PS Lithofacies, Diagenesis, and Reservoir Quality Evaluation of Wolfcamp Unconventional Succession in the Midland Basin, West Texas*

Hualing Zhang[1], Xavier Janson[1], Li Liu[1], and Ziyuan Wang[1]

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[1]Bureau of Economic Geology, Jackson School of Geoscience, The University of Texas at Austin, Austin, Texas, United States (hualing-zhang@utexas.edu)

Abstract

The Lower Permian Wolfcamp deep-water basinal succession in the Midland Basin has recently become an important target for unconventional reservoirs. However, uncertainty remains for reservoir characterization of the Wolfcamp due to the complexity of lithofacies in this region. This study combines petrophysical observations from cores, thin sections, and scanning electron microscope cubes with chemostratigraphic data from X-ray fluorescence (XRF) and total organic matter content (TOC). Lithofacies investigation were made using 4 drilling cores from Counties Glasscock (180 ft), Sterling (110 ft), and Irion (80 ft and 60ft), Texas. Based on core analysis, microscopic observations and XRF data, four lithofacies were defined in the Glasscock core representing the Wolfcamp upper calcareous interval: (1) fusulinid bioclast packstone, (2) calcareous mudstone, (3) brecciated mudstone, and (4) laminated skeletal mudstone. While the Wolfcamp lower siliciclastic interval is reflected by 5 lithofacies identified in Sterling and Irion cores as (5) clean litharenite, (8) calcite cemented litharenite, (7) clay-coated litharenite, (8) siltstone, and (9) siliceous mudstone. The Wolfcamp succession reveals a complex diagenetic history, ranging from compaction, recrystallization, replacement, cementation, and dissolution. Primary pores are rarely preserved due to significant compaction showing concavo-convex grain contact and sedimentary rock fragments as pseudo matrix. Isopachous and blocky carbonate cements further occlude initial pore space, especially in the calcareous interval. However, chlorite coating in lithofacies 7 inhibits further quartz cementation of primary pore space, making it a potential reservoir target. Measured core plug porosity and permeability suggest moderate porosity up to 10.2%, and very low permeability ranging from 0.001 to 0.197md. The highest porosity and permeability are reported in lithofacies1 and 7. Combining this result with XRF and TOC data, lithofacies 7 is expected to have the best reservoir quality since it is more organic-rich and laterally extensive across this region. Findings in this study demonstrate variations in lithofacies and complicated diagenesis in the Wolfcamp succession that controls reservoir quality. Future work will incorporate well log correlation for regional reservoir characterization across the Midland Basin.

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Qilong Fu, Robert W. Baumgardner, Jr., and H. Scott Hamlin, Early Permian (Wolfcampian) succession in the Permian basin: icehouse platform, slope carbonates, and basinal mudrocks, in review.

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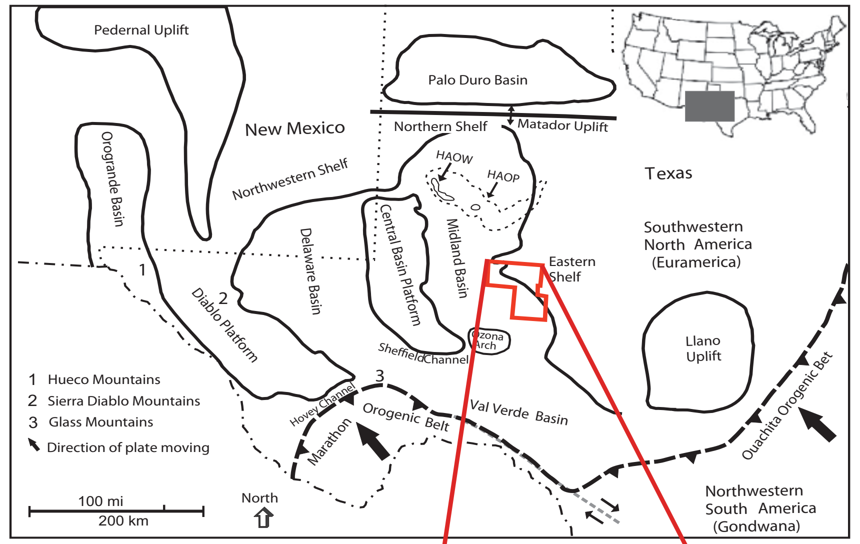
Introduction

The Permian Basin of west Texas and southeast New Mexico is one of the world's significant hydrocarbon-producing provinces, with mixed siliciclastic-carbonate reservoirs. Original estimation of oil in place regarding to conventional sandstone reservoirs was more than 10 B bbl (Tyler and others, 1984). But with the recent advance in geological understanding and technology, the unconventional reservoirs have become an important target for petroleum exploration.

In the Midland Basin, the Wolfcampian succession was deposited in a deep-marine environment. The Wolfcamp basinal sequences consists of complex subaqueous density-flow deposits alternating with more organic matter-rich hemipelagic sediments. Lithofacies composition change rapidly within meter scale and shows great lateral heterogeneity (Hamlin and Baumgardner, 2012). Thus there is still a significant amount of uncertainty in terms of the integrated description of lithofacies heterogeneity.

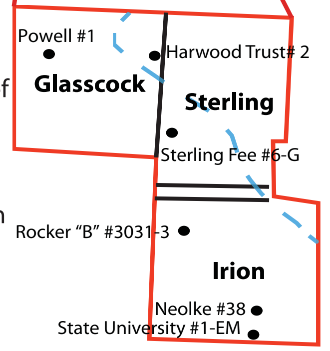
Geological Setting and Study Area

The Permian Basin region is a complexly deformed segment of the late Paleozoic Marathon-Ouachita foreland bordering the southern margin of the North American Craton. Deformation caused by plate convergence and continental suturing between Gondwana and Laurasia ended diachronously in the Late Pennsylvanian in the Ouachita Mountains, and Early Permian in the Marathon region (Poole et al., 2005). During the Wolfcampian, the Midland Basin is relative deep water



Map of the Permian Basin area with major basin structures (From Qilong et. al, in review).

The study area is located at the nose of the Eastern Shelf of the Midland Basin in Glasscock, Sterling, and Irion Counties, Texas.
Four drilling cores that cored a portion of the Wolfcampian succession were studied.



Period	Global Stage	NA Stage	Substage	Fusulinid Zones	Stratigraphic Name	Operational Name
Lower Permian	Kungurian	Leonardian		PL-2	Dean	Dean
	Kungurian (279.3)	Leonardian		PL-1	Lower Leonard	Wolfcamp A
	Artinskian (290.1)	Wolfcampian	Lenoxian	PW-3 Upper Hueco	Wolfcamp	Wolfcamp B
	Sakmarian (295.5)					
	Asselian (298.9)		Nealian	PW-2 Lower Hueco		Wolfcamp C
Pennsylvanian	Gzhelian	Virgilian		PW-1 Bursum	Bursum Fm.	Wolfcamp D Cline
	Kasimovian	Missourian		Cisco	Cisco	
				Canyon	Canyon	
	M.	D.		Strawn	Strawn	Strawn

Stratigraphic and operational names of formations in the Midland Basin (Modified from Baumgardner et. al, 2016).

Methods

This study combined petrographic observations from cores, thin sections, and scanning electron microscope cubes with chemostratigraphic data from X-ray Fluorescence (XRF), X-ray Diffraction (XRD) and total organic matter content (TOC) in order to provide an integrated characterization for the Wolfcamp succession.

The SEM samples were cut into around 9mm^3 cubes, and milled by Argon-Ion Miller. The milling process was conducted by Leica EM TIC020 Triple Ion Beam Miller under current of 2.8 mA and 8KV accelerating voltage for 2-3 hours at BEG CRC.
High-resolution energy dispersive XRF data were generated by a Bruker Tracer III (T3S2270) for major elements and a Bruker Tracer IV (T4S2602) for trace elements.

Bruker Tracer III for XRF data collection

FEI Nova NanoSEM 430 for SEM cube observation

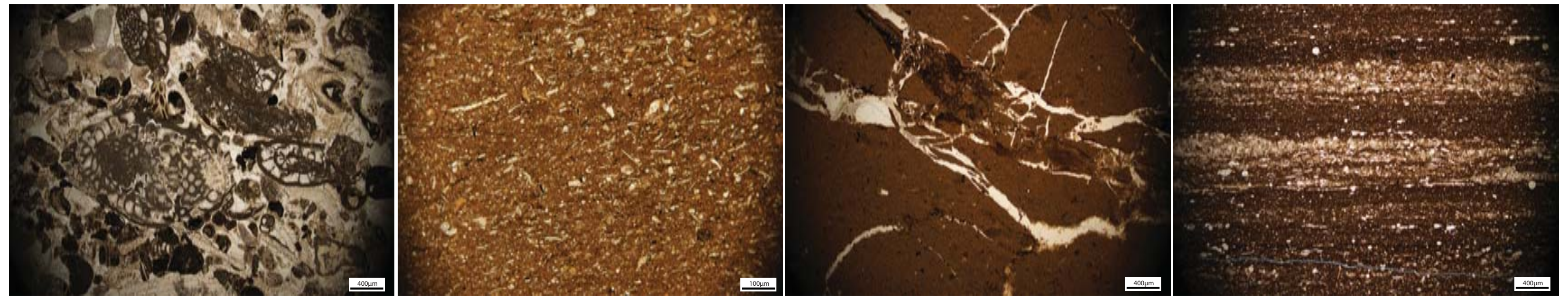
Results --- Lithofacies

Petrographic observations show that upper Wolfcamp (Wolfcamp B) is more calcareous, dominating by calcareous mudstone with carbonate rock intervals, while lower Wolfcamp (Wolfcamp C) is a more siliciclastic interval, which is dominated by medium-fine-grained turbidity sandstone, siltstone with interbedded siliceous mudstone. In total, nine lithofacies and facies associations were defined.

Wolfcamp B Examples

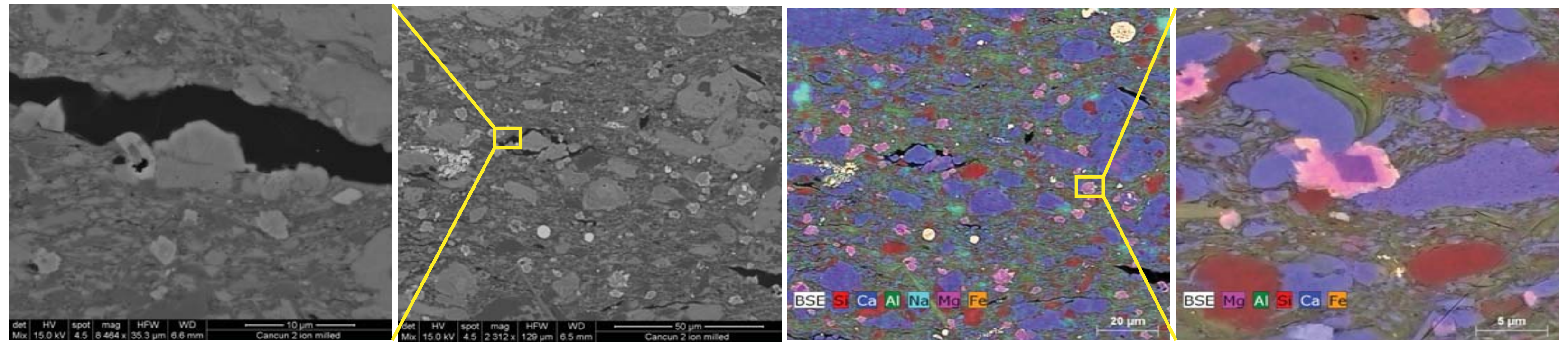
Fusulinid bioclastic packstone — Calcareous mudstone — Brecciated mudstone — Laminated calcareous mudstone

Four lithofacies were defined in the Glasscock core representing the upper Wolfcamp calcareous interval: (1) fusulinid bioclastic packstone, (2) calcareous mudstone, (3) brecciated mudstone, and (4) laminated calcareous mudstone.



Fusulinid bioclast packstone — Calcareous mudstone — Brecciated mudstone — Laminated calcareous mudstone

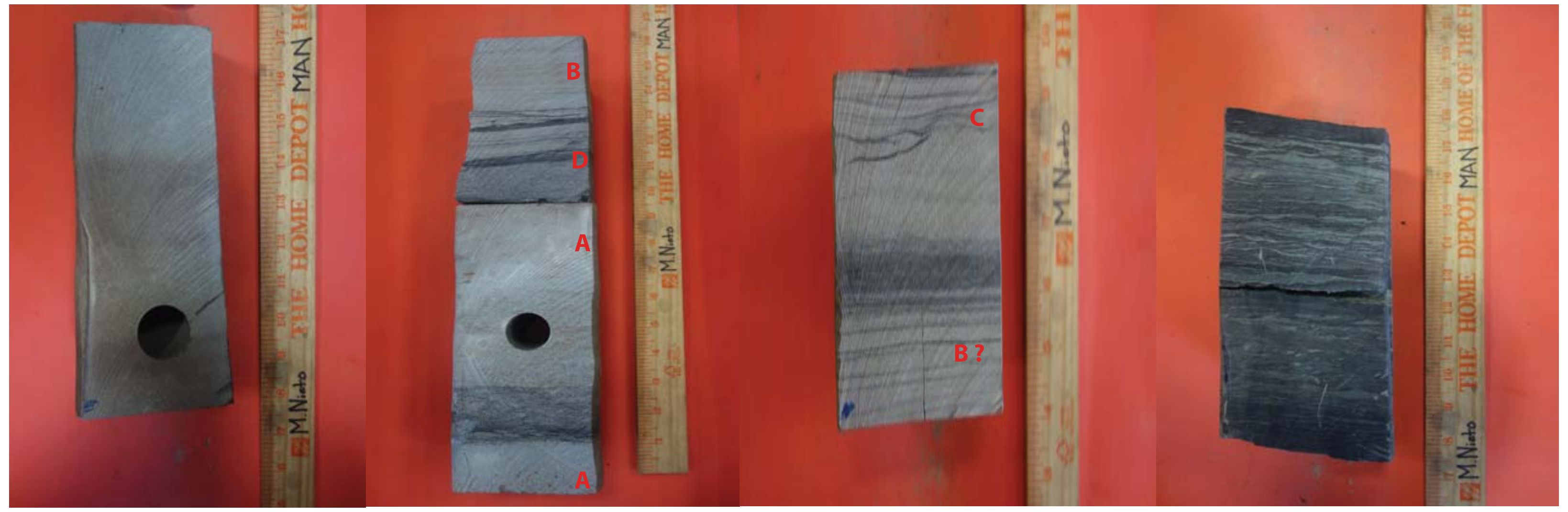
Calcareous mudstone under SEM/ EDS



Organic Matter — Highly compacted with evidence in clay mineral directional alignment and the shape of pyrite — EDS shows dolomite with pyrite overgrowth

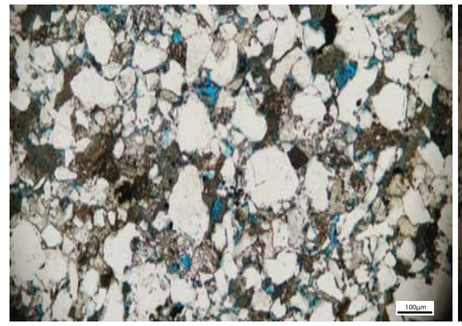
Wolfcamp C Examples

Wolfcamp C interval is dominated with sandstone with interbedded siltstone/mudstone. Incomplete Bouma sequence is commonly observed.

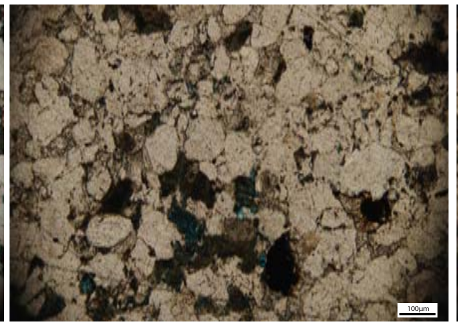


Massive fine-medium grain sandstone — Incomplete Bouma sequence — Siltstone with soft sediment deformation

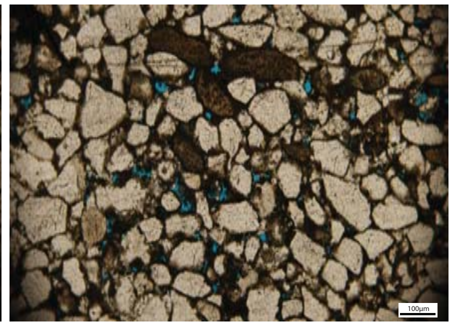
Lower Wolfcamp siliciclastic interval is reflected by 5 lithofacies and facies associations identified in Sterling and Irion cores as: (5) clean litharenite, (8) calcite cemented litharenite, (7) clay-coated litharenite, (8) siltstone, and (9) siliceous mudstone.



Clean litharenite



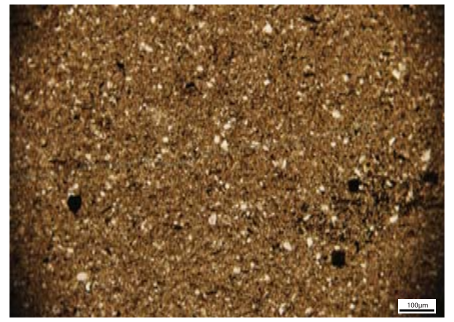
Calcite cemented litharenite



Clay-coated litharenite

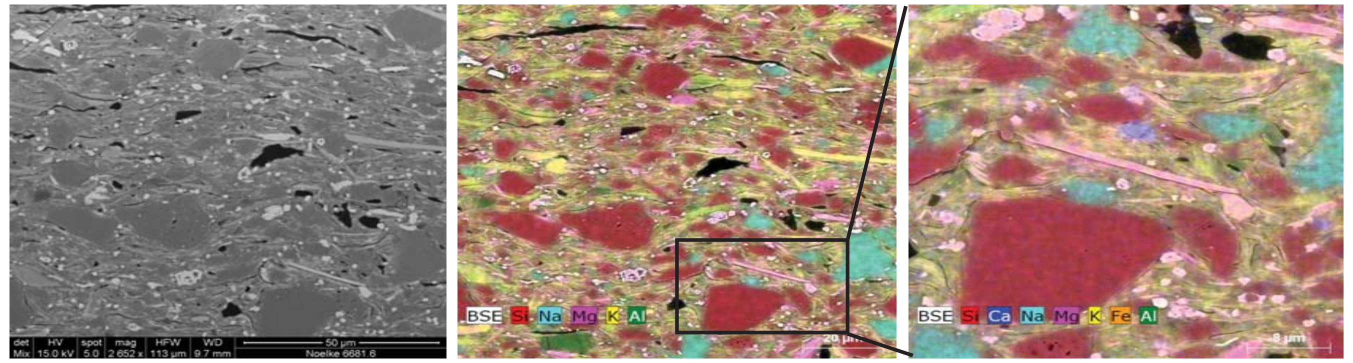
Litharenite with mudclast

Siltstone



Siliceous mudstone

Siliceous mudstone under SEM/ EDS



Results --- Mineral contents and TOC

Wolfcamp B (Hardwood Trust #2 core)

Average Weight Percent									
Quartz	Total Clay Minerals	Carbonate	Dominated Carbonate	F+P+S *	TOC	Total	TOC highest	TOC lowest	n
12.6	15.3	60.7	Calcite	9.7	1.7	100	6.0	0.9	30

Data= 30 XRD samples from calcareous mudstone
* F=Feldspar; P= Pyrite; S= Siderite

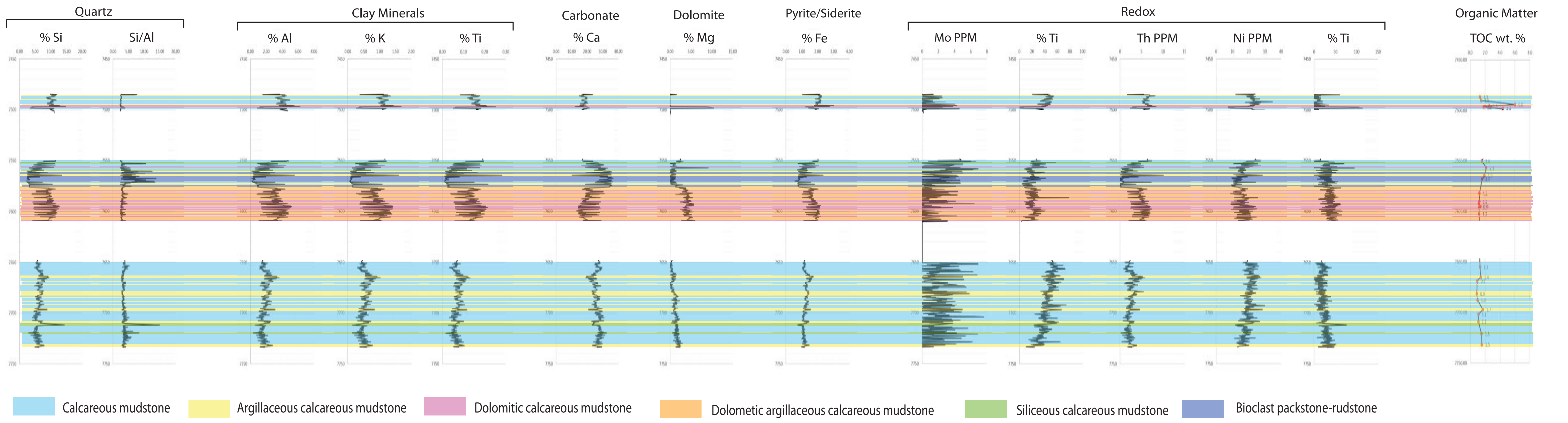
Wolfcamp C (Noekle #38 core)

Average Weight Percent									
Quartz	Total Clay Minerals	Dominated Clay Mineral	Carbonate	F+P+S *	TOC	Total	TOC highest	TOC lowest	n
30.7	42.6	Illite	3.2	22.2	1.3	100	2.5	0.82	20

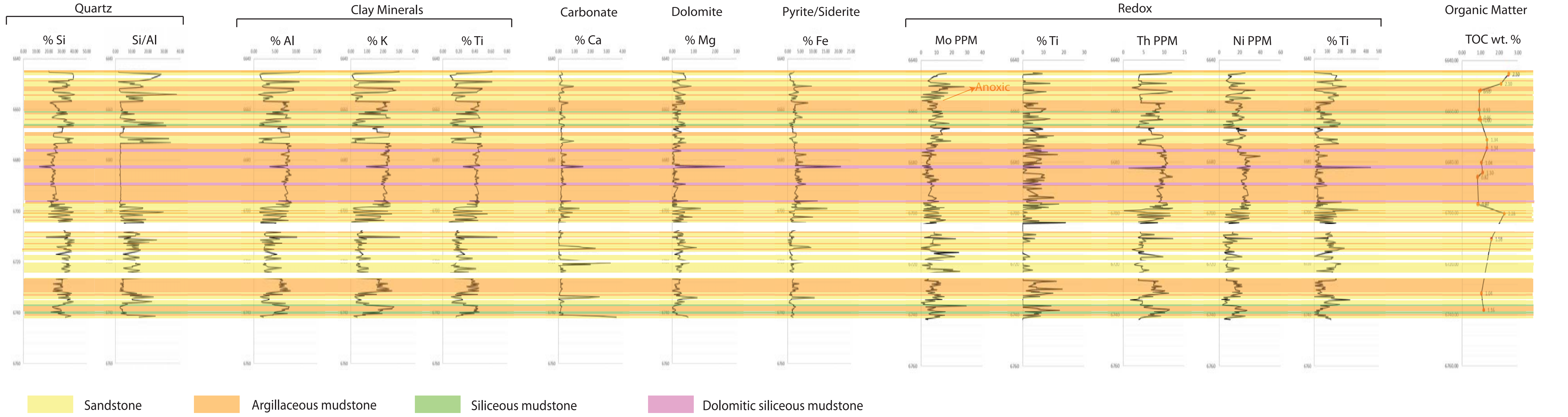
Data= 20 XRD samples from siliceous mudstone
* F=Feldspar; P= Pyrite; S= Siderite

Results --- Mudstone Facies Associations Stacking from XRF

Wolfcamp B (Hardwood Trust #2 core)

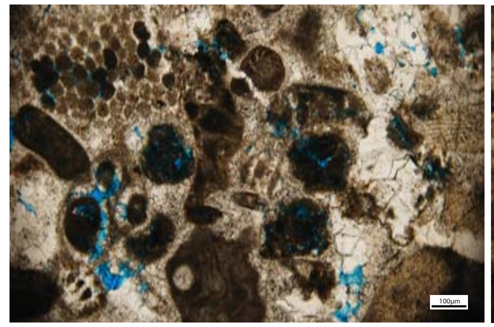


Wolfcamp C (Noekle #38 core)



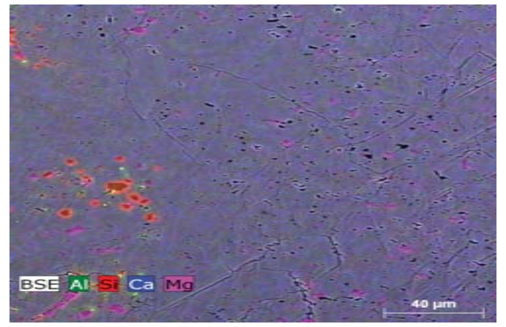
Results --- Diagenesis

Calcareous Diagenesis



Dissolution pores

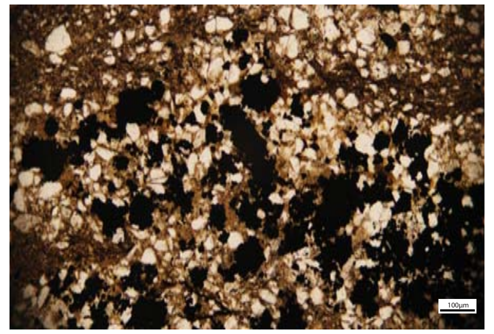
Isopachous calcite (red circle) followed by blocky calcite precipitation in fusulinid bioclastic packstone



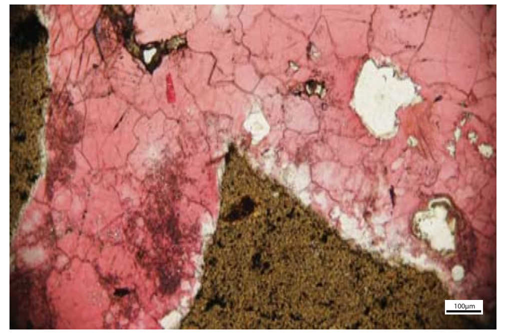
Dolomite cement filling micro-pores in fusulinid bioclastic packstone

Siltstone/ Mudstone Diagenesis

Calcite cement filled in intraparticle pores

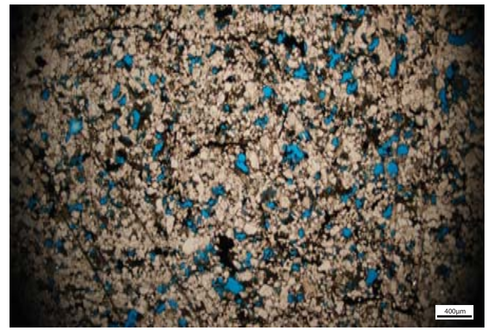


Pyrite cement in siltstone

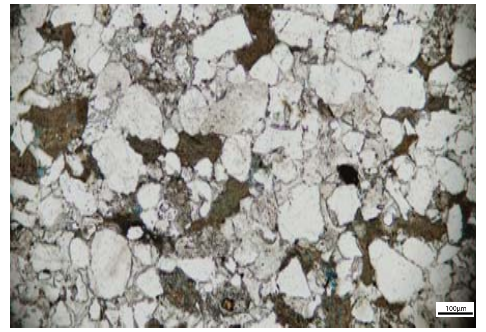


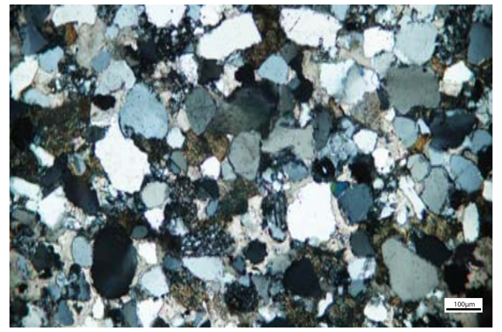
Calcite cement in brecciated mudstone

Sandstone Diagenesis

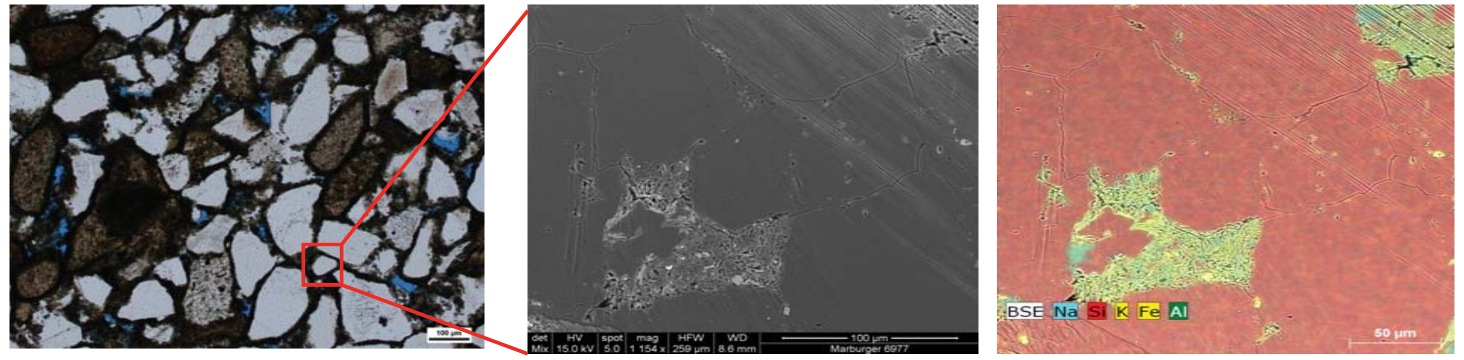


Dissolution in clean litharenite





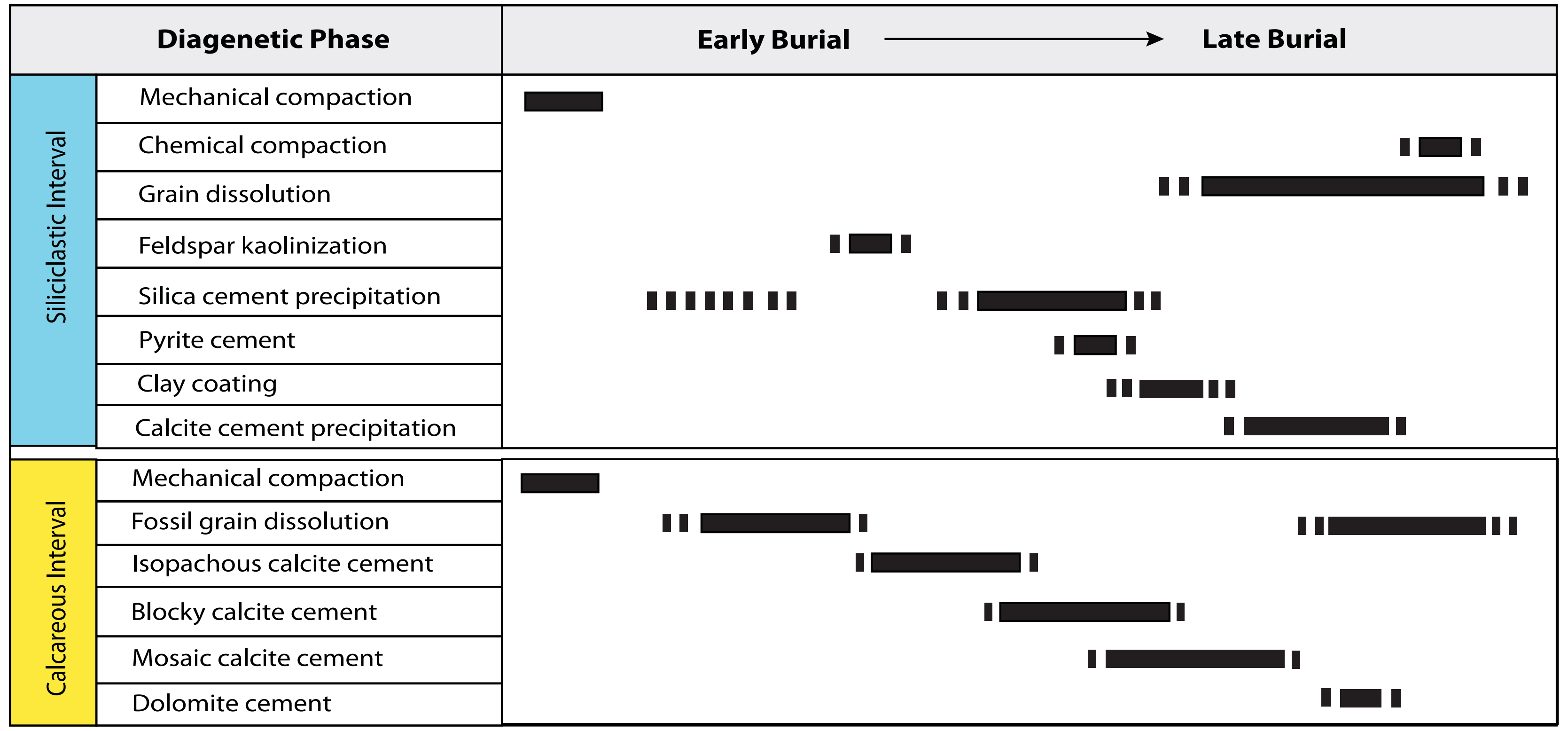
Quartz overgrowth and calcite cementation in litharenite



Clay coating in litharenite (Inhibit qurtz overgrowth, posity preservation)

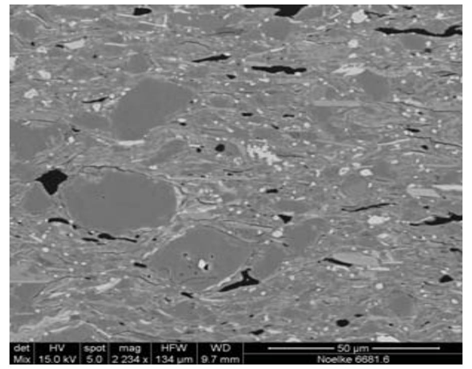
Clay coating is a mixture of chlorite and illite

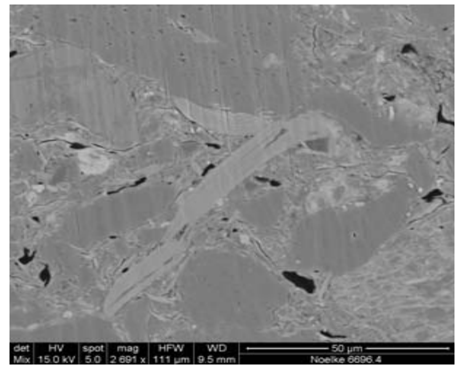
Results --- Generalized Paragenesis



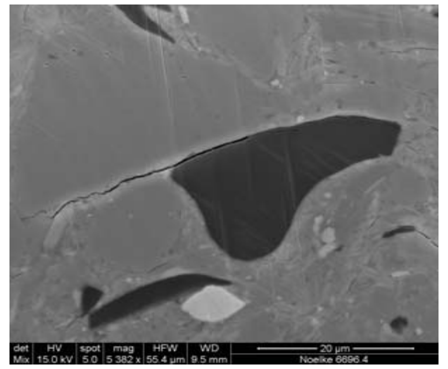
Results --- Pore System and Reservoir Quality

Siliceous Mudstone



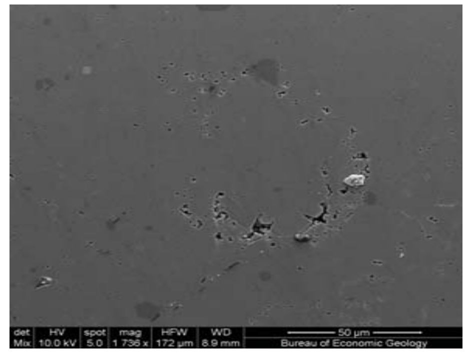


Minor intergranular pores

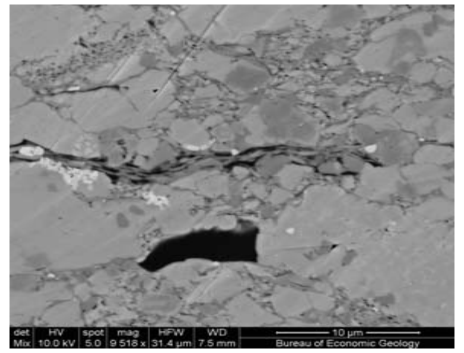


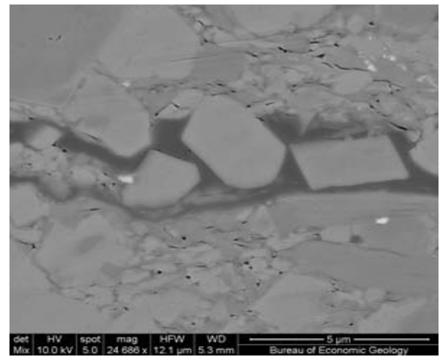
No organic pore

Packstone/ Calcareous Mudstone



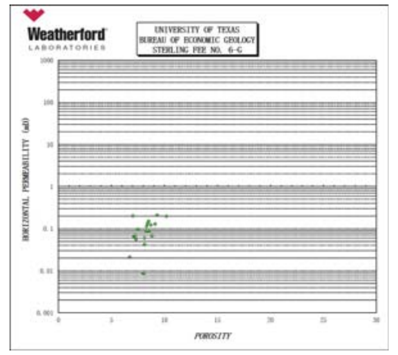
Intragranular pores within the fusulinid



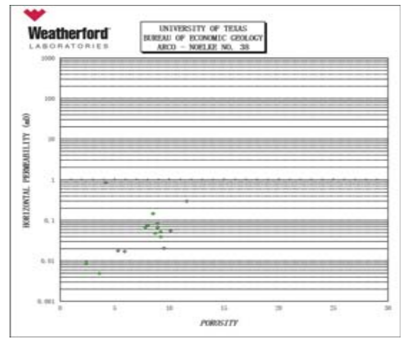


Intergranular pores and intragranular pores
Intragranular pores are concentrated in clay minerals
Organic pores are rare

Litharenite Porosity-Permeability Test Result



27 core plus in total
Average porosity= 8.2%
Average permeability= 0.1 md



20 core plugs in total
Average porosity= 7.6%
Average permeability= 0.1 md

Conclusion

Based on the integration of petrographic observation and geochemical data analysis, 4 lithofacies and 5 mudstone facies associations were defined in the upper Wolfcamp (Wolfcamp B) calcareous interval. The lower Wolfcamp (Wolfcamp C) siliciclastic interval is reflected by 5 lithofacies with litharenite facies associations and 4 mudstone facies associations. The Wolfcamp succession reveals a complex diagenetic history, ranging from compaction, pyrite, calcite, dolomite and silica cementation, to dissolution.

Primary pores in litharenite and packstone are rarely preserved due to significant compaction and later cementation. However, chlorite-illite-coated litharenite inhibits further quartz cementation of primary pore space, making it a potential reservoir target. Also, the secondary porosity created by dissolution in both intervals is of great importance of Wolfcamp reservoir potential. The mudstone facies show mostly intergranular porosity between clay minerals, but organic pores are rare.

Measured core plug porosity and permeability suggest moderate porosity up to 11.6%, and low permeability ranging from 0.001 to 0.300 md. The highest porosity and permeability are reported in clay-coated litharenite.

The Wolfcamp mudrock succession is fairly organic rich. The average TOC is higher in the calcareous interval with an average of 1.7 % comparing to the siliciclastic interval at 1.3%. This is probably due to the influence by detrital sediment influx from the eastern shelf during Early Wolfcampian (Hamlin and Baumgardner, 2016).

Sedimentation in the Wolfcamp succession is highly controlled by density-flow current, probably turbidity flow. The turbidity current brings both calcareous and siliciclastic sediments from the Eastern Shelf as sea level changes. This increases the lithology heterogeneity thus increases heterogeneity in reservoir quality.

Clay-coated litharenite is considered to have the best reservoir potential since it shows good porosity and permeability value, and is regionally continuous. It is usually present at the base of incomplete Bouma sequence identified in cores.

Acknowledgment

We are grateful to State of Texas Advanced Oil and Gas Resource Recovery (STARR) project 30 for funding this research. And we appreciate the Bureau of Economic Geology, Jackson School of Geoscience at the University of Texas at Austin for providing the cores and facilities to complete the research.

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