ERCB/AGS Open File Report 2008-13

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Mineralogy, Permeametry, Mercury Porosimetry and Scanning Electron Microscope Imaging of the Banff and Exshaw Formations: Shale Gas Data Release

Energy Resources Conservation Board

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Alberta Geological Survey

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Mineralogy, Permeametry, Mercury Porosimetry and Scanning Electron Microscope Imaging of the Banff and Exshaw Formations: Shale Gas Data Release

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Abstract

This report constitutes a data release of bulk and clay mineralogy, permeametry and mercury porosimetry analyses, and Scanning Electron Microscope imaging of selected samples from the Banff and Exshaw formations generated for the ERCB/AGS project on shale gas resources in Alberta. This data release is complimentary to other manuscripts and data being released from the same project as listed in Table 1 of this report.

1 Introduction

ERCB/AGS initiated a project in 2007 to evaluate shale gas resources in Alberta, to determine the quantity and spatial extent of these resources. The first formations chosen for evaluation are the Colorado Group, and the Banff and Exshaw formations. Alberta Geological Survey is releasing a series of reports to disseminate data and knowledge from the project.

This report disseminates results from bulk and clay mineralogy, permeametry measurements, mercury porosimetry analysis, scanning electron microscope (SEM) images and environmental scanning electron microscope (ESEM) images from selected samples of the Banff and Exshaw formations. A list of all the analyses and associated reports is listed in Table 1. The data generated from the project will be combined with additional data to map and estimate shale gas resources in the province.

Table 1. Analyses performed on core and outcrop samples, and the organization that performed the analyses as part of the resource evaluation project.

Type of Analysis	Company/ Analyst	Notes
Isotherm	Schlumberger; CBM Solutions	Beaton et al. (2009a, b)
Mercury porosimetry, envelope and helium pycnometry	Department of Physics, University of Alberta (D. Schmitt)	Pawlowicz et al. (2009), this report
Permeametry	Department of Earth and Atmospheric Sciences, University of Alberta (M. Gingras)	Pawlowicz et al. (2009), this report
Rock Eval™/TOC	Geological Survey of Canada; Schlumberger; CBM Solutions	Beaton et al. (2009a, b)
Organic petrography	Geological Survey of Canada (J. Reyes)	Beaton et al. (2009a, b)
Petrographic analysis (thin section)	Vancouver Petrographics; CBM Solutions	Work in progress
Scanning electron microscope (SEM) with energy-dispersive X-ray (EDX)	Department of Earth and Atmospheric Sciences, University of Alberta (G. Braybrook)	Pawlowicz et al. (2009), this report
Environmental scanning electron microscope (ESEM)	Department of Biology, University of Alberta (R. Bhatnagar)	Pawlowicz et al. (2009), this report
X-ray diffraction (bulk and clay mineral)	SGS Minerals Services Ltd. (H. Zhou); CBM Solutions	Pawlowicz et al. (2009), this report

Alberta Geological Survey is also releasing a series of reports to introduce the project and distribute information related to specific formations (Rokosh et al., 2009a–c).

2 Sample Location and Description

The location map (Figure 1) displays all Banff and Exshaw formation core and outcrop samples sites associated with the project. Tables 2 and Table 3, and Appendices 1 and 2 list the precise locations of the sample sites.

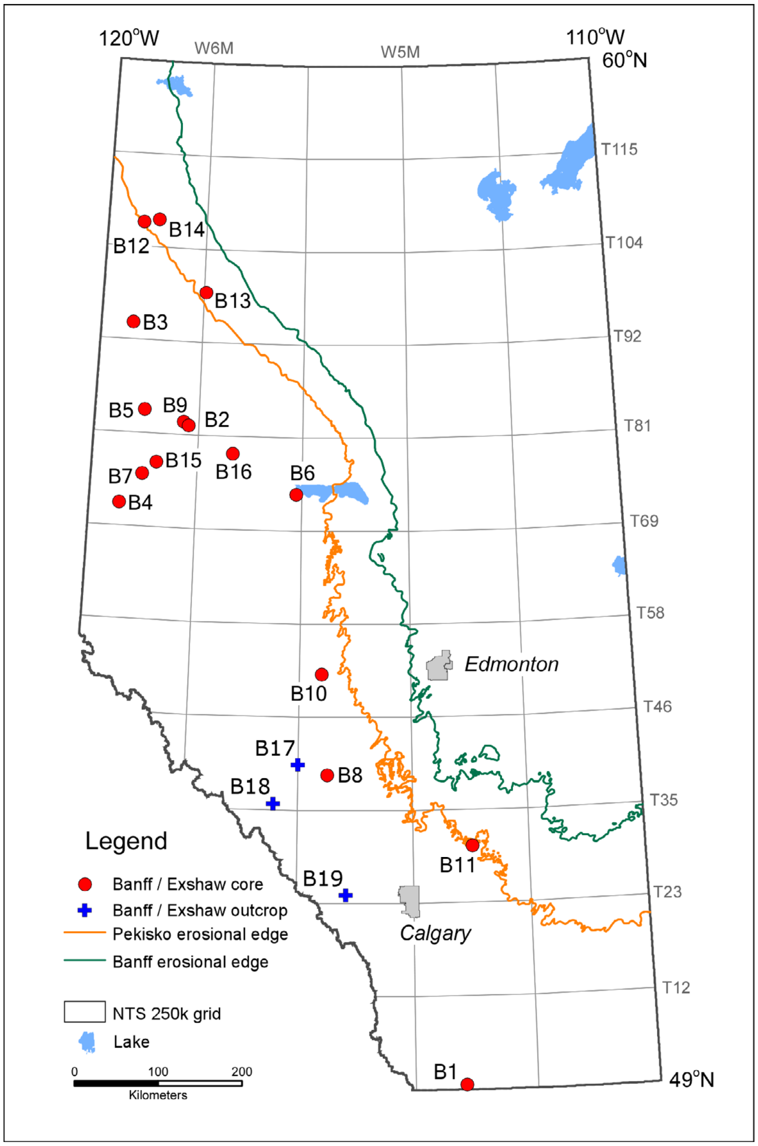

Figure 1. Core and outcrop sites sampled for the Banff and Exshaw formations. See Appendices 1 to 4 for a list of all sites and the type and results of analyses run on various samples.

Table 2. Core sample sites in the Banff and Exshaw formations.

Site No.	UWI	Latitude (NAD 83)	Longitude (NAD 83)	Year Drilled	No. of Samples	Formation
B01	100/01-20-001-24W4/00	49.045566	-113.165460	1981	3	Banff/Exshaw
B02	100/02-14-082-02W6/00	56.103477	-118.193028	1950	6	Banff
B03	100/02-28-094-09W6/00	57.179218	-119.376578	1952	6	Banff
B04	100/04-23-072-10W6/00	55.245950	-119.431068	1972	4	Banff/Exshaw
B05	100/06-04-084-07W6/00	56.252096	-119.047260	1974	2	Banff
B06	100/07-08-074-14W5/00	55.394566	-116.113837	1949	8	Banff/Exshaw
B07	100/08-08-076-07W6/00	55.568451	-119.040018	2002	2	Banff
B08	100/08-27-039-11W5/00	52.383168	-115.491096	1955	14	Banff
B09	100/08-30-082-02W6/00	56.135519	-118.293350	1985	3	Banff/Exshaw
B10	100/09-06-052-11W5/00	53.463004	-115.601615	1954	8	Banff/Exshaw
B11	100/12-36-030-22W4/00	51.614422	-112.978894	1950	4	Banff/Exshaw
B12	100/15-05-107-08W6/00	58.264601	-119.290939	2001	4	Banff
B13	100/15-27-098-25W5/00	57.539368	-117.965423	2002	1	Banff
B14	100/16-18-107-06W6/00	58.296137	-118.982929	1954	2	Banff
B15	100/16-24-077-06W6/00	55.693279	-118.777249	1986	3	Banff
B16	102/06-02-079-22W5/00	55.817907	-117.332954	1984	2	Banff

Table 3. Outcrop sample sites in the Banff and Exshaw formations.

Site No.	Datum	UTM Zone	Easting	Northing	Site Location Name	No. of Samples	Formation
B17	NAD83	11	567642	5816426	Nordegg (railroad section)	30	Banff, Exshaw
B18	NAD83	11	539339	5769916	Kootenay Plains (mountain section)	1	Banff
B19	NAD83	11	628902	5661581	Jura Creek	28	Banff, Exshaw

3 Analytical Methods and Results

A total of 59 outcrop and 72 core samples was selected for analysis. The analyses itemized in Table 1 were performed on selected samples, as indicated in Appendices 3 and 4.

3.1 Bulk and Clay Mineralogy

X-ray powder diffraction (XRD) will identify the mineralogy of a sample. An estimate of the weight percent (wt. %) of each mineral is provided in Appendix 5 for bulk mineralogy and Appendix 6 for clay mineralogy.

SGS Minerals Services Ltd. (http://www.ca.sgs.com/home.htm [January 2009]) performed X-ray diffraction analysis and interpretation, and X-ray fluorescence spectroscopy (XRF) on the core samples. CBM Solutions Ltd. (http://www.cbmsolutions.com [January 2009]) performed XRD analysis and interpretation on outcrop samples using industry-standard techniques.

SGS Minerals uses a Siemens D5000 diffractometer with cobalt radiation and Siemens Search/Match software for peak identification. Mineral proportions are based on relative peak heights and may be strongly influenced by crystallinity, structural group or preferred orientations (H. Zhou, SGS Minerals Services Ltd., pers. comm., 2008). The calculation of mineral abundances from both bulk mineral analysis and clay mineral separates is based on relative peak intensity and is reconciled with a whole-rock analysis by XRF (results provided in Appendix 5b). The detection limit of minerals is approximately 0.5–2.0 wt. % according to SGS, but can be as high as 3–5 wt. % (http://www.xrd.us [January 2009]). However, XRD does not detect amorphous compounds.

CBM Solutions uses a Siemens D5000 or D500 with copper or cobalt X-ray tube and search/match software for peak identification. A commercial Rietveld analysis program for quantification of the mineralogy analyzed the XRD results. The accuracy of the Rietveld analysis is ±3% in minerals with fixed cell dimensions. In samples with substantial disordered clay minerals, the total percentage of clay was determined by Rietveld fitting and then the relative abundance of the clay species was quantified by integrating the areas under the 00l peak. The Lorentz and polarization contributions to the X-ray intensity in this study were corrected following the procedures of Pecharsky and Zavalij (2003, p. 192). Due to the presence of disordered phases and the need for a combination of methodologies, the accuracy of the results varies sample by sample. For samples in which substantial montmorillonite, random mixed-layer clays and/or degraded illite are present, the percentage mineralogy reported here is best considered semiquantitative.

Bulk mineralogy and X-ray fluorescence spectroscopy data are in Appendix 5a and b; clay mineralogy is in Appendix 6a and b.

3.2 Permeametry

Spot permeametry (Gingras et al., 2004) was carried out at the University of Alberta on a portable probe permeameter (CoreLabs Model PP-250), with nitrogen as the pore fluid. Note that the diameter of a nitrogen molecule is about 0.15 nm (1.5 angstroms), while the diameter of a methane molecule is about 0.4 nm (4.0 angstroms). Each sample was tested 4–6 times. The average Kl for each sample in Table 4 was calculated by removing high and low recorded values, then averaging remaining values.

Table 4. Summary of permeametry data for samples from the Banff and Exshaw formations.

AGS Sample No.	Core Depth (ft)	Core Depth (m)	UWI	Formation	Average Kl (shale)	Average Kl (other)
6919	12000	3657.6	100/08-27-039-11W5/00	U Banff	0.648333	
6937	11710.5	3569.4	100/04-23-072-10W6/00	Exshaw/L. Banff	0.965	
8691		2612.7	100/16-24-077-06W6/00	L. Banff	0.0020667	
6923	12245	3732.3	100/08-27-039-11W5/00	M. Banff	0.0031325	
6924	12399	3779.2	100/08-27-039-11W5/00	M. Banff	0.139	
6925	12441	3792.0	100/08-27-039-11W5/00	L.-M. Banff	0.0203667	
6928	12468	3800.2	100/08-27-039-11W5/00	L. Banff	0.004228	
6933		2795.3	100/01-20-001-24W4/00	Exshaw	0.153	
6935	11668	3556.4	100/04-23-072-10W6/00	L. Banff	0.002147	
6941	3803	1159.2	100/07-08-074-14W5/00	Banff	0.04575	
8682	6440	1962.9	100/02-14-082-02W6/00	L. Banff	0.0086025	
8688	7373	2247.3	100/06-04-084-07W6/00	L. Banff	3.775	
8693		2610.0	100/16-24-077-06W6/00	L. Banff	0.003488	0.013 (silt layer)

3.3 Scanning Electron Microscope and Energy-Dispersive X-Ray Analysis

The purpose of the scanning electron microscope (SEM) analysis is to characterize the microfabric of the samples, and the morphology, size and distribution of the pores. The SEM can also provide a mineralogical analysis using energy dispersive X-rays (EDX), as well as backscattering images on selected samples. An SEM fitted with an EDX spectrometer analyzed most of the samples. An environmental scanning electron microscope (ESEM) analyzed selected samples, which allowed variations in sample size with minimal sample preparation; however, an EDX system was not available for this microscope.

All samples that underwent ESEM analysis were examined in high vacuum mode using a secondary electron detector at 15–20 kV with a Philips/FEI XL 30 ESEM. The ESEM equipment has a resolution of 2.5 nm and a magnification up to 200 000×. The SEM was a JEOL 6301F (field emission scanning electron microscope) with magnification ranging from 20× to 250 000×. Semiqualitative elemental analysis (EDX) was available via a PGT X-ray analysis system. The resolution of EDX mineralogical analysis is 1 μm.

The SEM and ESEM images are in Appendix 7. Each image has a brief description; the descriptions are strictly observational.

3.4 Mercury Porosimetry

Mercury porosimetry is a technique to quantify intrusion pore diameter, size range of diameters, pore volume and pore surface area of the samples (Webb and Orr, 1997). Porosimeter work was done at the University of Alberta. All samples were put under vacuum in a cold oven for degassing prior to analysis. Mercury was introduced into the sample and the volume of mercury forced into pore space in the sample used to calculate pore volume for the sample. The data graphed here is only one of a number of columns of data available for analysis.

The graphs of incremental intrusion versus pore diameter (Appendix 8) show the equivalent spherical diameter at which the pore volume is concentrated (Webb and Orr, 1997).

The data in this study were generated using the Washburn equation ($D = -4\gamma\cos\theta/P$), where γ is the surface tension, θ is the assumed contact angle of mercury, P is the applied pressure and D is the equivalent pore diameter. The term 'equivalent' is used because the equation assumes all pores are the equivalent shape of a cylinder; in reality, this is not the case. The surface tension (485 dynes/cm), contact angle (130°) and equilibration time (10 seconds) between successive increases in pressure used in the procedure are all recommended by the manufacturer.

If pores are assumed to be dominated by 'slit-like' openings, as in clay-dominated sediment, then the data may be recalculated using $W = -2\gamma\cos\theta/P$, where W is the width between plates (Webb and Orr 1997). However, the samples in this study are dominantly silt-rich shale/mudstone or shaley siltstone, so we are comfortable using the Washburn equation as a starting point of analysis.

A summary of the procedure can be found in Webb and Orr (1997) and D'Souzae and More (2008).

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Appendices

Appendix 1 – Banff/Exshaw Formations Core Sample Location, Depth and Lithology

Legend

Column Label	Label Description
Sample No.	AGS sample number
Site No.	Site location number
Location - UWI	Well location - unique well identifier
Location - Latitude (NAD 83)	Well location - degrees latitude (North American Datum 1983)
Location - Longitude (NAD 83)	Well location - degrees longitude (North American Datum 1983)
Sample Depth (metres)	Depth of sample from core in metres (measured from core)
Lithology	Brief lithological description of sample
Formation Division	Subdivision of formation sampled
Year Sampled	Year sample collected

Sample No.	Site No.	Location			Sample Depth (metres)	Lithology	Formation Division	Year Sampled
		UWI	Latitude (NAD 83)	Longitude (NAD 83)				
6931	B01	100/01-20-001-24W4/00	49.045566	-113.165460	2783.3	Grey dolomitic mudstone	Lower Banff	2007
6932	B01	100/01-20-001-24W4/00	49.045566	-113.165460	2789.5	Black coal	Exshaw?	2007
6933	B01	100/01-20-001-24W4/00	49.045566	-113.165460	2795.3	Black shale	Exshaw	2007
8047	B02	100/02-14-082-02W6/00	56.103477	-118.193028	1975.1-1983.9	Combined samples: 8684, 85	Lower Banff	2008
8681	B02	100/02-14-082-02W6/00	56.103477	-118.193028	1958.0	Grey calcareous mudstone	Lower Banff	2008
8682	B02	100/02-14-082-02W6/00	56.103477	-118.193028	1962.9	Dark grey calcareous shale	Lower Banff	2008
8683	B02	100/02-14-082-02W6/00	56.103477	-118.193028	1968.6	Dark grey shale	Lower Banff	2008
8684	B02	100/02-14-082-02W6/00	56.103477	-118.193028	1975.1	Medium grey calcareous mudstone, see sample 8047	Lower Banff	2008
8685	B02	100/02-14-082-02W6/00	56.103477	-118.193028	1983.9	Grey calcareous. mudstone, see sample 8047	Lower Banff	2008
8686	B02	100/02-14-082-02W6/00	56.103477	-118.193028	1987.3	Dark grey shale	Lower Banff	2008
8017	B03	100/02-28-094-09W6/00	57.179218	-119.376578	1576.3	Dark grey calcareous mudstone	Lower Banff	2008
8696	B03	100/02-28-094-09W6/00	57.179218	-119.376578	1329.5	Laminated lime mudstone & siltst with organic debris	Upper Banff	2008
8697	B03	100/02-28-094-09W6/00	57.179218	-119.376578	1364.0	Grey calcareous. mudstone with organic debris	Upper Banff	2008
8698	B03	100/02-28-094-09W6/00	57.179218	-119.376578	1455.4	Dark grey calcareous mudstone	Middle Banff	2008
8699	B03	100/02-28-094-09W6/00	57.179218	-119.376578	1498.1	Dark grey calcareous mudstone	Lower Banff	2008
8700	B03	100/02-28-094-09W6/00	57.179218	-119.376578	1539.2	Interbedded calcareous mudstone & siltstone	Lower Banff	2008
6934	B04	100/04-23-072-10W6/00	55.245950	-119.431068	3549.7	Black shale	Lower Banff	2007
6935	B04	100/04-23-072-10W6/00	55.245950	-119.431068	3556.4	Black shale	Lower Banff	2007
6936	B04	100/04-23-072-10W6/00	55.245950	-119.431068	3565.2	Black shale, finely laminated	Lower Banff	2007
6937	B04	100/04-23-072-10W6/00	55.245950	-119.431068	3569.4	Massive black shale	Exshaw?/Lower Banff?	2007
8687	B05	100/06-04-084-07W6/00	56.252096	-119.047260	2234.2	Dark grey shale	Lower Banff	2008
8688	B05	100/06-04-084-07W6/00	56.252096	-119.047260	2247.3	Dark grey shale	Lower Banff	2008
6938	B06	100/07-08-074-14W5/00	55.394566	-116.113837	1040.4	Light green grey calcareous mudstone	Banff	2007
6939	B06	100/07-08-074-14W5/00	55.394566	-116.113837	1082.0	Light green grey calcareous shale	Banff	2007
6940	B06	100/07-08-074-14W5/00	55.394566	-116.113837	1118.9	Light green grey calcareous mudstone	Banff	2007
6941	B06	100/07-08-074-14W5/00	55.394566	-116.113837	1159.2	Light green grey calcareous mudstone	Banff	2007
6942	B06	100/07-08-074-14W5/00	55.394566	-116.113837	1204.0	Medium grey calcareous shale	Banff	2007
6943	B06	100/07-08-074-14W5/00	55.394566	-116.113837	1235.4	Medium grey calcareous mudstone	Banff	2007
6944	B06	100/07-08-074-14W5/00	55.394566	-116.113837	1258.8	Dark grey calcareous shale	Banff	2007
6945	B06	100/07-08-074-14W5/00	55.394566	-116.113837	1273.8	Black shale	Exshaw?	2007
8694	B07	100/08-08-076-07W6/00	55.568451	-119.040018	2904.0	Dark grey calcareous mudstone	Middle Banff	2008
8695	B07	100/08-08-076-07W6/00	55.568451	-119.040018	2911.8	Dark grey calcareous mudstone with silt laminea	Middle Banff	2008
6917	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3611.7	Shale	Upper Banff	2007
6918	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3626.6	Lime mudstone	Upper Banff	2007
6919	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3657.6	Shale	Upper Banff	2007
6920	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3665.8	Shale	Upper Banff	2007
6921	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3673.6	Shale	Upper Banff	2007
6922	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3706.4	Lime mudstone	Middle Banff	2007
6923	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3732.3	Lime mudstone	Middle Banff	2007
6924	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3779.2	Laminated silt/carbonate?	Middle Banff	2007
6925	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3792.0	Laminated silt, high gamma	Lower -Middle Banff	2007

Sample No.	Site No.	Location			Sample Depth (metres)	Lithology	Formation Division	Year Sampled
		UWI	Latitude (NAD 83)	Longitude (NAD 83)				
6926	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3790.2	Laminated silt	Lower -Middle Banff	2007
6927	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3796.4	Laminated silt	Lower -Middle Banff	2007
6928	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3800.2	Laminated carbonate silt	Lower Banff	2007
6929	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3807.3	Black mudstone	Lower Banff	2007
6930	B08	100/08-27-039-11W5/00	52.383168	-115.491096	3814.0	Light grey mudstone	11' below Wabamun Contact	2007
8046	B09	100/08-30-082-02W6/00	56.135519	-118.293350	1994.5-1998.6	Combined samples: 8678, 79	Lower Banff	2008
8678	B09	100/08-30-082-02W6/00	56.135519	-118.293350	1994.5	Dark grey shale	Lower Banff	2008
8679	B09	100/08-30-082-02W6/00	56.135519	-118.293350	1998.6	Dark grey shale	Lower Banff	2008
8680	B09	100/08-30-082-02W6/00	56.135519	-118.293350	2004.5	Dark grey shale	Exshaw/Lower Banff?	2008
6946	B10	100/09-06-052-11W5/00	53.463004	-115.601615	2282.6	Shale	Upper Banff	2007
6947	B10	100/09-06-052-11W5/00	53.463004	-115.601615	2287.5	Shale	Upper Banff	2007
6948	B10	100/09-06-052-11W5/00	53.463004	-115.601615	2295.4	Shale	Upper Banff	2007
8003	B10	100/09-06-052-11W5/00	53.463004	-115.601615	2297.3	Grey dolostone	Upper Banff	2007
8004	B10	100/09-06-052-11W5/00	53.463004	-115.601615	2439.6	Grey dolomitic mudstone	Lower Banff	2007
8005	B10	100/09-06-052-11W5/00	53.463004	-115.601615	2442.7	Calcareous mudstone	Lower Banff	2007
8006	B10	100/09-06-052-11W5/00	53.463004	-115.601615	2446.0	Black shale	Exshaw?	2007
8007	B10	100/09-06-052-11W5/00	53.463004	-115.601615	2446.3	Grey limestone	Wabaman	2007
8008	B11	100/12-36-030-22W4/00	51.614422	-112.978894	1633.9	Lime mudstone	Lower Banff	2007
8009	B11	100/12-36-030-22W4/00	51.614422	-112.978894	1638.3	Lime mudstone with thin black shale	Lower Banff	2007
8010	B11	100/12-36-030-22W4/00	51.614422	-112.978894	1638.9	Black shale	Exshaw	2007
8011	B11	100/12-36-030-22W4/00	51.614422	-112.978894	1639.5	Limestone	Wabaman	2007
8019	B12	100/15-05-107-08W6/00	58.264601	-119.290939	505.6	Grey calcareous shale	Upper Banff	2008
8020	B12	100/15-05-107-08W6/00	58.264601	-119.290939	512.4	Oilstained calcareous grainstone	Upper Banff	2008
8021	B12	100/15-05-107-08W6/00	58.264601	-119.290939	518.0	Green mudstone	Upper Banff	2008
8022	B12	100/15-05-107-08W6/00	58.264601	-119.290939	522.0	Reddish mudstone	Upper Banff	2008
8018	B13	100/15-27-098-25W5/00	57.539368	-117.965423	879.8	Grainstone	Middle Banff ?	2008
8689	B14	100/16-18-107-06W6/00	58.296137	-118.982929	544.7	Grey mudstone	Upper Banff	2008
8690	B14	100/16-18-107-06W6/00	58.296137	-118.982929	621.2	Grey mudstone	Lower Banff	2008
8691	B15	100/16-24-077-06W6/00	55.693279	-118.777249	2612.8	Dark grey shaley mudstone	Lower Banff	2008
8692	B15	100/16-24-077-06W6/00	55.693279	-118.777249	2619.5	Black shale with silt beds	Lower Banff	2008
8693	B15	100/16-24-077-06W6/00	55.693279	-118.777249	2610.0	Dark grey mudstone	Lower Banff	2008
8038	B16	102/06-02-079-22W5/00	55.817907	-117.332954	1712.9-1715	Dark blue-grey mudstone	Lower Banff	2008
8039	B16	102/06-02-079-22W5/00	55.817907	-117.332954	1709.0	Dark blue-grey mudstone	Lower Banff	2008
8012	Duplicate	Duplicate of 6921	52.383168	-115.491096		Shale	Upper Banff	2007
8013	Duplicate	Duplicate of 6947	53.463004	-115.601615		Shale	Upper Banff	2007
8014	Duplicate	Duplicate of 6935	55.245950	-119.431068		Black shale	Lower Banff	2007
8015	Duplicate	Duplicate of 8699	57.179218	-119.376578		Dark grey calcareous mudstone	Lower Banff	2008

Appendix 2 – Banff/Exshaw Formations Outcrop Sample Location, Depth and Lithology

Legend

Column Label	**Label Description**
Sample No.	AGS sample number
Site No.	Site location number
Site Location	Description of outcrop site
UTM Zone (NAD 83)	Site location - UTM Zone (North American Datum 1983)
Easting	Site location - UTM easting
Northing	Site location - UTM northing
Elevation (metres ASL)	Elevation of sampled site in metres above sea level
Lithology Formation Division	Brief lithological description of sample Subdivision of formation sampled
Sample Depth and Description	Sample location on section

Sample #	Site #	Site Location	Year Sampled	UTM (NAD 83)			Elevation (metres ASL)	Lithology	Formation Division	Sample Depth and Description
				Zone	Easting	Northing				
6506	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Shale	Exshaw	Duplicate of 6540
6533	B17	Nordegg - railway sec.	2007	11	567651	5816441	1309	Shale	Lower Banff	1.0 m interval, Lower Banff
6534	B17	Nordegg - railway sec.	2007	11	567651	5816441	1309	Shale	Exshaw	0-2.4 m above Palliser contact
6535	B17	Nordegg - railway sec.	2007	11	567651	5816441	1309	Bentonite	Exshaw	2.1 m above Palliser contact (1 cm)
6536	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Limestone	Palliser	.6 m below Exshaw contact
6537	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Shale	Exshaw	.05 m above Palliser contact
6538	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Shale	Exshaw	1.0 m above Palliser contact
6539	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Shale	Exshaw	1.7-1.8 m above Palliser contact
6540	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Shale	Exshaw	2.3-2.4 m above Palliser contact
6541	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Silt dolostone	Exshaw dolostone	3.7 m above Palliser contact
6542	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Shale	Lower Banff	6.4 m above Palliser contact
6543	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Shale	Lower Banff	7.4 m above Palliser contact
6545	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Siltstone	Lower Banff	11.2 m above Palliser contact
6546	B17	Nordegg - railway sec.	2007	11	567642	5816426	1327	Shale	Lower Banff	13.2 m above Palliser contact
6547	B17	Nordegg - railway sec.	2007	11	567651	5816454	1307	Lime mudstone	Banff	17.4 m above Palliser contact
6548	B17	Nordegg - railway sec.	2007	11	567651	5816454	1307	Lime mudstone	Banff	21.4 m above Palliser contact
6549	B17	Nordegg - railway sec.	2007	11	567651	5816454	1307	Lime mudstone	Banff	29.4 m above Palliser contact
6550	B17	Nordegg - railway sec.	2007	11	567651	5816454	1307	Lime mudstone	Banff	37.4 m above Palliser contact
7301	B17	Nordegg - railway sec.	2007	11	567651	5816454	1307	Lime mudstone	Banff	45.4 m above Palliser contact
7302	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime shale	Banff	53.4 m above Palliser contact
7303	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime mudstone	Banff	53.5 m above Palliser contact
7304	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime shale	Banff	61.4 m above Palliser contact
7305	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime mudstone	Banff	61.5 m above Palliser contact
7307	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime shale	Banff	71.4 m above Palliser contact
7308	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime mudstone	Banff	71.5 m above Palliser contact
7309	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime shale	Banff	83.4 m above Palliser contact
7310	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime mudstone	Banff	83.5 m above Palliser contact
7311	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime shale	Banff	103.4 m above Palliser contact
7312	B17	Nordegg - railway sec.	2007	11	587663	5816478	1315	Lime mudstone	Banff	103.5 m above Palliser contact
7313	B17	Nordegg - railway sec.	2007	11	567698	5816526	1316	Lime mudstone	Banff	120 m above Palliser contact
7314	B18	Kootney Plains - mountain sec.	2007	11	539339	5769916	1512	Shale	Banff	~100 m above Palliser contact (2 m shale)
6507	B19	Jura Creek	2007	11	628902	5661581	1509	Sandstone	Exshaw	0-.04 m above Palliser contact
6508	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	.04-.09 m above Palliser contact
6509	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	.09-.36 m above Palliser contact
6510	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	.36-.76 m above Palliser contact
6511	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	.76-1.01 m above Palliser contact
6512	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	1.01-1.26 m above Palliser contact
6513	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	1.26-1.29 m above Palliser contact

Sample #	Site #	Site Location	Year Sampled	UTM (NAD 83)			Elevation (metres ASL)	Lithology	Formation Division	Sample Depth and Description
				Zone	Easting	Northing				
6514	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	1.29-1.57 m above Palliser contact
6515	B19	Jura Creek	2007	11	628902	5661581	1509	Bentonite	Exshaw	1.57-1.61 m above Palliser contact
6516	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	1.57-1.61 m above Palliser contact
6517	B19	Jura Creek	2007	11	628902	5661581	1509	Shale - shear	Exshaw	2.01-2.51 m above Palliser contact
6518	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	2.33-2.41 m above Palliser contact
6519	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	2.51-2.89 m above Palliser contact
6520	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	2.89-3.04 m above Palliser contact
6521	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	3.04-3.54 m above Palliser contact
6522	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	3.54-4.04 m above Palliser contact
6523	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	4.04-4.54 m above Palliser contact
6524	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	4.54-5.04 m above Palliser contact
6525	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	5.04-5.54 m above Palliser contact
6526	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	5.54-6.04 m above Palliser contact
6527	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	6.04-6.54 m above Palliser contact
6528	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	6.54-7.04 m above Palliser contact
6529	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	7.04-7.54 m above Palliser contact
6530	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	7.54-8.04 m above Palliser contact
6531	B19	Jura Creek	2007	11	628902	5661581	1509	Limestone	Palliser	0- -.05 m above Palliser contact
6907	B19	Jura Creek	2007	11	628902	5661581	1509	Shale	Exshaw	Duplicate of 6521
7287	B19	Jura Creek	2007	11	628873	5661532	1523	Shale	Lower Banff	+1.3 m above Exshaw dolostone
7288	B19	Jura Creek	2007	11	628873	5661532	1523	Shale	Lower Banff	+3.0 m above Exshaw dolostone
6544	AGS standard	AGS standard	2007	AGS standard	AGS standard	AGS standard	AGS standard	Rock powder	AGS standard	AGS standard
6914	AGS standard	AGS standard	2007	AGS standard	AGS standard	AGS standard	AGS standard	Rock powder	AGS standard	AGS standard
7253	AGS standard	AGS standard	2007	AGS standard	AGS standard	AGS standard	AGS standard	Rock powder	AGS standard	AGS standard
7279	AGS standard	AGS standard	2007	AGS standard	AGS standard	AGS standard	AGS standard	Rock powder	AGS standard	AGS standard
7349	AGS standard	AGS standard	2007	AGS standard	AGS standard	AGS standard	AGS standard	Rock powder	AGS standard	AGS standard

Appendix 3 – Banff/Exshaw Formations Core Samples Analyzed

Legend

Y = Sample data presented in this report

x = Sample data presented in other Alberta Geological Survey reports (see Table 1 for details)

Analyses presented in this report

Column Label	Label Description
Sample No.	AGS sample number
Site No.	Site location number
Rock Eval™	Analysis to test for organic maturity and total organic carbon (TOC)
X-ray Diff-Bulk	X-Ray diffraction analysis of whole-rock mineralogy
X-ray Diff-Clay	X-Ray diffraction analysis of clay mineralogy
Organic Pet.	Organic petrology examines organic macerals
Thin Section	Thin section of sample
Thin Section Photo	Photograph of thin section
Adsorption Isotherm	Gas adsorption analysis to determine gas-holding capacity of sample
SEM	Scanning electron microscope
ESEM	Environmental scanning electron microscope
Mini-perm	Analysis to determine permeability
Porosity	Analysis to determine porosity

Sample No.	Site No.	Rock Eval™	Xray Diff-Bulk	Xray Diff-Clay	Organic Pet.	Thin Section	Thin Section Photo	Adsorption Isotherm	SEM	ESEM	Mini-perm	Porosity
6931	B01	x	Y			x	x					Y
6932	B01	x										
6933	B01	x				x					Y	
8047	B02	x						x				
8681	B02	x										
8682	B02	x				x					Y	
8683	B02	x	Y	Y								
8684	B02	x	Y						Y			Y
8685	B02	x										
8686	B02	x										
8017	B03	x	Y									
8696	B03	x										
8697	B03	x										
8698	B03	x										Y
8699	B03	x										
8700	B03	x				x						Y
6934	B04	x	Y	Y		x						
6935	B04	x									Y	
6936	B04	x				x			Y	Y		Y
6937	B04	x				x					Y	
8687	B05	x										
8688	B05	x	Y	Y		x	x		Y		Y	Y
6938	B06	x										
6939	B06	x				x						
6940	B06	x										
6941	B06	x									Y	
6942	B06	x				x						
6943	B06	x	Y									
6944	B06	x										
6945	B06	x										
8694	B07	x										
8695	B07	x				x				Y		Y
6917	B08	x										
6918	B08	x										
6919	B08	x									Y	
6920	B08	x										
6921	B08	x										
6922	B08	x				x	x					
6923	B08	x									Y	
6924	B08	x				x	x				Y	
6925	B08	x									Y	
6926	B08	x	Y			x						
6927	B08	x										
6928	B08	x									Y	
6929	B08	x										
6930	B08	x										
8046	B09	x						x				
8678	B09	x										
8679	B09	x				x						Y
8680	B09	x	Y									
6946	B10	x										
6947	B10	x	Y									
6948	B10	x										
8003	B10	x										
8004	B10	x										
8005	B10	x				x						
8006	B10	x				x				Y		Y
8007	B10	x										
8008	B11	x										
8009	B11	x										
8010	B11	x										
8011	B11	x										
8019	B12	x										
8020	B12											
8021	B12	x	Y			x						
8022	B12	x				x						
8018	B13					x						
8689	B14	x				x						
8690	B14	x				x			Y			Y
8691	B15	x									Y	
8692	B15	x	Y			x			Y			Y
8693	B15	x									Y	
8038	B16	x	Y			x						
8039	B16	x										
8012	Duplicate	x										
8013	Duplicate	x										
8014	Duplicate	x										
8015	Duplicate	x										

Appendix 4 – Banff/Exshaw Formations Outcrop Samples Analyzed

Legend

Y = Sample data presented in this report

x = Sample data presented in other Alberta Geological Survey reports, see Table 1 for details.

YY = Clay separated

Analyses presented in this report

Column Label	Label Description
Sample No.	AGS sample number
Site No.	Site location number
Geochem	Inorganic geochemical analysis
Rock Eval™	Analysis for organic maturity and total organic carbon (TOC)
X-ray Diff-Bulk	X-Ray diffraction analysis of whole-rock mineralogy
X-ray Diff-Clay	X-Ray diffraction analysis of clay mineralogy
Organic Pet.	Organic petrology examines organic macerals
Thin Section	Thin section of sample
Thin Section Photo	Photograph of thin section
Adsorption Isotherm	Gas adsorption analysis to determine gas-bearing capacity

Sample No.	Site No.	Geochem	Rock Eval™	Xray Diff-Bulk	Xray Diff-Clay	Organic Pet.	Thin Section	Thin Section Photo	Adsorption Isotherm
6506	B17	x	x						
6533	B17	x	x	Y	Y				
6534	B17	x	x	Y	YY				x
6535	B17	x							
6536	B17	x	x	Y					
6537	B17	x	x	Y	Y				
6538	B17	x	x	Y	Y				
6539	B17	x	x	Y	Y	x			
6540	B17	x	x	Y	Y				
6541	B17	x	x	Y	Y		x	x	
6542	B17	x	x	Y	Y	x			
6543	B17	x	x	Y	YY				x
6545	B17	x	x	Y	Y				
6546	B17	x	x	Y	Y				
6547	B17	x	x	Y					
6548	B17	x	x	Y	YY	x	x	x	x
6549	B17	x	x	Y			x	x	
6550	B17	x	x	Y			x	x	
7301	B17	x	x	Y			x	x	
7302	B17	x	x	Y	Y				
7303	B17	x	x	Y	Y		x	x	
7304	B17	x	x	Y	YY		x	x	x
7305	B17	x	x	Y	Y		x	x	
7307	B17	x	x	Y	Y		x	x	
7308	B17	x	x	Y	Y		x	x	
7309	B17	x	x	Y	YY		x	x	
7310	B17	x	x	Y	Y		x	x	
7311	B17	x	x	Y	Y	x	x	x	
7312	B17	x	x	Y			x	x	
7313	B17	x	x	Y			x	x	
7314	B18	x	x	Y	Y				
6507	B19	x	x	Y	Y		x	x	
6508	B19	x	x	Y	Y				
6509	B19	x	x	Y	Y		x	x	
6510	B19	x	x	Y	Y	x			
6511	B19	x	x	Y	Y				
6512	B19	x	x	Y	Y				
6513	B19	x	x	Y	Y				
6514	B19	x	x	Y	Y	x	x	x	
6515	B19	x							
6516	B19	x	x	Y	Y				
6517	B19	x	x	Y	YY				x
6518	B19	x	x	Y	Y				
6519	B19	x	x	Y	Y				
6520	B19	x	x	Y	Y				
6521	B19	x	x	Y	Y	x			
6522	B19	x	x	Y	Y				
6523	B19	x	x	Y	Y				
6524	B19	x	x	Y	Y				
6525	B19	x	x	Y	YY	x			x
6526	B19	x	x	Y	Y				
6527	B19	x	x	Y	Y				
6528	B19	x	x	Y	Y				
6529	B19	x	x	Y	Y				
6530	B19	x	x	Y	Y				
6531	B19	x	x	Y		x	x	x	
6907	B19	x	x						
7287	B19	x	x	Y	YY				
7288	B19	x	x	Y	Y				
6544	AGS std	x							
6914	AGS std	x							
7253	AGS std	x							
7279	AGS std	x							
7349	AGS std	x							

Appendix 5 – Banff/Exshaw Formations Bulk Mineralogy

Appendix 5a – Bulk X-Ray Diffraction

Legend

Anat.	Anatase	Jaro.	Jarosite
Ank.	Ankerite	Kaol.	Kaolinite
Apa.	Apatite	Micro.	Microcline
Bass.	Bassanite	Mont.	Montmorillonite
Bio.	Biotite	Musc.	Muscovite
Chlo.	Chlorite	Ortho.	Orthoclase
ClCh.	Clinochlore	Paly.	Palygorskite
DI	Degraded illite	Rhod.	Rhodochrosite
Dolo.	Dolomite	RMLC	Random mixed layer clays
FlAp.	Fluorapatite	Rut.	Rutile
Gyp.	Gypsum	Sep.	Sepiolite
Heul.	Heulandite	Sid.	Siderite
Ilme.	Ilmenite	tr	Trace amounts

Note: outcrop samples were tested by CBM Solutions and core samples were tested by SGS Mineral Services.

Sample No.	Sample Type	Sample Site	Quartz	Feldspar			Pyrite	Musc.	Clay Minerals								Carbonates			Sulphates	Anatase	Brookite	Ilmenite	Hematite	Total
				Albite	Micro.	Ortho.			Kaol.	Illite	Paly.	Sep.	RMLC	Mont.	ClCh.	Chlo.	Calcite	Dolo.	Ank.	Gypsum					
6507	outcrop	B19	21.7	3.5		20.3	9.8		1.2								26.0	17.6							100.0
6508	outcrop	B19	40.9			13.1	5.1		1.1	3.4							4.0	32.3							100.0
6509	outcrop	B19	68.1			14.1	2.6		2.2	5.8							4.5	2.6							100.0
6510	outcrop	B19	65.6			13.4	2.8		3.4	6.6							6.5	1.6							100.0
6511	outcrop	B19	71.1			12.2	2.7		2.4	5.9							3.9	1.8							100.0
6512	outcrop	B19	66.2			13.4	1.4		2.9	9.1							4.1	3.0							100.0
6513	outcrop	B19	18.4	4.0		19.6	0.6		10.0	40.6							4.6	2.2							100.0
6514	outcrop	B19	69.5	2.0		5.2	0.3		2.2	11.5							9.3								100.0
6516	outcrop	B19	65.0	1.9		9.2	0.2			16.7							7.0								100.0
6517	outcrop	B19	66.9	4.0		14.7			1.2	7.6							4.5			1.2					100.0
6518	outcrop	B19	45.4	2.3		19.3	0.3		3.0	16.3							13.4								100.0
6519	outcrop	B19	60.9	1.7		13.7	1.0		1.1	11.7							10.0								100.0
6520	outcrop	B19	65.0	1.1		10.8	1.4		1.1	13.6							3.6	3.4							100.0
6521	outcrop	B19	53.0	1.7		17.5	0.5		1.0	24.0							2.1	0.3							100.0
6522	outcrop	B19	68.3	1.2		11.1	0.3		0.9	14.4							3.5	0.4							100.0
6523	outcrop	B19	50.4	2.0		1.0			9.3	32.7							3.8	0.8							100.0
6524	outcrop	B19	34.6	1.3		8.9	1.5			43.3							9.0	1.6							100.0
6525	outcrop	B19	47.4	6.8		19.4			1.0	20.6							1.8	0.0		2.9					100.0
6526	outcrop	B19	22.3	2.1		19.8	3.3			24.1							20.8	7.7							100.0
6527	outcrop	B19	24.2	4.2		19.1	2.9		4.8	29.4							11.7	2.8		1.0					100.0
6528	outcrop	B19	20.8	6.0		13.5	1.8		4.9	27.2							21.2	3.3		1.4					100.0
6529	outcrop	B19	17.8	3.4		15.0	2.5			19.8							37.2	4.3							100.0
6530	outcrop	B19	22.1	3.4		18.3	3.1			28.2							21.8	3.1							100.0
6533	outcrop	B17	36.3	3.7		16.7	0.4		7.1	5.5			tr				10.6	19.6							100.0
6534	outcrop	B17	74.9	1.8		6.9			1.2	6.4							8.9								100.0
6537	outcrop	B17	66.2	0.5		12.5				4.0							16.3	0.5							100.0
6538	outcrop	B17	82.4	0.8		10.1				5.1							1.6								100.0
6539	outcrop	B17	7.2	3.9		71.1	0.3		1.4	4.3							9.1	2.7							100.0
6540	outcrop	B17	30.2	2.0		19.9	0.3			8.7							17.7	21.1							100.0
6541	outcrop	B17	29.2	1.0		12.7	0.4			3.4							10.1	43.3							100.0
6542	outcrop	B17	33.0	2.0		20.4				6.7							14.9	22.9							100.0
6543	outcrop	B17	39.7	4.3		9.7				7.4						11.6	27.3								100.0
6545	outcrop	B17	28.3	1.1		5.6	0.1			3.1			0.0	2.9		4.1	23.9	29.8		1.0					100.0
6546	outcrop	B17	29.2	1.1		5.8	0.1			3.2			5.2				24.7	30.7							100.0
6547	outcrop	B17	12.5	0.6		3.3											66.1	17.5							100.0
6548	outcrop	B17	53.0	1.2		0.6										0.1	45.1								100.0
6549	outcrop	B17	45.3			1.4											34.4	18.9							100.0
6550	outcrop	B17	12.1	0.6		3.6											53.9	29.9							100.0

Sample No.	Sample Type	Sample Site	Quartz	Feldspar			Pyrite	Musc.	Clay Minerals								Carbonates			Sulphates	Anatase	Brookite	Ilmenite	Hematite	Total
				Albite	Micro.	Ortho.			Kaol.	Illite	Paly.	Sep.	RMLC	Mont.	ClCh.	Chlo.	Calcite	Dolo.	Ank.	Gypsum					
6926	core	B08	13.1	2.1		3.2		3.7	0.6								61.9	11.9	3.4						99.9
6931	core	B01	30.9	4.3	13.4		1.3	9.8										34.5	5.7						99.9
6934	core	B04	26.1	5.0	4.1		0.8	13.3							4.2		31.0	7.4	8.2						100.1
6943	core	B06	26.8	3.2		7.6	0.3	4.8	2.6								34.4	14.2	6.1						100.0
6947	core	B10	31.6	--		23.4	6.7	26.9			9.4						1.3				0.8				100.1
7287	outcrop	B19	31.7	4.5		10.0				9.1							36.3		8.3						100.0
7288	outcrop	B19	28.1	4.8		6.1			1.0	11.8							41.3	6.9							100.0
7301	outcrop	B17	4.5	1.6													52.9	3.1	37.8						100.0
7302	outcrop	B17	20.8	3.4			1.2			21.2							42.1	11.3							100.0
7303	outcrop	B17	16.7	2.6		3.1	1.1			10.0							57.3	9.2							100.0
7304	outcrop	B17	15.9	0.1		9.1	1.7			8.9							37.3	0.3	26.8						100.0
7305	outcrop	B17	18.6	1.1		2.6	0.8			9.5							52.4	2.4	12.7						100.0
7307	outcrop	B17	22.4	2.1		2.8	1.1			17.5							36.0	2.5	15.8						100.0
7308	outcrop	B17	35.8	0.7		1.5	0.3			7.8							44.0	2.0	7.9						100.0
7309	outcrop	B17	13.1	1.9		6.2	3.2			9.0							51.5	0.1	15.0						100.0
7310	outcrop	B17	13.4	1.2		1.9	0.9			4.4							73.5	4.8							100.0
7311	outcrop	B17	15.0	3.2		5.7			1.7	15.6						tr	47.2	11.6							100.0
7312	outcrop	B17	27.5														70.9	1.6							100.0
7313	outcrop	B17	3.9				0.4										91.4	4.3							100.0
7314	outcrop	B18	7.6	4.7		6.9	2.1			4.1							33.9	5.5	35.2						100.0
8017	core	B03	24.2	7.2		8.0	2.0	19.7	2.6			3.8			4.6		10.0	8.5	9.4						100.0
8021	core	B12	41.1	2.1		13.6	1.8	18.5		10.4	10.3						0.5		1.0		0.8				100.1
8038	core	B16	32.0	4.7		4.0	2.9	15.5			3.5	4.7					12.3	2.6	4.3						86.5
8680	core	B09	45.7	7.3		5.3	8.9	20.9			9.3				1.1		0.6					0.9			100.0
8683	core	B02	29.9	5.0	3.1		2.2	27.7	3.9						3.7		11.0	6.8	5.3					1.3	99.9
8684	core	B02	28.1	6.5		7.2	1.4	17.7	2.3			3.4					15.0	9.9	8.5						100.0
8688	core	B05	46.0			9.1	6.1	23.8	7.4		5.8						0.9				0.6	0.3			100.0
8692	core	B15	51.3	3.0		5.9	1.1	17.5	1.8						4.9		3.9	5.2	5.0			0.5			100.1

Appendix 5b – X-Ray Fluorescence

Legend

Sample No.	AGS sample number
SiO_2	Silica oxide
Al_2O_3	Aluminum oxide
Fe_2O_3	Iron oxide
MgO	Magnesium oxide
CaO	Calcium oxide
Na_2O	Sodium oxide
K_2O	Potassium oxide

TiO_2	Titanium oxide
P_2O_5	Phosphorous oxide
MnO	Manganese oxide
Cr_2O_3	Chromium oxide
V_2O_5	Vanadium oxide
LOI	loss on ignition - amount of material loss due to heating
Total	Total weight percent
%	Percent
DUP	Duplicate

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3	V_2O_5	LOI	Total
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
6926	18.40	2.55	0.70	2.40	38.90	0.24	0.86	0.14	0.05	0.01	<0.01	0.02	33.60	97.80
6931	46.10	7.42	2.93	7.41	11.60	0.53	3.24	0.53	0.09	0.08	0.05	<.01	17.30	97.30
6934	38.50	7.37	2.82	3.44	20.70	0.58	2.03	0.35	0.12	0.04	0.02	0.02	22.50	98.50
6943	37.50	4.80	2.03	3.35	24.50	0.47	1.74	0.32	0.08	0.04	0.01	0.01	22.80	97.60
6947	60.80	16.40	4.23	2.13	0.60	0.39	6.85	0.92	0.18	0.01	0.02	0.02	6.12	98.70
8017	46.10	11.30	4.35	4.75	9.97	0.99	2.82	0.60	0.11	0.08	0.02	<.01	18.00	99.10
8021	64.50	14.30	4.76	2.27	0.42	0.42	4.73	0.81	0.19	0.02	0.02	0.01	5.56	98.00
8038	48.30	7.27	3.98	2.08	8.73	0.53	2.44	0.35	0.72	0.04	0.02	0.03	24.60	99.10
8680	64.00	12.90	5.37	1.33	0.16	0.83	3.17	0.61	0.09	0.02	<.01	0.15	10.30	99.00
8683	49.80	12.00	4.23	2.02	7.98	0.64	3.66	0.56	0.08	0.03	0.02	0.13	16.40	98.60
8684	47.20	10.20	4.01	3.33	13.30	0.62	2.68	0.59	0.11	0.06	<.01	0.03	16.60	98.80
8688	66.90	14.00	3.99	1.10	0.48	0.39	3.56	0.77	0.07	0.03	0.02	0.07	7.30	98.50
8692	66.90	9.59	2.61	2.54	4.57	0.62	2.71	0.45	0.13	0.02	0.02	0.07	9.35	99.50
8692DUP	66.30	9.56	2.61	2.53	4.59	0.60	2.73	0.45	0.11	0.03	0.02	0.06	9.41	99.00

Appendix 6 – Banff/Exshaw Formations Clay Mineralogy

Appendix 6a – Quantitative Clay X-Ray Diffraction

RMLC	Random mixed-layered clays
Mont.	Montmorillonite
*	Clay separation done on sample before clay XRD

Sample No.	Sample Type	Sample Site	Clay Minerals				
			Kaolinite	Illite	RMLC	Mont.	Chlorite
6507	outcrop	B19	100				
6508	outcrop	B19	24	76			
6509	outcrop	B19	28	72			
6510	outcrop	B19	34	66			
6511	outcrop	B19	29	71			
6512	outcrop	B19	24	76			
6513	outcrop	B19	20	80			
6514	outcrop	B19	16	84			
6516	outcrop	B19		100			
6517*	outcrop	B19	13	87			
6518	outcrop	B19	16	84			
6519	outcrop	B19	9	91			
6520	outcrop	B19	8	92			
6521	outcrop	B19	4	96			
6522	outcrop	B19	6	94			
6523	outcrop	B19	22	78			
6524	outcrop	B19		100			
6525*	outcrop	B19	5	95			
6526	outcrop	B19		100			
6527	outcrop	B19	14	86			
6528	outcrop	B19	15	85			
6529	outcrop	B19		100			
6530	outcrop	B19		100			
6533	outcrop	B17	56	44			
6534*	outcrop	B17	15	85			
6537	outcrop	B17		100			
6538	outcrop	B17		100			
6539	outcrop	B17	25	75			
6540	outcrop	B17		100			
6541	outcrop	B17		100			
6542	outcrop	B17		100			
6543*	outcrop	B17		39			61
6545	outcrop	B17		31		29	41
6546	outcrop	B17		38	62		
6547	outcrop	B17					
6548*	outcrop	B17					100
6549	outcrop	B17					
6550	outcrop	B17					
7287*	outcrop	B19		100			
7288	outcrop	B19	7	93			
7301	outcrop	B17					
7302	outcrop	B17		100			
7303	outcrop	B17		100			
7304*	outcrop	B17		100			
7305	outcrop	B17		100			
7307	outcrop	B17		100			
7308	outcrop	B17		100			
7309*	outcrop	B17		100			
7310	outcrop	B17		100			
7311	outcrop	B17	10	90			
7312	outcrop	B17					
7313	outcrop	B17					
7314	outcrop	B18		100			

Appendix 6b – Qualitative Clay X-Ray Diffraction

Sample No.	Sample Site	Sample Type	Crystalline Mineral Assemblage (relative proportions based on peak height)			
			Major	Moderate	Minor	Trace
6934	B04	core	illite	(quartz), (calcite)	kaolinite, chlorite	(*siderite), (*pyrite)
8683	B02	core	illite	(quartz)	kaolinite, (calcite), chlorite	(*ankerite)
8688	B05	core	illite		kaolinite, (quartz)	(*pyrite)

* Tentative identification due to low concentrations, diffraction line overlap or poor crystallinity

( ) Not a clay mineral

Appendix 7 – Banff/Exshaw Formations Scanning Electron Microscope and Environmental Scanning Electron Microscope Images and Description

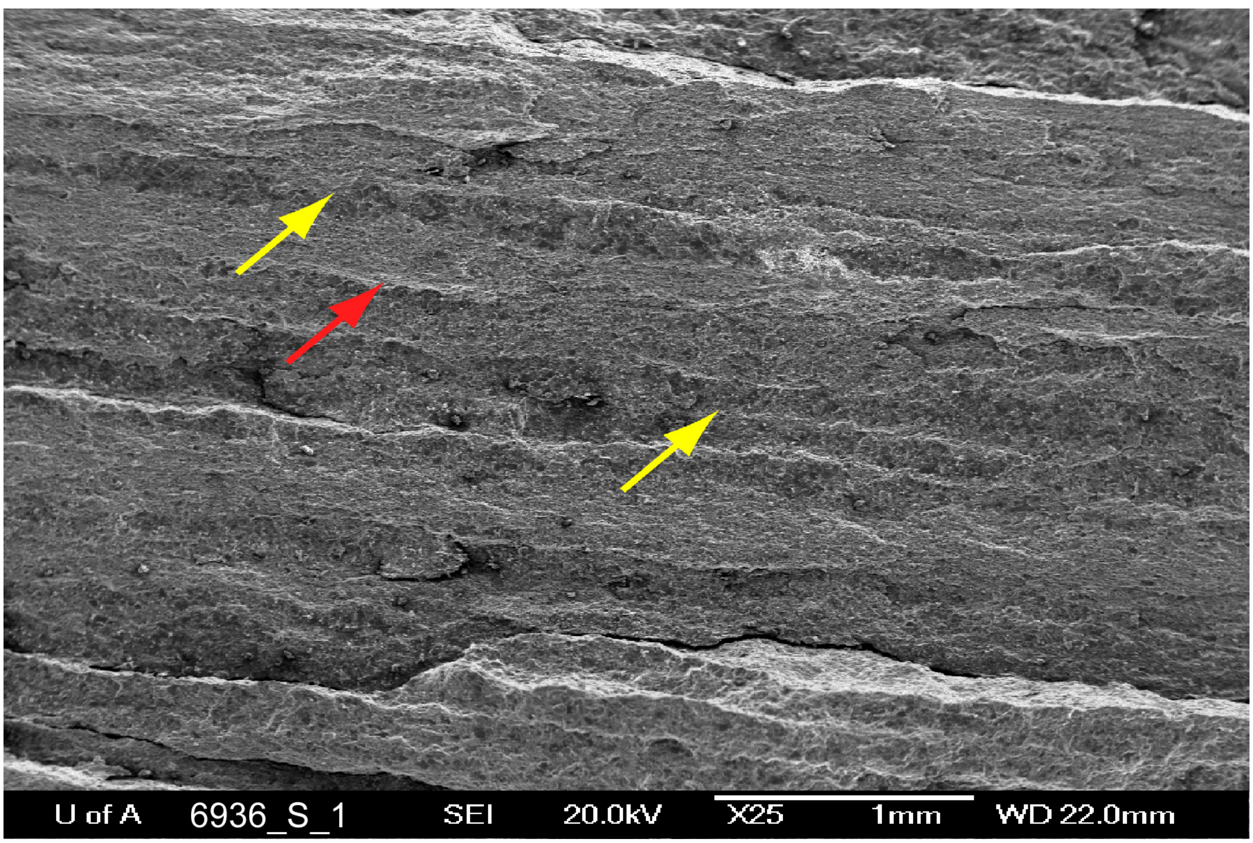
Scanning Electron Microscope (SEM) Images and Descriptions of Banff Formation shales

1) Sample 6936 — Lower Banff Fm.
100/04-23-072-10W6/00 — 11,697 feet core depth (3565.2 m)

This is a sample of finely laminated, red shale. The bedding plane trends approximately east in all images, and up is northward.

a)

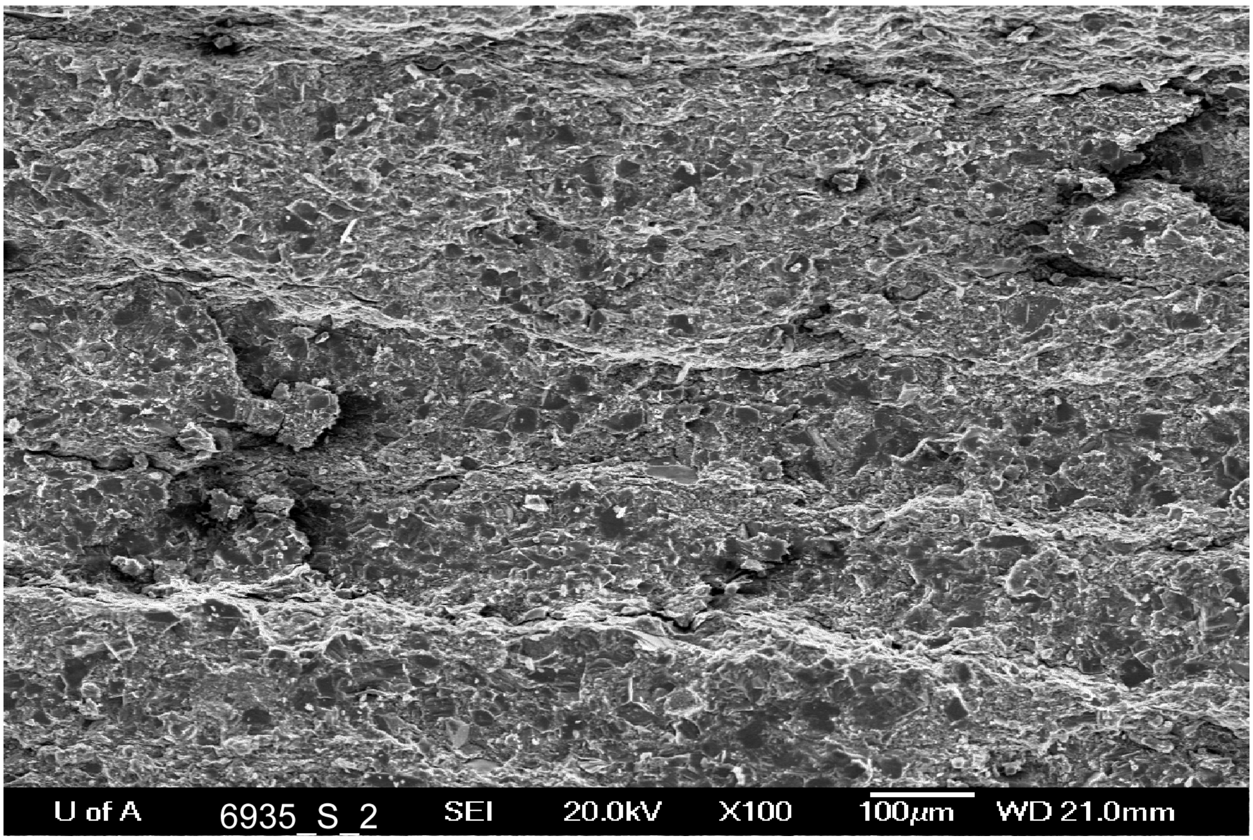
Image	Magnification
6936_S_1	25×



This photo shows continuous (yellow arrows) and discontinuous (red arrow) silt layers in a matrix of clay-sized minerals. The continuous silt layers are about 0.25 to 0.5 millimetres (mm) thick. Silt grains (dark grey) are also observed floating in the matrix. At this scale of observation, both the silt layers and the matrix appear to be devoid of porosity. Fracturing is largely parallel to subparallel to bedding and is likely due to expansion during core retrieval.

b)

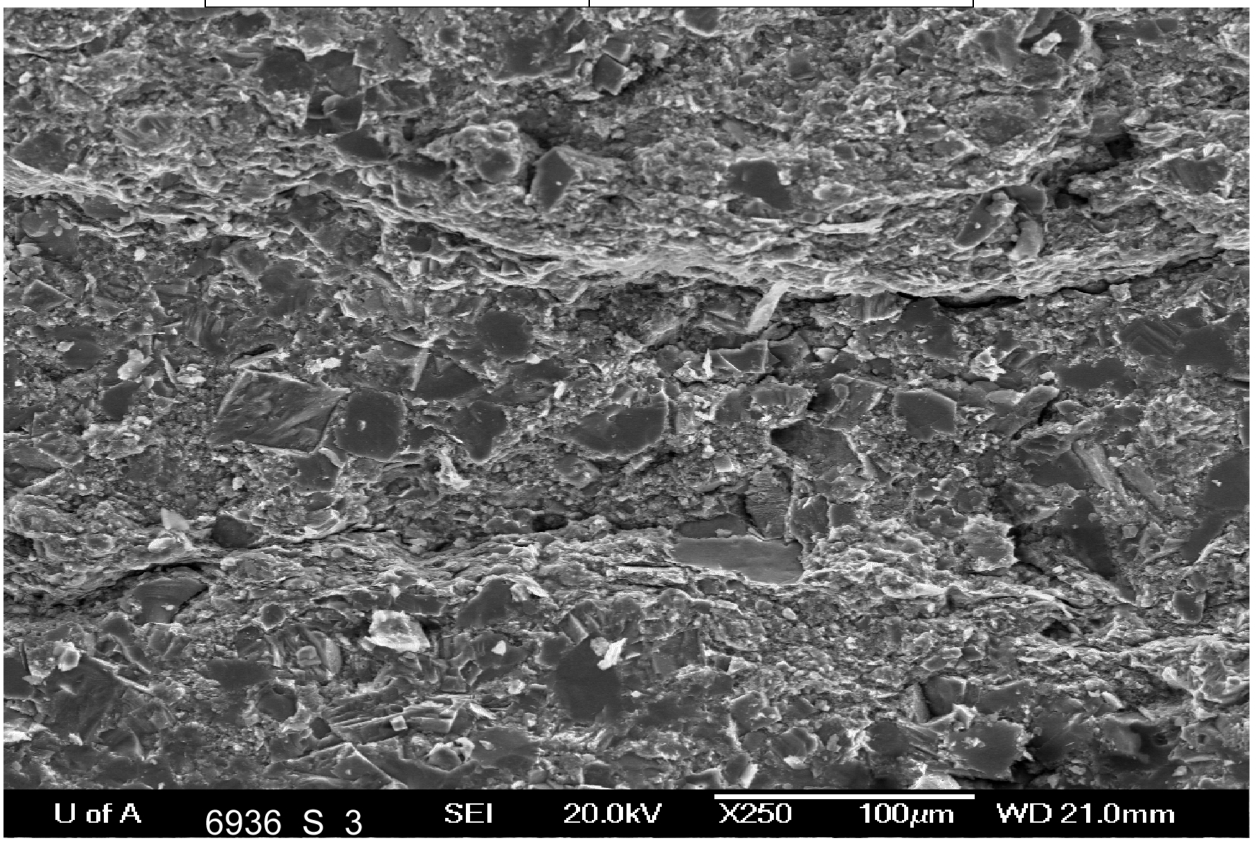
Image	Magnification
6936_S_2	100×



This is a high magnification photo of silty clay taken near the tip of the lower right arrow in 6936_S_1. Silt grains are less than 40–50 µm (microns) in diameter and largely appear to be floating in the matrix. At this scale, the layers appear to be devoid of porosity. Fracturing is linear to curvilinear and parallel to subparallel to bedding.

c)

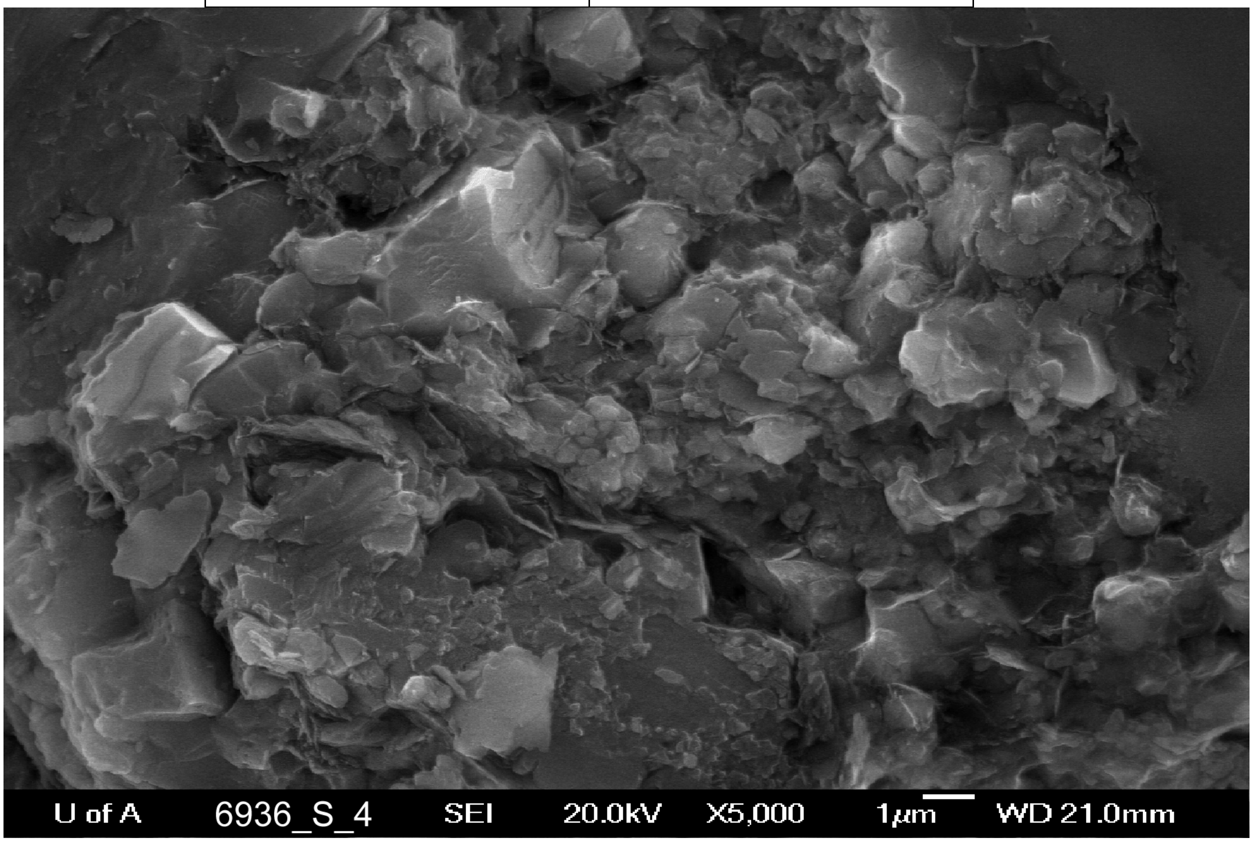
Image	Magnification
6936_S_3	250×



This photo, taken near the centre of the 6936_S_2, shows silt grains that are dominantly less than 50 μm in diameter, although a few have a long axis of 70–80 μm. Many of the grains in this view are in contact, so the silty layer is in part grain supported. Energy dispersive X-ray (EDX) analysis of grain mineralogy suggests a dominance of quartz and, to a lesser degree, sodium feldspar and crystals of dolomite (rhomboids). EDX analysis of the matrix suggests a dominance of quartz and calcite cement. Grain morphology ranges the entire gamut from angular to rounded edges and poor to good sphericity. Curvilinear fracturing is evident and has created porosity along the fracture plane. At this scale of viewing, porosity is also evident at some grain-grain contacts and grain-matrix contacts, and is dominantly a few micrometres in pore diameter, excluding along the fracture plane. Intraparticle and matrix porosity may also be evident but is difficult to discern at this scale.

d)

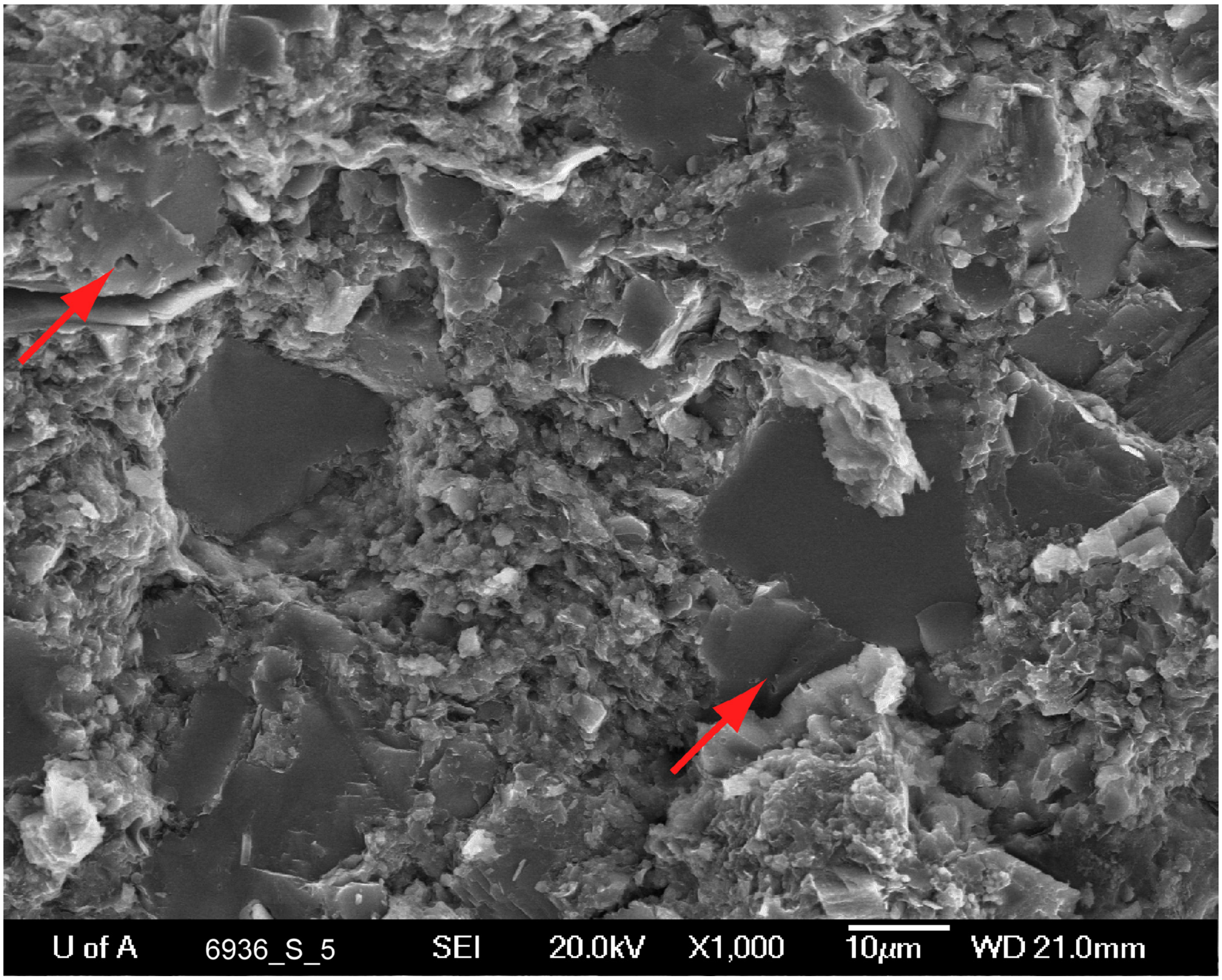
Image	Magnification
6936_S_4	5000×



This is a high magnification view of the matrix. The matrix is dominated by quartz overgrowth of a variety of morphologies and crystal sizes and, to a lesser extent, clay plates. Quartz overgrowth appears to occur between grains and coating grains, significantly decreasing porosity. Hence, the morphology of the grains viewed in all the photos of sample 6936 (Lower Banff) may not reflect depositional grain morphology. Microporosity is evident between overgrowth crystals. Clay mineralogy was not identified in this photo.

e)

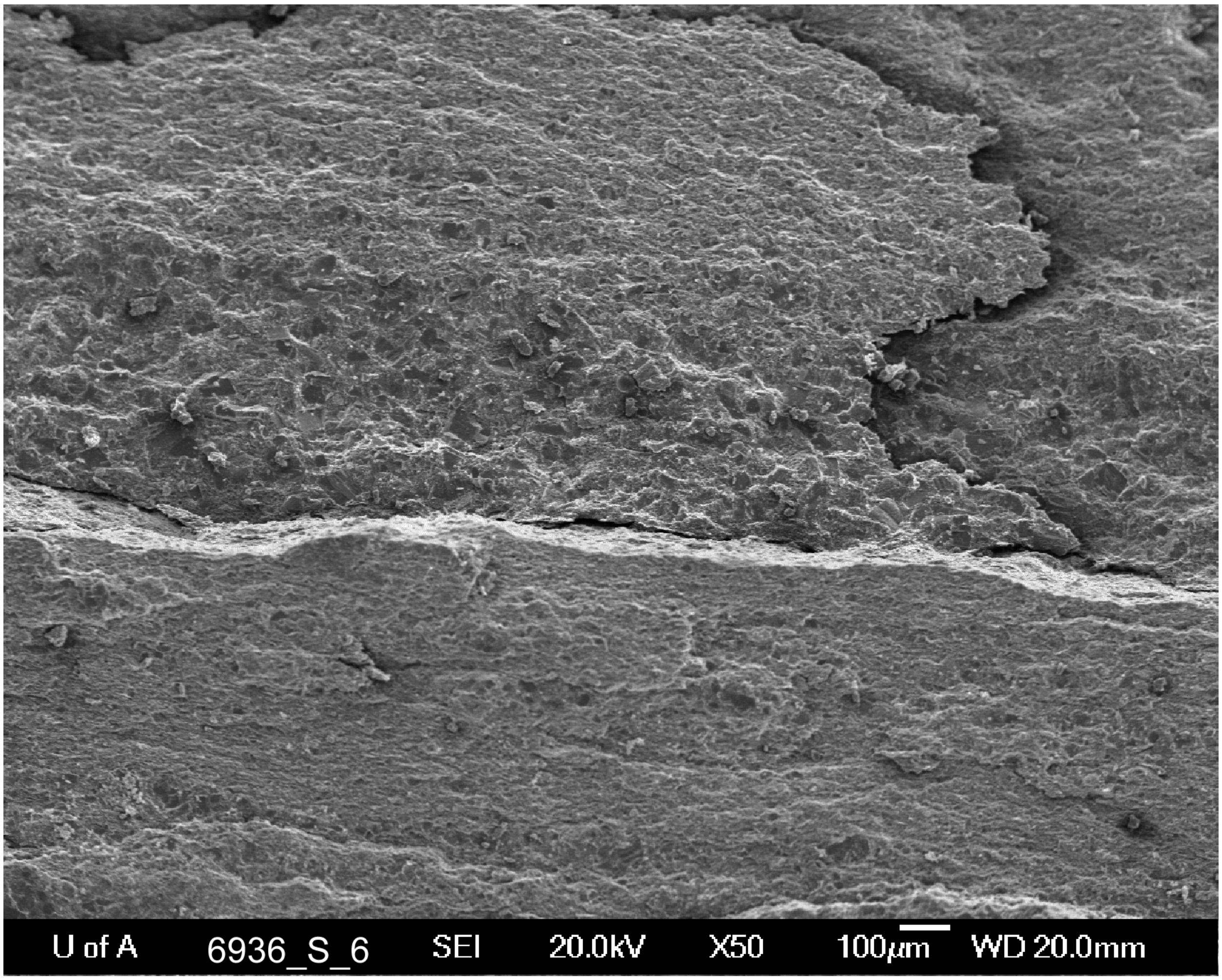
Image	Magnification
6936_S_5	1000×



This view of the grains and matrix shows the presence of matrix porosity as well as intraparticle porosity (red arrows). The diameter of matrix pores is dominantly less than a few micrometres.

f)

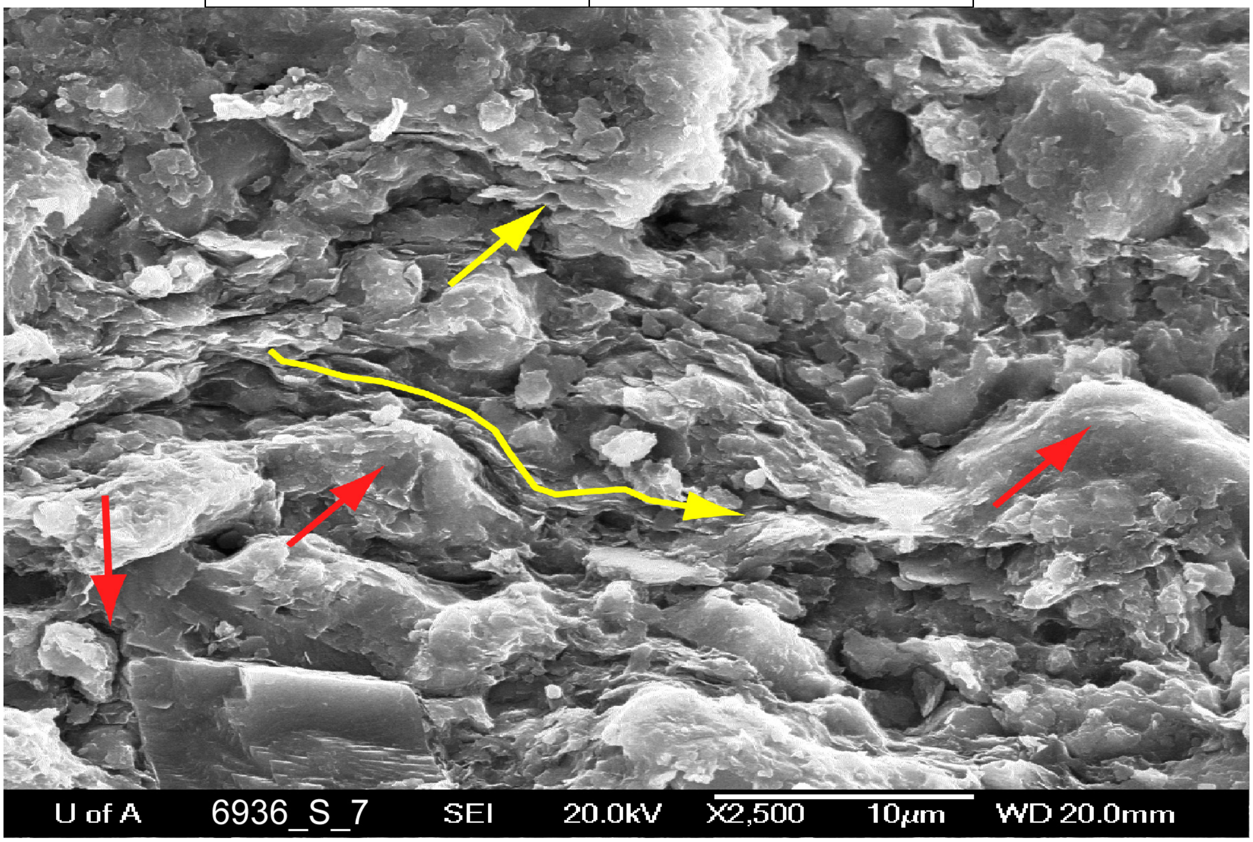
Image	Magnification
6936_S_6	50×



This image was taken in the upper right portion of the first image (6936S_1). Only the bottom portion of the present image can be seen in 6936S_1. The silt layer forms a sharp contact with the underlying clay-sized material, wherein a few floating silt grains can be viewed. The fracture plane appears to be coincident with the silt-clay contact and presumably formed after core retrieval. At this scale of observation, no porosity is evident in the silt layer.

g)

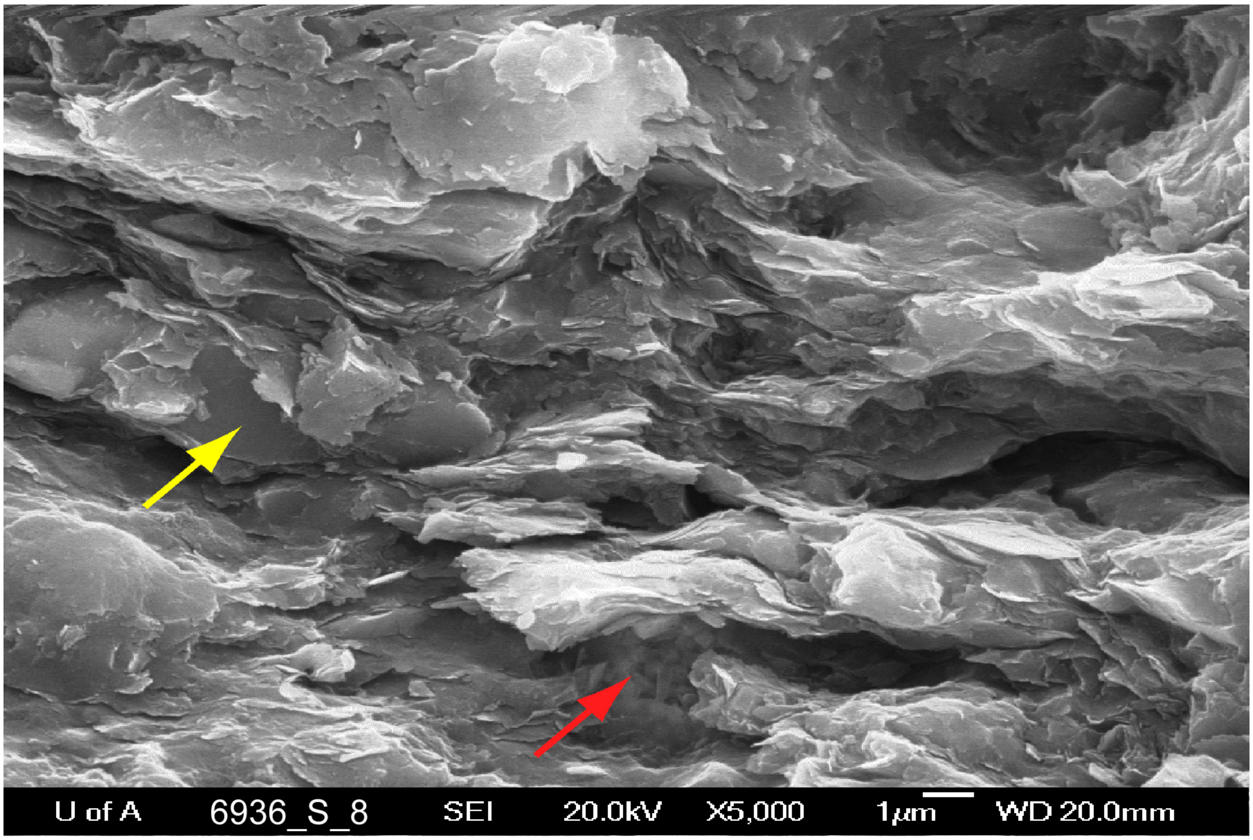
Image	Magnification
6936_S_7	2500×



High-magnification view of the clay layer in the previous photo, showing the presence of silt grains (red arrows), up to 10 µm across, with clay fabric that appears to drape around the grains due to compaction (long yellow arrow above draping clay). Porosity is evident at grain contacts, as seen in the lower left quadrant (down-pointing red arrow) although this may be due to microfracturing during core unloading; porosity is also visible occasionally between slightly crenulated clay plates, as seen near the yellow arrow (upper middle of the image).

h)

Image	Magnification
6936_S_8	5000×



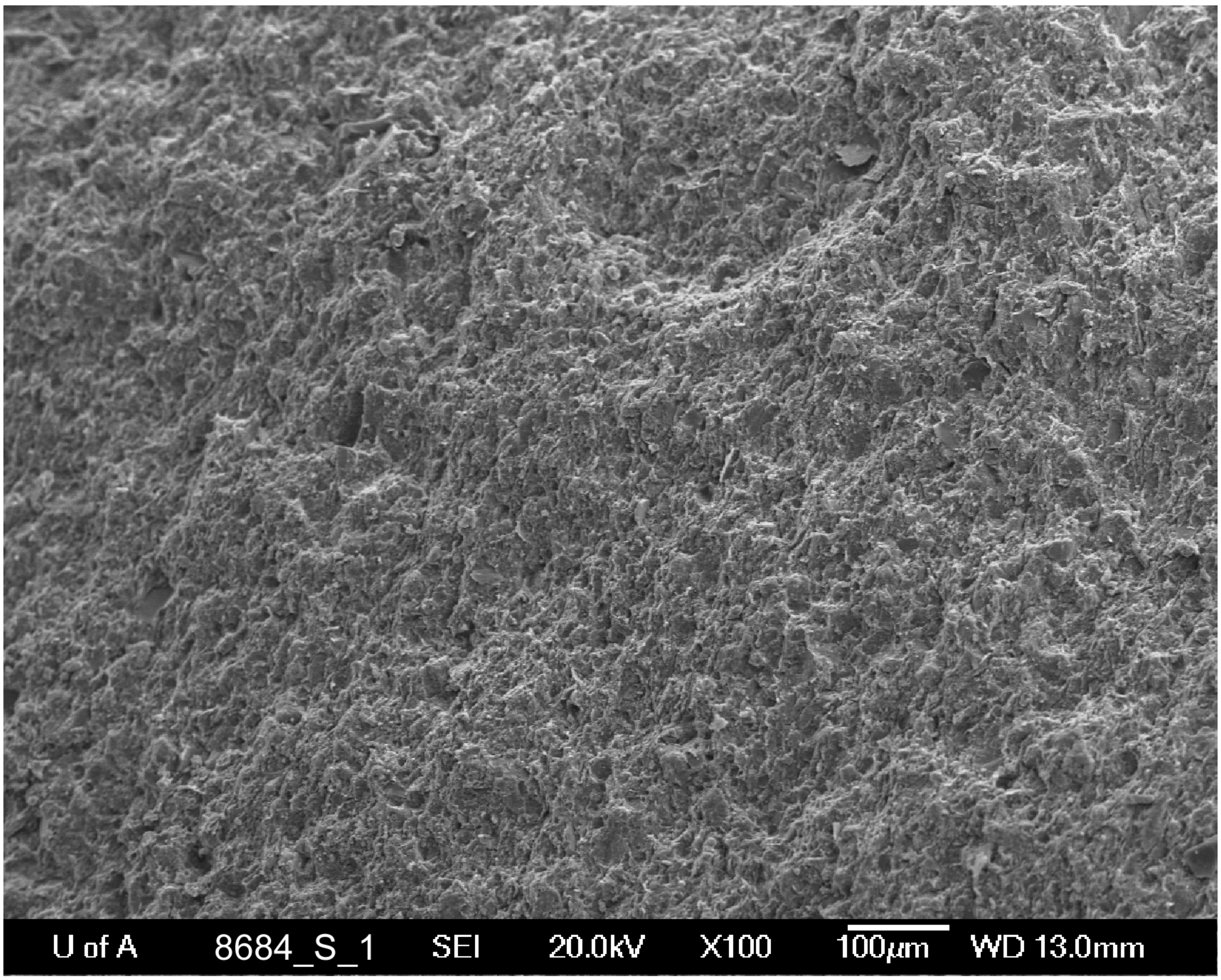
This is a close up view of silt compaction. This particular sample is not shown on the previous image (6936_S_7). Clay plates in this view exhibit a degree of curvature due to compaction around grains. The red arrow points to what appears to be framboidal pyrite. The yellow arrow identifies a quartz grain from EDX analysis.

2) Sample 8684 **Lower Banff Fm.**
100/02-14-082-02W6/00 **6,480 feet core depth (1875.1 m)**

The sample is medium grey, calcareous shale. All images are perpendicular to the bedding plane. The bedding plane in all images trends approximately northeast.

a)

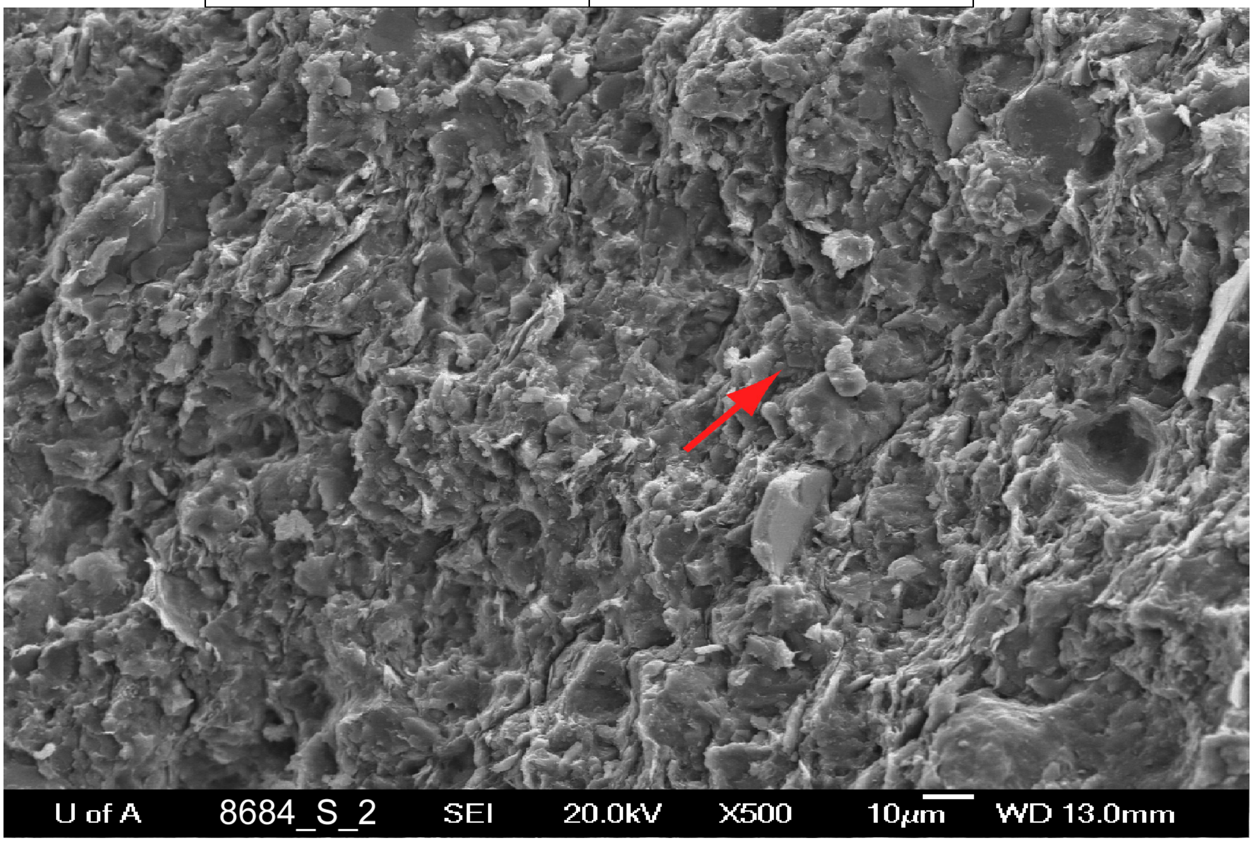
Image	Magnification
8684_S_1	100×



This is a low magnification overview of the sample, showing homogeneous texture with a few scattered coarse crystals. At this scale, the sample exhibits little porosity. An EDX analysis of the sample revealed an abundance of calcium, silicon, magnesium and potassium.

b)

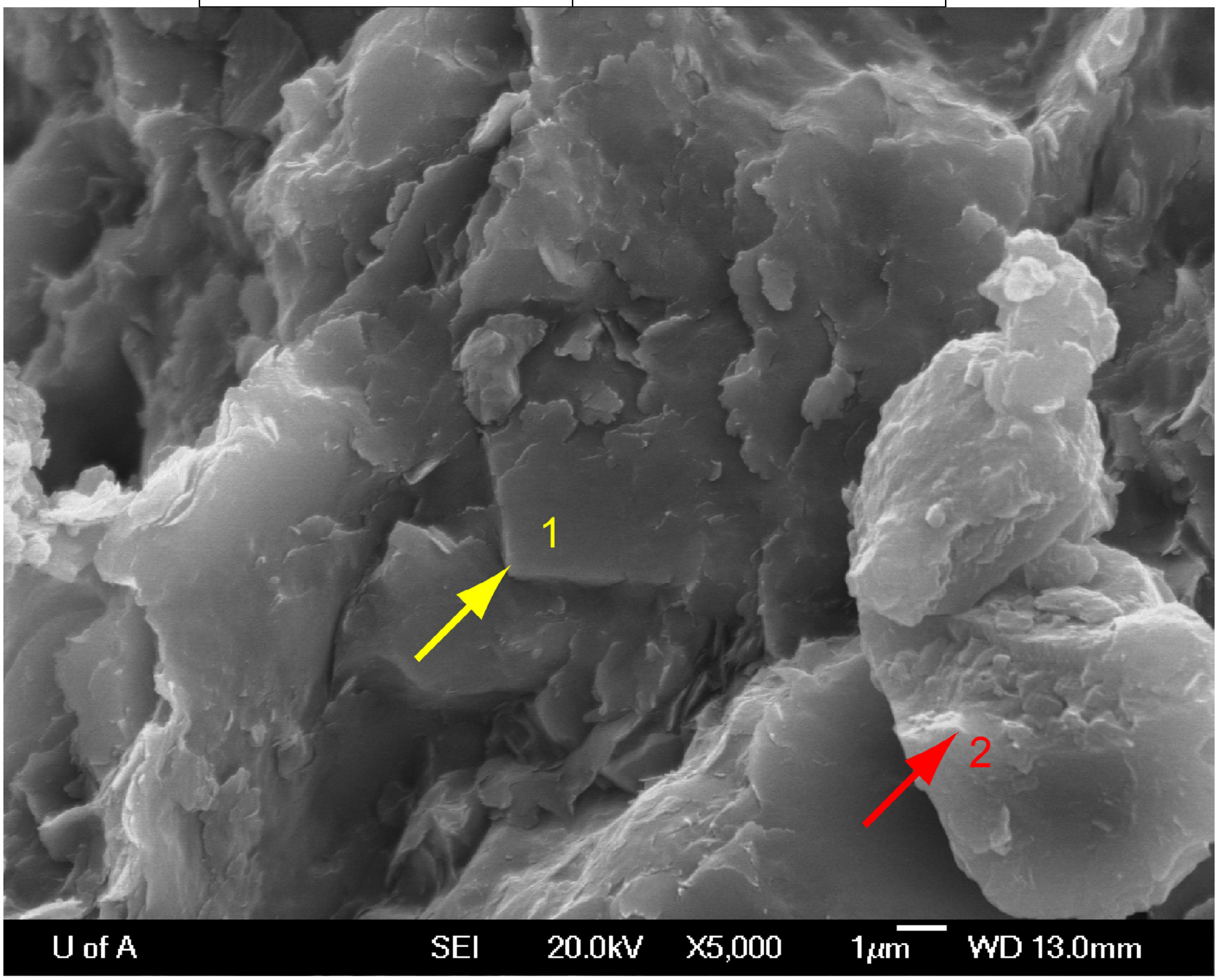
Image	Magnification
8684_S_2	500×



Well-cemented sample with an uneven texture that gives it an appearance of being dominated by minerals other than clay. EDX analysis of the sample revealed potassium-rich clay (illite/muscovite) with quartz, calcite, small crystals of dolomite (~5 μm) and a small amount of pyrite. The red arrow points to the location of the next image.

c)

Image	Magnification
8684_S_3	5000×



The edges of a small, euhedral crystal of dolomite (yellow arrow) are shown encased in an illitic matrix. The large grain in the lower right quadrant of the image is calcite (red arrow).

EDX for sample 8684 (note that the depth of the EDX analysis is about 2 μm, so the chemistry below the surface may dominate the chemistry of the surface mineral):

Composition	**Image**	**ID on Image**
dolomite (EDX 8684_002)	8684_S_2	1
calcite (EDX 8684_003)	8684_S_3	2

2) Lower Banff, Sample 8688, 100/06-04-084-07W6/00, 7373 ft. core depth (2247.3 m)

The sample is dark grey shale with a bedding plane in all images that trends north.

a)

Image	Magnification
8688_S_1	100×
8688_S_2	100×

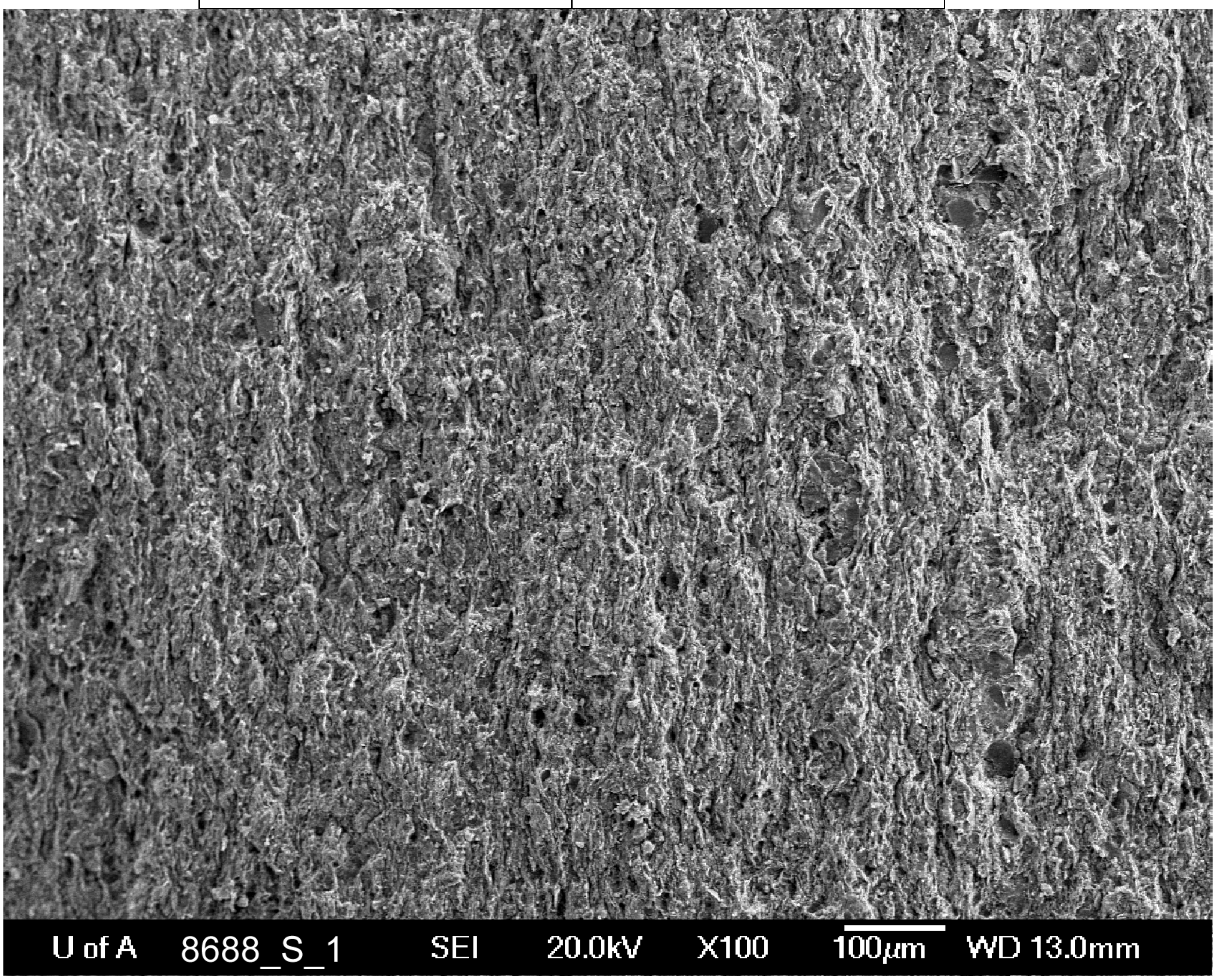
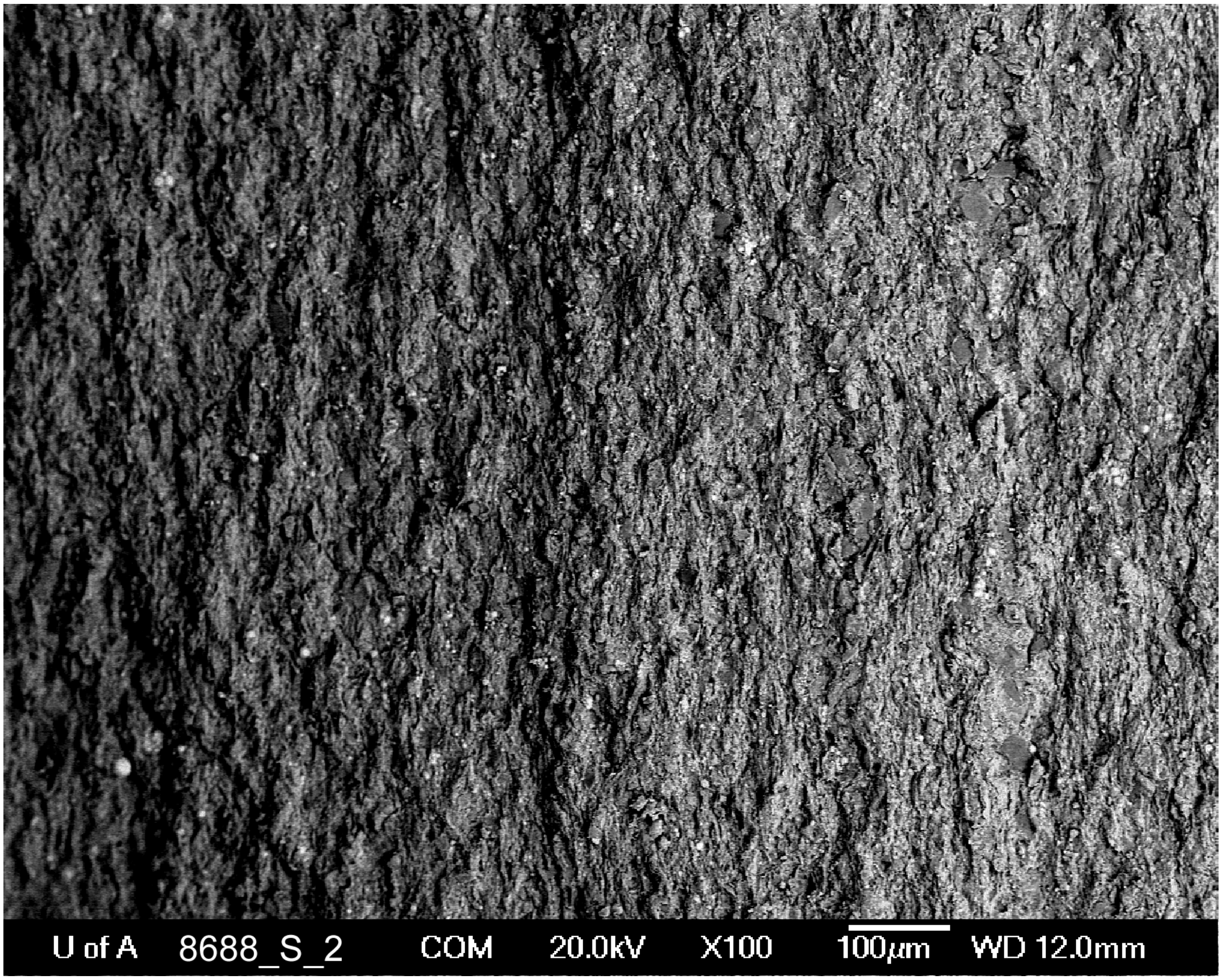


Image 8688_S_1 is a low magnification view of apparently homogeneous clay-rich shale with a few scattered coarse grains. Some porosity is evident (dark area), although some of this may be due to plucked grains. An EDX overview (8688_S_001) indicates that the sample is rich in quartz and clay with no carbonate minerals.



This is a backscattered image where white or light areas are heavy minerals, especially pyrite, that are scattered throughout the sample.

b)

Image	Magnification
8688_S_3	500×
8688_S_4	2500×
8688_S_6	10000×

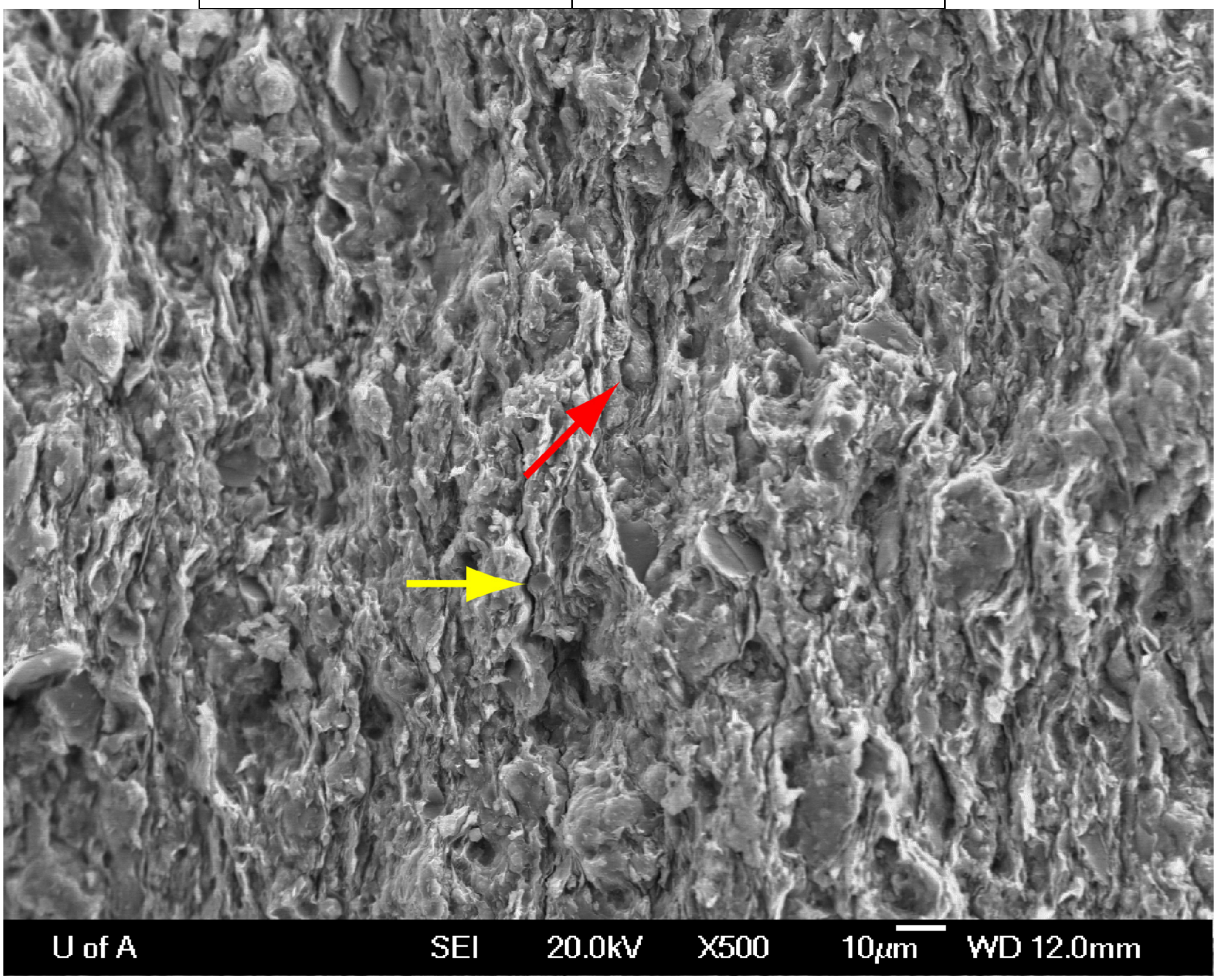


Image 8688_S_3 exhibits a relative abundance of silt-sized grains that protrude between clay sheets with the result that the clay sheets crenulate from draping around grains. Bedding-parallel fracturing is abundant; observe the fracture (yellow arrow) that approximately bisects the image into east and west halves. The sample seems to have a small amount of porosity, but the effectiveness of the porosity is questionable. The next image is taken near the tip of the red arrow.

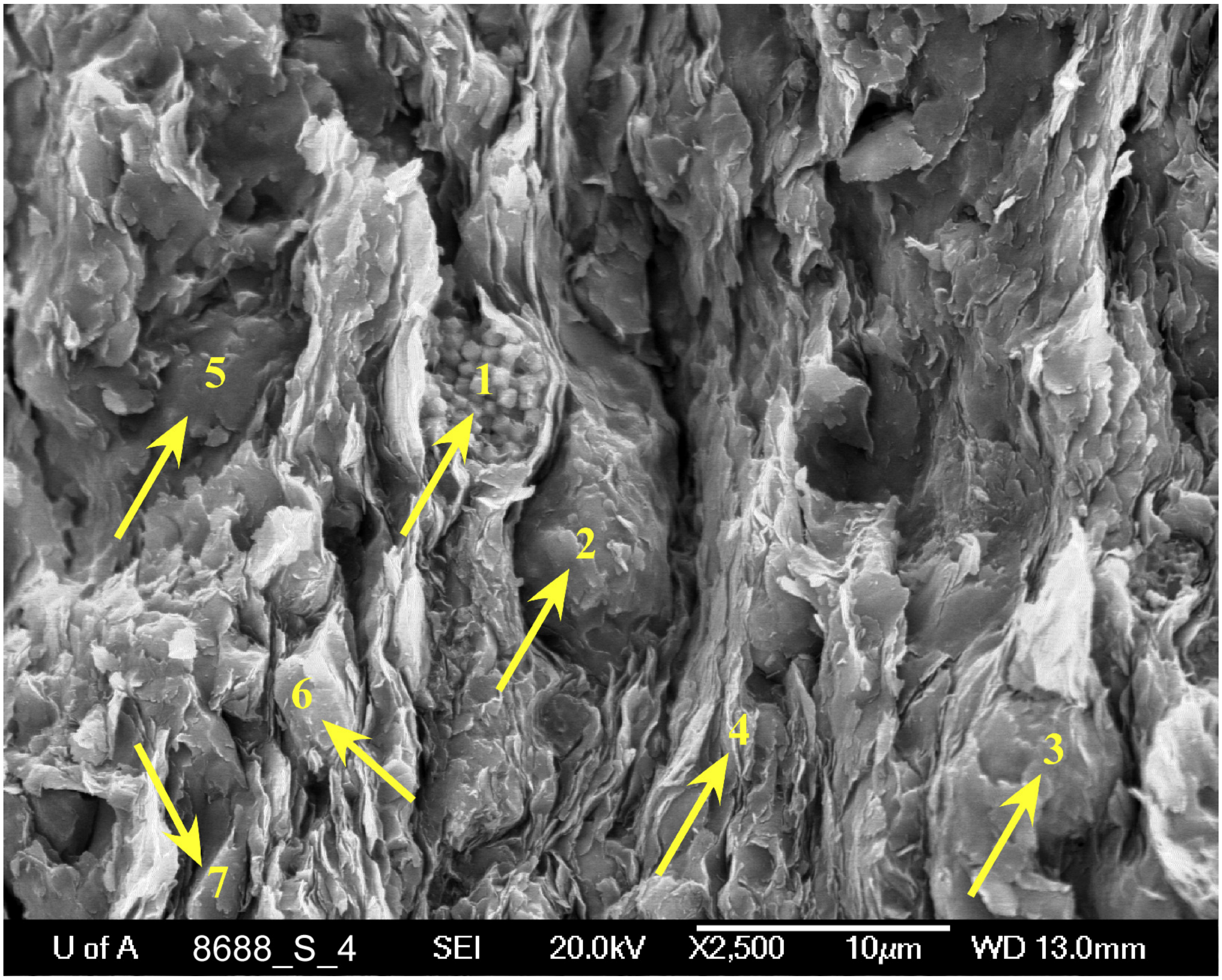


Image 8688_S_4 shows numerous minerals that have protruded between clay sheets, and a fracture in the extreme upper left edge of the image. There is microporosity between some of the clay sheets and at the edges of some of the silt-sized grains, although it is difficult to judge the effectiveness of the porosity. The pyrite mineral identified as '3' appears to be wrapped in clay. The depth of the EDX analysis is about 2 μm, so the chemistry below the surface has dominated the chemistry of the surface minerals.

Composition	Image	ID on Image
pyrite (EDX 8688_S_002)	8688_S_4	1
quartz (EDX 8688_S_003)	8688_S_4	2
pyrite (EDX 8688_S_004)	8688_S_4	3
muscovite? (EDX 8688_S_005)	8688_S_4	4
quartz (EDX 8688_S_006)	8688_S_4	5
quartz (EDX 8688_S_007)	8688_S_4	6
feldspar (EDX 8688_S_008)	8688_S_4	7

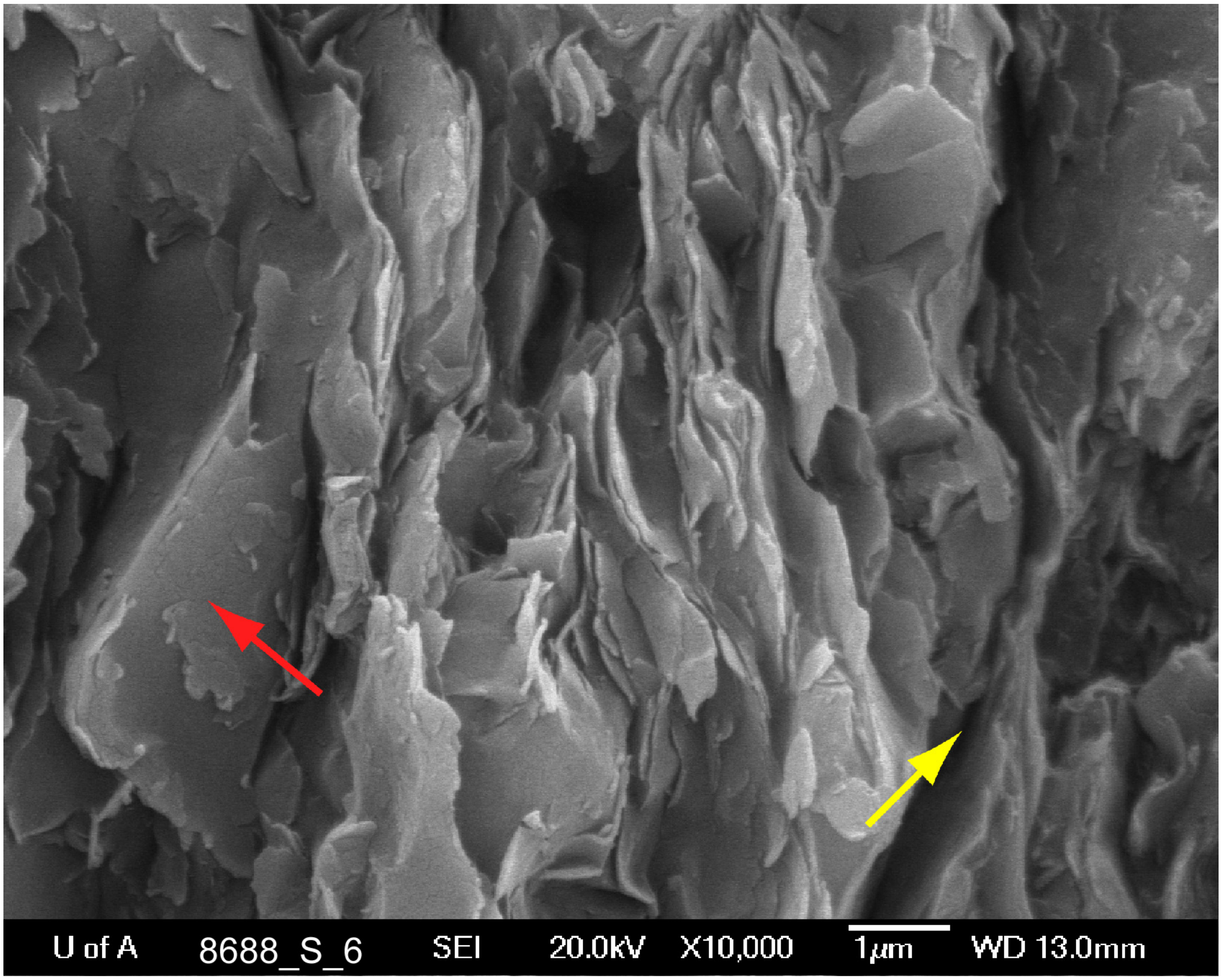
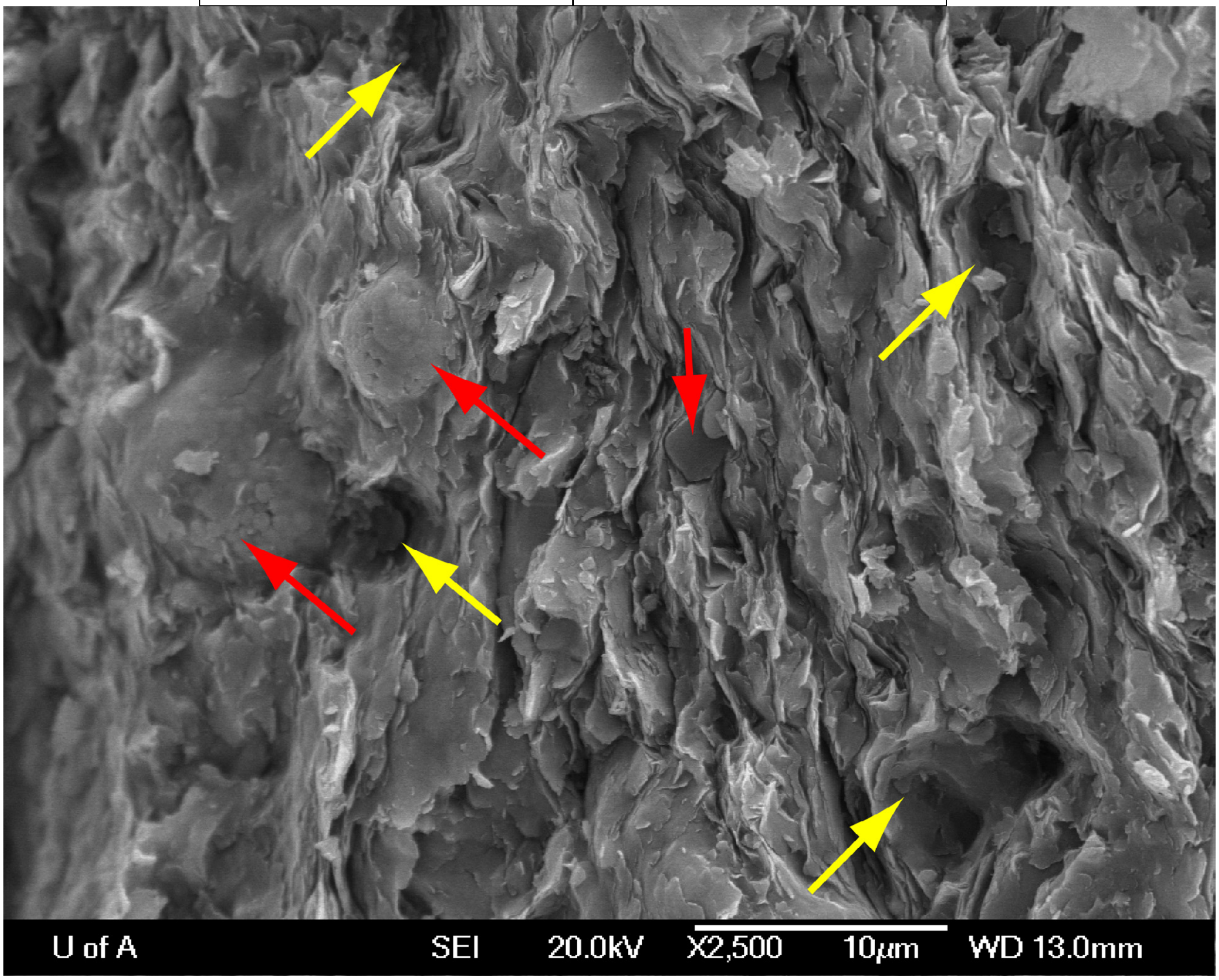


Image 8688_S_6 overlaps the previous image on the bottom left corner. The feldspar crystal identified in the previous two images is shown by the red arrow. A bedding plane fracture is shown by the yellow arrow. The slight crenulations or waviness of the clay sheets may be caused by differential compaction around silt-sized grains.

c)

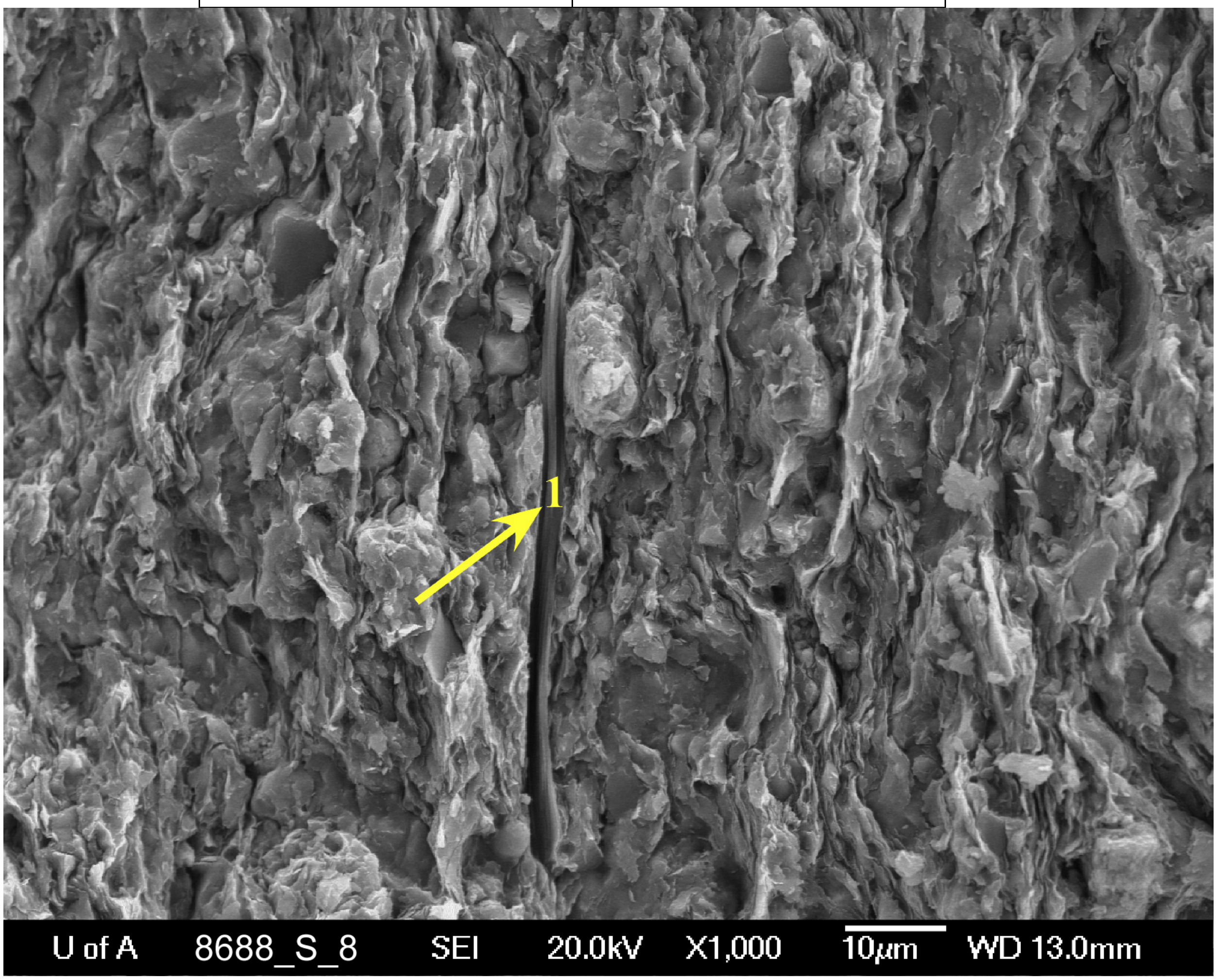
Image	Magnification
8688_S_7	2500×



Similar to the previous image, framboidal pyrite is identified by the two red arrows on the left half of the image, while the yellow arrows identify positions of plucked grains, the size of which approximates fine silt. The down-pointing red arrow in the centre of the image points to a quartz grain that is similar in size to the plucked sites.

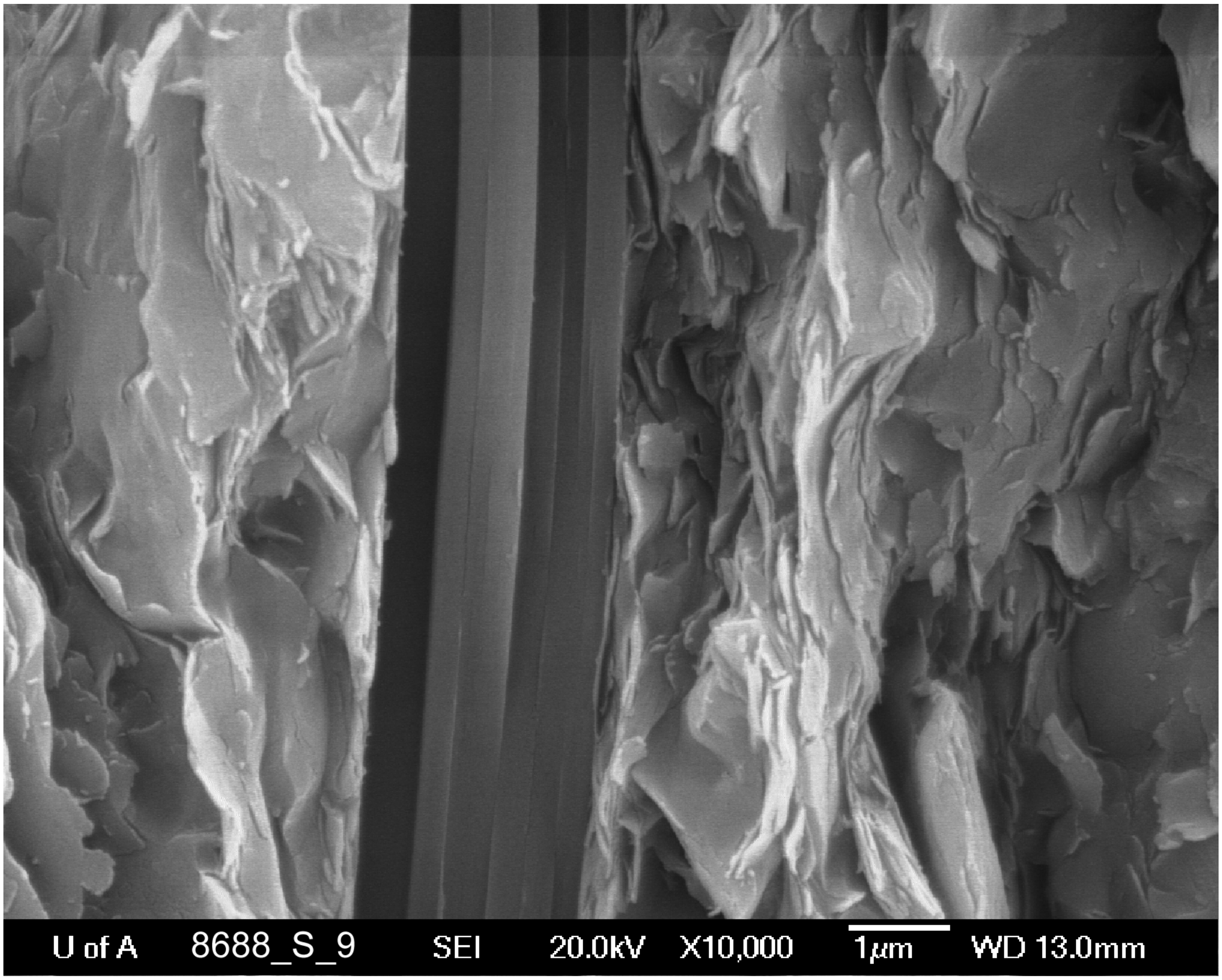
d)

Image	Magnification
8688_S_8	1000×
8688_S_9	10000×



The last two images are very similar in texture and mineralogy to images 8688_S_3 and 8688_S_7 except for the presence of the long (50 μm), thin mineral in the centre of images 8688_S_9 and 8688_S_9. EDX analysis suggests that the mineral is from the mica group.

Composition	**Image**	**ID on Image**
mica (EDX 8688_S_009)	8688_S_8	1



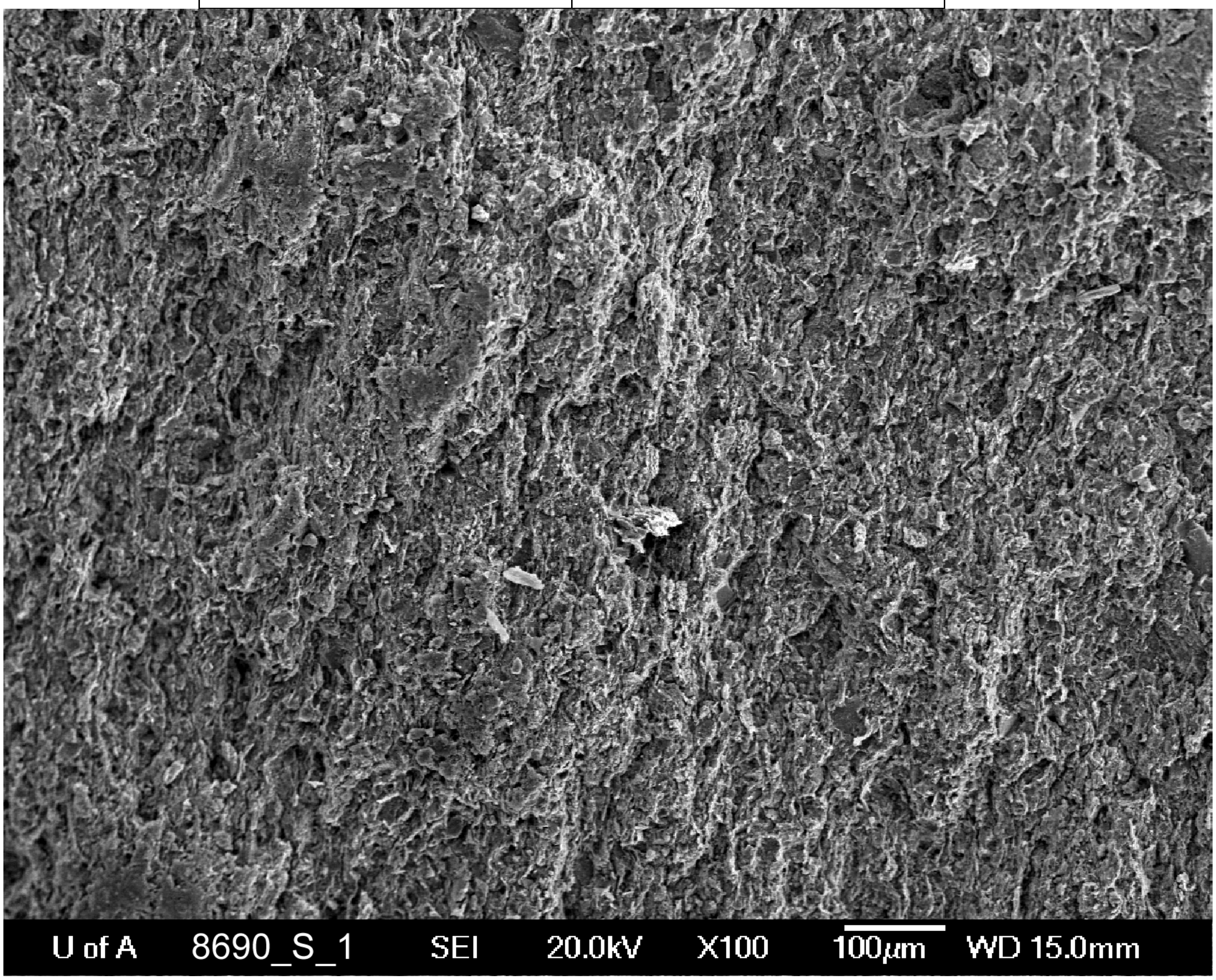
The plates are less than 0.25 μm in width.

3) Sample 8690 **Lower Banff Fm.**
100/16-18-197-06W6/00 **2,038 feet core depth (621.2 m)**

The sample is grey shale/mudstone. The trend of the bedding plane is approximately northeast in all images.

a)

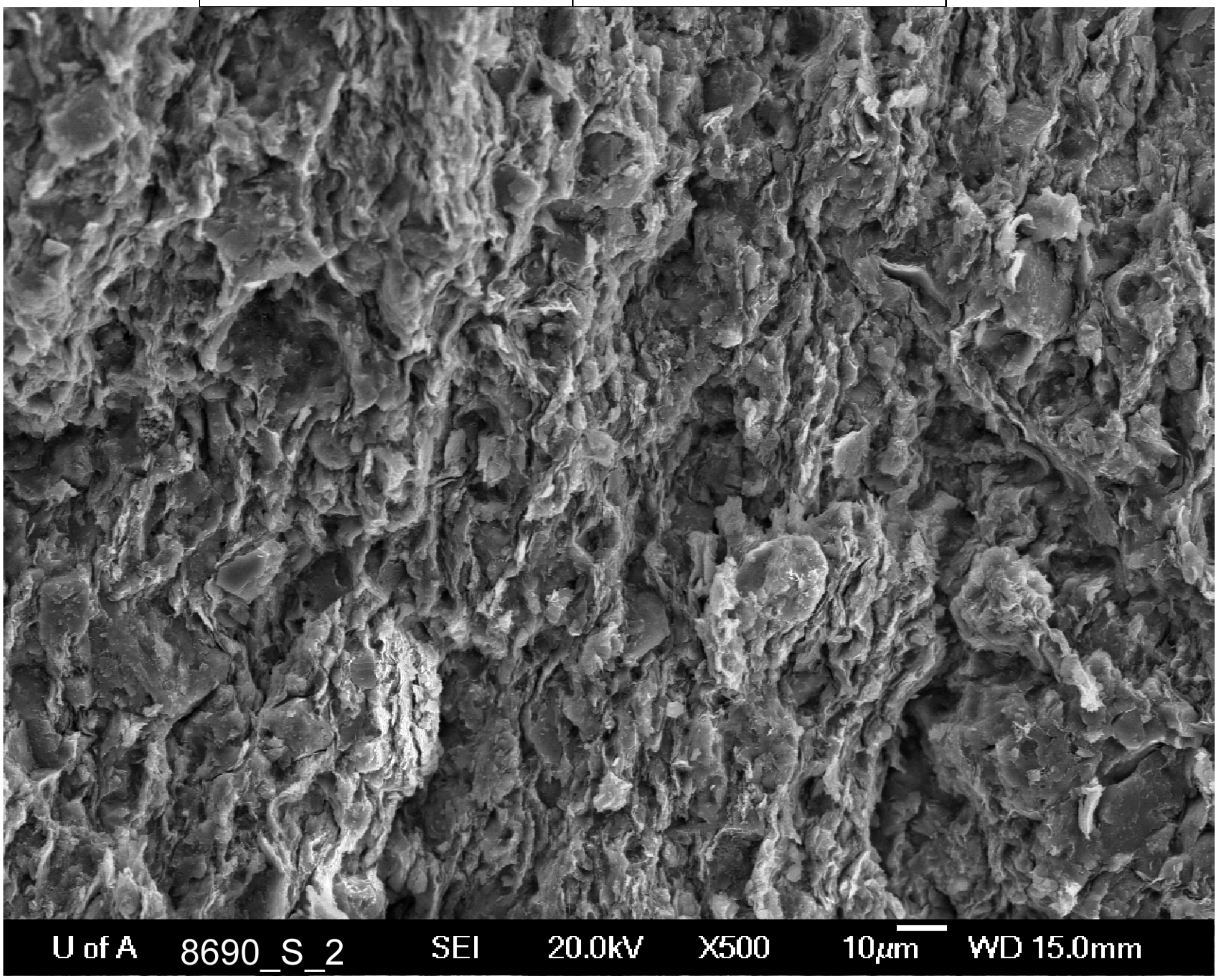
Image	Magnification
8690_S_1	100×



Although the bedding plane in these samples trends approximately north-northeast, there is only a weak display of bedding in this sample. Porosity seems to be fairly high (visual estimate 5%–7%?). A close examination reveals numerous thin fractures, some of which cross the bedding trend at a low angle. EDX analysis of the chemistry reveals an abundance of calcium, silicon, potassium, titanium and magnesium, indicating clay with dolomite/calcite. The clay is likely dominated by illite.

b)

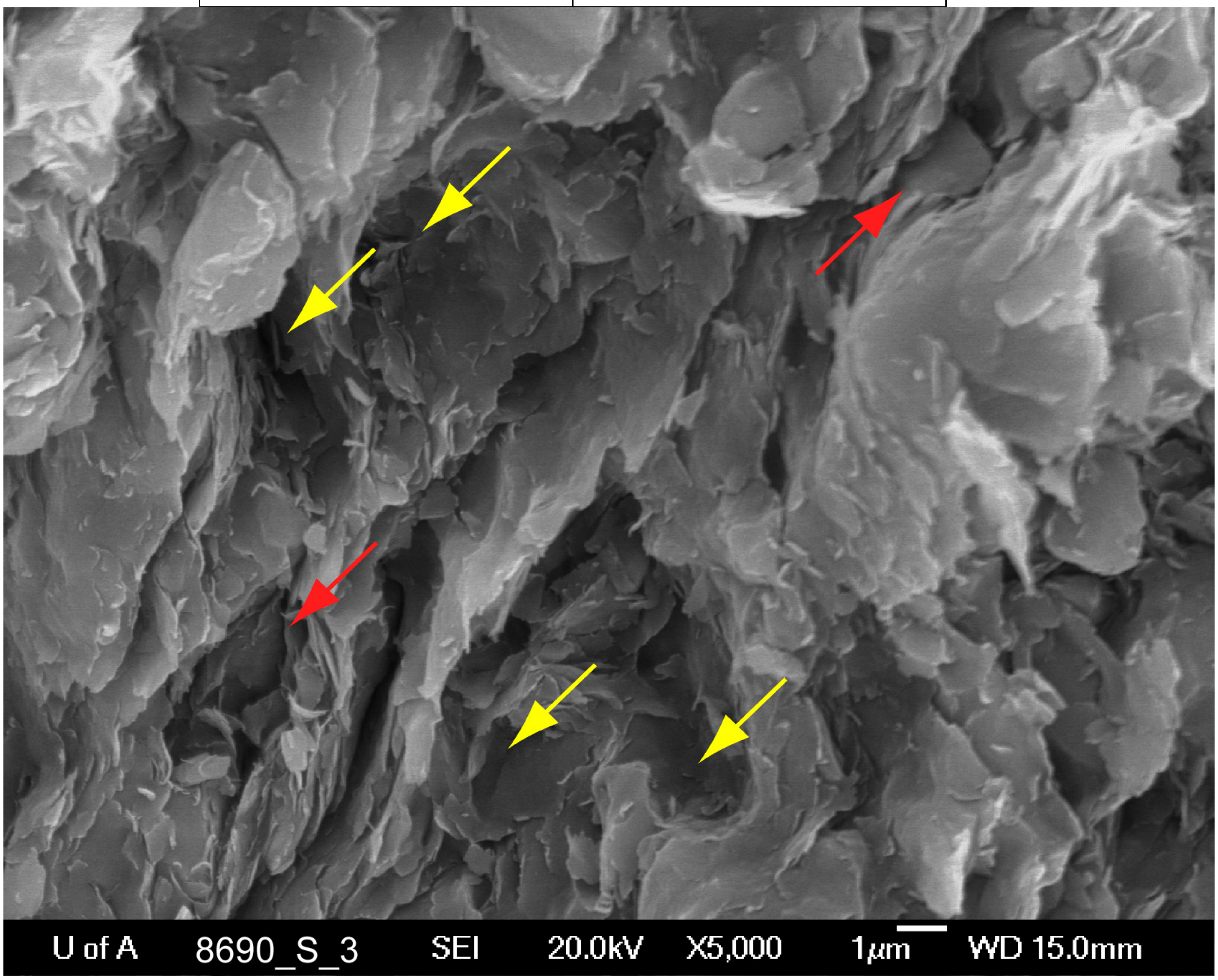
Image	Magnification
8690_S_2	500×



This image is taken near the centre of the previous photo. There appears to be an abundance of silt-sized particles that are embedded between clay sheets, giving the sheets a crenulated appearance. The sample is very well fractured, which adds to the observation of a high degree of porosity between clay sheets and at the edges of many particles. Pyrite framboids are occasionally observed when the image is zoomed.

c)

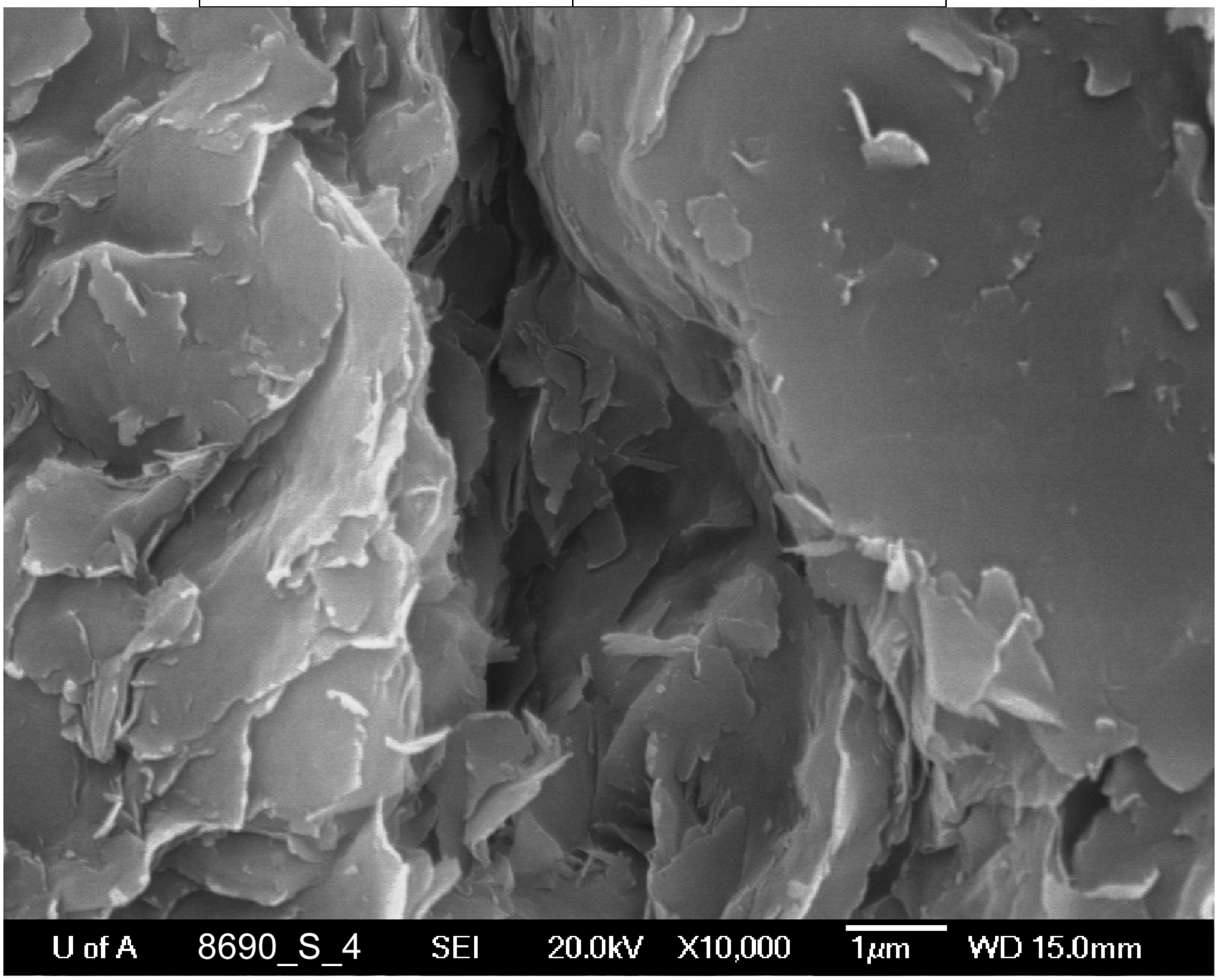
Image	Magnification
8690_S_3	5000×



At this magnification, clay plates are not well aligned, perhaps due to draping and wrapping around silt particles such as in the lower left quadrant (red arrow). The sites of plucked grains can be seen at the yellow arrows. A quartz(?) silt grain is visible at the red arrow in the upper right quadrant. Dark areas between clay sheets and around some of the silt grains indicate visible porosity, although porosity at grain contacts may have been opened slightly during unloading.

d)

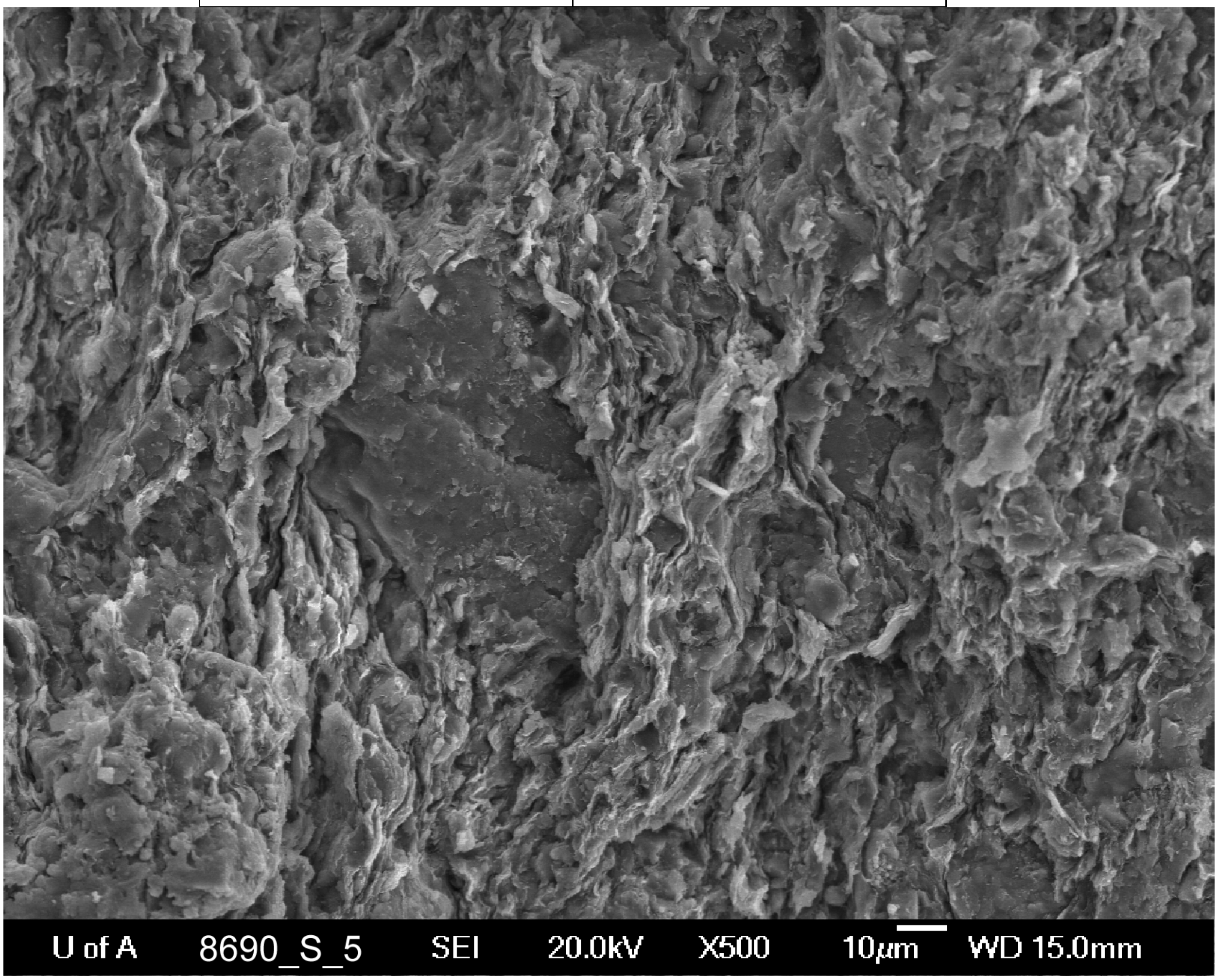
Image	Magnification
8690_S_4	10000×



View of the shape of a pore at the contact of clay domains (*see* Bennett et al. 1991 for a definition of a clay ‘domain’). The pore is approximately 5–6 µm wide and 10–12 µm long. The large grain in the upper right quadrant is mica (muscovite/biotite). Porosity is also visible (dark areas) in the lower right corner between clay sheets.

e)

Image	Magnification
8690_S_5	10000×



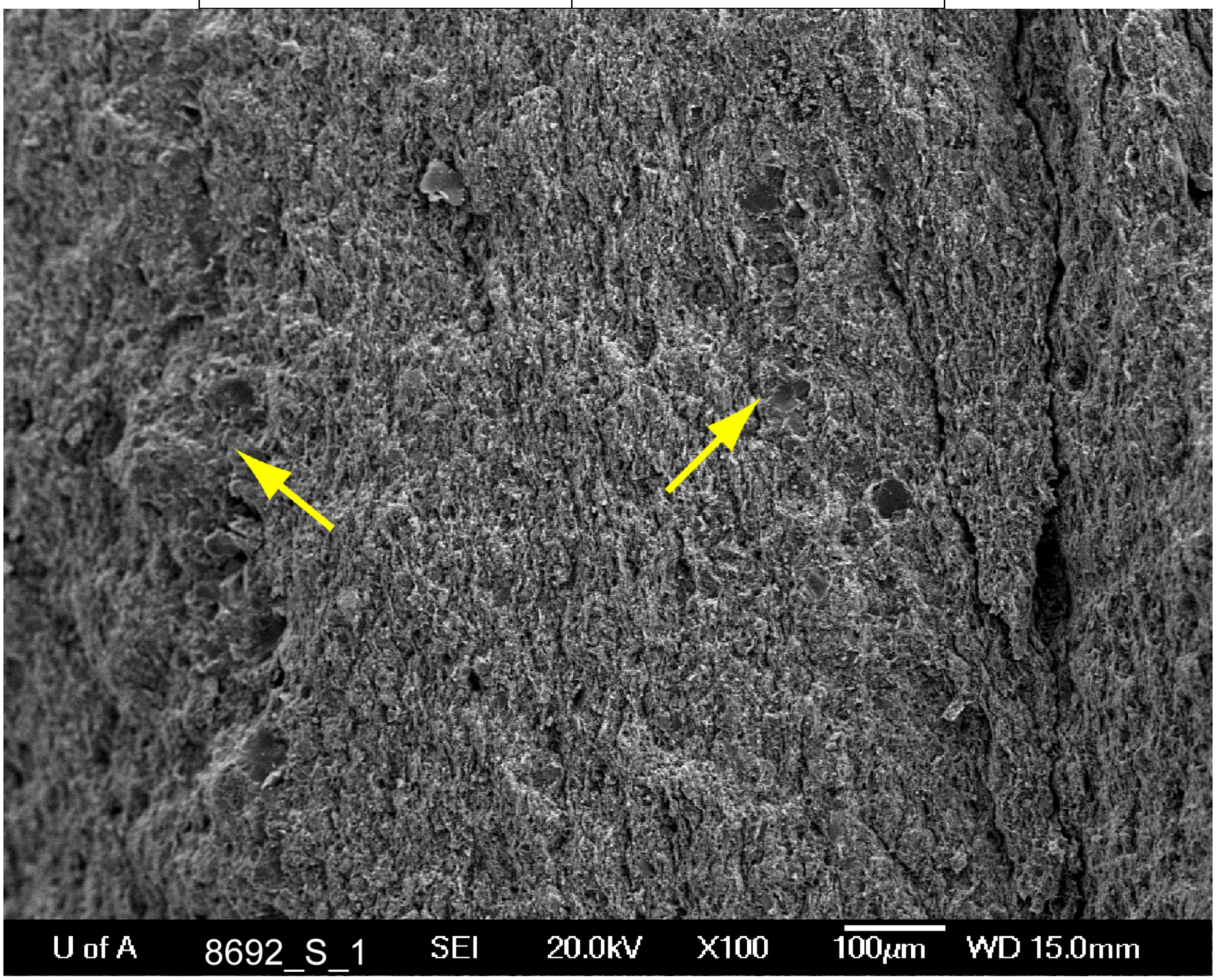
EDX analysis of the large particle in the left centre of the view suggests that the particle is muscovite/biotite mica surrounded by illite/smectite clay.

4) Sample 8692 **Lower Banff Fm.**
100/16-24-077-06W6/00 **2619.5 m core depth**

The sample is red shale with silt laminae. The bedding plane trends north in all images.

a)

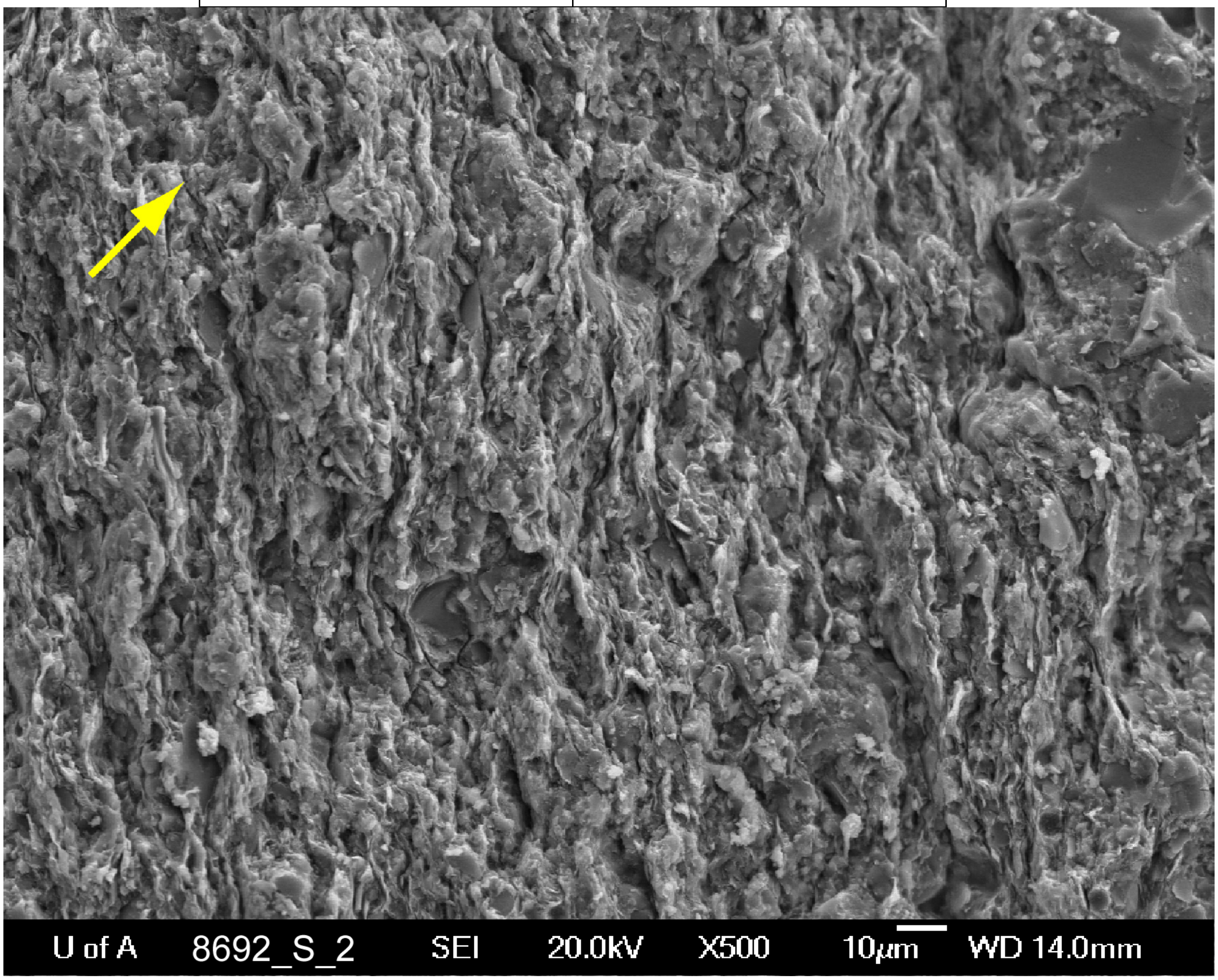
Image	Magnification
8692_S_1	100×



This is a low-magnification image showing low to moderate porosity in the centre of the image, where the pores appear to be dominantly slit or eye shaped. The yellow arrows identify what appear to be discontinuous laminae (right side) and relatively continuous laminae (left side). The next image is located near the tip of the yellow arrow on the right. EDX analysis of this image indicates clay mineralogy with a relatively low aluminum content (smectite?).

b)

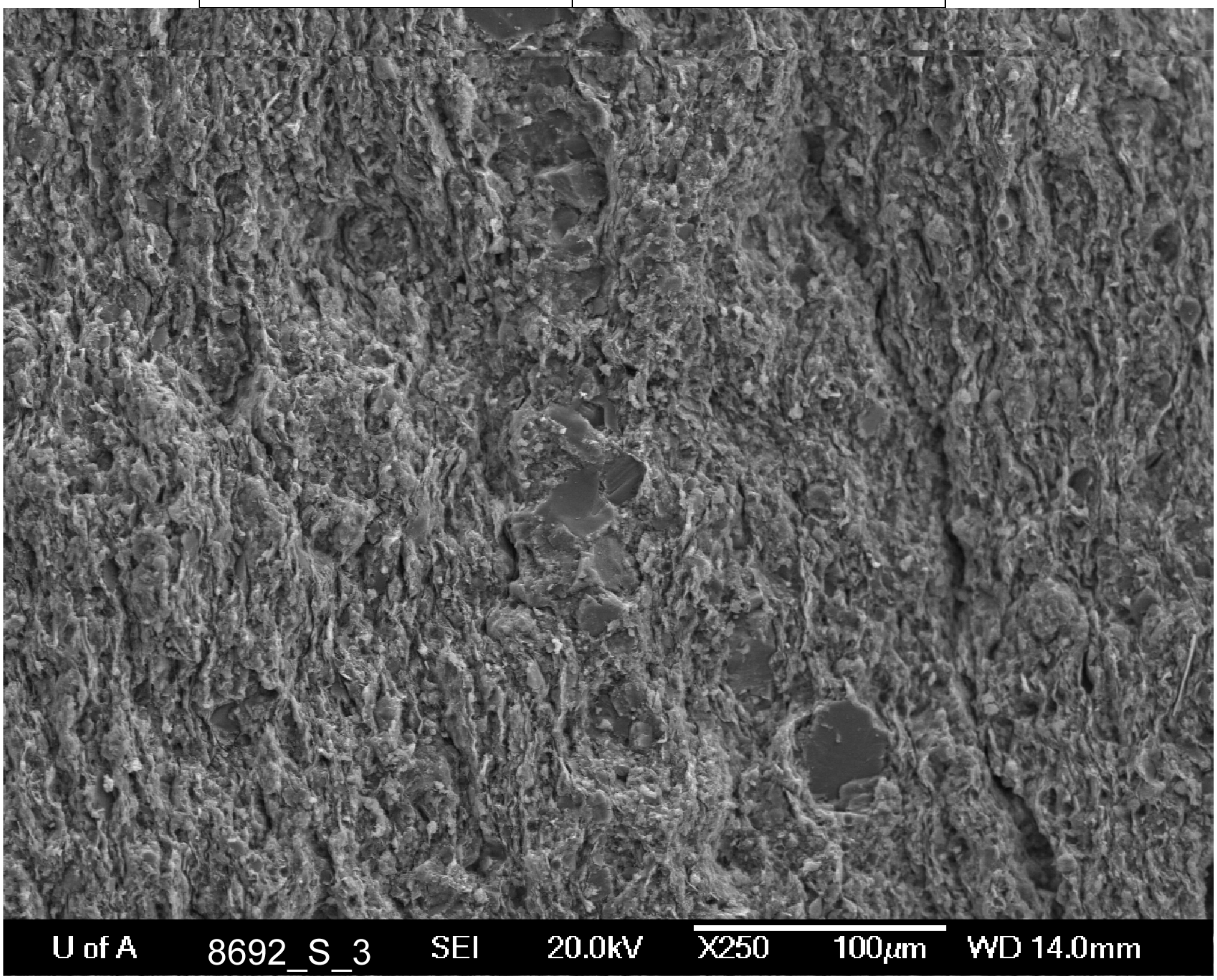
Image	Magnification
8692_S_2	500×



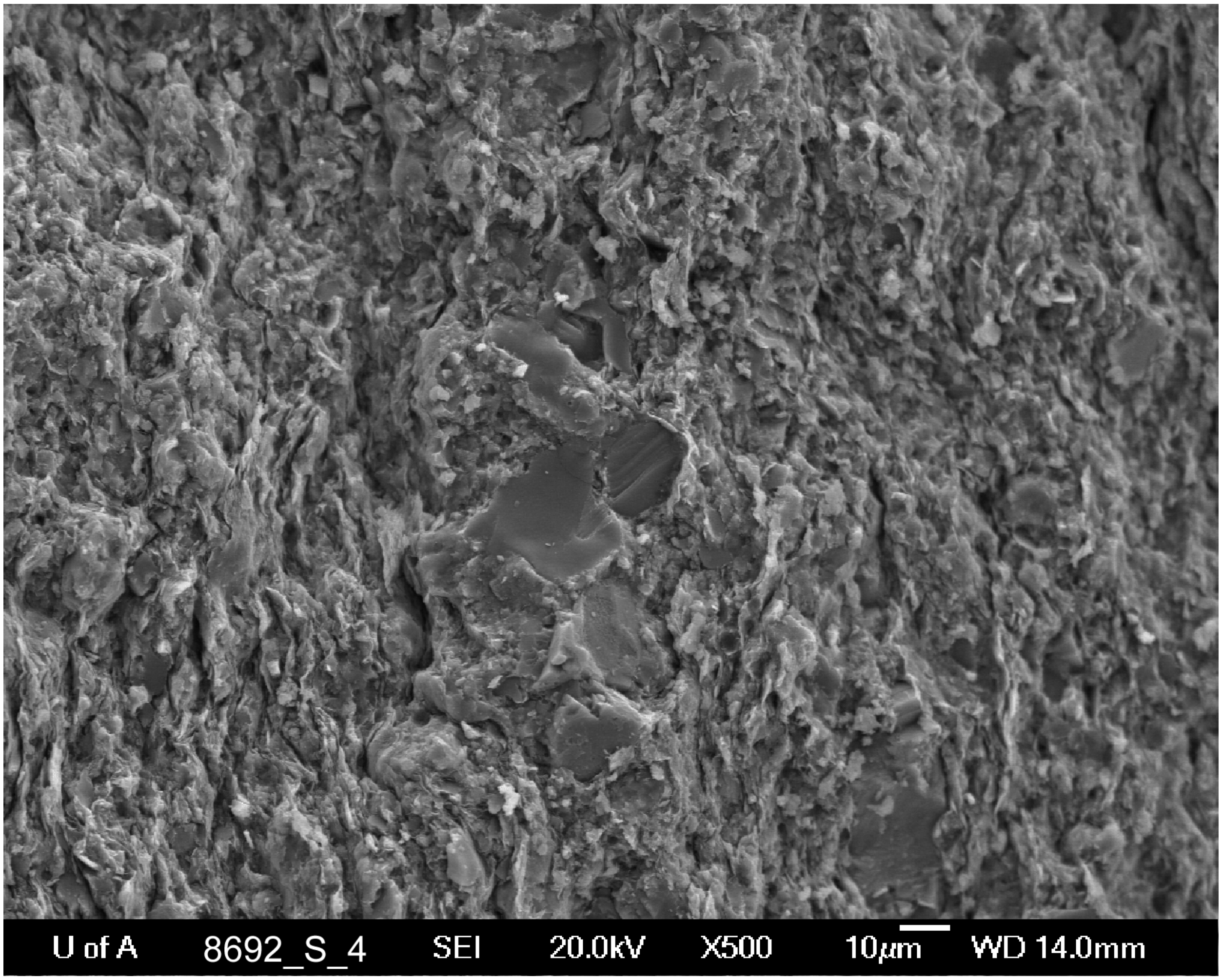
At this magnification, the sample appears to be very silty, with the silt dispersed as fine grains between clay sheets. The sample exhibits some fine fractures (unloading fractures?) that trend at a low angle to bedding and cut across bedding, as seen by following the fracture near the tip of the yellow arrow in the upper left quadrant of the photo. Porosity is seen at the edges of some of the silt grains and between clay sheets. Two minerals identified by an EDX analysis are sodium feldspar and calcite.

c)

Image	Magnification
8692_S_3	250×
8692_S_4	500×



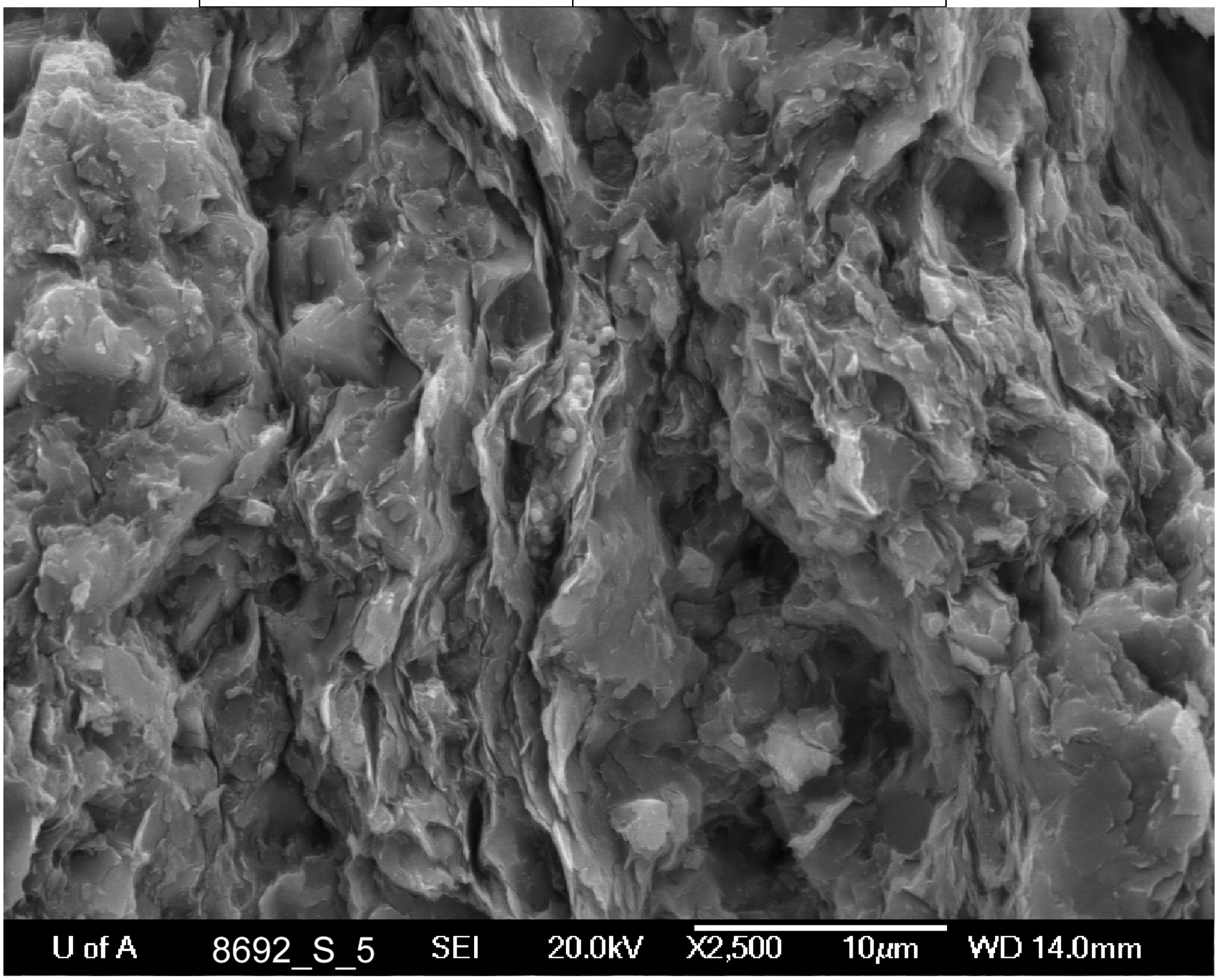
Images 8692_S_3 and 8692_S_4 are close ups of the discontinuous silt layer observed in image 8692_S_1. The lamina is about 50 µm or 2–3 grains thick. A close examination of the image reveals an abundance of fine fractures trending generally north.



The lamina is well cemented, although some porosity can be seen in 8690_S_4 along grain contacts, especially near the upper end of the image.

d)

Image	Magnification
8692_S_5	2500×



A pyrite framboid can be seen between clay sheets in the centre of the image. The clay layer traversing north to south along the centre of the image shows some crenulation that is likely due to compaction around silt grains that are hidden from view.

e)

Image	Magnification
8692_S_6	5000×
8692_S_7	1500×

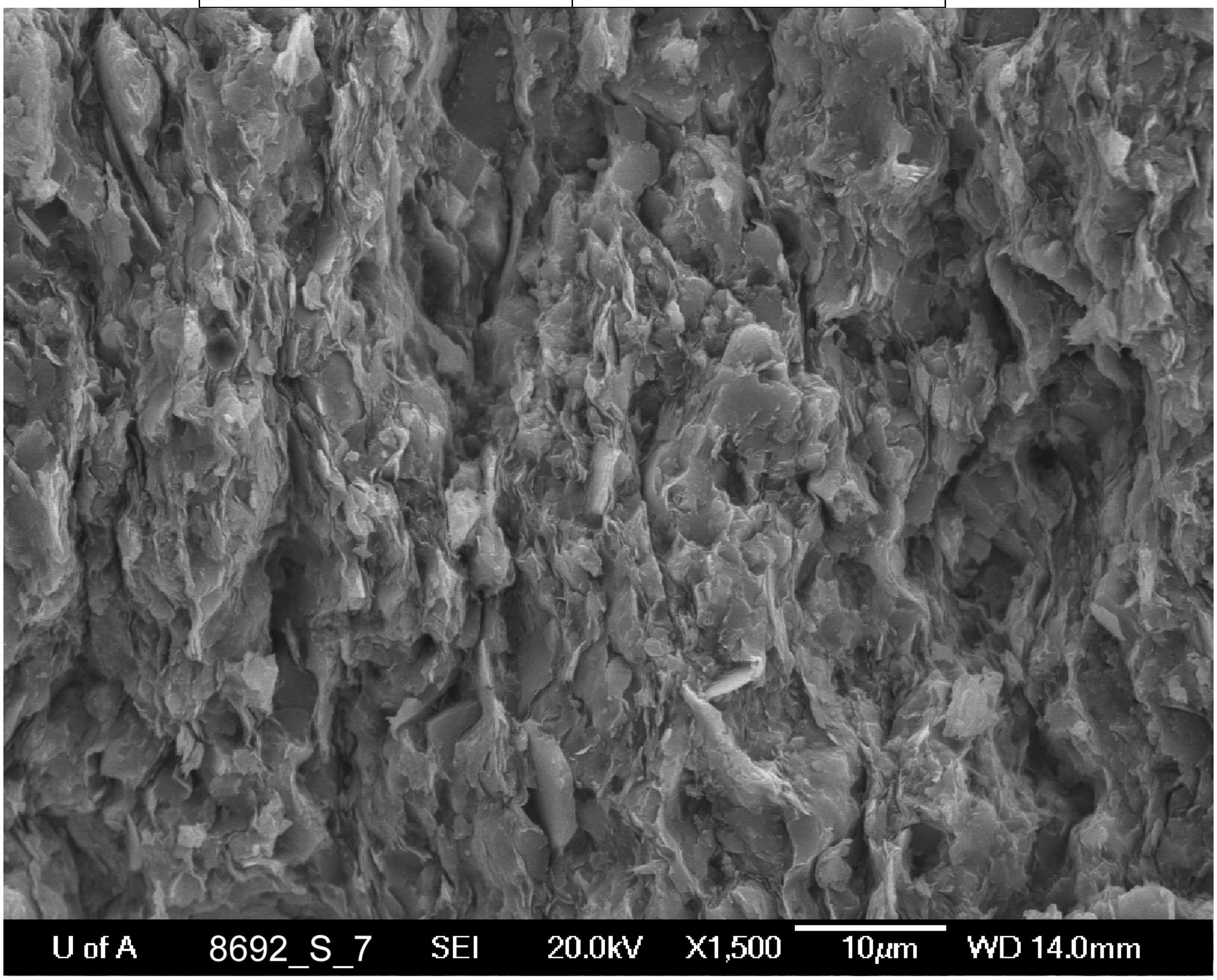


Image 8692_S_7 is viewed prior to 8692_S_6. Image 8692_S_7 is well cemented and clay rich with a silt content perhaps as high as 20–30%. A visual estimation of porosity in the image suggests a maximum of about 2–3%.

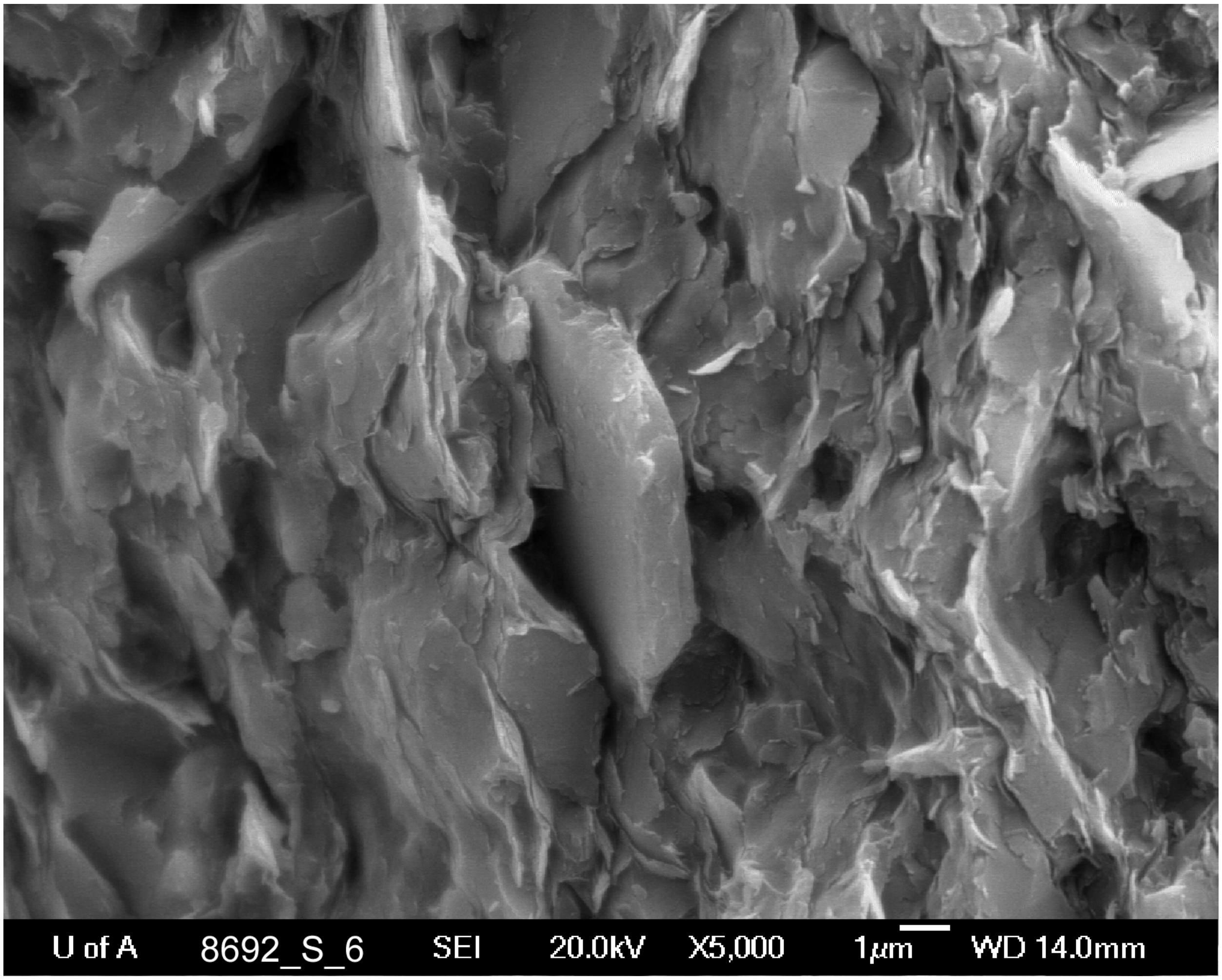
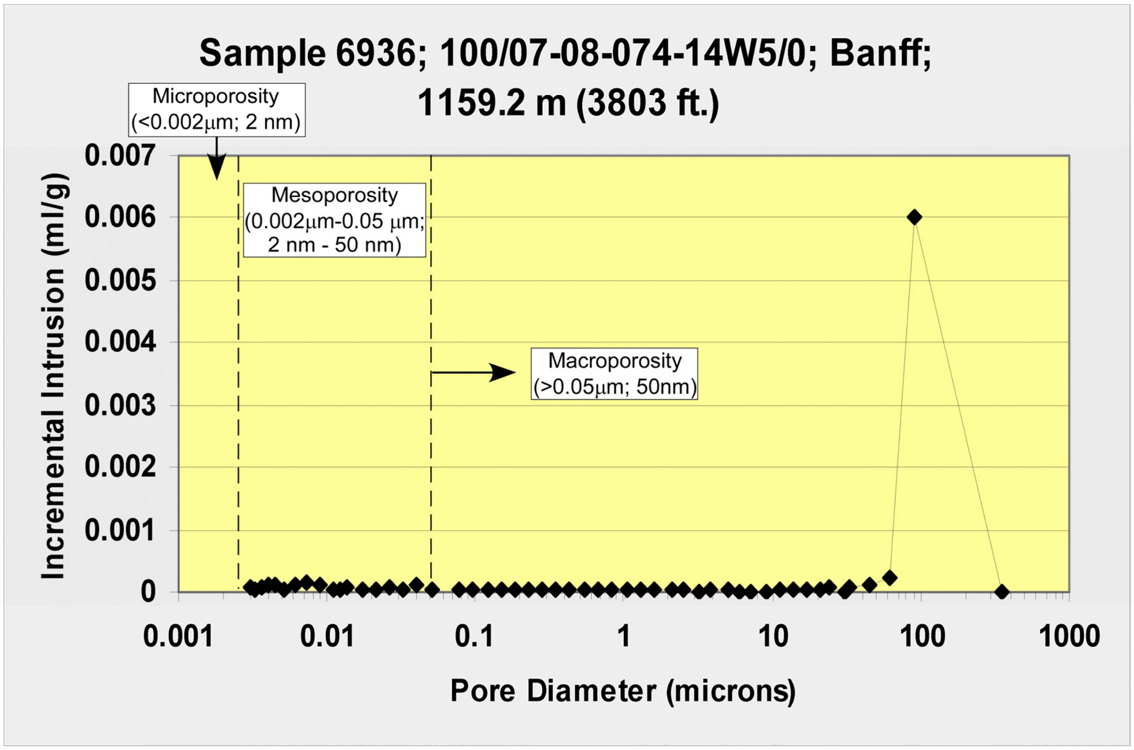


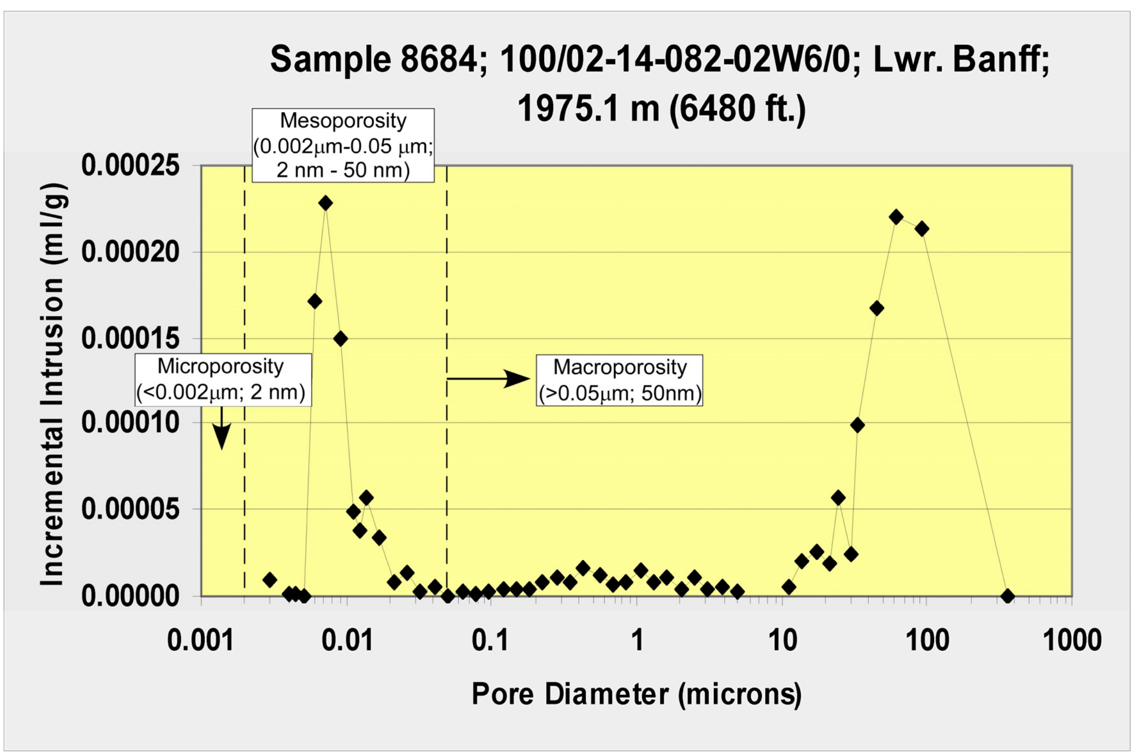
Image 8692_S_6 is a high-magnification view of a crystal identified by EDX as sodium feldspar (located in the lower part of image 8692_S_7). Porosity is observed throughout the image.

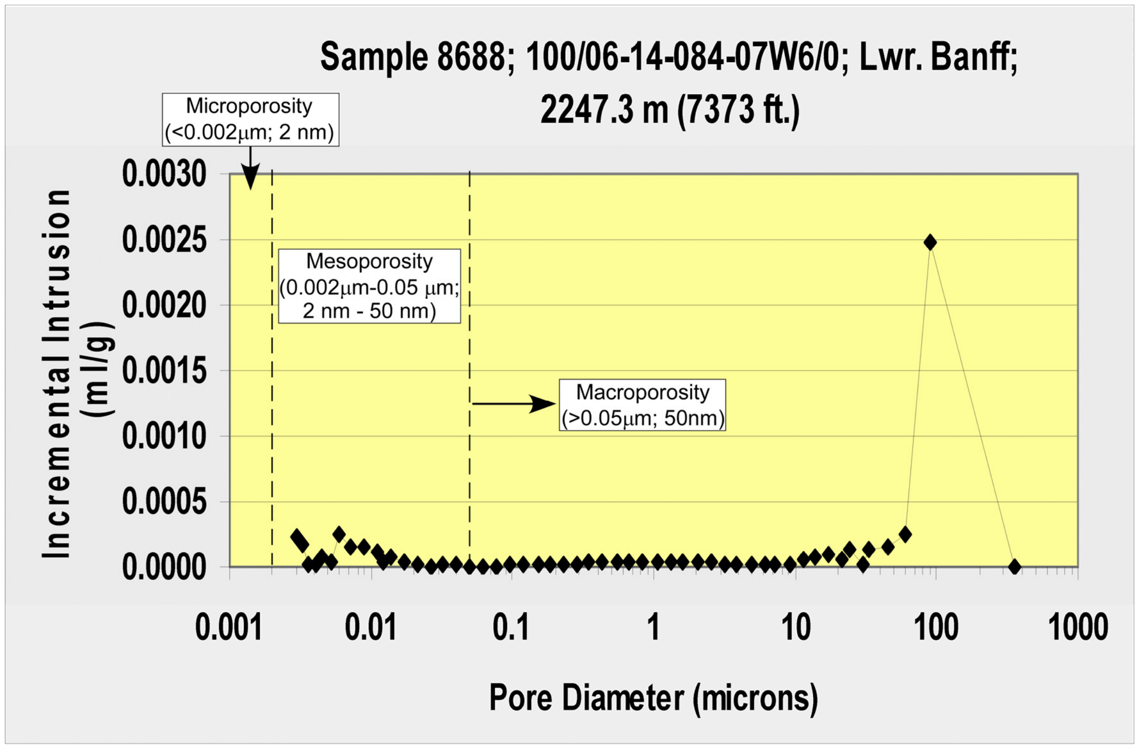
EDX for sample 8692:

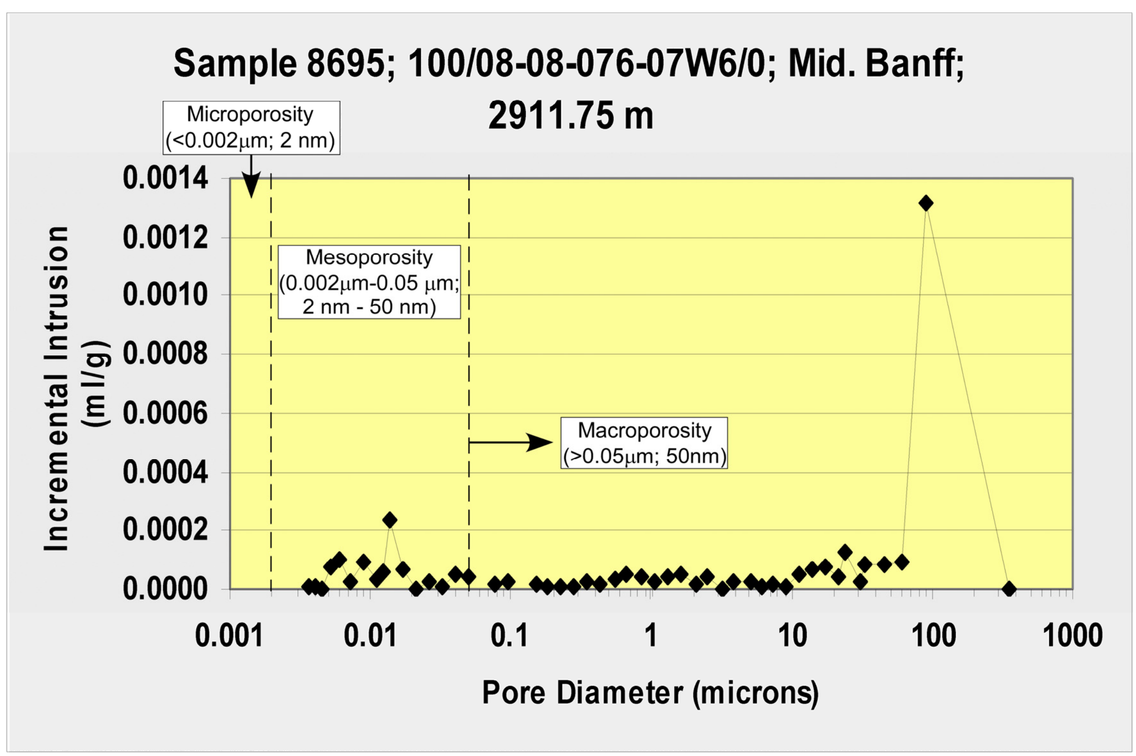
Composition	**Image**	**ID on Image**
quartz (EDX not recorded)	8692_S_1	none
sodium feldspar (EDX 8692S_002)	8692_S_2	none
calcite (EDX8692S_003)	8692_S_2	none

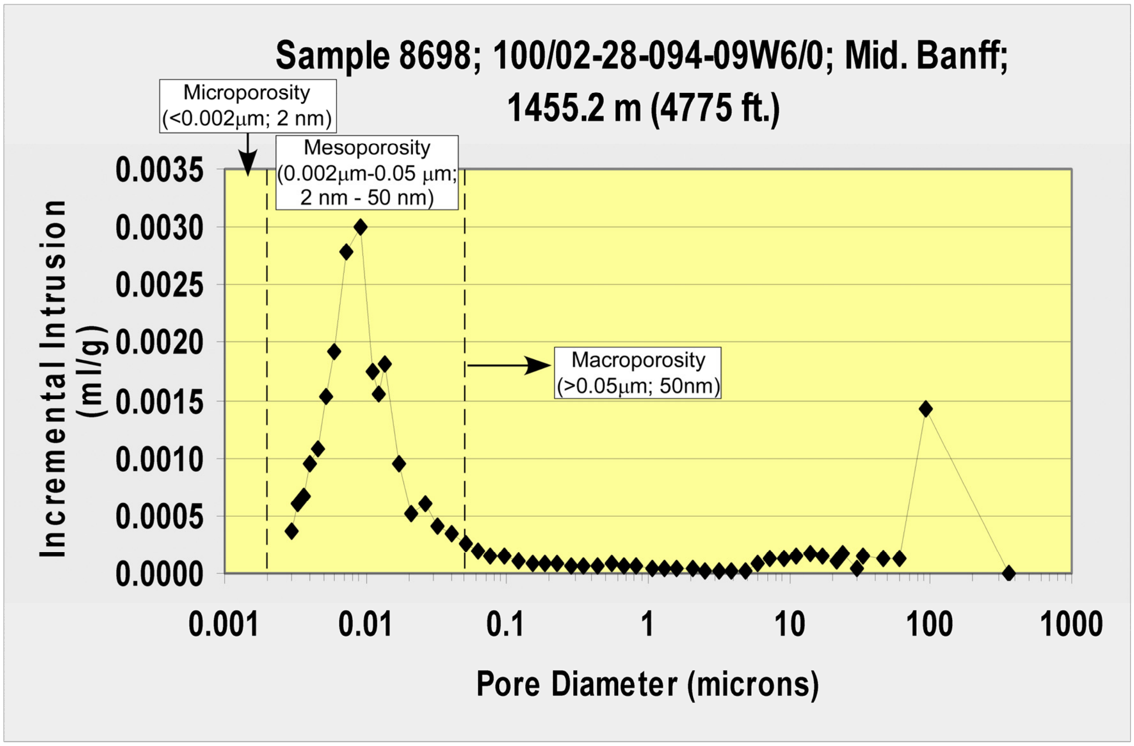
Appendix 8 – Banff/Exshaw Formations Mercury Porosimetry Graphs

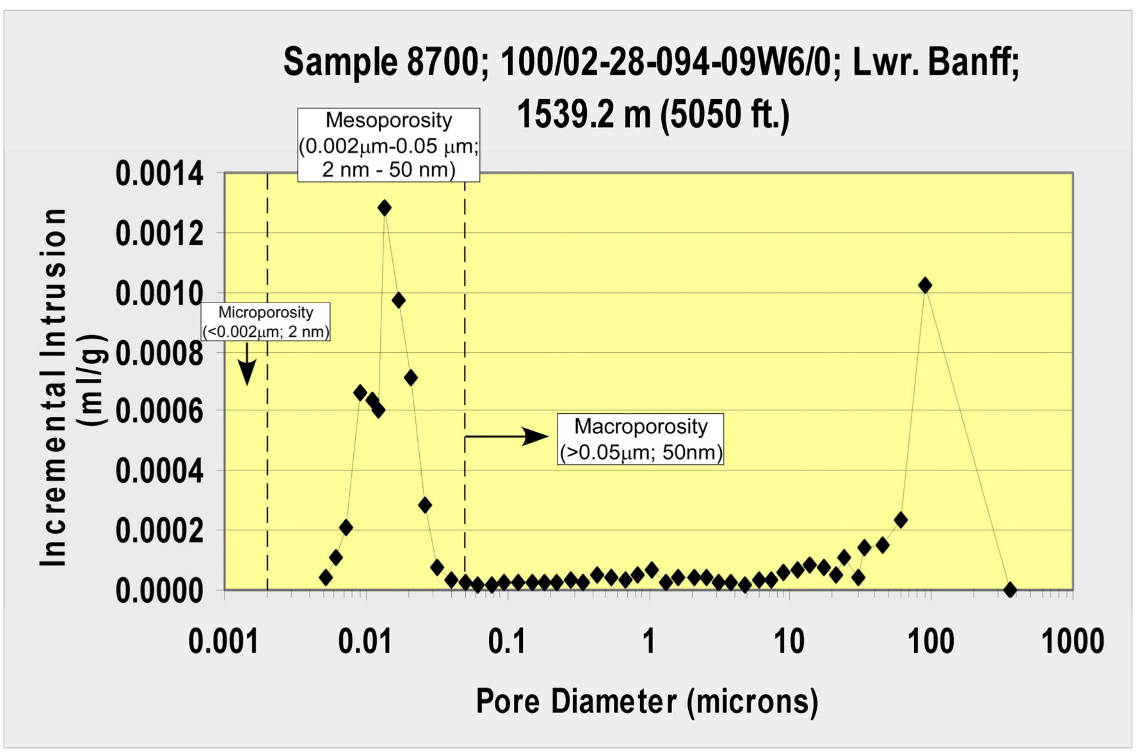





Sample 8688; 100/06-14-084-07W6/0; Lwr. Banff;
2247.3 m (7373 ft.)
Microporosity
(<0.002µm; 2 nm)
Mesoporosity
(0.002µm-0.05 µm;
2 nm - 50 nm)
Macroporosity
(>0.05µm; 50nm)
Incremental Intrusion
(ml/g)
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0.001
0.01
0.1
1
10
100
1000
Pore Diameter (microns)


Sample 8695; 100/08-08-076-07W6/0; Mid. Banff;
2911.75 m
Microporosity
(<0.002µm; 2 nm)
Mesoporosity
(0.002µm-0.05 µm;
2 nm - 50 nm)
Macroporosity
(>0.05µm; 50nm)
Incremental Intrusion
(ml/g)
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.001
0.01
0.1
1
10
100
1000
Pore Diameter (microns)


Sample 8698; 100/02-28-094-09W6/0; Mid. Banff;
1455.2 m (4775 ft.)
Microporosity
(<0.002μm; 2 nm)
Mesoporosity
(0.002μm-0.05 μm;
2 nm - 50 nm)
Macroporosity
(>0.05μm; 50nm)
Incremental Intrusion
(ml/g)
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0.001
0.01
0.1
1
10
100
1000
Pore Diameter (microns)


Sample 8700; 100/02-28-094-09W6/0; Lwr. Banff;
1539.2 m (5050 ft.)
Mesoporosity
(0.002μm-0.05 μm;
2 nm - 50 nm)
Microporosity
(<0.002μm; 2 nm)
Macroporosity
(>0.05μm; 50nm)
Incremental Intrusion
(ml/g)
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.001
0.01
0.1
1
10
100
1000
Pore Diameter (microns)