Reservoir Characterization and Petroleum Potential of the Mowry Formation: Powder River Basin, Converse and Campbell Counties, Wyoming

BRIAN HANKINS

MS Geology

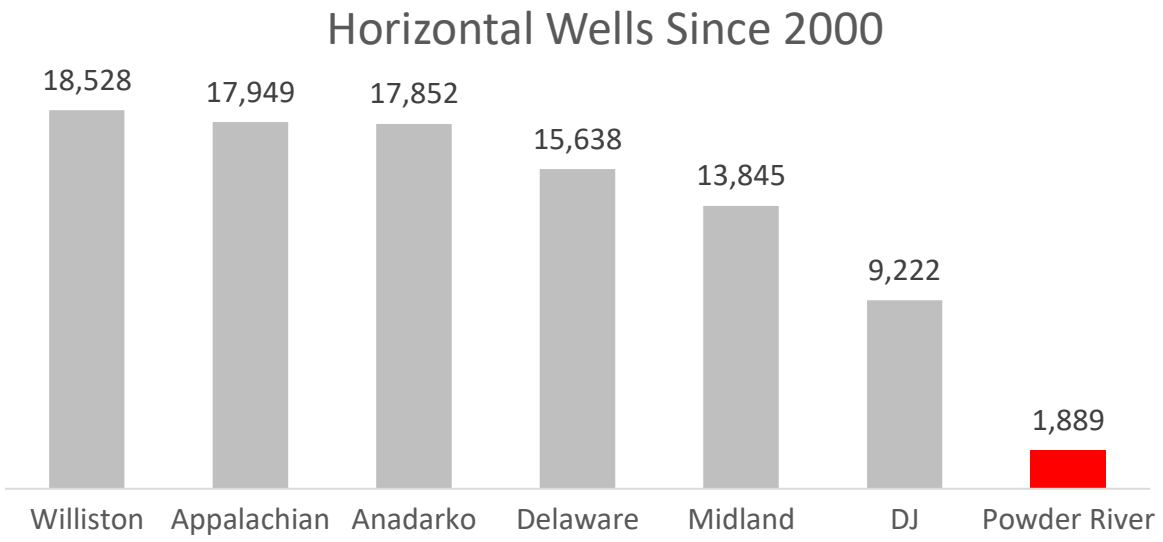
Spring 2021

hankins@mines.edu

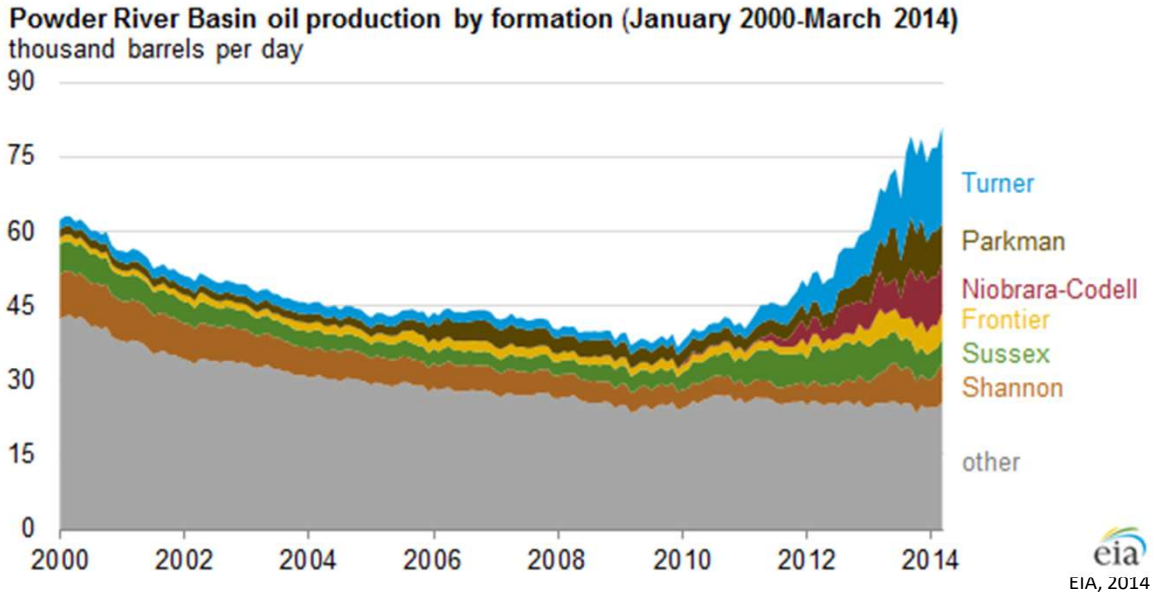
Outline

- What's new with Mowry Production
- Source Rock Characterization
- Silica Diagenesis
  - Initial findings
- Pore Characterization Workflow
- Next steps

Motivation



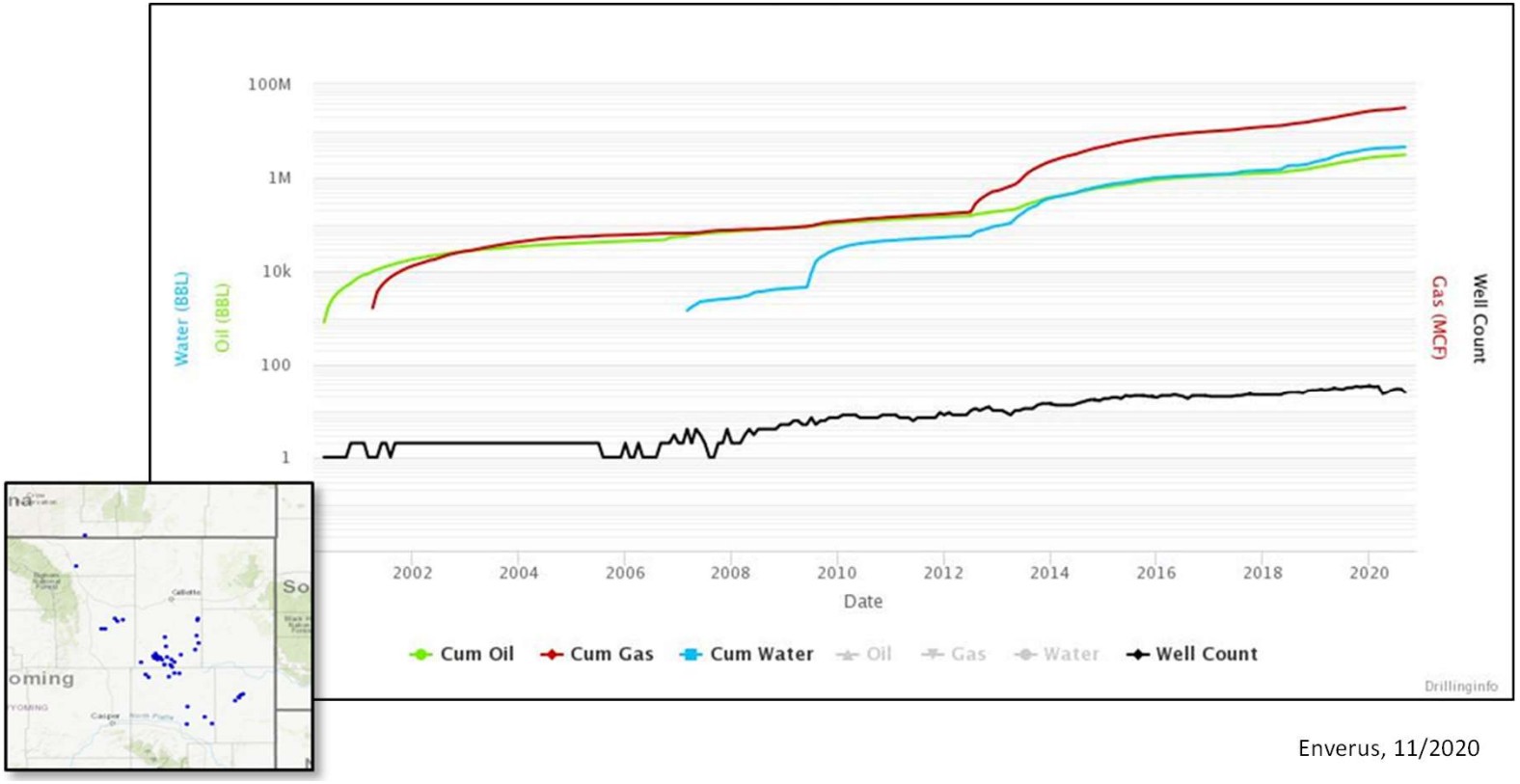
Enverus, 11/2020



EIA, 2014

Mowry Production (2018-2020)

- 14 New Wells
  - 29 from 2000-2017
- Cum Oil and Gas Doubled
  - Oil: 1.5 MMbbls to 3.1 MMbbls
  - Gas: 16.4 BCF to 31.0 BCF
- Best Cum Oil: 199.2Mbbls
- Average First 6-Month Production Significantly Improved
  - From 13.4 Mbbls to 61.7 Mbbls
  - Top 10 wells all drilled in 2018-2019
- Avg Oil Gravity
  - Prior to 2018: 45.6 API
  - 2018-2019: 49.1 API



Enverus, 11/2020

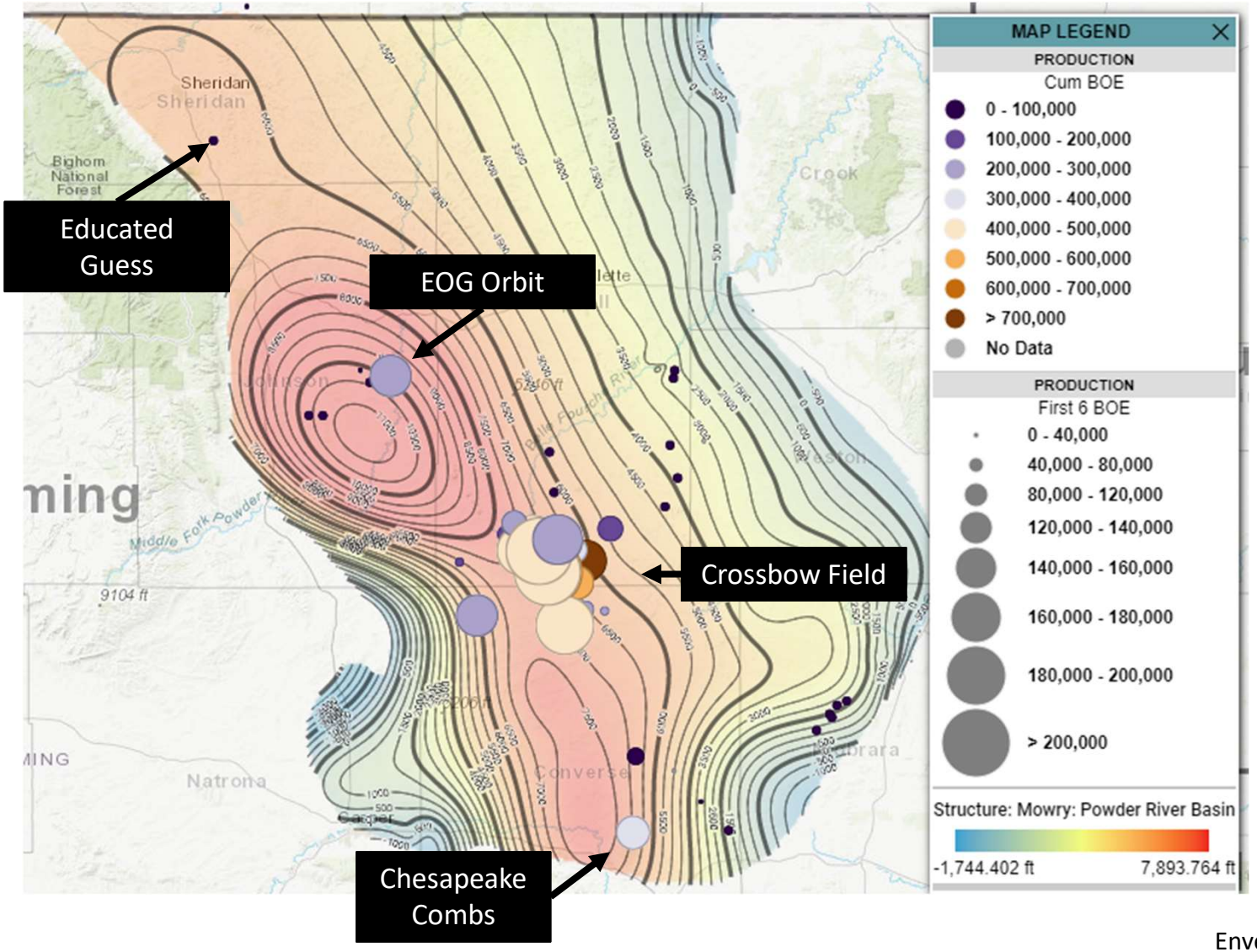
Production Data

Rank	Operator	Well	First 6 Oil	Cum Oil	First 6 Gas	Cum Gas	First 6 BOE	Cum BOE	Months Produced	Oil Gravity	2nd Month GOR
1	EOG RESOURCES INC	FLATBOW 870-2833H	97221	179822	730623	1459521	218992	423076	18	51	7750
2	EOG RESOURCES INC	ORBIT 53-1201H	87353	132106	325462	524439	141597	219513	12	45	2820
3	EOG RESOURCES INC	BALLISTA 204-1102H	81582	177626	906214	2304632	232618	561731	27	52.5	11480
4	PEAK POWDER RIVER RESOURCES LLC	ROUSH FED 2-27-22MH	78450	168080	73141	238918	90640	207900	21		910
5	EOG RESOURCES INC	FLATBOW 423-1720H	73946	180396	583793	1595112	171245	446248	27	51	7860
6	EOG RESOURCES INC	TIBURON 296-2436H	72533	153694	547213	1522316	163735	407413	22	48	6340
7	EOG RESOURCES INC	BALLISTA 4-1023H	58228	94319	1014223	1845107	227265	401837	15	52	15880
8	EOG RESOURCES INC	MARYS DRAW 272-3130H	55795	111100	808516	1826111	190548	415452	23	51	12730
9	SAMSON RESOURCES COMPANY	OGALALLA FED 31-2116 40-75MH	55143	94827	579484	1228319	151724	299547	15	55	10990
10	BALLARD PETROLEUM HOLDINGS LLC	DILTS 41-13-24 MH	53086	76699	700186	1060299	169784	253415	11	55	12980
11	PEAK POWDER RIVER RESOURCES LLC	ROUSH FED 1-2MH	50397	199207	114822	613718	69534	301493	61	46	1680
12	EOG RESOURCES INC	BOLT 1-3526H	45687	173857	578729	3810659	142142	808967	87	57	11850
13	EOG RESOURCES INC	ARBALEST 26-2234H	39502	120668	501009	2308424	123004	505405	72	56	12100
14	ANADARKO E&P ONSHORE LLC	DORA FED 3570-5-M5H	36267	48566	105642	153937	53874	74222	9	42	1980
15	PEAK POWDER RIVER RESOURCES LLC	IBERLIN 1-4MH	31216	109457	71049	370869	43058	171269	74	46	2090
16	ANSCHUTZ OIL COMPANY LLC	GRACIE FEE 4271-3-10-14W MH	30306	49523	344517	593042	87726	148363	13	46	10200
17	PEAK POWDER RIVER RESOURCES LLC	STODDARD FED 1-21MH	27216	89229	332838	1754030	82689	381567	68	56	7530
18	EOG RESOURCES INC	MARYS DRAW 210-23H	23661	70030	196685	998808	56442	236498	83	50	11360
19	ATX ENERGY PARTNERS LLC	TATANKA 16-2MH	22555	68609	24897	92369	26705	84004	24	45	880
20	EOG RESOURCES INC	BLADE 200-2116H	22291	124882	79640	854842	35564	267356	77	48	2860
21	PEAK POWDER RIVER RESOURCES LLC	SUCHAN FED 1-15MH	18607	62155	71121	337358	30461	118381	63	51	3160
22	DEVON ENERGY	STATE IBERLIN RANCH 3626-4MH	18309	68031	85779	417371	32605	137593	88	48.5	4670
23	EOG RESOURCES INC	ARBALEST 248-16H	15327	65029	300937	1827524	65483	369616	97	50	16720
24	PRIMA EXPLORATION INC	SIMBA FED 4778-20-44M-H	14551	48879	42145	176499	21575	78295	74	47	3190
25	ATX ENERGY PARTNERS LLC	BUFFALO 14 1MH	11440	52186	16587	136625	14205	74957	70	43	170
26	DEVON ENERGY	STATE WRIGHT 3643-1MH	10348	40919	11986	67048	12346	52094	98	41	1840
27	DEVON ENERG	ORYX 2653-3MH	8212	42075	3860	24786	8855	46206	94	39	480
28	ANADARKO E&P ONSHORE LLC	TRINITY FEE 3367-7-31M-H	7082	20863	64407	268627	17816	65634	80	55.5	
29	CENTURY OIL AND GAS LLC	BACON CREEK FEDERAL 45-69-16-21-1TH	5785	22902	14273	51047	8164	31410	69	40	12470
30	CHESAPEAKE OPERATING LLC	COMBS 17-33-70 USA B MW40H	525	903	721397	1924904	120758	321720	35	44	1630

Enverus, 11/2020

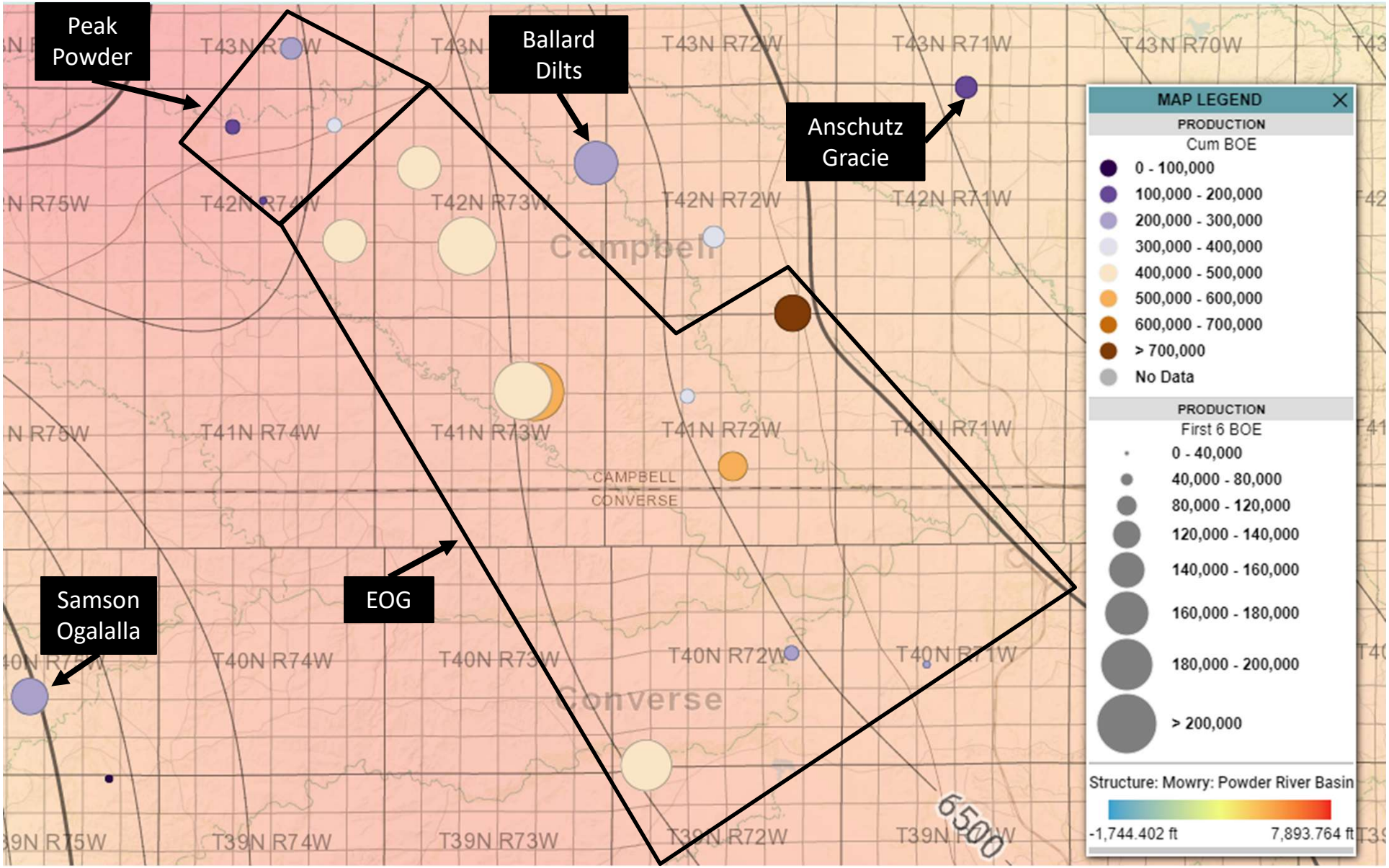
Historic Production

Horizontal Mowry Production



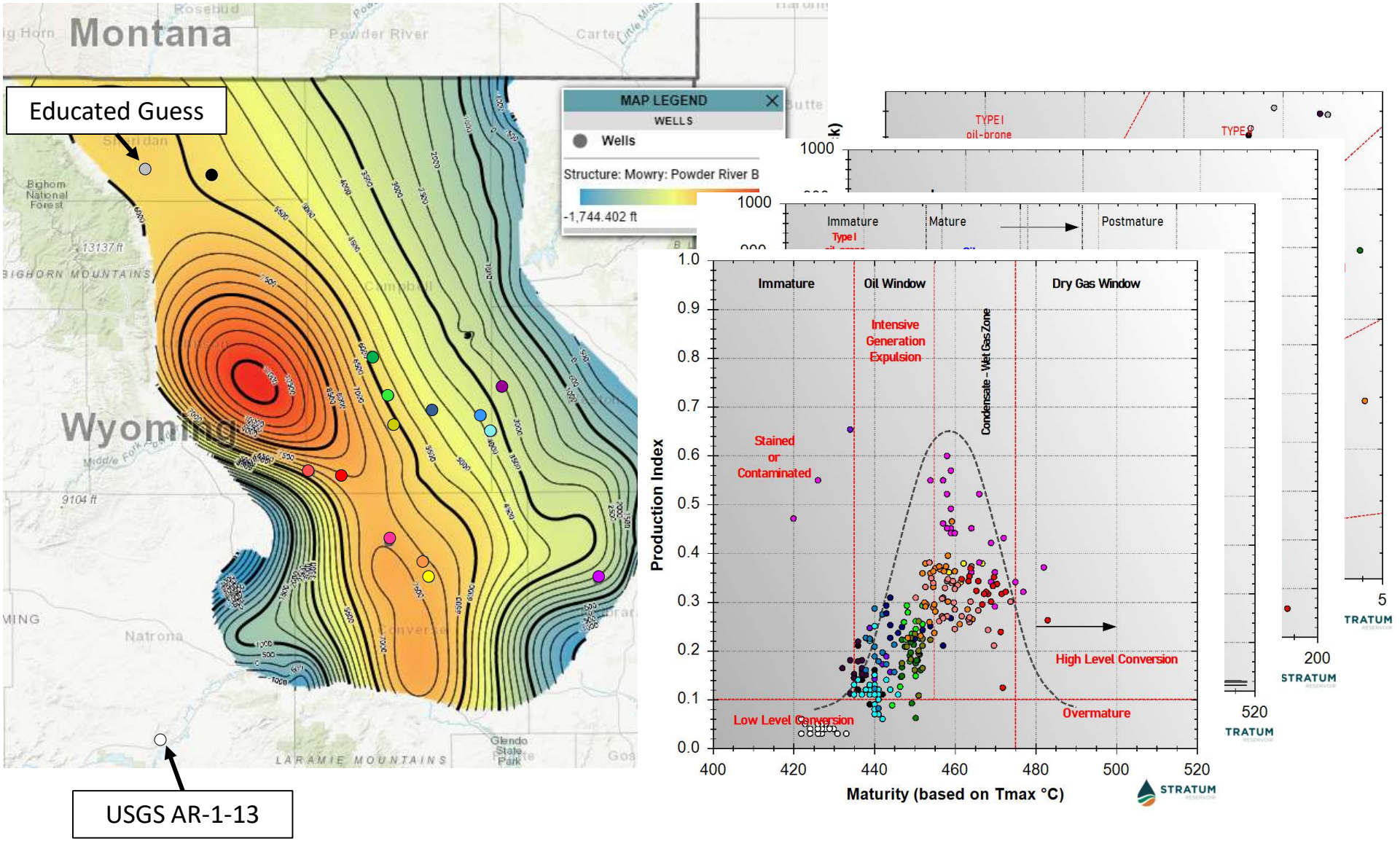
Enverus, 11/2020

Historic Production

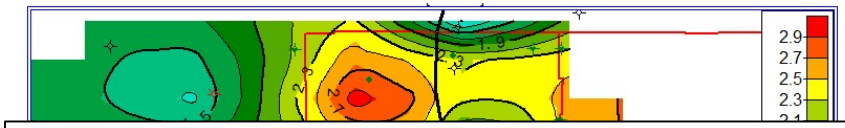


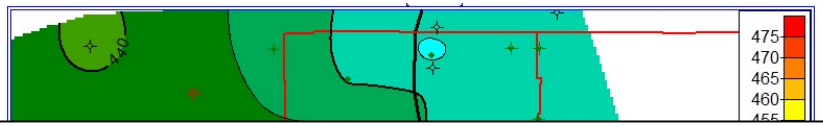
Enverus, 11/2020

Hydrocarbon Generation



Hydrocarbon Generation





Step 1: $HI_0 = \left(\frac{\%\ Type\ I}{100} x750\right) + \left(\frac{\%\ Type\ II}{100} x450\right) + \left(\frac{\%\ Type\ III}{100} x125\right) + \left(\frac{\%\ Type\ IV}{100} x50\right)$

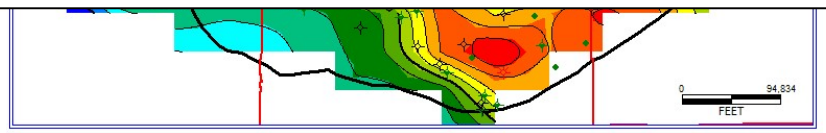
Step 2: $TR_{HI} = 1 - \frac{HI_{pd}[1200 - HI_o(1 - PI_o)]}{HI_o[1200 - HI_{pd}(1 - PI_{pd})]}$

Step 3: $TOC_o = \frac{HI_{pd}\left(\frac{TOC_{pd}}{1+k}\right) x\ 83.33}{\left[HI_o\ x\ (1 - TR_{HI})\left(83.33 - \left(\frac{TOC_{pd}}{1+k}\right)\right)\right] - \left[HI_{pd}\left(\frac{TOC_{pd}}{1+k}\right)\right]}$

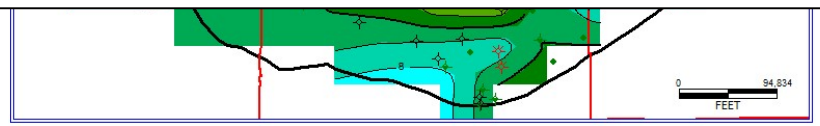
Step 4: $S2_o = \frac{HI_o\ x\ TOC_o}{100}$

Step 5: $Generated\ Hydrocarbons = S2_o - S2_{pd}$

Jarvie et al., 2007



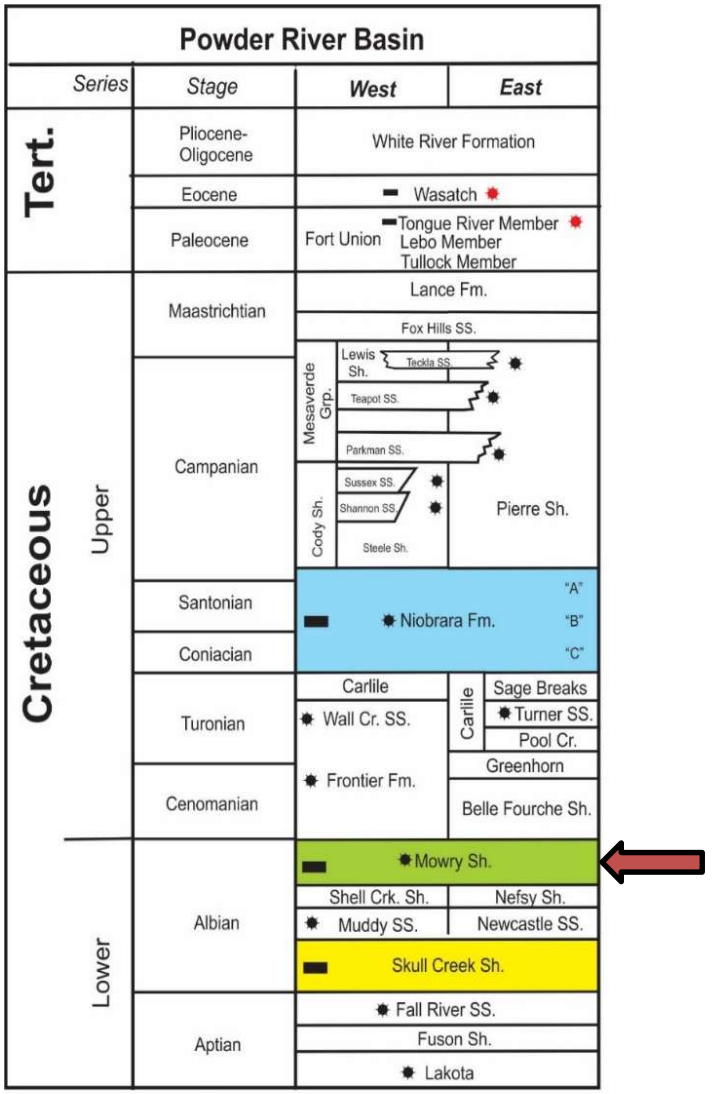
Mowry Generated Hydrocarbons Map



Mowry Available Hydrocarbons Map

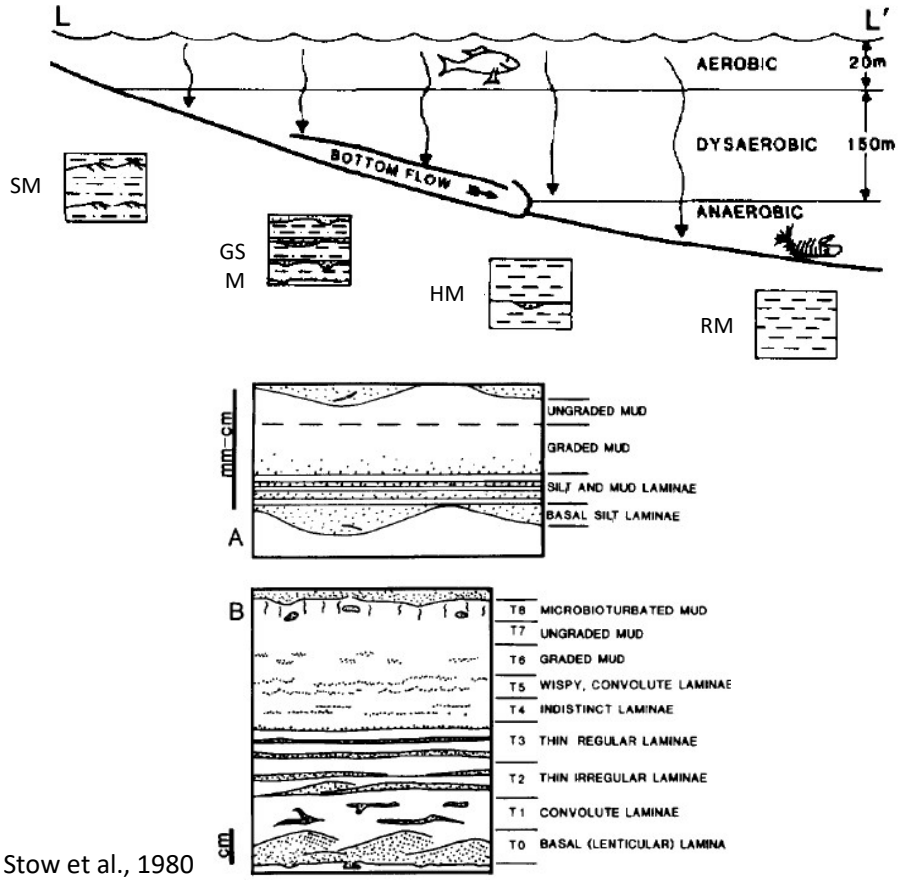
Mowry Geologic Overview

Blakey, 2017



(Sonnenberg, 2019)

Mowry Depositional Mechanism



Stow et al., 1980

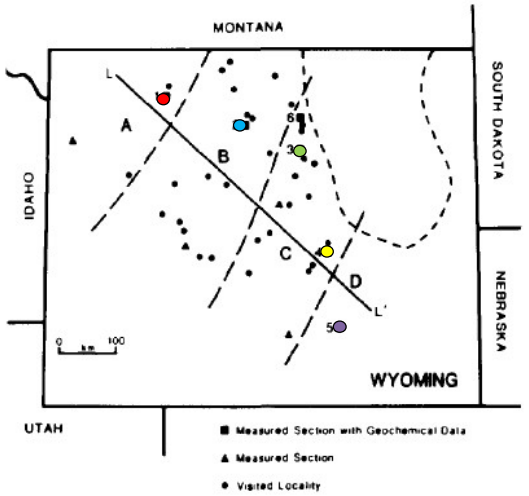


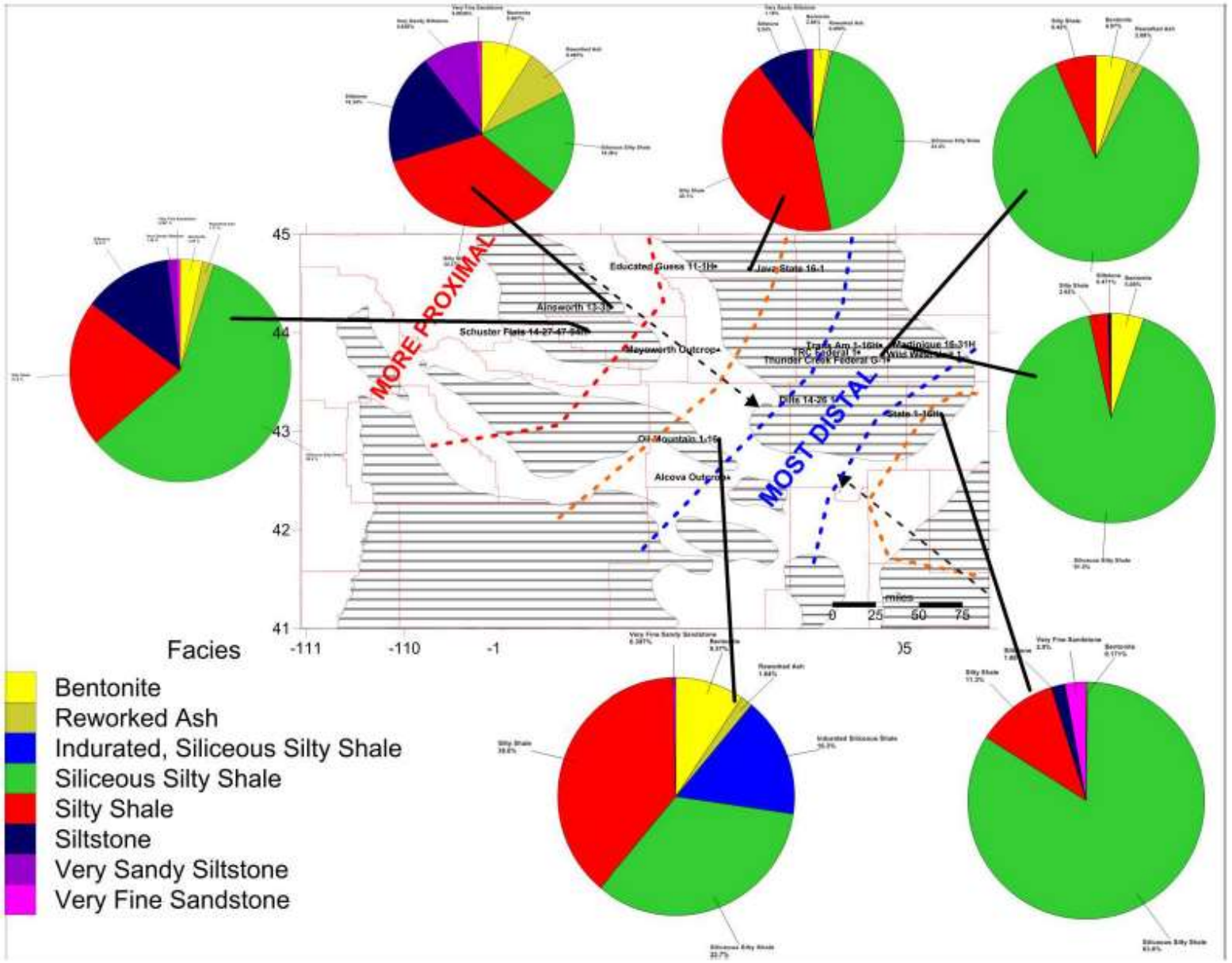
Table 1. Percentage Estimates of Each Mowry Shale Lithofacies at Five Geochemical Sample Locations*

Locality	SM	GSM	HM	RM
Cody	80	5	15	—
Tensleep	5	75	15	5
Mayoworth	5	25	65	5
Goose Egg	—	15	65	20
Medicine Bow	—	—	10	90

*SM = silty mudstone, GSM = graded siltstone and mudstone, HM = homogeneous mudstone, RM = radiolarian-mudstone. See Figure 3 for sample locations.

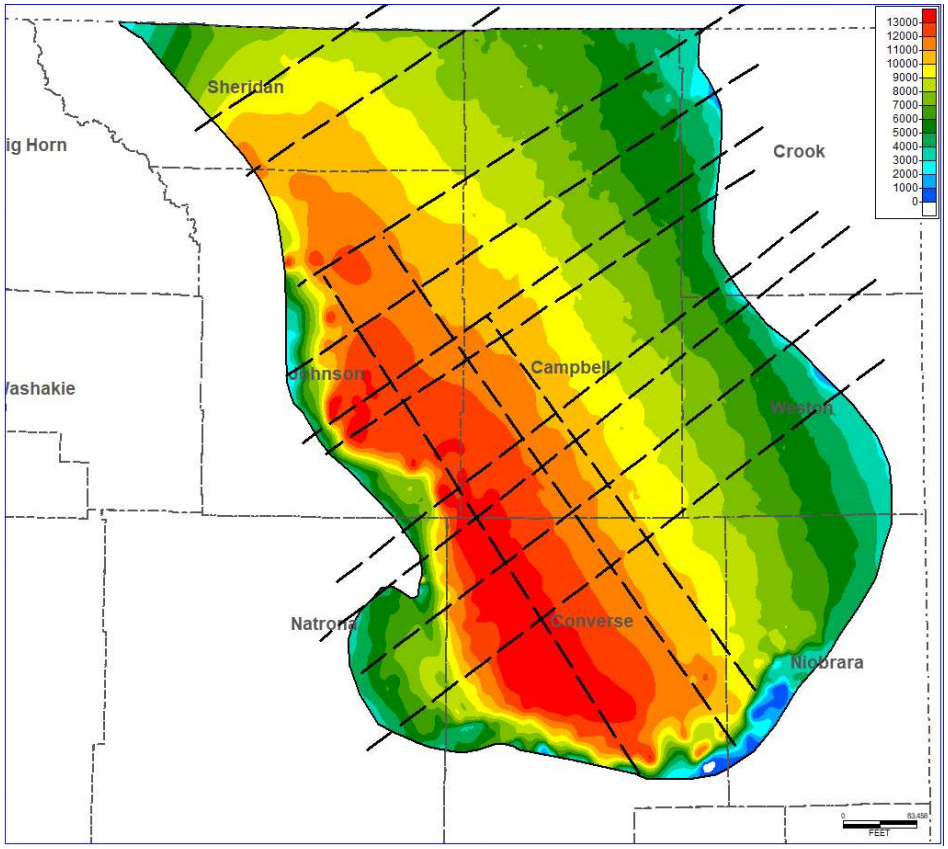
Davis et al., 1989

Facies Distributions

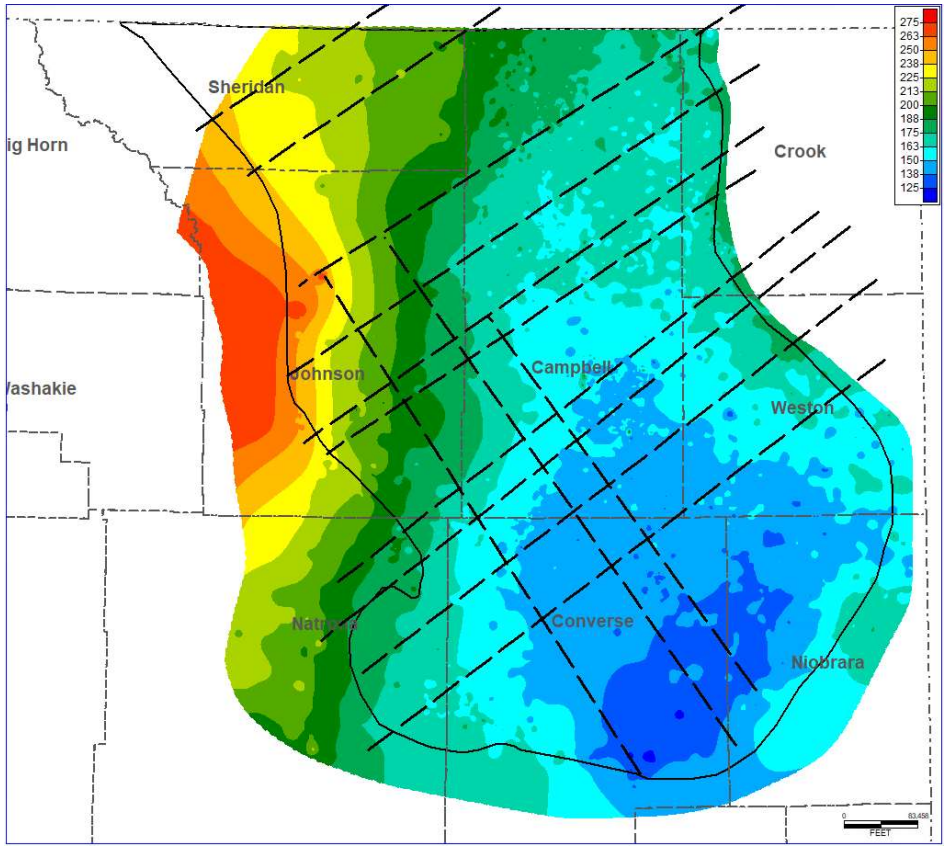


Hollon, 2014

Mowry Structure and Isopach Maps, PRB



Structure Map (TVD)
CI: 1,000’

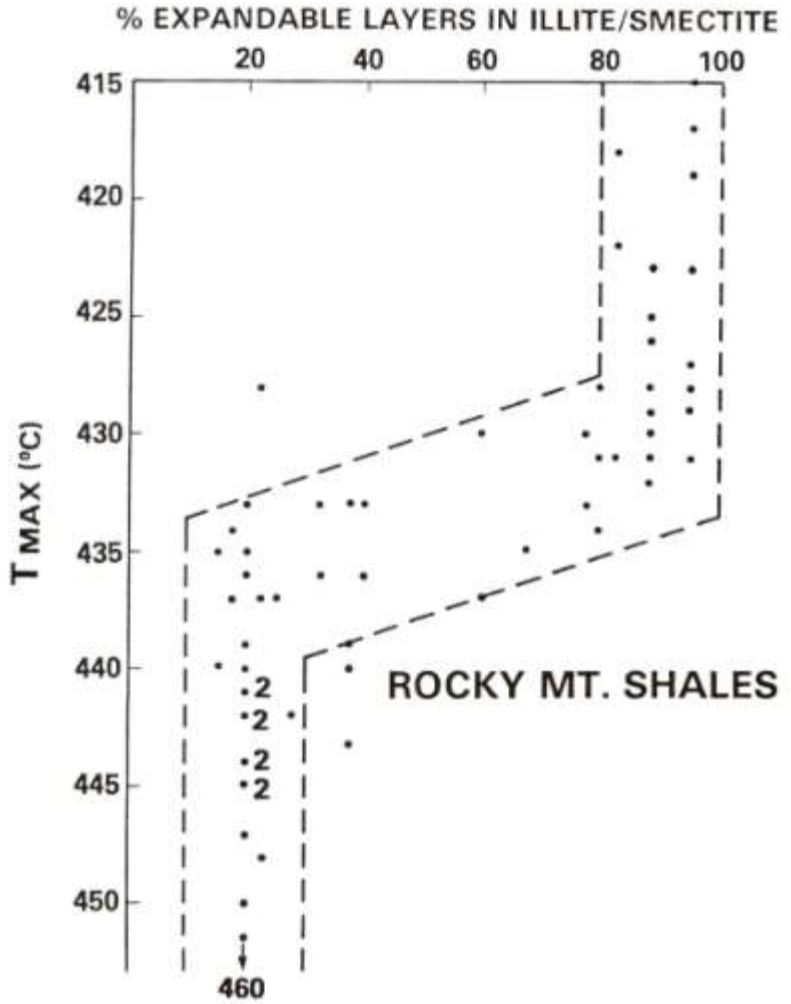


Gross Thickness
CI: 12.5’

Socianu, 2020

Diagenetic History

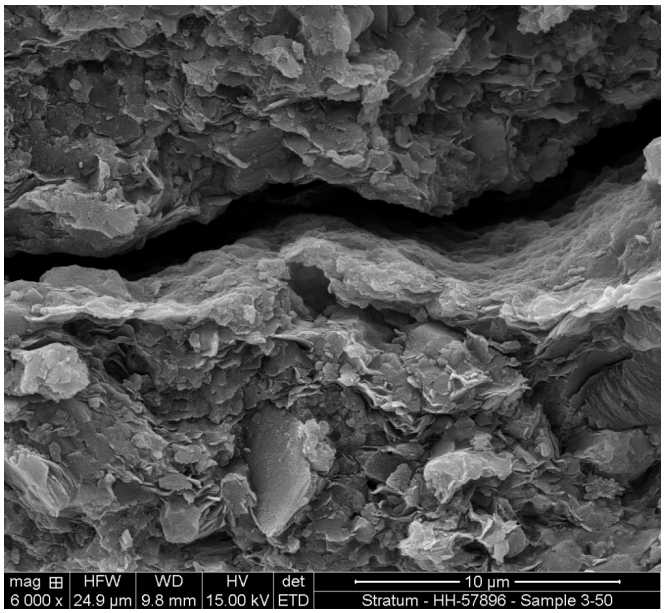
- Compaction
- Smectite to Illite Transformation
- Opal-A → Opal-CT → Quartz
- Silica Cementation
- Oil Generation and Expulsion
- Organic Matter Porosity Development

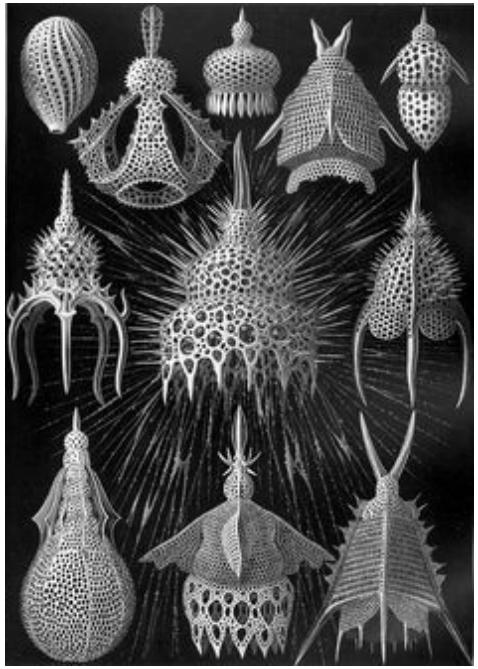


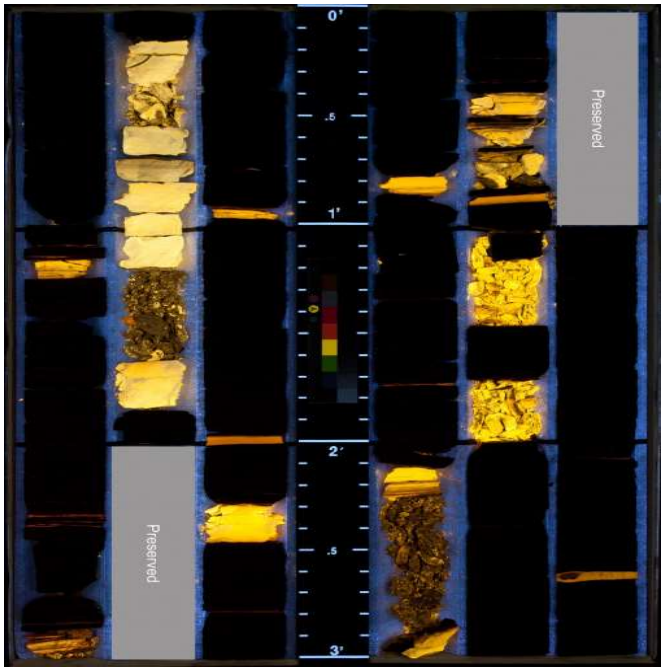
Burtner and Warner, 1986

Silica Source

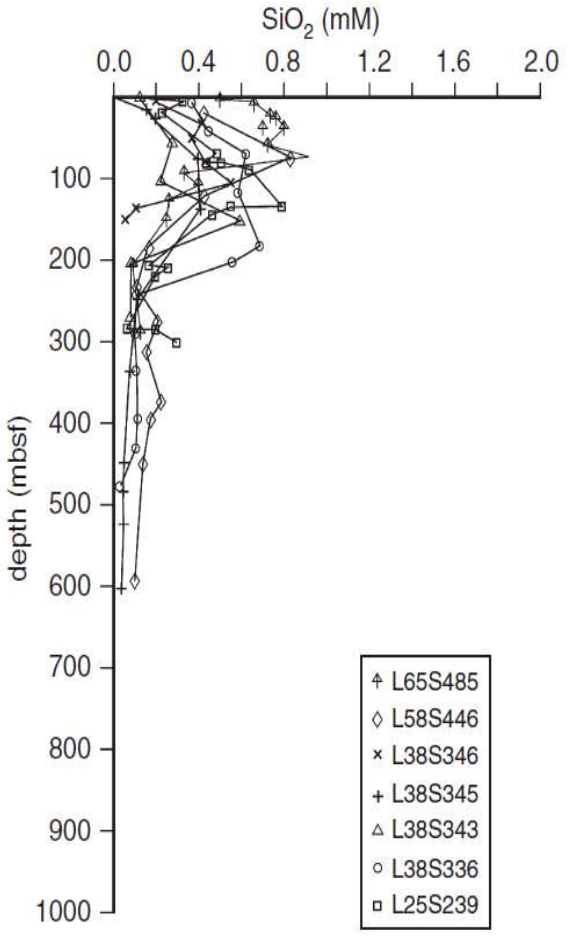
- Illitization of Smectite
- Volcanic Ash
- Biogenic Opal
- Microbial Activity

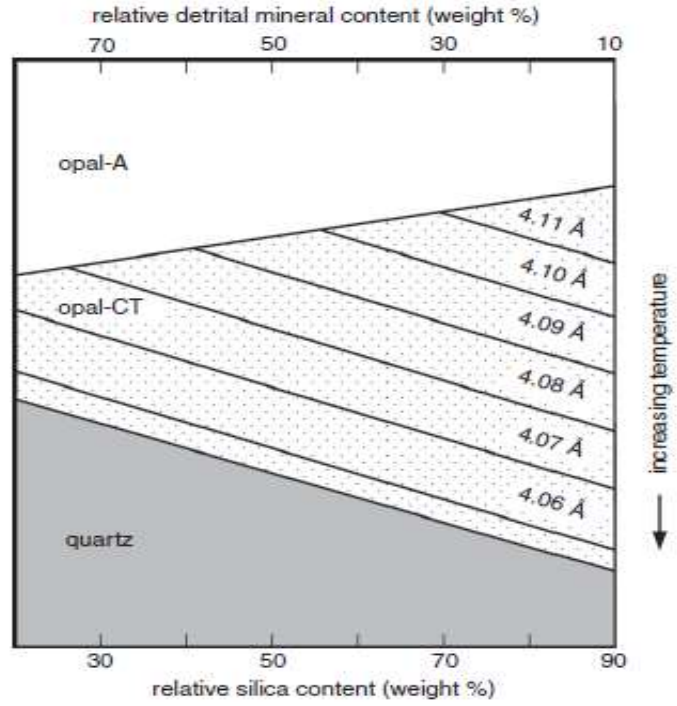


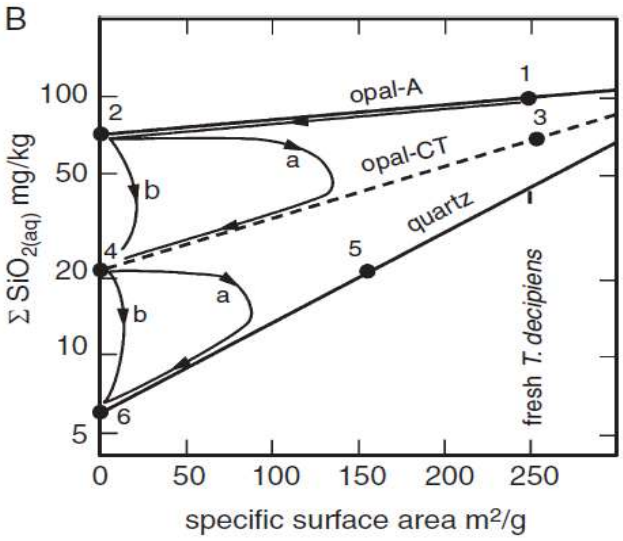


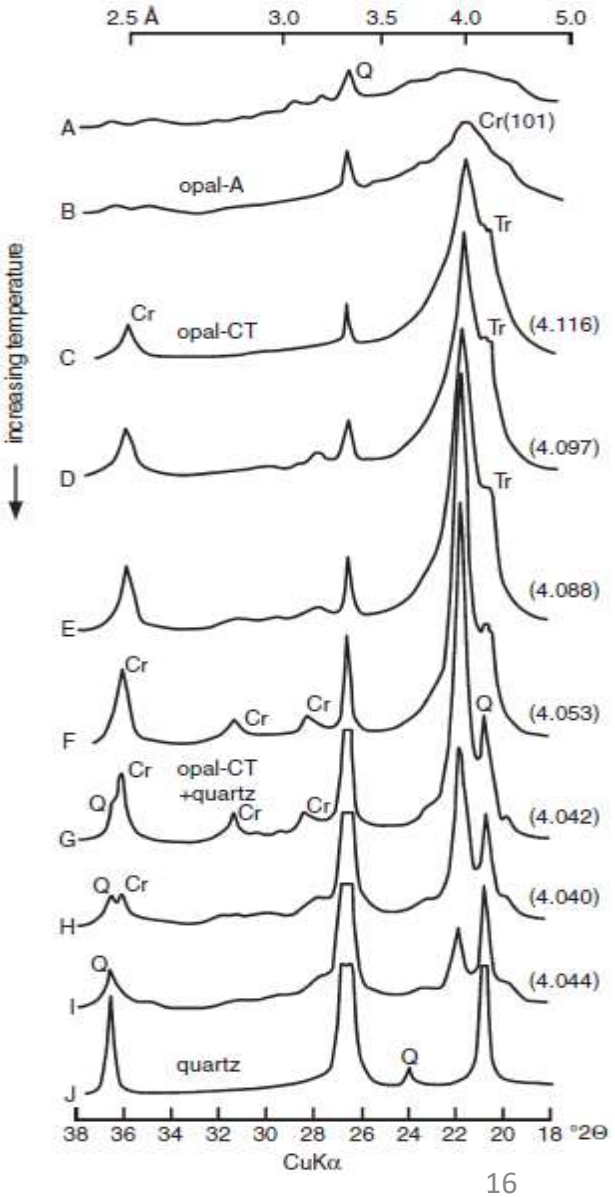


Biogenic Silica Diagenesis



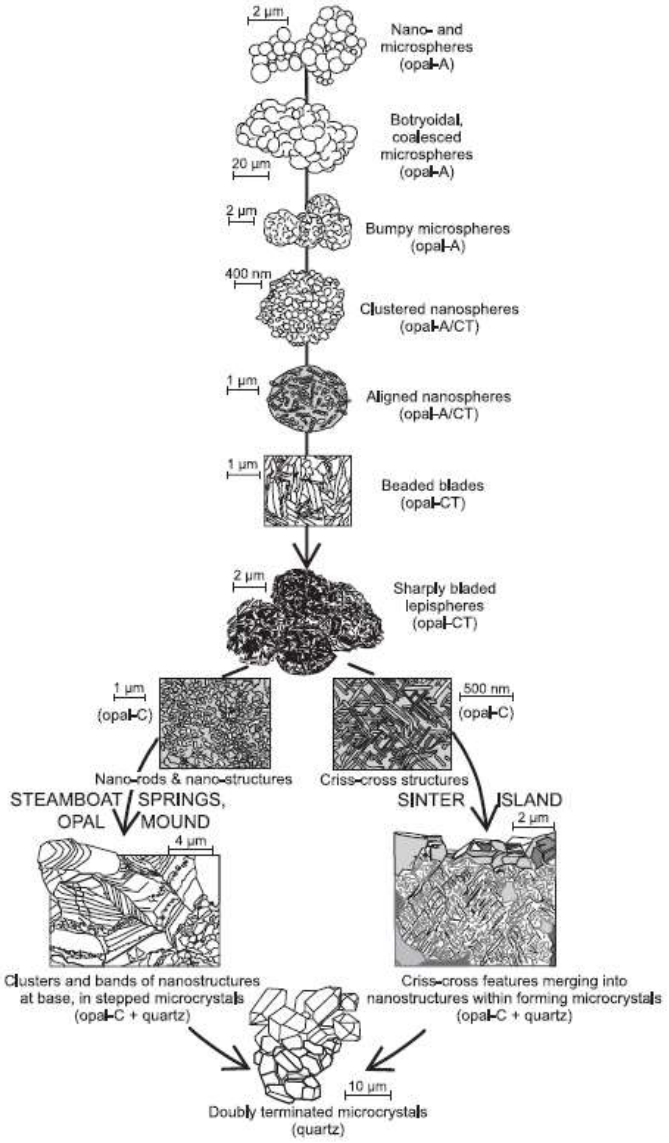


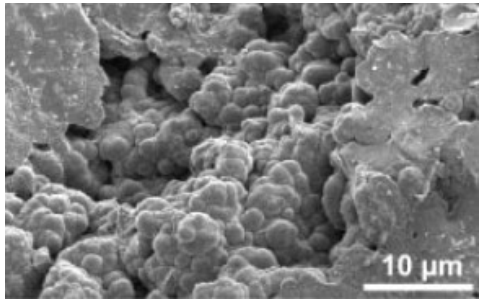


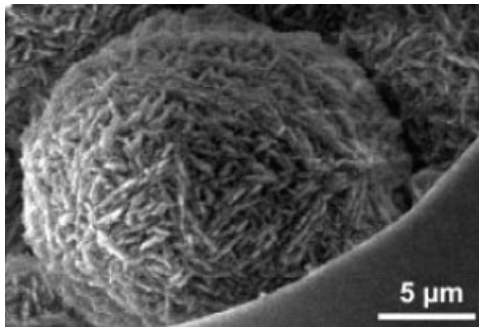


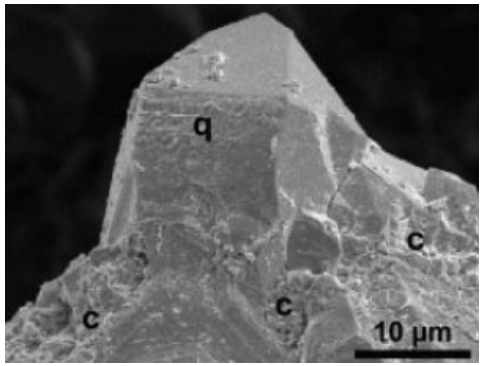
Hesse, 2011

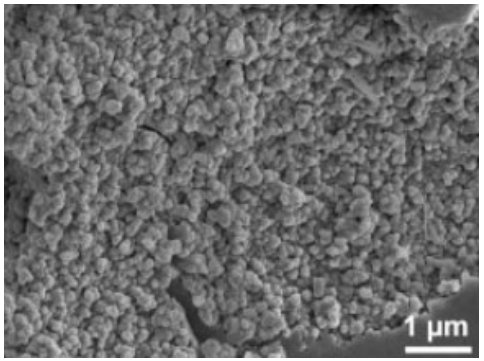
Biogenic Silica Morphology

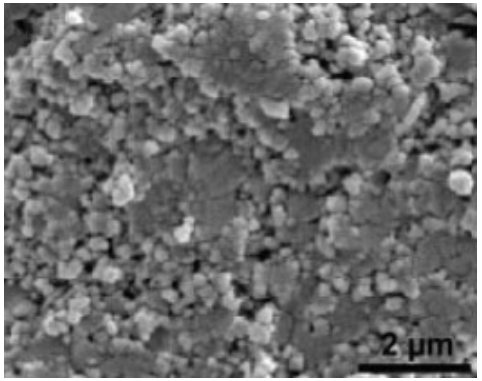


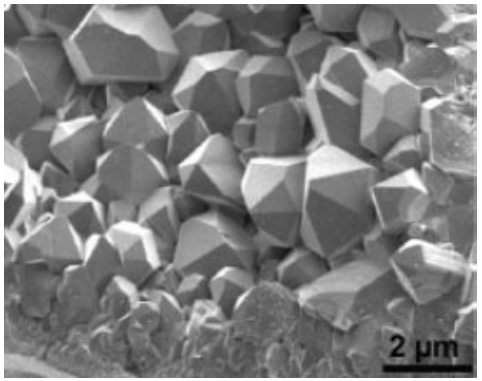






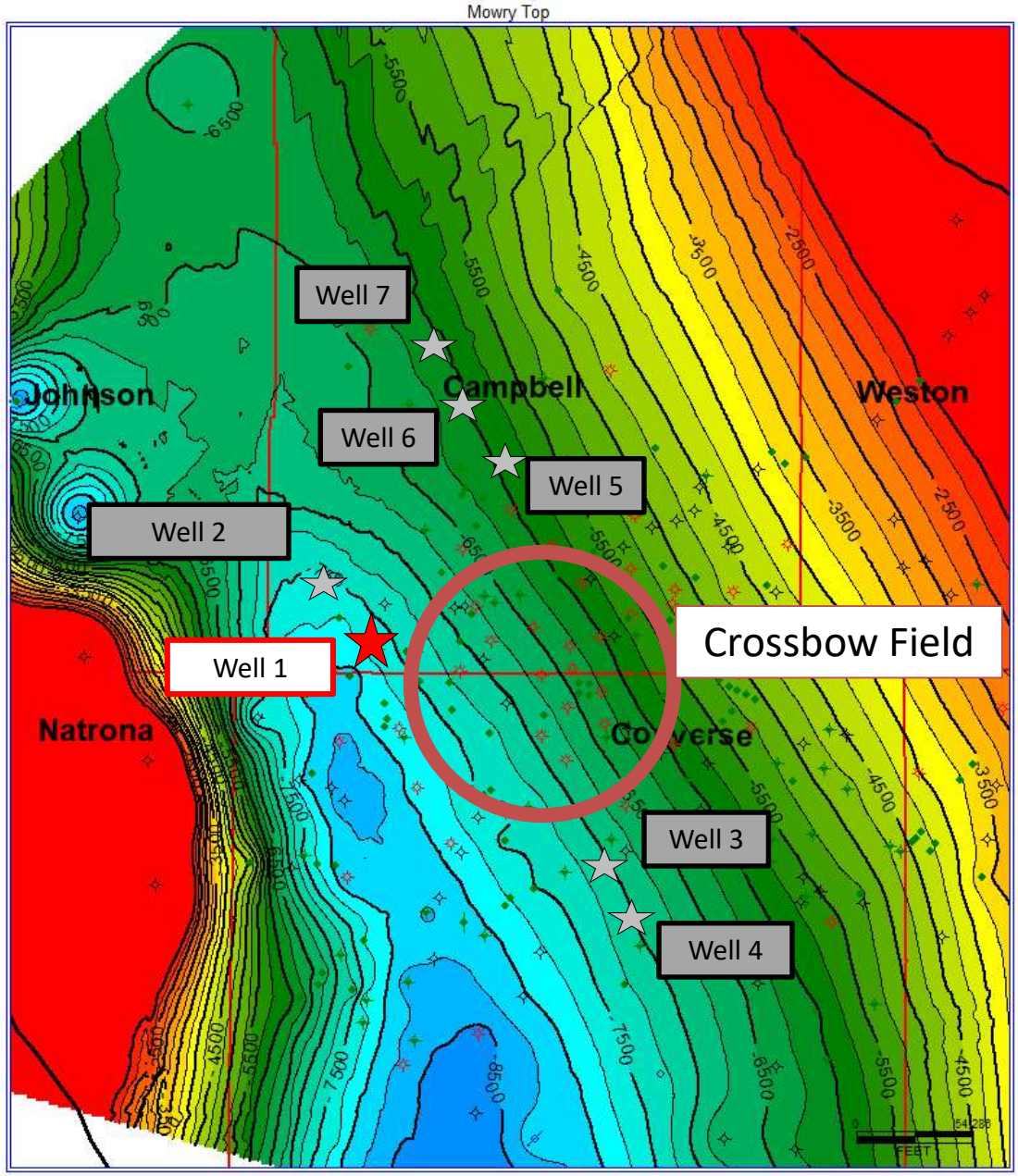






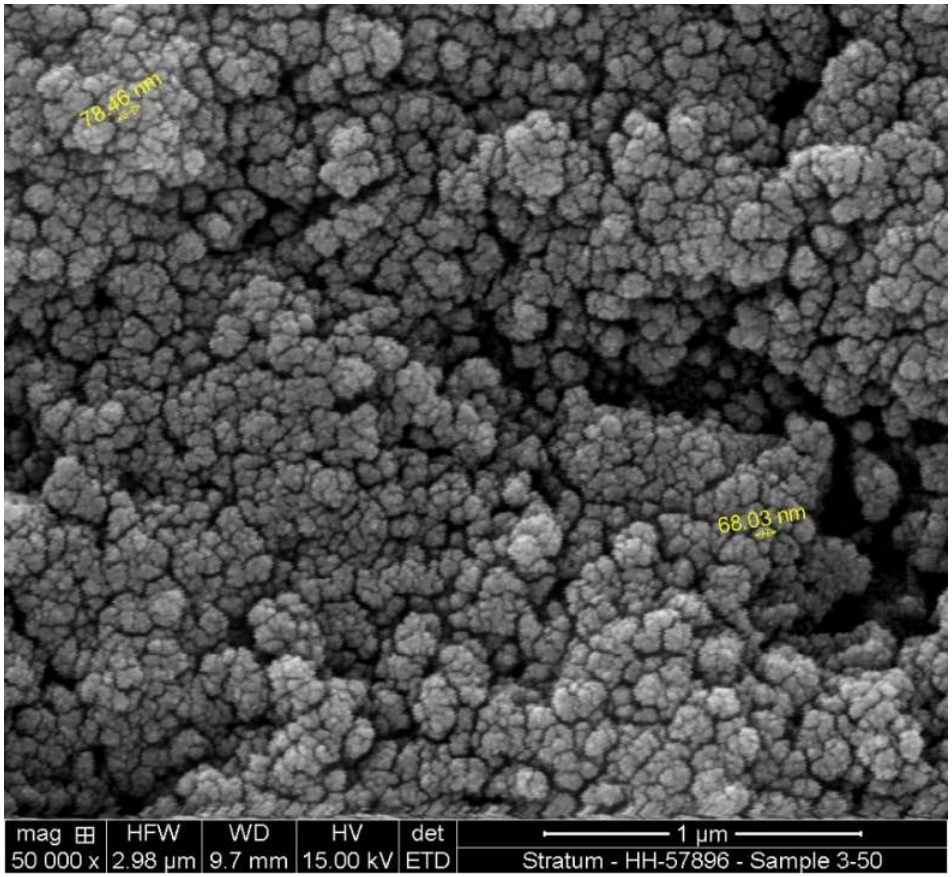
Lynne, 2007

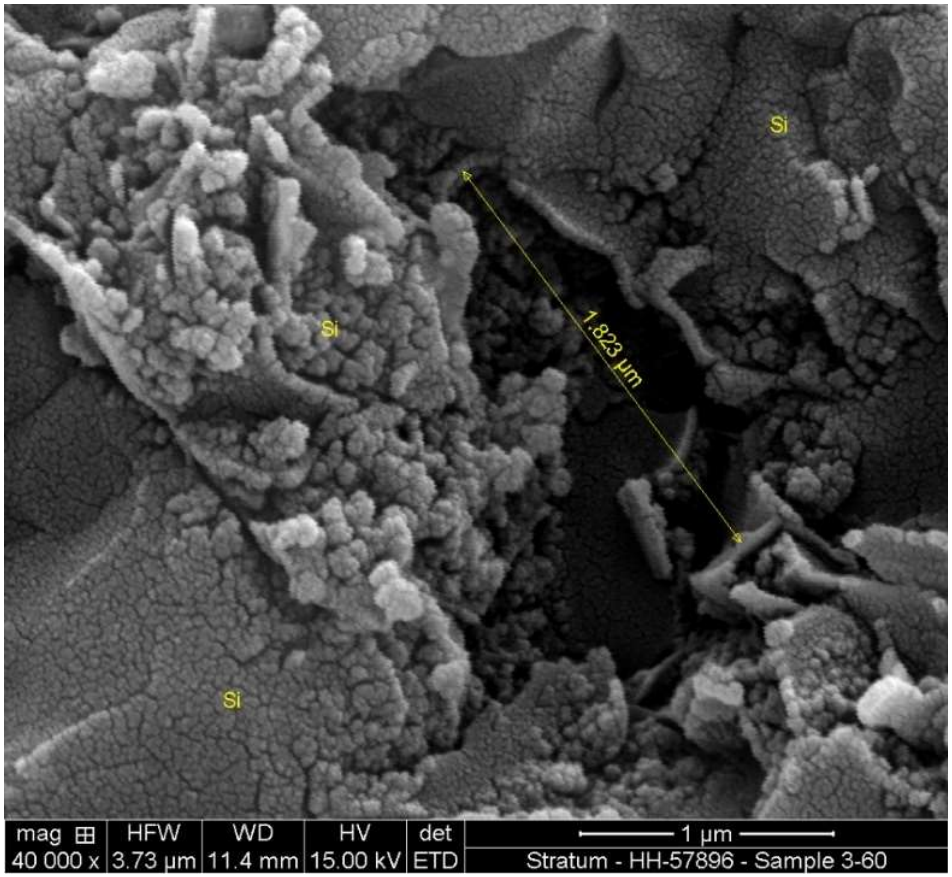
Study Area



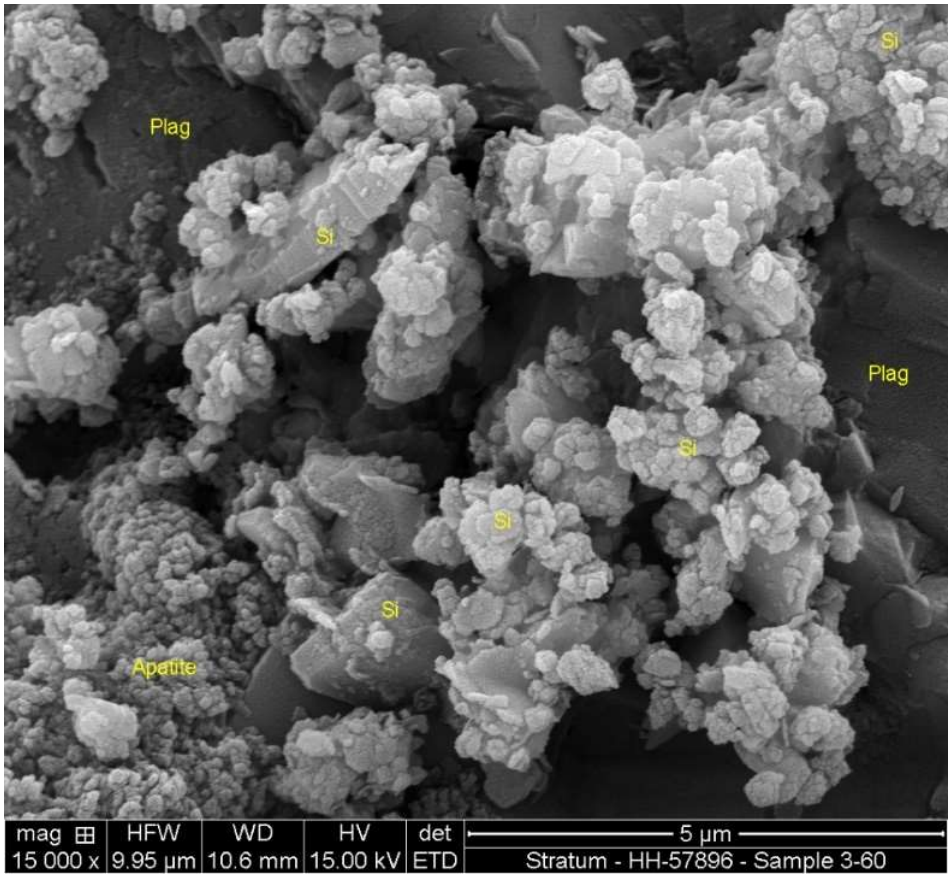
Top of Mowry
Structure Map
Contour Interval: 250’

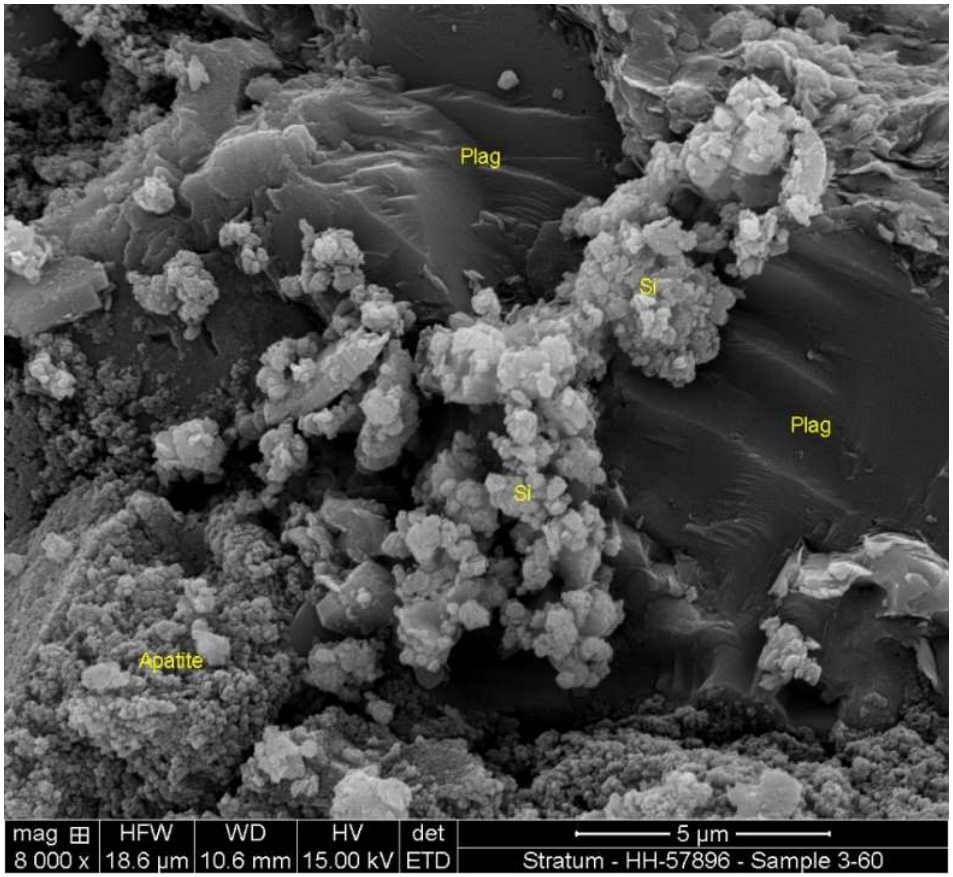
SEM Observations



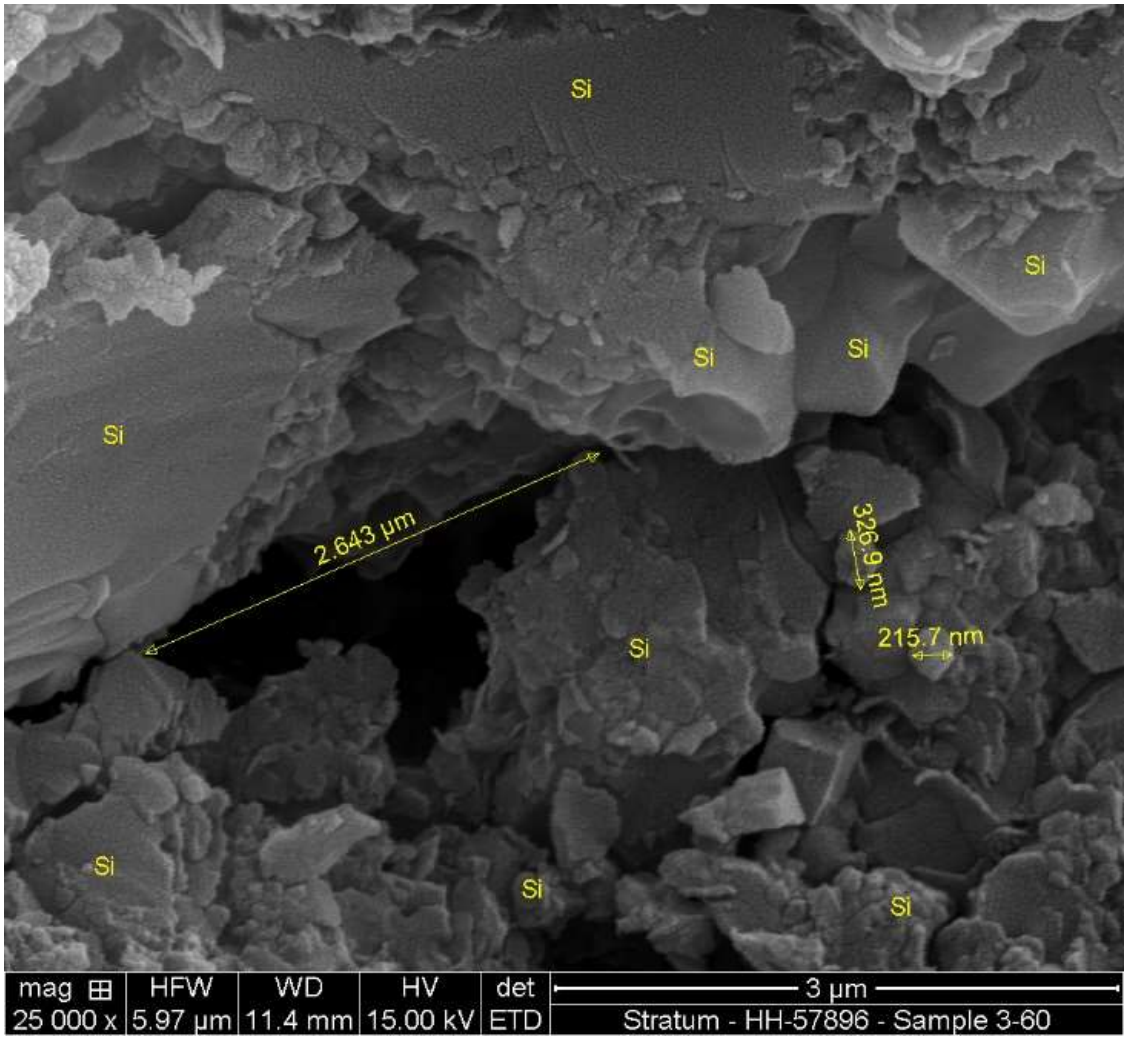


SEM Observations

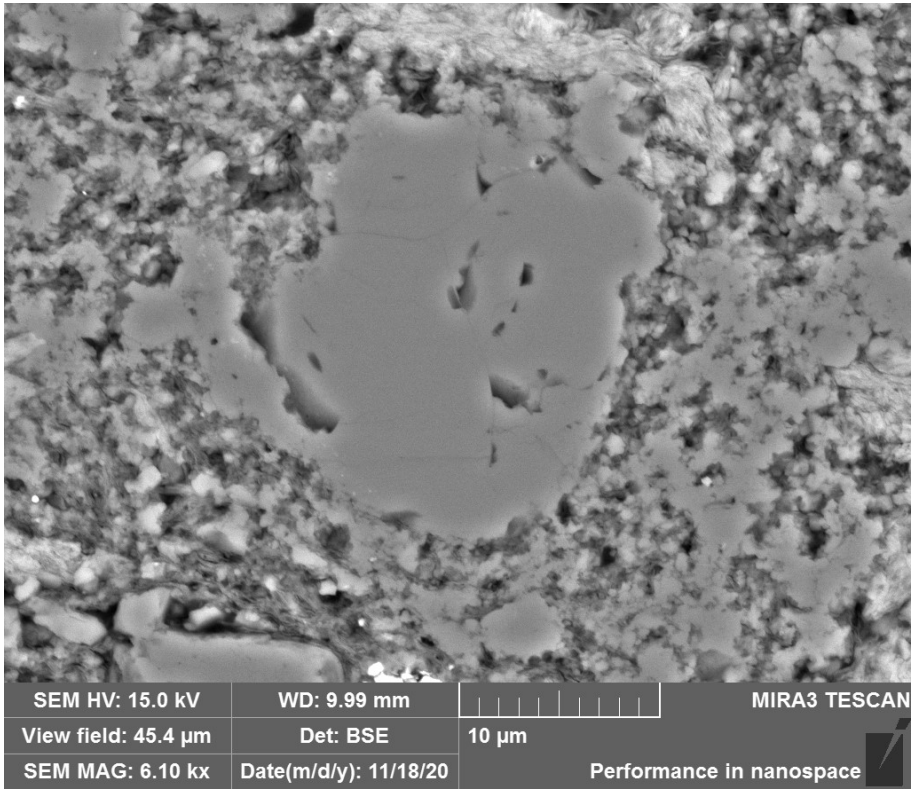


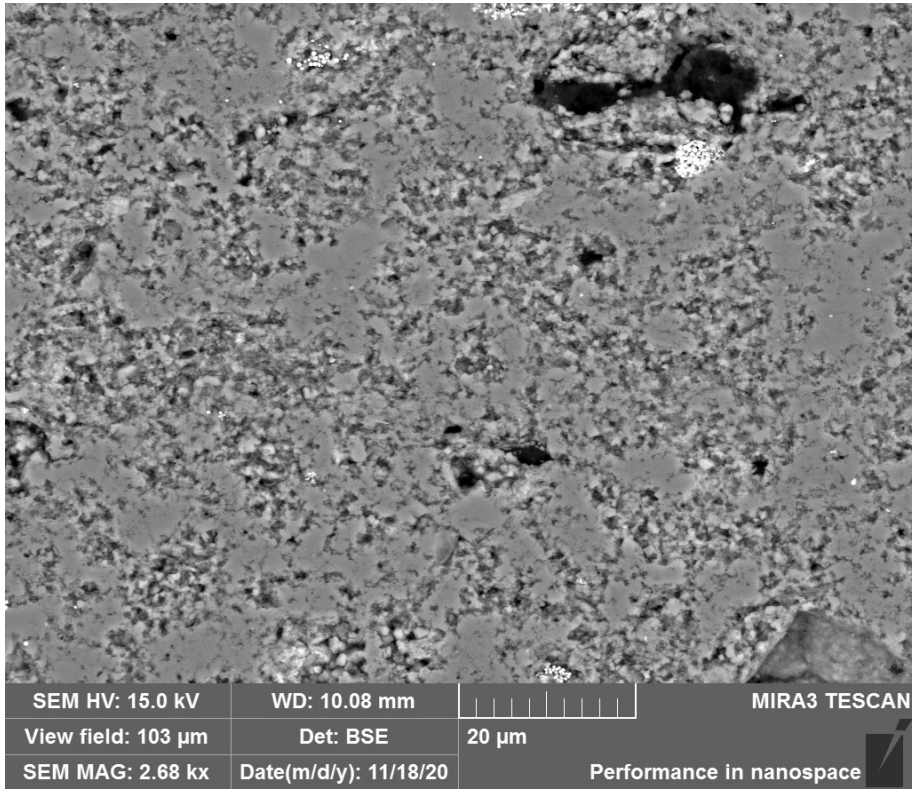


SEM Observations

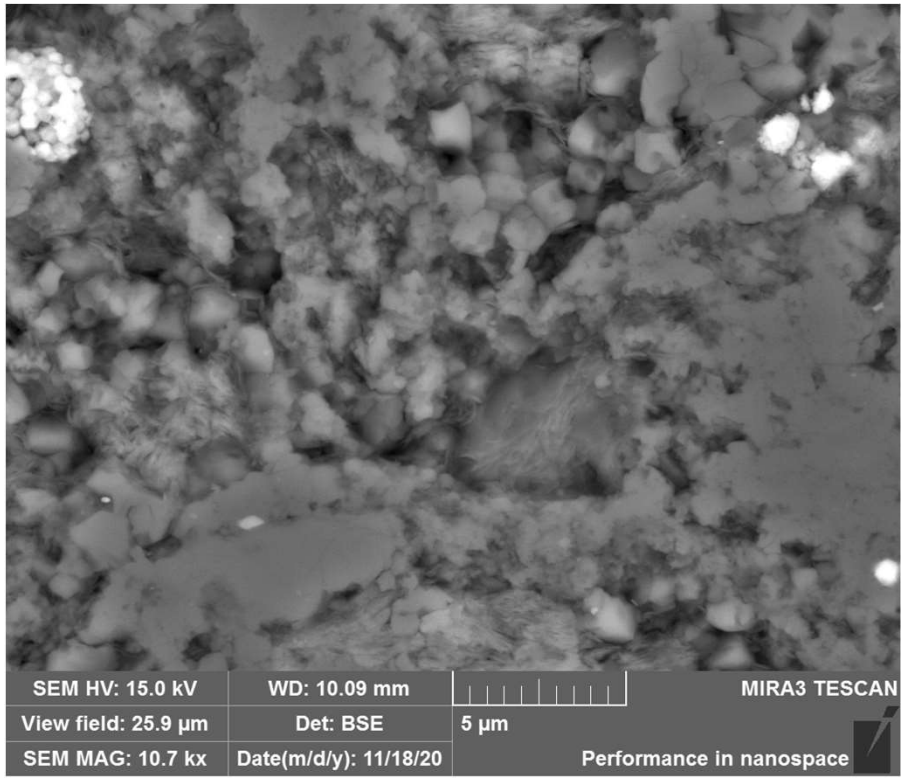


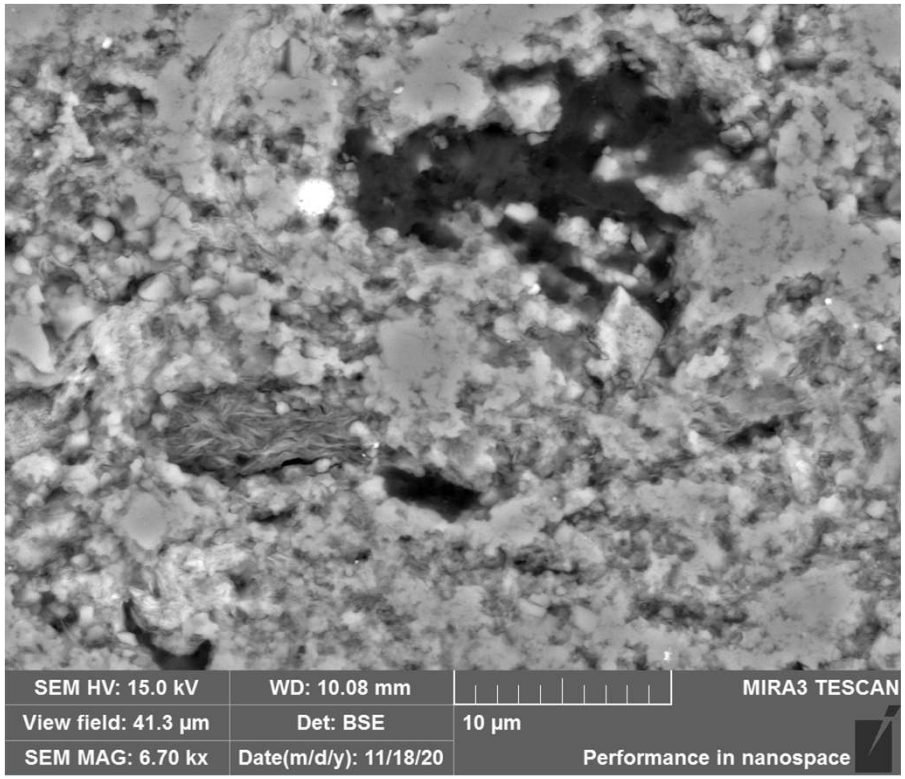
SEM Observations



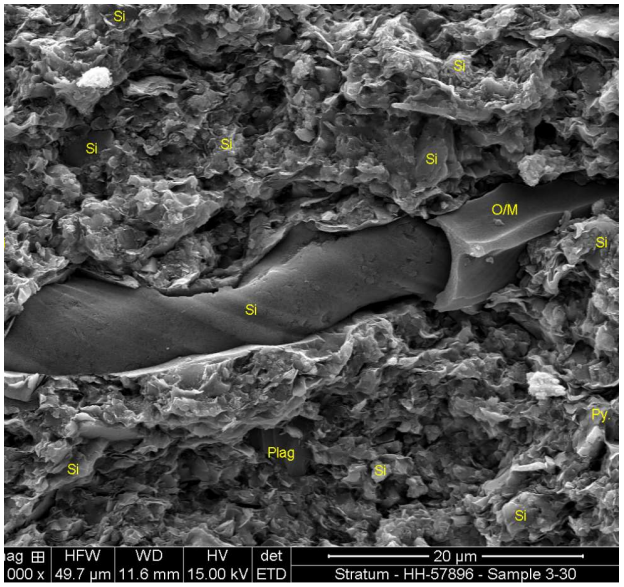


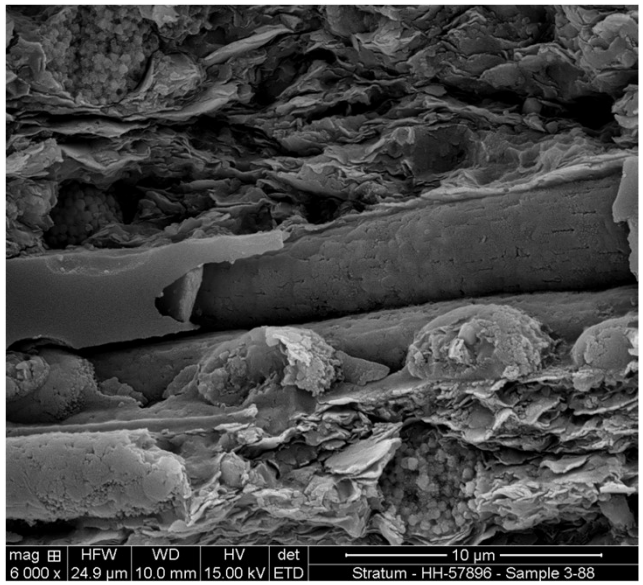
SEM Observations

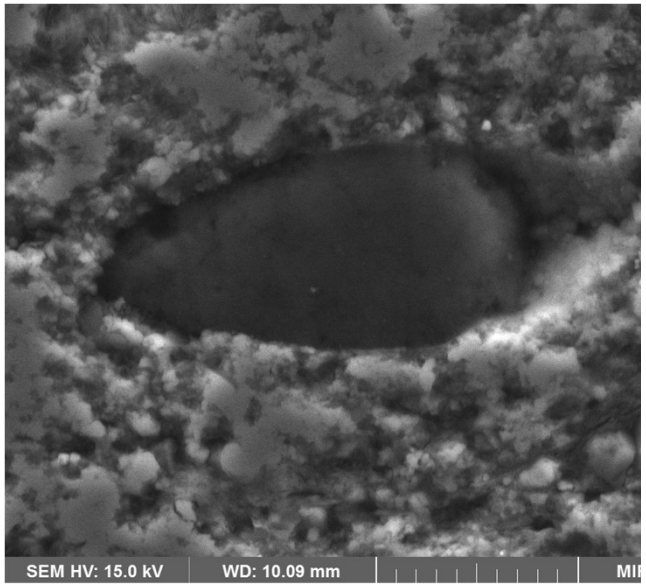


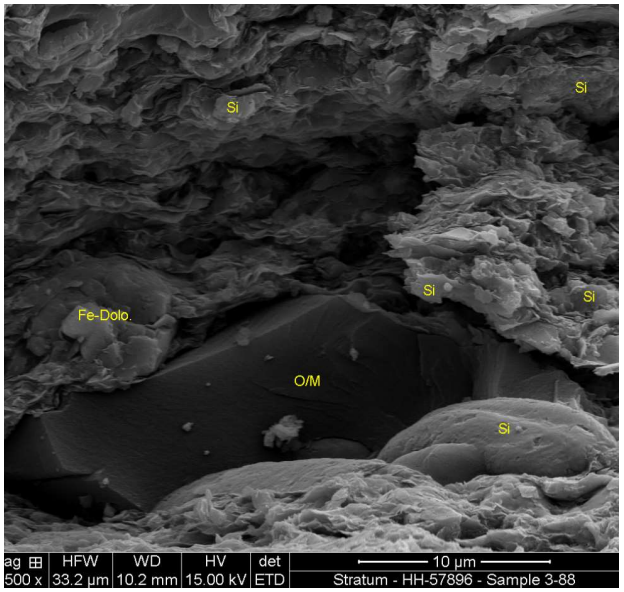


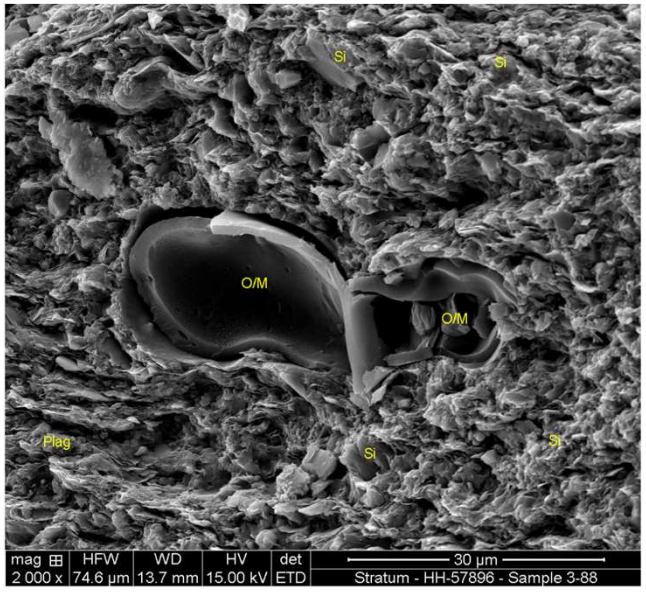
SEM Observations

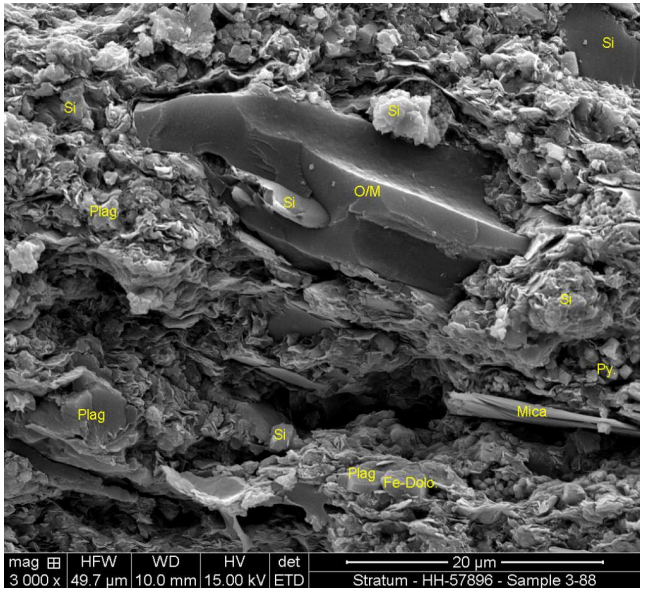




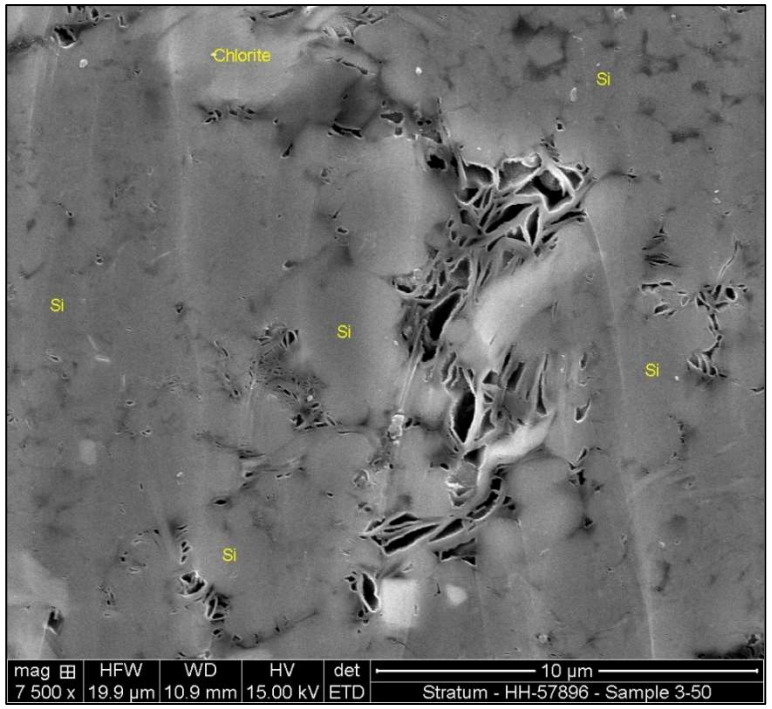


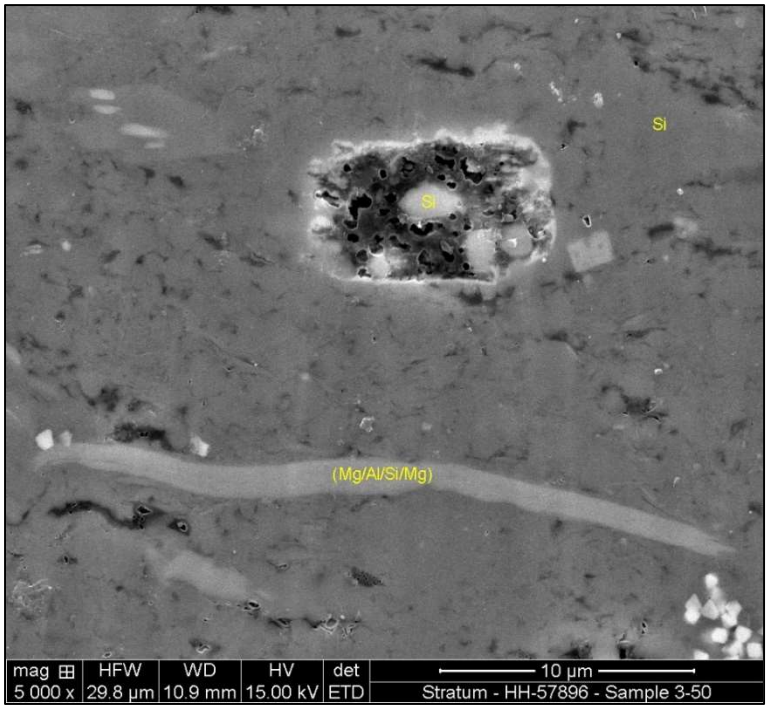


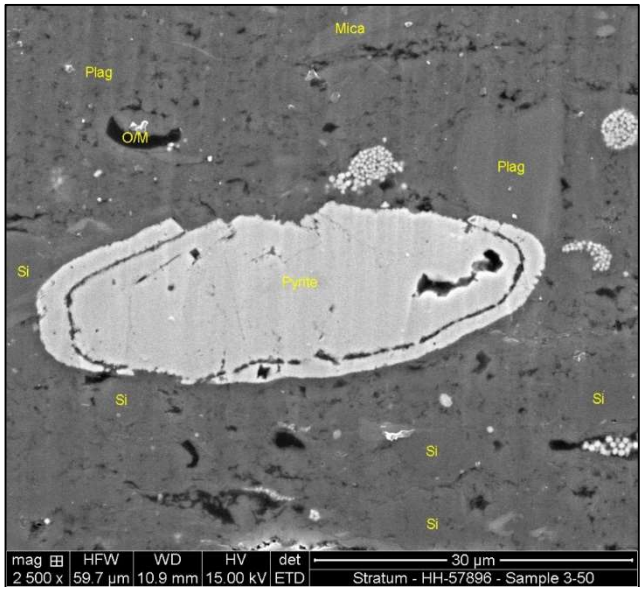




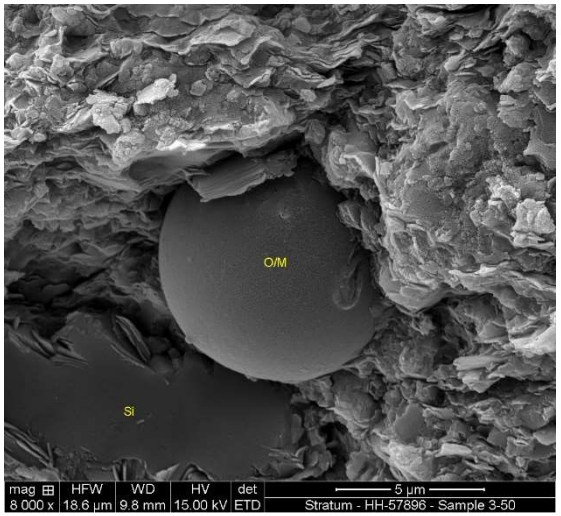
SEM Observations

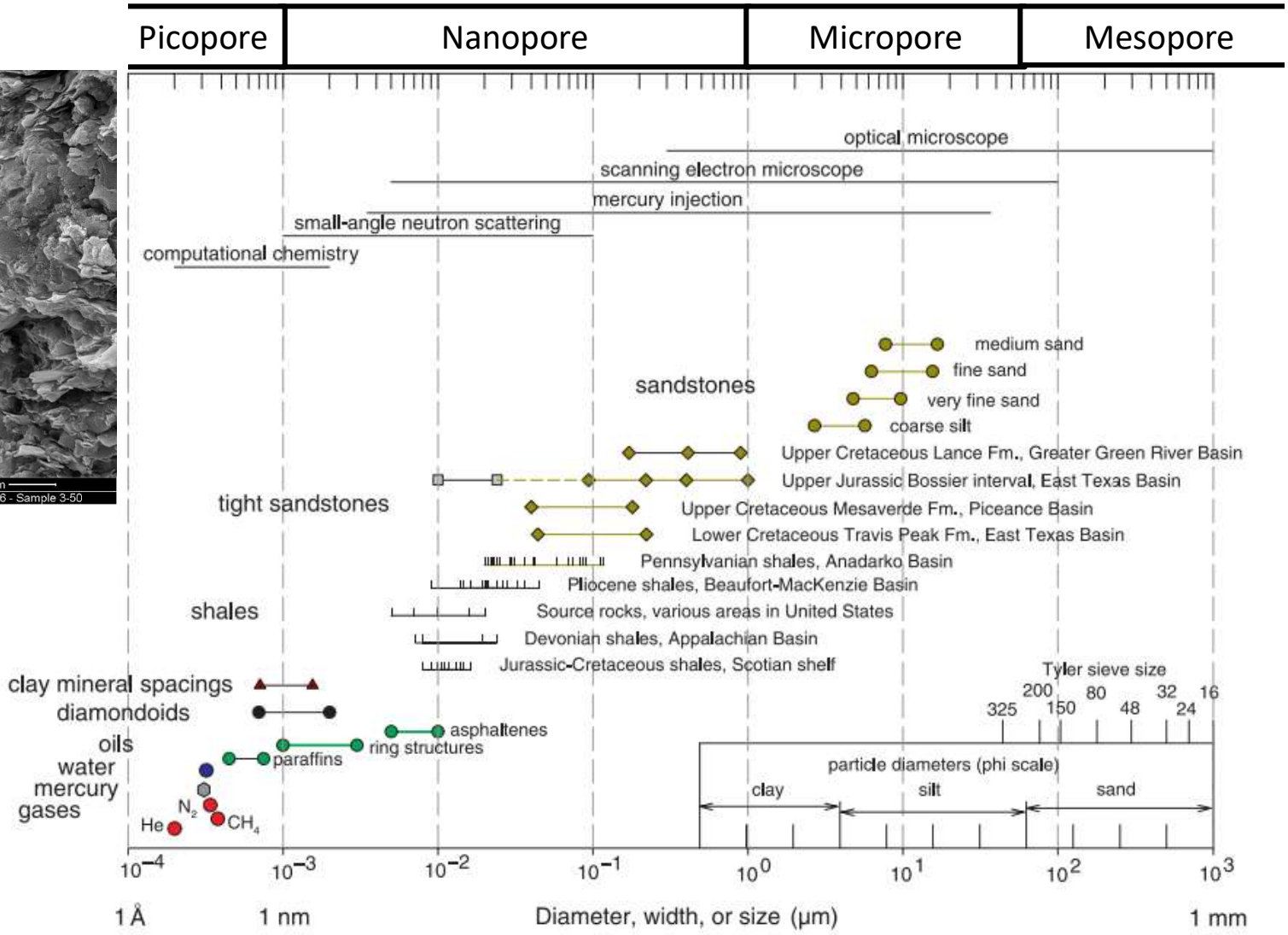






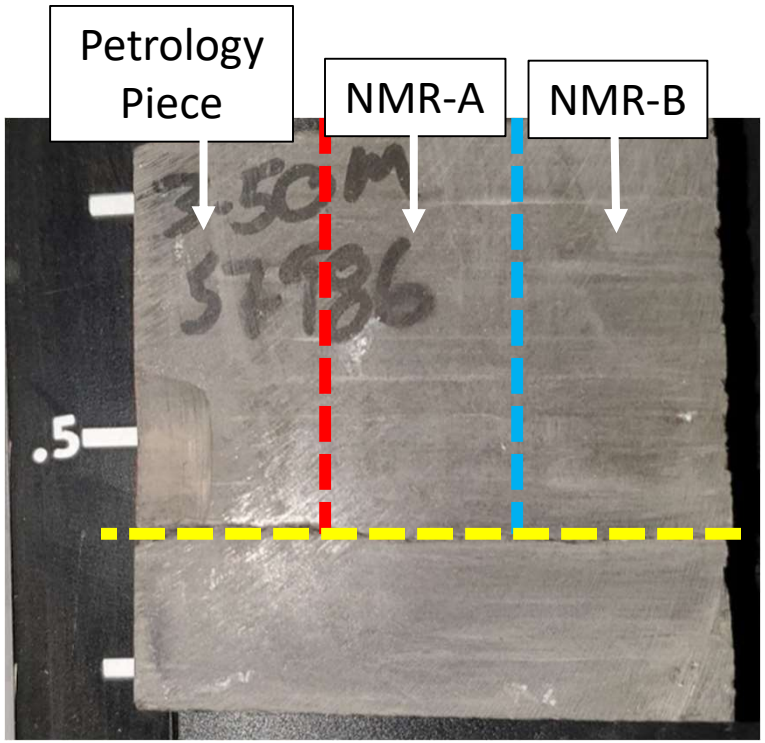
Micro-Quartz Pore Sizes

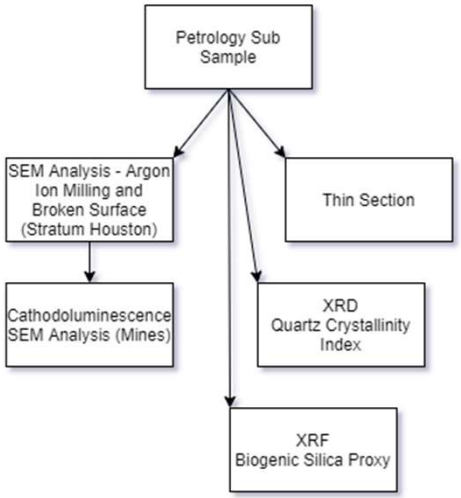


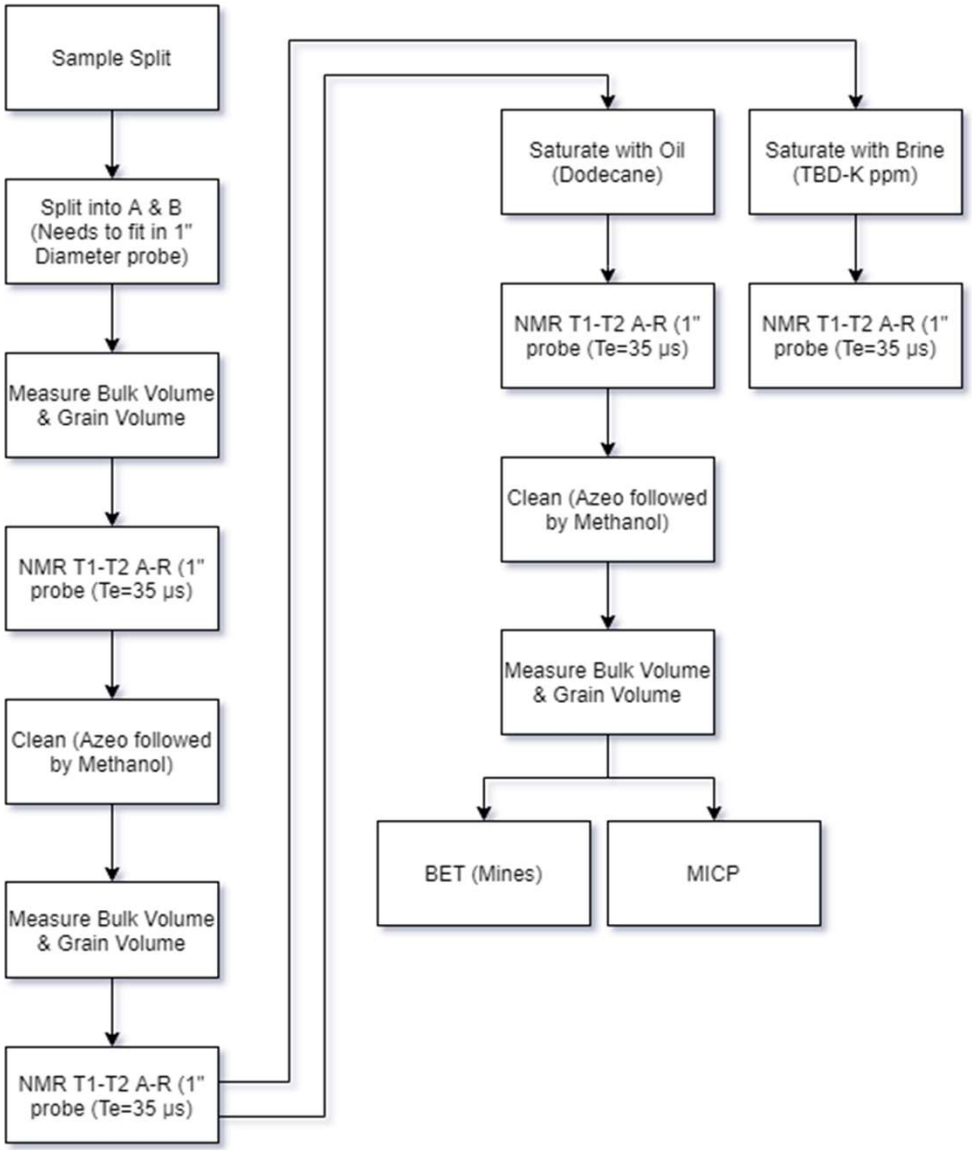


Modified from Loucks et al., 2012

Pore Characterization Laboratory Workflow







Next Steps in Research

- Continue the evaluation of the microcrystalline quartz
  - Analyze up-dip samples
  - Characterize types and distribution
  - Characterize the Pores
- Develop Diagenetic History Model

Thank You

- Steve Sonnenberg
- Marsha French
- Jeff May
- Kathy Emme
- Devon Energy
- Stratum Reservoir

MUDTOC Consortium Sponsors Fall 2020

Sponsoring Member Companies

Anschutz Exploration Corporation

Red Willow Production Company

Antero Resources

Crestone Peak Resources

TGS

EOG Resources

Chevron

White Eagle Exploration

2M

HighPoint Resources

Stratum Reservoir

Cimarex

devon

Enverus

GMT Exploration Company LLC

Whiting

Supporting Companies

GeoMark

IHS

Schlumberger

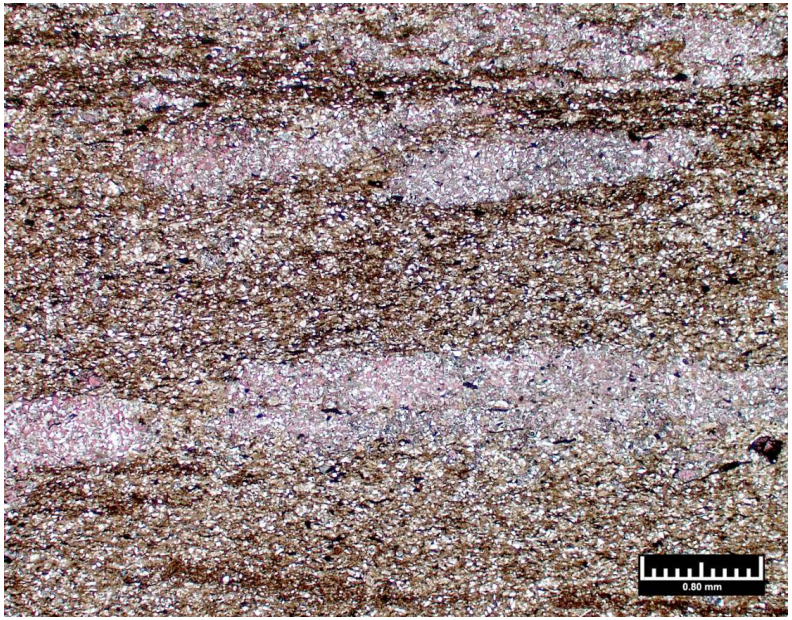
MJ Systems

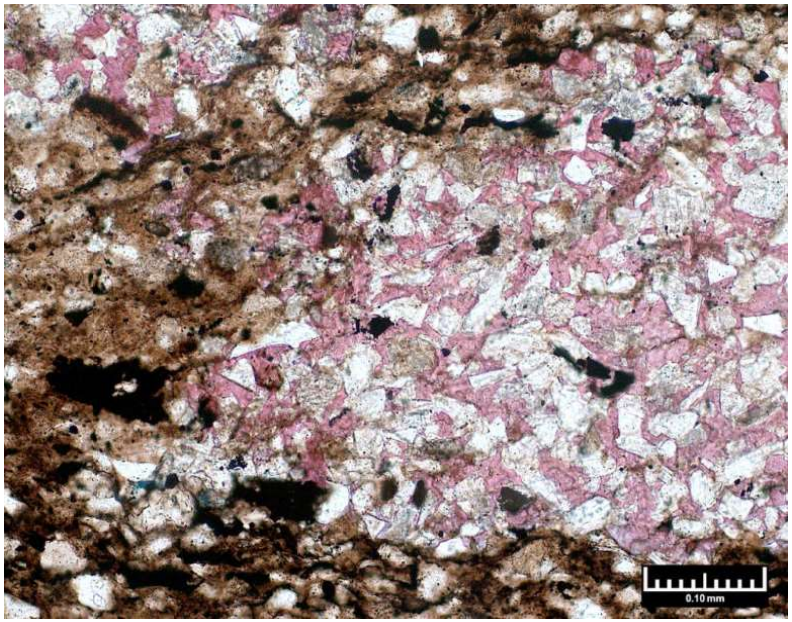
The Energy of enerPLUS

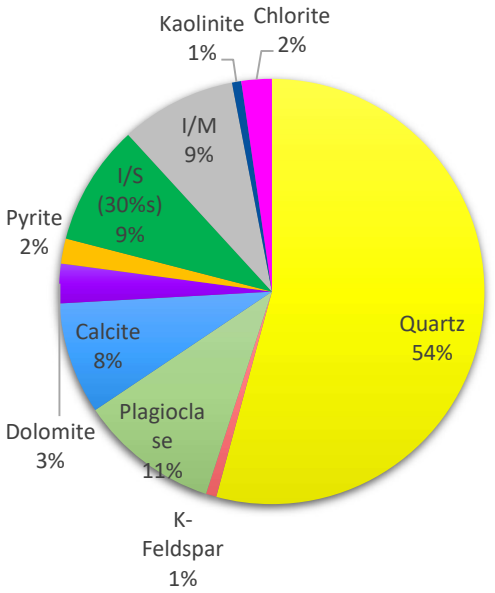
PlatteRiver Associates Inc.

Mike Johnson & Associates

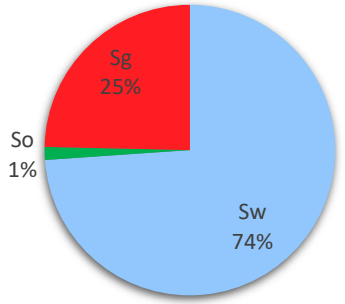
Facies 1: Calcareous Cemented Argillaceous Siltstone



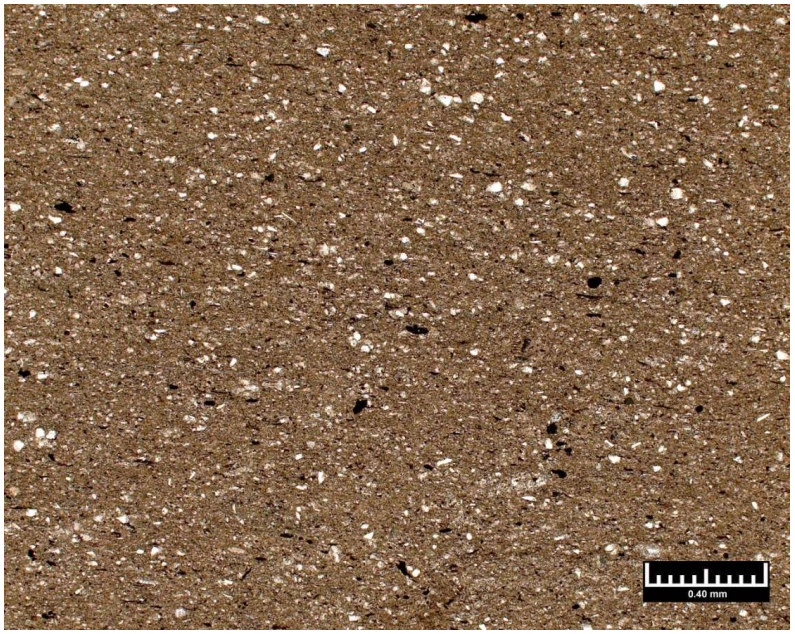


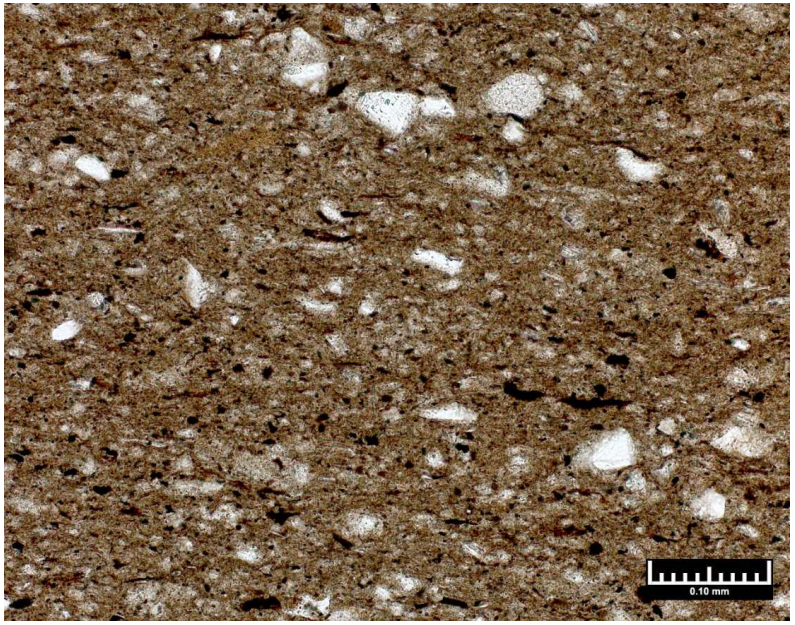


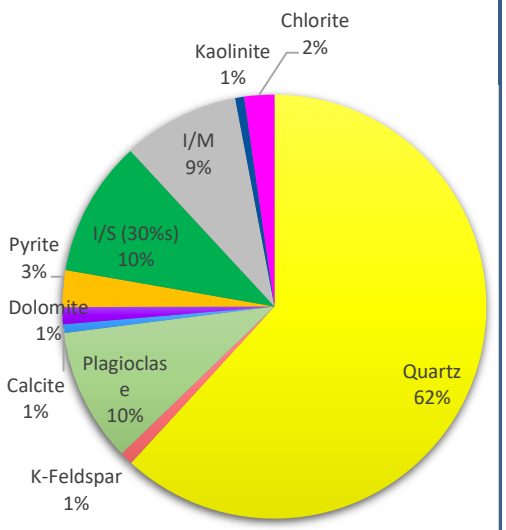
ϕ (%) = 4.983
K (md) = 0.000851
TOC (Wt.%) = 2.21
n = 1



Facies 2: Non-Laminated Silty Mudstone





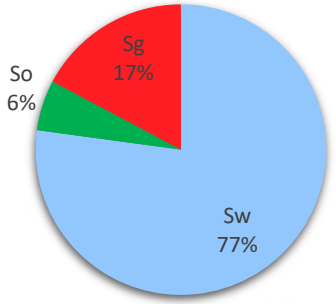


ϕ (%) = 6.881

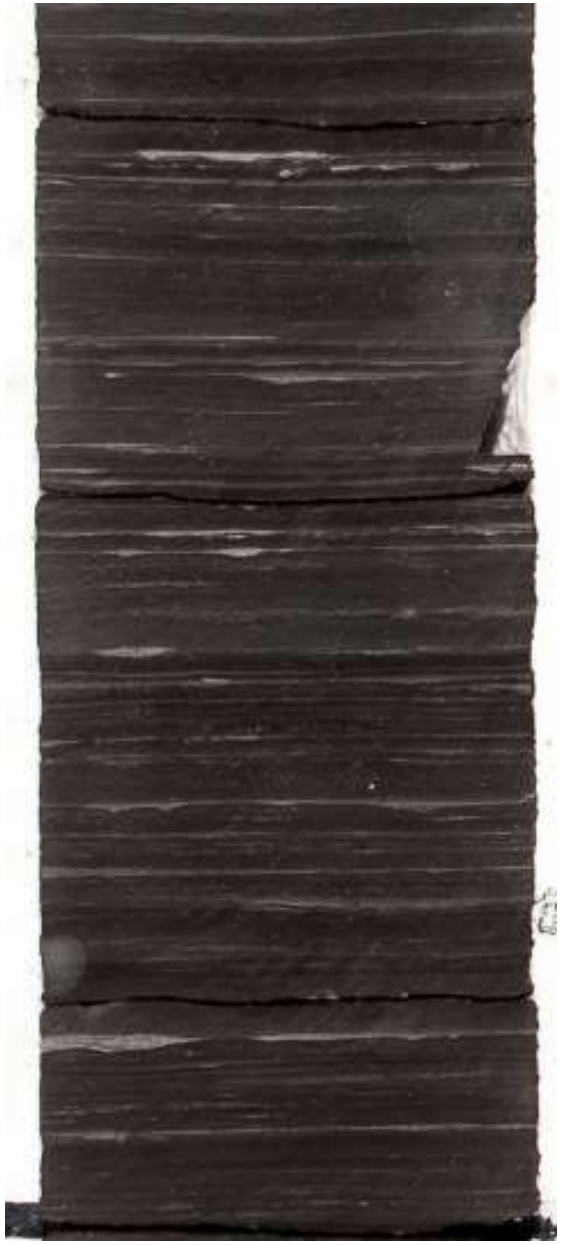
K (md) = 0.000907

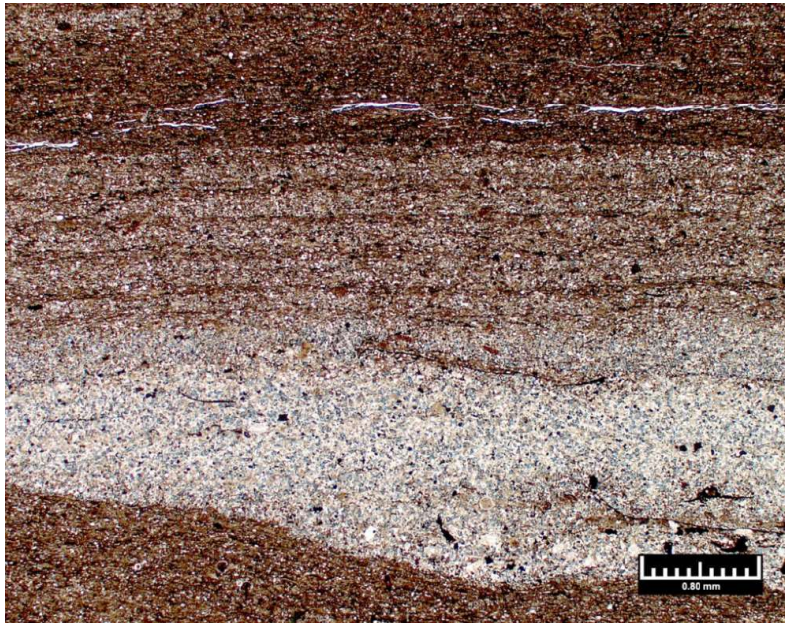
TOC (Wt.%) = 2.36

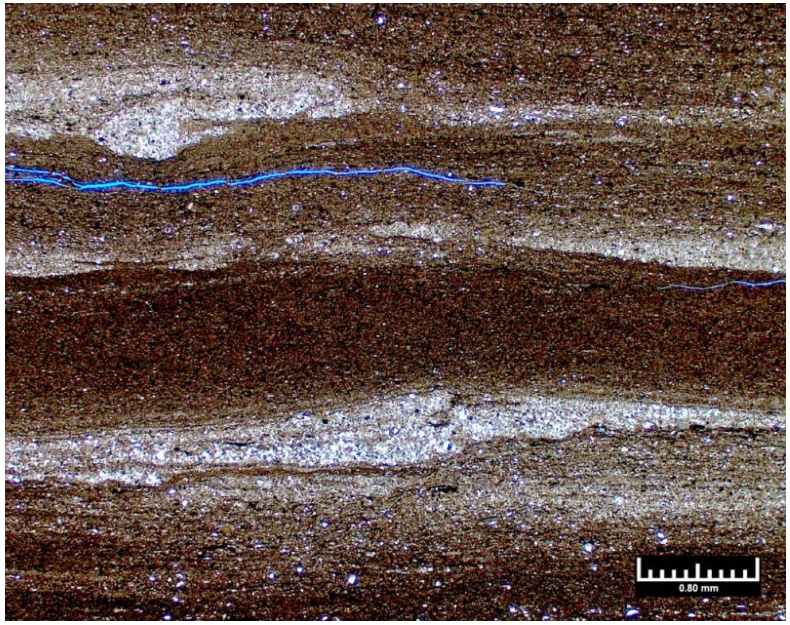
n = 7

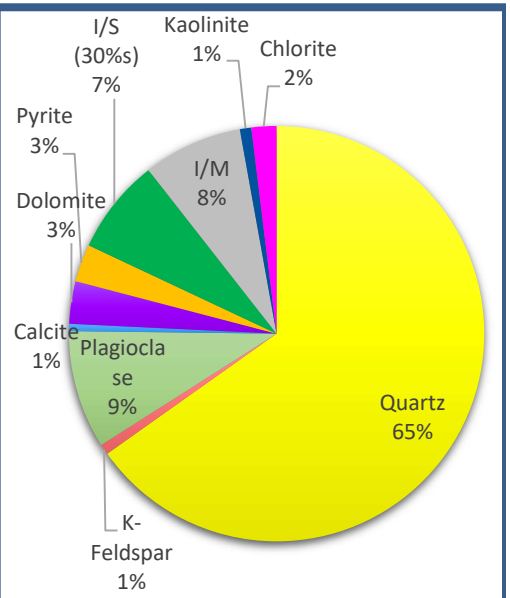


Facies 3: Graded Siliceous Silty Mudstone







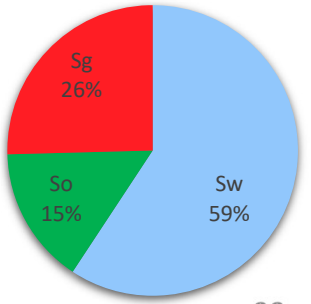


ϕ (%) = 6.668

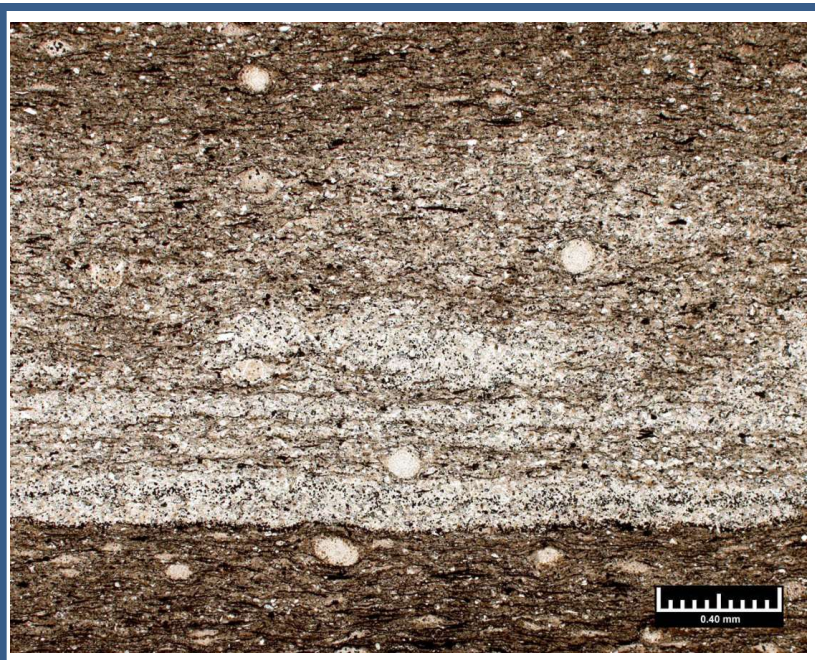
K (md) = 0.000738

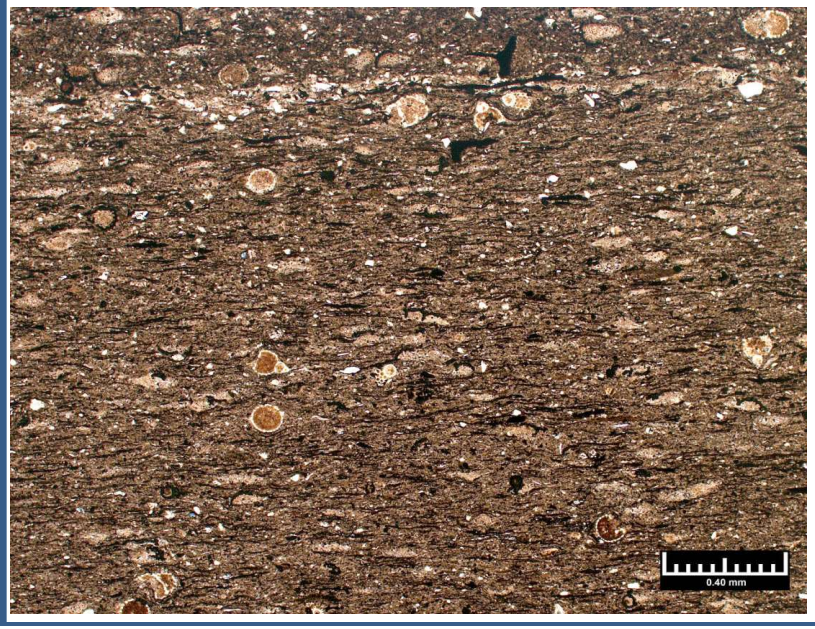
TOC (Wt.%) = 2.35

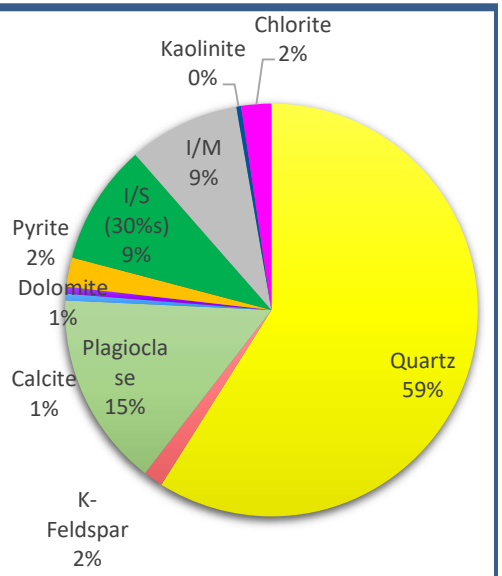
n = 6



Facies 4: Laminated Siliceous Silty Mudstone





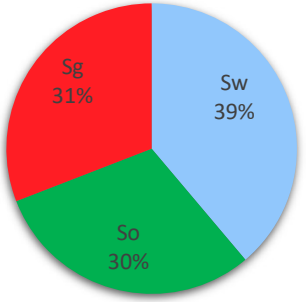


ϕ (%) = 6.458

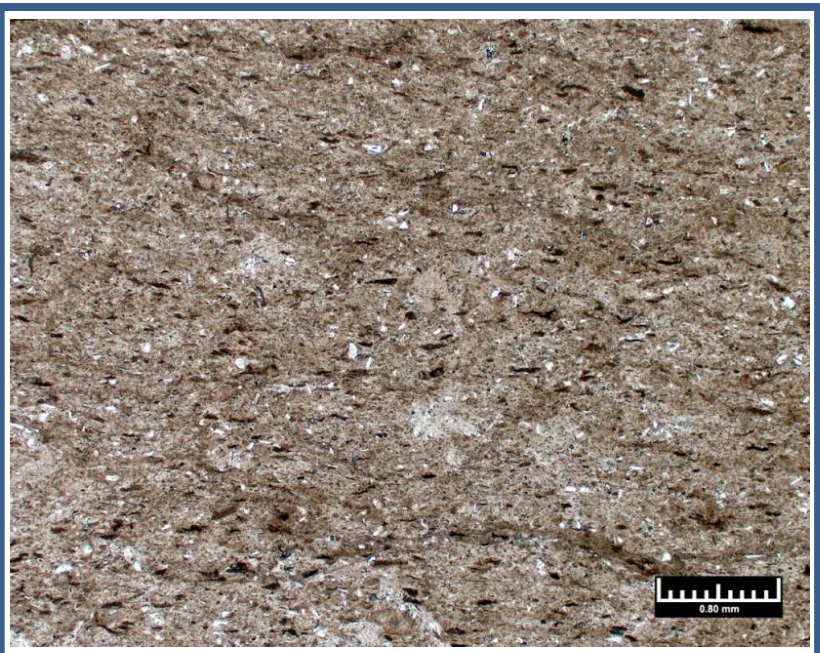
K (md) = 0.000538

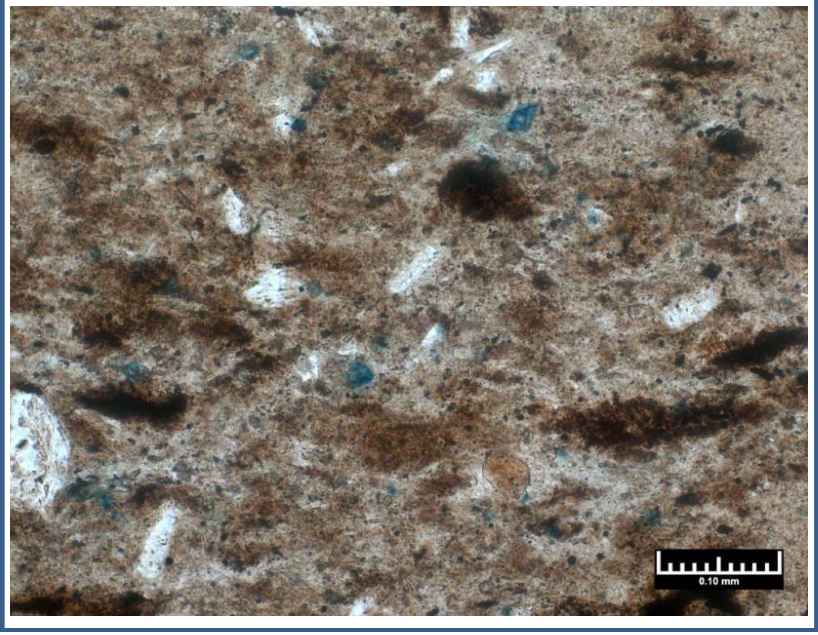
TOC (Wt.%) = 2.54

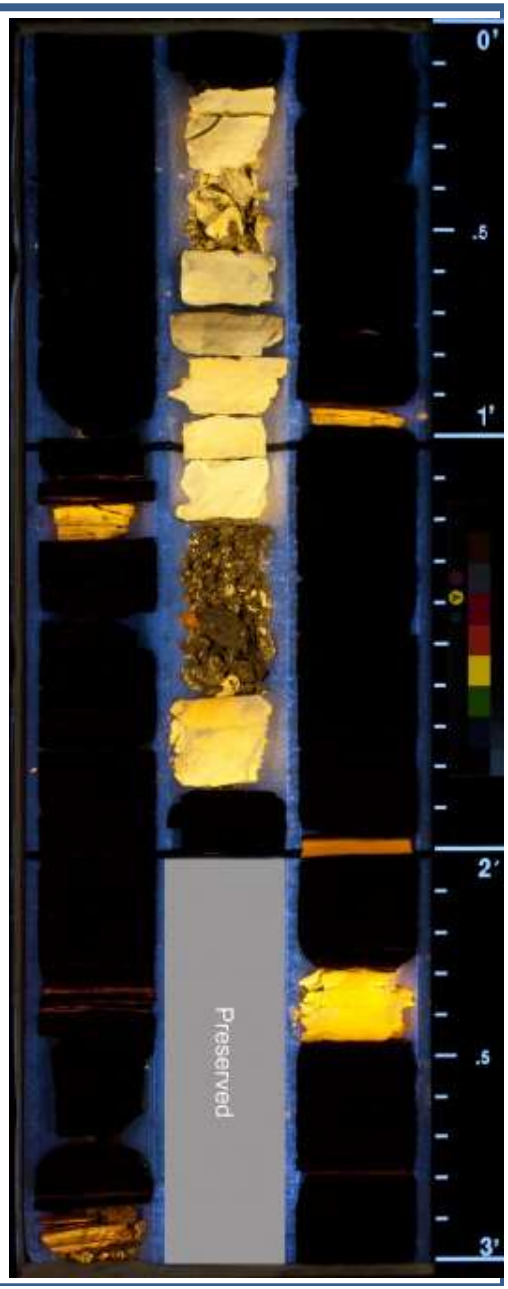
n = 2



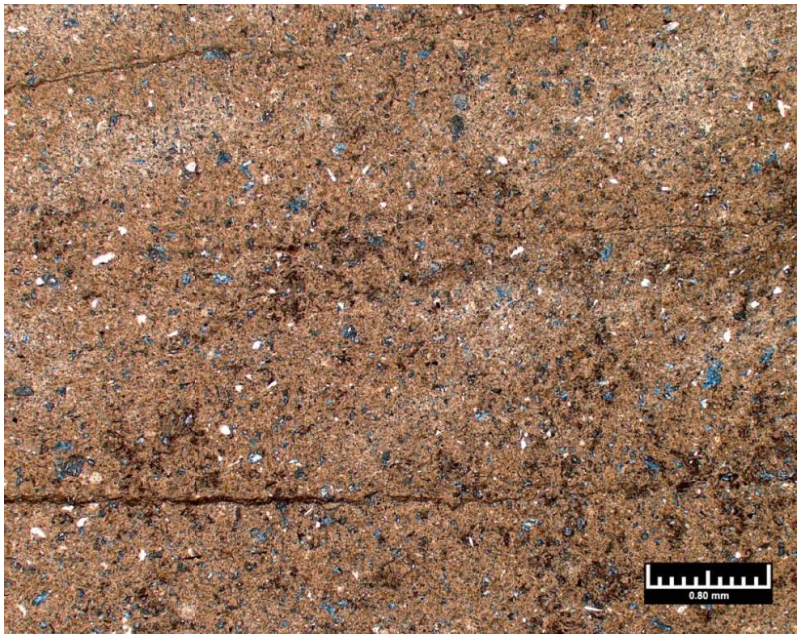
Facies 5: Altered Volcanic Ash

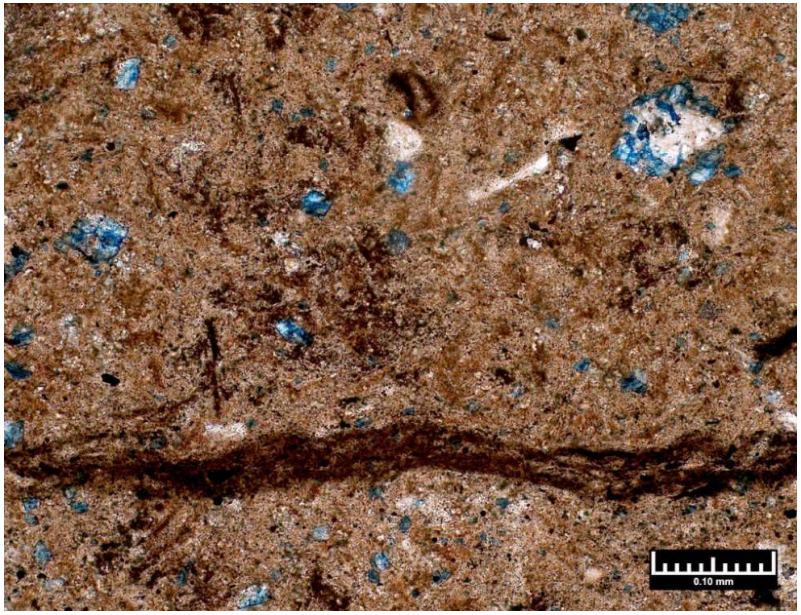


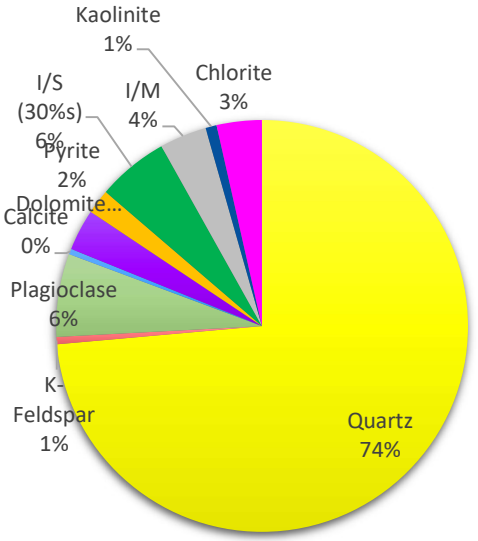




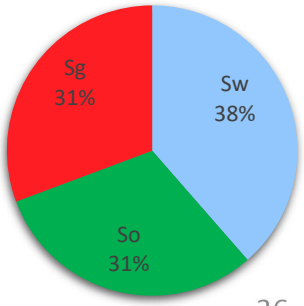
Facies 6: Siliceous Mudstone



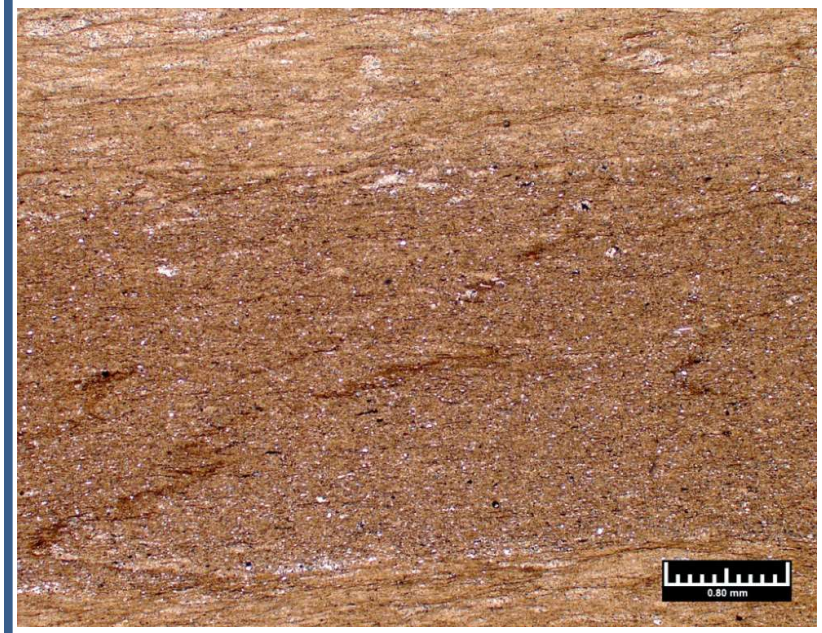


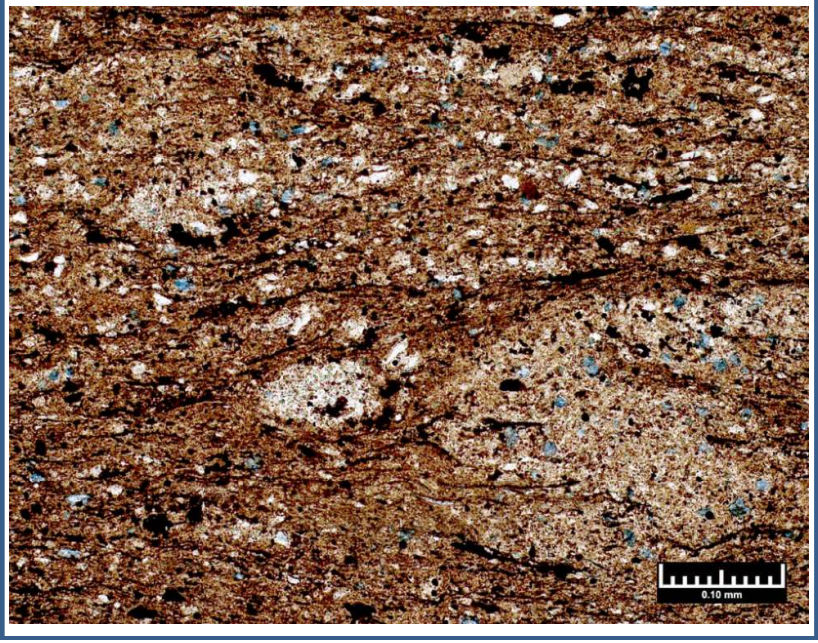


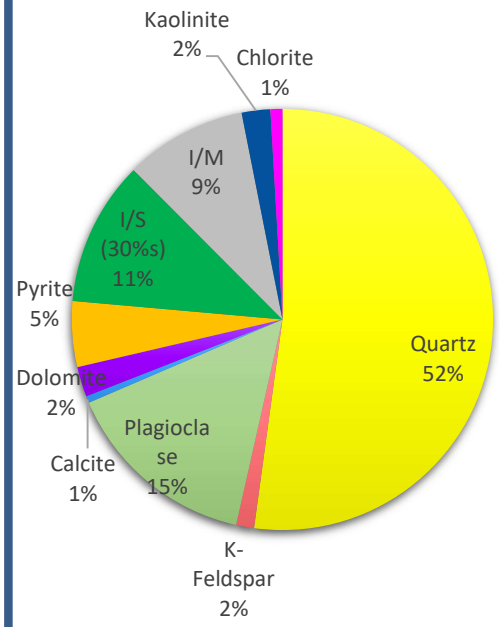
ϕ (%) = 5.863
K (md) = 0.000540
TOC (Wt.%) = 2.18833
n = 7



Facies 7: Bioturbated Siliceous Mudstone





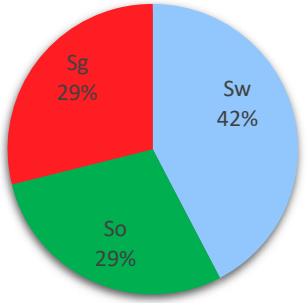


ϕ (%) = 7.279

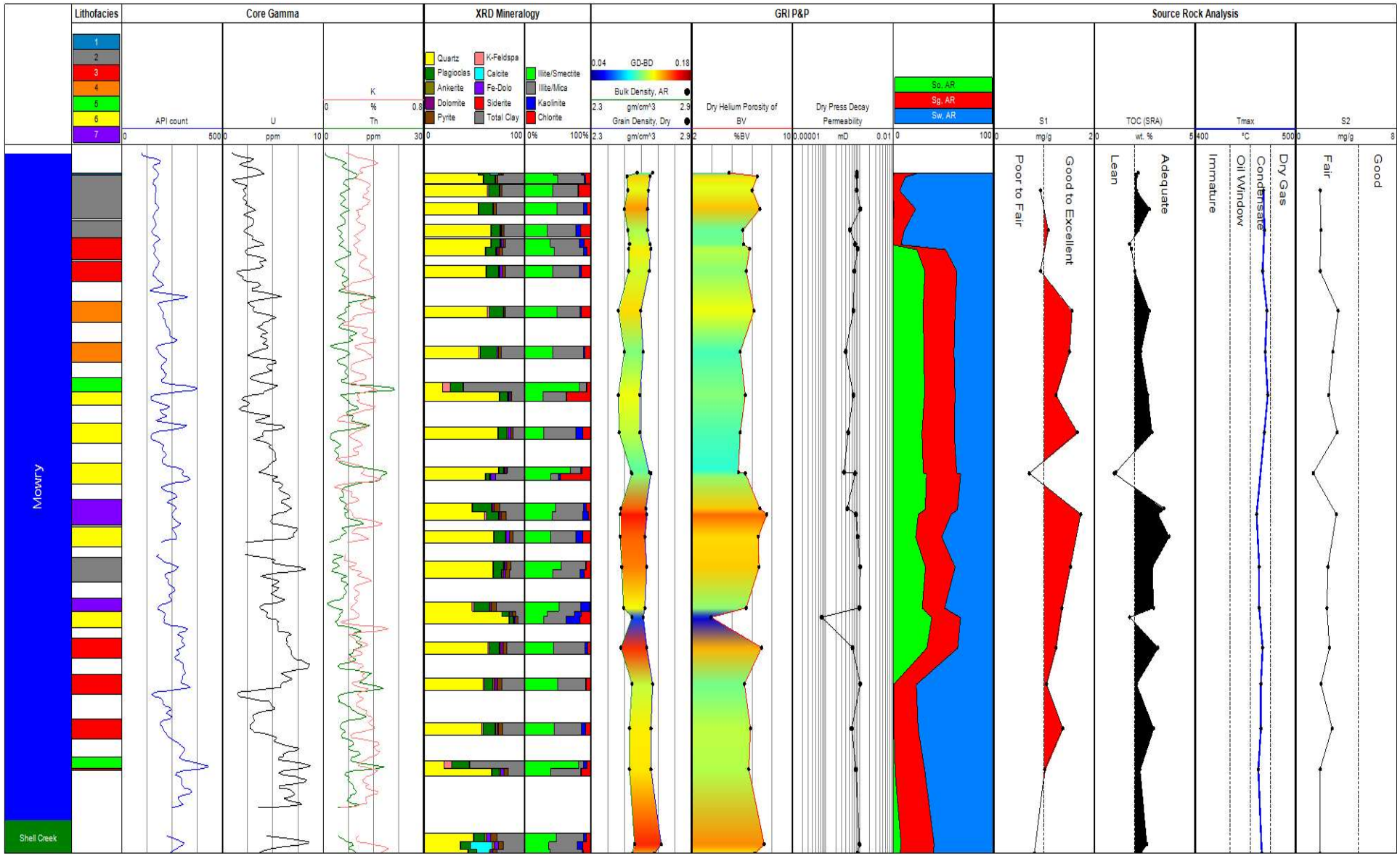
K (md) = 0.000758

TOC (Wt.%) = 3.2

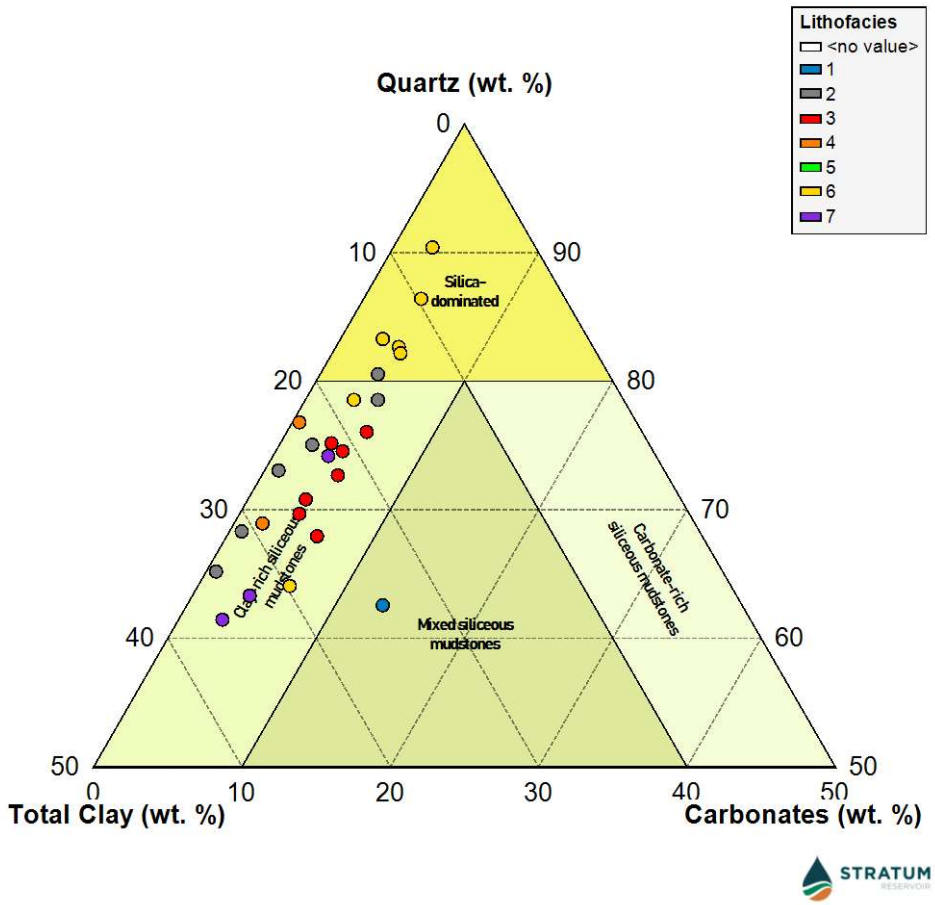
n = 3

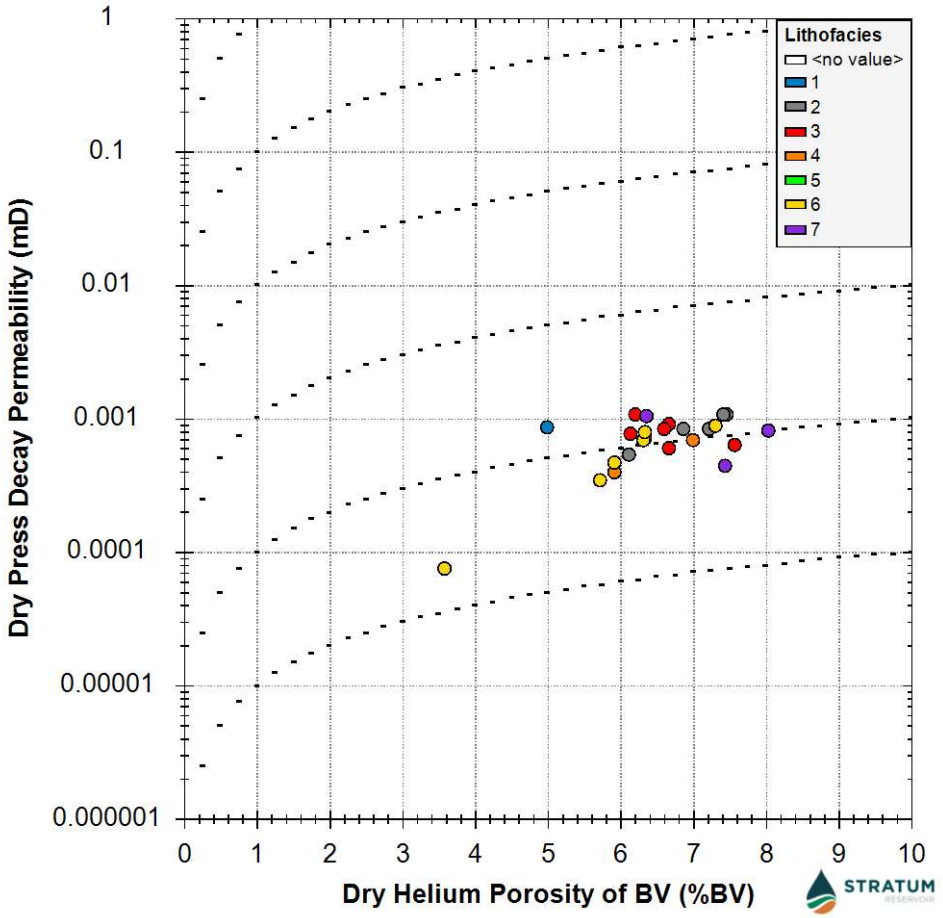


Micro-Facies Analysis



Micro-Facies Analysis





Micro-Facies Analysis