Silica Diagenesis and its Pore-Scale Influence on the Characteristics of the Upper and Lower Bakken Shales, Williston Basin, North Dakota and Montana

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- Project Introduction
- XRF Data
- Microscopy
- XRD Data
- NO2 Physisorption Data

• Conclusions and Recommendations for Future Analysis

The Williston Basin



- Intracratonic Basin above Precambrian Trans-Hudson Orogenic Belt
- Variable subsidence from Cambrian to Mesozoic
- Laramide Orogeny-reactivated basement structures





The Bakken Formation





Sandberg et al., 1988

Silica Diagenetic Sequence

Below is the basic sequence of silica transformation during diagenesis, but in reality it is very nuanced. We will look at some examples of each phase in some interesting SEM photos.





Fig. 1. Solubilities of the various silica phases along the two-phase curve, water plus vapor. Plotted as log concentration vs. reciprocal of absolute temperature, after FOUR-NIER (1973, Fig. 2).

Modified from Dralus, 2013

Silica Diagenetic Sequence



Robin et al., 2010.



Lynn et al., 2007





Lynn et al., 2007



Motivation for Study





X-ray elemental map of a dissolved radiolarian test (dashed line) being replaced by pyrite in the Mowry shale (*Milliken and Olsen*, 2017)



SEM Photomicrograph of authigenic microquartz (dashed lines), K-feldspar, calcite, and organic matter (*Xu*, 2019)

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Core Overview: Locations







Gunnison State



Clarion Mertes





Sonnenberg et al., 2011



Sonnenberg et al., 2011





Core Description: Gunnison State

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Gur	nnison State	e Mineral N Lower Bakk	Aodel Core	Description Part 1 of 4	Gunr	nison State Min دەر	eral Mo ver Bakken S	del Core Descri	Part 2 of 4	Gunn	ison State Min	ieral Mo wer Bakken 5	del Core Descr ^{hale}	ption Part 3 of 4	Gunr	ison State N Lower Bal	Mineral Mo kken Shale / Upp	del Core Desc er Bakken Shale	ription Part 4 of 4
Depth (0)	Si/Ca/ Normalia	e Can ed Phot	Mineral M (Qtz / Calcit % Normal	todel #/Bite Facios Epech	Depth (h)	Si / Ca / K Normalized	Core Photos	Minanal Model (Dtz / Calcite / Hite % Normalized)	Faces	Depth (H)	Si/Cs/K Normalized	Care Photos	Mineral Mesdal (Diz / Calcine / IliPia % Normakzed)	Facies	Depth (h)	Si/Ga/R Normalized	Core Photos	Mineral Model (Ditr / Calche / Bite % Normalized)	Facies
8213			42.5/10.4	/ 47.1	8208.8334	1000000000	Sec. 1	55.1/1.0/43.9		8204.5 -	South States	Print and	44.4/1.0/54.6		8143.1673	- Constanting	1000	60.8/1.2/38.0	
8213.1667	- detected		39.3/1.5/	59.2	8209	Theorem of		18.8/0.4/80.7	1 (A (A (A (A (A (A (A (A (A (8204.8334 -	Contraction (-	43.3/1.8/54.9		8143.2507	-	1-3	53.3/1.3/45.4	100 million (100 million)
8213.3334	-99999		34.0/0.6/	65.4	8209.1667			563/26/412		8205	1.1.1.1.1.1.1.1.1		435/17/54.8		8143.5007	4		49,8/12/49,0	
8213.5	-100000		49.5/0.9/	49.6	8209.3334	- Babbabb	1	66.1/2.2/31.7		and the second	Sector and	-						410/03/88/253	
8213.6667	- 00000	111	62.9/3.0/	34.1	8209.5		1	58.9/1.3/39.9		8205.1667 -	1000000		49.6 / 9.8 / 40.6		8143.6673		and the second	63.4/0.9/35,7	
8213.8334	- 20000		40.0/1.7/	58.3	8209.6667		•	57.8/3.0/39.3		8205.3334 -	0000000000		55.7/2/0/42.3		8143,8340	-		53.7/1.2/45.1	
8214	- 22222		31.5/0.9/	67.7	8209.8334	- CHARTER A	-	14.1/0.9/85.0		8205.5	ista de la com		39.3/57/55.0		8144,0007		1.50	505/16/479	
R714 1667	10000		358/11/	63.5	8210		1	7647437693		8205.6667 -	- tata tata tata tata		40.2 / 4.4 / 55.4						
8214,7334	100000		41.0/21/	56.9	6210	and the set of the		20/47 4:37 09/3		8205.8334 .	1000000000	Contra I	13.5/0.6/85.8		8144.1674	-		56.0/1.6/42.5	
8214,4167	-00000		265/27/	70.9	8210.1667			24.5 / 12.9 / 62.6		8206	interest in the		51.6/2.3/46.1		8144.3340	4	1000	69.2/14/29.5	•
8214.5	100000		41.0/1.2/	57.8	8210,3334			7.9/0.4/91.7	•	8206.1667 -	NEW CONTRACTOR		33.7/0.8/65.4		B144.5007	-	1000	49.4 / 1.3 / 49.4	-
8214,6667	100000		352/10/	63.8	8210.5		-	8.8/0.6/90.7		8206.3334	101111111111	4	42.6/5.0/52.4		8144,6674		10000	47.7/1.5/50.8	
8214.8334	199999	894 B	367/10/	62.3	8210.6667	- Charles	2.3	4,1/0,4/1087		8206.5	1000000000		55.071.9743.1				10.00		-
8215	100000		30.5/0.6/	68.9	8210.8334		100	3.5/86.3/10.2		8206.6667			53.5/1.5/45.0		8144.8539	-		52.970.7746.4	
8215.0834	- 00000		11,570.37	88.2	2222			201022102		8206.8334	101010-0010	4	56.6 / 8.3 / 35.1		8145.0007	-		46.7/15/51.8	•
8215.25	-9999		93/05/9	0.2	8211			28/874/98		8207 -	HEALTHAN	2/21	40.9/1.5/57.6		8145.1673			47.7/7.0/45.3	
10015 3334	1414141414		-	44	8211.1667			3.9/85.3/10.8		*****		1000	227.007.07.0		8145,2507	7		57,176.6736.3	
8215,3354	- Added a		-30.0.10.7.	57,1 100.3	8211.3334	-	1.00	3.8/83.6/12.6		8207.1067	Contraction of the		35.5/0/05/9		8145,4174			45.1/17.4/37.5	
8215.6667	1000000		296/12/	69.1	8211.5			41/822/136		8207.3334 -	144444444		43.6 / 1.1 / 55.3		8203	-	1.	26,7/21/71.2	
8215.8334	1000000		28.2/1.1/	70.7	(5554570.0)		A TANK	0.001202020032011		8207.5	NAME OF T	-	49.6/13/49.1		8203.1667	100000000		31.9/37/64.4	
8216	100000		29.8/1.2/	69.0	6/11/000/	10000		43/842/115		5207 0234	0.0.00000000000000000000000000000000000	1000	3737127010		8203.3334	1000000	in the second	\$2,4/0.9/66.7	
8216.35	0.000		191/09/	100	8212	- Sectores -	1000	22.0/06/774		6207.6334	1404044606		30.073.4730.0		#203.5	100000000		20.7/0.4/78.9	
6210.25	1000000						1 Case			5206	tation to the second	-	53.1/1.7/45.1		8203.6667		1	32.0/1.1/66.8	
8216.5	-100000		25.1/1.6/	73.3	8212.1667			22.1/0.9/76.9		8208.1667 -		p-	56.2/13/424		8203.8334	- 1993	1	37.1/0.9/61.9	
8216.5834	- 96666		4.0/0.2/9	95.8	8212.3334	- Statistics		0.6/0.5/99.0		8208.3334 •	1 de la de la de		29.8/0.7/69.5		8204	12222	1	32.1/4.1/63.7	
8216.8334	- 44444		27/02/1	07.1	8212.5	- 100000000		38.8 / 1.7 / 59.5		8208.5		ter 1	23.7 / 1.1 / 75.2			100000000			-
8217.0834	- 200		23.8/1.8/	74.4	8212.6667	-00000000	1	\$75/12/412		8208.6667	10000000	12 1	30.8/4.7/64.5		8204.1667	-1-1-1-1-1-1-1-	and the second second	51.0/1.4/47.6	-
8217.3334		12	147/213	/ 64.0	8212,8334	100000000	+	667/58/275	•		1000000				02043334			420/03/3/3	
		Leg	end														Legend	1	
	Calcium	- XAF Sca	n Point	Calcaneous mudrock Argillaceous mudrock												Calcium	 XRF Scan Pol 	int A	alcareous mudrock rgillaceous mudrock
	Potassium	GSLSHS	51	Sticious muchack										I		Potassium	GSUSH51		Briess machinek
	Silicon	GSLSLO	9	Highly silicious mudroch	ę											Silican	GSUSLOSI	H	lightly silicious mudrock

Core Description: Clarion Mertes

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Clario	n Mertes Mine	eral Mod	el Core Descr	iption Part for t	Clari	on Mertes Mi	neral Mod	del Core Descrip	otion Pert 2 of 5	Clari	on Mertes Mir	neral Mo	del Core Descrip	ntion Parts of S	Clari	ion Mertes Mine	eral Mod	lel Core Descrip	ition ^{Part4 of 5}	Clari	on Mertes Mi	neral Mo	del Core Descr	iption Parts of s
Day (B. FI)	S/G/K Remained	38	Mineral Rholei (Dit / Calche / Who Ni Romadueit)	factor.	Depth-10	S//Ce/M Normalized	Com Findes	Minural Model (Dz./Cakite/Bite 'N Normalized)	Лисия	Dept-M	Sr/Ga/H. Hermitiand	Care Hysics	Minural Model (Dis/Cabilite //Bite In Homailand)	factor	Overt-PE	Sal Gal R Remailed	38	Minueral Maskel 12ter / Galeke / Silke 76 Normalized	facie	Depth (N)	Si/Ca/4 Normalized	Core Photos	Minard Model Ebs / Gildre / Bite N Norvalient	Taciev
723.25	<u> 1941-1955</u>		357/12/632		7219.8254			40.3/0.6/59.1		7215.0067			21.0/54/718		7212.3334			252/02/748		1258,0167	-	13	21.8 / 0.2 / 78.1	
7228.8 -			268/11/744		7220.0834	-	TE	421/10/569		7215.9167			184/12/864			and the	4	20.00		7209.1667	-806865	- 14	11.070.1768.9	
7221.75 -		1	224/13/761		TIMESIA		九圓	107/87/154					186/12/892		7212,4167	7	100	11.9/2.0/82.1		7209.4167	-0.0000		56.570,1785.6	
7224 -			190/12/798		7220(3254					7210.0004		1	2001(E0011=1)		7212.6667	- 100 Beer	5	0.7/254/739		7309.6667	-		3.8/0.4/96.8	
		1			7220.5834	-	1	457/14/545		72164334			21.9708/772		7212,9167	- HARRING	100	43.1/0.7/568		7209.75	-		60/43/896	
7234.25 -			11.9707/874		7220.8554			47.2 / 6.8 / 45.8		7217.0634			164708/838							7105	11111		41/01/05.0	
7224.5 -			184/16/90.0			Reference.			_	0.50200200			245.292730.1		7213,1067		122	457/03/343					4.170.1735	
7224.75 -		50	22.7/13/75.6		7221.0834			163/10/926		7217.3394			29.4/08/698		- ALTERIN	100000	10.	3431507800		7210.25			160/394/448	
		深			7221,8894	-		13.4/22.4/44.2		7217.5834	-300000	- 2	382/07/612		7213.6667	-		24.5716.7758.8		7210.3334	-		34/01/965	•
2225 -	1010010	1	49/12/019		7221.8			565/169/268		7217.8334	-		31.6/0.8/67.6		7213.9167		6	123/01/826		7210.5834	-	1	133/04/861	
7225.25 -			21.6/3.9/743		7221.25			758/80/162		7218.0654	-	PC.	34.6/1.1/643		7214.1667	- 2001335	1	38/01/941		71054314			14/04/002	
1001			141/562803		7223	-866666		761/78/168		7210.3334	- 2000000		992/08/668	-	7214.4167	800007		204/274/522						
7216.76	20200		152/05/043		7222.25			555/10/435		7218.5834		14	53.6/0.5/45.8		7214.6667	-	2.	18.0/02/81.8		7211.0614	-		13.2/1.1/852	
122019		5								0.00000000		-			2254.25	0.000		624/264/11.0		10000000			12000000	
7236 -	202203		178/62/768		7222.5			20.9/4.6/665		7219.0834	-200.000	12	378/12/618				156	and sample and		7211.3134	- <mark>Massak</mark>		16.2/0.2/83.6	
7226.0634	100000	PU	03/06/838		7222,75			32.7/13/763		12:212:21					7214,9167	- 2000000		95/09/896		7211.5814	-		205/0.9/78.6	
100000		R			7223	. <mark>Alternationale and a second a second</mark>		160/11/832		1206.000			3/3/1//6(3		7215.1667	-0000000		23.5/6.1/70.4		7211.8234			160/11/830	
7226.5834		2	563/159/298			000000				7219.5834			38.7 / 0.6 / 60.7		7215-4167	-860000		227/14/258		7212.0834			18.4/0.7/80.9	l.
	Talicium 🗕	Legeno XRF Scan Po CMLSH51		alcarenus mudrock rgillaceous mudrock																				

CALSIOS

Highly stilicious mudrock

Core Description: Koch

Roch Mil	Upper Bakke	Core Description	Part 1 of 2	K	och Mineral ۸ _{ال}	Aodel Co aper Bakken S	re Description	Part
Si / C Norm	a/K Core alized Photos	Mineral Model (Qtz / Calcile / Illine % Normalized)	Facies	Depth (ft)	SL/Ca/K NormaKoud	Core Photos	Mineral Model (Qtz / Calcite / Ilite % Normalized)	Facies
100000				7029.75 -		-	1.3/84.9/13.7	
-		56.1/25.8/18.1		7030 -			30.8/10.1/59.0	
- 1993	N.	39.1 / 3.0 / 57.9		7030.25			30.2/110/588	
- 3888		70.4/0.8/28.7						
-		42.7/1.9/55.5		7030.50 -			25.0/2.1/72.9	
-83		39.7/1.7/58.6		7030.75 -			24.1/2.4/73.5	
_	Υ.	45.6/28/51.6		7031 -		-	24,4/2.2/73.5	
-	1	68.7/0.7/30.5		7031.1667 -			25.4/6.1/68.5	
· -		58.0 / 1.0 / 41.0		1021 4167			258/16/726	
		64.6/0.4/35.0		7031,4107			256/14/726	
	1	66.0 / 0.5 / 33.5		7031.6667 -			26.1/2.0/71.9	
833	la l	57.7/2.3/40.0		7031.9167 -			30.7/8.0/61.3	
		WALLAL MA	~					
		73/47 1/57 23/0	•	7032.25 -			70.0/1.2/28.8	
		54.2/5.8/40.0		7032.5			56.9/4.1/39.0	
	-	55.6/3.6/40.8		7032.75 -			64.9/2.4/32.7	
	.	5	-	7033 -			24.6 / 0.7 / 74.7	
	H	43.2/3.2/53.6						
		434/14/552		7033.25			29.2/1.5/69.3	
	i	45/47 1/47 55.5		7033.5			57.9/1.5/40.6	
8 1 - 1993		48.2 / 14.1 / 37.8		7033.75	entre series de la companya de la co	and the second second	33.1/1.6/65.3	

Highly silicious mudrock

Core Description: Harvey Grey

Harv	rey Grey Mino ເ	eral Mode ower Bakken 5	el Core Descripti	on Part 1 of 2	Ha	arvey Grey Miner	ral Mode wer Bakken S	el Core Descript ^{Shale}	ion
Depth (%)	SI/Ca/K Normalized	Core Photos	Mineral Model IOrz / Cakite / Illite % Normalized)	Facies	Depth (ft)	Si/Ca/K Normalized	Core Photos	Mineral Model (Qtz / Calcite / Elite % Normalized)	Facies
9054 -			33.7/0.8/65.5		9050	-		35.6/41.0/23.5	
					9050.25			46.9 / 7.1 / 46,0	
054.0834 -			44.9 / 7.7 / 47.4		9050 5			34.7/1.7/63.6	
054.3334 -			41.5/6.4/52.1						
054.5834 -			33.8 / 6.5 / 59.7		9050,75			30.5/1.4/68.1	
054.8334 -			373/52/575						
					9051			32.2/1.2/66.6	
055.0834 -			33.1/3.8/63.0		9051.25			25.9/0.9/73.2	
055.3334 _			21.2/13/77.5		9051.5			328/41/631	
			12 8 2 8 4 2 9 8 8 9 7 9 4 4 1					2007 507 500	
055.5834 -			24.2/0.7/75.1		9051.75			39.3 / 4.8 / 55.9	
055,8334 -			28.0/81/63.9		9052	-		38.3 / 1.4 / 60.3	
	direction of				9052.25	- 838833893		44.5/1.5/54.1	
056.0834 -			23.0/7.2/69.7		9052.5			51.0/1.0/48.0	
056.3334 -			27.3/7.2/65.6		00.0000400				
			Logie a persona de la competencia de la		9052.75			40.2 / 1.7 / 58.2	
056.5834 -			21.3/5.7/73.0		9053	-		44.4/1.2/54.4	
056.8334 -			8.7 / 0.7 / 90.5	•	9053.25			47.1/07/52.2	
057.0834 -			22.0/7.9/70.1		0053.6		-		
057.25 -			46.5 / 42.7 / 10.8		3033.3			40.5712758.5	
9057.5 -			8.6/47.4/44.0		9053.75		1	28.0/1.6/70.4	
	C. C	Legend	1	1		1000000000000000			
	2407 11		Calca	neous mudrock					
1000000	aicium		Argill	aceous mudrock					
Participant P	massium	ucinan	Silici	ous muchock					
5	mcon .	HULSLUSI	High	y silicious mudrock					











Si Concentration Jointplots with KDEs





- Core=Clarion_Mertes
- Core=Koch
- Core=Harvey_Grey

Using Python on XRF Data: Statistics

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	10 th Percentile (Si wt%)	50 th Percentile (Si wt%)	90 th Percentile (Si wt%)
Gunnison State	12.23	24.96	32.20
Clarion Mertes	12.13	17.14	24.49
Harvey Grey	17.52	21.5	24
Koch	20.92	29.82	39.77
Lower Shale	12.25	20.42	28.17
Upper Shale	21	29.12	36.81
Argillaceous Mudrock Facies	10.64	17.72	24.44
Siliceous Mudrock Facies	16.44	22.95	28.32
Highly Siliceous Mudrock Facies	22.89	32.52	40.58

Sampling Methodology

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Sample Names	Sampled Core	Sample Depth (ft)	Relative Silica Concentration
CMLSHISI	Clarion Mertes	7221.75	High
CMLSLOSI	Clarion Mertes	7210.33	Low
HGLSHISI	Harvey Grey	9052.50	High
HGLSLOSI	Harvey Grey	9056.83	Low
GSLSHISI	Gunnison State	8212.83	High
GSLSLOSI	Gunnison State	8210.33	Low
GSUSHISI	Gunnison State	8144.33	High
GSUSLOSI	Gunnison State	8145.00	Low
KOUSHISI	Koch	7036.58	High
KOUSLOSI	Koch	7030.75	Low



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FESEM Analysis: High-Silica







FESEM images from CMLSHISI



FESEM images of KOUSHISI

FESEM Analysis: Low-Silica









FESEM images from GSLSLOSI



FESEM images from GSUSLOSI

Thin Section Analysis: Lower Shale



Thin section photomicrographs from the Clarion Mertes core with images from high-silica samples on top and low-silica samples on the bottom Thin section photomicrographs from the Harvey Grey core with images from high-silica samples on top and low-silica samples on the bottom

Thin Section Analysis: Upper Shale



Thin section photomicrographs from the Koch core with images from high-silica samples on top and low-silica samples on the bottom

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XRD Data

Sample	Sample	Sample	TECTOSILICATES			CARBONATES			PHYLLOSILICATES
Name	Core	Depth (ft)	Quartz	K-spar	Plag.	Calcite	Dolomite	Siderite	Total Clay
CMLSHISI	Clarion Mertes	7221.75	49.1	4.1	1.0	25.2	1.6	0.0	13.8
CMLSLOSI	Clarion Mertes	7210.33	32.6	7.9	3.9	Tr	Tr	0.0	54.2
HGLSHISI	Harvey Grey	9052.50	46.9	5.2	2.1	Tr	4.6	0.0	29.6
HGLSLOSI	Harvey Grey	9056.83	22.6	7.6	2.1	Tr	2.2	0.0	49.2
GSLSHISI	Gunnison State	8212.83	60.7	4.5	2.0	3.6	2.5	0.0	20.5
GSLSLOSI	Gunnison State	8210.33	24.5	5.6	3.2	0.0	1.8	0.0	57.0
GSUSHISI	Gunnison State	8144.33	62.7	4.2	1.8	Tr	1.1	0.0	21.4
GSUSLOSI	Gunnison State	8145.00	44.2	5.6	2.2	Tr	3.2	0.0	30.4
KOUSHISI	Koch	7036.58	41.7	5.4	2.2	0.6	2.3	0.0	28.8
KOUSLOSI	Koch	7030.75	21.7	6.4	2.0	Tr	3.4	0.0	54.7

XRD Data: Proportions





XRD Data Compared with Mineral Model

Sample	Sample	Sample	ľ	lormalized Measurem	d XRD Tents	Min Cal	eral Mode Iculations]
Name	Core	Depth (ft)	<mark>Quartz</mark>	Calcite	Total Clay	<mark>Quartz</mark>	Calcite	Illite
CMLSHISI	Clarion Mertes	7221.75	<mark>55.7</mark>	<mark>28.6</mark>	<mark>15.7</mark>	<mark>75.8</mark>	<mark>8.0</mark>	<mark>16.2</mark>
CMLSLOSI	Clarion Mertes	7210.33	<mark>37.5</mark>	<mark>0.1</mark>	<mark>62.4</mark>	<mark>3.4</mark>	<mark>0.1</mark>	<mark>96.5</mark>
HGLSHISI	Harvey Grey	9052.50	<mark>61.2</mark>	<mark>0.1</mark>	<mark>38.6</mark>	<mark>51.0</mark>	<mark>1.0</mark>	<mark>48.0</mark>
HGLSLOSI	Harvey Grey	9056.83	<mark>31.4</mark>	<mark>0.1</mark>	<mark>68.4</mark>	<mark>8.7</mark>	<mark>0.7</mark>	<mark>90.5</mark>
GSLSHISI	Gunnison State	8212.83	<mark>71.6</mark>	<mark>4.2</mark>	<mark>24.2</mark>	<mark>66.7</mark>	<mark>5.8</mark>	<mark>27.5</mark>
GSLSLOSI	Gunnison State	8210.33	<mark>30.1</mark>	<mark>0.0</mark>	<mark>69.9</mark>	<mark>7.9</mark>	<mark>0.4</mark>	<mark>91.7</mark>
GSUSHISI	Gunnison State	8144.33	<mark>74.5</mark>	<mark>0.1</mark>	<mark>25.4</mark>	<mark>69.2</mark>	<mark>1.4</mark>	<mark>29.5</mark>
GSUSLOSI	Gunnison State	8145.00	<mark>59.2</mark>	<mark>0.1</mark>	<mark>40.7</mark>	<mark>46.7</mark>	<mark>1.5</mark>	<mark>51.8</mark>
KOUSHISI	Koch	7036.58	<mark>58.6</mark>	<mark>0.8</mark>	<mark>40.5</mark>	<mark>75.4</mark>	<mark>1.6</mark>	<mark>23.0</mark>
KOUSLOSI	Koch	7030.75	<mark>28.4</mark>	0.1	71.5	<mark>24.1</mark>	<mark>2.4</mark>	73.5

Quartz Crystallinity Index Calculations

Sample	Sample	Sample	TECTOSILICATES		
Name Core		Depth (ft)	Quartz wt%	Crystallinity Index	
CMLSHISI	Clarion Mertes	7221.75	49.1	5.4	
CMLSLOSI	Clarion Mertes	7210.33	32.6	7.3	
HGLSHISI	Harvey Grey	9052.50	46.9	2.8	
HGLSLOSI	Harvey Grey	9056.83	22.6	7.9	
GSLSHISI	Gunnison State	8212.83	60.7	2.9	
GSLSLOSI	Gunnison State	8210.33	24.5	5.0	
GSUSHISI	Gunnison State	8144.33	62.7	2.9	
GSUSLOSI	Gunnison State	8145.00	44.2	4.8	
KOUSHISI	Koch	7036.58	41.7	3.4	
KOUSLOSI	Koch	7030.75	21.7	5.8	

Outline

 $\mathbf{\Delta}$

- Project Introduction
- Core Samples and XRF Data
- Microscopy
- XRD and Quartz Crystallinity Index Data
- NO2 Physisorption Data

• Conclusions and Recommendations for Future Analysis

NO2 Physisorption Data



Process	Measurement	GSUSHISI	GSUSLOSI	GSLSHISI	GSLSLOSI
	Pore Surface	0.79202	0.56455	1.437	1.0434
Adcorption	Area	m²/g	m²/g	m²/g	m²/g
Ausorption	Pore Volume	0.0013921	0.0010698	0.008065	0.00288
		cc/g	cc/g	2 cc/g	cc/g
	Pore Surface	0.67321	0.46953	3.3606	1.2238
Decorption	Area	m²/g	m²/g	m²/g	m²/g
Description	Pore Volume	0.0011354	0.0009020	0.008447	0.002682
		cc/g	7 cc/g	8 cc/g	8 cc/g

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Important Conclusions



• The most silica-rich intervals of the upper and lower shales contain biogenic silica

- The biogenic silica comes from radiolarians and has been partially replaced by pyrite in roughly half of the tests. Calcite in ptygmatic fractures was also replaced by pyrite, which means that these fractures occurred and were filled before diagenesis.
- The radiolarians in these intervals are in the form of microcrystalline quartz that can be tracked by QCI calculations made with XRD data.
- Dissolution and reprecipitation of silica could be creating or preserving pore spaces within the most silica-rich parts of the shales, but more data is needed to draw this conclusion with confidence

Recommendation for Future Analysis

- Determine the resolution of location-dependent trends in detrital versus biogenic silica deposition, particularly between the shale margins and depocenters. This could be done with QCI measurements from quartz-heavy XRD data as well
- Attempt to correlate shale intervals that contain abundant biogenic silica with core samples taken from across the Williston Basin.
- Perform FESEM microscopy on the thin section samples created for this project to identify any other replacement minerals besides pyrite, as well as compare accessory minerals with those found in rough sample FESEM analysis.
- Perform physisorption analysis on as many highly siliceous shale intervals as possible from the other core samples used in this project and throughout the Williston Basin. A greater sample size is needed to determine the existence of the preliminary pore volume and surface area trends observed in the data gathered in this project.

MUDTOC Consortium Sponsors Spring 2021



