APPENDIX B:

CORE PLUG POROSITY CALCULATIONS AND DATA

Appendix B explains the process of calculating the porosity of a standard size core plug using a Boyle's law porosimeter and reports the ancillary core plug measurements of the Bartlesville sandstone in Table B.2.

The following linear equation (B.1) is used to calculate the sand grain volume (*Vg*) of a core plug:

$$Vg = -Vi\left(\frac{Pi}{Pf}\right) + Vt \tag{B.1}$$

where:

Vg: sand grain volume of the core plug (mm^3)

Vi: system initial volume (reference chamber plus corresponding piping and connections) (mm^3)

Vt: system total volume (reference chamber, sample chamber, and corresponding piping and connections) (mm^3)

Pi: initial pressure (psi)

Pf: final pressure (psi)

Vi and *Vt* are determined by calibrating the Boyle's law porosimeter with five non-porous calibration cylinders of varying bulk volumes. The bulk volume (*Vb*) of each calibration cylinder, equivalent to *Vg* in this case, is measured with Vernier calipers. The *Pi* and *Pf* of each calibration cylinder is recorded using the Boyle's law porosimeter (Table B.1). *Pi*/*Pf* verses *Vg* for each calibration cylinder is cross-plotted and a linear regression is fit to the data. The slope of the regression line corresponds to *Vi* and the y-intercept of the regression line corresponds to *Vt* (Figure B.1)

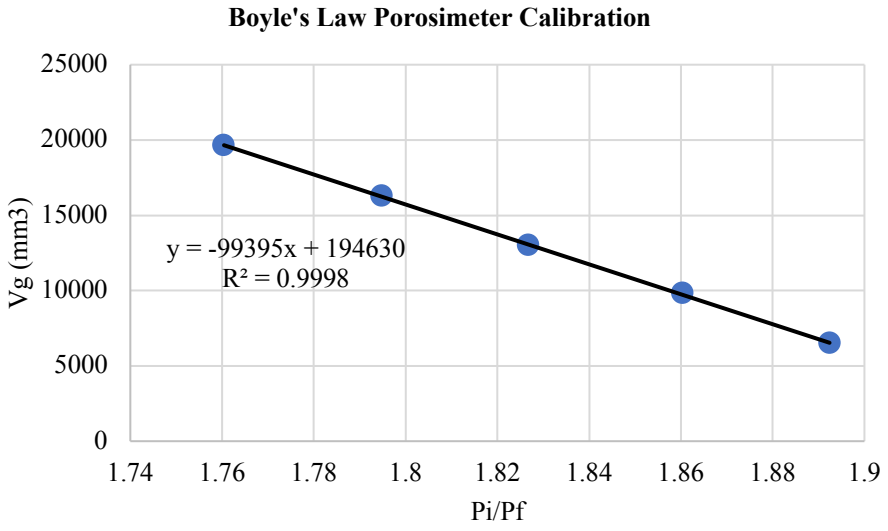

Figure B.1 Cross-plot of *Pi*/*Pf* verses *Vg* for calibration cylinders. A linear regression is used to empirically derive *Vi* and *Vt*.

According to the regression line:

$Vi = 99395\ \text{mm}^3$

$Vt = 194630\ \text{mm}^3$

With the calibration complete, the *Pi* and *Pf* of each core plug sample can be measured with the Boyle's law porosimeter and input into Equation (B.2), an updated form of Equation (B.1), to solve for *Vg*:

$$Vg = -99395\left(\frac{Pi}{Pf}\right) + 194630 \tag{B.2}$$

The porosity (ϕ) of each core plug can be solved with *Vg* and *Vb* using Equation (B.3):

$$\phi = \frac{Vb - Vg}{Vb} \tag{B.3}$$

The mean absolute error of this method is determined using Equation (B.2) and Equation (B.3) to solve for *Vg* and porosity (ϕ) of the calibration cylinders (Table B.1). Because the calibration cylinders are non-porous, the deviation of the calculated porosity from 0 is the absolute error of each measurement. The mean absolute error for the five calibration cylinders is 0.0053; consequently, porosity calculations are accurate to ±0.53%.

Sample	**Length (mm)**	**Diameter (mm)**	***Vb*** **(mm^3)**	***Pi*** **(psi)**	***Pf*** **(psi)**	***Pi/Pf***	***Vg***	**Porosity**	**Absolute Error**
1	12.71	25.5	6491	142.63	75.37	1.89	6535	-0.0068	0.0068
2	19.22	25.5	9816	142.28	76.48	1.86	9720	0.0098	0.0098
3	25.43	25.5	12987	144.6	79.16	1.83	13067	-0.0062	0.0062
4	31.89	25.5	16286	145.59	81.12	1.79	16241	0.0028	0.0028
5	38.45	25.5	19637	145.78	82.81	1.76	19654	-0.0009	0.0009
								Mean	**0.0053**

Table B.1 Relevant measurements of the calibration cylinders and the determination of mean absolute error. See above for details and abbreviations.

Sample	Orientation	Plug Length (mm)	Plug Diameter (mm)	Vb (mm^3)	Pi (psi)	Pf (psi)
Sl-LA-1a	d	37.46	25.10	18536	145.75	80.89
Sl-LA-1a	s	37.48	25.06	18486	148.49	82.19
Sl-LA-1a	⊥d	37.64	25.09	18610	145.44	80.69
Sr-CS-3a	h	37.42	24.74	17988	144.94	80.31
Sr-LA-1a	h	37.44	24.53	17694	143.61	79.04
Sr-LA-1a	s	37.43	24.70	17935	145.11	80.13
Sr-LA-1a	⊥d	37.44	24.53	17694	143.84	79.15
Sr-LA-2 a	d	37.53	24.69	17968	146.24	81.09
Sr-LA-2 a	s	37.49	24.65	17891	148.37	82.48
Sr-LA-2 a	⊥d	37.48	24.80	18105	143.66	79.78
Srx-CF-2a	d	37.60	25.01	18472	144.62	79.90
Srx-CF-2a	s	37.39	24.80	18061	144.31	79.61
Srx-CF-2a	⊥d	37.52	25.03	18462	144.28	80.03
Srx-LA-1a	d	37.47	24.81	18115	145.11	80.00
Srx-LA-1a	s	37.42	24.95	18295	144.63	79.73
Srx-LA-1a	⊥d	37.34	24.53	17647	144.68	79.58
Srx-LA-2a	d	37.48	24.75	18032	144.78	79.67
Srx-LA-2a	s	37.56	24.77	18100	144.43	79.31
Srx-LA-2a	⊥d	37.41	24.88	18188	144.57	79.41
Ss-CF-1a	h	37.42	24.30	17354	143.72	78.89
Ss-CF-1a	v	37.42	24.38	17469	144.96	79.59
Ss-CF-2a	h	37.44	24.41	17521	144.24	79.14
Ss-CF-2a	v	37.40	24.51	17646	143.79	78.91
Sw-CS-3a	h	37.50	24.74	18027	145.41	80.99
Sx-CF-1a	d	37.45	24.82	18119	144.69	79.79
Sx-CF-1a	s	37.46	24.80	18095	143.60	79.32
Sx-CF-1a	⊥d	37.58	24.73	18051	147.26	81.17
Sx-CF-2a	d	37.95	25.27	19033	148.66	82.52
Sx-CF-2a	s	37.47	25.23	18733	147.39	81.46
Sx-CF-2a	⊥d	37.45	25.14	18590	151.08	83.51
Sx-LA-1a	d	37.62	25.07	18570	146.06	80.79
Sx-LA-1a	s	37.43	25.02	18403	146.69	81.16
Sx-LA-1a	⊥d	37.47	25.05	18467	145.04	80.33

Table B.2. The ancillary measures of each core plug required to calculate porosity using a Boyle's law porosimeter. See above for details and abbreviations. See Table 3.2 for explanation of core plug sample notation and orientation.

APPENDIX C

CORE PLUG PERMEABILITY CALCULATIONS AND DATA

Appendix C explains the process of calculating core plug permeability and reports the ancillary core plug measurements in Table C.1.

Darcy's Law (Equation C.1) is used to calculate the permeability of a core plug when using axial, steady-state flow in a Hassler-type confining chamber:

$$k = \frac{q\mu L}{\mathrm{A}\Delta P} * 1000 \tag{C.1}$$

where:

k: permeability (mD)

q: volumetric flow rate (cm^3/s)

μ: 0.0182 cP, viscosity of air at 70°F

L: core plug length (cm)

A: cross-section area of sample (cm^2)

ΔP: difference in upstream and downstream pressure (atm)

ΔP and q are measured via the Hassler-type apparatus once steady-state flow conditions are reached. L and A of the core plug are measured using Vernier calipers. μ is considered constant throughout the experiment(s).

Sample	Orientation	Plug Length (cm)	Plug Cross-Sectional Area (cm^2)	q (cm^3/s)	ΔP (atm)
Sl-LA-1a	d	3.746	11.02	0.025	0.069
Sl-LA-1a	s	3.748	11.03	0.024	0.056
Sl-LA-1a	⊥d	3.764	11.13	0.023	0.426
Sr-CS-3a	h	3.742	11.00	0.021	0.614
Sr-LA-1a	h	3.744	11.01	0.021	0.010
Sr-LA-1a	s	3.743	11.00	0.024	0.024
Sr-LA-1a	⊥d	3.744	11.01	0.023	0.024
Sr-LA-2 a	d	3.753	11.06	0.024	0.144
Sr-LA-2 a	s	3.749	11.04	0.023	0.320
Sr-LA-2 a	⊥d	3.748	11.03	0.013	1.340
Srx-CF-2a	d	3.760	11.10	0.023	0.021
Srx-CF-2a	s	3.739	10.98	0.023	0.030
Srx-CF-2a	⊥d	3.752	11.06	0.022	0.462
Srx-LA-1a	d	3.747	11.03	0.023	0.018
Srx-LA-1a	s	3.742	11.00	0.020	0.012
Srx-LA-1a	⊥d	3.734	10.95	0.025	0.088
Srx-LA-2a	d	3.748	11.03	0.022	0.015
Srx-LA-2a	s	3.756	11.08	0.017	0.007
Srx-LA-2a	⊥d	3.741	10.99	0.019	0.011
Ss-CF-1a	h	3.742	11.00	0.014	0.005
Ss-CF-1a	v	3.742	11.00	0.019	0.005
Ss-CF-2a	h	3.744	11.01	0.019	0.008
Ss-CF-2a	v	3.740	10.99	0.018	0.007
Sw-CS-3a	h	3.750	11.04	0.019	0.791
Sx-CF-1a	d	3.745	11.02	0.015	0.005
Sx-CF-1a	s	3.746	11.02	0.020	0.010
Sx-CF-1a	⊥d	3.758	11.09	0.021	0.013
Sx-CF-2a	d	3.795	11.31	0.024	0.027
Sx-CF-2a	s	3.747	11.03	0.022	0.016
Sx-CF-2a	⊥d	3.745	11.02	0.025	0.098
Sx-LA-1a	d	3.762	11.12	0.023	0.016
Sx-LA-1a	s	3.743	11.00	0.023	0.020
Sx-LA-1a	⊥d	3.747	11.03	0.024	0.155

Table C.1. The ancillary measure of each core plug required to calculate permeability. See above for details and abbreviations. See Table 3.2 for explanation of core plug sample notation and orientation.

APPENDIX D

PROBE PERMEABILITY DATA

Circumferential and flat-slab measurements of permeability taken by the probe permeameter on each core sample of the Bartlesville sandstone are reported in Tables D.1 – D.21. All permeability measurements are in millidarcies (mD).

Sl-LA-1b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
829.42	-	2.88	2.76	-	4.67	-	2.74	6.99	4.44	3.52	2.79	3.75	6.75	-	2.88	-
829.45	4.62	3.74	3.37	-	4.39	3.64	5.89	3.28	3.51	3.95	5.46	7.93	7.75	-	6.49	6.51
829.48	5.85	3.66	3.16	-	4.84	6.97	5.72	2.59	3.02	2.31	1.81	2.63	3.03	-	-	-
829.52	2.1	2.21	1.63	-	1.96	1.73	4.17	1.19	1.36	1.01	0.589	0.5488	1.02	-	1.98	2.44
829.55	4.15	1.41	2.15	-	2.7	1.24	1.85	1.96	2.29	2.07	1.67	2.38	5.62	-	-	2.65
829.58	3.4	3.64	3.17	-	3.98	3.45	4.21	2.71	4.42	3.41	3.17	5.81	9.78	-	3.44	2.99
829.62	4.22	3.36	3.03	-	3.59	3.12	5.79	1.64	1.44	1.21	1.08	1.01	1.67	-	5.02	4.31
829.65	4.27	1.99	1.81	-	2.83	2.6	3.33	3.33	4.64	4.99	4.6	3.35	4.05	-	3.76	3.02
829.68	2.79	2.05	5.22	-	5.61	8.25	4.69	4.72	5.18	4.53	6.44	5.09	5.86	-	9.12	5.63
829.72	8.71	5.73	6.89	-	9.48	9.34	8.92	6.13	12.6	9.52	7.48	5.91	6.42	-	9.95	8.08
829.75	3.32	8.39	6.34	-	7	-	3.99	2.4	4.46	4.55	3.75	3.73	-	-	-	-

Table D.1. Measurements of permeability taken on the circumferential surface of Sl-LA-1b by the probe permeameter. All permeability values are in mD.

Sl-LA-1b Flat Slab Probe Permeability Measurements		
Depths (ft)	**Thick Flat Slab**	**Thin Flat Slab**
829.42	3.21	2.26
829.45	3.86	3.1
829.48	3.49	2.62
829.52	2	1.86
829.55	1.31	0.826
829.58	4.35	2.93
829.62	3.42	2.97
829.65	2.3	1.29
829.68	11	10.2
829.72	13.3	8.24
829.75	6.55	9.02

Table D.2. Measurements of permeability taken on the flat slab surface of Sl-LA-1b by the probe permeameter. All permeability values are in mD.

Sr-LA-1b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
834.49	-	20.3	16.7	-	17	-	-	-	13	9.94	9.34	8.61	8.79	-	-	21
834.52	8.79	11.5	14.2	-	14.8	8.75	-	9.23	12	8.8	13.7	9.99	11	-	7.46	7.25
834.55	15	10.2	9.46	-	10.5	12.2	9.95	10.2	11.7	14.6	12	11.2	11.8	-	14.6	14.3
834.59	18.6	15.6	12.9	-	9.83	10.4	11.4	11	10.4	10.2	10.2	10	9.76	-	9.56	11.1
834.62	13.4	10.3	12.7	-	12.6	10.2	12.2	10.6	7.07	6.25	6.61	8.99	9.87	-	9.94	10.8
834.65	13.3	9.57	12.1	-	9.86	9.62	10.1	8.52	8.61	10.1	8.41	7.17	6.63	-	7.16	9.96
834.68	11.7	10.8	10.7	-	8.1	8.84	9.15	7.82	7.63	7.42	9.58	8.47	11.6	-	12.1	13.5
834.72	11.2	11.6	12.2	-	10.3	10.2	9.99	8.03	8.72	12.8	6.74	6.52	8.4	-	9.47	12.5
834.75	9.83	9.72	10.1	-	10	9.35	9	8.66	12.4	-	-	-	-	-	11.5	11

Table D.3. Measurements of permeability taken on the circumferential surface of Sr-LA-1b by the probe permeameter. All permeability values are in mD.

Sr-LA-1b Flat Slab Probe Permeability Measurements		
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**
834.49	59.7	60.6
834.52	23.4	26
834.55	43	39.7
834.59	33.9	37.6
834.62	30.1	33.8
834.65	23.5	25.9
834.68	33.3	44.9
834.72	36	36.4
834.75	25.1	28.7

Table D.4. Measurements of permeability taken on the flat slab surface of Sr-LA-1b by the probe permeameter. All permeability values are in mD.

Sr-LA-2b Flat Slab Probe Permeability Measurements		Sr-CS-3b Flat Slab Probe Permeability Measurements	
Depth (ft)	**Thick Flat Slab**	**Depth (ft)**	**Thick Flat Slab**
817.15	0.6047	815.20	0.5506
817.18	0.1749	815.23	0.7678
817.22	0.1379	815.27	0.58
817.25	0.21	815.30	0.7291
817.28	0.1426	815.33	0.5554
817.32	0.4053	815.37	0.6482
817.35	0.4967	815.40	0.6887
817.38	0.0578	815.43	0.8117
817.42	0.0715	815.47	0.8042
817.45	0.2889	815.50	0.6599
817.48	0.2217		
817.52	0.6249		
817.55	0.2254		
817.58	1.16		
817.62	0.9403		
817.65	0.2638		
817.68	0.0833		
817.72	0.2429		
817.75	0.6424		

Table D.5. Measurements of permeability taken on the flat slab surface of Sr-LA-2b and Sr-CS-3b by the probe permeameter. All permeability values are in mD.

Srx-LA-1(I)b Circumferential Probe Permeability Measurements																
Depths (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
832.67	6.88	9.16	8.31	9.34	9.46	-	-	8.14	10.6	12.5	10.7	11.6	7.11	-	-	15.6
832.70	6.72	6.95	7.89	8.28	7.56	7.13	9.64	11.1	10.7	13	10.6	9.95	9.86	-	4.82	5.63
832.74	11.9	14.4	12.5	-	7.92	10.2	7.45	13	8.21	8.9	8.66	5.58	4.73	-	11.6	8.82
832.77	5.1	21.8	9.34	-	5.76	6.1	7.97	7.97	8.85	9.94	11.8	12.8	14.2	-	-	-
832.80	18.4	13.5	15.5	-	13.6	11.5	7.32	6.73	7.68	9.74	12.2	12.2	11	-	16.3	16.5
832.84	8.74	9.63	9.37	-	15.7	-	14.3	9.11	10.4	11.7	9.79	8.12	8.34	-	11.1	9.9
832.87	10.3	7.02	6.07	6.3	5.38	6.01	6.83	15.2	12.3	7.5	8.16	9.2	-	-	6.33	9.48
832.90	8.72	10.3	10.9	7.81	6.98	5.27	5.71	6.42	4.38	5.62	4.29	7	10.7	-	8.23	8.82
832.93	11.1	10.8	10.6	12.5	12.3	8.64	7.14	8.08	7.31	7.12	6.48	6.95	9.51	-	14.8	12.4
832.97	9.75	10.6	10.3	8.47	-	14.4	11.1	10.5	10.9	7.78	12.7	12.8	14	-	9.53	9.02
833.00	16.4	15.7	13.9	14.2	15.3	26.8	-	11.3	14.2	11.8	11.2	10	8.16	-	13.8	13.7

Table D.6. Measurements of permeability taken on the circumferential surface of Srx-LA-1(I)b by the probe permeameter. All permeability values are in mD.

Srx-LA-1(I)b Flat Slab Probe Permeability Measurements		
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**
832.67	15.6	31.8
832.70	20.4	14.7
832.74	26.5	29.3
832.77	13.5	11.7
832.80	11.7	11.4
832.84	20.3	26.2
832.87	34.2	40.1
832.90	25.3	13.1
832.93	12	20.9
832.97	5.57	9.81
833.00	20.8	15.6

Table D.7. Measurements of permeability taken on the flat slab surface of Srx-LA-1(I)b by the probe permeameter. All permeability values are in mD.

Srx-LA-1(II)b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
832.63	3.34	5.09	2.02	2.73	3.72	2.92	2.63	3.1	3.65	4.37	4.76	3.54	3.77	3.9	2.46	2.3
832.67	3.51	4.33	5.44	4.38	4.69	3.77	3.68	4.31	5.31	5.6	4.03	4.44	2.98	3.52	4.49	3.8
832.70	4.19	5.85	3.35	3.71	3.32	3.14	3.46	3.48	2.26	3.44	4.73	3.66	4.12	3.6	2.95	-
832.73	4.87	4.47	2.74	3.44	2.89	3.89	3.44	4.41	3.62	4.51	5.69	3.13	2.44	2.83	2.93	4.41
832.77	5.55	5.6	4.07	3.8	3.5	2.15	2.85	2.44	1.88	3.15	3.34	4.62	5.61	4.13	2.74	4.35
832.80	3.48	2.6	2.81	3.39	4.87	2.11	2	2.48	1.41	5.44	2.69	2.25	2.35	4.05	4.51	4.47
832.83	2.78	4.85	2.39	3.19	2.58	2.74	3.24	4.49	2.79	3.39	2.93	3.49	3.25	1.88	1.8	3.77
832.87	4.77	4.19	4.36	2.17	2.02	2.58	4.22	2.74	1.54	2.29	3.82	5.85	4.56	2.53	2.83	4.06
832.90	3.26	3.47	4.74	4.91	3.55	3.69	3.93	4.05	3.8	6.09	6.84	3.46	3.68	3.2	3.22	3.15
832.93	6.37	3.61	5.04	5.25	3.33	3.65	4.14	4.48	5.56	5.39	4.64	5.65	5.69	3.6	3.56	3.99
832.97	3.39	5.35	4.53	3.8	2.12	4.53	3.53	4.52	2.1	4.92	3.78	3.36	4.2	4.48	4.76	5.98
833.00	4.29	5.39	5.21	4.45	1.97	1.85	3.67	3.85	2.73	2.98	6.03	2.49	3.34	3.1	2.95	2.82

Table D.8. Measurements of permeability taken on the circumferential surface of Srx-LA-1(II)b by the probe permeameter. All permeability values are in mD.

Srx-LA-1(II)b Flat Slab Probe Permeability Measurements		
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**
832.63	3.49	3.24
832.67	2.37	4
832.70	2.03	3.14
832.73	1.99	2.82
832.77	4.02	4.85
832.80	2.14	3.17
832.83	2.02	2.41
832.87	1.89	2.56
832.90	3.45	3.33
832.93	4.61	6.58
832.97	1.46	1.99
833.00	3.06	3.41

Table D.9. Measurements of permeability taken on the flat slab surface of Srx-LA-1(II)b by the probe permeameter. All permeability values are in mD.

Srx-CF-1b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
842.80	12	10.3	14.3	-	9.05	4.43	6.29	8.23	5.09	9.9	8.88	9.88	6.88	-	7.86	10.4
842.84	12.5	10.9	8.41	9.5	7.85	7.03	6.71	8.06	9.31	12.6	12.4	13.7	11.3	-	8.46	11.5
842.87	8.57	8.82	11.1	12.8	9.24	12.8	11.9	10.4	10.2	12.7	12.7	13.7	11.1	-	9.5	7.53
842.90	9.83	9.65	10.8	13.6	15.3	11.3	12.6	11.1	10.7	14	14.4	16.8	15	-	13.9	11
842.93	11.2	11.4	13.4	14.1	13	10.5	9.24	11.6	12.3	15.7	11.9	18.3	14.5	-	14.2	12.7
842.97	12.1	16.3	17.3	18.5	15.6	9.28	10	11	11.7	15.1	15.7	15	14.5	-	12.2	13.3
843.00	14	10.7	12	11.9	11	8.29	10.2	8.36	10.1	12.9	15	14.2	13.6	-	12.7	13.7

Table D.10. Measurements of permeability taken on the circumferential surface of Srx-CF-1b by the probe permeameter. All permeability values are in mD.

Srx-CF-1b Flat Slab Probe Permeability		
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**
842.80	20.6	31
842.84	27.2	31.9
842.87	45.9	37.2
842.90	44.4	38.1
842.93	75.2	72.5
842.97	51.2	42.2
843.00	15.8	19.3

Table D.11. Measurements of permeability taken on the flat slab surface of Srx-CF-1b by the probe permeameter. All permeability values are in mD.

Srx-CF-2b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
824.70	11.4	12.4	14	-	16	15	15.1	13.5	9.73	6.2	5.59	6.95	5.82	-	8.59	15.5
824.74	11.1	14.2	15.1	-	14.7	15.7	12.9	9.66	2.68	4.36	3.99	2.45	2.5	-	9.03	5.57
824.77	8.02	4.82	11.8	-	4.97	6.57	6.35	5.39	6.42	2.85	1.24	0.8767	0.8047	-	5.55	10.5
824.80	7.56	9.02	6.37	-	10.3	7.34	8.82	4.46	1.38	0.6368	0.6569	0.8909	1.07	-	1.04	3.3
824.84	2.75	4.38	6.81	-	2.01	4.08	2.33	1.32	0.6926	1.1	1.81	1.62	0.5023	-	0.99	3.3
824.87	0.6015	1.3	1.96	-	4.68	1.17	1.23	0.5082	0.6138	1.17	2.6	3.45	1.92	-	1.55	0.9011
824.90	0.6557	0.4625	0.4913	-	-	0.6224	0.9045	0.7701	-	2.27	3.21	3.5	2.31	-	3.83	1.58
824.93	0.8892	2.82	0.6151	-	2.28	0.7985	0.8853	1.75	2.09	1.48	0.9354	2.49	0.9385	-	2.98	2.59
824.97	1.92	1.97	1.09	-	1.39	1.89	1.86	1.55	1.22	0.7312	1.19	0.8288	1	-	1.31	2.93
825.00	1.16	1.79	-	-	3.26	1.94	-	-	-	0.1304	0.1013	0.1052	0.2723	-	1.58	1.15

Table D.12. Measurements of permeability taken on the circumferential surface of Srx-CF-2b by the probe permeameter. All permeability values are in mD.

Srx-CF-2b Flat Slab Probe Permeability Measurements		
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**
824.70	24.9	25.5
824.74	5.81	6.69
824.77	9.09	8.88
824.80	2.55	2.35
824.84	1.28	0.6113
824.87	0.4221	0.5771
824.90	1.56	1.44
824.93	1.97	2.11
824.97	2.56	2.47
825.00	1.68	1.7

Table D.13. Measurements of permeability taken on the flat slab surface of Srx-CF-2b by the probe permeameter. All permeability values are in mD.

Ss-CF-2b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
821.45	7.3	9.07	10.6	-	9.61	12.6	16.9	12.4	8.45	8.65	9.61	9.41	9.35	-	7.84	8.56
821.49	6.24	9.67	10.1	-	11.8	16.7	13.6	10.8	12.9	10.6	10	13.7	9.73	-	7.17	6.01
821.52	9.78	9.8	8.49	-	14.1	12.1	14.1	13.6	11.8	7.49	10.6	11.3	14.8	-	10	11.9
821.55	7.7	4.43	9.89	-	10.3	17.9	11.6	11.3	-	6.98	-	9.47	12.3	-	10.5	7.41
821.59	6.16	6.3	10.7	-	9.11	7.91	6.93	7.1	10.4	8.5	7.2	10.7	10	-	12.1	8.17
821.62	9.98	8.73	7.51	-	5.52	7.65	6.41	-	10.9	7.68	6.86	11.1	7.69	-	10.9	11.6
821.65	8.28	10.3	10.5	-	9.14	7.49	7.85	9.49	12.8	13.8	15.5	13.6	-	-	9.99	12
821.68	8.78	12.1	10.4	-	10.9	9.84	12.7	15.7	6.5	9.78	12.1	15.4	9.7	-	11.9	11.6
821.72	9.64	12	10.7	-	10	11.5	13.2	11.2	8.89	11.1	12.2	12.9	9.01	-	12.1	14.6
821.75	10.3	12.3	9.8	-	8.38	14.2	11.9	13	10.7	13.2	12.5	11.8	9.01	-	12.8	11.1

Table D.14. Measurements of permeability taken on the circumferential surface of Ss-CF-2b by the probe permeameter. All permeability values are in mD.

Ss-CF-2b Flat Slab Probe Permeability Measurements			Ss-CF-1b Flat Slab Probe Permeability Measurements		
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**	**Depth (ft)**	**Thick Flat Slab**	**Thin Flat Slab**
821.45	26	31.2	845.74	57.5	50.5
821.49	50.7	68.7	845.77	80.2	75.9
821.52	73.2	78.4	845.80	84.2	60.7
821.55	86	77.3	845.84	54	43.3
821.59	138	124	845.87	48.6	57.9
821.62	126	121	845.90	104	105
821.65	112	112	845.93	99.6	82.3
821.68	128	108	845.97	55.5	59.3
821.72	133	111	846.00	95.9	106
821.75	110	120			

Table D.15. Measurements of permeability taken on the flat slab surface of Ss-CF-2b by the probe permeameter. All permeability values are in mD.

Sx-LA-1b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
837.33	5.19	3.03	4.88	-	5.38	4.24	4.98	3.7	4.85	3.75	4.32	4.28	4.53	-	11.2	4.89
837.38	4.23	4.17	4.73	-	5.85	4.71	6.63	5.49	6.04	5.63	7.22	11.7	8.37	-	5.61	3.27
837.42	6.12	5.51	5.9	-	4.53	4.15	5.2	5.55	5.7	4.89	7.42	6.37	5.5	-	5.72	5.67
837.47	6.62	6.17	4.27	-	6.54	5.75	5.89	6.25	6.45	8.29	8.83	6.51	6.42	-	5.83	5.61
837.50	9.64	7.63	1.76	-	6.52	5.63	6.82	7.51	8.79	9.68	9.45	6.02	7.6	-	6.78	7.81
837.55	4.59	4.99	4.96	-	6.72	5.45	5.34	4.77	5.95	6.03	5.97	7.86	9.46	-	8.13	6.07
837.58	9.03	7.85	5.41	-	9.12	8.93	9.32	6.91	7.45	7.72	9.54	7.6	7.4	-	7.58	9.62
837.63	6.49	8.95	10.5	-	12.8	8.95	10.8	7.07	6.98	7.92	10.5	9.12	9.97	-	9.05	9.45
837.67	12.5	11.8	12.6	-	11	10.4	15.4	11.4	9.79	10	11.2	15.9	15.2	-	8.14	9.03
837.72	7.5	12.9	12.6	-	12	13.3	10.8	10.5	12.1	10.1	10.7	14.1	15.8	-	-	11.7
837.75	20.2	17.2	15.8	-	13	7.5	8.38	7.4	7.13	6.61	17.5	8.19	14	-	6.6	10.5

Table D.16. Measurements of permeability taken on the circumferential surface of Sx-LA-1b by the probe permeameter. All permeability values are in mD.

Sx-LA-1b Flat Slab Probe Permeability Measurements		
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**
837.33	9.13	4.85
837.38	12.2	6.13
837.42	15.5	11.9
837.47	17.3	12.6
837.50	24.8	19.1
837.55	27.5	21.7
837.58	18.9	13.4
837.63	24.1	23.4
837.67	29	24.3
837.72	31.8	33.2
837.75	24.9	25.9

Table D.17. Measurements of permeability taken on the flat slab surface of Sx-LA-1b by the probe permeameter. All permeability values are in mD.

Sx-CF-1b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
843.95	11.4	14.4	9.7	-	10.4	10.1	13.9	10.1	12.6	10.9	11.5	8.8	10.5	-	14.5	9.12
843.99	9.71	10.6	10.9	-	10.9	10.8	11.7	12.2	10.3	12.3	7.53	12.1	10.8	-	11.6	9.46
844.02	13.3	10.3	13.8	-	9.67	11.6	13.6	13.4	14.4	10.4	6.17	5.41	5.91	-	13.4	16.5
844.05	14.4	13	10.2	-	9.93	16.2	13.5	12.8	14	14.8	5.03	4.46	10	-	13.6	16.3
844.09	13.3	14.4	9.72	-	7.12	8.94	13.8	16.4	17.7	14.3	12.8	7.7	1.52	-	15.9	19
844.12	14.7	13.9	12.3	-	9.43	10.6	11.2	15.9	15.9	13.4	10.6	12.6	8.98	-	14	14
844.15	14.6	15.6	10.9	-	10.8	11.8	12.7	14.7	12.6	12.3	11.5	12.8	12.1	-	14.3	11.5
844.18	-	10.1	10.5	-	11.7	8.6	10.1	10.9	8.9	10.7	12.1	9.51	12	-	-	-
844.22	10.1	13.7	12.4	-	15.3	6.82	8.38	14.2	9.98	9.19	7.35	9.56	8.46	-	9.91	13.1
844.25	9.79	12.6	-	-	8.95	4.98	7.52	9.43	11.3	11	9.98	11.2	12.1	-	14.7	16.1

Table D.18. Measurements of permeability taken on the circumferential surface of Sx-CF-1b by the probe permeameter. All permeability values are in mD.

Sx-CF-1b Flat Slab Probe Permeability Measurements		
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**
843.95	63.4	59.4
843.99	71.9	66.6
844.02	65.7	63.5
844.05	82	78.5
844.09	71.1	79.2
844.12	64.7	88.8
844.15	58.8	59.8
844.18	56.4	75.7
844.22	45.1	46.9
844.25	70.6	76.5

Table D.19. Measurements of permeability taken on the flat slab surface of Sx-CF-1b by the probe permeameter. All permeability values are in mD.

Sx-CF-2b Circumferential Probe Permeability Measurements																
Depth (ft)	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**
825.26	3.58	4.08	3.35	-	-	-	-	5.77	7.5	-	5.81	-	-	-	4.25	3.06
825.29	4.02	4.34	4.09	-	-	4.74	-	9.48	9.17	9.66	9.55	8.19	6.65	-	7.73	6.05
825.32	4.83	4.61	-	-	4.67	7.04	-	9.48	10.7	10.6	9.47	10.5	9.13	-	7.91	10.8
825.35	11.1	6.65	5.22	-	5.59	8.18	9.65	9.63	10.9	10.6	10.6	5.81	8.18	-	9.27	9.73
825.39	7.67	5.69	7.43	-	7.03	7.15	9.02	11.2	9.71	11	9.45	11.5	8.91	-	10.7	10.7
825.42	5.97	4.61	9.32	-	7.88	10.7	10.7	9.96	11.6	10.4	11.4	8.1	9.01	-	9.67	3.52
825.45	6.53	6.73	10.6	-	10.2	10.2	9.5	9.18	13.5	7.8	13.1	10.3	10.9	-	10.4	7.98
825.49	4.55	7.45	12	-	6.61	10.2	16.1	8.28	14.1	9.96	9.01	6.63	10	-	9.32	8.61
825.52	8.31	2.5	12.6	-	9.64	10.8	7.89	8.77	11.1	9.9	10.3	8	8.57	-	10	6.72
825.55	6.23	9.22	10.4	-	8.76	14.6	8.14	11.1	10.7	9.59	11.4	9.04	7.34	-	9.97	11
825.59	8.87	5.8	10.4	-	9.8	14.2	14.7	10	12.4	10.2	15.8	10.5	10.5	-	13	10.4
825.62	9.69	11.2	10.7	-	9.1	11.1	13.1	9.72	14.1	10.9	10.6	11.4	8.24	-	10.8	10.1
825.65	9.88	10.4	10.7	-	10.1	11.7	9.45	12.4	13.2	11.8	12.5	10.2	12.5	-	11.6	12
825.68	19.6	12.4	12.8	-	9.71	12.1	12.5	12	13.7	11.7	12	9.18	11.3	-	10.5	11.3
825.72	16.1	11.8	16.8	-	9.37	11.1	12.7	11.3	13.6	15.2	13.3	13.7	13.8	-	11.9	15
825.75	11.1	10.5	13.4	-	8.13	10.9	11.5	11.5	12.9	15.5	15.6	13.5	-	-	11.7	10.3

Table D.20. Measurements of permeability taken on the circumferential surface of Sx-CF-2b by the probe permeameter. All permeability values are in mD.

Sx-CF-2b Flat Slab Probe Permeability Measurements			Sw-CS-3b Flat Slab Probe Permeability Measurements	
Depth (ft)	**Thick Flat Slab**	**Thin Flat Slab**	**Depth (ft)**	**Thick Flat Slab**
825.26	16.5	11.3	813.65	0.0414
825.29	14.5	15.6	813.68	0.0754
825.32	27.9	23.9	813.72	0.0824
825.35	34.6	30.1	813.75	0.0461
825.39	40.2	38.9		
825.42	34.4	40.7		
825.45	41.8	36.5		
825.49	33.5	43.3		
825.52	59.3	67.1		
825.55	52.9	47.7		
825.59	78.3	82.6		
825.62	49.7	38.3		
825.65	54.9	50.5		
825.68	75.2	79.6		
825.72	64.6	69.5		
825.75	81	70.3		

Table D.21. Measurements of permeability taken on the flat slab surface of Sx-CF-2b by the probe permeameter. All permeability values are in mD.

APPENDIX E

PRECISION OF THE PROBE PERMEAMETER

The reproducibility of probe permeameter measurements were assessed by executing seventy-five consecutive measurements at the same point on a flat-slabbed surface of the Bartlesville sandstone (Figure E.1). The rubber tip seal was replaced at the beginning of the experiment. From the data, it appears six preparatory measurements are necessary to fully seat the rubber seal into the probe tip. Measurements seven through sixty-seven exhibit a slight increasing trend of permeability before the rubber seal begins to fail. Throughout this study the rubber tip seal is replaced at intervals of approximately fifty measurements (not including preparatory measurements). The arithmetic average and standard deviation of measurements seven through fifty-seven is 9.40 mD and 0.08 mD, respectively. The coefficient of variation is 0.009; thus, the instrument is considered precise within 0.9% of a measurement.

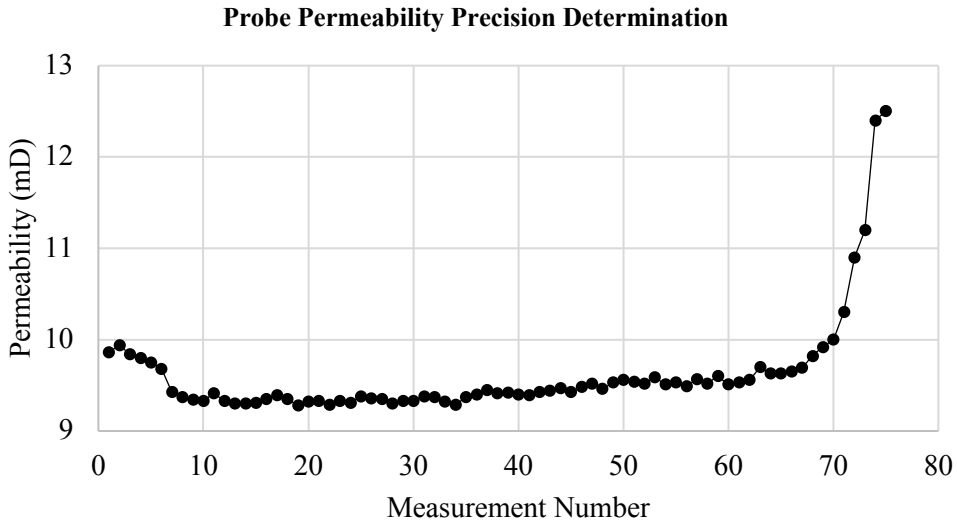

Figure E.1 Six preparatory measurements are required to fully seat the rubber seal. The rubber seal begins to fail near measurement sixty-seven.

APPENDIX F

PROBE PERMEABILITY VERSES CORE PLUG PERMEABILITY

The arithmetic average core plug permeability of each sampled lithofacies is cross plotted with the geometric average of flat-slab permeability of the corresponding lithofacies sampled by the probe permeameter (Figure F.1). Since probe permeameter data points are oriented parallel to the horizontal plane, core plug permeability measurements oriented perpendicular to the stratal plane ($K \perp d$) are not considered in the arithmetic average of core plug permeabilities to remove the effects of near-vertical baffling of pore fluid flow; consequently, only core plug permeability measurements in the direction parallel to strike (Ks) and parallel to dip (Kd) are considered. The data points correspond by lithofacies, 4^{th} order element, and 5^{th} order element, but the exact depths do not correspond for six of the thirteen samples.

The calculated permeabilities of the two methods exhibit a positive linear trend with an 80% linear coefficient of determination. The data fall under the line of unity to form a slope of 0.41. The average flat-slab probe permeability measurements become increasingly greater ($1 - 2.2x$) than the core plug permeability measurements for core plug permeabilities of ~10 - 60 mD.

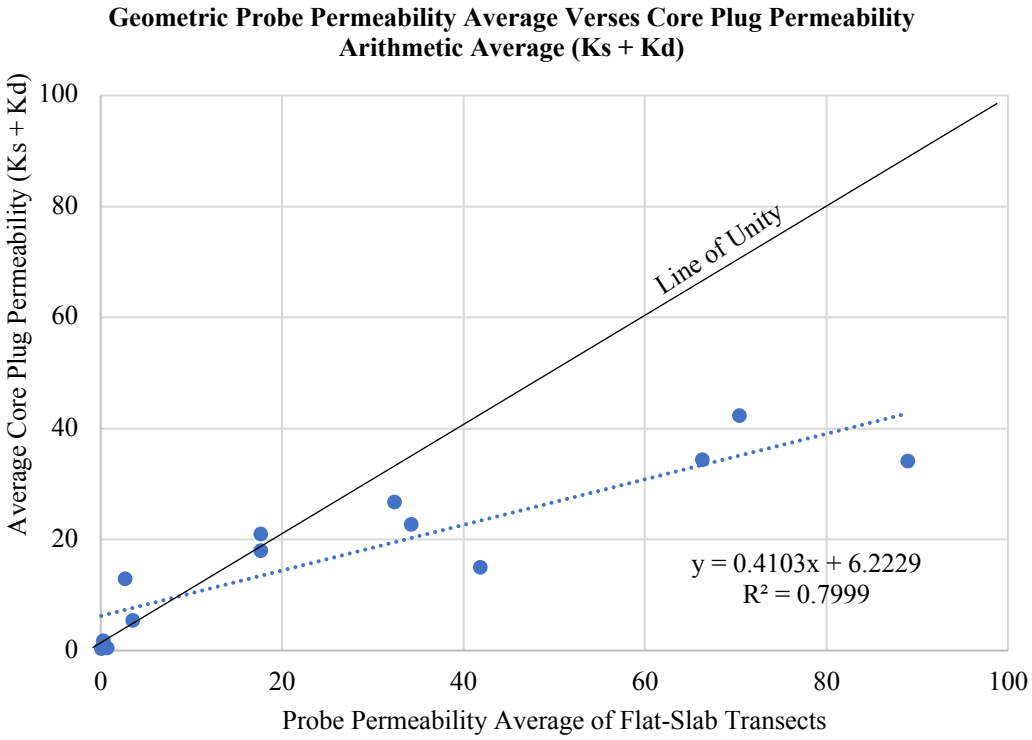

Figure F.1. Comparison of the geometric average of flat-slab probe permeability and arithmetic average of core plug Kd and Ks of corresponding core samples. The line of unity is demonstrated by a solid black line and the trendline by a dashed blue line.

APPENDIX G

CALCULATIONS OF THE PETROPHYSICS OF 4TH AND 5TH ORDER ARCHITECTURE ELEMENTS

The petrophysics of higher order architecture elements were calculated using a weighted arithmetic mean (Equation G.1), a weighted geometric mean (Equation G.2), and a weighted harmonic mean (Equation G.3). See section 3.5.1 Upscaling Technique for more details.

$$\phi = L_1\phi_1 + L_2\phi_2 + \cdots L_n\phi_n \tag{G.1}$$

where:

ϕ = Porosity of higher-order facies architecture element

L_1 = Proportion of lithofacies 1 within facies architecture element

ϕ_1 = Permeability of lithofacies 1 within facies architecture element

$$K = e^{\left(\frac{L_1 ln(K_1)+L_2 ln(K_2)+\cdots L_n ln(K_n)}{L_1+L_2+\cdots L_n}\right)} \tag{G.2}$$

where:

K = Permeability of higher-order facies architecture element

L_1 = Proportion of lithofacies 1 within facies architecture element

K_1 = Permeability of lithofacies 1 within facies architecture element

$$K = \frac{(L_1 + L_2 + \cdots L_n)}{(\frac{L_1}{K_1} + \frac{L_2}{K_2} + \cdots \frac{L_n}{K_n})}$$

(G.3)

where:

K = Permeability of higher-order facies architecture element

L_1 = Proportion of lithofacies 1 within facies architecture element

K_1 = Permeability of lithofacies 1 within facies architecture element