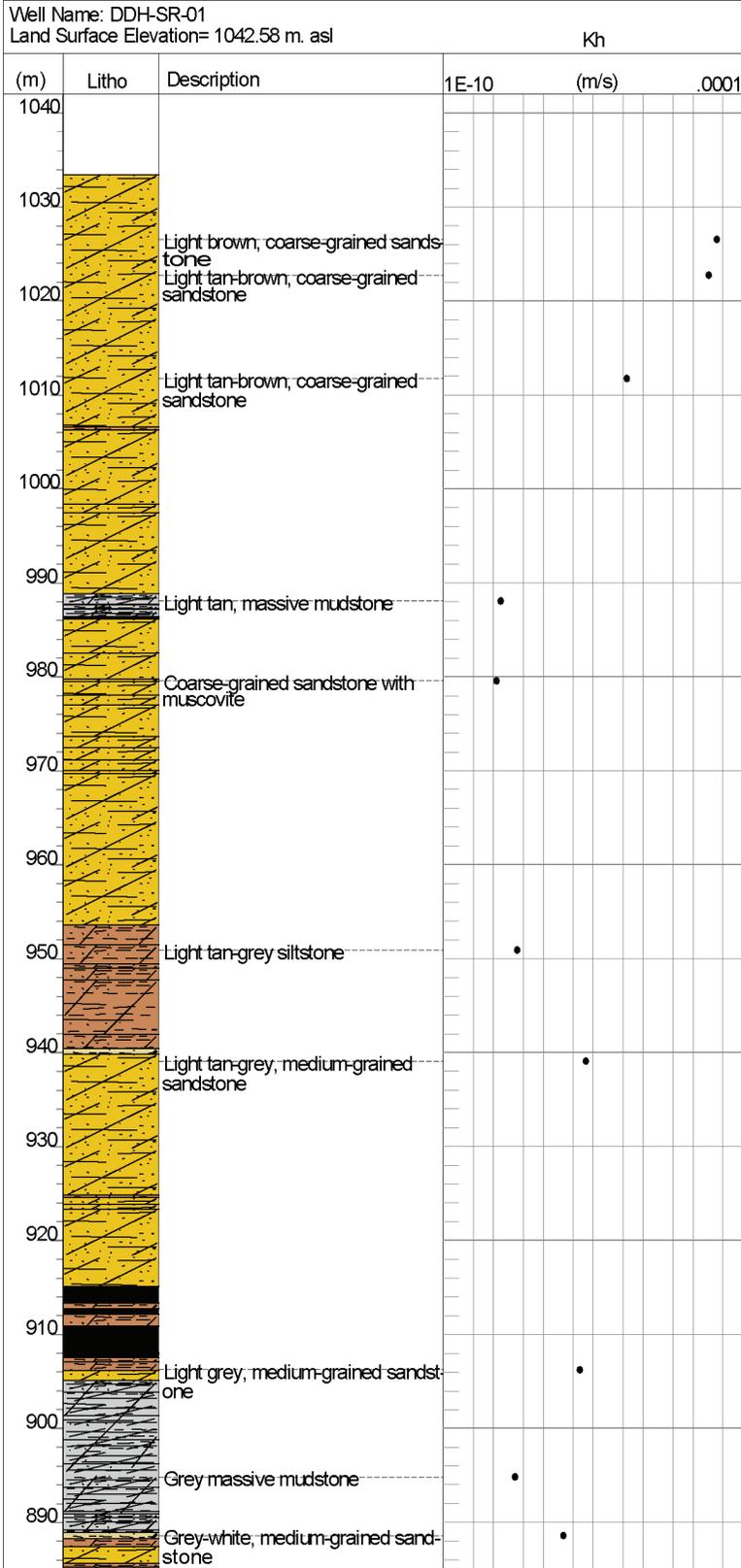
Appendix 2 – Summary Plots of Air Permeameter Results



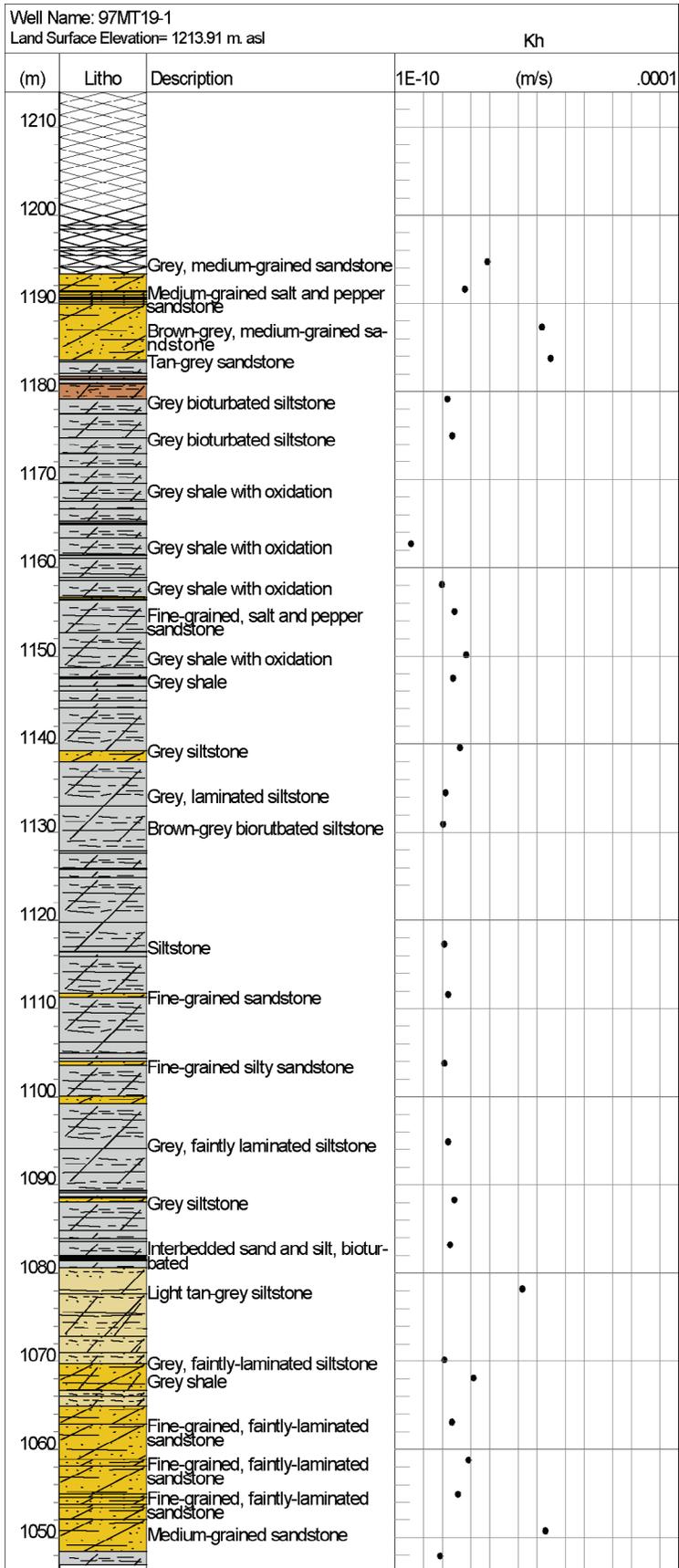


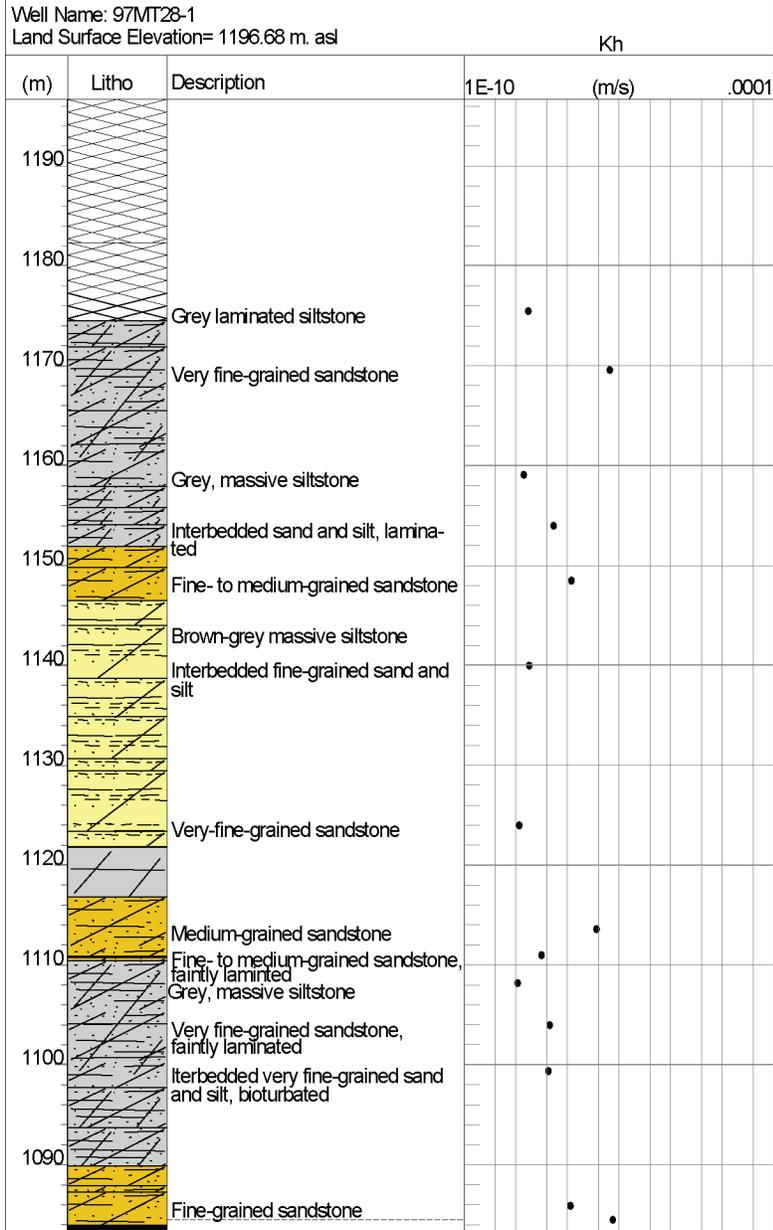
Appendix 3 – Borehole Strip Logs with Hydraulic Conductivity



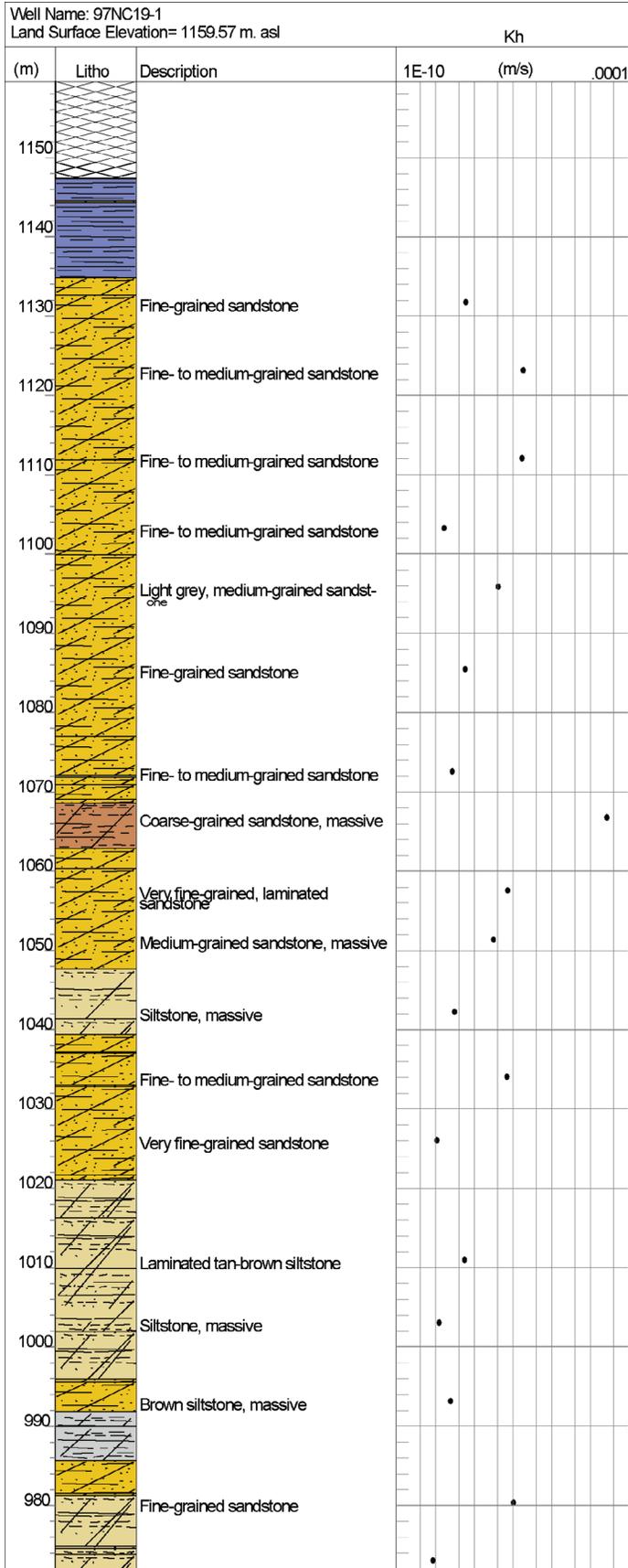


Well Name: DDH-SR-01 (cont'd)		Land Surface Elevation= 1042.58 m. asl		Kh	
(m)	Litho	Description	1E-10	(m/s)	.0001
880		Light grey siltstone	•		
		Coarse-grained, salt and pepper sandstone			•
870		Light grey, coarse-grained sandstone		•	
		Coarse-grained, sandstone with muscovite			•
850		Light grey siltstone	•		
840		Light grey siltstone	•		
830		Light grey, medium-grained sandstone with muscovite		•	
		Light grey siltstone	•		
820		Coarse-grained sandstone		•	
		Light tan-grey, fine-grained sandstone	•		
810		Light grey, medium-grained sandstone		•	
		Tan-grey, medium-grained sandstone		•	
800		Tan-grey blocky mudstone	•		
		Light grey, medium-grained sandstone	•		
790		Coarse-grained sandstone			•
		Light tan, fine-grained sandstone		•	
780			•		





Well Name: 97NC05-1 Land Surface Elevation= 1158.17 m. asl		Kh			
(m)	Litho	Description	1E-10	(m/s)	.0001
1150					
1140					
1130		Medium-grained sandstone			
1120		Fine-grained sandstone			
1110		Grey, fine-grained sandstone			
1100		Grey, coarse-grained sandstone			
1090		Grey, medium-grained sandstone			
1080		Grey, fine-grained sandstone			
1070		Grey, fine-grained sandstone			
1060		Grey, medium-grained sandstone			
1050		Grey, medium-grained sandstone			
1040		Grey, fine-grained, faintly-laminated sandstone			
1030		Grey, very fine-grained, weakly laminated sandstone			
1020		Grey, fine-grained sandstone			
1010		Grey, fine-grained sandstone			
1000		Grey, very fine-grained sandstone			
990		Grey, fine-grained sandstone			
980		Grey, coarse-grained sandstone			
970		Grey, very fine-grained sandstone			
960		Grey, fine-grained sandstone			
950		Grey, medium-grained sandstone			
940		Grey, fine-grained sandstone			
		Grey, very fine-grained cross-bedded sandstone			
		Dark grey siltstone			
		Fine-grained sandstone			
		Interbedded sand and silt			
		Grey, structureless siltstone			
		Dark grey, faintly-laminated mudstone			
		Grey, faintly-laminated siltstone			
		Grey, structureless siltstone			
		Grey, fine-grained sandstone			
		Grey, faintly-laminated mudstone			
		Grey, structureless siltstone			
		Grey, faintly-laminated siltstone			
		Grey, faintly-laminated siltstone			
		Grey, faintly-laminated siltstone			
		Fine-grained sandstone			
		Fine-grained sandstone			



Well Name: 97NC20-1		Land Surface Elevation= 1163.09 m. asl		Kh		
(m)	Litho	Description	1E-10	(m/s)	.0001	
1160						
1150		Light grey, bedded siltstone	•			
		Very fine-grained silty sandstone	•			
1140		Siltstone		•		
		Conglomerate bed within sandstone		•		
		Fine-grained, salt and pepper sandstone		•		
1130		Dark grey, faintly-laminated siltstone	•			
		Fine-grained silty sandstone			•	
		Fine-grained sandstone			•	
1110		Laminated siltstone	•			
		Very fine-grained silty sandstone			•	
1100		Weakly-laminated siltstone	•			
1090		Dark grey mudstone	•			
1080		Siltstone	•			
		Very fine-grained sandstone	•			
1070						
1060		Bioturbated siltstone	•			
		Fine-grained sandstone		•		
1050		Laminated mudstone	•			
		Very fine-grained, weakly-laminated sandstone	•			
1040		Laminated mudstone with silt and clay	•			
1030		Bioturbated grey siltstone	•			
		Laminated mudstone with silt and clay	•			
1020		Grey bioturbated siltstone	•			
1010		Grey silty mudstone	•			
		Grey siltstone	•			
1000		Siltstone	•			
		Grey, faintly laminated siltstone	•			
990		Siltstone	•			
		Faintly-laminated siltstone	•			

Well Name: 97NC44-1

Land Surface Elevation= 1035.31 m. asl

