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Energy Resources Conservation Board

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Alberta Geological Survey

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Full-size images of Appendix 1 and 2 are in the ZIP file accompanying this report on the Alberta Geological Survey website (http://www.ags.gov.ab.ca/publications/abstracts/OFR_2009_13.html).

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Acknowledgments

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Abstract

Exposed Upper Cretaceous and Tertiary rock formations in southern Alberta were sampled for petrographic study. This report describes the mineralogy, diagenesis and porosity of the Porcupine Hills, Willow Creek, St. Mary River, Whitemud, Kneehills Tuff (Battle Formation), Blood Reserve, Oldman, Foremost and Milk River formations. It presents detailed descriptions and high-quality photographs to highlight the properties of the rocks and help interpret clastic rocks for evaluation of uranium potential. We then used these descriptions to make comparisons between the physical properties of southern Alberta exposed bedrock and those of the rocks containing sandstone-hosted uranium deposits in other areas of the world.

Anomalous uranium values in shale and sandstone of the St. Mary River and Willow Creek formations suggest that uranium-enrichment processes were active in these formations. Grain size, composition and porosity of sandstones in southern Alberta are significantly different from those of sandstones in world-class sandstone-hosted uranium districts. Additional studies of uranium emplacement in the clastic rocks of southern Alberta are needed to understand the history and potential of uranium enrichment.

The comprehensive petrographic data in this report will have applications in geological mapping and stratigraphic studies, as well as evaluations of mineral and hydrocarbon potential, of Upper Cretaceous and Tertiary rocks in southern Alberta.

1 Introduction

In 2006, Alberta Geological Survey initiated a program to evaluate the sandstone-hosted uranium potential of southern Alberta. Anomalous uranium values in shale and sandstone of the St. Mary River and Willow Creek formations provide evidence that uranium-enrichment processes were active in these formations. Staff of AGS collected samples from outcrops of Upper Cretaceous and Tertiary formations (Table 1) during field programs in 2006 and 2007 and, from these samples, prepared the thin sections described in this report. The purpose of this thin section study is to compare the properties of rocks found in southern Alberta with those in areas known to host sandstone-type uranium mineralization.

Sample locations and descriptions of sampling criteria are described in Matveeva and Kafle (2009) and Matveeva and Anderson (2007).

2 Sample Selection and Methodology

The main purpose of this study is to evaluate the mineralogy, diagenesis and porosity of the Porcupine Hills, Willow Creek, St. Mary River, Whitemud, Kneehills Tuff (Battle Formation), Blood Reserve, Oldman, Foremost and Milk River formations. Twenty-five samples were evaluated by thin-section petrography. Thin sections were prepared by impregnating the rock samples with blue-dyed epoxy to identify porosity and then ground to a standard 30 μm (microns, 10^{-3} mm) thickness on a glass slide. Thin-section slides were stained for feldspar and carbonate minerals, and covered with glass to enhance photographic quality.

Table 1 provides the sample number, formation, rock type, lithofacies, estimated porosity and maximum permeability (K_{max}) for each of the samples studied. Petrographic descriptions of the samples in Section 3 are organized by formation, with each formation accompanied by a summary table, a ternary plot of detrital-grain composition and a plot of porosity versus permeability. The point-count analysis is based on a count of 300 grains to determine the statistical distribution of the mineralogy. The 'open' or intergranular porosity is also point-counted in this analysis with a separate channel on a point-counting machine (i.e., if there were 30 points of intergranular porosity in the 300-grain count, the porosity calculation would be 30/330 or 9.1%). In a point-count analysis, this sample would have 330 data points, of which 300 are the grain counts (mineralogy) and 30 are the porosity.

A 'lithofacies' is defined as a mappable subdivision of a designated stratigraphic unit, distinguished from adjacent subdivisions on the basis of lithology, including mineralogy and petrographic characteristics that influence the appearance, composition or texture of a rock. Note that lithofacies are unique to stratigraphic formations, and are numbered in the order in which samples from one formation were described.

Sand size class was described according to the Wentworth Sand Size classification (Wentworth, 1922):

Very coarse upper (vcU): 1410–200 μm
Very coarse lower (vcL): 1000–1410 μm
Coarse upper (cU): 710–1000 μm
Coarse lower (cL): 500–710 μm
Medium upper (mU): 350–500 μm
Medium lower (mL): 250–350 μm
Fine upper (fU): 177–250 μm
Fine lower (fL): 125–177 μm
Very fine upper (vfU): 88–125
Very fine lower (vfL): 62–88 μm

Table 1. Samples with detailed thin-section descriptions.

Sample No.	U (ppm)	Formation	Rock Type	Lithofacies	Porosity (%)	Permeability (Kmax; mD)
07USA0104	0.25	Porcupine Hills	Litharenite	Litho 1	~22	~1
07USA0011	5.61	Willow Creek	Litharenite	Litho 1	~12	~1
07USA0023	7	Willow Creek	Litharenite	Litho 1	~15	~10
07USA0025	2.92	Willow Creek	Litharenite	Litho 2	~6	<0.10
07USA0027	16.2	Willow Creek	Shale	Litho 3	~5	>0.01
07USA0028	3.71	Willow Creek	Litharenite	Litho 2	~11	~1
07USA0030	5.66	Willow Creek	Litharenite	Litho 2	~7	~0.5
07USA0036	1.3	Willow Creek	Litharenite	Litho 2	~3	<0.01
07USA0091	0.66	Willow Creek	Feldspathic Litharenite	Litho 4	~1	<0.01
07USA0093	6.65	Willow Creek	Packstone	Litho 5	~3	<0.10
06USA0024	66.9	St. Mary River	Shale	Litho 1	~5	<0.10
07USA0001	0.63	St. Mary River	Litharenite	Litho 2	~20	~200
07USA0078	0.81	St. Mary River	Feldspathic Litharenite	Litho 3	~4	<0.01
07USA0082	13	St. Mary River	Shale	Litho 4	~5	<0.01
07USA0085	8.03	St. Mary River	Shale	Litho 5	~5	<0.01
06USA0071	4	Whitemud	Feldspathic Litharenite	Litho 1	~5	<0.10
07USA0109	2.05	Kneehills Tuff	Tuff	Litho 1	~3	<0.01
06USA0027	0.73	Blood Reserve	Feldspathic Litharenite	Litho 1	~5	<0.10
07USA0005	1.03	Oldman	Litharenite	Litho 1	n/a	n/a
07USA0094	0.66	Oldman	Feldspathic Litharenite	Litho 2	~10	~0.50
07USA0096	0.64	Oldman	Feldspathic Litharenite	Litho 2	~16	~1
07USA0102	7.48	Oldman	Shale	Litho 3	~5	<0.01
07USA0038	0.65	Foremost	Litharenite	Litho 1	~25	~200
07USA0048	0.52	Foremost	Litharenite	Litho 1	~30	~500
06USA0045	7.36	Milk River	Feldspathic Litharenite	Litho 1	~5	<0.10

Roundness of the grains was described in accordance with the classification of Folk (1968, p. 10–11). In Tables 3–11, ‘sbang’ stands for subangular and ‘sbrnd’ for subrounded. Sorting is also in accordance with the classification of Folk, 1968, p. 42).

Porosity estimates were based on a visual estimate in the thin section (i.e., effective porosity based on the amount of blue-dyed epoxy plus the estimate of microporosity within clays and partially altered grains). Permeability was estimated from the plot of total porosity versus grain size in Figure 1 (Ethier and King, 1991). X-ray diffraction (XRD) is the best tool for precise identification of the detrital-clay mineralogy but was not used in this study.

Appendix 1 contains overview hand-specimen photographs and thin-section photomicrographs, and Appendix 2 presents selected annotated photomicrographs taken in both plane- and cross-polarized light. Appendix 3 provides macro views, with detailed descriptions, of the thin-section photomicrographs for all samples.

Thin-sections photomicrographs of the seven rock samples listed in Table 2 are included in Appendix 1, but there are no descriptions because other samples from the same formation are described in detail. However, we think it will be beneficial to include these photos to give a better representation of the variability of rock types in the formations.

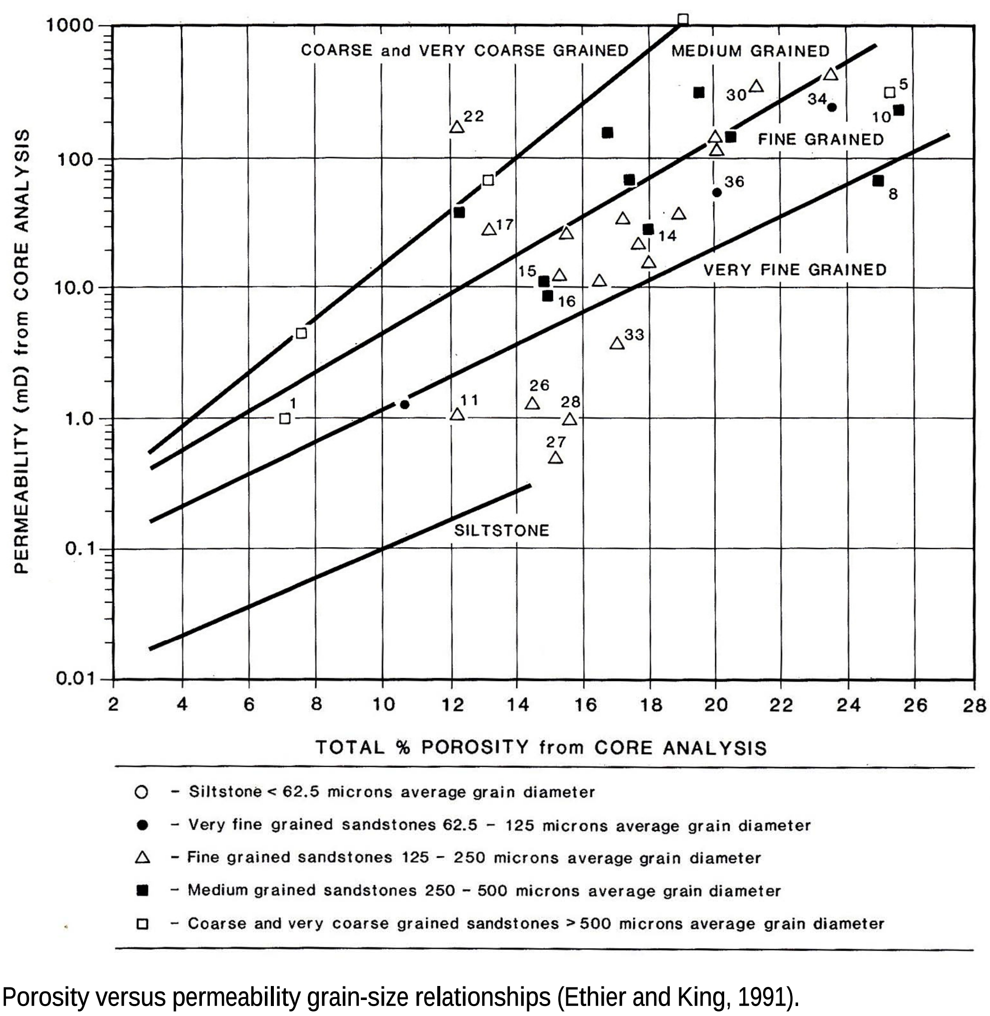


Figure 1. Porosity versus permeability grain-size relationships (Ethier and King, 1991).

Table 2. Samples with images included in Appendix 1 but with no detailed descriptions.

Sample No.	Formation	Rock Type	Easting (Zone 12, NAD83)	Northing (Zone 12, NAD83)
07USA0012	Willow Creek	Sandstone	313063	5476143
07USA0033	Willow Creek	Shale	324024	5479520
07USA0071	Unknown	Shale	337555	5437218
07USA0081	St. Mary River	Sandstone	342495	5519092
07USA0090	Willow Creek	Sandstone	340399	5449934
07USA0100	Oldman	Shale	412647	5438822
07USA0107	Edmonton Group	Shale	362074	5566085

3 Petrographic Interpretation

3.1 Porcupine Hills Formation

3.1.1 Petrology

Sample location 07USA104: UTM 294141E, 5579712N (Zone 12, NAD83)

Porcupine Hills Formation sample 07USA0104, a medium-grained, moderately sorted litharenite (Figure 2) informally designated in this study as Lithofacies 1 (Litho 1), shows a massive to slightly laminated (crossbedded?) texture.

Mineralogy of detrital (framework) grains is monocrystalline quartz (29%), polycrystalline quartz (2%), chert (48%), plagioclase feldspar (2%), sedimentary lithoclasts (8%), dolomite lithoclasts (1%), calcareous lithoclasts (4%), and accessory phosphate, muscovite and heavy minerals (Table 3).

Monocrystalline quartz occurs as ‘clear,’ mainly inclusion free, subangular to subrounded grains that lack overgrowth cement. Polycrystalline quartz consists of several quartz crystals sutured together to form a single grain. Chert consists of microscopic silica grains that commonly show a ‘speckled’ texture (i.e., clay inclusions).

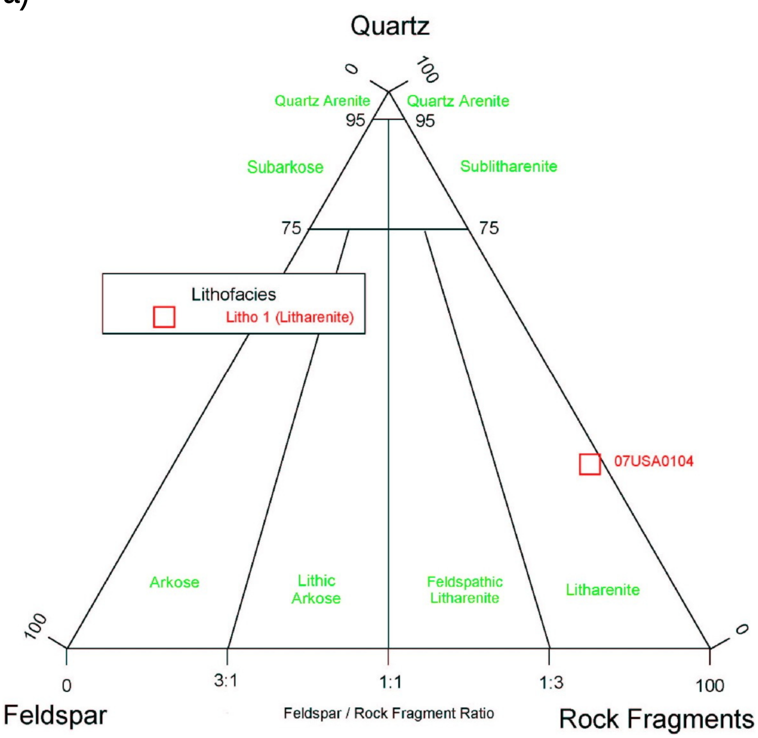
Plagioclase feldspar occurs as ‘cloudy’ angular grains that often show albite twinning and clay alteration along cleavage planes. In addition, partial feldspar dissolution contributes minor isolated and irregular intragranular microporosity (non-effective).

Sedimentary lithoclasts are mainly quartz-rich siltstone and very fine grained sandstone, with minor clay-rich ‘mudstone’ grains. The clay-rich grains are poorly compacted within a fairly competent matrix. Dolomite lithoclasts contain several silt-size dolomite crystals sutured together to form a single grain. Calcareous lithoclasts are micrite and microsparite.

Accessory phosphate occurs as rounded, dark brown, peloidal grains that are isotropic (i.e., opaque) under cross-polarized light. Muscovite occurs as clear elongated grains with parallel cleavage planes. Heavy minerals are dominantly high-relief grains identified as zircon.

Cements or diagenetic minerals include kaolinite (3%), calcite (2%), dolomite (1%) and trace amounts of pore-lining clay and pyrite. Kaolinite occurs as milky white, pseudo-hexagonal crystals that create microporosity at the expense of primary intergranular porosity.

a)



b)

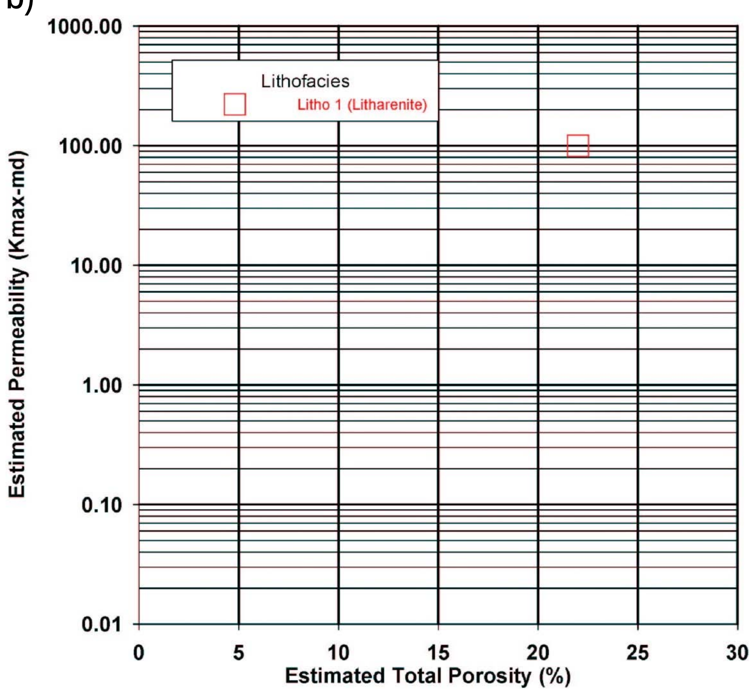


Figure 2. Porcupine Hills Formation: a) ternary composition plot (Folk, 1968), b) porosity versus permeability.

Table 3. Petrography summary, Porcupine Hills Formation.

Sample:	07USA0104					
Lithofacies:	Litho 1					
Rock Name (Folk, 1968):	Litharenite					
Framework Grains						
Monocrystalline Quartz	29					
Polycrystalline Quartz	2					
Chert	48					
Alkali Feldspar						
Plagioclase Feldspar	2					
***Sedimentary Lithoclasts**	8					
Metamorphic Lithoclasts						
Igneous / Volcanic Lithoclasts						
Dolomite Lithoclasts	1					
Carbonate Lithoclasts	4					
Fossils						
Glauconite						
Phosphate	trace					
Muscovite	trace					
Heavy Minerals	trace					
Cements						
Quartz						
Calcite	2					
Ferroan Calcite						
Dolomite	1					
Siderite						
Pore Lining Clay	trace					
Bitumen						
Kaolinite	3					
Pyrite	trace					
Matrix						
Detrital Clay						
Organic / Coaly Material						
Texture						
Grain Size	mL					
Sorting	moderate					
Roundness	sbang-sbrnd					
Pore Types						
Intergranular	main					
Secondary	minor					
Intragranular Microporosity	minor					
Clay Microporosity	minor					
Reservoir Quality						
Thin Section (effective) Porosity %	18					
Core (total) Porosity %	~22					
Permeability (Kmax-md)	>100					
Reservoir Quality	Good					

***mainly quartz-rich siltstone and very fine grained sandstone**

Calcite has a blocky texture and characteristic red colour when stained with the mixture of Alizarin Red S and potassium ferricyanide (i.e., thin-section staining procedure). Dolomite has a rhombic crystal morphology and lack of carbonate stain (i.e., lack of colour).

Interstitial clay occurs as thin clay coats that are volumetrically insignificant. Colour, texture and birefringence suggest a mainly illite clay composition. Pyrite occurs as isolated opaque crystals that likely formed as a replacement of organic material.

3.1.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is ~18%, compared with the estimated total porosity of 22% (Table 3). Primary intergranular (effective) porosity is the main pore type. We interpret a minor portion of the effective porosity as secondary, formed after extensive grain dissolution.

The slight discrepancy between the thin-section (effective) and core (total) porosities reflects intragranular microporosity (non-effective) associated with partially dissolved chert and feldspar grains, plus minor clay microporosity (non-effective) associated mainly with kaolinite. We estimate that microporosity accounts for ~20% of the total porosity.

The main controls on permeability and reservoir quality are grain size (pore throat size), volume of cements and compaction. Permeability and reservoir quality of the Porcupine Hills Formation should be good (>100 mD) due to the medium grain size (large pore throats), low volume of cements and poor sediment compaction (i.e., friable sand).

3.2 Willow Creek Formation

Sample location 07USA0011: UTM 313063E, 5476143N (Zone 12, NAD83)
Sample location 07USA0023: UTM 316951E, 5477551N (Zone 12, NAD83)
Sample location 07USA0025: UTM 318504E, 5477784N (Zone 12, NAD83)
Sample location 07USA0027: UTM 319917E, 5478626N (Zone 12, NAD83)
Sample location 07USA0028: UTM 319917E, 5478626N (Zone 12, NAD83)
Sample location 07USA0030: UTM 320968E, 5479675N (Zone 12, NAD83)
Sample location 07USA0036: UTM 324831E, 5479617N (Zone 12, NAD83)
Sample location 07USA0091: UTM 340399E, 5449934N (Zone 12, NAD83)
Sample location 07USA0093: UTM 340515E, 5449903N (Zone 12, NAD83)

We informally classified the nine samples from the Willow Creek Formation into the following lithofacies or rock types, based on mineralogy and grain size:

1) Lithofacies 1 (Litho 1) is a very fine to fine-grained, poor to moderately sorted litharenite (samples 07USA0011, 07USA0023). Porosity is ~12%–15% and permeability is ~1–10 mD. Microporosity (non-effective) is ~30%–60% of the total porosity.
2) Lithofacies 2 (Litho 2) is a lower to upper fine grained, moderately to moderately well sorted calcareous litharenite (samples 07USA0025, 07USA0028, 07USA0030, 07USA0036). Porosity is ~3%–11% and permeability ranges from <0.1 to ~1 mD. Microporosity is ~40%–80% of the total porosity.
3) Lithofacies 3 (Litho 3) is organic-rich shale (sample 07USA0027). Porosity is ~5% and microporosity is the dominant pore type. Permeability should be <0.01 mD.
4) Lithofacies 4 (Litho 4) is a lower very fine grained, poorly sorted, dolomitic, feldspathic litharenite grading upward into a sandy dolomite (sample 07USA0091). Porosity is ~1% and permeability is <0.01 mD. Microporosity is the dominant pore type.

5) Lithofacies 5 (Litho 5) is a limestone (sample 07USA0093) described as a peloidal packstone (Dunham, 1962). Porosity is ~3% and permeability is <0.10 mD. Microporosity is the dominant pore type.

Due to their variability, we describe each lithofacies or rock type separately.

3.2.1 Lithofacies 1 (Litharenite)

3.2.1.1 Petrology

Samples 07USA0011 and 07USA0023, very fine to fine-grained, poor to moderately sorted litharenite (Figure 3), show a laminated texture with common to abundant organic material and minor detrital clay concentrated within specific laminations. In addition, quartz-filled fractures parallel the bedding plane (see Appendix 3, sample 07USA0011).

Mineralogy of detrital grains is monocrystalline quartz (20%–30%), polycrystalline quartz (1%), chert (24%–29%), plagioclase feldspar (9%–10%), sedimentary lithoclasts (5%), metamorphic lithoclasts (3%), and accessory muscovite and heavy minerals (Table 4).

Alteration of detrital grains is mainly partial dissolution of feldspar and chert grains, which contributes minor isolated and irregular intragranular microporosity (non-effective).

Monocrystalline quartz occurs as ‘clear,’ mainly inclusion free, subangular to subrounded grains that lack overgrowth cement. Polycrystalline quartz consists of several quartz crystals sutured together to form a single grain. Chert consists of microscopic silica grains that commonly show a ‘speckled’ texture (i.e., clay inclusions).

Plagioclase feldspar occurs as ‘cloudy’ angular grains that often show albite twinning and clay alteration along cleavage planes. In addition, partial feldspar dissolution contributes minor isolated and irregular intragranular microporosity (non-effective).

Sedimentary lithoclasts include both quartz-rich siltstone and clay-rich ‘mudstone’ grains. The clay-rich grains are poorly compacted between the more competent detrital grains. Metamorphic lithoclasts are thin elongated grains that we interpret as schist.

Accessory muscovite occurs as clear elongated grains with parallel cleavage planes. Heavy minerals are high-relief grains that are mainly zircon.

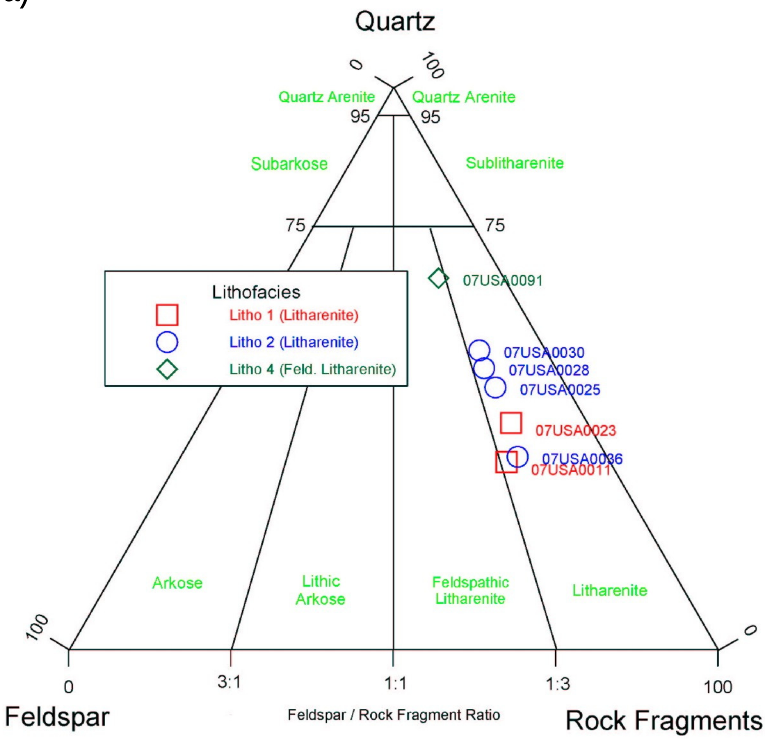
Cements are mainly pore-lining siderite (10%) in sample 07USA0023. Other minor cements include quartz (2%–5% within bedding plane fractures), pore-lining clay (1%–2%) and trace pyrite (1%).

Micro-siderite crystals line open porosity in sample 07USA0023. The minute crystals may be altered to limonite (see described thin section photo plate in Appendix 3), based on the low birefringence in cross-polarized light. Pore-lining clay forms thin clay rims, which may have a smectite composition. Pyrite formed as opaque crystals often associated with organic material.

Other rock components include common to abundant organic/coaly material (7%–25%) concentrated within specific laminations (i.e., parallel to bedding). Opaque fragments are poorly compacted between the more competent detrital grains.

Detrital clay (2%–5%), often associated with organic material, is also concentrated along the bedding plane. Colour, texture and birefringence suggest that the clay is mainly illite, with detrital clay partially altered to limonite.

a)



b)

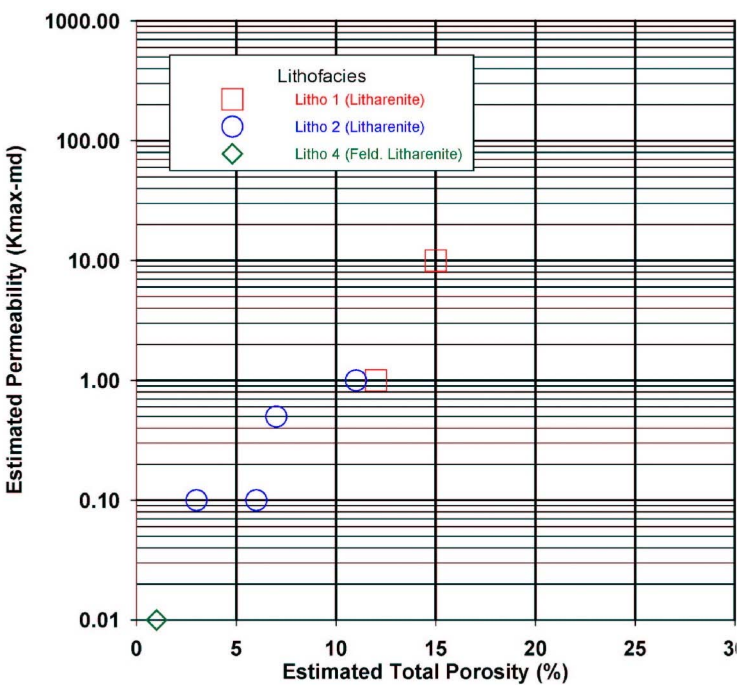


Figure 3. Willow Creek Formation: a) ternary composition plot (Folk, 1968), b) porosity versus permeability.

Table 4. Petrography summary, Willow Creek Formation.

Sample:	07USA0011	07USA0023	07USA0025	07USA0027	07USA0028	07USA0030
Lithofacies:	Litho 1	Litho 1	Litho 2	Litho 3	Litho 2	Litho 2
Rock Name (Folk, 1968):	Litharenite	Litharenite	Litharenite	Shale	Litharenite	Litharenite
Framework Grains						
Monocrystalline Quartz	20	30	30	4	39	40
Polycrystalline Quartz	1	1	2		2	2
Chert	24	29	17	1	18	19
Alkali Feldspar						
Plagioclase Feldspar	10	9	8	1	9	8
Sedimentary Lithoclasts	5	5	4		5	3
Metamorphic Lithoclasts	3	3	1			2
Igneous / Volcanic Lithoclasts			1		4	2
Dolomite Lithoclasts						
Calcareous Lithoclasts			1		4	3
Fossils			7		1	
Glauconite						
Phosphate						
Muscovite	trace	trace	trace		trace	trace
Heavy Minerals	trace	trace	trace		trace	trace
Cements						
Quartz	5	2		1		
Calcite			17		9	13
Ferroan Calcite						
Dolomite			5		2	5
Siderite		10				
Pore Lining Clay	2	1			1	1
Bitumen						
Kaolinite			5		6	2
Pyrite	trace	1	trace	5	trace	trace
Matrix						
Detrital Clay	5	2		78		
Organic / Coaly Material	25	7	2	10		
Texture						
Grain Size	vfU-fU	fL	fL		fL	fL
Sorting	poor	moderate	moderate		moderate	mod well
Roundness	sbang-sbrnd	sbang-sbrnd	sbang-sbrnd		sbang-sbrnd	sbang-sbrnd
Pore Types						
Intergranular	main	main	minor		main	main
Secondary		minor			minor	minor
Intragranular Microporosity	minor	minor	minor		minor	minor
Clay Microporosity	main	common	main	main	common	common
Reservoir Quality						
Thin Section (effective) Porosity %	5	10	3	<1	7	4
Core (total) Porosity %	~12	~15	~6	~5	~11	~7
Permeability (Kmax-md)	~1	~10	<0.1	<0.01	~1	~0.5
Reservoir Quality	Poor	Fair	Poor	Poor	Fair	Poor

*local quartz-filled bedding plane fractures (Litho 1)
**induced fractures in Sample 07USA0025; thin section (efffective) porosity is highly subjective

Sample:	07USA0036	07USA0091	07USA0093			
Lithofacies:	Litho 2	Litho 4	Litho 5			
Rock Name (Folk, 1968):	Litharenite	Feld. Lith.	***Packstone			
Framework Grains						
Monocrystalline Quartz	20	32				
Polycrystalline Quartz	5	1				
Chert	16	8				
Alkali Feldspar						
Plagioclase Feldspar	10	5				
Sedimentary Lithoclasts	7	3				
Metamorphic Lithoclasts	5	1				
Igneous / Volcanic Lithoclasts	10					
Calcareous Lithoclasts			50			
Fossils						
Glauconite	trace					
Phosphate						
Muscovite	trace	trace				
Heavy Minerals	trace	trace				
Cements						
Quartz						
Calcite	24		20			
Ferroan Calcite						
Dolomite	2	50	10			
Siderite						
Pore Lining Clay						
Bitumen						
Kaolinite	1					
Pyrite	trace	trace				
Matrix						
Detrital Clay / Micrite**			20			
Organic / Coaly Material						
Texture						
Grain Size	fU	vfL	mL-vcU			
Sorting	moderate	poor	poor			
Roundness	sbang-sbrnd	sbang-sbrnd				
Pore Types						
Intergranular			main			
Secondary						
Intragranular Microporosity	minor	main				
Clay Microporosity	main					
Reservoir Quality						
Thin Section (effective) Porosity %	<1	<1	<1			
Core (total) Porosity %	~3	~1	~3			
Permeability (Kmax-md)	<0.10	<0.01	<0.10			
Reservoir Quality	Poor	Poor	Poor			

*induced fractures in Sample 07USA0036
**micrite (lime mud) in Sample 07USA0093
***Dunham (1962) limestone classification

3.2.1.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is ~5%–10%, compared with the estimated total porosity of 12%–15% (Table 4). Primary intergranular (effective) porosity is the main pore type.

The large discrepancy between the thin-section (effective) and core (total) porosities reflects intragranular microporosity (non-effective) associated with partially dissolved chert and feldspar grains, plus clay microporosity (non-effective) associated mainly with detrital clay. We estimate that microporosity accounts for ~30%–60% of the total porosity.

Permeability and reservoir quality are poor to fair (~1–10 mD). Higher estimated permeability in sample 07USA0023 reflects the lower volume of organic and detrital-clay laminations. Vertical permeability is reduced in sample 07USA0011 due to the high volume of organic/coaly laminations.

3.2.2 Lithofacies 2 (Litharenite)

3.2.2.1 Petrology

Samples 07USA0025, 07USA0028, 07USA0030 and 07USA0036, lower to upper fine grained, moderately to moderately well sorted calcareous litharenite (Figure 3), have a predominantly massive texture.

Mineralogy of detrital grains is monocrystalline quartz (20%–40%), polycrystalline quartz (2%–5%), chert (16%–19%), plagioclase feldspar (8%–10%), sedimentary lithoclasts (3%–7%), metamorphic lithoclasts (nil–5%), volcanic lithoclasts (1%–4%, locally up to 10% in sample 07USA0036), local calcareous lithoclasts (1%–4%), local fossils (1%–7%), and accessory glauconite (sample 07USA0036), muscovite and heavy minerals (Table 4).

Alteration of detrital grains is mainly partial dissolution of feldspar, chert and volcanic grains, which contributes minor isolated and irregular intragranular microporosity (non-effective).

Monocrystalline quartz occurs as ‘clear,’ mainly inclusion-free, subangular to subrounded grains that lack overgrowth cement. Polycrystalline quartz consists of several quartz crystals sutured together to form a single grain. Chert consists of microscopic silica grains that commonly show a ‘speckled’ texture (i.e., clay inclusions).

Plagioclase feldspar occurs as ‘cloudy’ angular grains that often show albite twinning and clay alteration along cleavage planes. In addition, partial feldspar dissolution contributes minor isolated and irregular intragranular microporosity (non-effective).

Sedimentary lithoclasts include both quartz-rich siltstone and clay-rich ‘shale’ grains. The clay-rich grains are poorly compacted between the more competent detrital grains. Metamorphic lithoclasts are thin elongated grains interpreted as schist.

Volcanic lithoclasts are highly altered (microporous) grains that often contain randomly orientated plagioclase laths within a siliceous microcrystalline matrix. Calcareous lithoclasts are spar-rich grains with silt-size calcite crystals sutured together to form a single grain. Fossils, identified as pelecypods, have a foliated texture.

Accessory muscovite occurs as clear elongated grains that show parallel cleavage planes. Heavy minerals are high-relief grains, identified mainly as zircon.

Other miscellaneous components include local organic/coaly material (2% in sample 07USA0025) that appears to be concentrated in faint laminations (see Appendix 3, sample 07USA0025).

Cements are dominated by calcite (9%–24%) with lesser amounts of dolomite (2%–5%), kaolinite (1%–6%) and trace pyrite. Calcite has a blocky texture and distinct pink stain from preparation of the thin-section (i.e., slides stained with Alizarin Red S). In contrast, dolomite has a poor rhombic crystal morphology and lack of staining.

Kaolinite occurs as milky white, pseudohexagonal crystals that create microporosity at the expense of primary intergranular porosity. Pyrite occurs as discrete opaque crystals.

3.2.2.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is <1% in sample 07USA0036 and 3%–7% in the remaining samples from this formation, compared with estimated total porosities of 3% in 07USA0036 and 6%–11% in the remaining samples (Table 4). Primary intergranular (effective) porosity is generally the main pore type, with microporosity as the main pore type in sample 07USA0036.

We estimate that microporosity associated with partial grain dissolution plus clay microporosity account for ~40% of the total porosity. The exception is the highly calcite-cemented sample 07USA0036, where microporosity is ~80% of the total porosity.

Permeability and reservoir quality are poor to fair (<0.10 up to ~1 mD). Low estimated permeability (<0.10 mD) in samples 07USA0025 and 07USA0036 reflects the higher volume of calcite cement. We interpret the common fractures in sample 07USA0025 as having formed during sample collection and thin-section preparation. The main control on reservoir quality appears to be the volume of calcite cement.

3.2.3 Lithofacies 3 (Shale)

3.2.3.1 Petrology

Sample 07USA0027, an organic-rich shale, has a blocky to fissile texture. Common horizontal fractures formed predominantly during sample collection and thin-section preparation.

Detrital clay (78%) is the main rock component, the remainder being organic material (10%), pyrite (5%), quartz cement (1%) and detrital grains (6%).

Illite is likely the main component of the detrital clay. Opaque organic/coaly material is often aligned parallel to the bedding plane.

Pyrite occurs as discrete framboidal crystals that often form as an alteration product of organic/coaly material. Rare quartz/micro-silica cement occurs within large open fractures, possibly an indication that some of the fractures are natural.

Detrital grains (i.e., ‘clear’ white images in Appendix 3, sample 07USA0027) are mainly quartz silt with minor chert and feldspar.

3.2.3.2 Pore Types and Reservoir Quality

Estimated total porosity is 5% and microporosity based on fluorescence imaging is the pore type. Natural microfractures appear to be absent in this sample.

Matrix permeability should be low (<0.01 mD) due to the shale rock type (i.e., minute pore throat size) and the lack of natural microfractures. Quartz/micro-silica cement within some fractures indicates that fractures may be conduits of higher permeability if the fracture intensity is higher in other areas.

3.2.4 Lithofacies 4 (Feldspathic Litharenite)

3.2.4.1 Petrology

Sample 07USA0091 is a lower, very fine grained, poorly sorted, dolomitic feldspathic litharenite (Figure 3) that grades into a sandy dolomite (i.e., dolomite is about 50% of the total sample composition). The sample has a massive texture.

Mineralogy of detrital grains is monocrystalline quartz (32%), polycrystalline quartz (1%), chert (8%), plagioclase feldspar (5%), sedimentary lithoclasts (3%), metamorphic lithoclasts (1%), and accessory muscovite and heavy minerals (Table 4).

Alteration of detrital grains is mainly partial dissolution of feldspar and chert grains, which formed minor isolated and irregular intragranular microporosity (non-effective).

Cements are dominated by dolomite (50%) with only trace pyrite. Dolomite occurs as tightly interlocking, coarse silt crystals that have completely obstructed primary porosity. Grains ‘floating’ in the dolomite matrix indicate that dolomitization occurred early in the diagenetic history (i.e., prior to significant compaction).

3.2.4.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is <1%, compared with the estimated total porosity of 1% (Table 4). Intragranular microporosity is the dominant pore type.

The main control on reservoir quality is the volume of dolomite cement, and permeability and reservoir quality are poor (<0.01 mD) due to the significance of tightly interlocking dolomite cement.

3.2.5 Lithofacies 5 (Packstone)

3.2.5.1 Petrology

Sample 07USA0093, limestone classified as a peloidal packstone (Dunham, 1962), has a massive texture and was described in hand specimen by Matveeva and Kafle (2009) as a dark grey, crumbly mudstone.

Carbonate lithoclasts (50%), described as rounded peloids and/or intraclasts, range from ~250 to 1500 μm in diameter (i.e., lower medium grained to upper very coarse grained).

Other rock components include lime mud or micrite matrix (20%), blocky calcite spar cement (20%) and coarse silt dolomite cement (10%). The precise distinction between micritic peloids and micrite matrix is somewhat subjective. Blocky spar is stained pink, whereas tightly interlocking dolomite crystals are not stained.

3.2.5.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is <1%, compared with the estimated total porosity of 3% (Table 4). Microporosity associated with micritic peloids and micrite matrix is the dominant pore type.

Permeability and reservoir quality are poor (<0.10 mD) due to the high volume of blocky spar cement and the lack of secondary dissolution porosity.

3.3 St. Mary River Formation

Sample location 06USA024: UTM 337532E, 5437219N (Zone 12, NAD83)
Sample location 07USA0001: UTM 354387E, 5432219N (Zone 12, NAD83)

Sample location 07USA0078: UTM 339994E, 5522913N (Zone 12, NAD83)
Sample location 07USA0082: UTM 342495E, 5519092N (Zone 12, NAD83)
Sample location 07USA0085: UTM 343561E, 5517234N (Zone 12, NAD83)

We informally classified the five samples from the St. Mary River Formation into the following lithofacies or rock types, based on mineralogy and grain size:

1) Lithofacies 1 (Litho 1) is radioactive shale (sample 06USA0024). Porosity is ~5% and permeability is <0.10 mD. Microporosity (non-effective) is the dominant pore type.
2) Lithofacies 2 (Litho 2) is lower medium grained, moderately sorted litharenite (sample 07USA0001). Porosity is ~20% and permeability is ~200 mD. Microporosity is ~25% of the total porosity.
3) Lithofacies 3 (Litho 3) is very fine grained, poorly sorted, dolomitic feldspathic litharenite (sample 07USA0078). Porosity is ~4% and permeability is <0.01 mD. Microporosity is the dominant pore type.
4) Lithofacies 4 (Litho 4) is organic-rich shale (sample 07USA0082) with polygonal fractures and/or mudcracks infilled with clay. Porosity is ~5% and permeability is <0.01 mD. Microporosity is the dominant pore type.
5) Lithofacies 5 (Litho 5) is organic-rich shale (sample 07USA0085) with a blocky to fissile texture. Porosity is ~5% and permeability is <0.01 mD. Microporosity is the dominant pore type.

Due to their variability, we describe each lithofacies or rock type separately.

3.3.1 Lithofacies 1 (Shale)

3.3.1.1 Petrology

Sample 06USA0024, a radioactive shale (67 ppm U), has a laminated texture with abundant quartz-filled fractures. It is likely organic-rich due to the highly opaque nature of the matrix.

Detrital clay (60%) is the main rock component, the remainder being abundant quartz infilling open fractures (25%), common pyrite (10%) and minor detrital grains (3%).

Quartz is identified by the white colour in plane light and low birefringence and undulatory extinction in cross-polarized light. Pyrite occurs as opaque crystals that have a metallic lustre under reflected light. Detrital grains are mainly quartz silt with minor chert and muscovite.

3.3.1.2 Pore Types and Reservoir Quality

Estimated total porosity is 5% and is microporosity associated with the suspected organic-rich matrix. Natural microfractures appear to be absent in this sample.

Matrix permeability should be low (<0.01 mD) due to the shale rock type (i.e., minute pore throat size), lack of natural microfractures and the significance of quartz cement infilling large horizontal fractures (i.e., 100% mineralized).

3.3.2 Lithofacies 2 (Litharenite)

3.3.2.1 Petrology

Sample 07USA0001, a lower medium-grained, moderately sorted litharenite (Figure 4), has a massive texture.

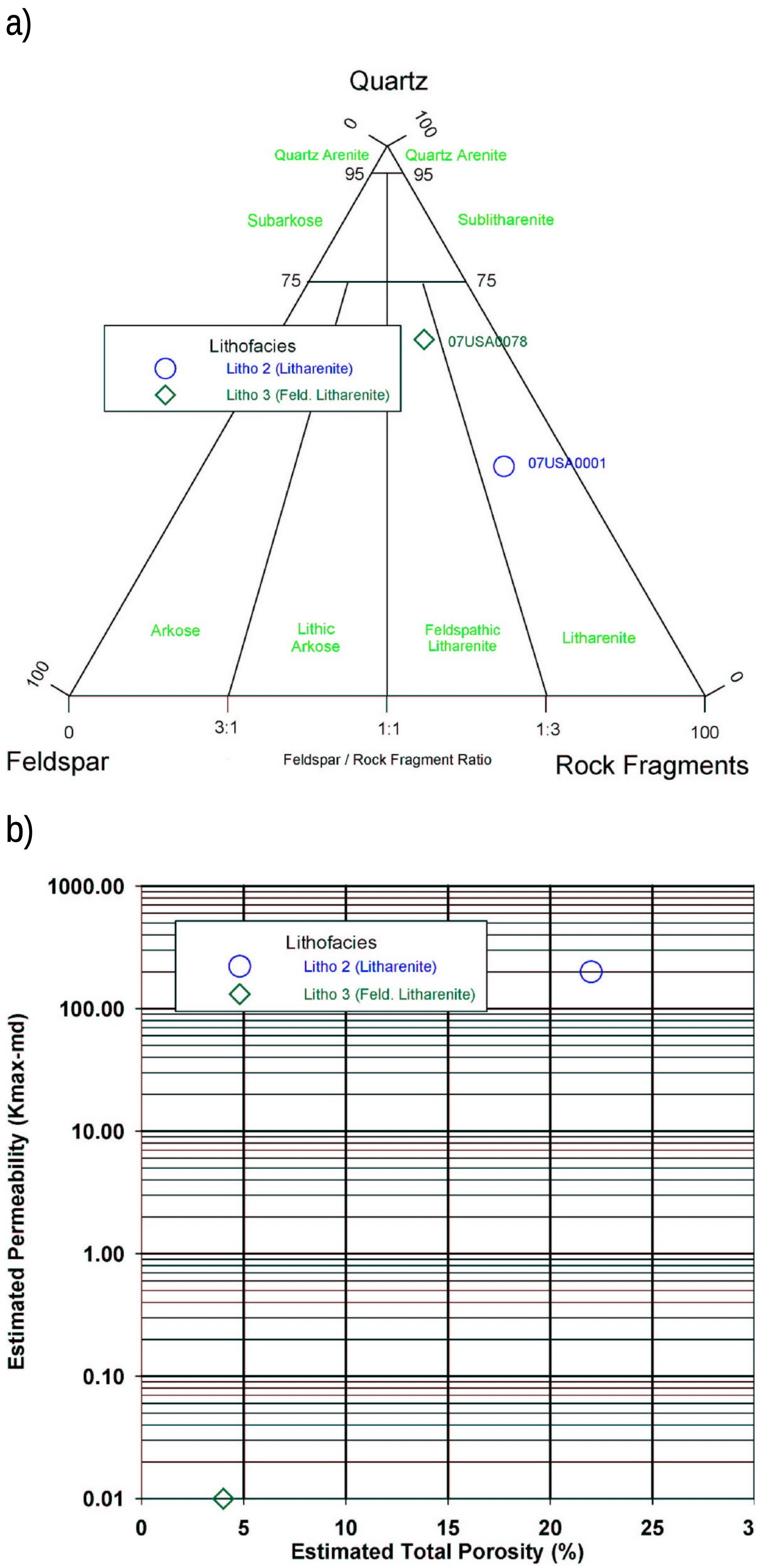


Figure 4. St. Mary River Formation: a) ternary composition plot (Folk, 1968), b) porosity versus permeability.

Mineralogy of detrital grains is monocrystalline quartz (32%), polycrystalline quartz (3%), chert (16%), plagioclase feldspar (9%), sedimentary lithoclasts (10%), metamorphic lithoclasts (1%), igneous/volcanic lithoclasts (7%), dolomite lithoclasts (2%), calcareous lithoclasts (4%), and accessory phosphate, muscovite and heavy minerals (Table 5).

Alteration of detrital grains is mainly partial dissolution of feldspar, chert and volcanic grains, which formed minor isolated and irregular intragranular microporosity (non-effective).

Monocrystalline quartz occurs as 'clear,' mainly inclusion free, subangular to subrounded grains that lack overgrowth cement. Polycrystalline quartz consists of several quartz crystals sutured together to form a single grain. Chert consists of micro-silica grains that commonly show a 'speckled' texture (i.e., clay inclusions).

Plagioclase feldspar occurs as 'cloudy' angular grains that often show albite twinning and clay alteration along cleavage planes. In addition, partial feldspar dissolution contributes minor isolated and irregular intragranular microporosity (non-effective).

Sedimentary lithoclasts include grains of quartz-rich siltstone and very fine grained sandstone, and clay-rich 'shale' grains. The clay-rich grains are poorly compacted between the more competent detrital grains.

Dolomite lithoclasts contain several silt-size dolomite crystals sutured together to form a single grain. Calcareous lithoclasts are rounded micrite and microspar-rich grains.

Volcanic grains are highly altered (i.e., microporous), with poorly defined plagioclase laths set in a light to medium green, chlorite-rich siliceous matrix.

Accessory phosphate occurs as rounded, dark brown peloidal grains that are isotropic (i.e., opaque) under cross-polarized light. Muscovite occurs as clear, elongated grains that show parallel cleavage planes. Heavy minerals are high-relief grains, identified mainly as zircon.

Cements or diagenetic minerals include kaolinite (6%), dolomite (5%), calcite (4%), pore-lining clay (1%) and pyrite. Kaolinite occurs as milky white, pseudohexagonal crystals that create microporosity at the expense of primary intergranular porosity.

Calcite has a blocky texture and a characteristic red stain due to the thin-section staining procedure. Dolomite has a rhombic crystal morphology and lack of carbonate stain.

Pore-lining clay occurs as thin clay coats that may have a water-sensitive or swelling-clay composition (i.e., smectite clay). Pyrite occurs as isolated opaque crystals.

3.3.2.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is 15%, compared with the estimated total porosity of 20% (Table 5). Primary intergranular (effective) porosity is the main pore type.

Microporosity associated with partial grain dissolution (i.e., intragranular) and clay microporosity associated mainly with kaolinite account for ~25% of the total porosity.

Permeability and reservoir quality are good (~200 mD) due to the medium grain size (i.e., large pore throats), relatively low volume of cement and poor sediment compaction.

Table 5. Petrography summary, St. Mary River Formation.

Sample:	06USA0024	07USA0001	07USA0078	07USA0082	07USA0085	
Lithofacies:	Litho 1	Litho 2	Litho 3	Litho 4	Litho 5	
Rock Name (Folk, 1968):	Shale	Litharenite	Feld. Lith.	Shale**	Shale	
Framework Grains						
Monocrystalline Quartz	3	32	45		2	
Polycrystalline Quartz		3				
Chert	1	16	4			
Alkali Feldspar						
Plagioclase Feldspar		9	8		trace	
Sedimentary Lithoclasts		10	2			
Metamorphic Lithoclasts		1	1			
Igneous / Volcanic Lithoclasts		7			trace	
Dolomite Lithoclasts		2	1			
Calcareous Lithoclasts		4				
Fossils			1			
Glauconite			trace			
Phosphate		trace	trace			
Muscovite	1	trace	7		trace	
Heavy Minerals		trace	trace			
Cements						
Quartz*	25					
Calcite		4				
Ferroan Calcite						
Dolomite		5	20			
Siderite						
Pore Lining Clay		1				
Bitumen						
Kaolinite		6				
Pyrite	10	trace	1	10	10	
Matrix						
Detrital Clay	60		10	90	78	
Organic / Coaly Material					10	
Texture						
Grain Size		mL	cslt-vfU			
Sorting		moderate	poor			
Roundness		sbang-sbrnd	ang-sbang			
Pore Types						
Intergranular		main				
Secondary						
Intragranular Microporosity		minor	minor			
Clay Microporosity	main	minor	main	main	main	
Reservoir Quality						
Thin Section (effective) Porosity %	<1	15	<1	<1	<1	
Core (total) Porosity %	~5	~20	~4	~5	~5	
Permeability (Kmax-md)	<0.1	~200	<0.01	<0.01	<0.01	
Reservoir Quality	Poor	Good	Poor	Poor	Poor	

***?quartz filled fractures in organic-rich shale sample (06USA0024)**

****polygonal texture is interpreted as an artifact formed during thin section manufacture process**

3.3.3 Lithofacies 3 (Feldspathic Litharenite)

3.3.3.1 Petrology

Sample 07USA0078, a very fine grained, poorly sorted, dolomitic feldspathic litharenite (Figure 4), has a massive to faintly laminated texture.

Mineralogy of detrital grains is monocrystalline quartz (45%), chert (4%), plagioclase feldspar (8%), sedimentary lithoclasts (2%), metamorphic lithoclasts (1%), dolomite lithoclasts (1%), fossil (pelecypod) fragments (1%), muscovite (7%), and accessory glauconite, phosphate and heavy minerals (Table 5).

Alteration of detrital grains is mainly in the form of clay inclusions, with chert grains and clay alteration along feldspar cleavage.

Cements are mainly dolomite (20%) with trace pyrite (1%). Dolomite occurs as rhombic crystals that have completely filled primary porosity. Pyrite occurs as opaque crystals with framboidal morphology, indicative of replacement of organic material.

Other rock components include detrital clay (10%), often concentrated within poorly defined laminations.

3.3.3.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is <1%, compared with the estimated total porosity of 4% (Table 5). Microporosity is the dominant pore type.

Permeability and reservoir quality are poor (<0.01 mD) due to the high volume of dolomite cement, high volume of detrital clay, very fine grain size and moderate sediment compaction.

3.3.4 Lithofacies 4 (Shale)

3.3.4.1 Petrology

Sample 07USA0082, organic-rich shale, has a polygonal texture that we interpret as the result of thin-section preparation.

Detrital clay (90%) is the main rock component, the remainder being pyrite (10%). Pyrite occurs as opaque crystals that have a metallic lustre under reflected light.

3.3.4.2 Pore Types and Reservoir Quality

Estimated total porosity is 5% and is microporosity associated with the suspected organic-rich matrix. Natural microfractures appear to be absent in this sample.

Matrix permeability should be low (<0.01 mD) due to the shale rock type (i.e., minute pore throat size), isolated micropores and the lack of natural microfractures.

3.3.5 Lithofacies 5 (Shale)

3.3.5.1 Petrology

Sample 07USA0085, organic-rich shale, has a laminated texture with organic/coaly material aligned parallel to bedding.

Detrital clay (78%) is the main rock component, the remainder being organic/coaly material (10%), pyrite (10%) and detrital grains (2%). Pyrite occurs as opaque crystals that have a metallic lustre under reflected light.

Detrital grains are mainly quartz silt (2%) and accessory feldspar, volcanic grains and muscovite.

3.3.5.2 Pore Types and Reservoir Quality

Estimated total porosity is 5% and is microporosity associated with the clay matrix. Natural microfractures are rare and seen only under fluorescent light (i.e., pinch-out texture).

Matrix permeability should be low (<0.01 mD) due to the shale rock type (i.e., minute pore throat size), isolated micropores and rare natural microfractures.

3.4 Whitemud Formation

Sample location 06USA0071: UTM 337101E, 5524555N (Zone 12, NAD83)

3.4.1 Petrology

Sample 06USA0071, a very fine to fine-grained, poorly sorted, argillaceous feldspathic litharenite (Figure 5) informally designated as Lithofacies 1 (Litho 1), has a massive texture.

Mineralogy of detrital grains is monocrystalline quartz (45%), polycrystalline quartz (1%), chert (7%), plagioclase feldspar (13%), sedimentary lithoclasts (10%), metamorphic lithoclasts (2%), muscovite (1%), and accessory glauconite and heavy minerals (Table 6).

Alteration of detrital grains is mainly confined to clay inclusions within chert and along feldspar cleavage, with minor incomplete grain dissolution contributing minor microporosity.

Monocrystalline quartz occurs as ‘clear,’ mainly inclusion free, angular to subangular grains that lack overgrowth cement. Polycrystalline quartz consists of several quartz crystals sutured together to form a single grain. Chert consists of micro-silica grains and commonly has a ‘speckled’ texture (i.e., clay inclusions).

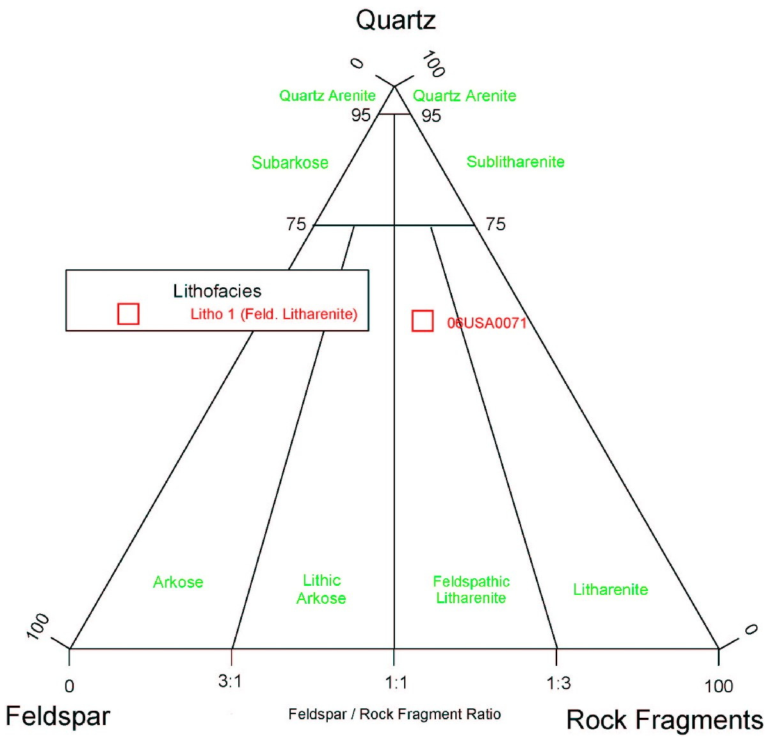
Plagioclase feldspar occurs as ‘cloudy’ angular grains that often show albite twinning and clay alteration along cleavage planes. In addition, partial feldspar dissolution contributes minor isolated and irregular intragranular microporosity (non-effective).

Sedimentary lithoclasts are mainly clay-rich ‘shale’ grains that are often compacted and deformed between the more competent detrital grains. The precise distinction between clay-rich sedimentary lithoclasts, pore-lining clay and detrital clay is somewhat subjective.

We interpreted metamorphic lithoclasts as schist, and clear muscovite grains show characteristic parallel cleavage. Accessory glauconite is distinguished by a green colour and granular texture, and high-relief heavy minerals are mainly zircon.

Cements include pore-lining clay (4%) and kaolinite (2%). We interpreted pore-lining clay as illite, based on colour, texture and birefringence. Kaolinite is milky white with a booklet morphology and associated microporosity.

a)



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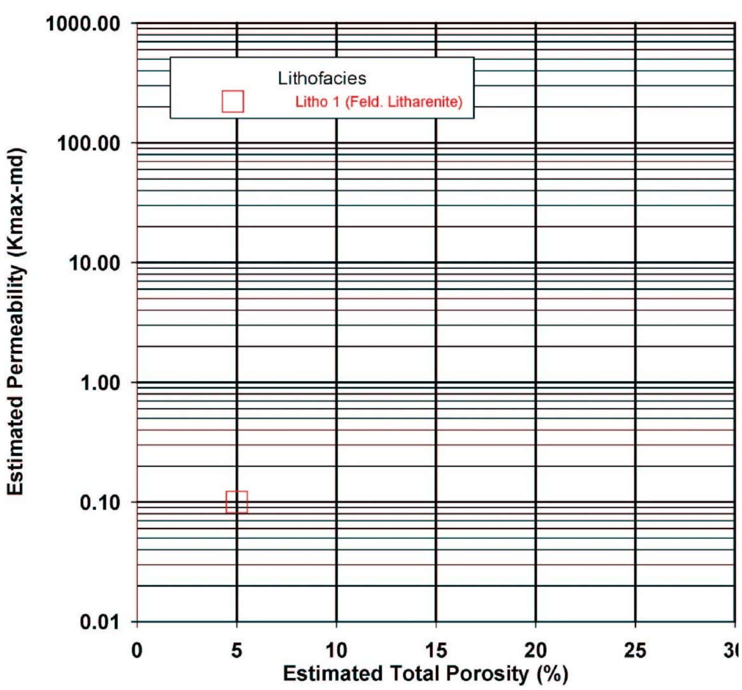


Figure 5. Whitemud Formation: a) ternary composition plot (Folk, 1968), b) porosity versus permeability.

Table 6. Petrography summary, Whitemud Formation.

Sample:	06USA0071					
Lithofacies:	Litho 1					
Rock Name (Folk, 1968):	Feld. Lith.					
Framework Grains						
Monocrystalline Quartz	45					
Polycrystalline Quartz	1					
Chert	7					
Alkali Feldspar						
Plagioclase Feldspar	13					
Sedimentary Lithoclasts	10					
Metamorphic Lithoclasts	2					
Igneous / Volcanic Lithoclasts						
Dolomite Lithoclasts						
Calcareous Lithoclasts						
Fossils						
Glauconite	trace					
Phosphate						
Muscovite	1					
Heavy Minerals	trace					
Cements						
Quartz						
Calcite						
Ferroan Calcite						
Dolomite						
Siderite						
Pore Lining Clay	4					
Bitumen						
Kaolinite	2					
Pyrite						
Matrix						
Detrital Clay	15					
Organic / Coaly Material						
Texture						
Grain Size	vfL-fL					
Sorting	poor					
Roundness	ang-sbang					
Pore Types						
Intergranular						
Secondary						
Intragranular Microporosity	minor					
Clay Microporosity	main					
Reservoir Quality						
Thin Section (effective) Porosity %	<1					
Core (total) Porosity %	~5					
Permeability (Kmax-md)	<0.10					
Reservoir Quality	Poor					

Detrital clay (15%) is a major rock component. Clays appear to be dispersed throughout the sample and, as previously stated, the precise distinction between detrital clay and compacted and deformed clay-rich sedimentary lithoclasts is somewhat arbitrary.

3.4.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is <1%, compared with the estimated total porosity of 5% (Table 6). Microporosity, associated mainly with detrital clay and clay-rich sedimentary lithoclasts, is the dominant pore type.

Permeability and reservoir quality are poor (<0.10 mD) due to the very fine grain size (small pore throats), high volume of detrital clay and moderate sediment compaction.

3.5 Kneehills Tuff (Battle Formation)

Sample location 07USA0109: UTM 354846E, 5640116N (Zone 12, NAD83)

3.5.1 Petrology

The Kneehills Tuff (Battle Formation) is reworked volcanic ash (sample 07USA0109) and has been described as volcanic tuff. This highly radioactive zone is dominated by volcanic ash (79%) with common bivalve shells (10%), quartz silt grains (10%) and local chlorite cement (1%).

The volcanic ash, or bentonitic clay, contains common undifferentiated and randomly orientated crystals embedded with the aphanitic matrix.

Bivalve shells are preserved and have a gently curved morphology with distinct sweeping extinction bands as the stage rotates under cross-polarized light. Quartz silt occurs as white silt-size grains randomly distributed throughout the sample.

Chlorite cement occurs as light green bladed crystals with low birefringence. Chlorite appears to be associated with bivalve shells.

3.5.2 Pore Types and Reservoir Quality

Thin section (effective) porosity is <1%, compared with the estimated total porosity of 3% (Figure 6, Table 7). Microporosity, associated mainly with the aphanitic volcanic ash matrix, is the dominant pore type.

Permeability and reservoir quality are poor (<0.10 mD) due to the volcanic ash (tuff) lithology and associated aphanitic matrix.

3.6 Blood Reserve Formation

Sample location 06USA0027: UTM 362254E, 5439529N (Zone 12, NAD83)

3.6.1 Petrology

Sample 06USA0027, a lower medium grained, moderately well sorted feldspathic litharenite (Figure 7) informally designated as Lithofacies 1 (Litho 1), has a massive texture.

Mineralogy of detrital grains is monocrystalline quartz (30%), polycrystalline quartz (2%), chert (15%), plagioclase feldspar (19%), sedimentary lithoclasts (8%), metamorphic lithoclasts (1%), igneous/volcanic lithoclasts (2%), dolomite lithoclasts (1%), and accessory muscovite and heavy minerals (Table 8).

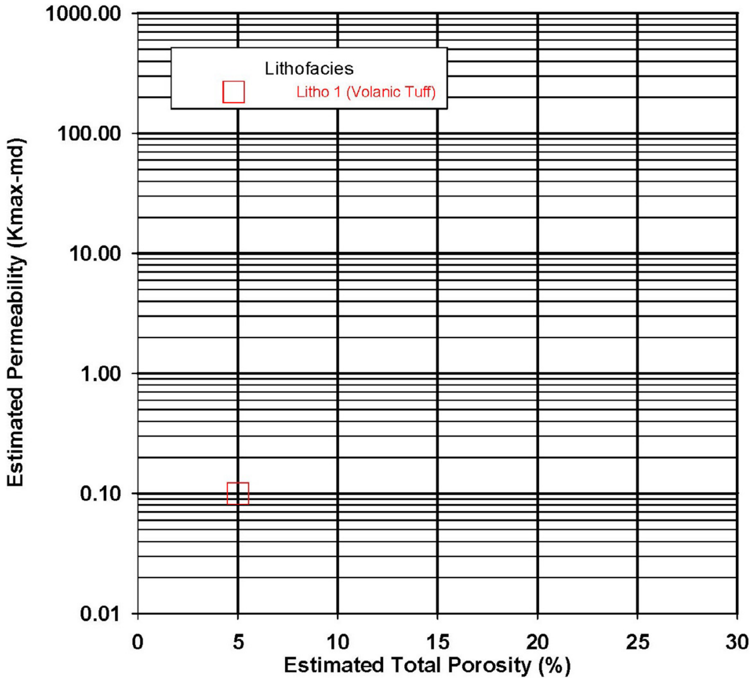


Figure 6. Kneehills Tuff (Battle Formation): porosity versus permeability.

Alteration of detrital grains is mainly partial dissolution of feldspar, chert and volcanic grains to form minor isolated and irregular intragranular microporosity (non-effective).

Monocrystalline quartz occurs as ‘clear,’ mainly inclusion free, subangular to subrounded grains that lack overgrowth cement. Polycrystalline quartz consists of several quartz crystals sutured together to form a single grain. Chert consists of micro-silica grains and commonly has a ‘speckled’ texture (i.e., clay inclusions).

Plagioclase feldspar occurs as ‘cloudy’ angular grains that often show albite twinning and clay alteration along cleavage planes. In addition, partial feldspar dissolution contributes minor isolated and irregular intragranular microporosity (non-effective).

Sedimentary lithoclasts include both grains of quartz-rich siltstone and very fine grained sandstone, and clay-rich ‘shale’ grains. The clay-rich grains are poorly compacted between the more competent detrital grains. Metamorphic lithoclasts are thin, elongated grains that we interpret as schist.

Volcanic grains are microporous with poorly defined plagioclase laths set in a highly altered siliceous matrix.

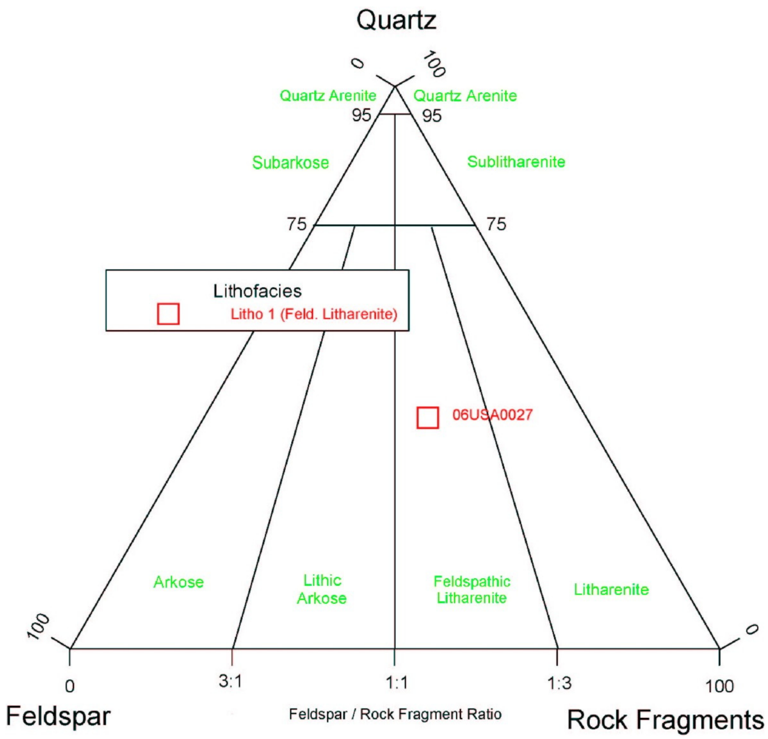
Dolomite lithoclasts contain several silt-size dolomite crystals sutured together to form a single grain.

Cements are dominated by early pore-lining chlorite clay (8%), followed by later pore-filling calcite (12%) and dolomite (2%). Light brownish green chlorite clay has a bladed texture in plane-polarized light. Calcite has a blocky texture, whereas dolomite shows a rhombic morphology.

Table 7. Petrography summary, Kneehills Tuff (Battle Formation).

Sample:	07USA0109					
Lithofacies:	Litho 1					
Rock Name (Folk, 1968):	Tuff					
Framework Grains						
Monocrystalline Quartz	10					
Polycrystalline Quartz						
Chert						
Alkali Feldspar						
Plagioclase Feldspar						
Sedimentary Lithoclasts						
Metamorphic Lithoclasts						
Igneous / Volcanic Lithoclasts						
Dolomite Lithoclasts						
Calcareous Lithoclasts						
Fossils	10					
Glauconite						
Phosphate						
Muscovite						
Heavy Minerals						
Cements						
Quartz						
Calcite						
Ferroan Calcite						
Dolomite						
Siderite						
Chlorite	1					
Bitumen						
Kaolinite						
Pyrite						
Matrix						
Volcanic Ash	79					
Organic / Coaly Material						
Texture						
Grain Size	n.a.					
Sorting	n.a.					
Roundness	n.a.					
Pore Types						
Intergranular						
Secondary						
Intragranular Microporosity						
Clay Microporosity	main					
Reservoir Quality						
Thin Section (effective) Porosity %	<1					
Core (total) Porosity %	~3					
Permeability (Kmax-md)	<0.01					
Reservoir Quality	Poor					

a)



b)

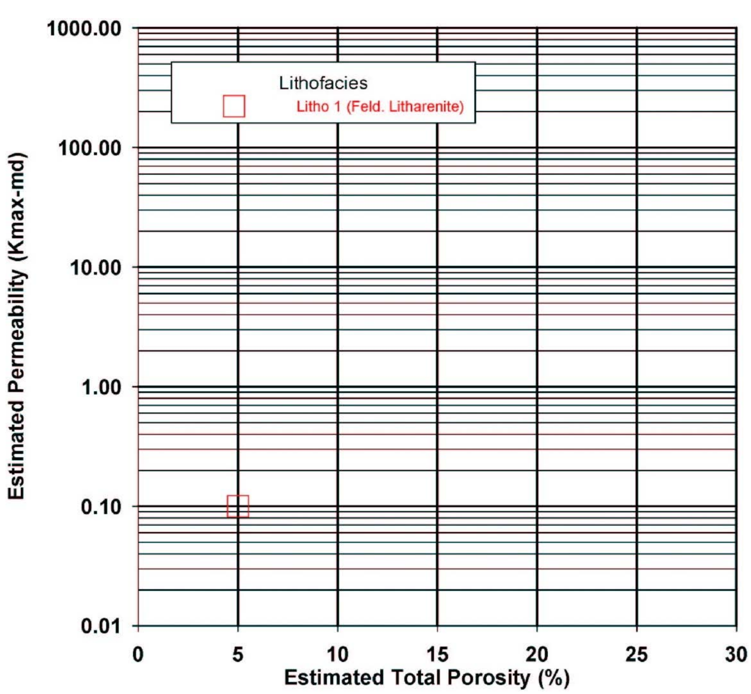


Figure 7. Blood Reserve Formation: a) ternary composition plot (Folk, 1968), b) porosity versus permeability.

Table 8. Petrography summary, Blood Reserve Formation.

Sample:	06USA0027					
Lithofacies:	Litho 1					
Rock Name (Folk, 1968):	Feld. Lith.					

Framework Grains

Monocrystalline Quartz	30					
Polycrystalline Quartz	2					
Chert	15					
Alkali Feldspar						
Plagioclase Feldspar	19					
Sedimentary Lithoclasts	8					
Metamorphic Lithoclasts	1					
Igneous / Volcanic Lithoclasts	2					
Dolomite Lithoclasts	1					
Calcareous Lithoclasts						
Fossils						
Glauconite						
Phosphate						
Muscovite	trace					
Heavy Minerals	trace					

Cements

Quartz						
Calcite	12					
Ferroan Calcite						
Dolomite	2					
Siderite						
Pore Lining Clay	8					
Bitumen						
Kaolinite						
Pyrite						

Matrix

Detrital Clay						
Organic / Coaly Material						

Texture

Grain Size	mL					
Sorting	mod well					
Roundness	sbang-sbrnd					

Pore Types

Intergranular						
Secondary						
Intragranular Microporosity	minor					
Clay Microporosity	main					

Reservoir Quality

Thin Section (effective) Porosity %	<1					
Core (total) Porosity %	~5					
Permeability (Kmax-md)	<0.10					
Reservoir Quality	Poor					

3.6.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is <1%, compared with the estimated total porosity of 5% (Table 7). Microporosity is the dominant pore type. Primary porosity appears to be completely filled by clay, calcite and dolomite cement.

Permeability and reservoir quality are poor (<0.10 mD) due to the high volume of cement and relatively high degree of sediment compaction.

3.7 Oldman Formation

Sample location 07USA0005: UTM 377298E, 5523329N (Zone 12, NAD83)
Sample location 07USA0094: UTM 374173E, 5441694N (Zone 12, NAD83)
Sample location 07USA0096: UTM 412647E, 5438822N (Zone 12, NAD83)
Sample location 07USA0102: UTM 412647E, 5438822N (Zone 12, NAD83)

We informally classified the four samples of the Oldman Formation into the following lithofacies or rock types, based on mineralogy and grain size:

1) Lithofacies 1 (Litho 1) is a lower fine grained, moderately sorted litharenite (sample 07USA0005). Porosity and permeability are uncertain due to extensive weathering/dissolution of grains and/or carbonate cement.
2) Lithofacies 2 (Litho 2) is upper very fine grained, moderately sorted, feldspathic litharenite (samples 07USA0094, 07USA0096). Porosity is ~10%–16% and permeability is ~0.50–1 mD. Microporosity is ~40%–50% of the total porosity.
3) Lithofacies 3 (Litho 3) is organic-rich shale (sample 07USA0102). Porosity is ~5% and microporosity is the dominant pore type. Permeability should be <0.01 mD. Due to the variability, we discuss each lithofacies or rock type separately.

3.7.1 Lithofacies 1 (Litharenite)

3.7.1.1 Petrology

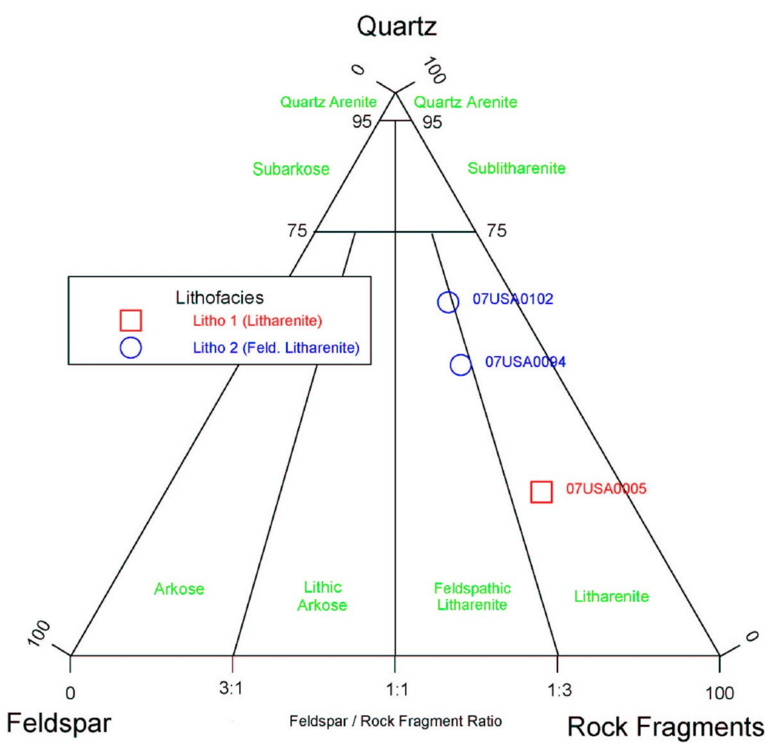
Sample 07USA0005, a lower fine grained, moderately sorted litharenite (Figure 8), shows a massive texture and extensive dissolution of grains and/or carbonate cement that we interpret as the result of surface weathering of the outcrop sample.

Mineralogy of detrital grains is monocrystalline quartz (25%), polycrystalline quartz (2%), chert (33%), plagioclase feldspar (12%), sedimentary lithoclasts (10%), metamorphic lithoclasts (2%), volcanic lithoclasts (5%), dolomite lithoclasts (1%), calcareous lithoclasts (2%), and accessory muscovite and heavy minerals (Table 9).

Alteration of detrital grains is extensive weathering/dissolution resulting from surface weathering of the outcrop sample.

Cements or diagenetic minerals include calcite (5%) and pore-lining clay (2%). Calcite has a blocky texture and characteristic red stain due to thin-section preparation. Pore-lining clay occurs as thin clay coats. Colour, texture and birefringence indicate that the clay is mainly illite.

a)



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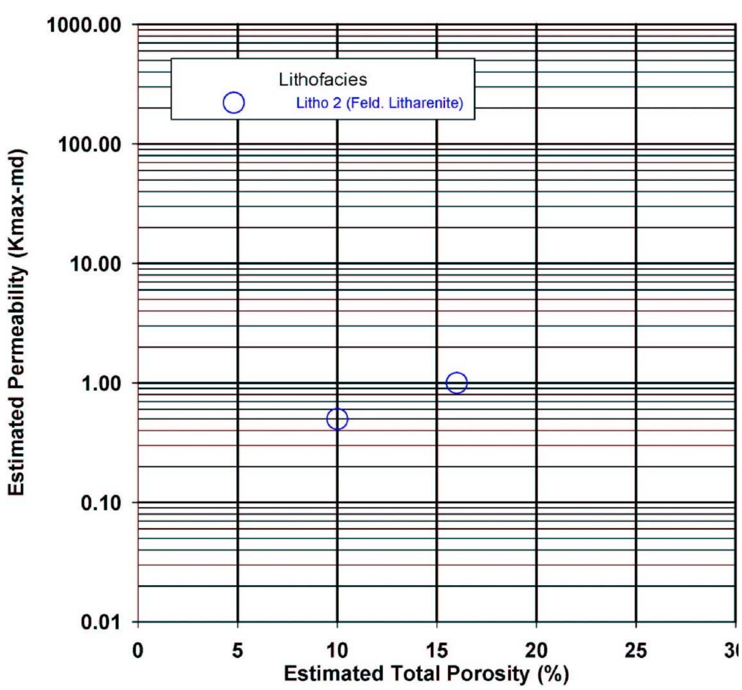


Figure 8. Oldman Formation: a) ternary composition plot (Folk, 1968), b) porosity versus permeability.

3.7.1.2 Pore Types and Reservoir Quality

Porosity is uncertain due to extensive weathering/dissolution of grains and/or carbonate cement. Primary intergranular (effective) porosity should be the main pore type.

Permeability is also uncertain due to suspected surface (outcrop) weathering/dissolution of grains and/or cement.

3.7.2 Lithofacies 2 (Feldspathic Litharenite)

3.7.2.1 Petrology

Samples 07USA0094 and 07USA0096, very fine grained, moderately sorted feldspathic litharenite (Figure 7), have a slightly laminated texture defined by slight grain-size variations.

Mineralogy of detrital grains is monocrystalline quartz (31%–41%), polycrystalline quartz (1%–2%), chert (12%), plagioclase feldspar (7%–9%), sedimentary lithoclasts (2%–3%), metamorphic lithoclasts (2%), igneous/volcanic lithoclasts (2%–3%), dolomite lithoclasts (nil–1%), calcareous lithoclasts (nil–1%), and accessory glauconite, muscovite and heavy minerals (Table 8).

Alteration of detrital grains is mainly partial dissolution of chert, feldspar and igneous/volcanic grains, which contributes isolated and irregular intragranular microporosity (non-effective).

Cements include calcite (15%), dolomite (9%–12%), pore-lining clay (2%–3%) and kaolinite (6%–7%). Calcite occurs as blocky crystals stained pink due to thin-section preparation. Dolomite has a rhombic crystal morphology and lack of staining.

Pore-lining clay or clay rims have a dark brown colour, are relatively thin and appear to be water-sensitive smectite. Kaolinite occurs as milky white, pseudohexagonal crystals that create significant microporosity at the expense of primary intergranular porosity.

3.7.2.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is 5%–9%, compared to the estimated total porosity of 10%–16% (Table 7). Primary intergranular (effective) porosity is the main pore type. Intragranular microporosity associated with partial grain dissolution, and clay microporosity associated mainly with kaolinite, account for ~40%–50% of the total porosity.

Permeability and reservoir quality are relatively poor (~0.5–1 mD) due to the very fine grain size (small pore throats) and high volume of cements. The main controls on reservoir quality appear to be grain size, volume of cement, degree of sediment compaction and the extent of secondary porosity formed after grain dissolution.

3.7.3 Lithofacies 3 (Shale)

3.7.3.1 Petrology

Sample 07USA0102, organic-rich shale, has a laminated texture with organic/coaly material aligned parallel to bedding.

Detrital clay (78%) is the main rock component, the remainder being organic/coaly material (15%), pyrite (5%) and quartz silt grains (2%).

Table 9. Petrography summary, Oldman Formation.

Sample:	*07USA0005	07USA0094	07USA0096	07USA0102		
Lithofacies:	Litho 1	Litho 2	Litho 2	Litho 3		
Rock Name (Folk, 1968):	Litharenite	Feld. Lith.	Feld. Lith.	Shale		
Framework Grains						
Monocrystalline Quartz	25	31	41	2		
Polycrystalline Quartz	2	2	1			
Chert	33	12	12			
Alkali Feldspar						
Plagioclase Feldspar	12	9	7			
Sedimentary Lithoclasts	10	3	2			
Metamorphic Lithoclasts	2	2	2			
Igneous / Volcanic Lithoclasts	5	3	2			
Dolomite Lithoclasts	2	1				
Calcareous Lithoclasts	2	1				
Fossils						
Glauconite		trace				
Phosphate						
Muscovite	trace	trace	trace			
Heavy Minerals	trace	trace	trace			
Cements						
Quartz						
Calcite	5	15	15			
Ferroan Calcite						
Dolomite		12	9			
Siderite						
Pore Lining Clay	2	3	2			
Bitumen						
Kaolinite		6	7			
Pyrite				5		
Matrix						
Detrital Clay				78		
Organic / Coaly Material				15		
Texture						
Grain Size	fL	vfU	vfL			
Sorting	moderate	moderate	moderate			
Roundness	ang-sbang	ang-sbang	ang-sbang			
Pore Types						
Intergranular	main?	main	main			
Secondary						
Intragranular Microporosity	minor	common	common			
Clay Microporosity	minor	common	common	main		
Reservoir Quality						
Thin Section (effective) Porosity %	n.a.	5	9	<1		
Core (total) Porosity %	n.a.	~10	~16	~5		
Permeability (Kmax-md)	n.a.	~0.5	~1	<0.01		
Reservoir Quality	n.a.	Poor	Poor	Poor		

***extensive weathering/dissolution of grains and/or carbonate cement (i.e. uncertain porosity + kmax)**

Opaque and minor orange-coloured organic/coaly material occurs in a detrital clay matrix. Pyrite occurs as opaque crystals that have a metallic lustre under reflected light. Quartz silt is randomly distributed and volumetrically insignificant.

3.7.3.2 Pore Types and Reservoir Quality

Estimated total porosity is 5% and is microporosity associated with the clay matrix. Natural microfractures have pinch-out textures (see Appendix 3, sample 07USA0102, lower photo); however, the extent of natural fractures is limited. We interpret large open fractures as induced by sampling and/or sample preparation.

Matrix permeability should be low (<0.01 mD) due to the shale rock type (i.e., minute pore throat size), isolated micropores and rare natural microfractures.

3.8 Foremost Formation

Sample location 07USA0038: UTM 422385E, 5536659N (Zone 12, NAD83)
Sample location 07USA0048: UTM 402797E, 5504380N (Zone 12, NAD83)

3.8.1 Petrology

The Foremost Formation samples (07USA0038, 07USA0048), fine- to medium-grained, moderately sorted litharenite (Figure 9) informally designated as Lithofacies 1 (Litho 1), show a massive texture.

Mineralogy of detrital grains is monocrystalline quartz (20%–21%), polycrystalline quartz (4%–5%), chert (40%–55%), plagioclase feldspar (7%–10%), sedimentary lithoclasts (1%–4%), metamorphic lithoclasts (1%–2%), igneous/volcanic lithoclasts (6%–10%), and accessory muscovite and heavy minerals (Table 10).

Alteration of detrital grains is mainly partial to extensive grain dissolution of chert, feldspar and volcanic grains. Partial grain dissolution contributes minor to common isolated and irregular intragranular microporosity. Where grain dissolution is extensive, secondary porosity has enhanced reservoir quality. Evidence for secondary porosity includes ‘oversized’ pores (i.e., larger than adjacent grains) and a remnant clay outline of the former grain boundary.

Monocrystalline quartz occurs as ‘clear,’ mainly inclusion free, subangular to subrounded grains that lack overgrowth cement. Polycrystalline quartz consists of several quartz crystals sutured together to form a single grain. Chert consists of micro-silica grains that commonly show a ‘speckled’ texture (i.e., clay inclusions).

Plagioclase feldspar occurs as ‘cloudy’ angular grains that often show albite twinning and clay alteration along cleavage planes. In addition, partial feldspar dissolution contributes minor isolated and irregular intragranular microporosity (non-effective).

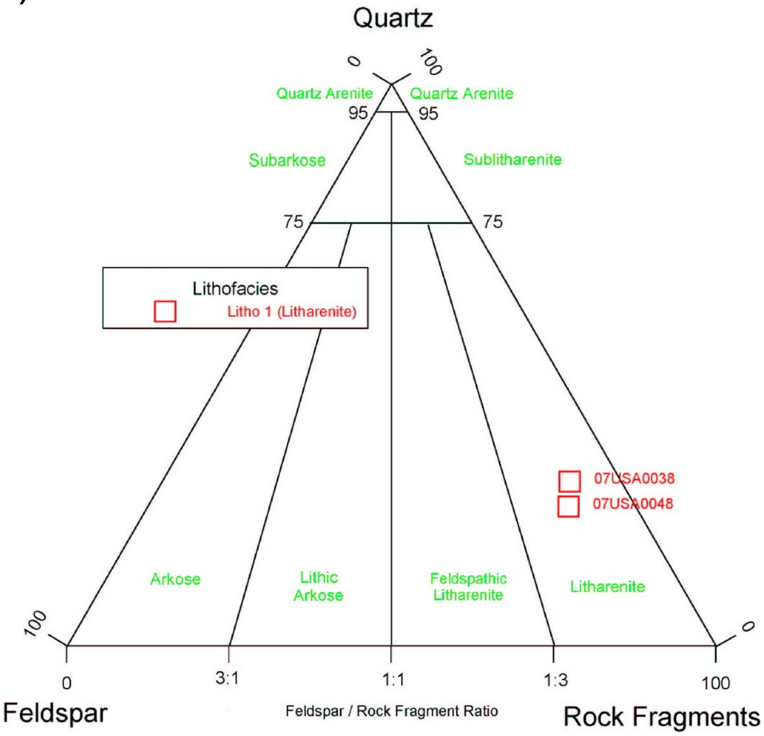
Sedimentary lithoclasts are mainly clay-rich ‘shale’ grains that are poorly compacted between the more competent detrital grains. Metamorphic lithoclasts are elongated grains interpreted as schist.

Volcanic lithoclasts contain randomly orientated plagioclase laths within a highly altered siliceous matrix.

Accessory muscovite occurs as clear elongated grains with parallel cleavage planes. Heavy minerals are high-relief grains identified mainly as zircon.

Organic/coaly fragments aligned parallel to faint bedding planes account for 5% of sample 07USA0038.

a)



b)

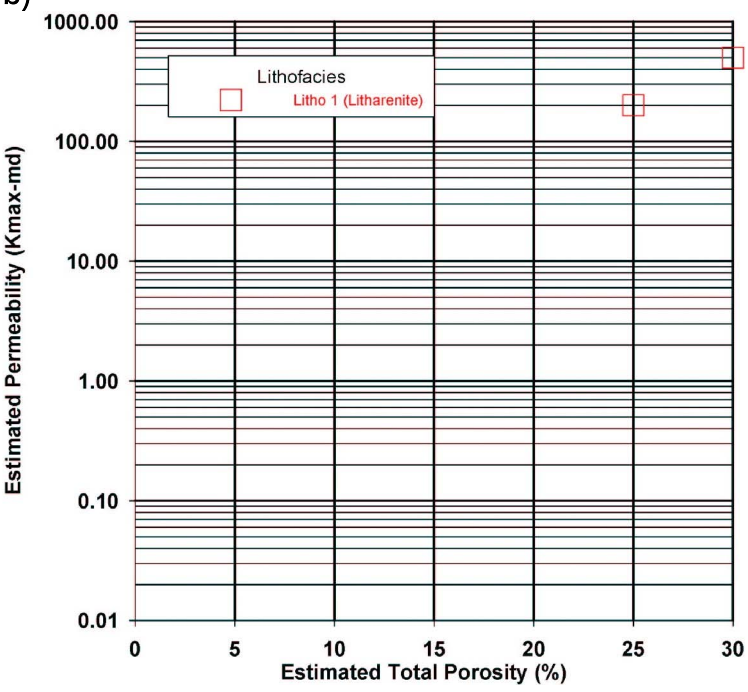


Figure 9. Foremost Formation: a) ternary composition plot (Folk, 1968), b) porosity versus permeability.

Table 10. Petrography summary, Foremost Formation.

Sample:	07USA0038	07USA0048				
Lithofacies:	Litho 1	Litho 1				
Rock Name (Folk, 1968):	Litharenite	Litharenite				
Framework Grains						
Monocrystalline Quartz	21	20				
Polycrystalline Quartz	5	4				
Chert	40	55				
Alkali Feldspar						
Plagioclase Feldspar	7	10				
Sedimentary Lithoclasts	4	1				
Metamorphic Lithoclasts	2	1				
Igneous / Volcanic Lithoclasts	10	6				
Dolomite Lithoclasts						
Calcareous Lithoclasts						
Fossils						
Glauconite						
Phosphate						
Muscovite	trace	trace				
Heavy Minerals	trace	trace				
Cements						
Quartz						
Calcite						
Ferroan Calcite						
Dolomite	1					
Siderite						
Pore Lining Clay	2	1				
Bitumen						
Kaolinite	3	2				
Pyrite						
Matrix						
Detrital Clay						
Organic / Coaly Material	5					
Texture						
Grain Size	fU	mL				
Sorting	moderate	mod well				
Roundness	sbang-sbrnd	sbang-sbrnd				
Pore Types						
Intergranular	main	main				
Secondary	minor	minor				
Intragranular Microporosity	common	minor				
Clay Microporosity	minor	minor				
Reservoir Quality						
Thin Section (effective) Porosity %	20	26				
Core (total) Porosity %	~25	~30				
Permeability (Kmax-md)	~200	~500				
Reservoir Quality	Good	Very Good				

Cement or diagenetic minerals are minor, with local kaolinite (2%–3%), pore-lining clay (1%–2%) and dolomite (<1%). Kaolinite occurs as milky white, pseudohexagonal crystals that create microporosity at the expense of primary intergranular porosity. Pore-lining clays often occur as a remnant clay outlines of dissolved feldspar grains. Dolomite occurs as rhombic crystals.

3.8.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is ~20%–26%, slightly lower than the estimated total porosity of 25%–30% (Table 9). Primary intergranular (effective) porosity is the main pore type. We interpret a minor portion of the effective porosity as secondary, formed after extensive grain dissolution.

The slight discrepancy between the thin-section (effective) and core (total) porosities reflects intragranular microporosity (non-effective) associated with partially dissolved chert, feldspar and volcanic grains, plus minor clay microporosity (non-effective) associated mainly with kaolinite. We estimate that microporosity to accounts for ~15%–20% of the total porosity.

Permeability and reservoir quality are good (~200–500 mD). Higher permeability in sample 07USA0048 reflects the slightly larger grain size (larger pore throats) and slightly lower volume of cements.

The main controls on permeability and reservoir quality are grain size (pore throat size), volume of cements, extent of secondary porosity and degree of sediment compaction.

3.9 Milk River Formation

Sample location 06USA0045: UTM 451850E, 5430499N (Zone 12, NAD83)

3.9.1 Petrology

Milk River Formation sample 06USA0045, a very fine to fine-grained, poorly sorted, argillaceous litharenite (Figure 9) informally designated as Lithofacies 1 (Litho 1), shows a mottled texture.

Mineralogy of detrital grains is monocrystalline quartz (40%), polycrystalline quartz (2%), chert (10%), plagioclase feldspar (7%), sedimentary lithoclasts (5%), metamorphic lithoclasts (2%), and accessory muscovite and heavy minerals (Table 10).

Alteration of detrital grains is a combination of clay inclusions within chert and along feldspar cleavage planes, plus partial dissolution of chert and feldspar resulting in minor intragranular microporosity.

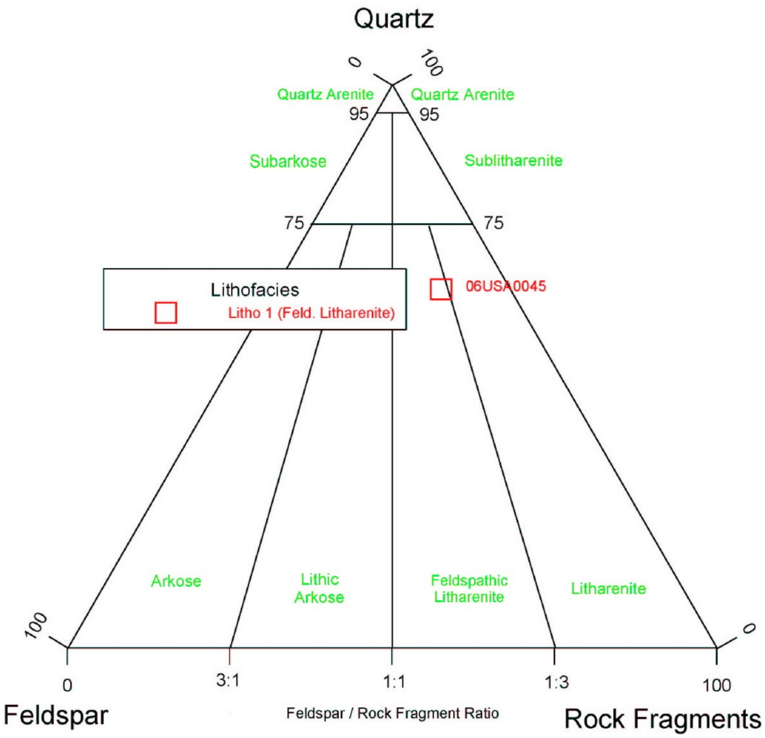
Cements include kaolinite (5%) and pyrite (1%). Opaque matrix accounts for 23% of the total sample composition. The highly opaque nature of the matrix may be the result of limonite alteration. This sample showed high thorium content (69 ppm), attributed to high content of rounded monazite grains, described in Matveeva and Anderson (2007).

3.9.2 Pore Types and Reservoir Quality

Thin-section (effective) porosity is <1%, compared with the estimated total porosity of 5% (Table 10). Microporosity (non-effective), associated mainly with kaolinite and the opaque matrix, is the dominant pore type. Primary porosity is absent.

Permeability and reservoir quality are poor (<0.10 mD) due to the very fine grain size (small pore throats) and high volume of detrital matrix.

a)



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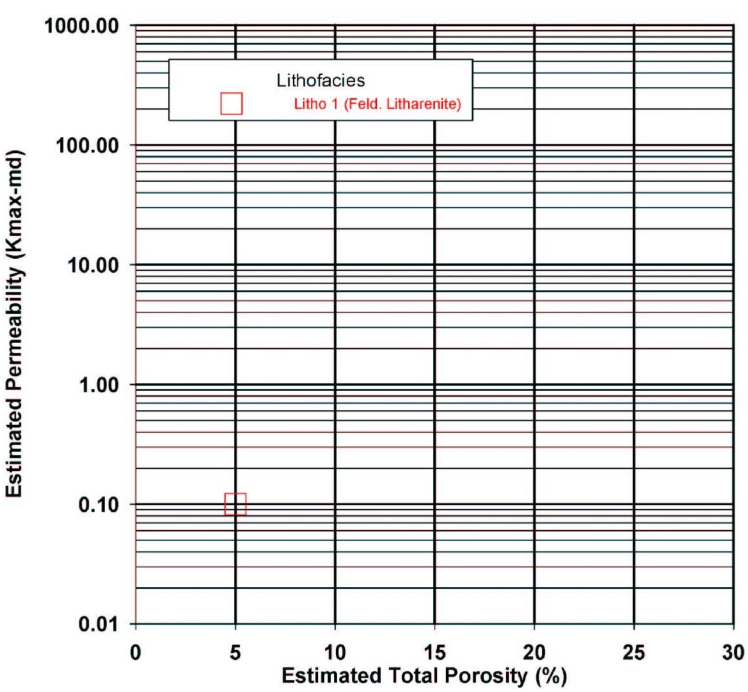

Figure 10. Milk River Formation: a) ternary composition plot (Folk, 1968), b) porosity versus permeability.

Table 11. Petrography summary, Milk River Formation.

Sample:	06USA0045					
Lithofacies:	Litho 1					
Rock Name (Folk, 1968):	Feld. Lith.					
Framework Grains						
Monocrystalline Quartz	40					
Polycrystalline Quartz	2					
Chert	10					
Alkali Feldspar						
Plagioclase Feldspar	7					
Sedimentary Lithoclasts	5					
Metamorphic Lithoclasts	2					
Igneous / Volcanic Lithoclasts						
Dolomite Lithoclasts						
Calcareous Lithoclasts						
Fossils						
Glauconite						
Phosphate						
Muscovite	trace					
Heavy Minerals	trace					
Cements						
Quartz						
Calcite						
Ferroan Calcite						
Dolomite						
Siderite						
Pore Lining Clay						
Bitumen						
Kaolinite	5					
Pyrite	1					
Matrix						
Detrital Clay	23					
Organic / Coaly Material						
Texture						
Grain Size	vfU-fU					
Sorting	poor					
Roundness	ang-sbang					
Pore Types						
Intergranular						
Secondary						
Intragranular Microporosity	minor					
Clay Microporosity	main					
Reservoir Quality						
Thin Section (effective) Porosity %	<1					
Core (total) Porosity %	~5					
Permeability (Kmax-md)	<0.10					
Reservoir Quality	Poor					

***matrix clay is stained with an opaque alteration product (i.e. possibly limonite)**

4 Observations and Conclusions

We carried out a compilation from published papers to understand properties of hostrocks from sandstone-hosted uranium deposits throughout the world. Important criteria for this deposit model include sandstone lithology (amount of feldspar, which carries uranium in its crystalline structure); the composition and amount of cement (may influence permeability for mineralizing solution); porosity and maturity (sorting and grain size) of the sediments; and the amount of organic matter (which acts a reducing agent for precipitation of uranium).

The physical attributes of some selected sandstone-hosted uranium deposits are as follows:

- In the YL (Yi-Li) basin of northwestern China, orebodies occur in alluvial, fan-braided facies. Sandstones are lithic subarkosic, with 30% quartz, 15%–20% feldspar, 2%–3% carbonaceous debris and 20%–40% rock fragments (tuff, andesite, granite, rhyolite, siltstone). Poor sorting is indicative of rapid deposition. Cement is composed of clays, silt and fine-grained sand (Min et al., 2005).
- In the uranium-rich Shirley basin of Wyoming, the sandstones are arkosic and medium to very coarse grained, and contain quartz, feldspar and rock fragments (quartz and feldspar). The cement comprises clay, siltstone, fine-grained sand and sparse calcite cement. Carbonaceous material dispersed in sand commonly forms the nuclei of small, richly mineralized pods up to 2 cm long. Euhedral grains of pyrite and marcasite are associated with the richer parts of the deposits (Melin, 1969).
- In Kazakhstan, the world's largest producer of sandstone-hosted uranium is hosted in sandstones that are medium to coarse grained and contain 65%–75% quartz, 18%–20% feldspar, 6%–14% siliceous debris, <1% calcite and <1% organic carbon (Fyodorov, 2005).
- In Gas Hills uranium district of Wyoming, the sandstones are poorly sorted feldspathic to arkosic, poorly cemented with calcite or limonite and derived from the Precambrian Granite Mountains. They contain 60% quartz and 40% feldspar (orthoclase and microcline; Anderson, 1969).
- In the Grants uranium district of New Mexico, the hostrocks of the Westwater Canyon Member are poorly sorted, fine- to very coarse grained feldspathic sandstone containing 30%–99% quartz, 2%–24% feldspar, 9%–17% clay and 1%–35% rock fragments. Mudstone and sandstone contain abundant montmorillonitic clay, derived from alteration of volcanic ash. Plant material (carbonized logs, branches, grass) and uraniferous humate are widespread (Crawley et al., 1985).

It is possible to identify certain common features from these five descriptions:

- arkosic to subarkosic composition with a high feldspar content (up to 20%)
- mostly medium to coarse grained
- poor sorting, indicative of short transport distance
- derivation from felsic volcanic rocks or granite, or a high content of felsic volcanic clasts

Southern Alberta rocks do not fit many of these criteria. Their feldspar content is low, their grain size is finer and the input of volcanic material to the most formations is significantly lower than what is described from the known uranium districts. A significant content of chert grains provides evidence of derivation from Paleozoic carbonate chert bands in Rocky Mountains. Organic content in some of the samples is similar to those of uranium-hosting sediments. It is important to keep in mind, however, that we described only 25 thin sections and some formations are represented by only one thin section. Reports published by Alberta Geological Survey (Matveeva and Anderson, 2007; Matveeva and Kafle, 2009) contain field observations and conclusions made during collection of the rock samples presented in this report.

5 References

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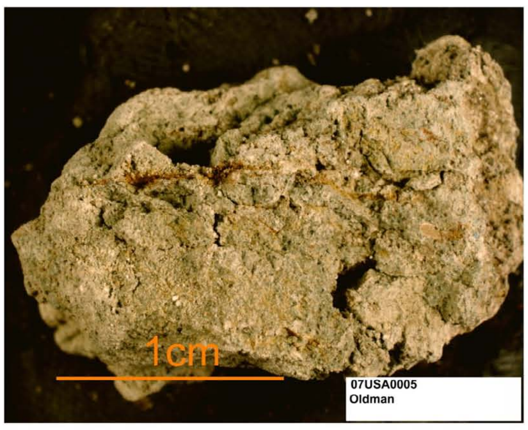
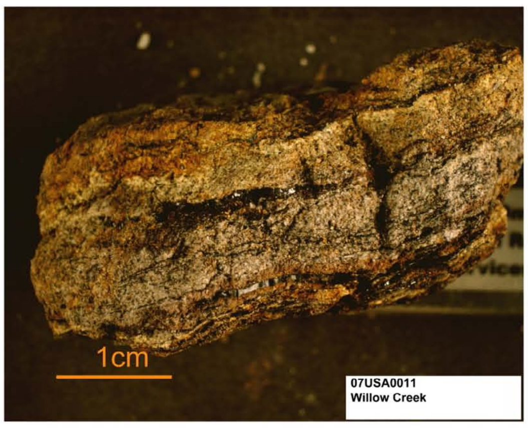
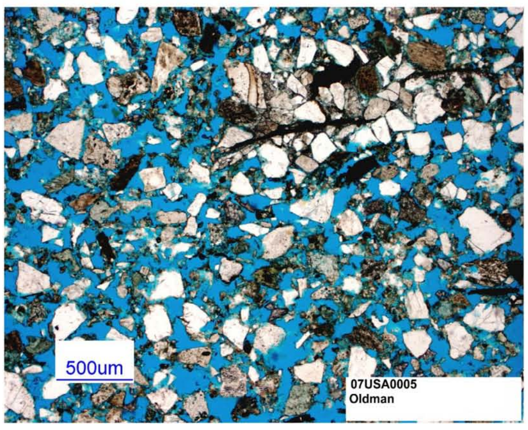
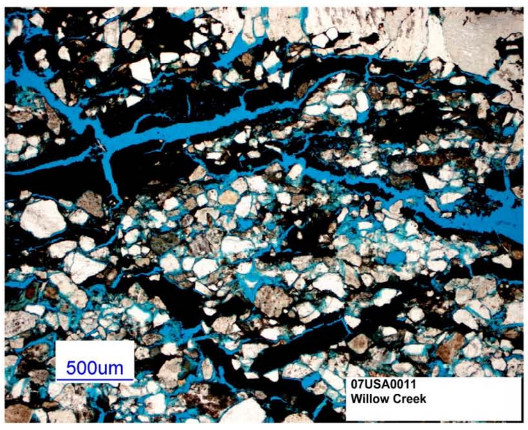
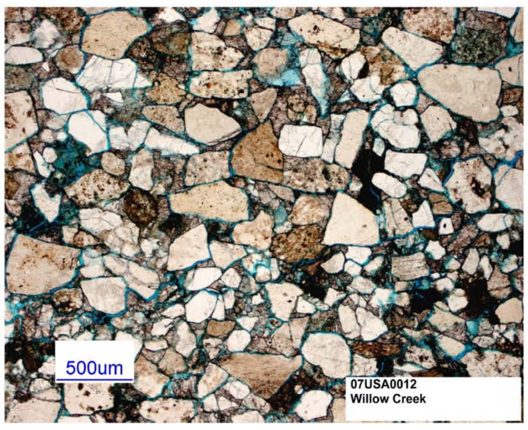
Appendix 1 — Overview Hand-Specimen Photographs and Thin-Section Photomicrographs

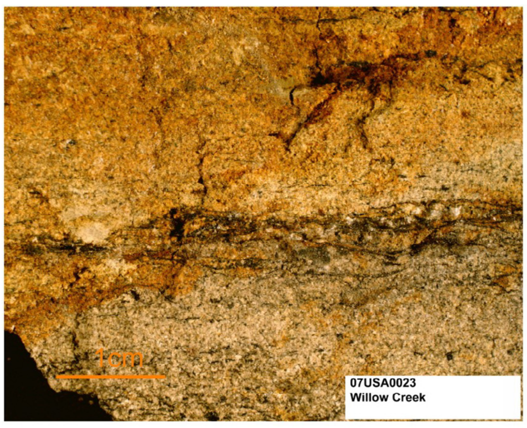


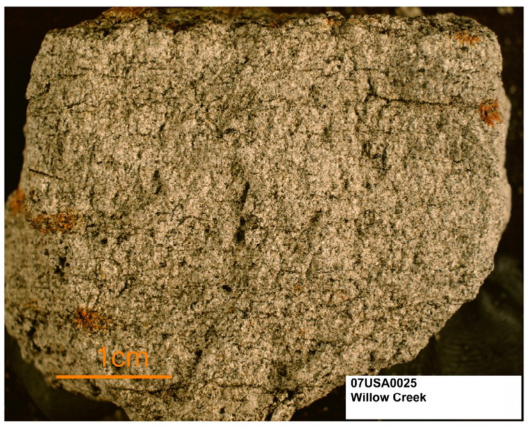


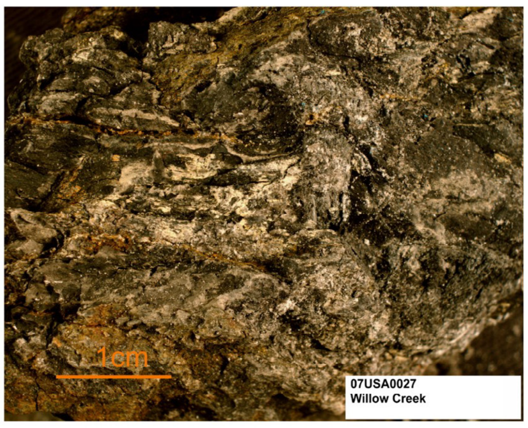


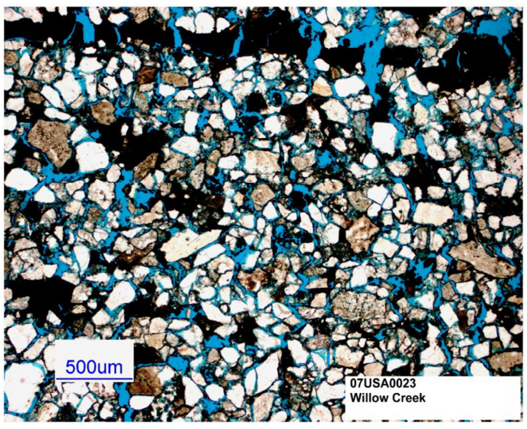


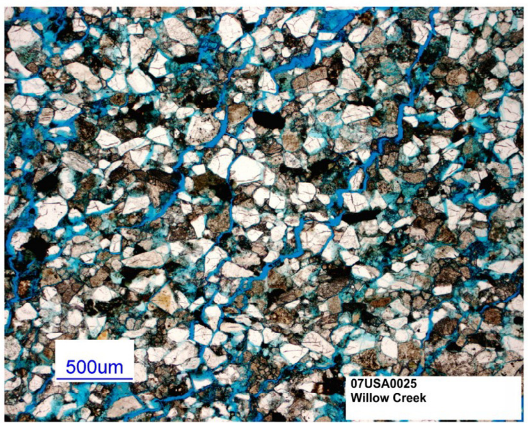


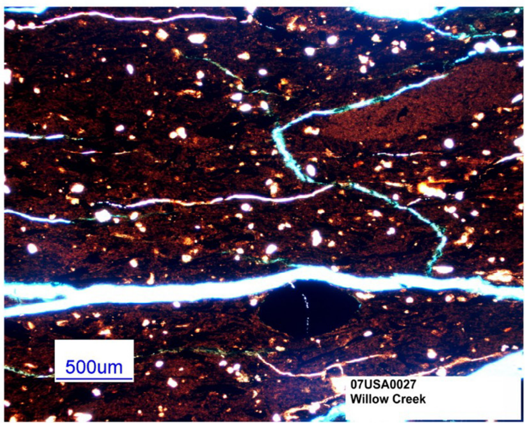


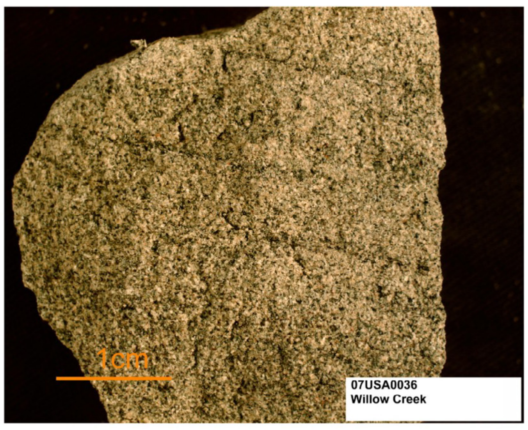


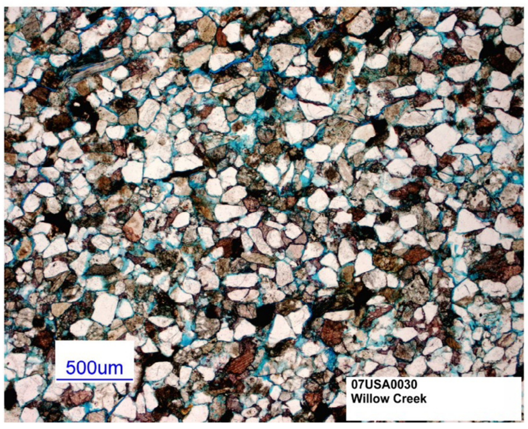


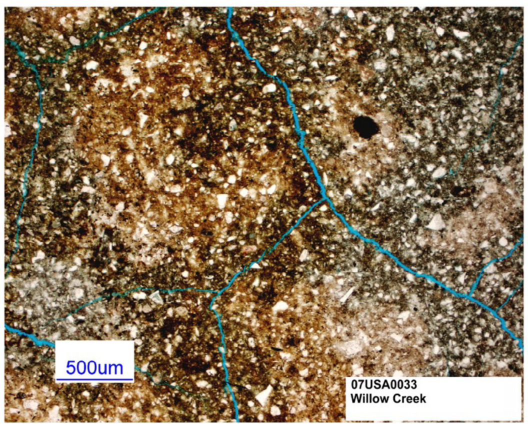


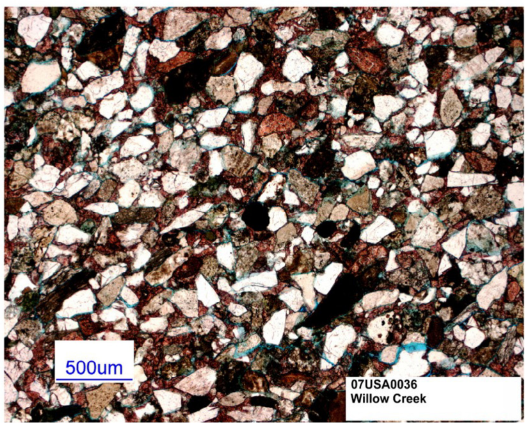


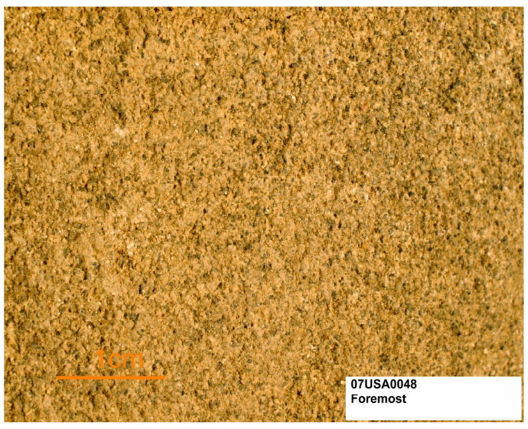








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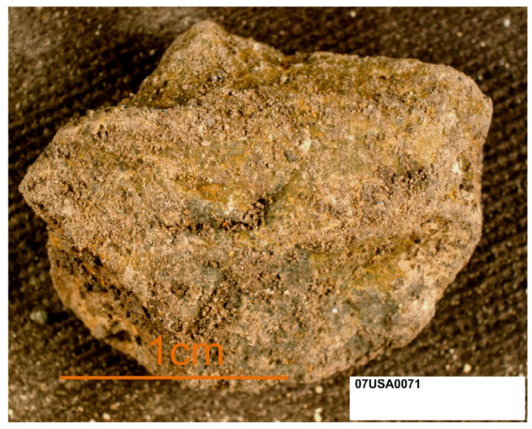
Foremost

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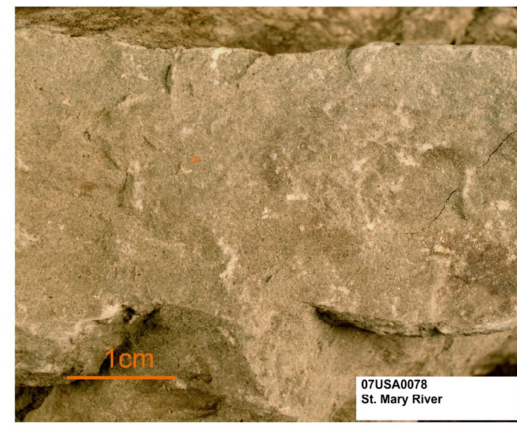
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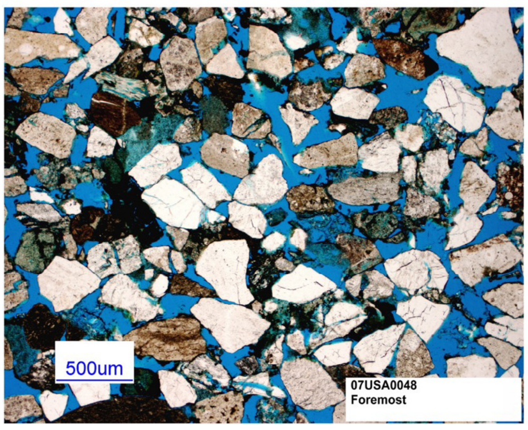
St. Mary River

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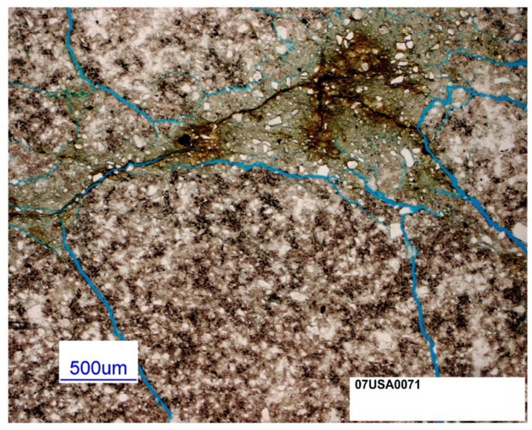
Foremost

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500um
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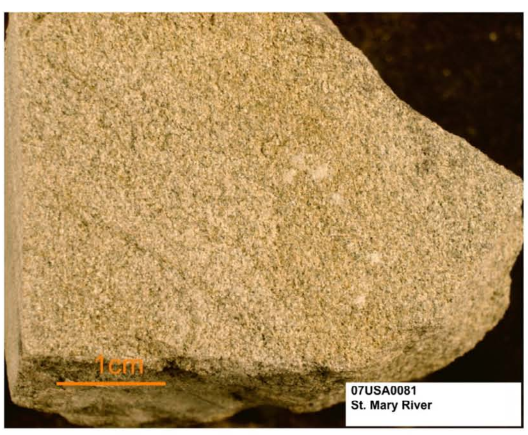
St. Mary River

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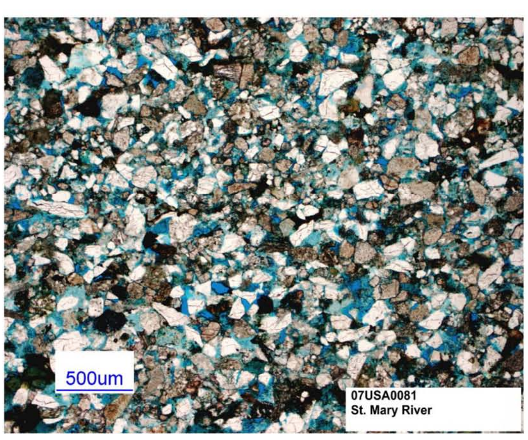
St. Mary River

1cm
07USA0082
St. Mary River

1cm
07USA0085
St. Mary River

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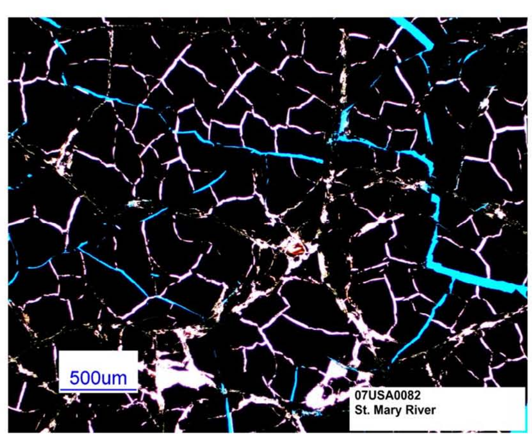
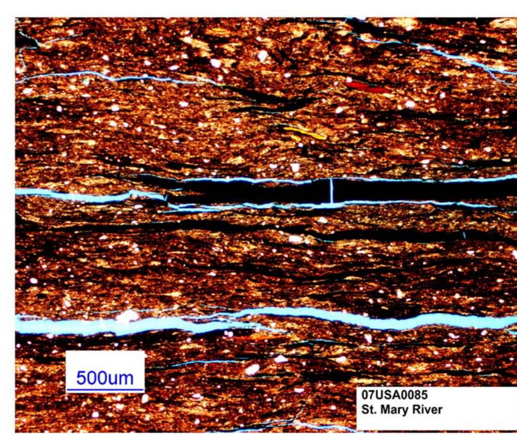
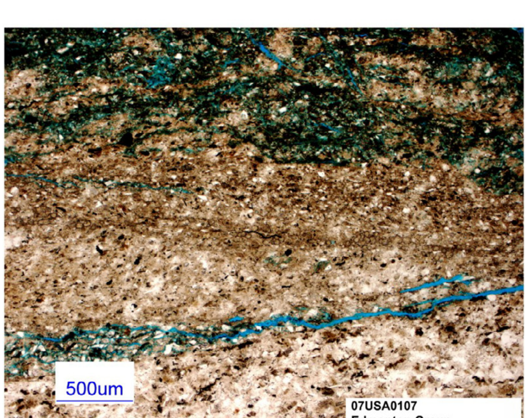
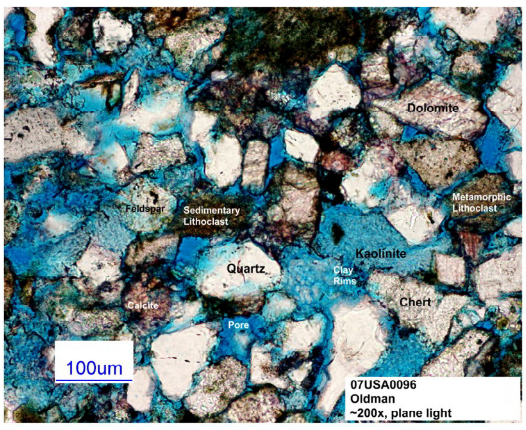
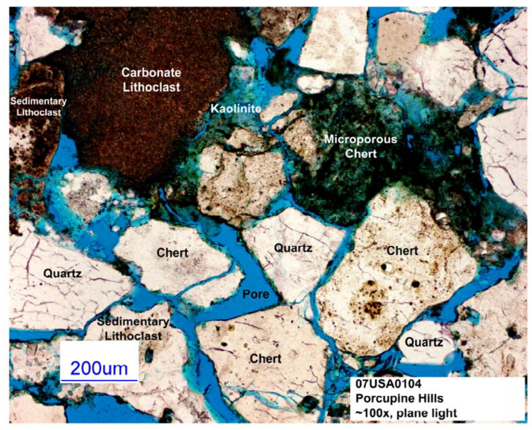
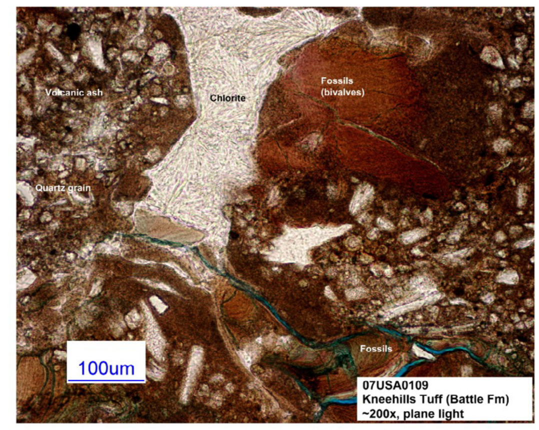

500um
07USA0082
St. Mary River

500um
07USA0085
St. Mary River

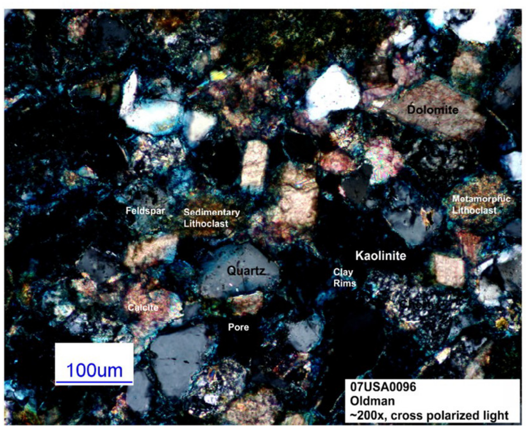
1cm
07USA0107
Edmonton Group

500um
07USA0107
Edmonton Group

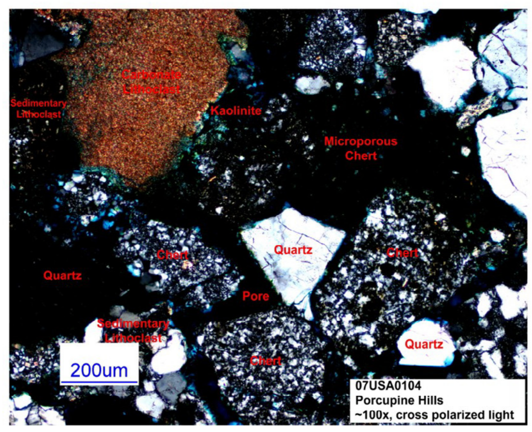
Appendix 2 — Selected Annotated Photomicrographs

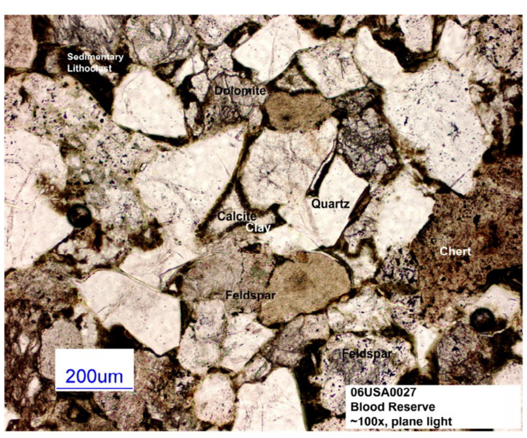


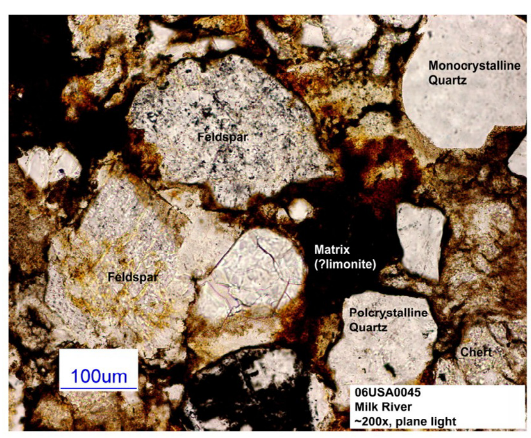


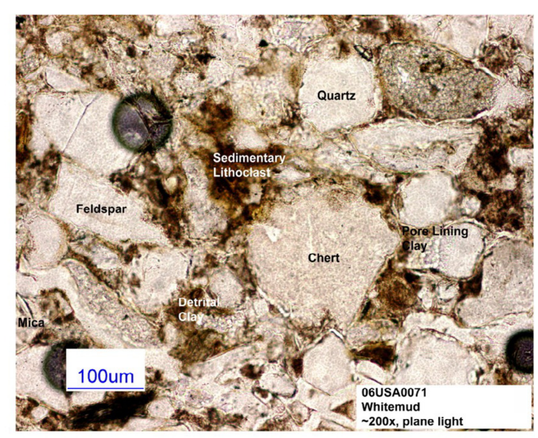


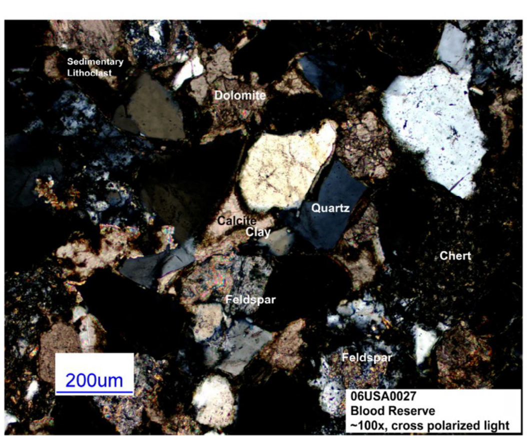


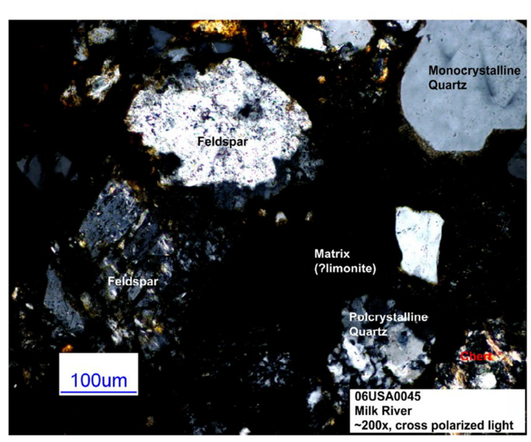


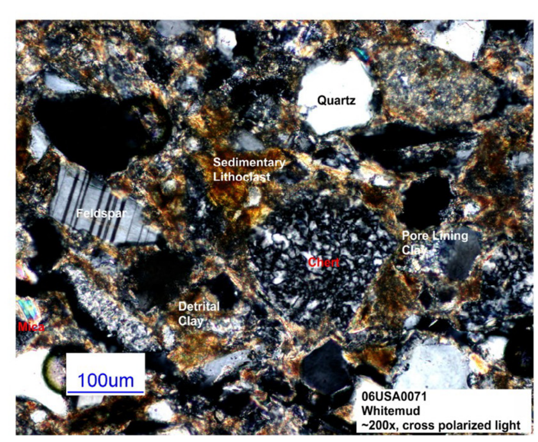


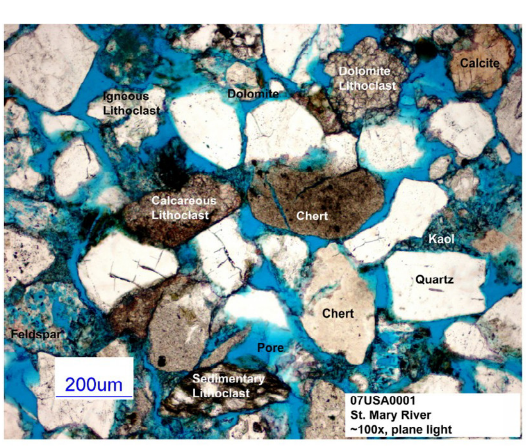


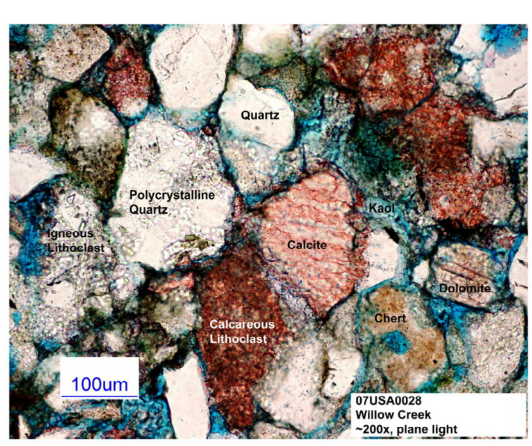


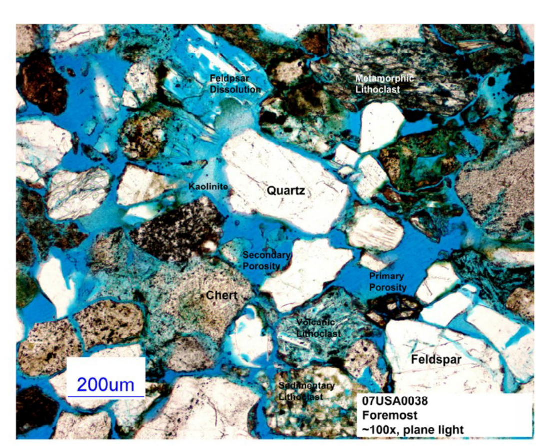


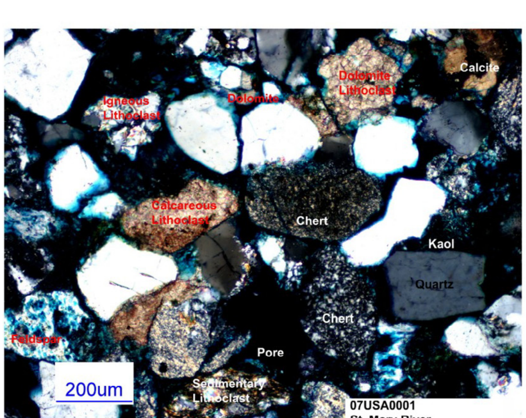


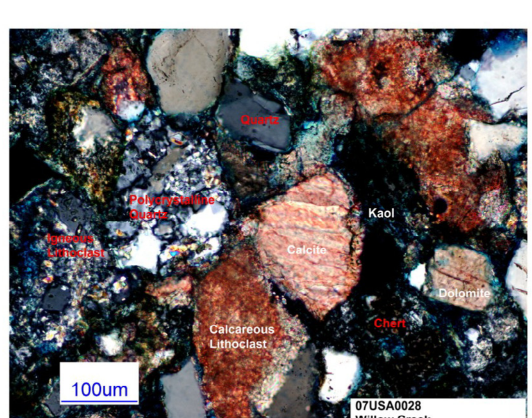


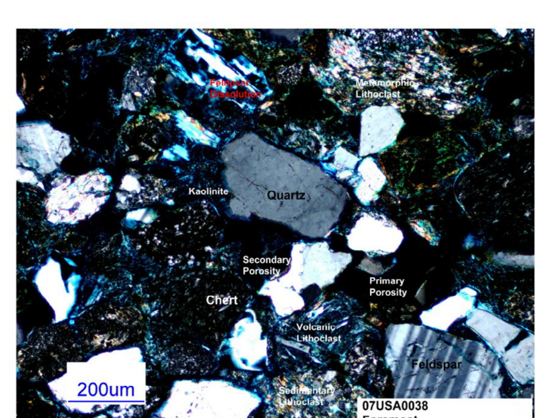












Appendix 3 — Macro Views, with Detailed Descriptions, of the Thin-Section Photomicrographs for all Samples

JMS Geological Consultants Ltd.

A PETROGRAPHIC STUDY

Of the

PORCUPINE HILLS, WILLOW CREEK
ST. MARY RIVER, WHITEMUD, KNEEHILLS TUFF
BLOOD RESERVE, OLMAN, FOREMOST
MILK RIVER FORMATIONS

Prepared by JMS Geological Consultants Ltd.

For

ALBERTA ENERGY AND UTILITIES BOARD
ALBERTA GEOLOGICAL SURVEY

November, 2007

ALBERTA GEOLOGICAL SURVEY
Formation: Porcupine Hills

JMS 07-3533
2007-11-26

Sample: **07USA0104**
Lithofacies: Litho 1
Rock Name: **Litharenite**

Reservoir Properties
TS Porosity (%): 18
Core Porosity (%): ~22
Kmax (md): >100

Grain Size: mL
Sorting: moderate

PHOTO A: 40x, plane light
Low magnification view shows a lower medium grained, moderately sorted litharenite Thin section (effective) porosity is ~18% (blue dyed epoxy). Good reservoir quality (estimated >100 md) reflects the medium grain size (large pore throats) and low volume of cements.

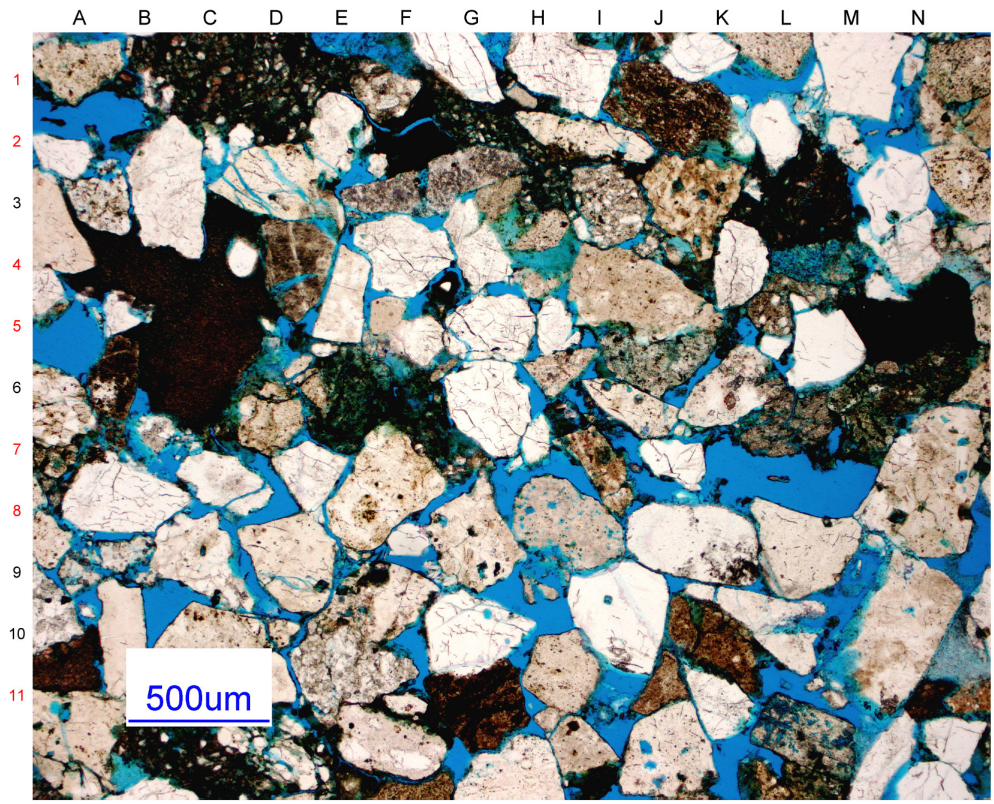
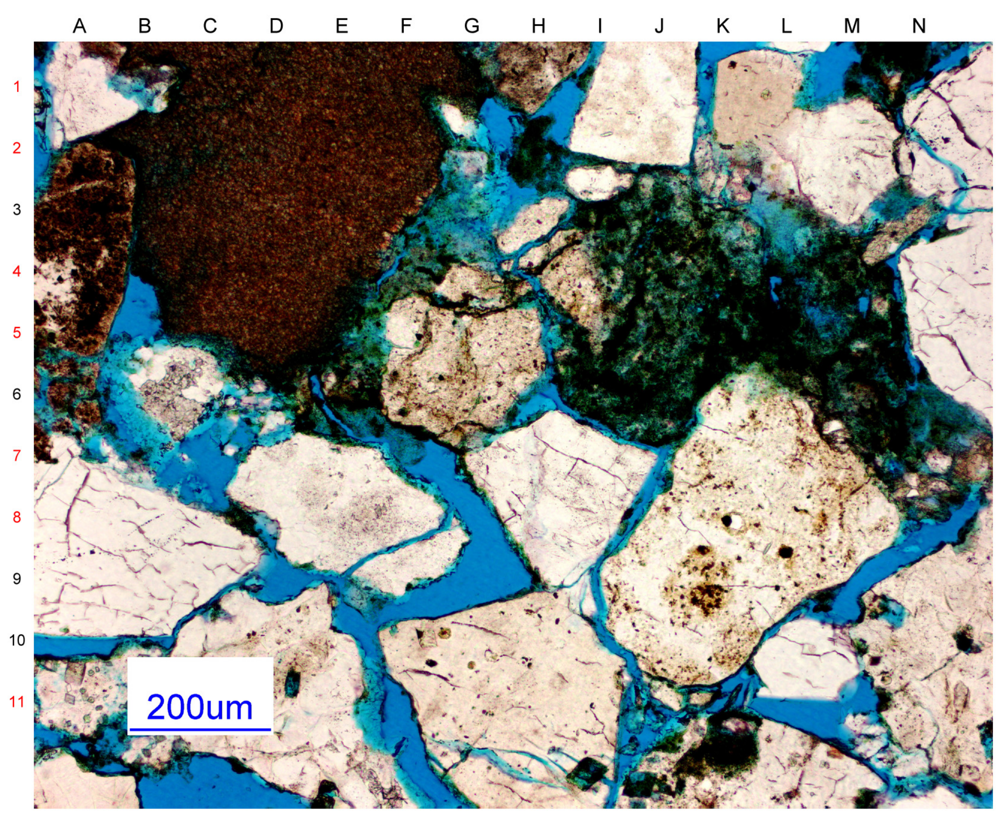


PHOTO B: 100x, plane light
High magnification view details the preservation of effective porosity. Cements are minor with local kaolinite (milky white clay in the top center), calcite and dolomite (not shown) and thin clay rims (near center). Note the high chert grain content (e.g. dense chert in the bottom center and microporous chert in the upper right) and texture of a carbonate lithoclast (top left).



Pore Types
Intergranular: main
Secondary: minor
Intragranular: minor
Microporosity: minor

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample: **07USA0011**
Lithofacies: Litho 1
Rock Name: **Litharenite**

Reservoir Properties
TS Porosity (%): 5
Core Porosity (%): ~12
Kmax (md): ~1

Grain Size: vfU-fU
Sorting: poor

PHOTO A: 40x, plane light
Low magnification view shows a very fine to fine grained, poorly sorted litharenite. Note the high volume of organic or coaly laminations (opaque) and local quartz-filled bedding plane fractures (top right). Porosity is ~12% and is a combination of mainly primary intergranular and clay microporosity.

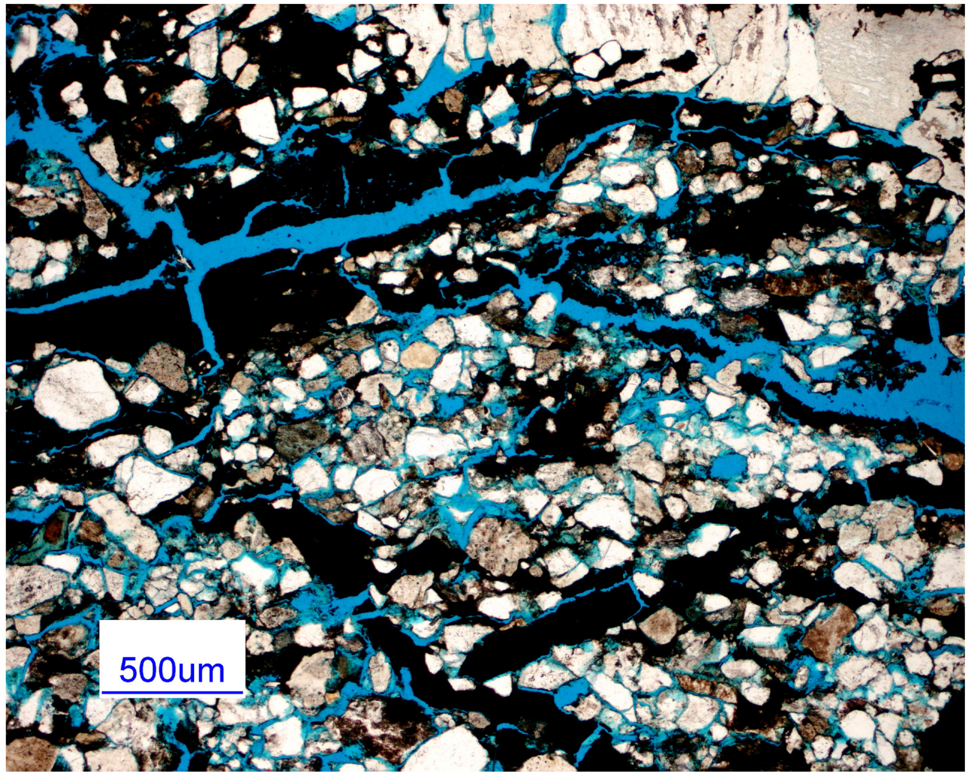
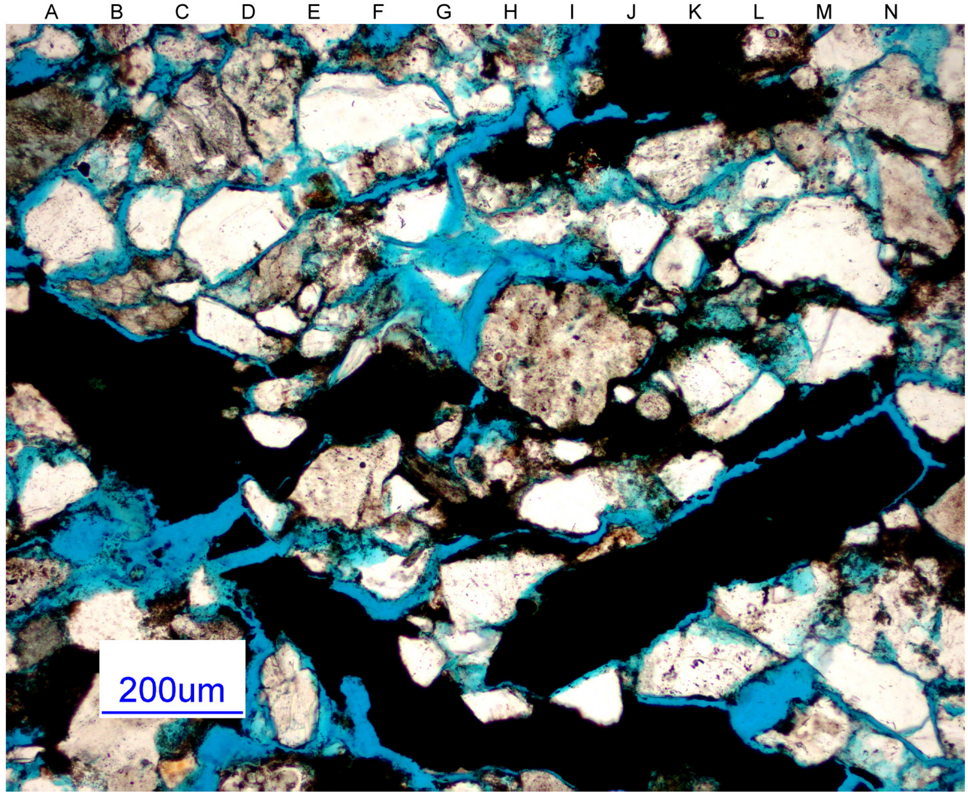


PHOTO B: 100x, plane light
High magnification view details the high chert content and high amount of coaly laminations. Open porosity (stained with blue dyed epoxy) is often lined with clay cement. Low expected permeability is due to the very fine grain size (small pore throats), high volume of organic or coaly laminations and pore lining clay cement.



Pore Types
Intergranular: main
Secondary:
Intragranular: minor
Microporosity: main

Sample: 07USA0011
Lithofacies: Litho 1
Rock Name: Litharenite

Reservoir Properties

TS Porosity (%):	5
Core Porosity (%):	~12
Kmax (md):	~1
Grain Size:	vfU-fU
Sorting:	poor

PHOTO C: 200x, plane light
High magnification view details the preservation of effective porosity. Note the "speckled" texture of chert (upper right center) reflecting clay and pyrite inclusions, a compacted clay-rich sedimentary lithoclast (left center), an elongated metamorphic grain (near center) and organic material (opaque).

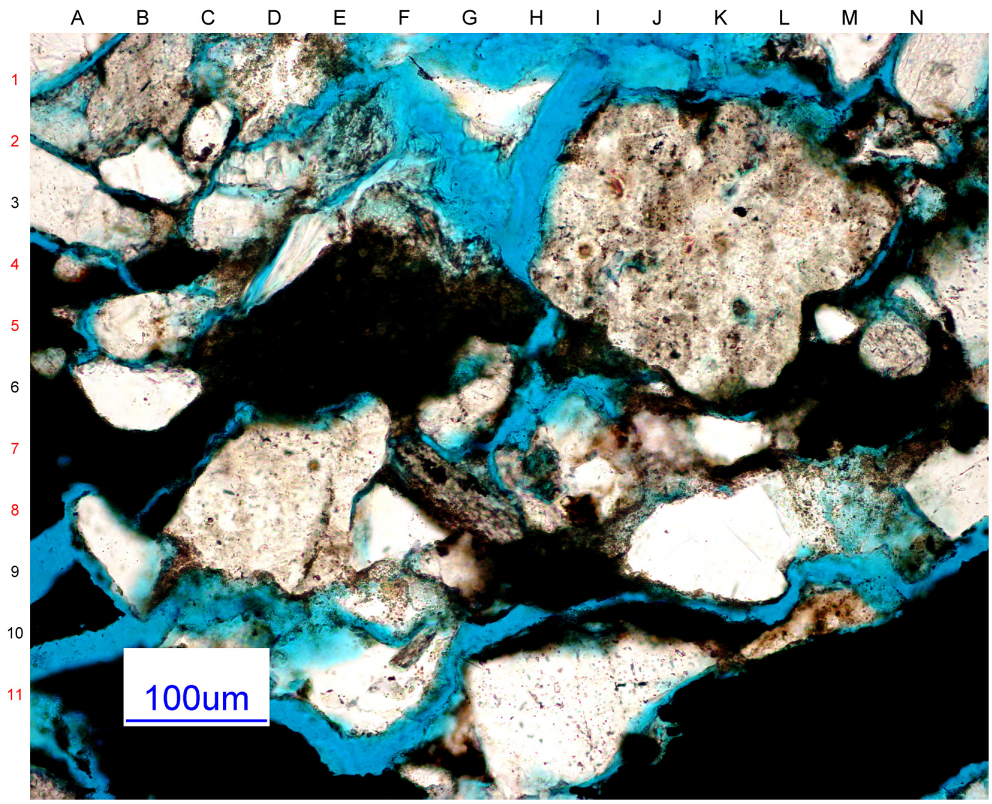
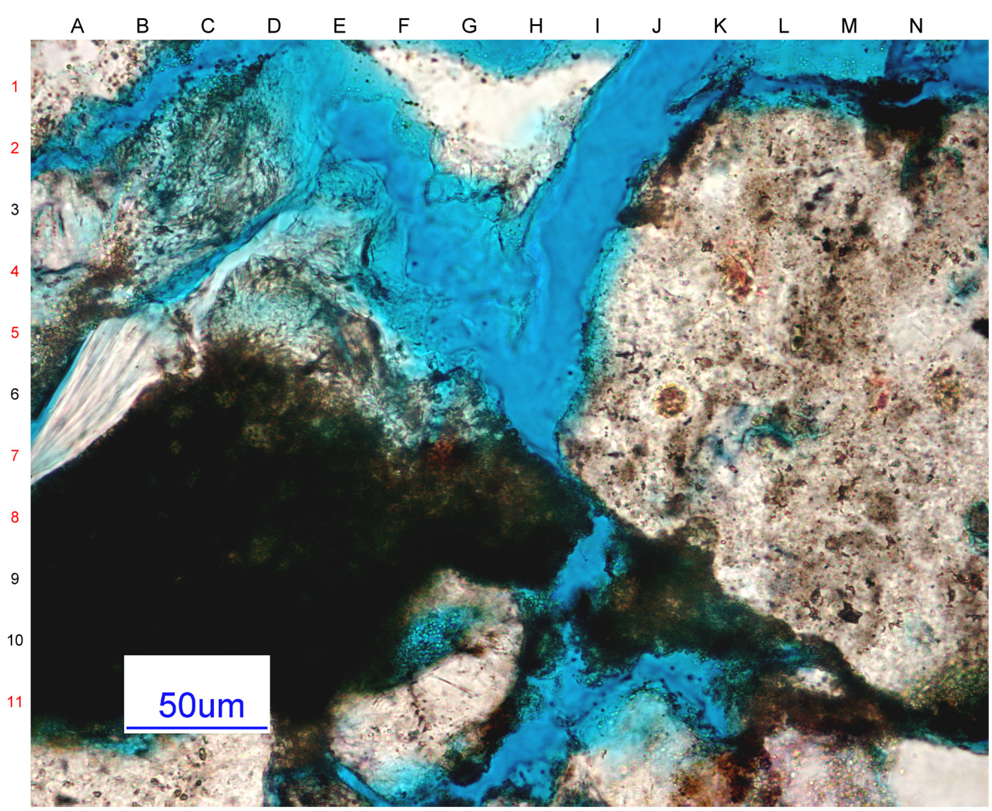


PHOTO D: 400x, plane light
High magnification view details thin clay coats (top left center) lining open porosity. XRD is needed to precisely identify the clay mineralogy; however, thin section observation of color and texture suggest a smectite (water-sensitive swellling clay) composition.



Pore Types

Intergranular:	main
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample: **07USA0023**
Lithofacies: Litho 1
Rock Name: **Litharenite**

Reservoir Properties

TS Porosity (%):	10
Core Porosity (%):	~15
Kmax (md):	~10
Grain Size:	fL
Sorting:	moderate

PHOTO A: 40x, plane light
Low magnification view shows a lower fine grained, moderately sorted litharenite. Thin section (effective) porosity is 10%. Microporosity is ~30% of the total porosity (i.e. ~1/3). Macroview image (opposite page) shows local organic laminations and quartz-filled bedding plane fractures.

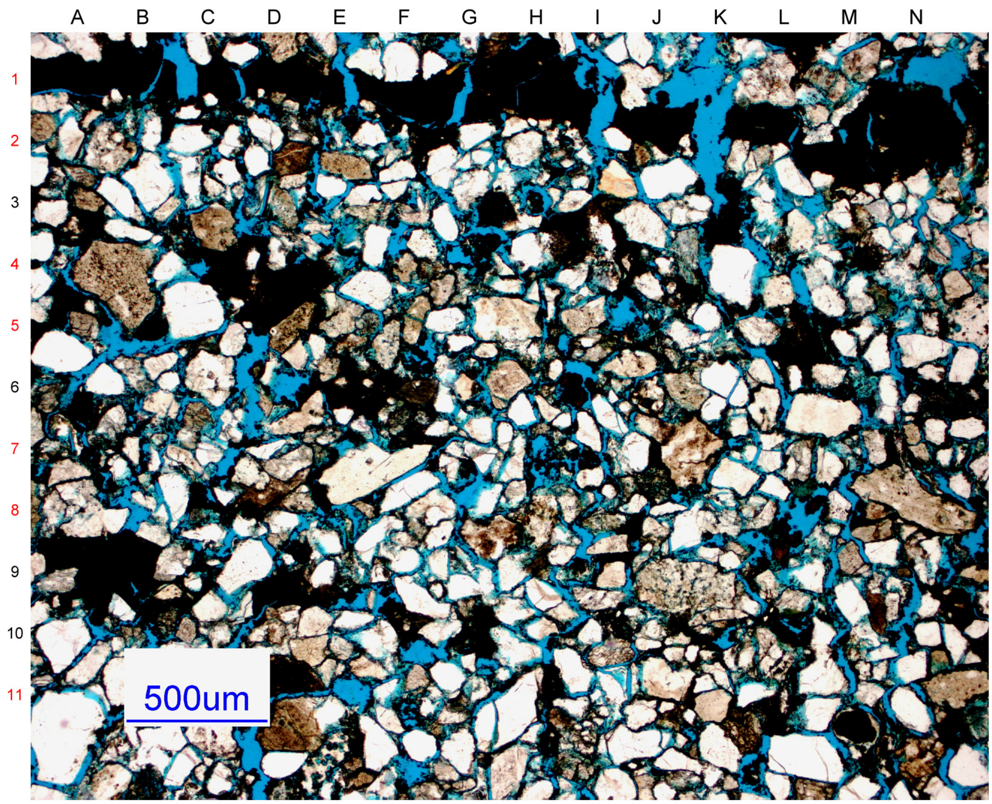
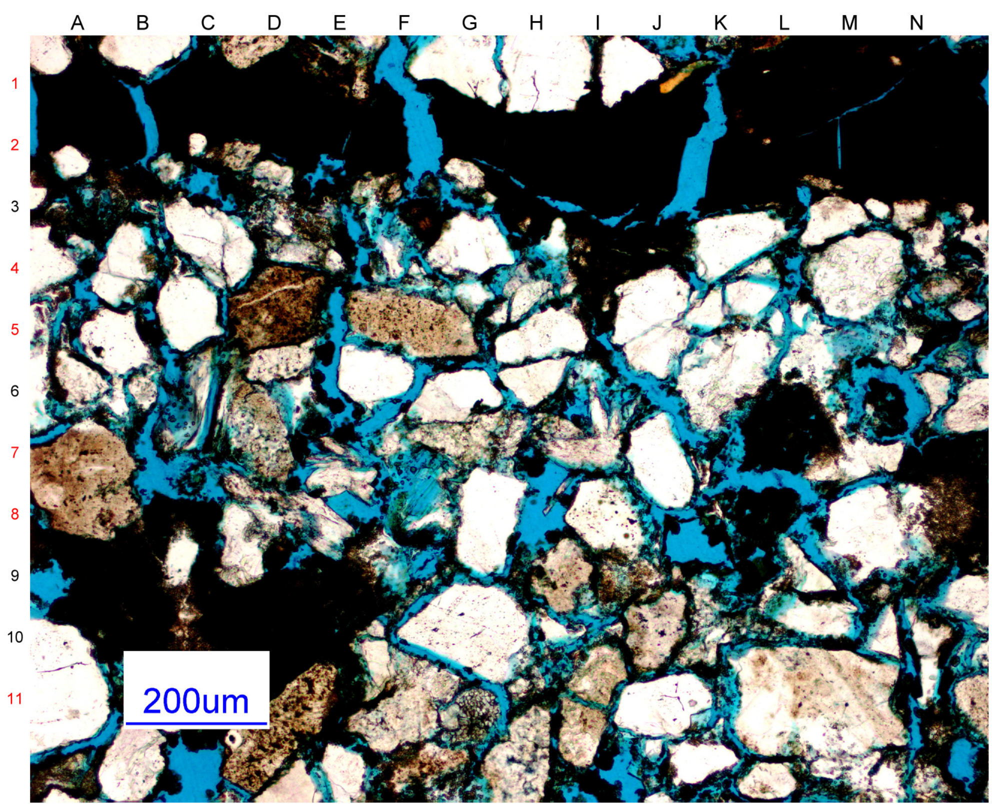


PHOTO B: 100x, plane light
High magnification view details the preservation of effective porosity (mainly primary). Note organic laminations (top) and open or effective porosity lined with micro-siderite crystals and/or authigenic clay cement.



Pore Types

Intergranular:	main
Secondary:	minor
Intragranular:	minor
Microporosity:	common

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample: **07USA0023**
Lithofacies: Litho 1
Rock Name: **Litharenite**

Reservoir Properties
TS Porosity (%): 10
Core Porosity (%): ~15
Kmax (md): ~10

Grain Size: fL
Sorting: moderate

PHOTO C: 200x, plane light
High magnification view further details the preservation of effective porosity. Micro-siderite crystals and/or pore lining clay are the main cements.

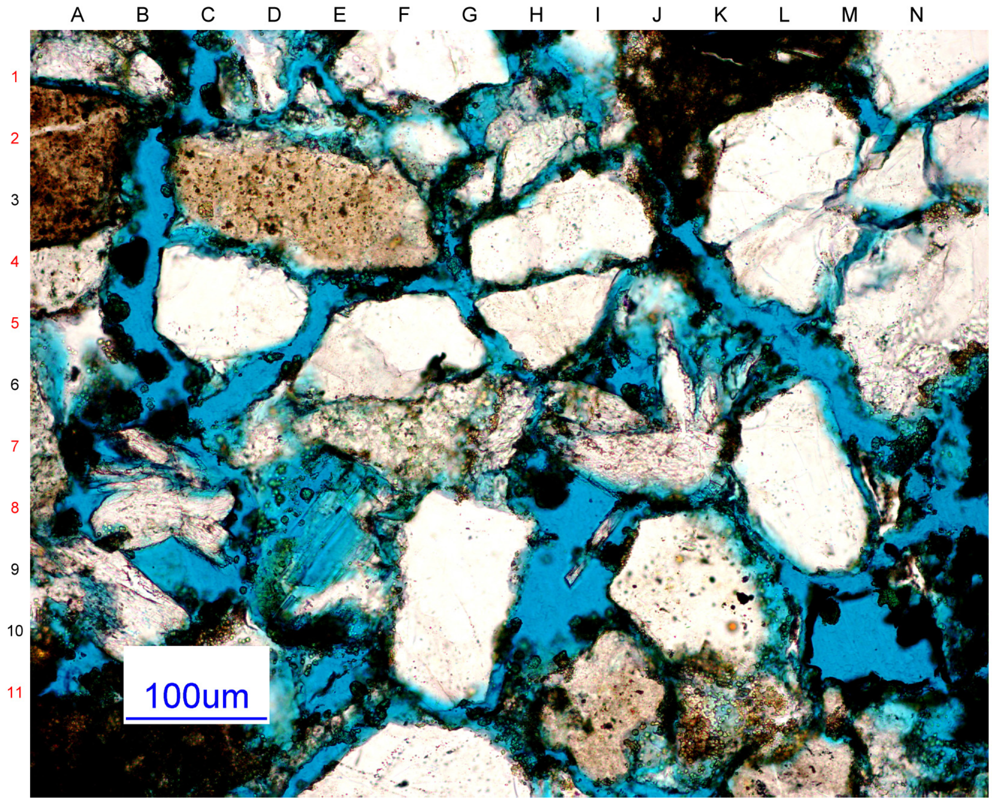
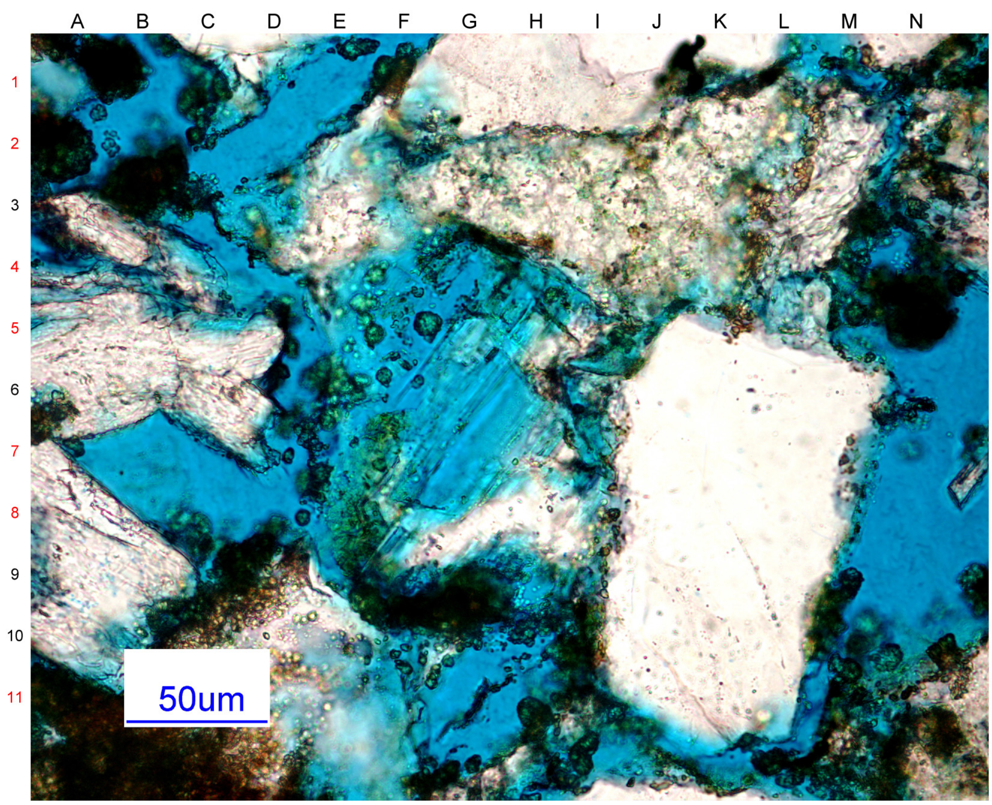


PHOTO D: 400x, plane light
High magnification view details the texture of micro-siderite crystals which appear to be intermixed with clay cement. Note plagioclase feldspar dissolution (center) and tabular clear crystals (?feldspar) in the far left center.



Pore Types
Intergranular: main
Secondary: minor
Intragranular: minor
Microporosity: common

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample:	**07USA0025**
Lithofacies:	Litho 2
Rock Name:	**Litharenite**

Reservoir Properties

TS Porosity (%):	3
Core Porosity (%):	~6
Kmax (md):	<0.10
Grain Size:	fL
Sorting:	moderate

PHOTO A: 40x, plane light
Low magnification view shows a lower fine grained, moderately sorted litharenite. Porosity is ~6% and reservoir quality is poor due to extensive calcite cementation. Induced fractures are common.

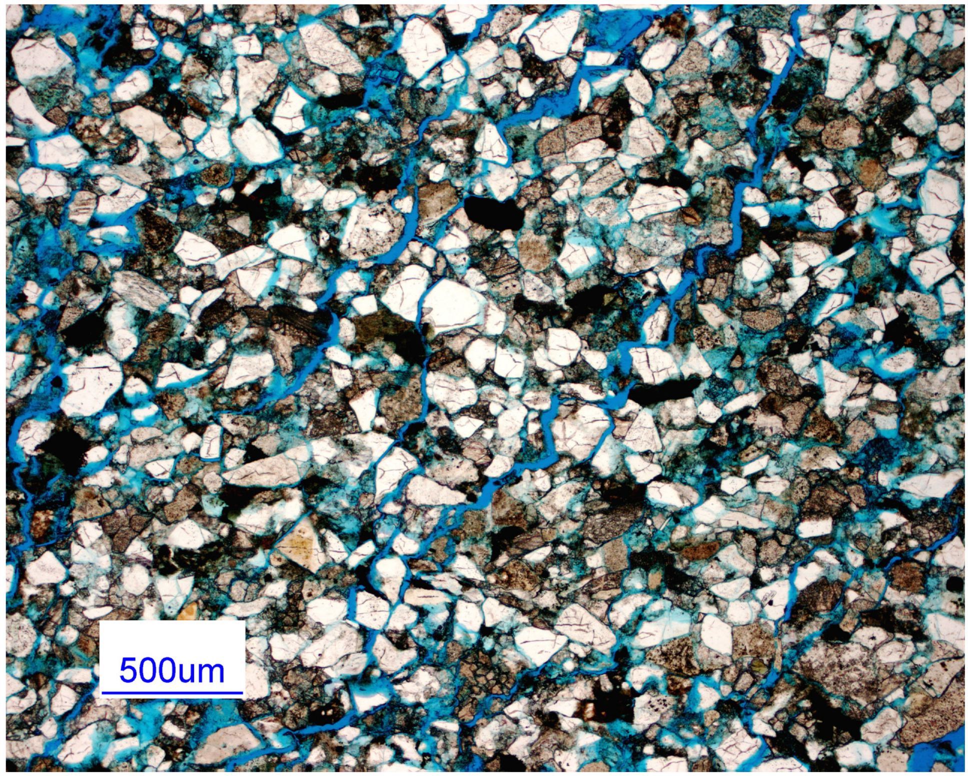
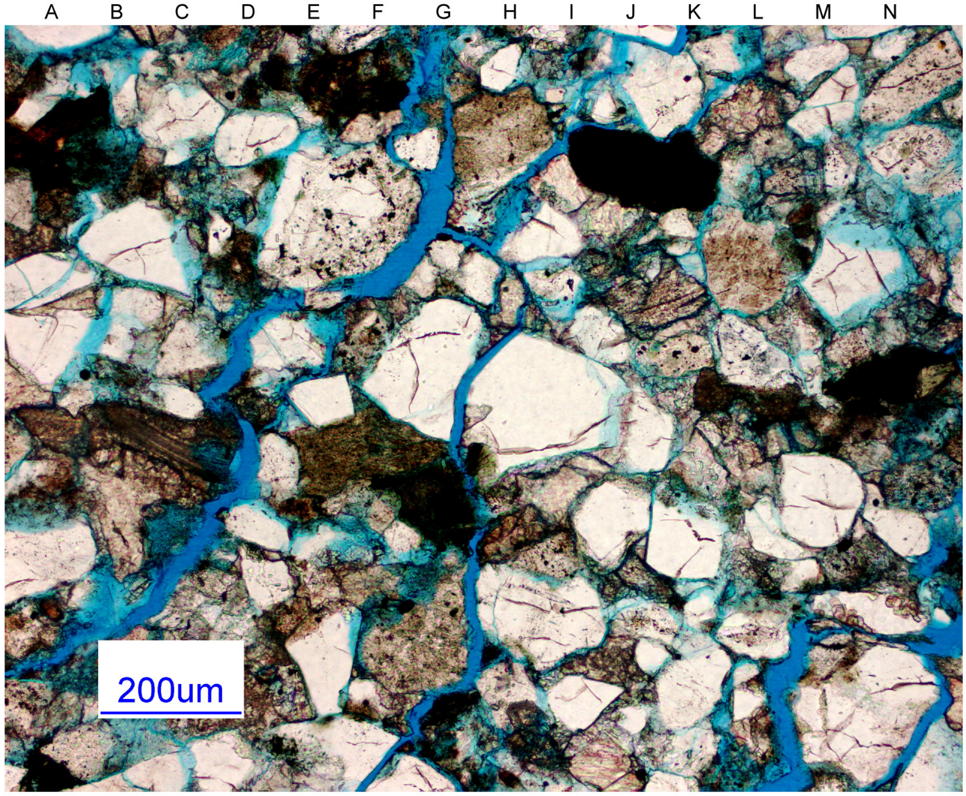


PHOTO B: 100x, plane light
High magnification view details the significance of calcite cement (e.g. right center). Note the shape of fossils (far left center). Fractures are induced and the precise determination of open or effective thin section porosity is highly subjective.



Pore Types

Intergranular:	minor
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample:	**07USA0025**
Lithofacies:	Litho 2
Rock Name:	**Litharenite**

Reservoir Properties

TS Porosity (%):	3
Core Porosity (%):	~6
Kmax (md):	<0.10
Grain Size:	fL
Sorting:	moderate

PHOTO C: 200x, plane light

High magnification view further shows the foliated texture of a bivalve (pelcypod) fossil near the center and the high volume of calcite cement (stained light pink). Induced fractures are also evident.

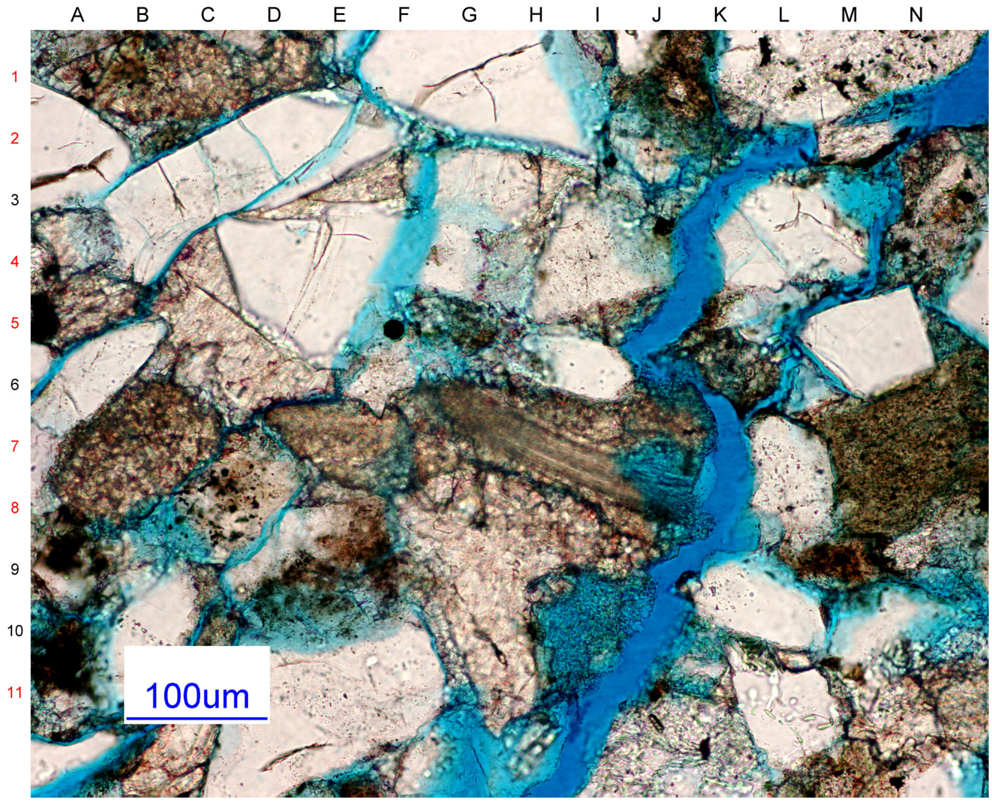
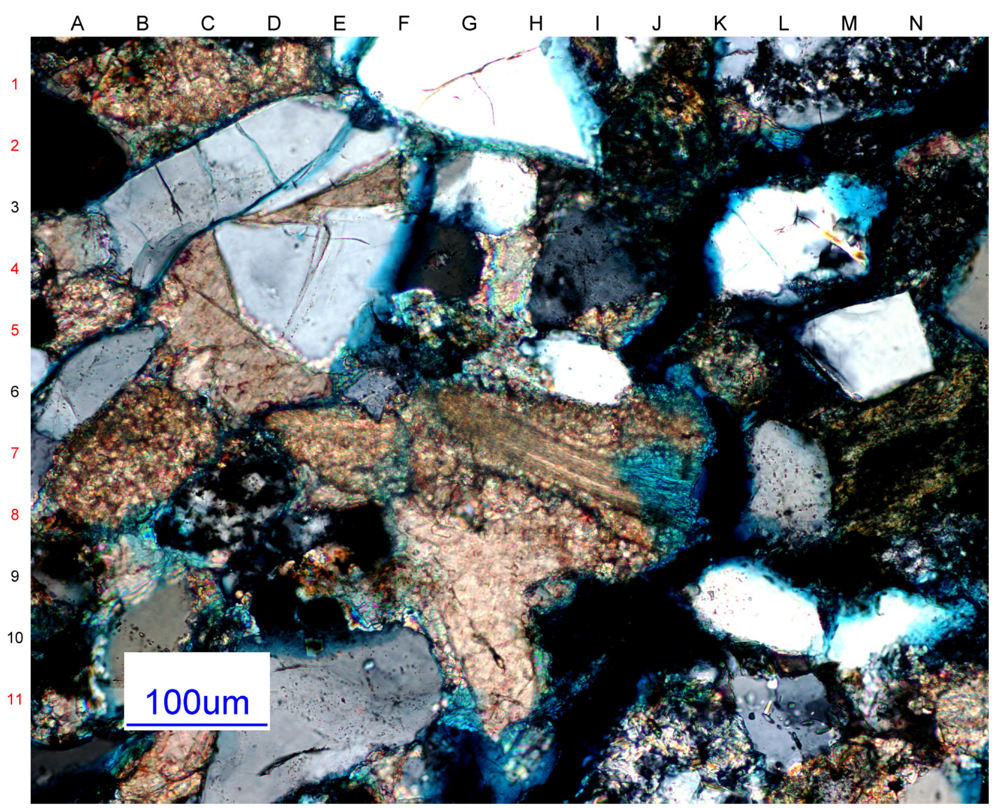


PHOTO D: 200x, cross nicols

High magnification cross polarized view details the high birefringence of calcite cement (e.g. lower center) and the undulatory or sweeping extinction and low birefringence of quartz grains. Note a carbonate lithoclast (i.e. grain) int he far left center.



Pore Types

Intergranular:	minor
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample: 07USA0027
Lithofacies: Litho 3
Rock Name: **Shale**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.01
Grain Size:	n.a.
Sorting:	n.a.

PHOTO A: 100x, plane light

High magnification view shows an organic-rich shale. Opaque fragments are organic material and the orange-brown matrix is clays (image is over-exposed to show the texture). "Bright" areas are mainly quartz silt grains.

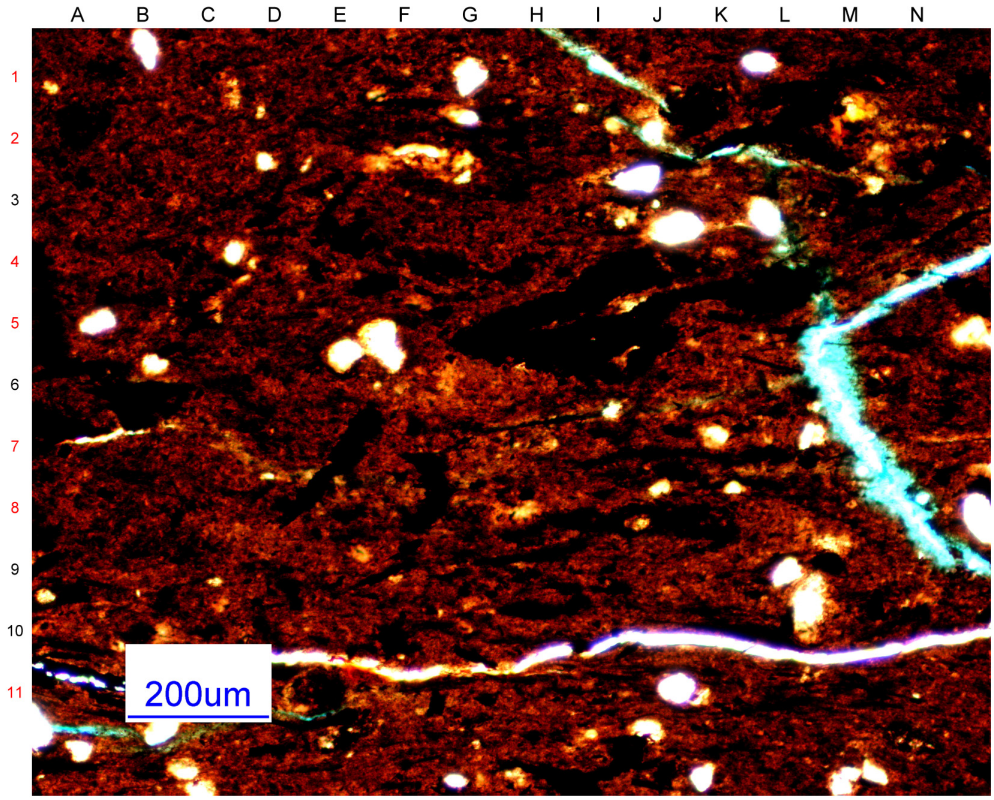
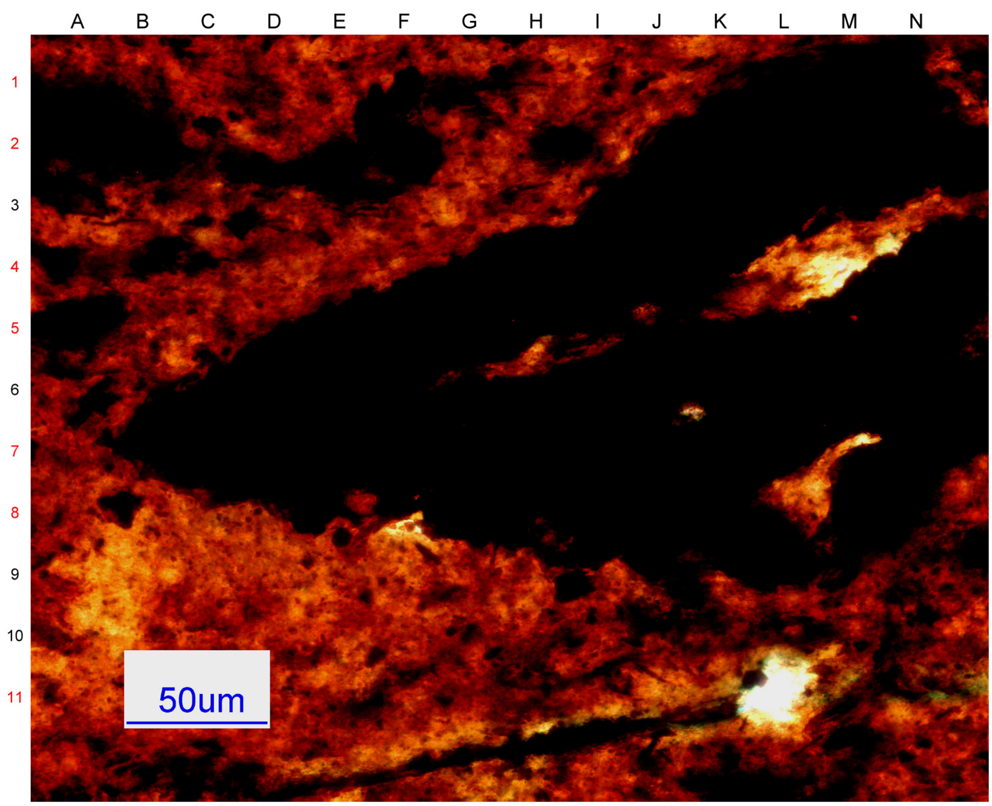


PHOTO B: 400x, plane light

High magnification view details the texture of opaque organic fragments. Microporosity is the main pore type. Most of the large open fractures (see macroview image on opposite page) are interpreted as induced.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample:	**07USA0027**
Lithofacies:	Litho 3
Rock Name:	**Shale**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.01
Grain Size:	n.a.
Sorting:	n.a.

PHOTO C: 100x, plane light
High magnification view shows open fractures partially cemented with quartz and/or micro-silica (e.g. upper and lower center). Note quartz silt grains in the opaque matrix.

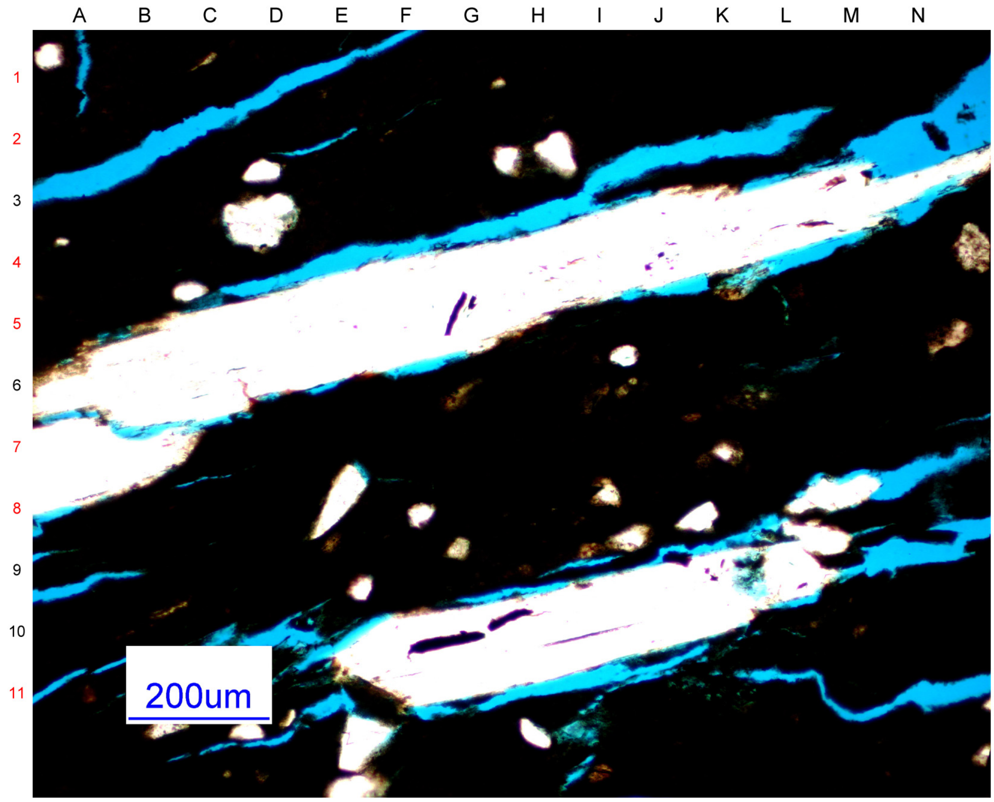
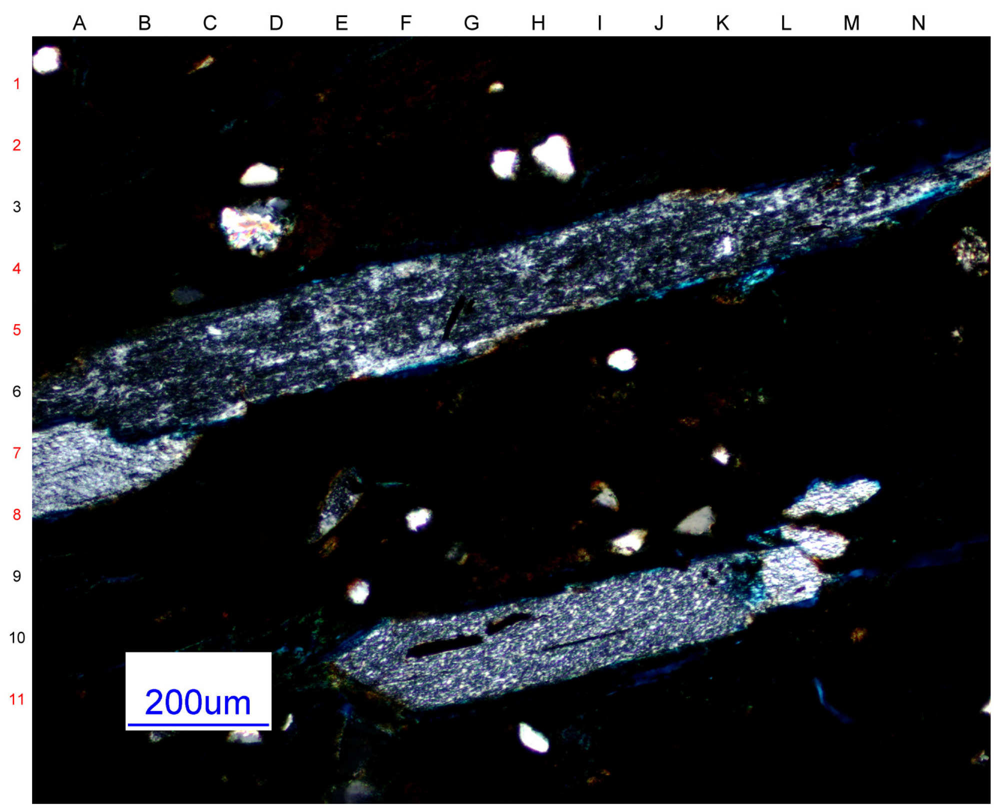


PHOTO D: 100x, cross nicols
High magnification view of Photo C taken under cross nicols details the birefringence and texture of quartz/micro-silica cement within open fractures. Other areas show the opaque matrix and low birefringence of quartz silt grains.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample:	**07USA0028**
Lithofacies:	Litho 2
Rock Name:	**Litharenite**

Reservoir Properties

TS Porosity (%):	7
Core Porosity (%):	~11
Kmax (md):	~1
Grain Size:	fL
Sorting:	moderate

PHOTO A: 40x, plane light

Low magnification view shows a lower fine grained, moderately sorted litharenite. Thin section (effective) porosity is 7%. Microporosity is ~35% of the total porosity (i.e. ~1/3). Calcite (stained pink) is the main cement.

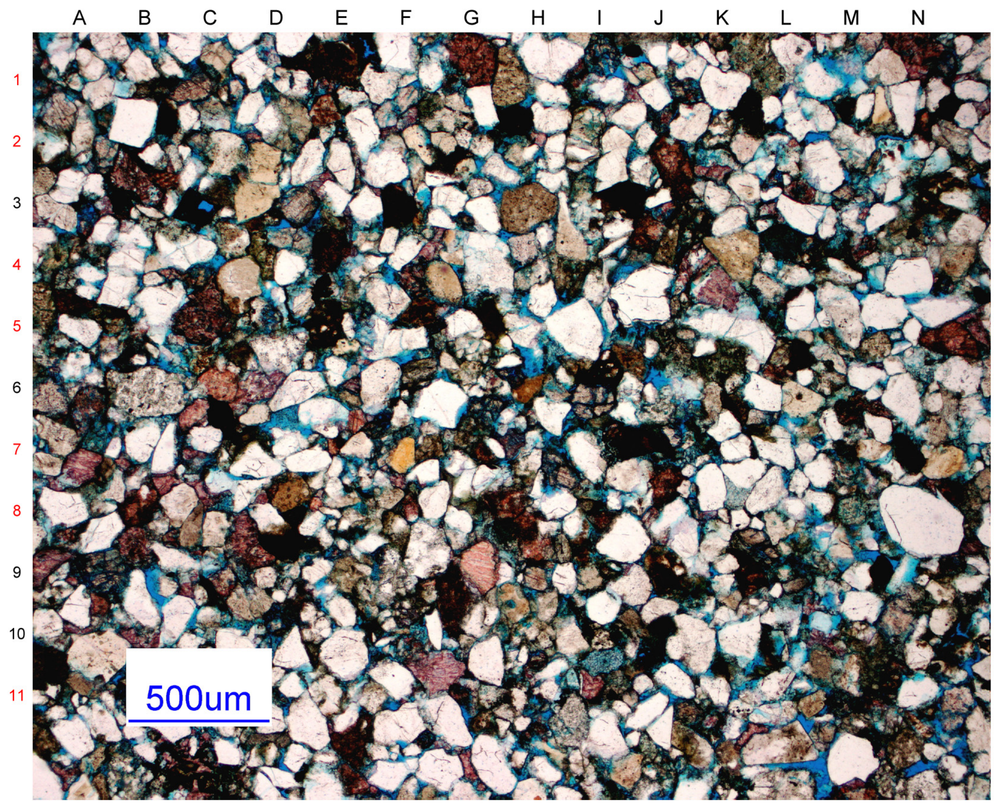
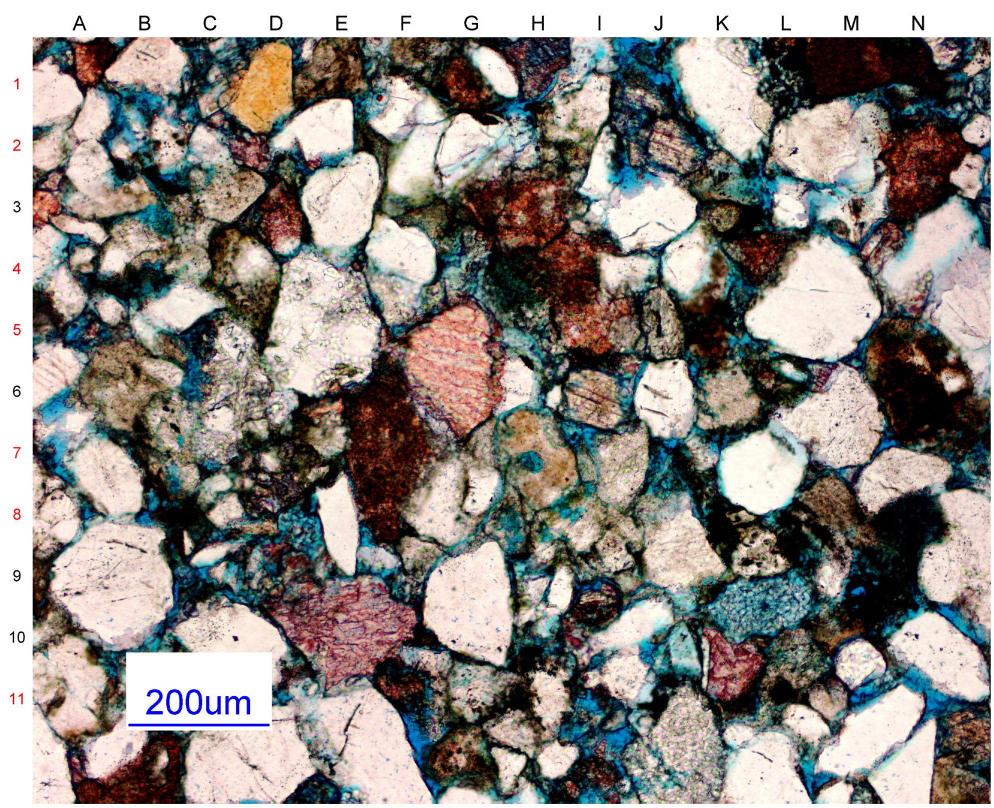


PHOTO B: 100x, plane light

High magnification view details the preservation of effective porosity (stained with blue dyed epoxy). Calcite (pink) is the main cement with common kaolinite (milky white clay booklets near the lower right) and lesser dolomite (non-stained rhombic crystals near the center).



Pore Types

Intergranular:	main
Secondary:	minor
Intragranular:	minor
Microporosity:	common

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample: **07USA0028**
Lithofacies: Litho 2
Rock Name: **Litharenite**

Reservoir Properties
TS Porosity (%): 7
Core Porosity (%): ~11
Kmax (md): ~1

Grain Size: fL
Sorting: moderate

PHOTO C: 200x, plane light
High magnification view further details calcite (pink), dolomite (e.g. far right center) and kaolinite (milky white) cements. Note partial chert grain dissolution (bottom right) and a calcareous lithoclast (bottom center).

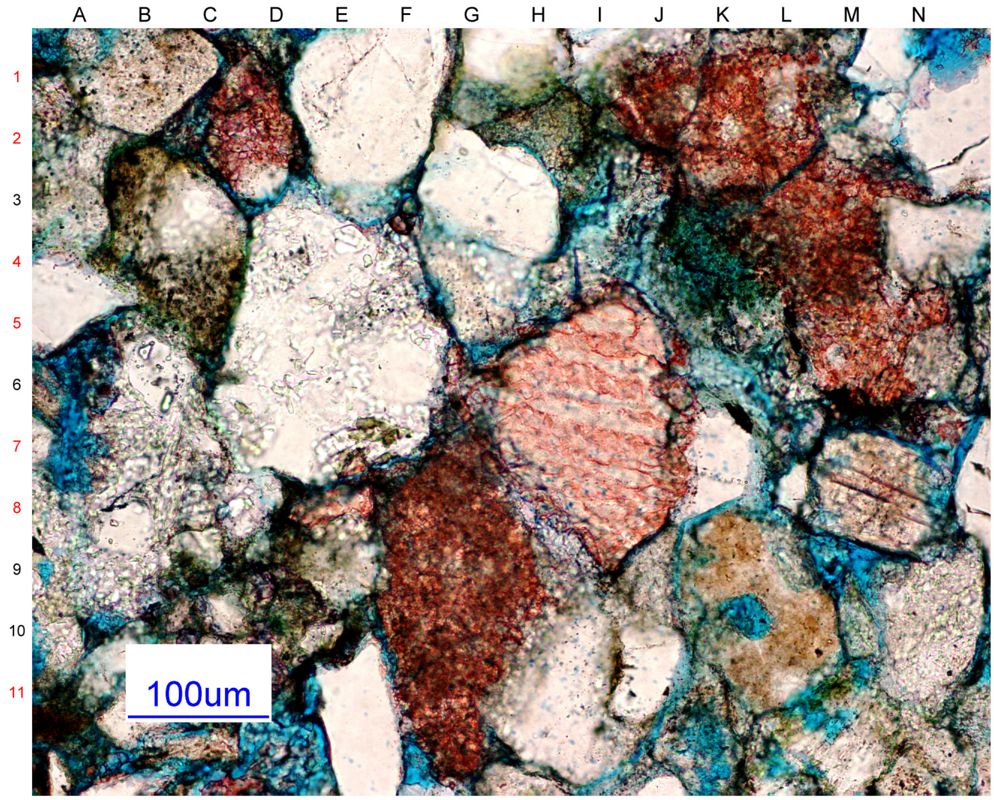
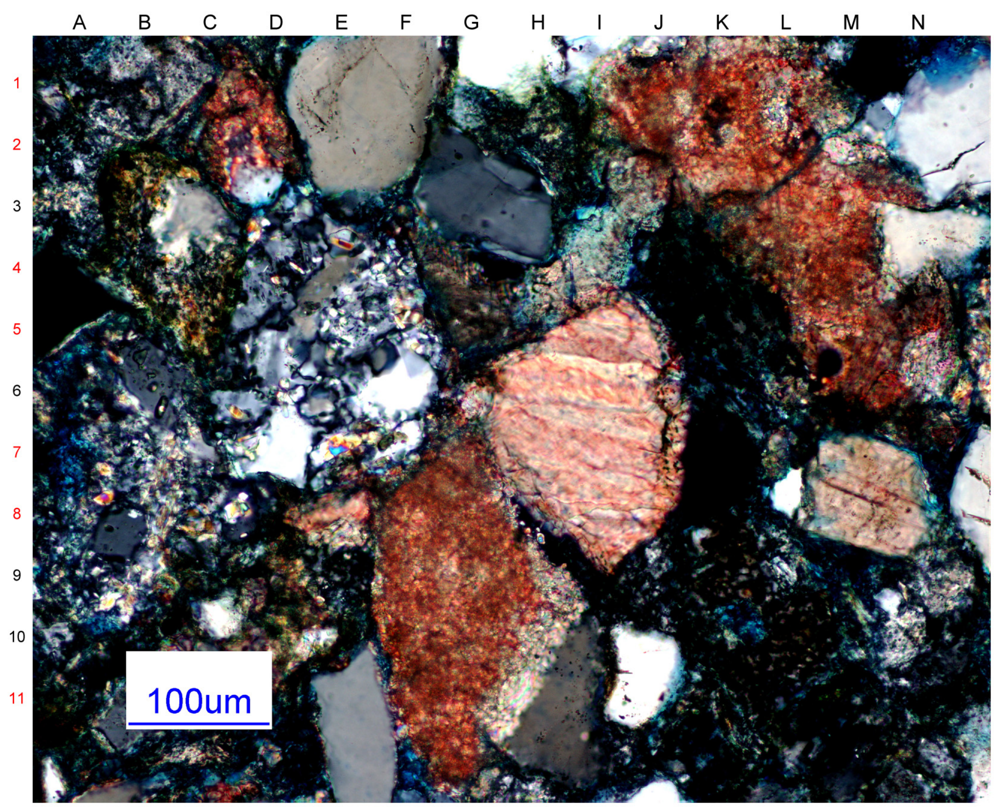


PHOTO D: 200x, cross nicols
High magnification view taken under cross polarized light details the minerals described above. In addition, note the texture of polycrystalline quartz (upper left) as well as an igneous lithoclast (far left center).



Pore Types
Intergranular: main
Secondary: minor
Intragranular: minor
Microporosity: common

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample: **07USA0030**
Lithofacies: Litho 2
Rock Name: **Litharenite**

Reservoir Properties

TS Porosity (%): 4
Core Porosity (%): ~7
Kmax (md): ~0.5

Grain Size: fL
Sorting: mod well

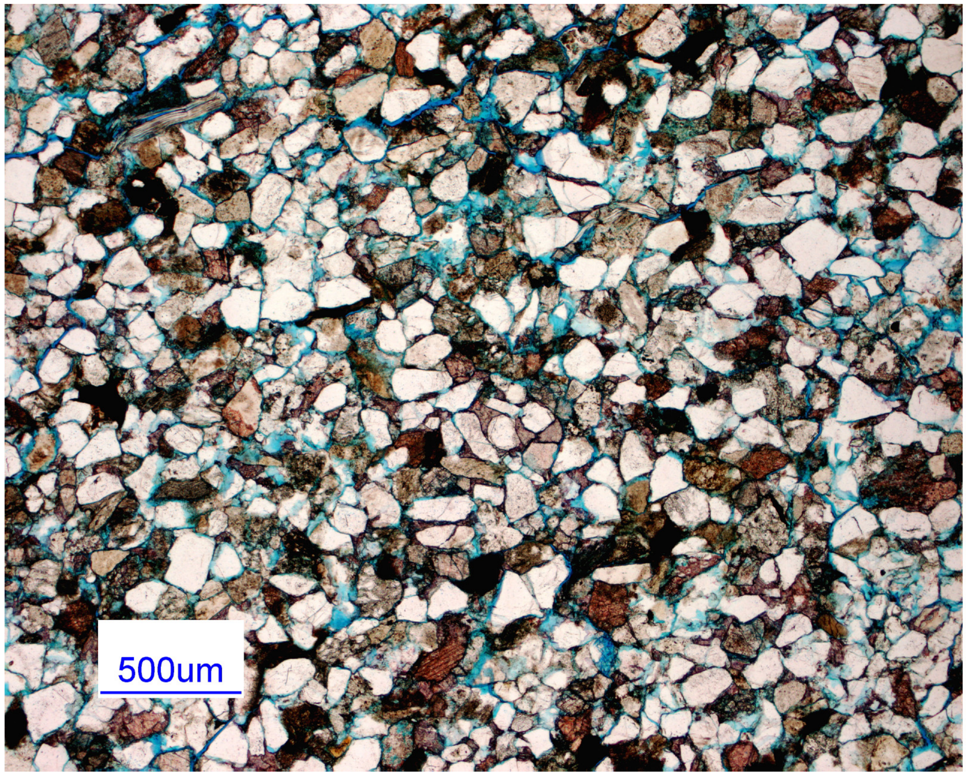


PHOTO A: 40x, plane light
Low magnification view shows a lower fine grained, moderately well sorted litharenite. Note the relatively good sorting. Lower porosity compared with the previous sample 07USA0028 reflects the higher volume of calcite and dolomite cements.

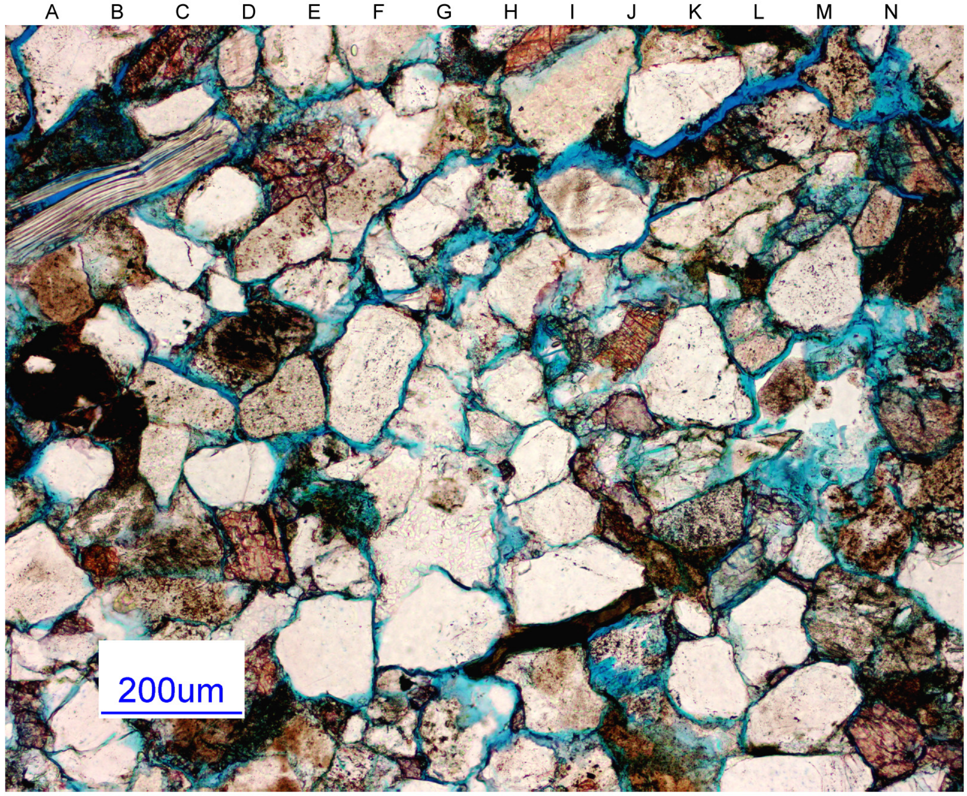


PHOTO B: 100x, plane light
High magnification view details the preservation of effective porosity (stained with blue dyed epoxy). Note a platy clear muscovite grain (top left) and a compacted brown and platy biotite grain (lower center). Open pores are lined with a thin layer of clay cement (likely illite; however, XRD is the best tool to determine the clay mineralogy).

Pore Types
Intergranular: main
Secondary: minor
Intragranular: minor
Microporosity: common

Geological JMS Consultants

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample:	**07USA0036**
Lithofacies:	Litho 2
Rock Name:	**Litharenite**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~3
Kmax (md):	<0.10
Grain Size:	fU
Sorting:	moderate

PHOTO A: 40x, plane light

Low magnification view shows an upper fine grained, moderately sorted litharenite. Porosity is destroyed by non-ferroan calcite (stained pink).

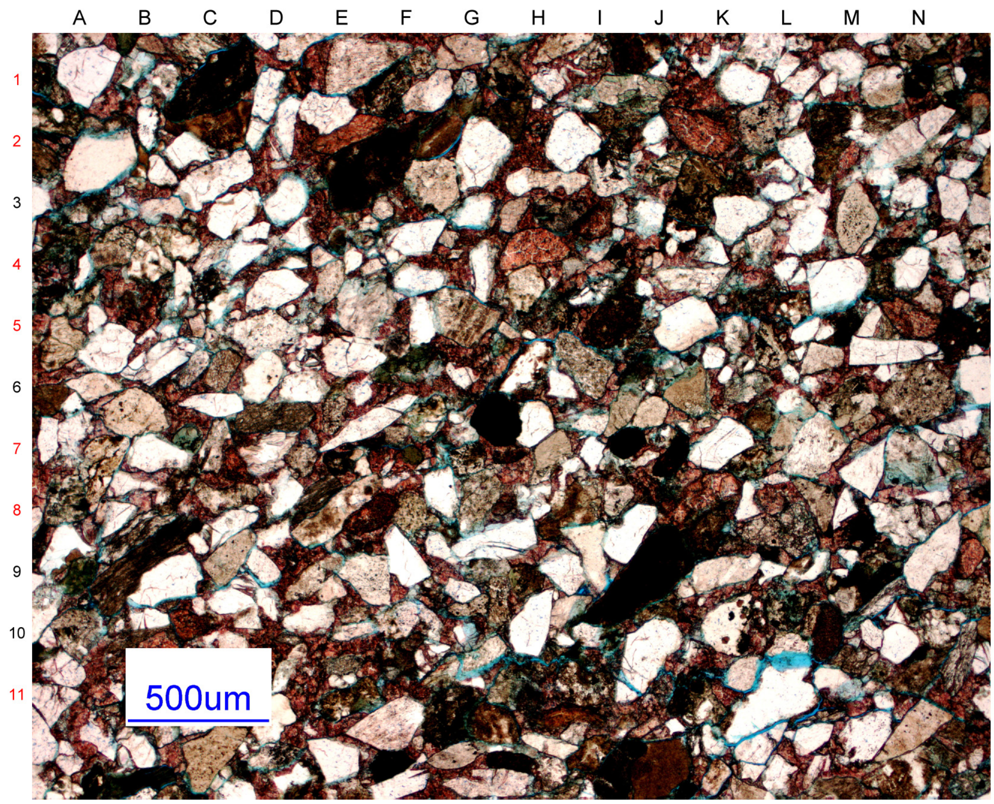
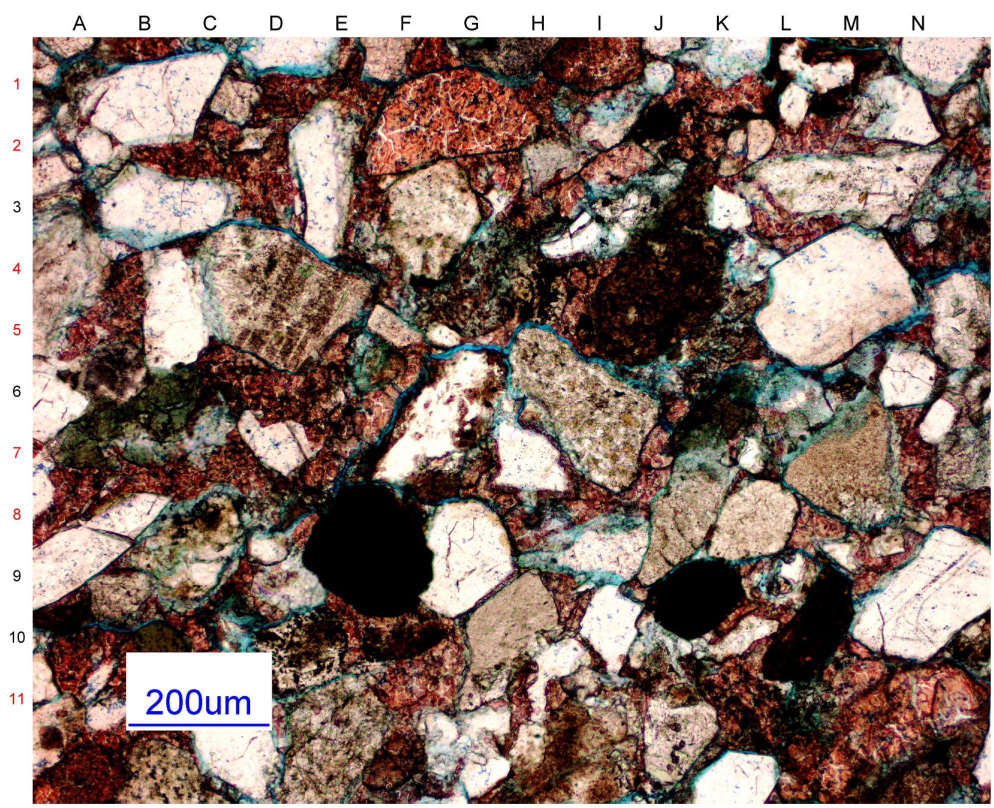


PHOTO B: 100x, plane light

High magnification view details the significance of calcite cement which completely occluded primary porosity. Note accessory glauconite (green colored mineral in the far left center) which suggest a marine influence in the depositional environment.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample: **07USA0091**
Lithofacies: Litho 4
Rock Name: **Feld. Litharenite**

Reservoir Properties
TS Porosity (%): <1
Core Porosity (%): ~1
Kmax (md): <0.01

Grain Size: vfL
Sorting: poor

PHOTO A: 40x, plane light
Low magnification view shows a lower very fine grained, poorly sorted feldspathic litharenite grading into a sandy dolomite. Dolomite accounts for ~1/2 of the total sample composition.

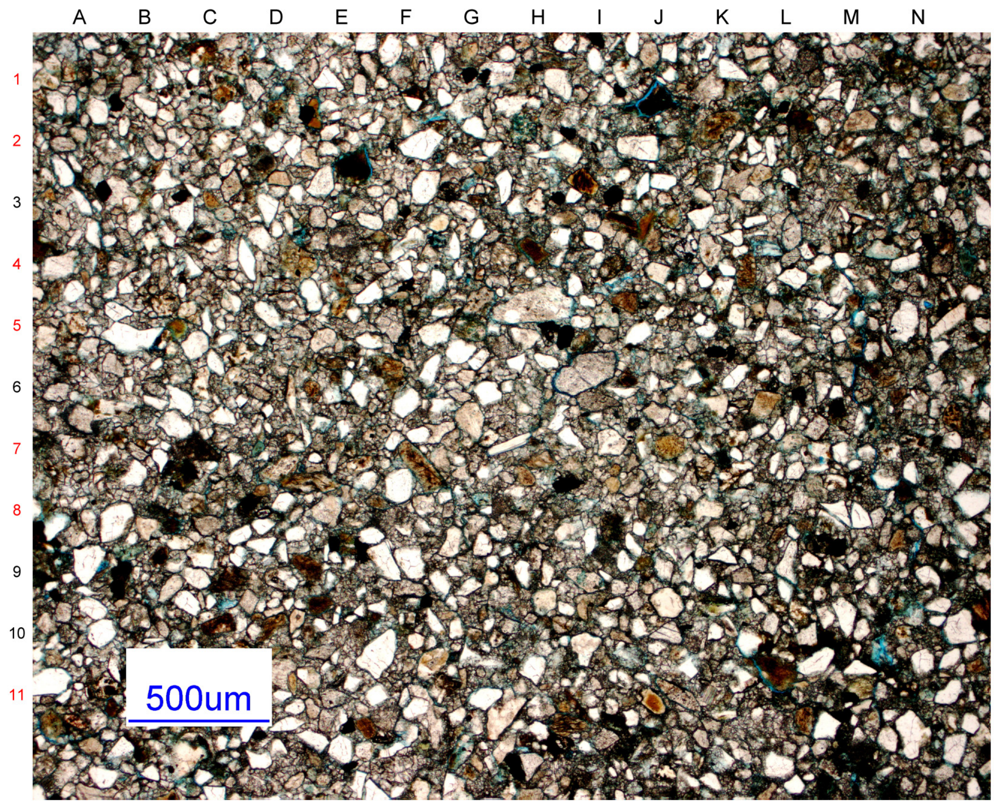
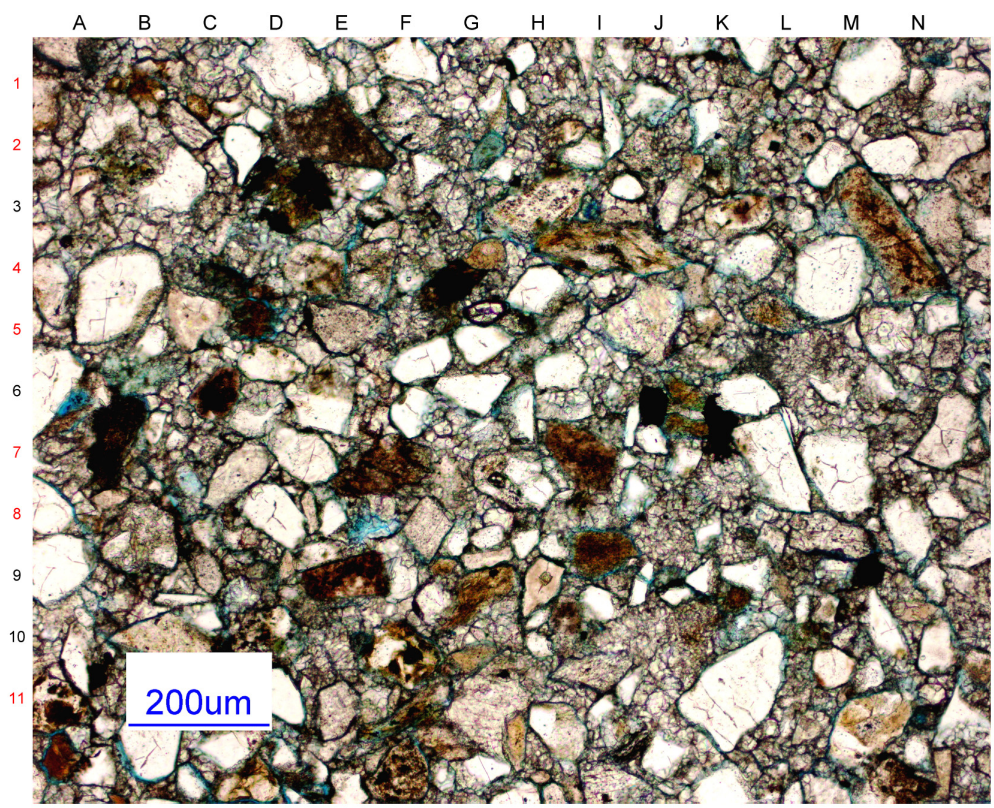


PHOTO B: 100x, plane light
High magnification view details framework grains almost floating in the tightly interlocking silt to very finely crystalline dolomite matrix. The sample is tight.



Pore Types
Intergranular:
Secondary:
Intragranular: main
Microporosity:

ALBERTA GEOLOGICAL SURVEY
Formation: Willow Creek

JMS 07-3533
2007-11-26

Sample: **07USA0036**
Lithofacies: Litho 5
Rock Name: **Packstone**

Reservoir Properties
TS Porosity (%): <1
Core Porosity (%): ~3
Kmax (md): <0.10

Grain Size: mL-vcU
Sorting: poor

PHOTO A: 40x, plane light
Low magnification view shows a peloidal packstone (Dunham, 1962). Macroview image (opposite page) further shows the variable grain size of rounded peloids or intraclasts? cemented with mainly blocky spar and lesser dolomite. Possible mudcracks are also infilled with blocky spar (see left portion of macroview image).

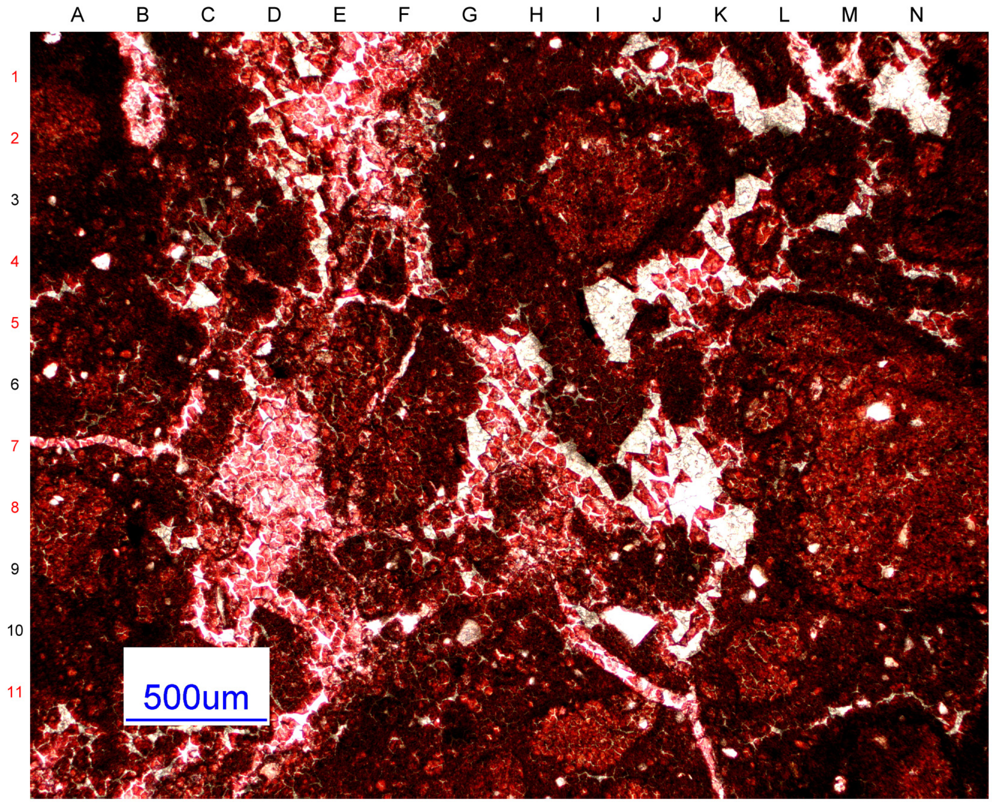
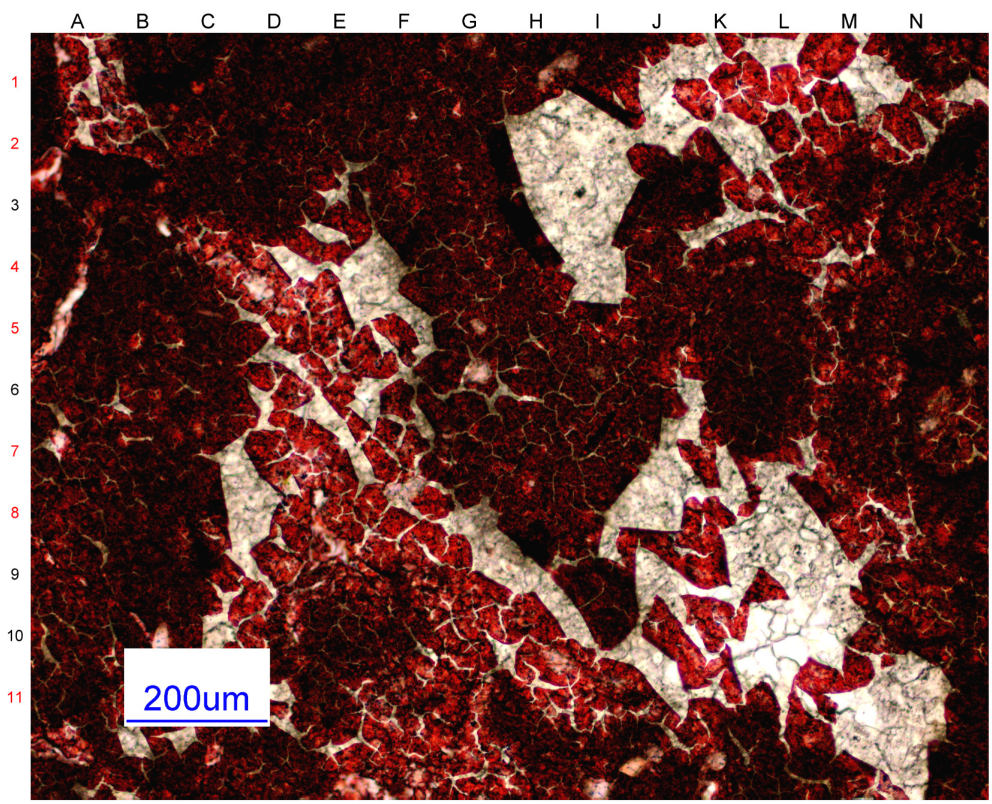


PHOTO B: 100x, plane light
High magnification view details calcite (pink stain) and dolomite (non-stained) cements. Micrite-rich peloids (top center) and micrite matrix (center) is often difficult to differentiate. Note tightly interlocking dolomite crystals (bottom right).



Pore Types
Intergranular: main
Secondary:
Intragranular:
Microporosity:

ALBERTA GEOLOGICAL SURVEY
Formation: St. Mary River

JMS 07-3533
2007-11-26

Sample: 06USA0024
Lithofacies: Litho 1
Rock Name: **Shale**

Reservoir Properties
TS Porosity (%): <1
Core Porosity (%): ~5
Kmax (md): <0.10

Grain Size: n.a.
Sorting: n.a.

PHOTO A: 40x, plane light
Low magnification view shows an organic-rich shale (i.e. highly opaque). The high radioactivity in this sample is not apparent in the opaque thin section (?possibly radioactive illite clays, need XRD analysis to confirm clay mineralogy). Mudcracks? and/or fractures are infilled with quartz.

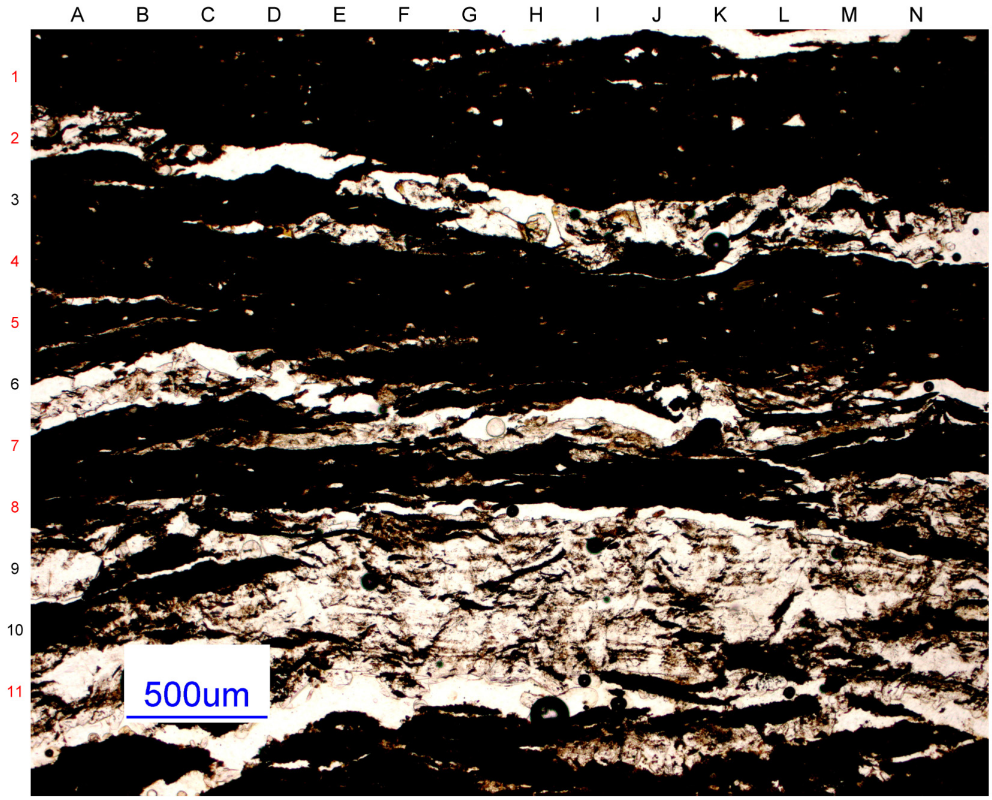
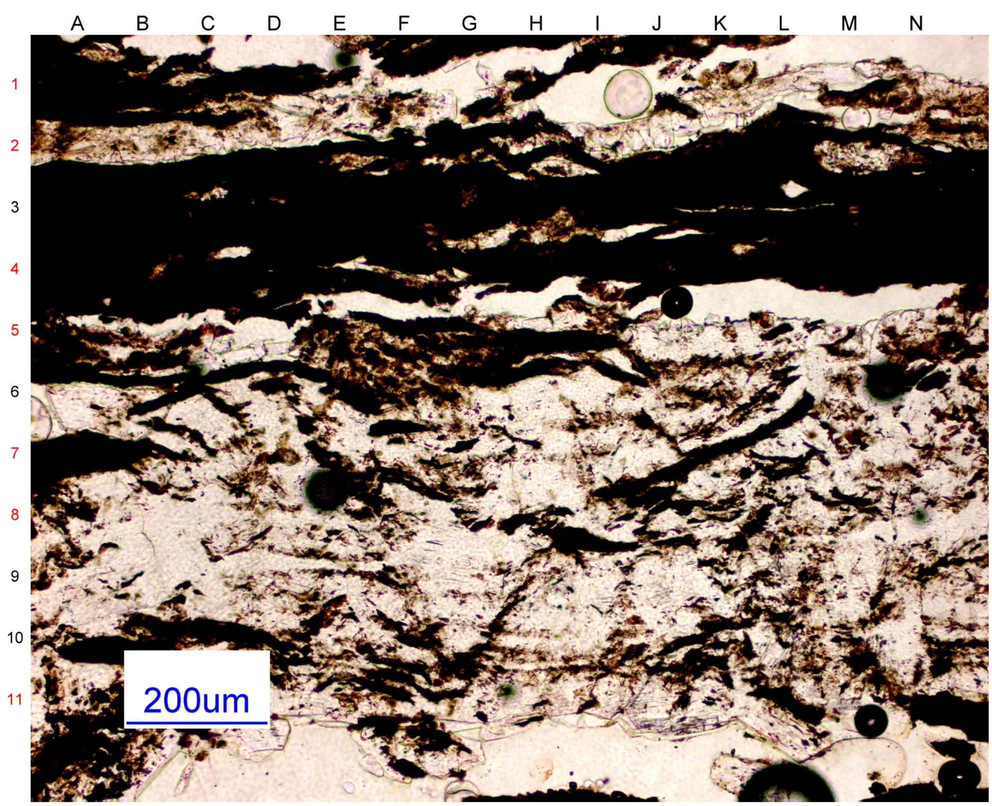


PHOTO B: 100x, plane light
High magnification view details quartz-filled fractures and/or mudcracks often aligned parallel to suspected bedding. The quartz identification is based upon the white color in plane light and low birefringence under cross nicols. The highly opaque matrix is most likely organic-rich.



Pore Types
Intergranular:
Secondary:
Intragranular:
Microporosity: main

ALBERTA GEOLOGICAL SURVEY
Formation: St. Mary River

JMS 07-3533
2007-11-26

Sample: **06USA0024**
Lithofacies: Litho 1
Rock Name: **Shale**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.10
Grain Size:	n.a.
Sorting:	n.a.

PHOTO C: 200x, plane light
Higher magnification view further shows the white color of quartz-filled fractures and the opaque nature of detrital clay.

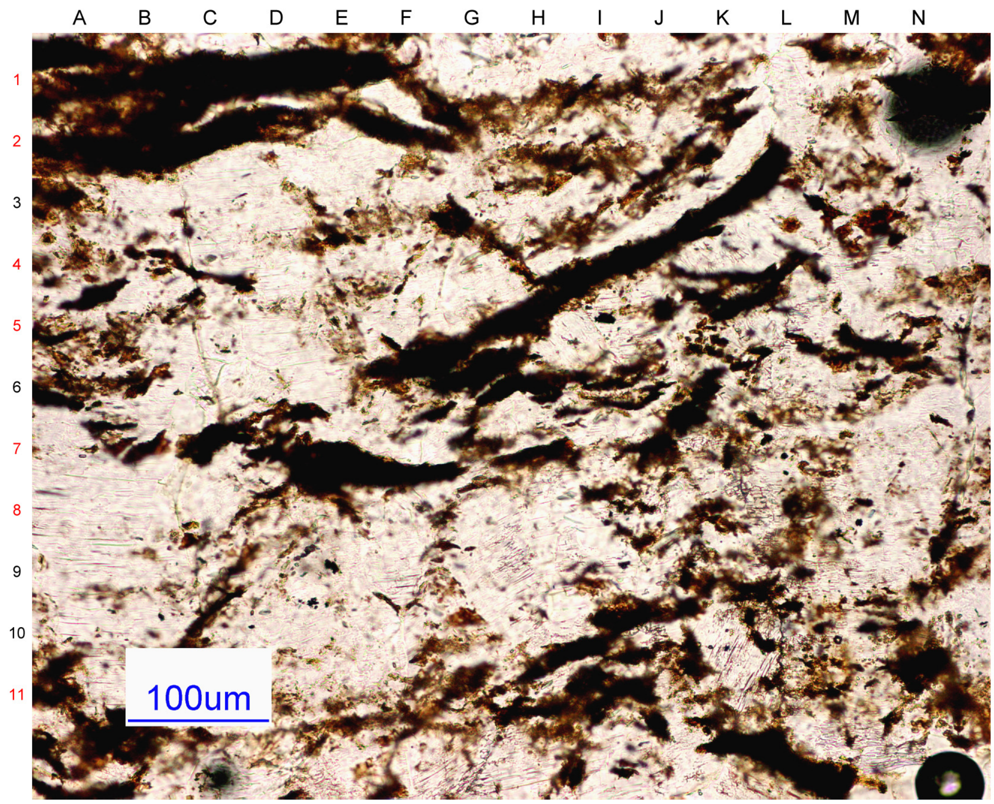
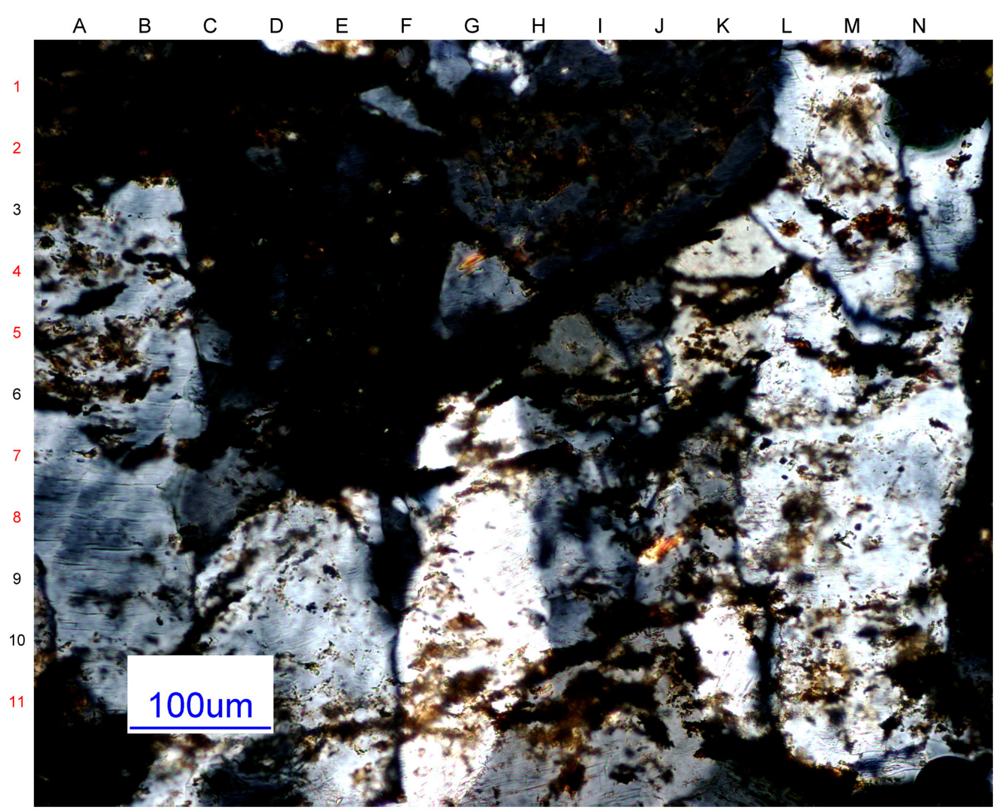


PHOTO D: 200x, cross nicols
High magnification view of Photo C taken under cross nicols details the undulatory extinction and low birefringence of this fracture filling mineral which is identified as quartz. The reason for the high radioactivity is uncertain.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: St. Mary River

JMS 07-3533
2007-11-26

Sample: 07USA0001
Lithofacies: Litho 2
Rock Name: Litharenite

Reservoir Properties
TS Porosity (%): 15
Core Porosity (%): ~20
Kmax (md): ~200

Grain Size: mL
Sorting: moderate

PHOTO A: 40x, plane light
Low magnification view shows a lower medium grained, moderately sorted litharenite. Thin section (effective) porosity is 15%. Microporosity is ~1/4 of the total porosity.

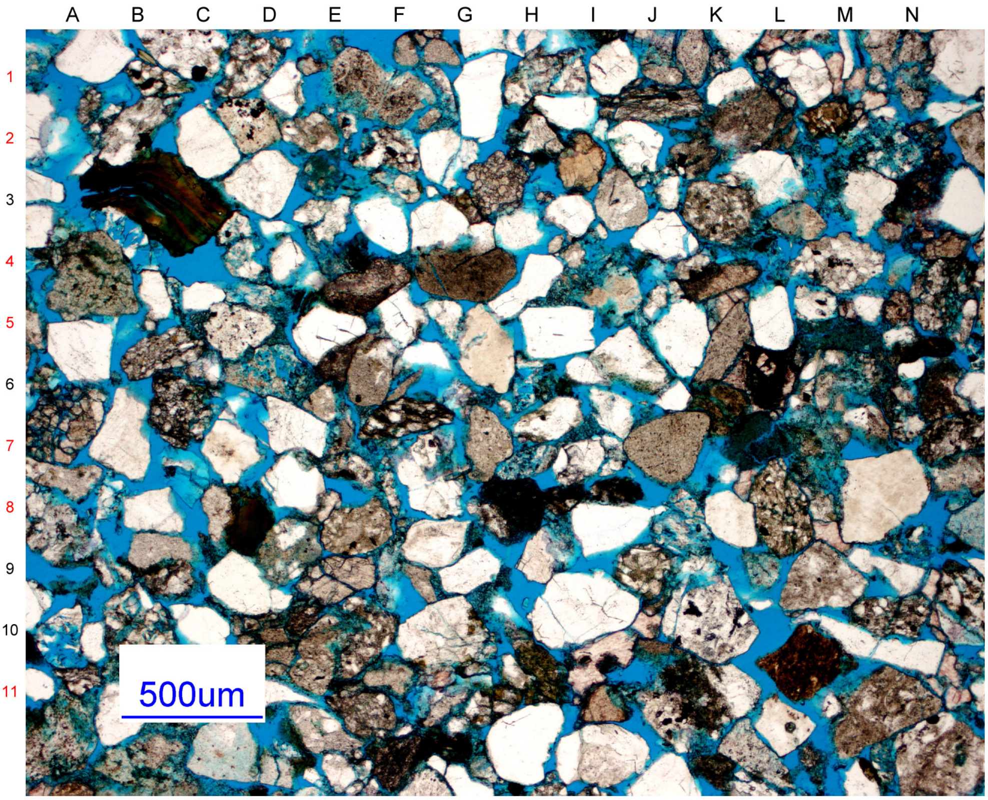
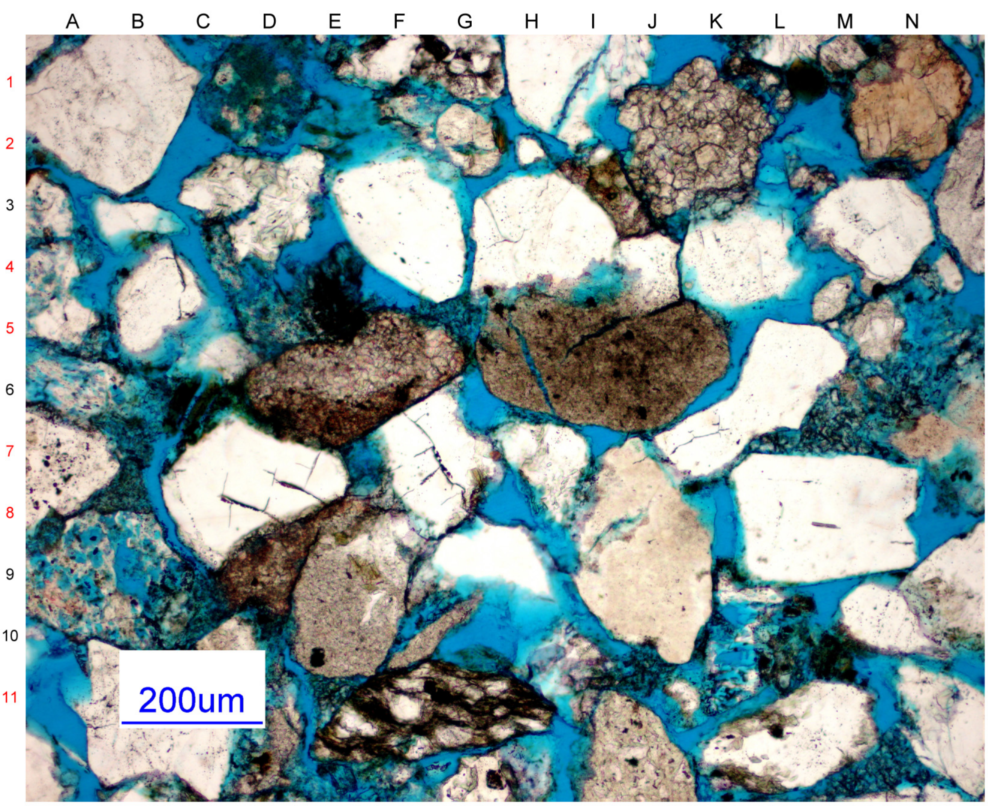


PHOTO B: 100x, plane light
High magnification view details the preservation of effective or primary intergranular porosity. Good reservoir quality (~200 md) reflects the medium grain size, relatively poor compaction and localized cements.



Pore Types
Intergranular: main
Secondary:
Intragranular: minor
Microporosity: minor

ALBERTA GEOLOGICAL SURVEY
Formation: St. Mary River

JMS 07-3533
2007-11-26

Sample:	**07USA0001**
Lithofacies:	Litho 2
Rock Name:	**Litharenite**

Reservoir Properties

TS Porosity (%):	15
Core Porosity (%):	~20
Kmax (md):	~200
Grain Size:	mL
Sorting:	moderate

PHOTO C: 200x, plane light

High magnification view details tightly interlocking crystals within a dolomite lithoclast (top left center) and clay inclusions with chert (lower left). Open porosity is partially cemented with calcite (top right with a pink stain), kaolinite (lower right center) and pore lining clay (e.g. thin clay rims near the center).

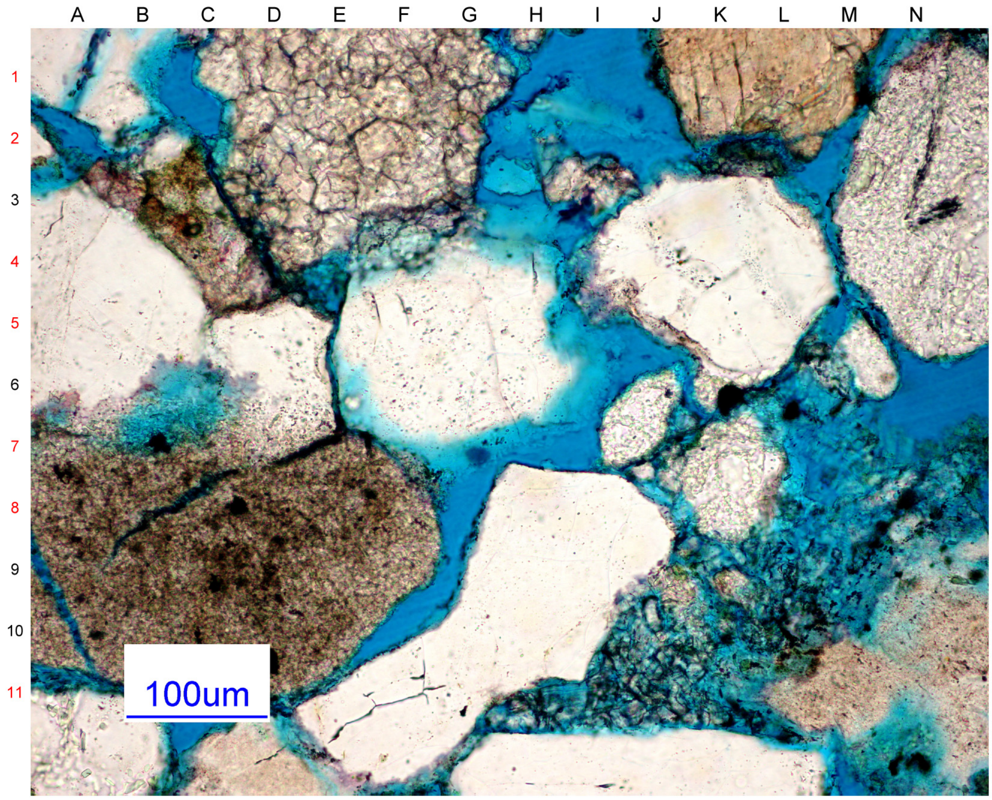
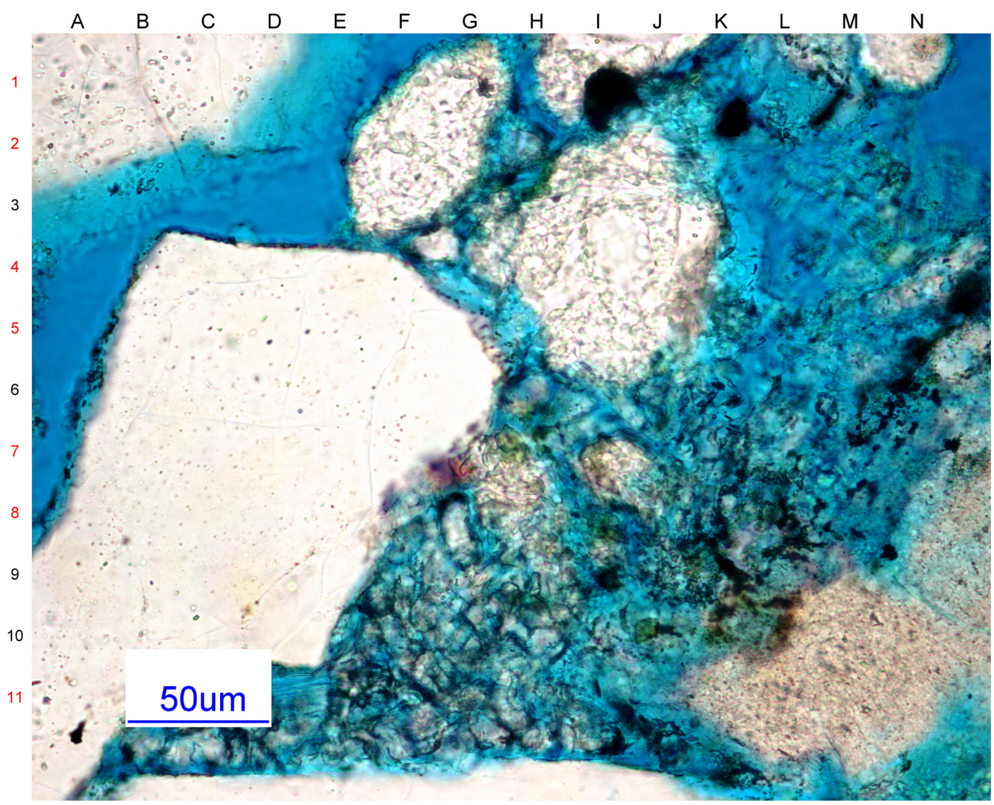


PHOTO D: 400x, plane light

High magnification view further details the milky white color and pseudo-hexagonal crystal morphology of kaolinite. Note microporosity between the clay booklets. Thin clay rims (upper left) may have a smectite composition (i.e. water-sensitive or swelling clay).



Pore Types

Intergranular:	main
Secondary:	
Intragranular:	minor
Microporosity:	minor

ALBERTA GEOLOGICAL SURVEY
Formation: St. Mary River

JMS 07-3533
2007-11-26

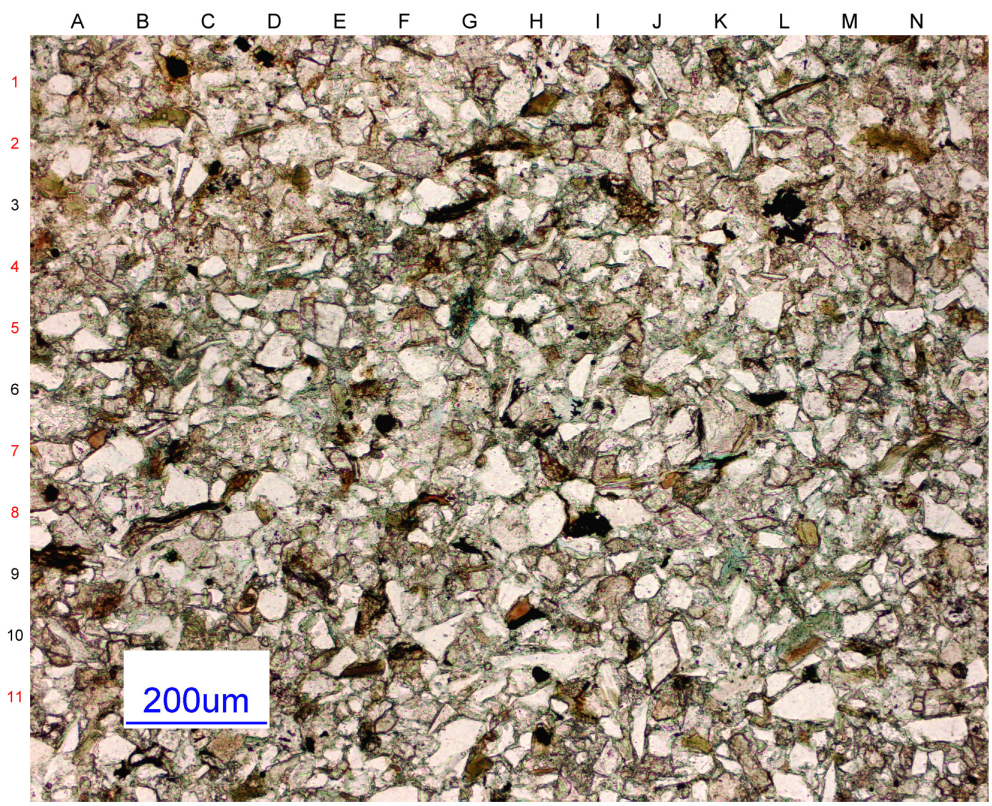
Sample: **07USA0078**
Lithofacies: Litho 3
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~4
Kmax (md):	<0.01
Grain Size:	cslt-vfU
Sorting:	poor

PHOTO A: 40x, plane light
Low magnification view shows a very fine grained, poorly sorted feldspathic litharenite. The sample is highly cemented with dolomite.

PHOTO B: 100x, plane light
High magnification view details the lack of open or effective porosity due to the significance of dolomite cement.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: St. Mary River

JMS 07-3533
2007-11-26

Sample: **07USA0078**
Lithofacies: Litho 3
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~4
Kmax (md):	<0.01

Grain Size:	cslt-vfU
Sorting:	poor

PHOTO C: 200x, plane light

Higher magnification view futher shows the silt to very fine grain size, high mica content (i.e. platy grains) and dolomite cementation (e.g. near center). Highly altered grains (upper right center) are feldspar.

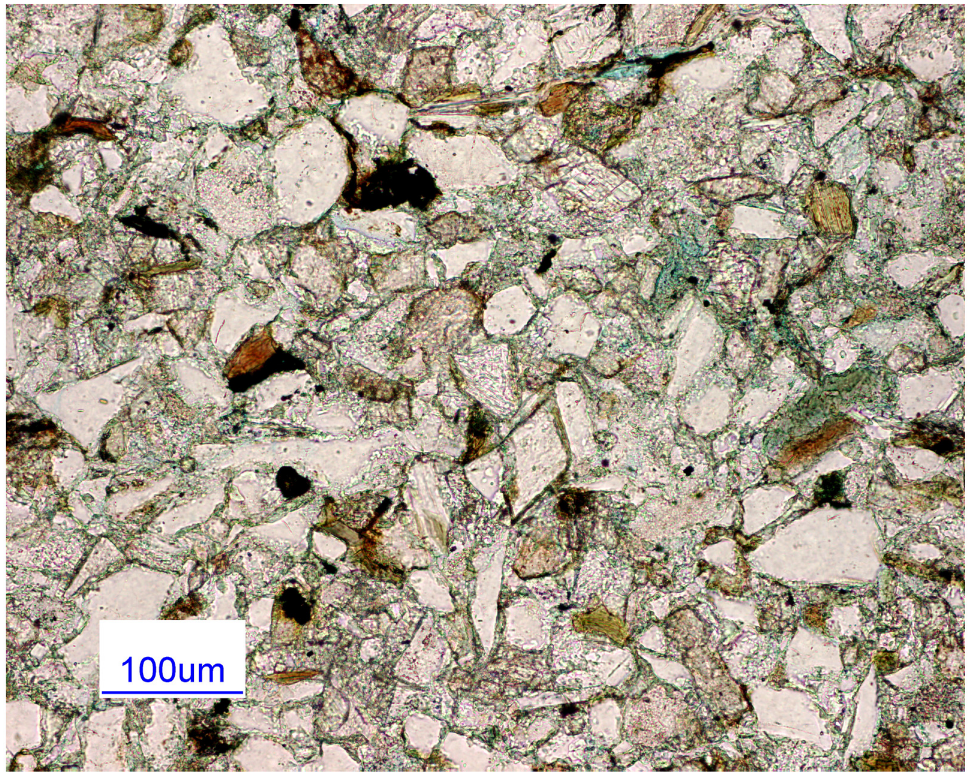
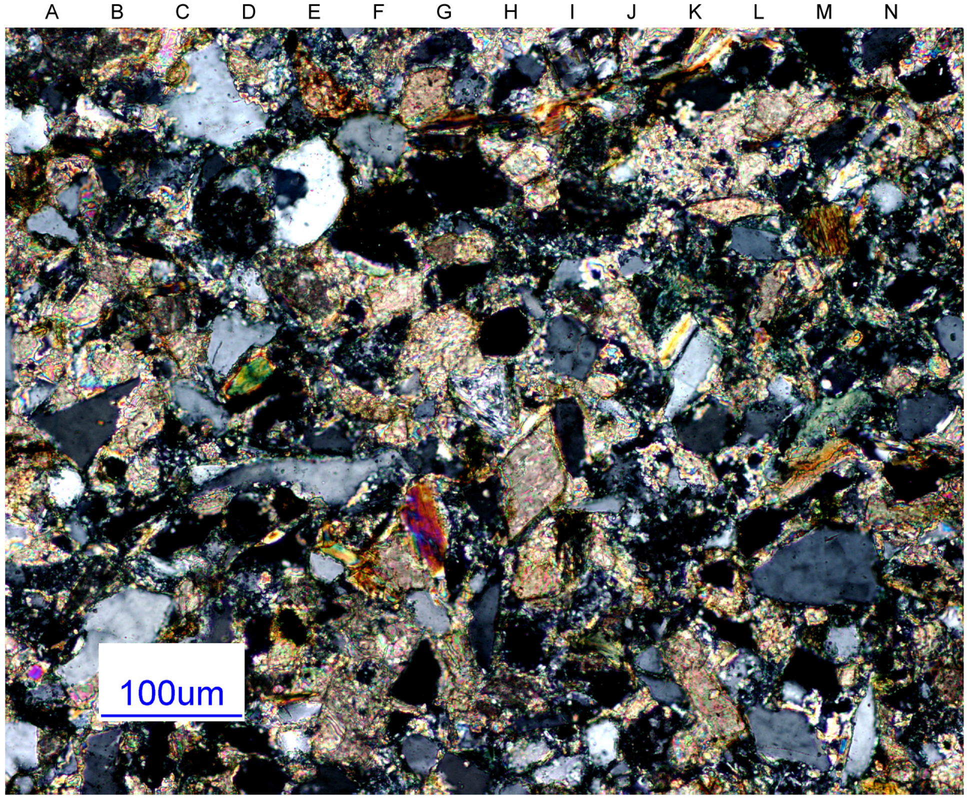


PHOTO D: 200x, cross nicols

High magnification view taken under cross polarized light better shows the extent of dolomite cement and the very high birefringence of platy muscovite grains.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: St. Mary River

JMS 07-3533
2007-11-26

Sample:	**07USA0082**
Lithofacies:	Litho 4
Rock Name:	**Shale**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.01
Grain Size:	n.a.
Sorting:	n.a.

PHOTO A: 100x, plane light

High magnification view shows an organic-rich shale (i.e. based upon the highly opaque nature of the slide). Polygonal fractures and/or mudcracks appear to be artifacts from the thin section manufacture process.

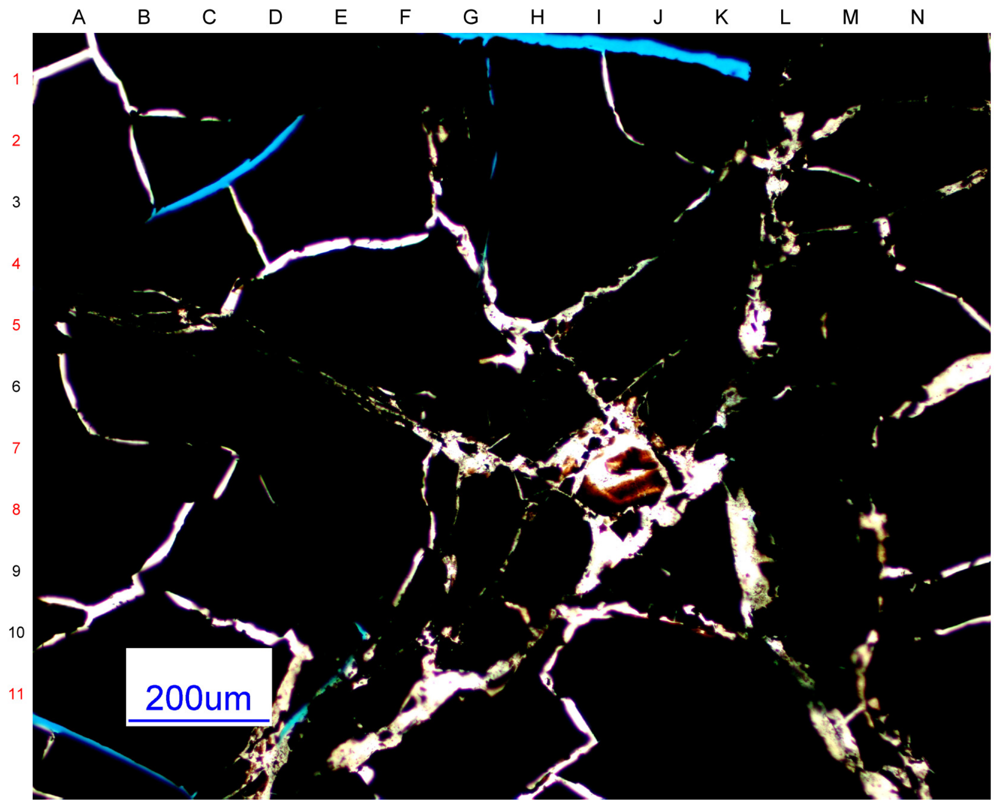
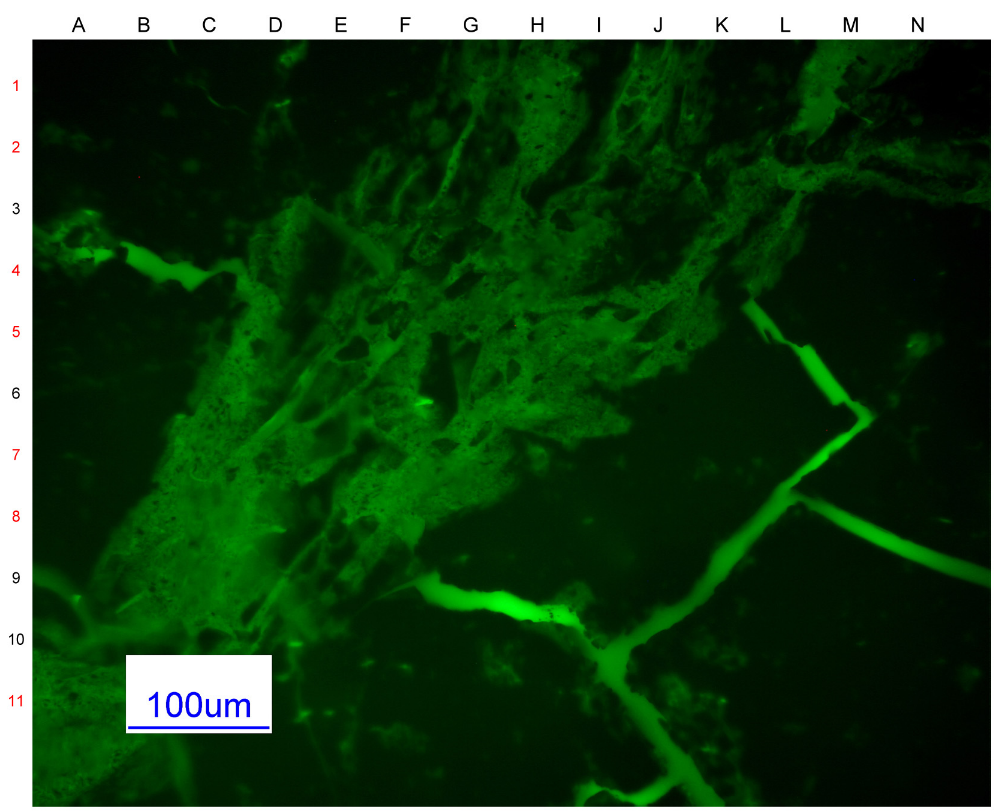


PHOTO B: 200x, UV

High magnification view taken under fluorescent light details micropores (light green) within the shale matrix. Note the lack of mineralization within the suspected induced fractures. The image is a close-up of Photo A (i.e. bottom center portion).



Pore Types

Intergranular:	
Secondary:	
Intragranular:	
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: St. Mary River

JMS 07-3533
2007-11-26

Sample: **07USA0085**
Lithofacies: Litho 5
Rock Name: **Shale**

Reservoir Properties
TS Porosity (%): <1
Core Porosity (%): ~5
Kmax (md): <0.01

Grain Size: n.a.
Sorting: n.a.

PHOTO A: 100x, plane light
High magnification view shows a shale with common organic / coaly material (bright yellow, orange and opaque). Note the laminated texture with organic material aligned parallel to bedding. Bright white areas represent quartz silt grains.

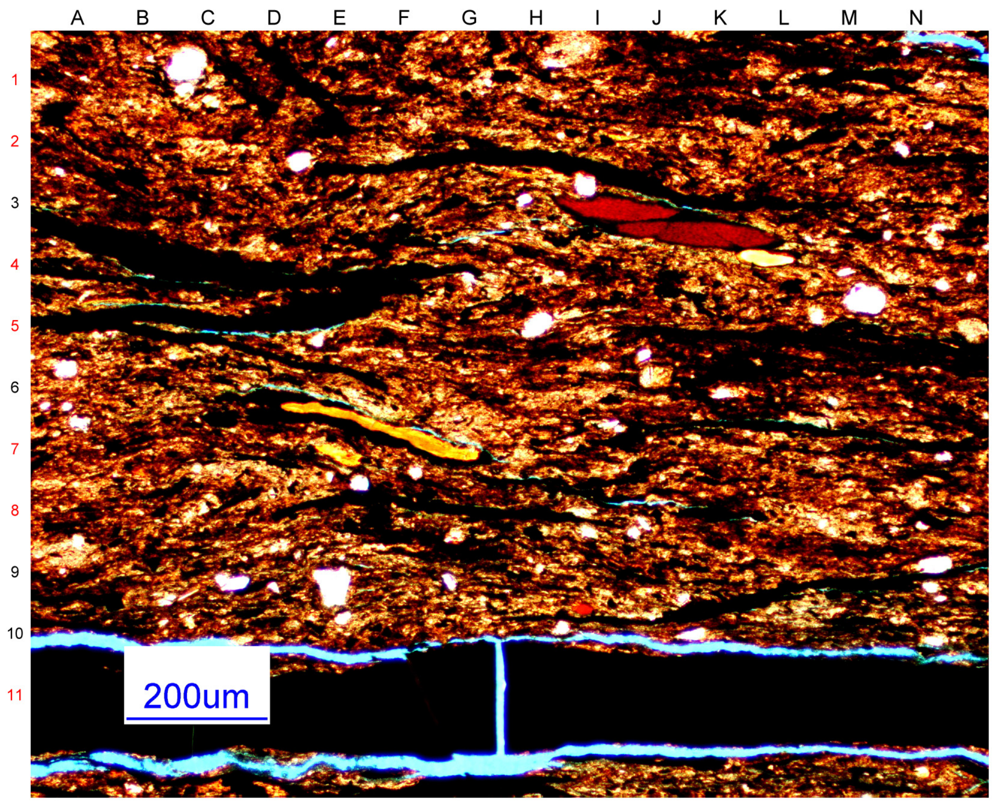
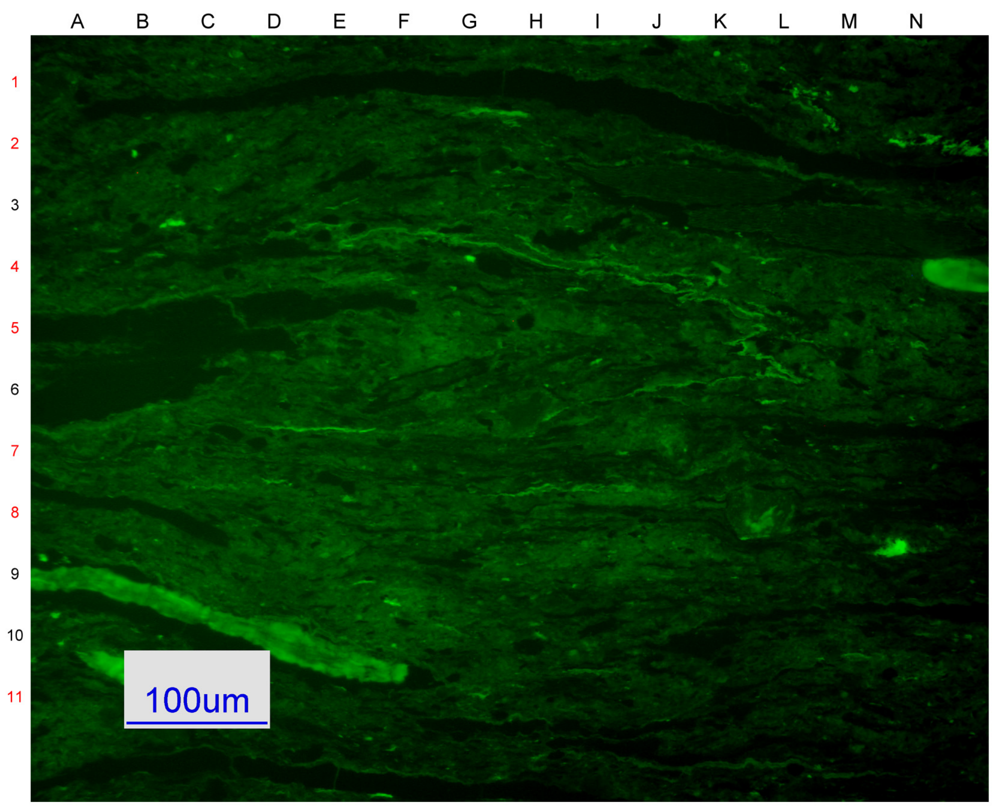


PHOTO B: 200x, UV
High magnification view taken under fluorescent light details the texture and microporosity within this rock type. Micropores are the "bright" areas of the image (e.g. bottom left within an organic fragment and top left within the clay matrix). Note pinch-out fractures (near left center) which are interpreted as natural.



Pore Types
Intergranular:
Secondary:
Intragranular:
Microporosity: main

ALBERTA GEOLOGICAL SURVEY
Formation:Whitemud

JMS 07-3533
2007-11-26

Sample: **06USA0071**
Lithofacies: Litho 1
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.10
Grain Size:	vfL-fL
Sorting:	poor

PHOTO A: 40x, plane light
Low magnification view shows a very fine to fine grained, poorly sorted argillaceous feldspathic litharenite. Microporosity is the dominant pore type.

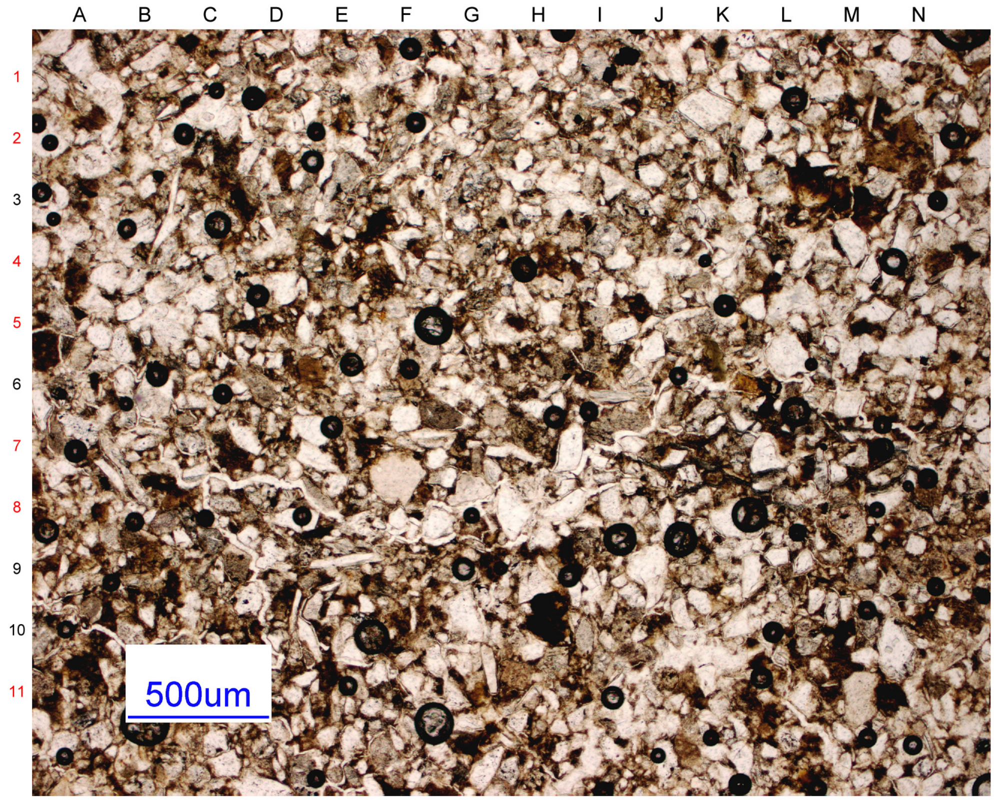
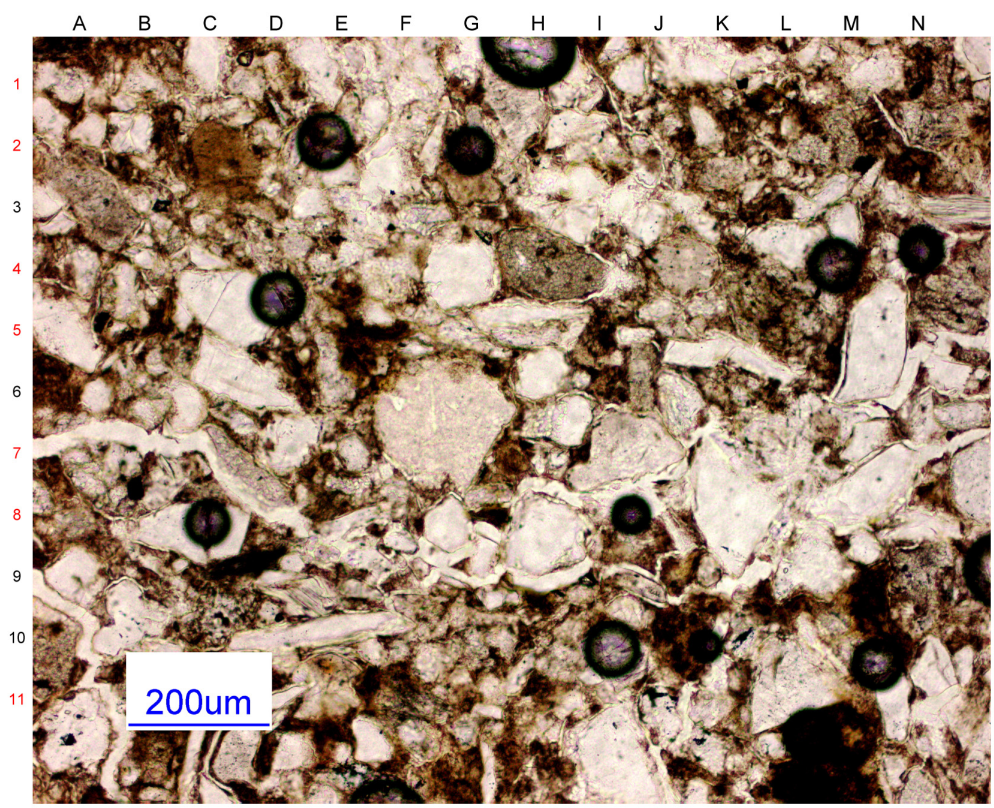


PHOTO B: 100x, plane light
High magnification view details the lack of open or effective porosity due to the high clay content. Circular images represent artifacts from the thin section manufacture process.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation:Whitemud

JMS 07-3533
2007-11-26

Sample: **06USA0071**
Lithofacies: Litho 1
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.10
Grain Size:	vfL-fL
Sorting:	poor

PHOTO C: 200x, plane light
High magnification view shows pore lining clay (right center) which may represent plant roots in this argillaceous sandstone. The precise distinction between pore lining clay, detrital clay and clay-rich grains is highly subjective.

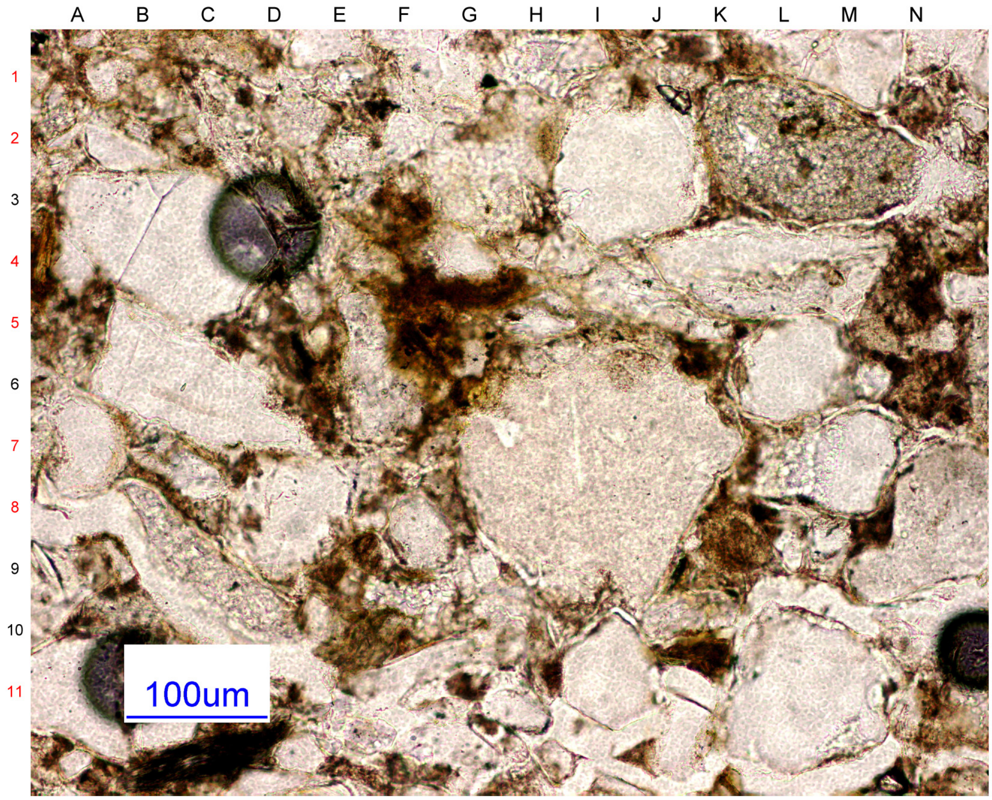
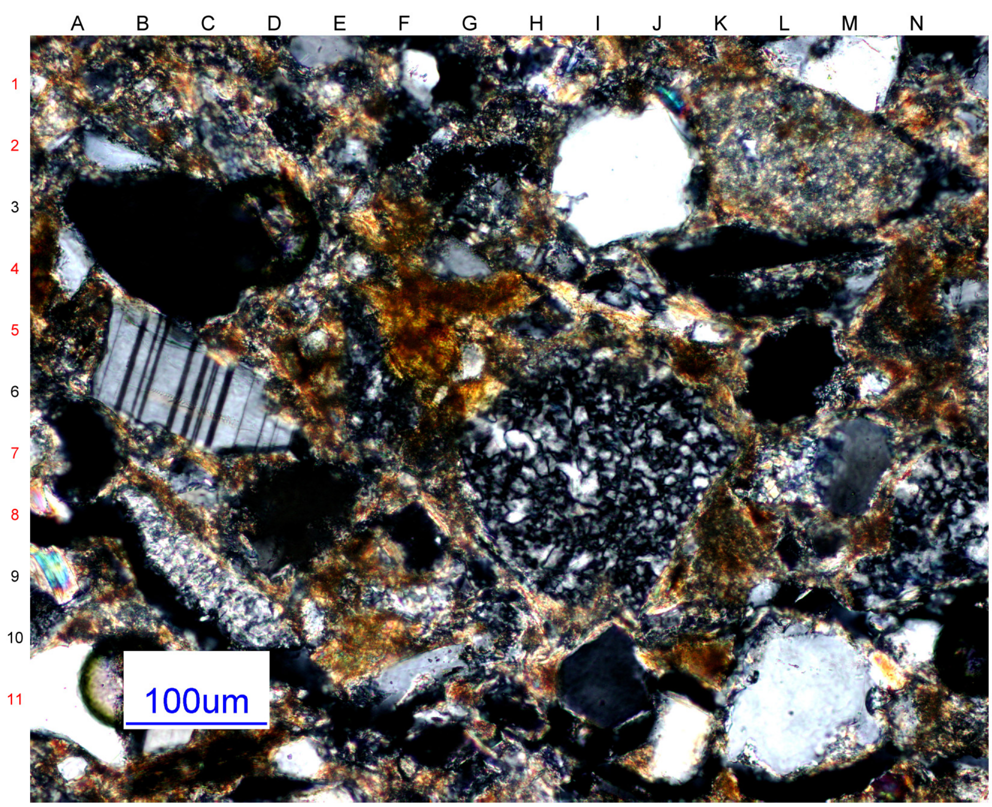


PHOTO D: 200x, cross nicols
High magnification view details the high birefringence of clay within sedimentary grains (upper left center) and pore lining clay (right center). Note the micro-silica texture of chert (center) and albite cleavage of plagioclase feldspar (left center).



Pore Types

Intergranular:	
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: Kneehills Tuff (Battle Formation)

JMS 07-3533
2007-11-26

Sample: **07USA0109**
Lithofacies: Litho 1
Rock Name: **Tuff**

Reservoir Properties
TS Porosity (%): <1
Core Porosity (%): ~3
Kmax (md): <0.01

Grain Size: n.a.
Sorting: n.a.

PHOTO A: 40x, plane light
Low magnification view shows a reworked volcanic ash deposit representing the Kneehills Tuff (Battle Formation). This highly radioactive zone is dominated by bentonitic clay (volcanic ash) with common quartz silt grains and abraded bivalve fossils.

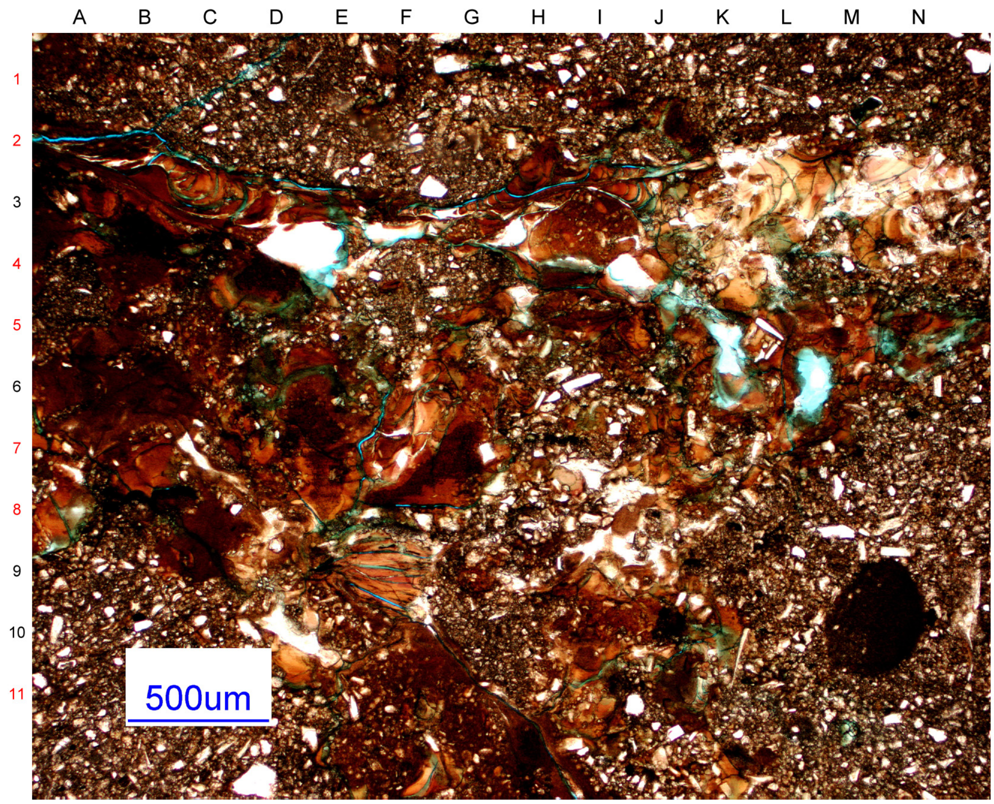
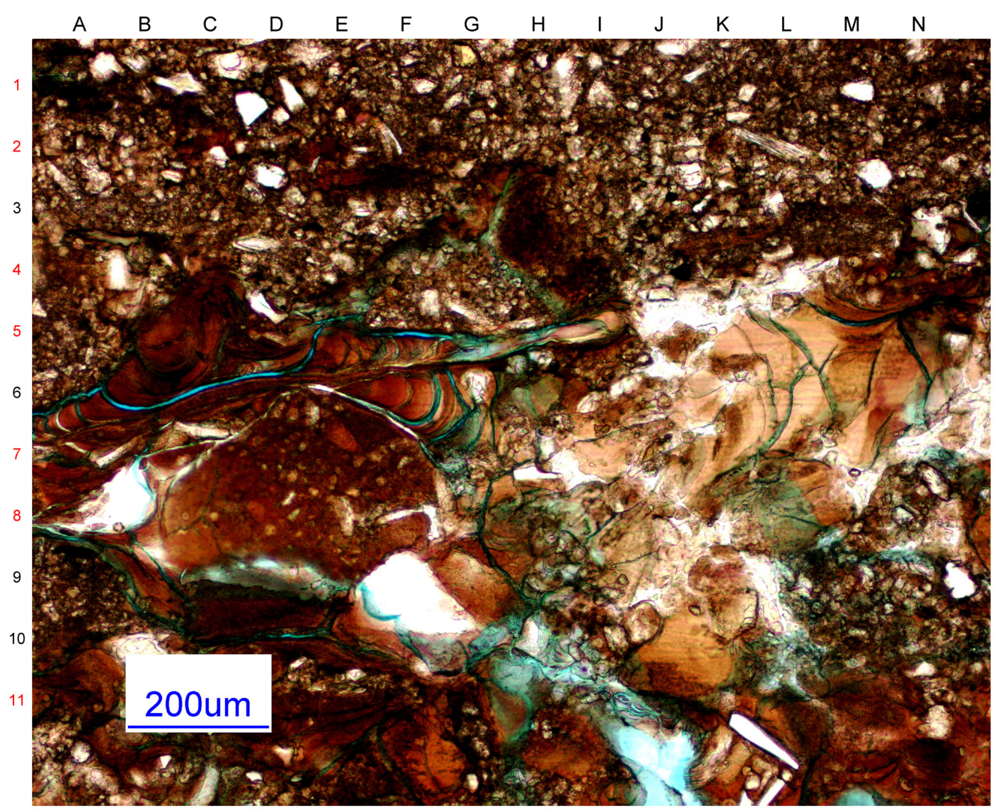


PHOTO B: 100x, plane light
High magnification view details the main rock components including volcanic ash (i.e. matrix), fossils (center) and quartz silt grains (white).



Pore Types
Intergranular:
Secondary:
Intragranular:
Microporosity: main

ALBERTA GEOLOGICAL SURVEY
Formation: Kneehills Tuff (Battle Formation)

JMS 07-3533
2007-11-26

Sample: 07USA0109
Lithofacies: Litho 1
Rock Name: Tuff

Reservoir Properties
TS Porosity (%): <1
Core Porosity (%): ~3
Kmax (md): <0.01

Grain Size: n.a.
Sorting: n.a.

PHOTO C: 200x, plane light
High magnification view from a different area details the texture of bivalve fossils (bottom and top center). Volcanic ash (i.e. matrix) contains common crystals. White grains (e.g. far left center) are quartz silt. Note local chlorite cement (bladed crystals) in the upper center.

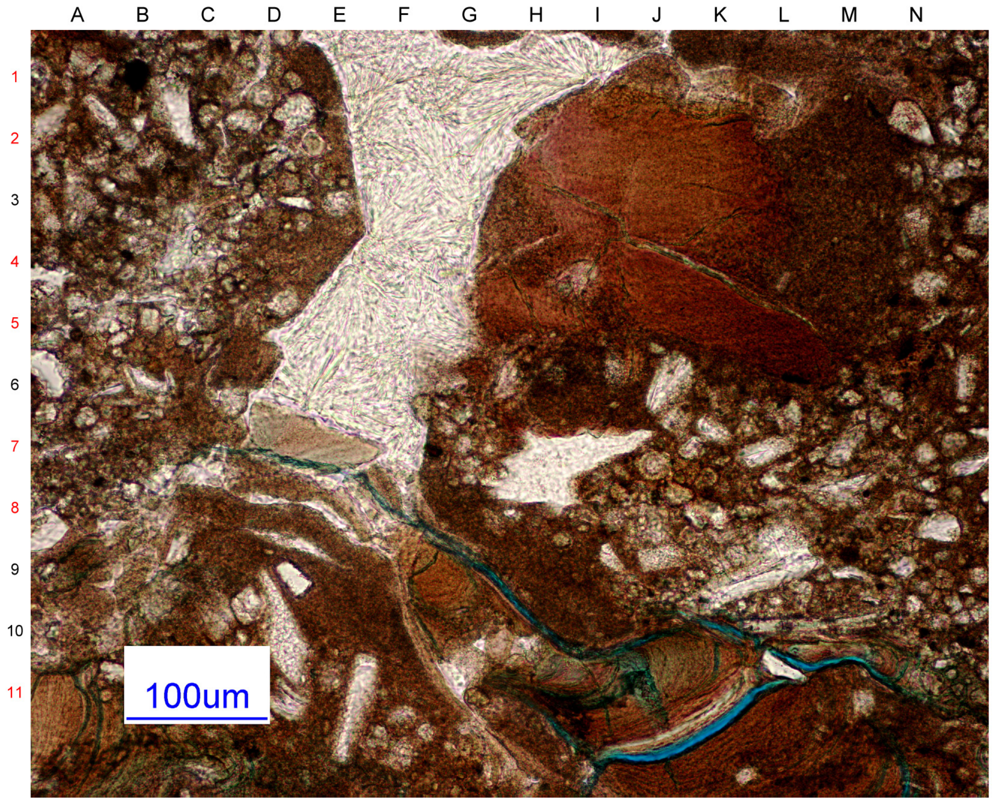
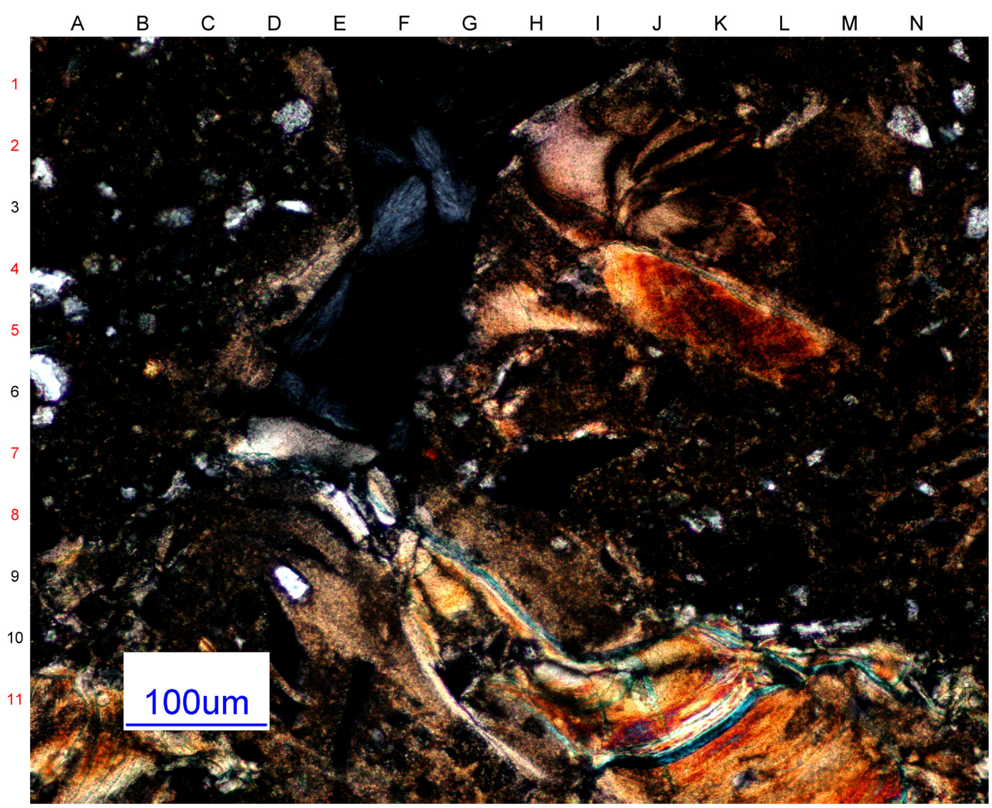


PHOTO D: 20x, cross nicols
High magnification view of Photo C taken under cross nicols shows the birefringence of fossils and chlorite cement. Bright white areas represent quartz silt grains. Volcanic ash has a low birefringence.



Pore Types
Intergranular:
Secondary:
Intragranular:
Microporosity: main

ALBERTA GEOLOGICAL SURVEY
Formation: Blood Reserve

JMS 07-3533
2007-11-26

Sample: **06USA0027**
Lithofacies: Litho 1
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.10
Grain Size:	mL
Sorting:	mod well

PHOTO A: 40x, plane light

Low magnification view shows a medium grained, moderately well sorted feldspathic litharenite. Low porosity reflects the high volume of cements.

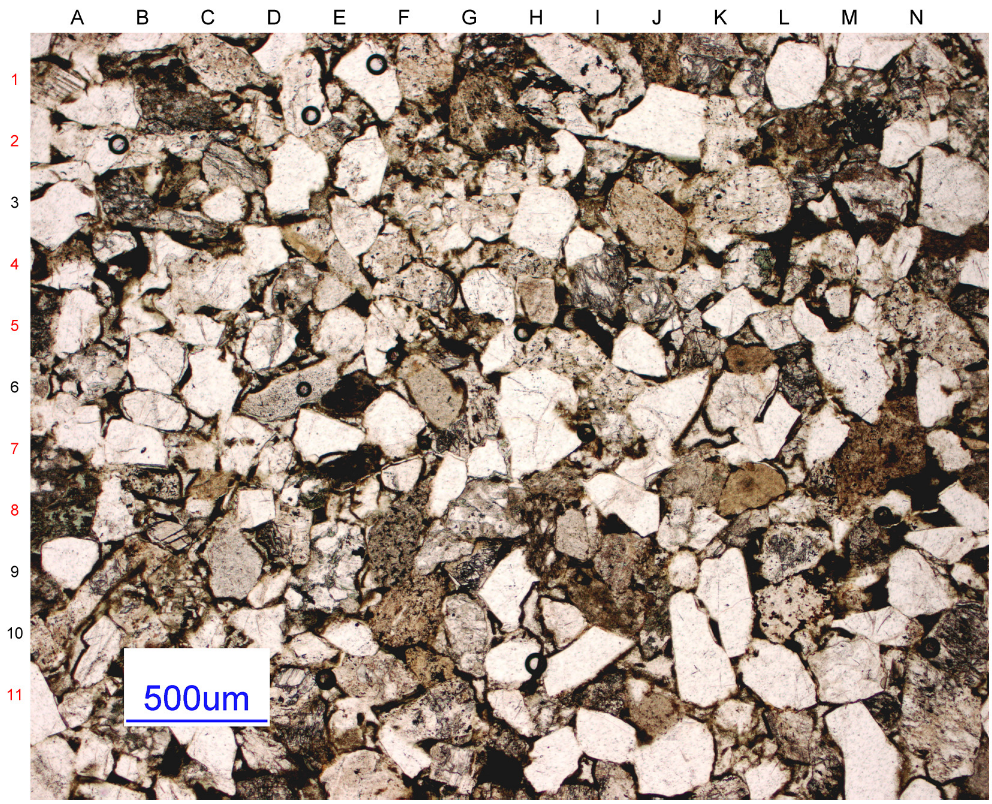
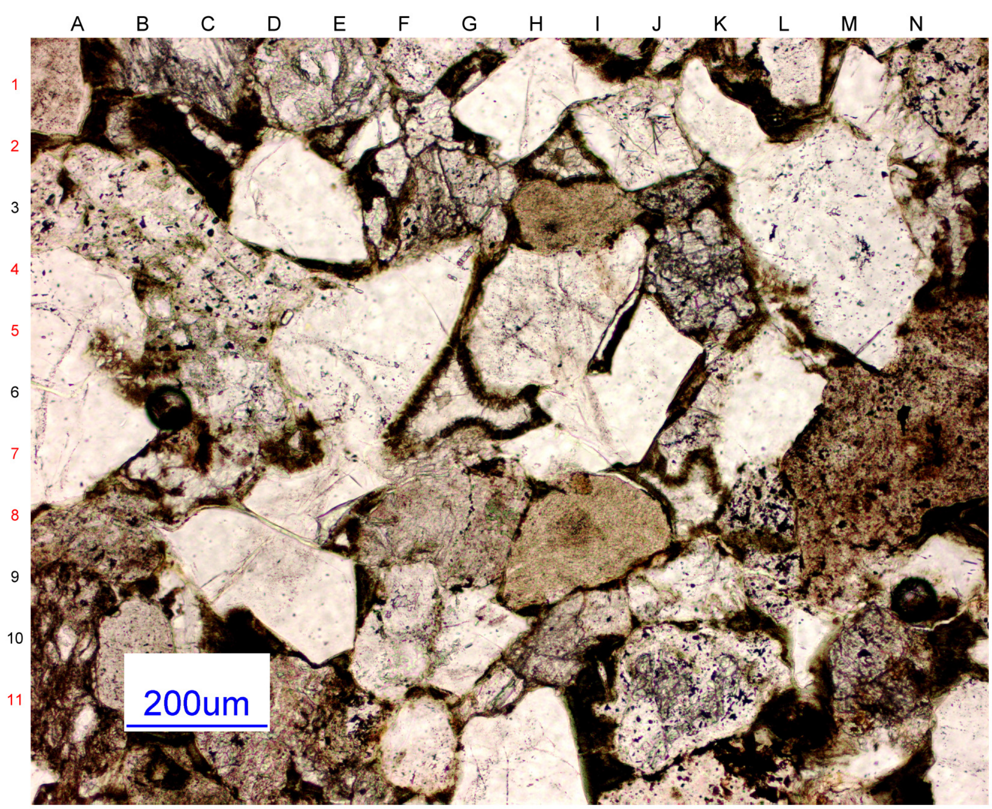


PHOTO B: 100x, plane light

High magnification view details the lack of open or effective porosity. Note the high feldspar (e.g. near center) and rock fragment (mainly chert, e.g. far right center) content.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	minor
Microporosity:	main

Sample: **06USA0027**
Lithofacies: Litho 1
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.10
Grain Size:	mL
Sorting:	mod well

PHOTO C: 200x, plane light
High magnification view details the high volume of pore lining clay and calcite (top center) cements. Note the "cloudy" texture of feldspar (near center) and local dolomite cement (lower right center).

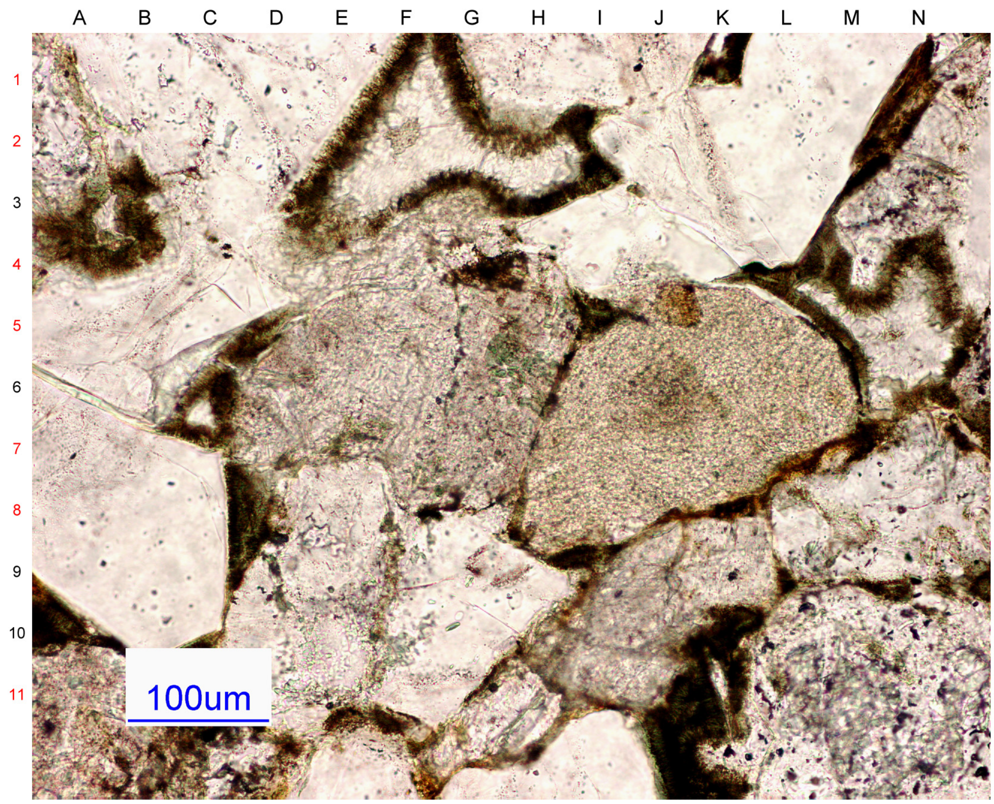
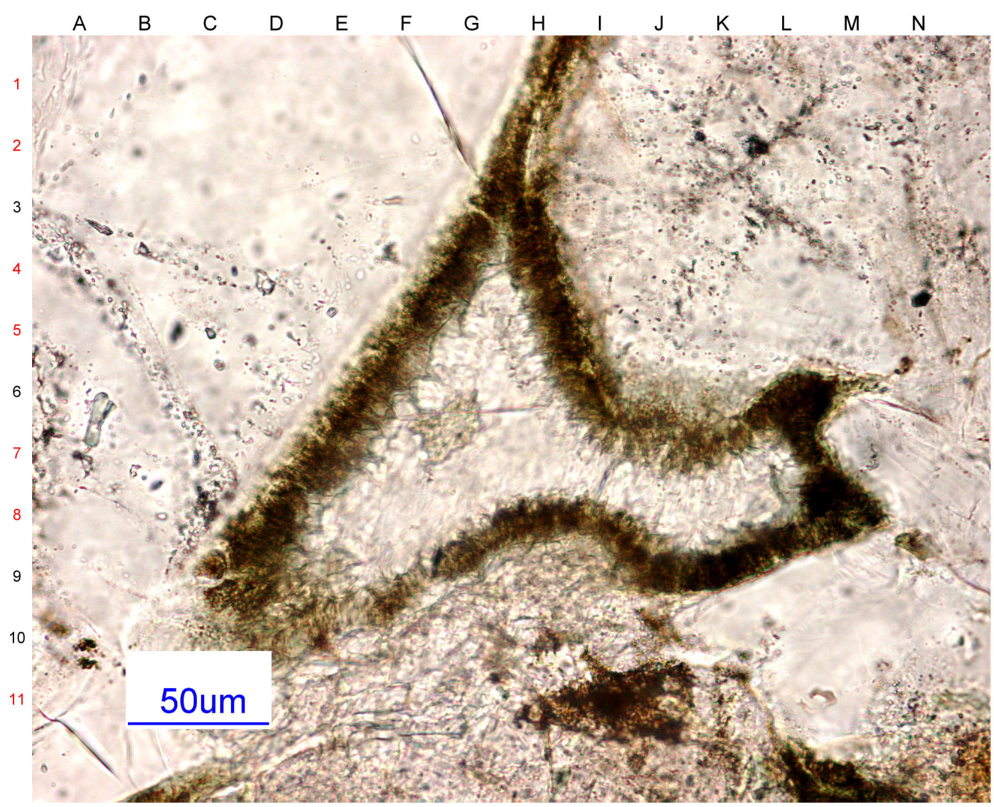


PHOTO D: 400x, plane light
High magnification view further details pore lining clay (chlorite) followed by later pore filling calcite.



Pore Types

Intergranular:	
Secondary:	
Intragranular:	minor
Microporosity:	main

ALBERTA GEOLOGICAL SURVEY
Formation: Oldman/Foremost

JMS 07-3533
2007-11-26

Sample: **07USA0005**
Lithofacies: Litho 1
Rock Name: **Litharenite**

Reservoir Properties
TS Porosity (%): n.a.
Core Porosity (%): n.a.
Kmax (md): n.a.

Grain Size: fL
Sorting: moderate

PHOTO A: 40x, plane light
Low magnification view shows a lower fine grained, moderately sorted litharenite. Porosity is uncertain due to extensive weathering of grains/cement. Note local calcite cement (upper center).

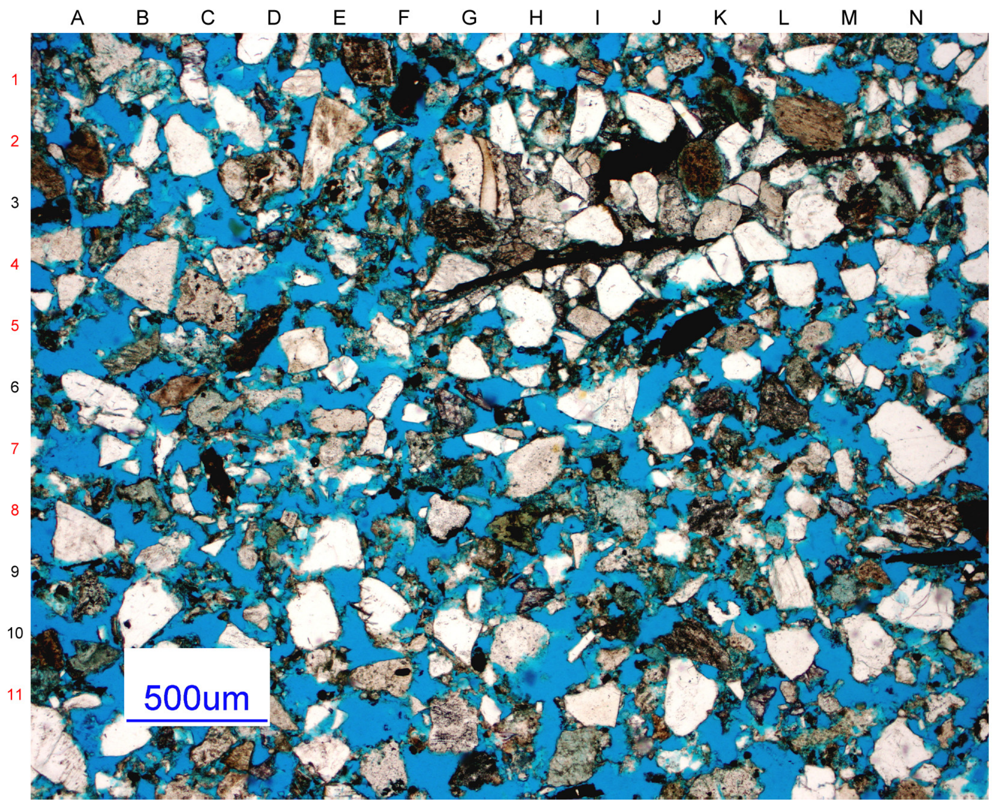
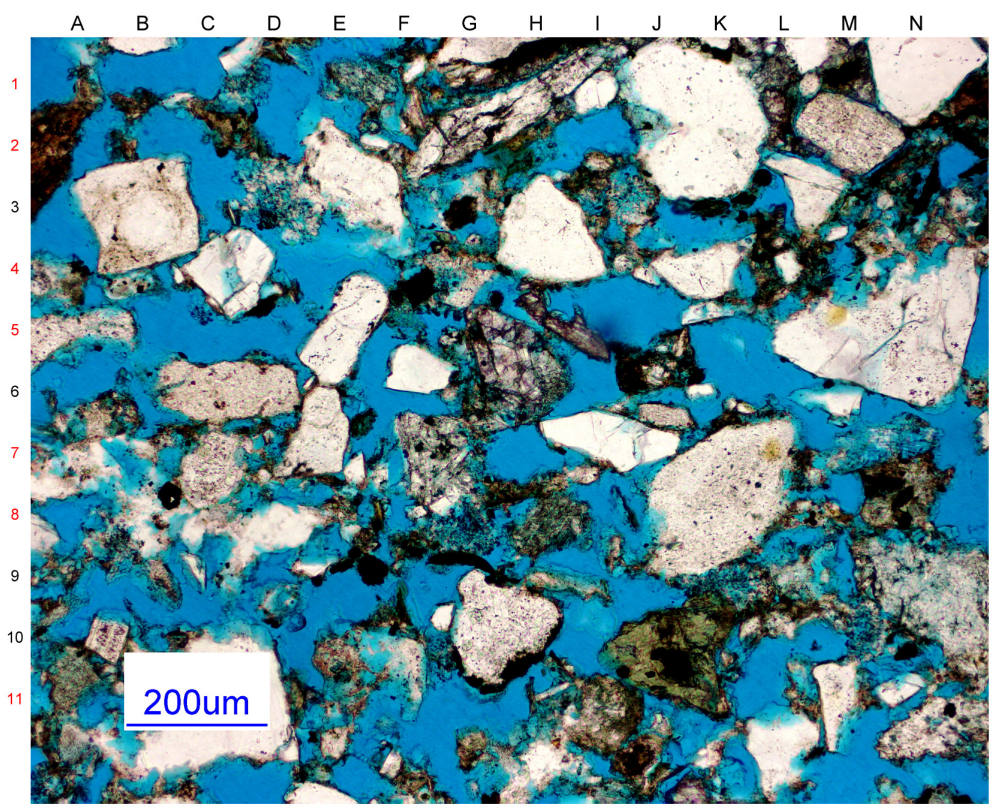


PHOTO B: 100x, plane light
High magnification view details the high degree of dissolution of grains and/or cement. Dissolution is most likely a surface phenomenon (i.e. weathering). Note the calcite crystal (upper center).



Pore Types
Intergranular: main?
Secondary:
Intragranular: minor
Microporosity: minor

ALBERTA GEOLOGICAL SURVEY
Formation: Oldman

JMS 07-3533
2007-11-26

Sample: **07USA0094**
Lithofacies: Litho 2
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%):	5
Core Porosity (%):	~10
Kmax (md):	~0.5
Grain Size:	vfU
Sorting:	moderate

PHOTO A: 40x, plane light
Low magnification view shows an upper very fine grained, moderately sorted feldspathic litharenite. Porosity is ~10% and is mainly primary with common microporosity.

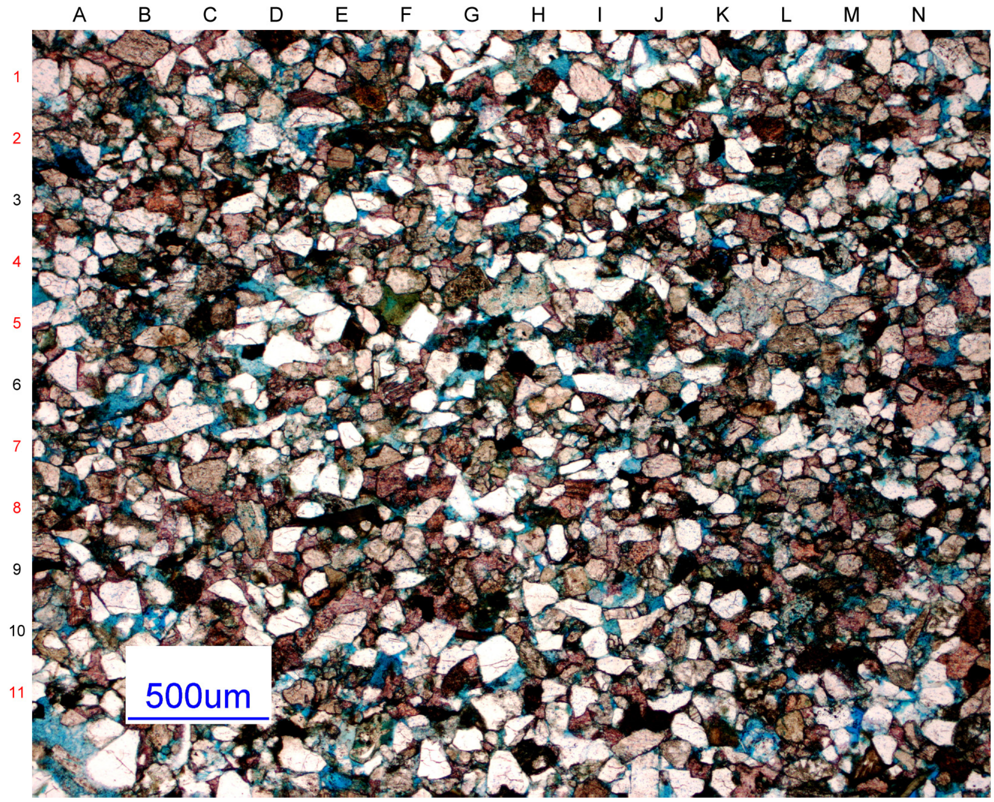
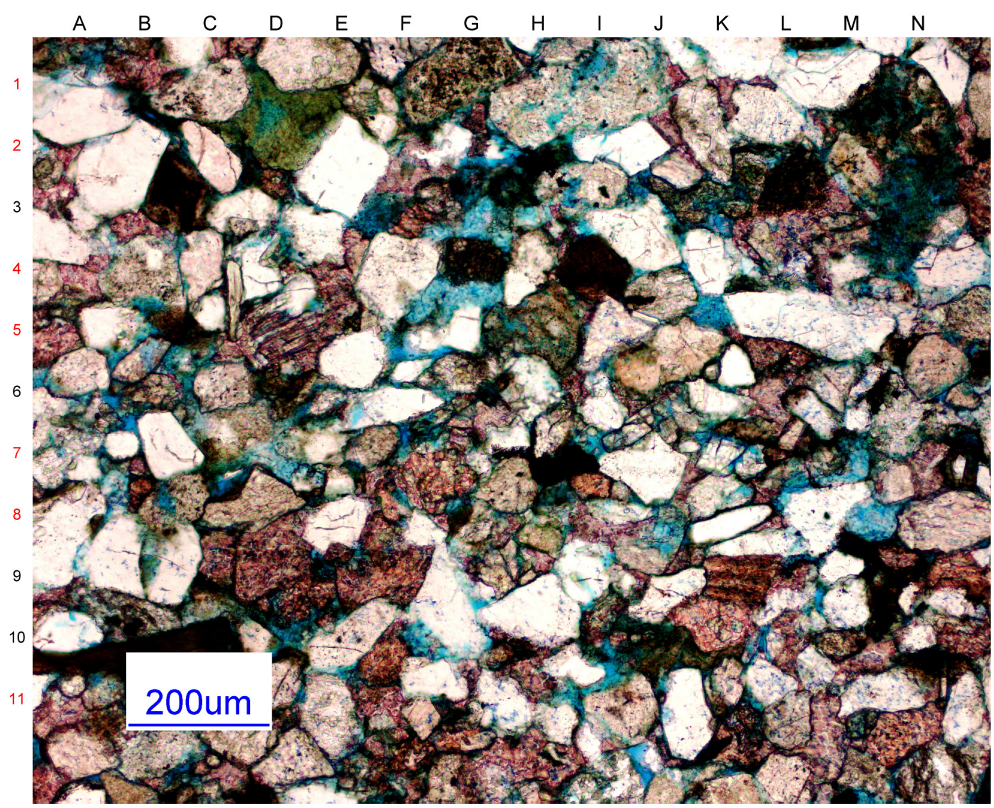


PHOTO B: 100x, plane light
High magnification view details the preservation of effective or primary intergranular porosity. Calcite (stained pink) and dolomite (non-stained near the right center) are the main cements with local kaolinite (milky white clay near the upper center). Note the green color of accessory glauconite (top left).



Pore Types

Intergranular:	main
Secondary:	
Intragranular:	common
Microporosity:	common

ALBERTA GEOLOGICAL SURVEY
Formation: Oldman

JMS 07-3533
2007-11-26

Sample: **07USA0094**
Lithofacies: Litho 2
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%): 5
Core Porosity (%): ~10
Kmax (md): ~0.5

Grain Size: vfU
Sorting: moderate

PHOTO C: 200x, plane light

High magnification view further shows the high volume of calcite (stained pink) and kaolinite (milky white) cements. Note partial grain dissolution (e.g. igneous lithoclast near the top right center and chert in the bottom right center) which contribute common intra-granular microporosity.

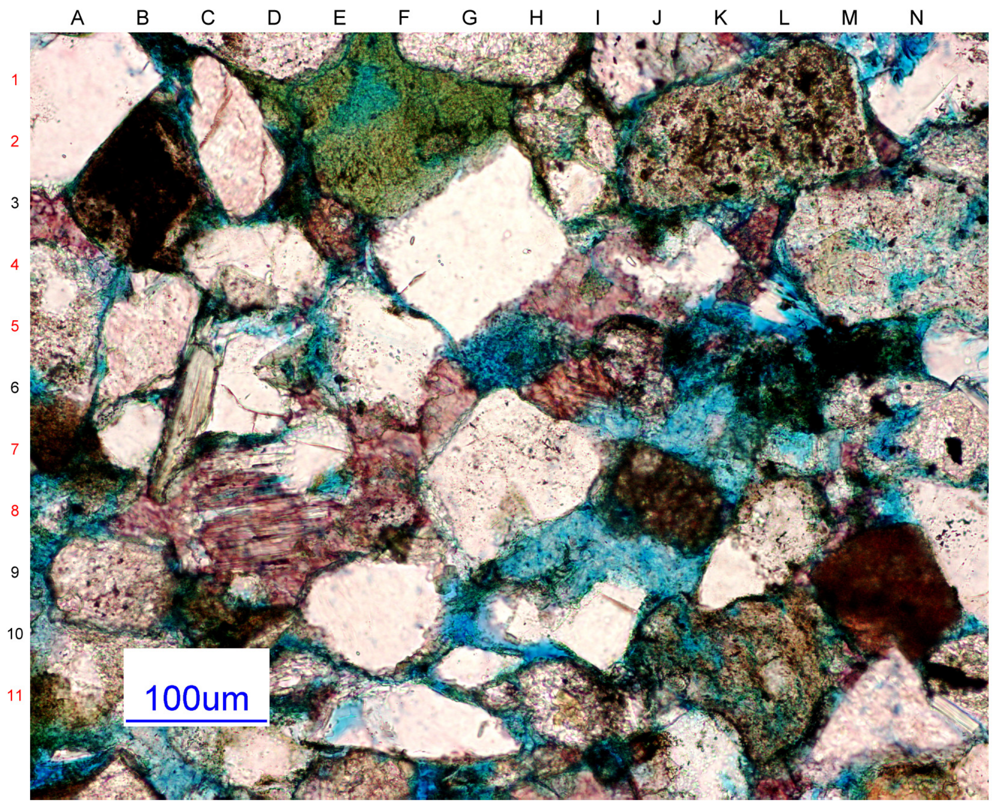
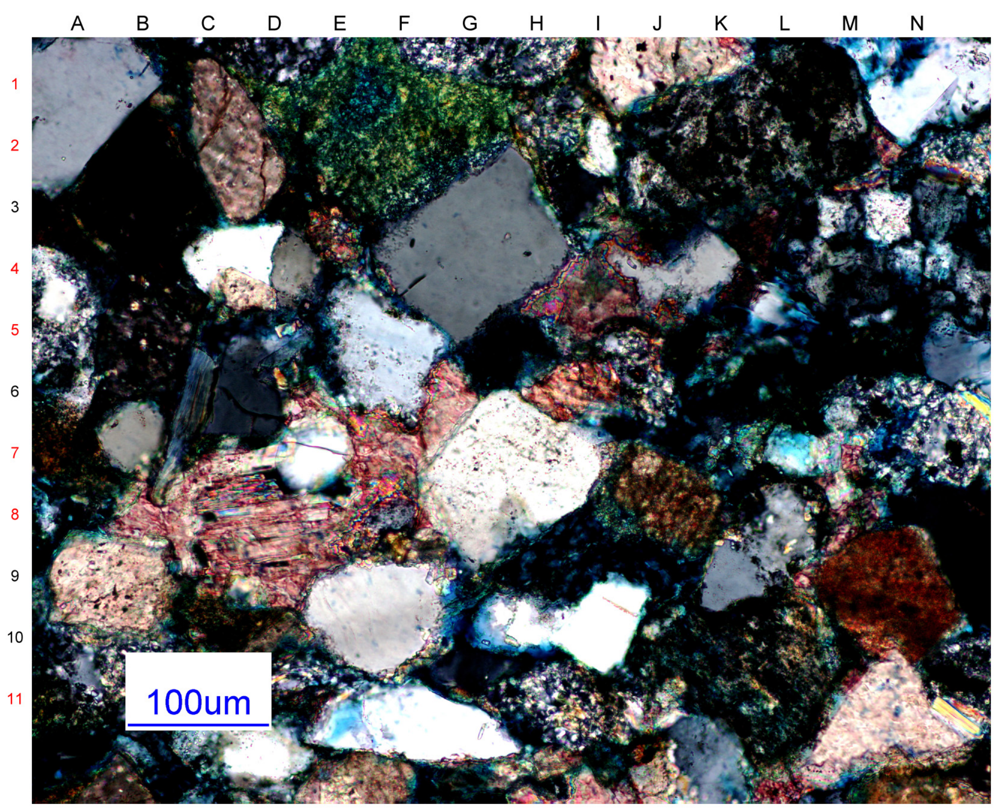


PHOTO D: 200x, cross nicols

High magnification view of Photo C taken under cross nicols details the green color and granular texture of glauconite (top left center) and the micritic texture of calcareous lithoclasts (lower right center). Note a dolomite crystal in the bottom left (i.e. rhombic morphology).



Pore Types

Intergranular: main
Secondary:
Intragranular: common
Microporosity: common

ALBERTA GEOLOGICAL SURVEY
Formation: Oldman

JMS 07-3533
2007-11-26

Sample: 07USA0096
Lithofacies: Litho 2
Rock Name: Feld. Litharenite

Reservoir Properties
TS Porosity (%): 9
Core Porosity (%): ~16
Kmax (md): ~1

Grain Size: vfL
Sorting: moderate

PHOTO A: 40x, plane light
Low magnification view shows a lower very fine grained, moderately sorted feldspathic litharenite. Thin section (effective) porosity is 9%. Microporosity is ~2/5 of the total porosity. Note the faint laminated texture.

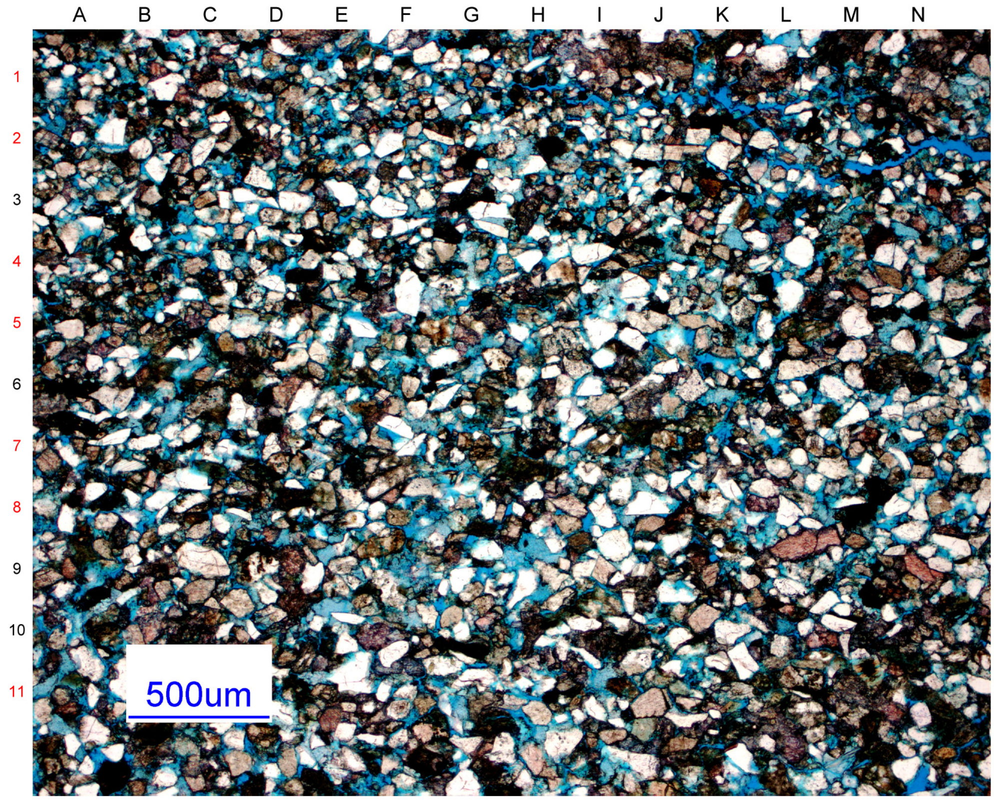
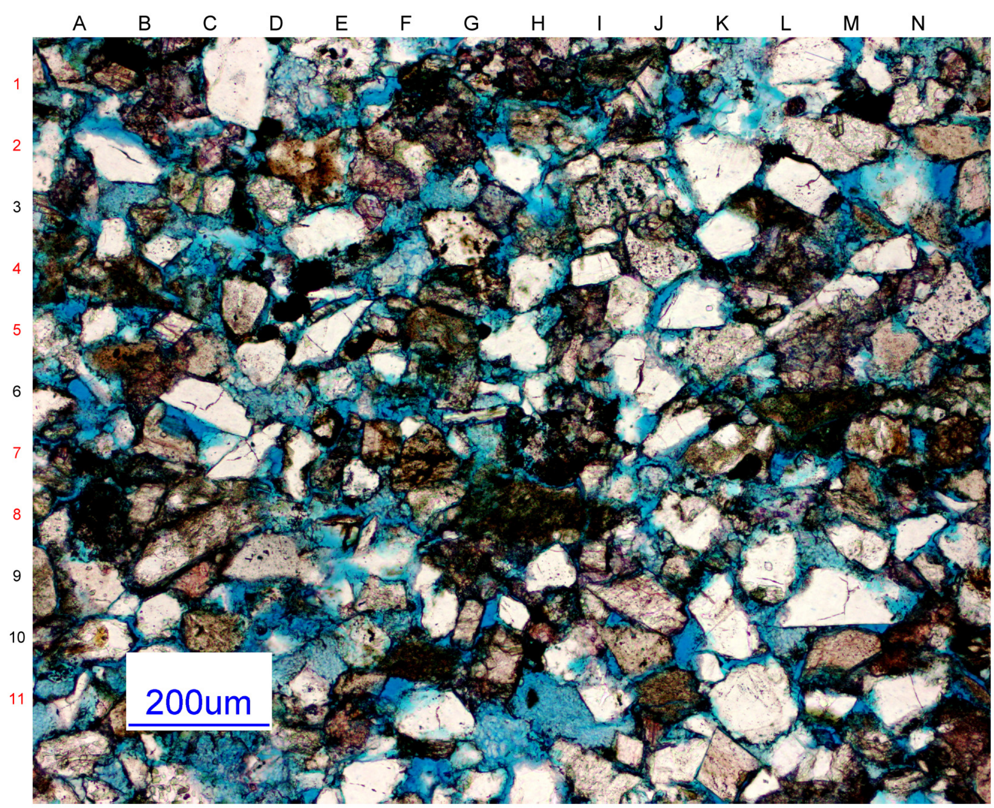


PHOTO B: 100x, plane light
High magnification view details the preservation of effective porosity. Relatively low estimated permeability (~1 md) reflects the very fine grain size (small pore throats) and the high volume of cements.



Pore Types
Intergranular: main
Secondary:
Intragranular: common
Microporosity: common

ALBERTA GEOLOGICAL SURVEY
Formation: Oldman

JMS 07-3533
2007-11-26

Sample: 07USA0096
Lithofacies: Litho 2
Rock Name: Feld. Litharenite

Reservoir Properties
TS Porosity (%): 9
Core Porosity (%): ~16
Kmax (md): ~1

Grain Size: vfL
Sorting: moderate

PHOTO C: 200x, plane light
High magnification view details kaolinite (milky white), pore lining clay (dark clay rims), dolomite (top right) and calcite (stained pink) cements. Note the high volume of associated microporosity within kaolinite.

A B C D E F G H I J K L M N

1 2 3 4 5 6 7 8 9 10 11

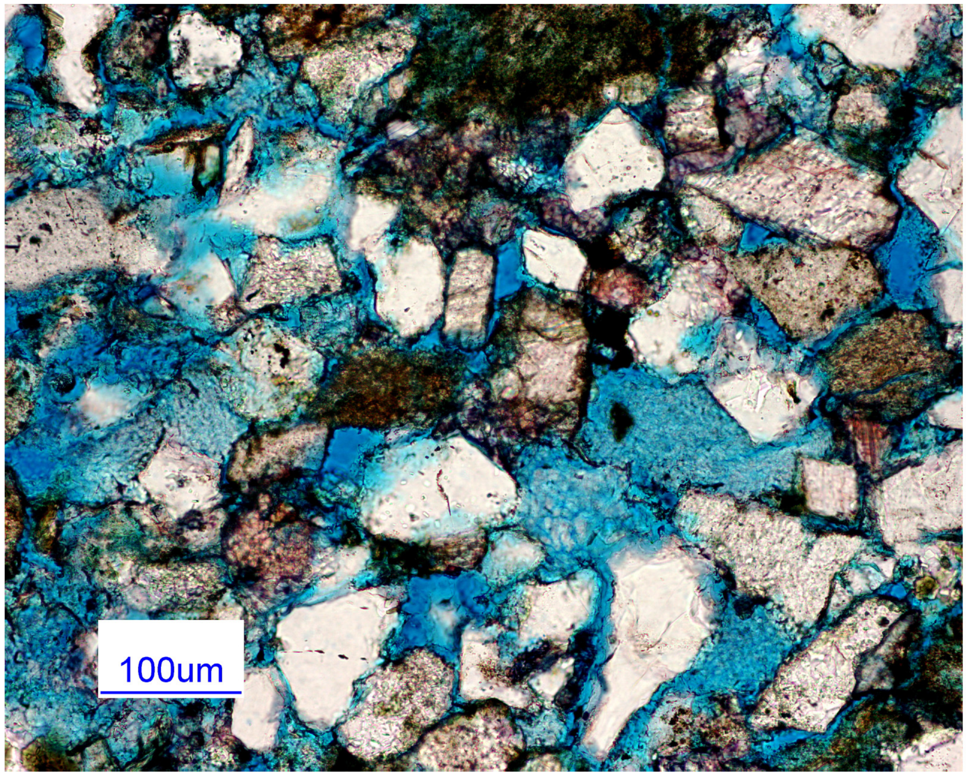
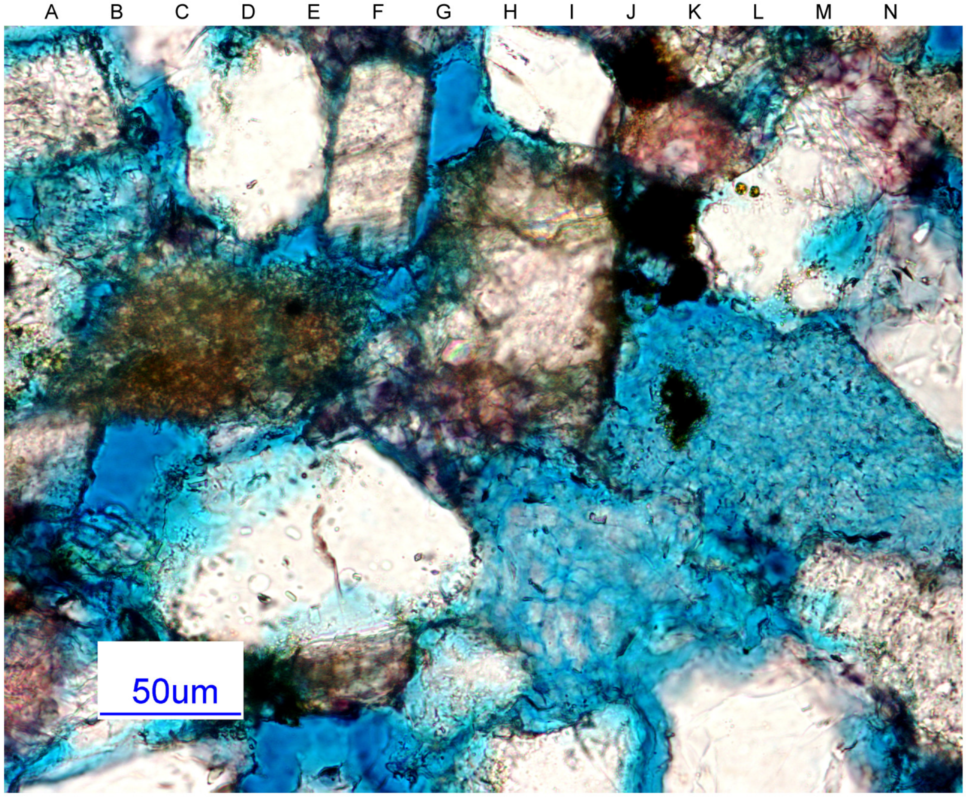


PHOTO D: 400x, plane light
High magnification view details kaolinite and pore lining clay cements. Calcite (pink and purple stain) and dolomite (upper center) are also seen. XRD is needed to precisely determine the clay mineralogy of pore lining clay (i.e possibly water-sensitive smectite).

A B C D E F G H I J K L M N

1 2 3 4 5 6 7 8 9 10 11



Pore Types
Intergranular: main
Secondary:
Intragranular: common
Microporosity: common

ALBERTA GEOLOGICAL SURVEY
Formation: Oldman

JMS 07-3533
2007-11-26

Sample: **07USA0102**
Lithofacies: Litho 3
Rock Name: **Shale**

Reservoir Properties
TS Porosity (%): <1
Core Porosity (%): ~5
Kmax (md): <-0.01

Grain Size: n.a.
Sorting: n.a.

PHOTO A: 100x, plane light
High magnification view shows an organic rich shale. The image is overexposed to show the matrix clay (dark orange) and the distribution of organic material (mainly opaque). Note the laminated texture.

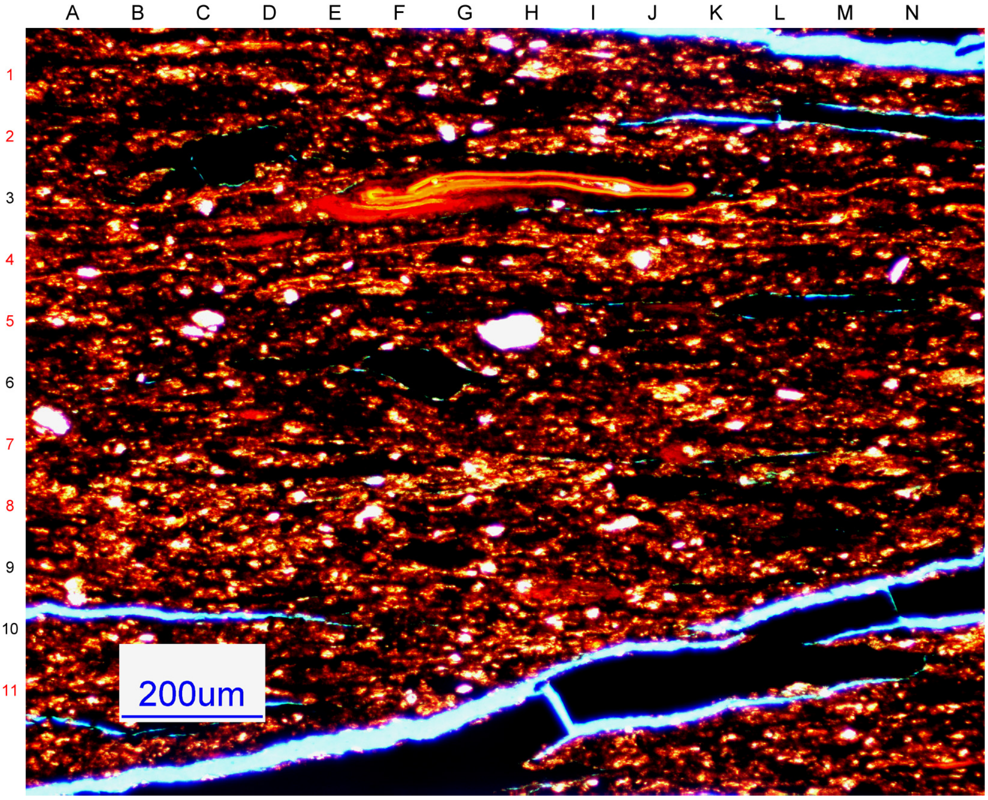
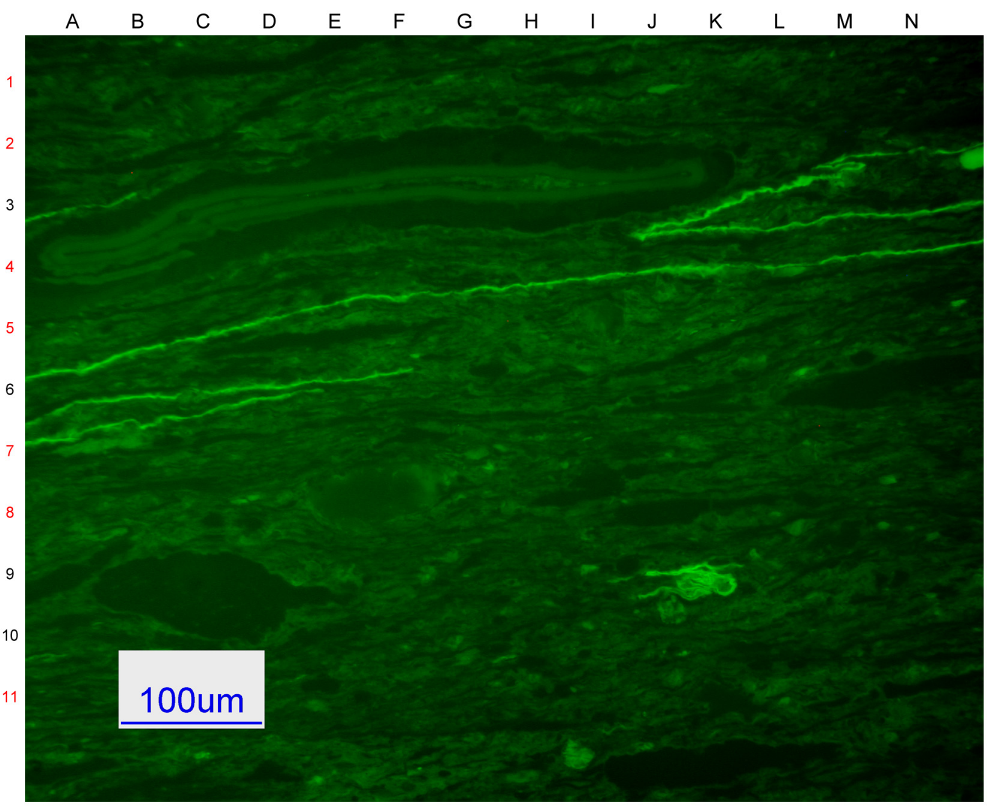


PHOTO B: 200x, UV
High magnification view taken under fluorescent light details rare natural fractures (i.e. pinch out texture) and poor microporosity (i.e. bright areas on the image).



Pore Types
Intergranular:
Secondary:
Intragranular:
Microporosity: main

ALBERTA GEOLOGICAL SURVEY
Formation: Foremost

JMS 07-3533
2007-11-26

Sample: **07USA0038**
Lithofacies: Litho 1
Rock Name: **Litharenite**

Reservoir Properties

TS Porosity (%):	20
Core Porosity (%):	~25
Kmax (md):	~200
Grain Size:	fU
Sorting:	moderate

PHOTO A: 40x, plane light

Low magnification view shows an upper fine grained, moderately sorted litharenite. Note local organic/coaly fragments aligned parallel to bedding. Good reservoir quality (~200 md) reflects the low volume of cements and poor sediment compaction (i.e. friable sand).

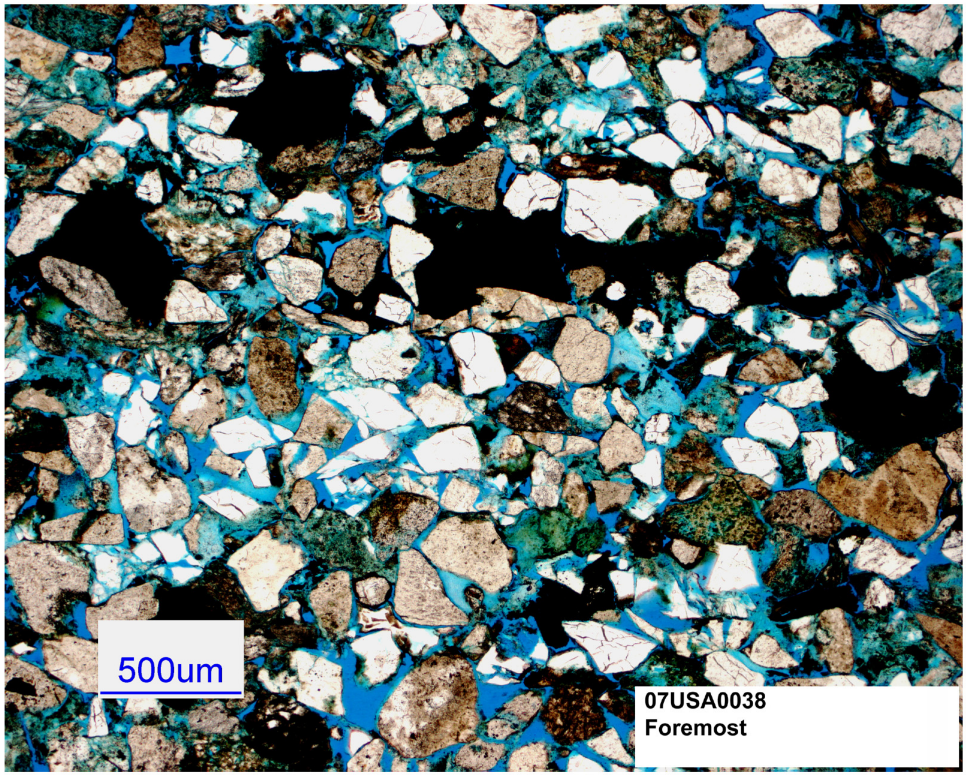
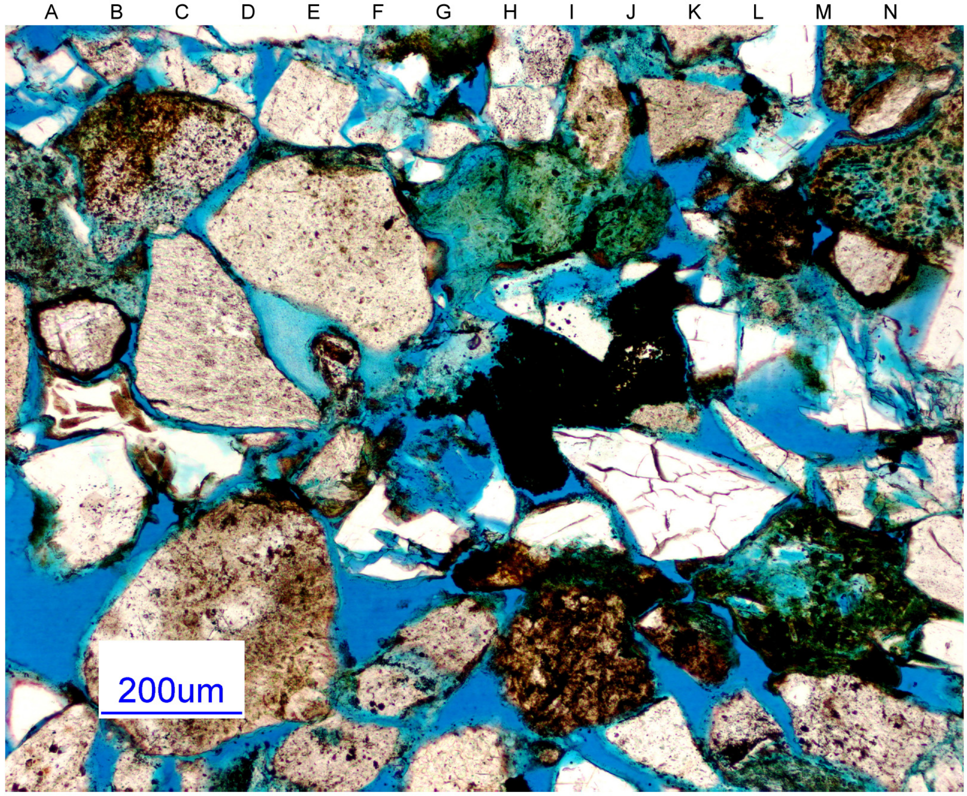


PHOTO B: 100x, plane light

High magnification view details the preservation of effective porosity. A minor portion of the effective porosity is interpreted as secondary (e.g. far right center) formed after extensive grain dissolution. Note highly altered volcanic grains (e.g. upper center) which contain intragranular microporosity.



Pore Types

Intergranular:	main
Secondary:	minor
Intragranular:	common
Microporosity:	minor

ALBERTA GEOLOGICAL SURVEY
Formation: Foremost

JMS 07-3533
2007-11-26

Sample:	**07USA0048**
Lithofacies:	Litho 1
Rock Name:	**Litharenite**

Reservoir Properties

TS Porosity (%):	26
Core Porosity (%):	~30
Kmax (md):	~500
Grain Size:	mL
Sorting:	mod well

PHOTO A: 40x, plane light

Low magnification view shows a medium grained, moderately well sorted litharenite. Thin section (effective) porosity is 26%. Porostiy is mainly primary with minor secondary dissolution and microporosity.

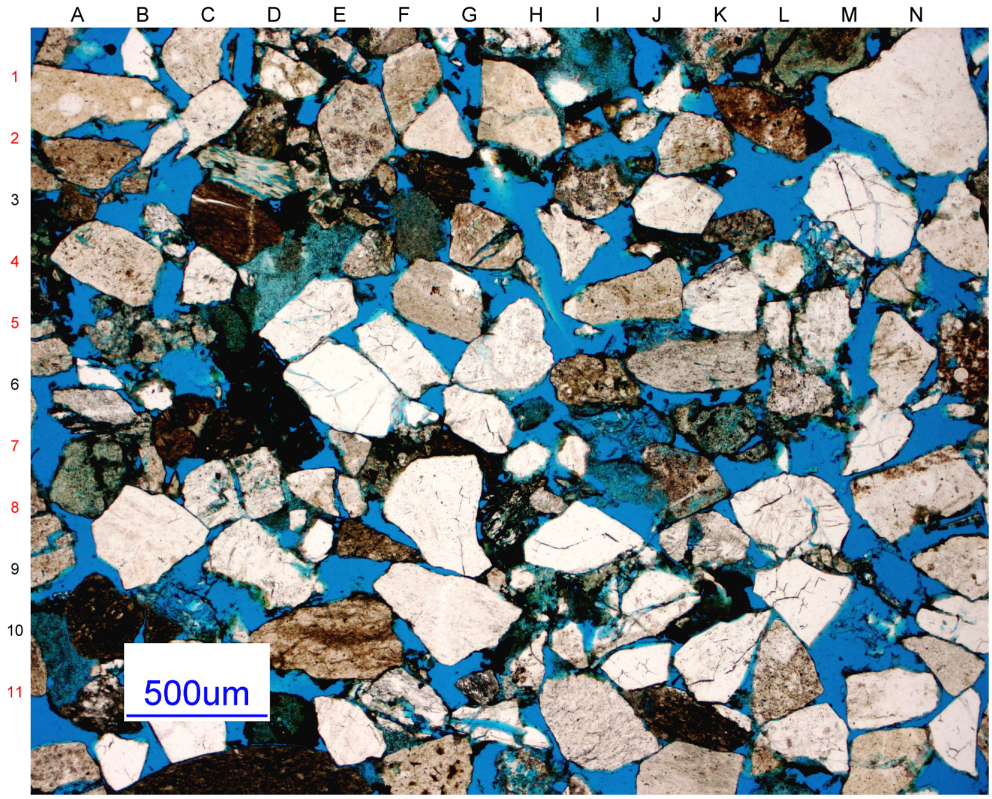
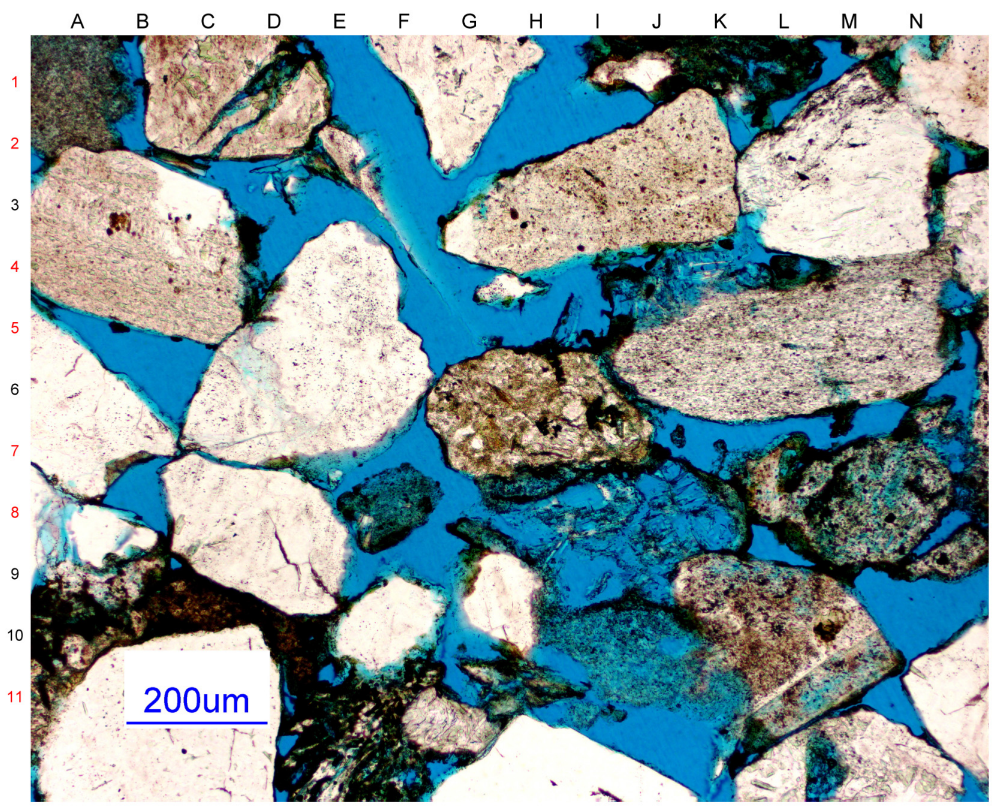


PHOTO B: 100x, plane light

High magnification view details the poor sediment compaction (i.e. friable sand) and low volume of kaolinite and pore lining clay cements. Note feldspar dissolution (lower center).



Pore Types

Intergranular:	main
Secondary:	minor
Intragranular:	minor
Microporosity:	minor

ALBERTA GEOLOGICAL SURVEY
Formation: Foremost

JMS 07-3533
2007-11-26

Sample:	**07USA0048**
Lithofacies:	Litho 1
Rock Name:	**Litharenite**

Reservoir Properties

TS Porosity (%):	26
Core Porosity (%):	~30
Kmax (md):	~500
Grain Size:	mL
Sorting:	mod well

PHOTO C: 200x, plane light
High magnification view further details feldspar dissolution near the center (i.e. secondary porosity) and partial chert dissolution in the far right (i.e. intragranular microporosity). Note clay rims lining a dissolved feldspar grain and kaolinite cement (bottom center).

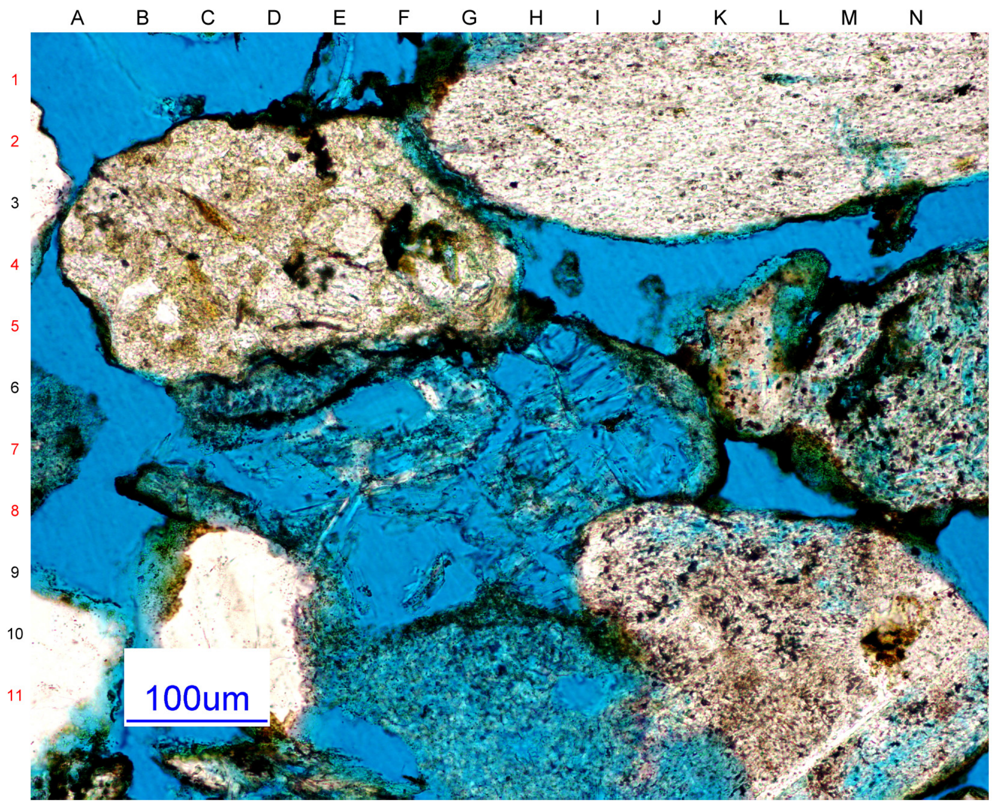
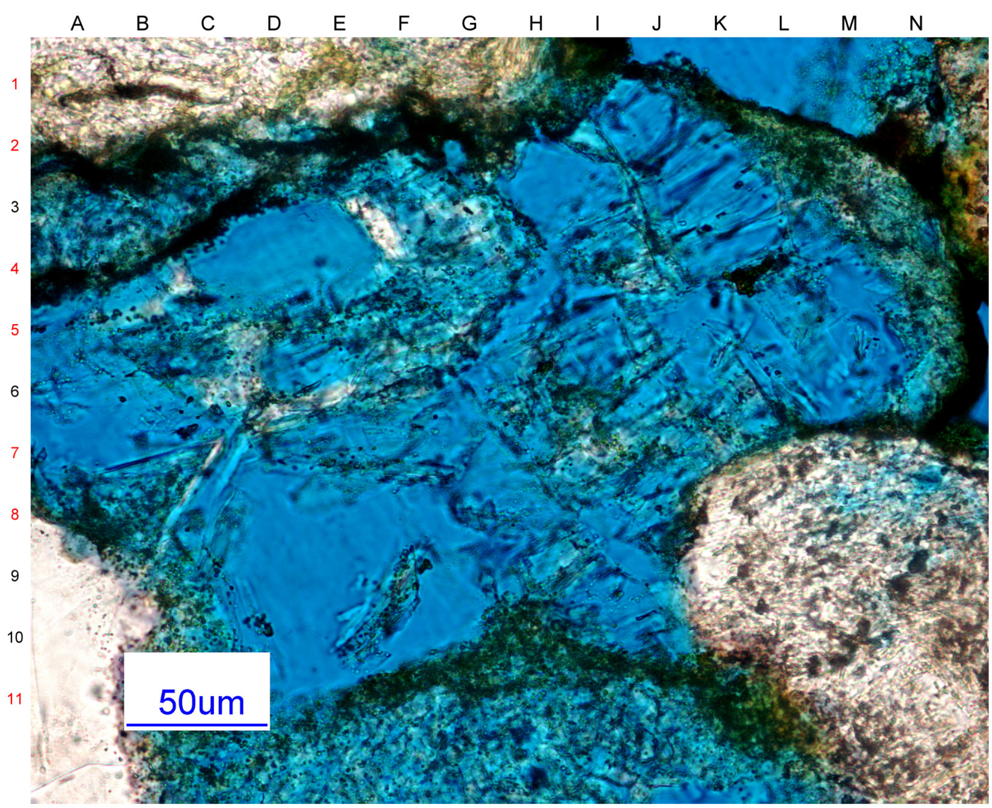


PHOTO D: 400x, plane light
High magnification view details clay rims lining a dissolved feldspar grain and the "fine" crystal size of kaolinite (bottom).



Pore Types

Intergranular:	main
Secondary:	minor
Intragranular:	minor
Microporosity:	minor

ALBERTA GEOLOGICAL SURVEY
Formation: Milk River

JMS 07-3533
2007-11-26

Sample: **06USA0045**
Lithofacies: Litho 1
Rock Name: **Feld. Litharenite**

Reservoir Properties

TS Porosity (%):	<1
Core Porosity (%):	~5
Kmax (md):	<0.10
Grain Size:	vfU-fU
Sorting:	poor

PHOTO A: 40x, plane light
Low magnification view shows a very fine to fine (locally medium) grained, poorly sorted feldspathic litharenite. Note the high volume of opaque matrix clay (i.e. possibly stained with limonite).

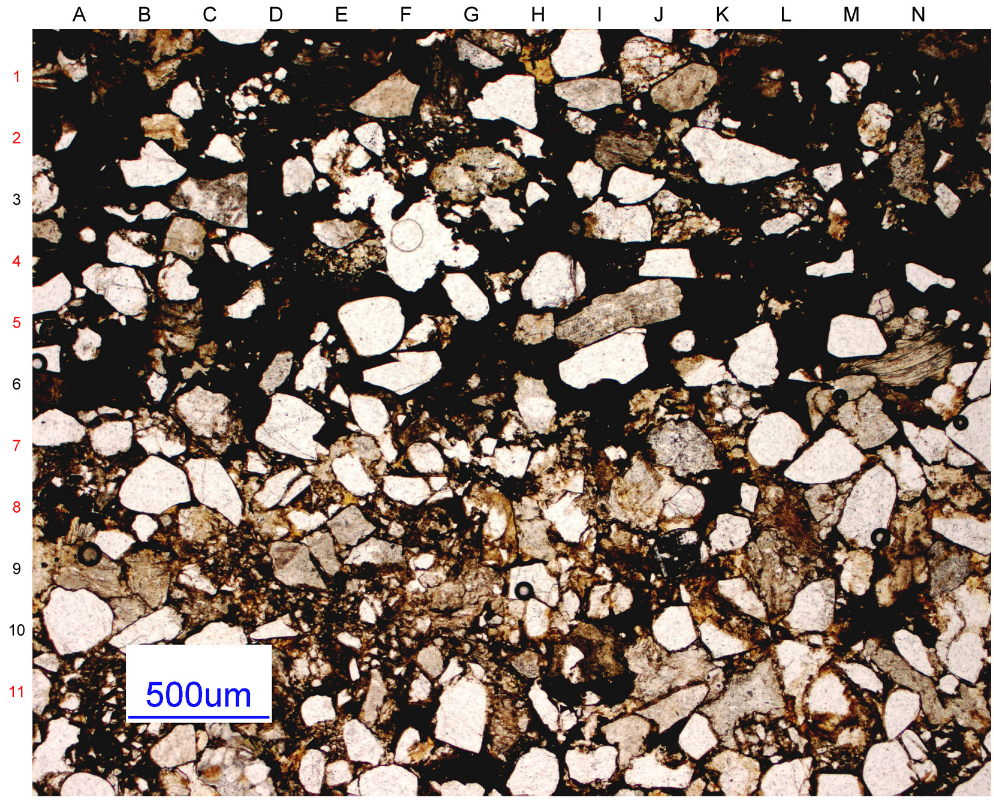
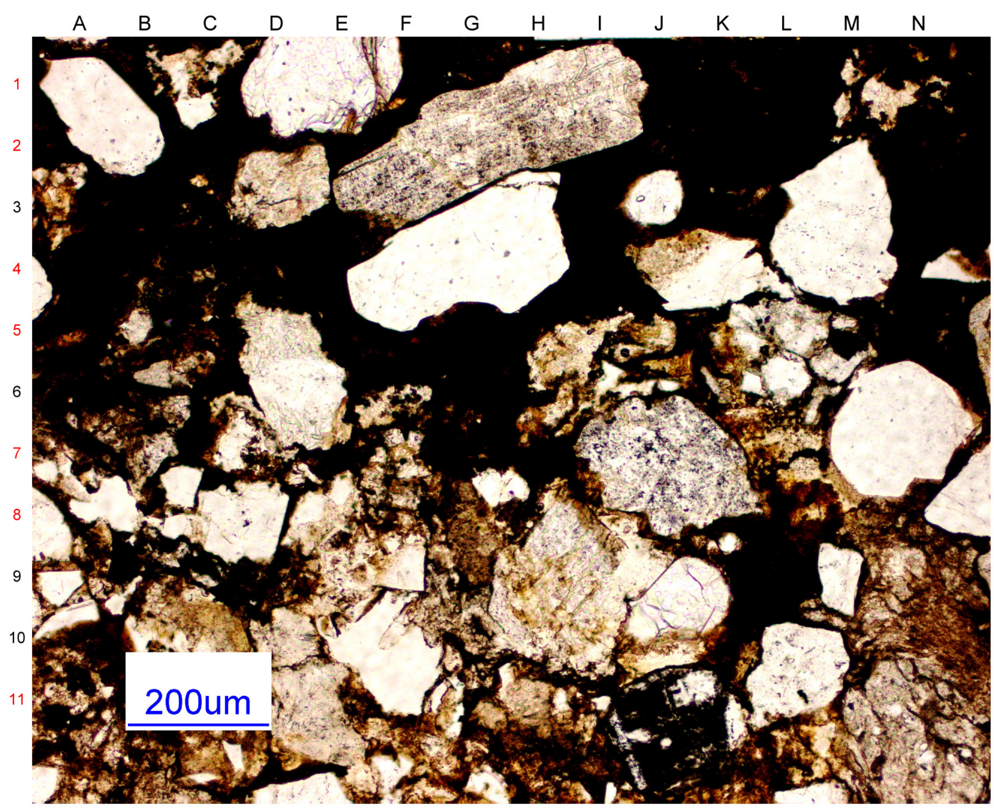


PHOTO B: 100x, plane light
High magnification view details the poor sorting, relatively angular grain shape and lack of open or effective porosity. Matrix or detrital clay is highly opaque (top).



Pore Types

Intergranular:	
Secondary:	
Intragranular:	minor
Microporosity:	main