PS Increased Organic Content in the Presence of Floccules: A Case Study of the Sharon Springs Member of the Pierre Shale, Cañon City Basin, South-Central Colorado*

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Abstract

Primary production within the Cañon City Basin, south-central Colorado, targets the fractured Upper Cretaceous Pierre Shale, which is sourced by the underlying Sharon Springs. The Sharon Springs Member of the Pierre Shale contains some of the most organic-rich sediments deposited in the Western Interior Cretaceous Seaway. Typically, organic carbon ranges from 2 to 11 weight percent while maturity of the source rock varies from immature to over-mature across the basin. Previous researchers variously ascribe the origin of the organic matter to fecal pellets, phytoclasts and amorphous material. Rock-Eval pyrolysis indicates that the kerogen present is of Type II marine origin; however, this does not explain the disproportionately high percentage of organic matter. Facies analysis of the Bull 42-4 core, containing the Sharon Springs within the Cañon City Embayment, reveals the presence of sediment gravity-flow deposits in the lowest facies of the Sharon Springs. When examined in petrographic thin-section, opaque spheroids represent the previously described fecal pellets or phytoclasts. FESEM analysis of these spheroids shows an amalgamation of fine clay particles with an absence of casing surrounding the spheroids, indicating that they are not fecal pellets. Analysis of a bentonite bed, which has characteristics of a sediment gravity-flow deposit, also contains diagenetically altered clay-aggregate spheroids. In stratigraphically higher facies, which show laminated fabric, the clay aggregates are elongated along the lamination, indicating a calmer environment of deposition with subsequent compaction. Detailed XRF analysis of the core indicates that deposition occurred within dysoxic, anoxic or euxinic conditions. Settling of clay particles is often aided by flocculation. In the presence of organic matter, the organic material will adsorb to the surface of the clay particles during flocculation. In flume studies performed by Schieber (2011), clay floccules formed in a current were shown to roll and compact into spheroids, similar to those seen in the sediment gravity-flow deposits. However, those formed in quiet water settled as uncompacted aggregates. As seen in the Bull core, uncompacted aggregates align with foliation during burial. Bulk XRD analysis illustrates that the entirety of the Sharon Springs, despite variations in facies and depositional environment, is a silica-rich argillaceous mudstone. Detrital matter in the form of quartz and plagioclase were brought into the system along with clay and likely some or all of the organic matter. Enhanced organic concentrations result from adsorption of organic matter to clay floccules with subsequent deposition in dysoxic to euxinic conditions.

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Increased Organic Content in the Presence of Clay Floccules: A Case Study of the Sharon Springs Formation, Canon City Embayment, South-Central, CO

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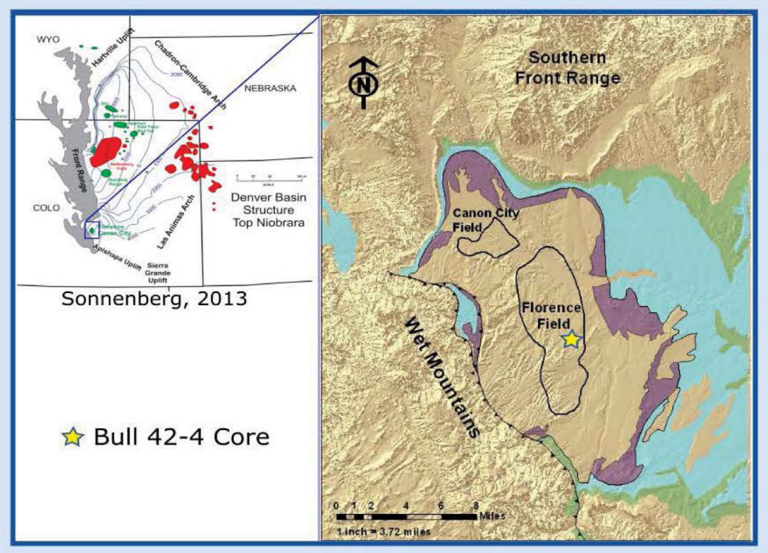
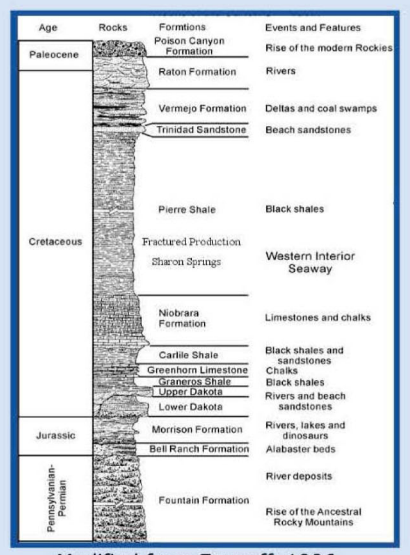
Introduction

Lying unconformably on the Niobrara, the Upper Cretaceous Pierre Shale is a time-transgressive unit deposited at the end of the Niobrara highstand in the Western Interior Cretaceous Seaway. The Sharon Springs Member of the Pierre Shale is highly variable on a regional scale; however, within the Canon City Embayment it is present as a black, organic-rich, weather resistant shale, which has served as the source rock for local oil production. Within the embayment, the Sharon Springs ranges in thickness from 15 to 50 feet and ranges in organic carbon from 2 to 11 wt%. Known as "the Barren Zone" (Gilbert, 1897), the Sharon Springs displays a scarcity of whole fossils and a relative abundance of transported bone and shell fragments. Analysis of the Bull 42-4 core, located centrally within the Canon City Embayment, shows that the shale consists of detrital quartz and plagioclase (30-46%); authigenic pyrite, anhydrite and apatite (6-10%); and clays which are pimarily illite (33-42%) with lesser amounts of kaolinite (4-10%) and mixed illite/smectite (1-3%).

Locally, the Sharon Springs is an excellent source rock. While this formation is regionally extensive, lithological variations may affect its source rock potential in other locations. Improving understanding of the depositional environement can aid in identification of other potential source rocks.





Modified from Evanoff, 1996

Objectives

1.) Re-examine the depositional environment and bottom water chemistry which led to the high preservation of organic carbon in the Sharon Springs Member of the Pierre Shale.

2.) Connect the geochemical interpretation with facies analysis from core description, thin-section description and SEM analysis

3.) Provide a better understanding of the depositional environment and depositional factors that enable the concentration of organic matter for identification of similar areas in the regionally diverse Sharon Springs and other similar formations

Methodology

- Core description and identification of facies
- In-depth thin-section and SEM analysis connected with identified facies
- Source rock analysis to determine wt% TOC
- Qualitative analysis of trends provided by XRF data collected every 3" on the core using the Thermo Scientific Niton XL3t Goldd+ handheld energy dispersive x-ray fluorescence analyzer
- Bulk XRD and clay analysis
- Biomarker analysis preformed on the core and gas chromatography preformed on an oil sample from a near-by well

Petrographic Thin-Section and FESEM

Facies

Facies 7 - Dark greenish-gray infaunal bioturbation, highly pyritized

Facies 6 - Olive-buff bentonite, fissile and friable

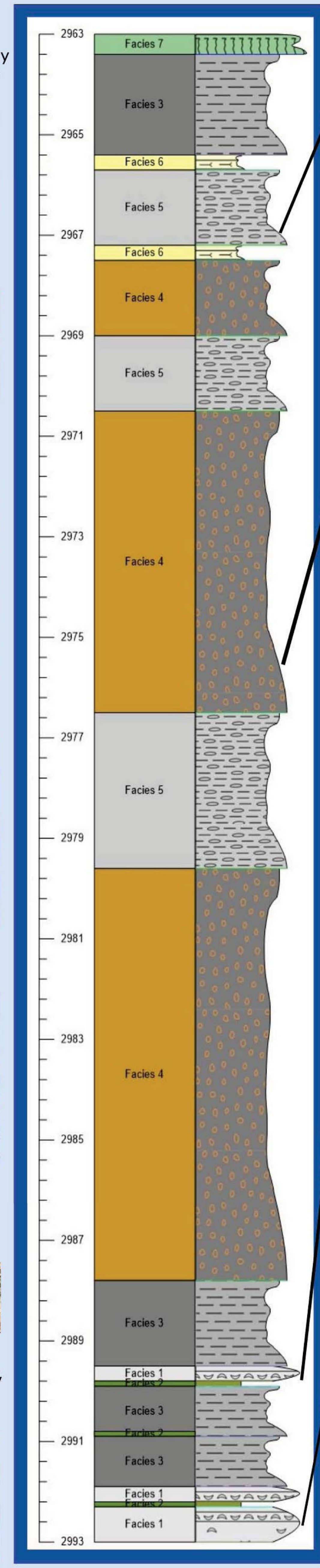
Facies 5 - Dark gray shale, layers of inocerimids and oysters, large pyrite framboids

Facies 4 - Dark gray shale, fissile, large pyrite framboids

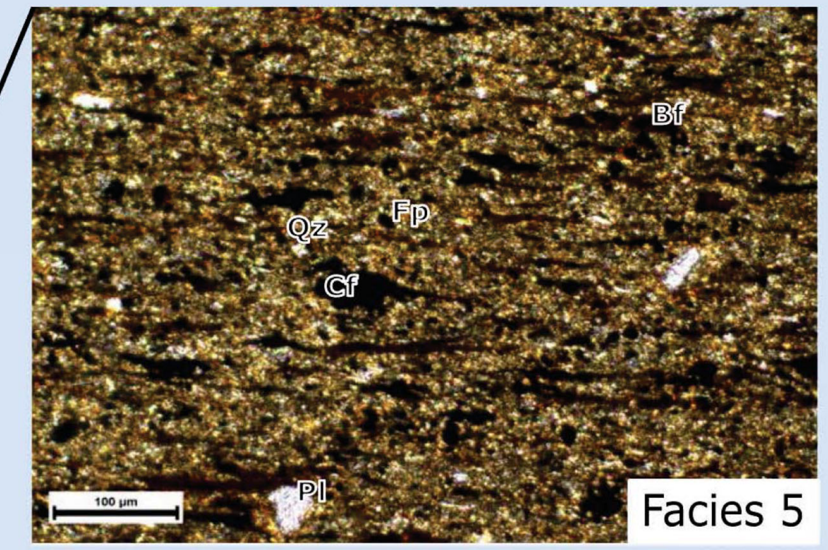
Facies 3 - Dark gray shale, fissile and rubblized

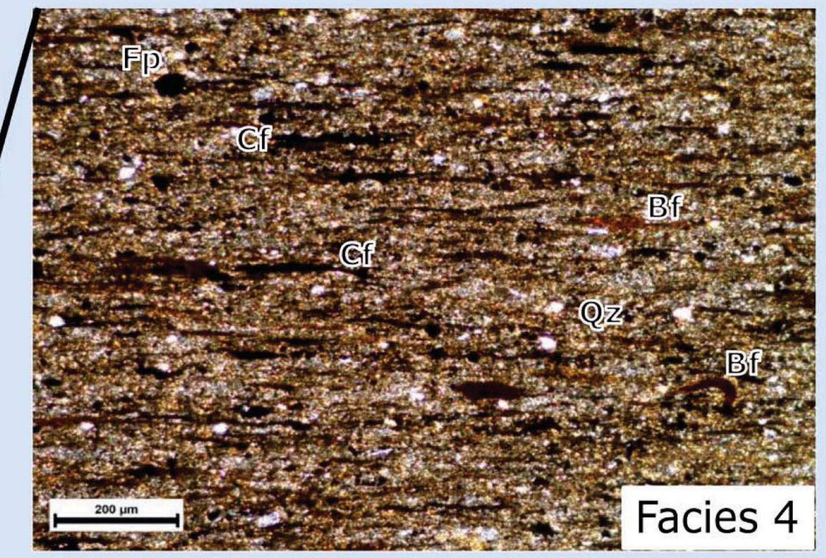
Facies 2 - Olive-gray cohesive bentonite, scouring lower surface winnowed upper surface

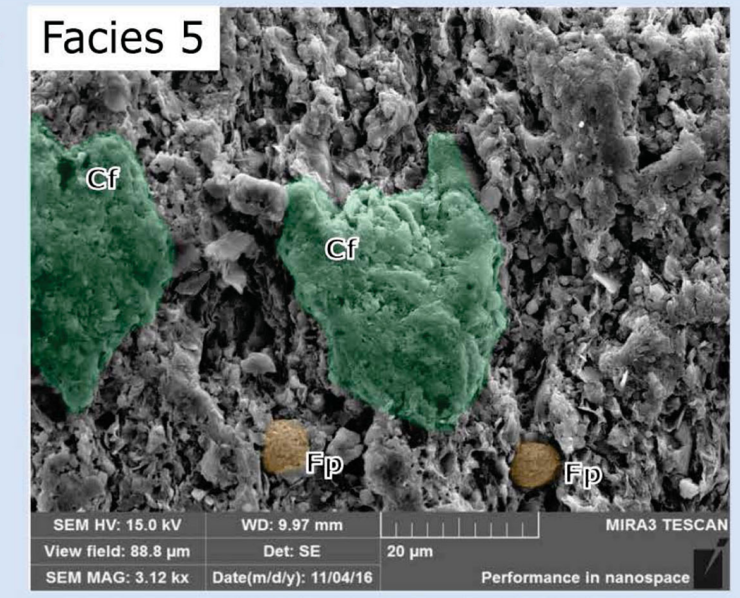
Facies 1 - Light-gray, friable, sediment gravity flow deposit, with randomly oriented bone fragments



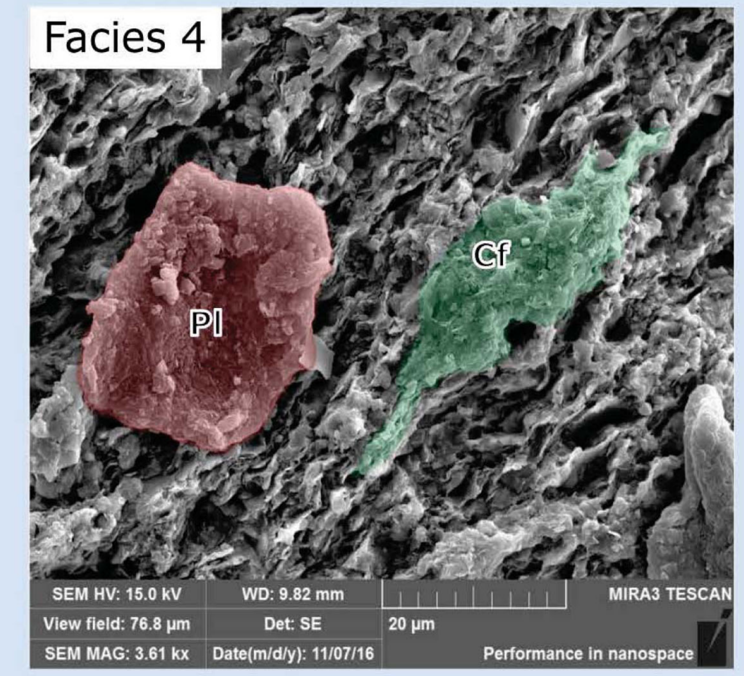
Current Transported Deposits





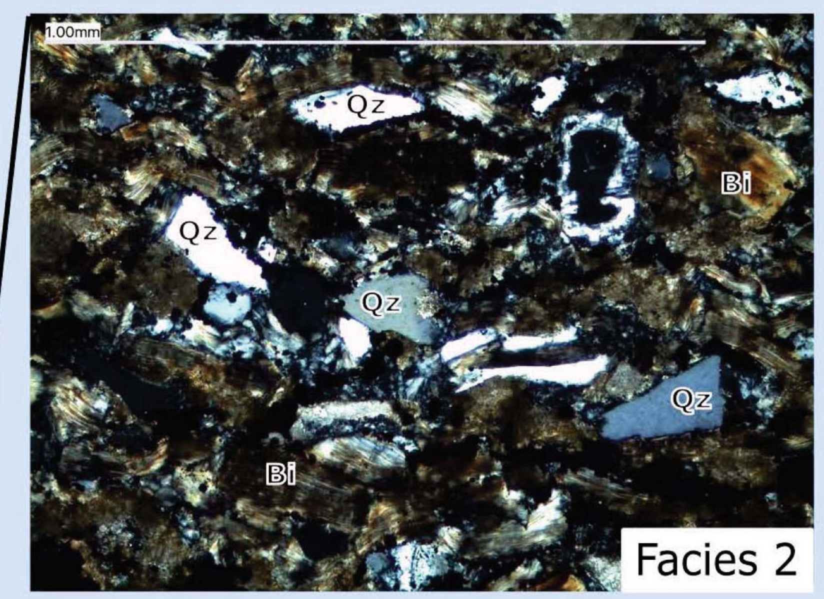


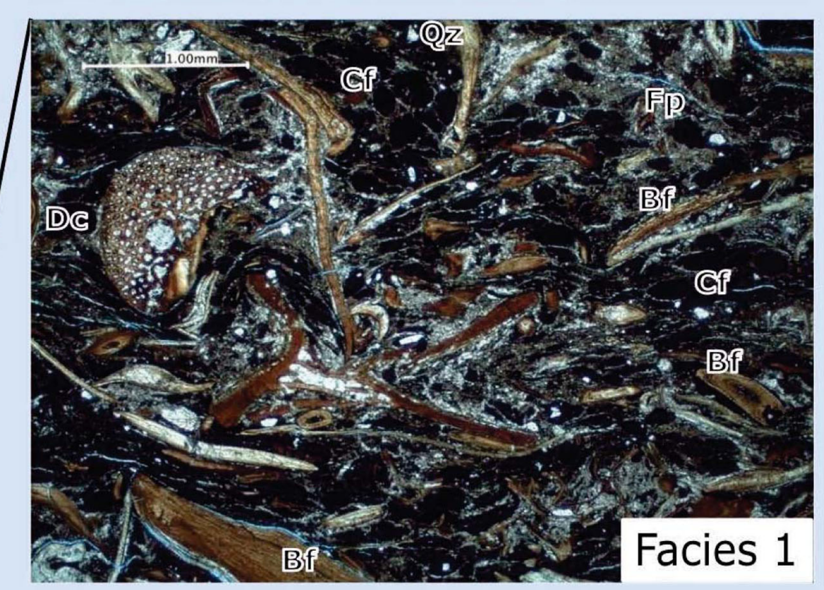
Legend
Fp - Framboidal pyrite
Qz - Quartz
Pl - Plagioclase
Cf - Clay floccule
Bf - Bone frag
Bi - Biotite
Dc - Diagenetic calcite

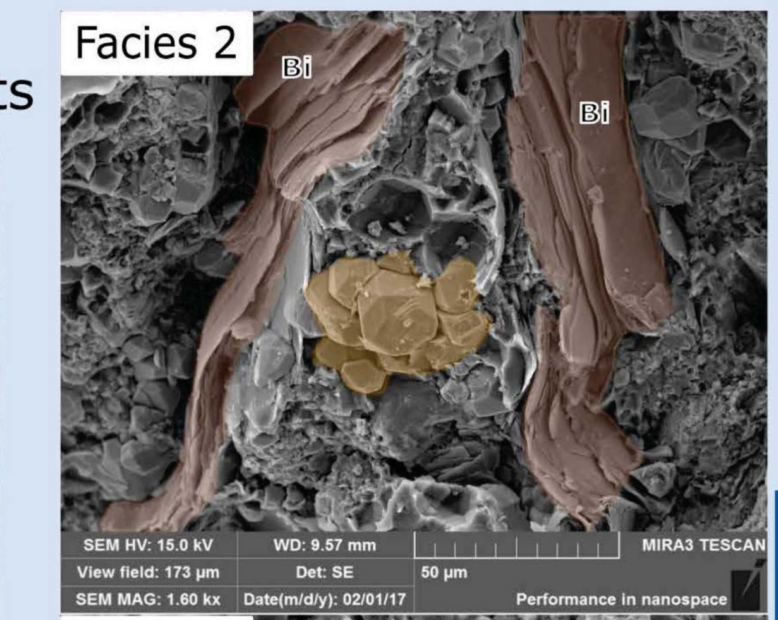


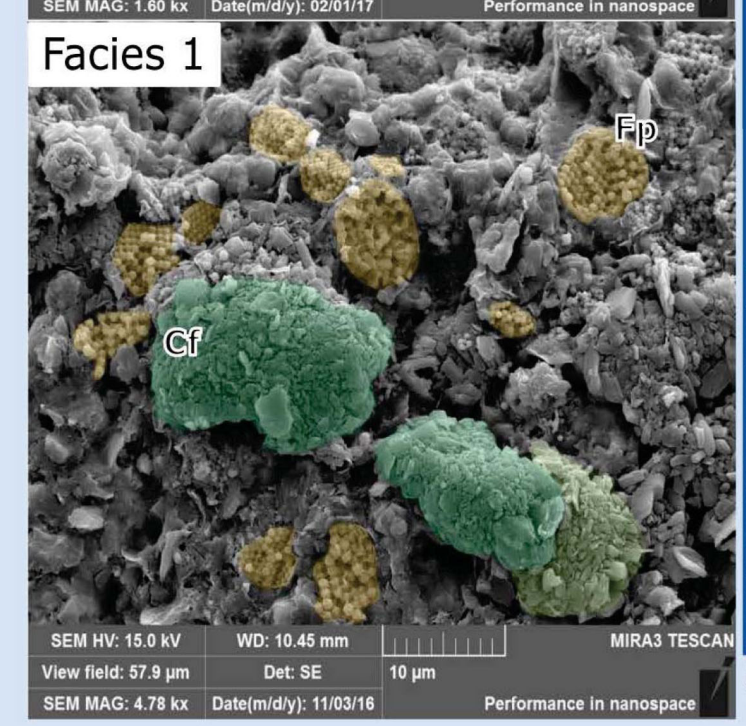
Clay floccules seen in Facies 4 are flattened and aligned with foliation. Clay floccules in Facies 5 are both flattened and whole. Lack of diagenetic calcite allowed for compaction of the floccules. Bulbous center indicates that floccules were deposited by current, not settling.

Sediment Gravity Flow Deposits

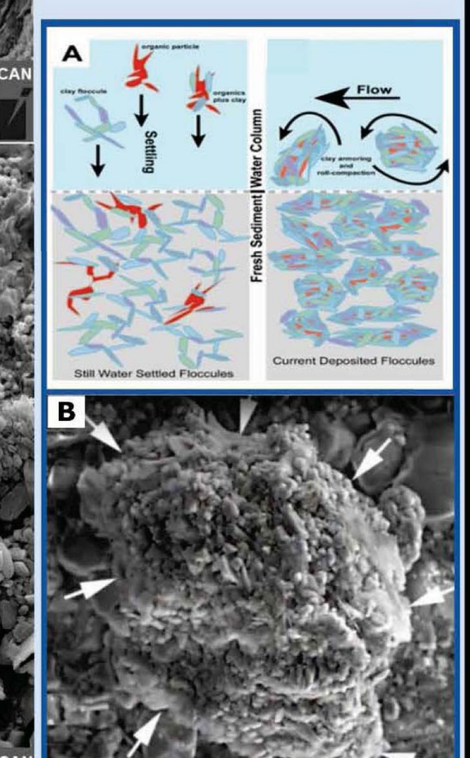








Clay floccules present in Facies 1 and 2 similar to those seen in flume study performed by Schieber, 2009. Presence of early diagenetic calcite in these facies accounts for lack of compaction.



A) Schieber, 2011 B) Schieber, 2007

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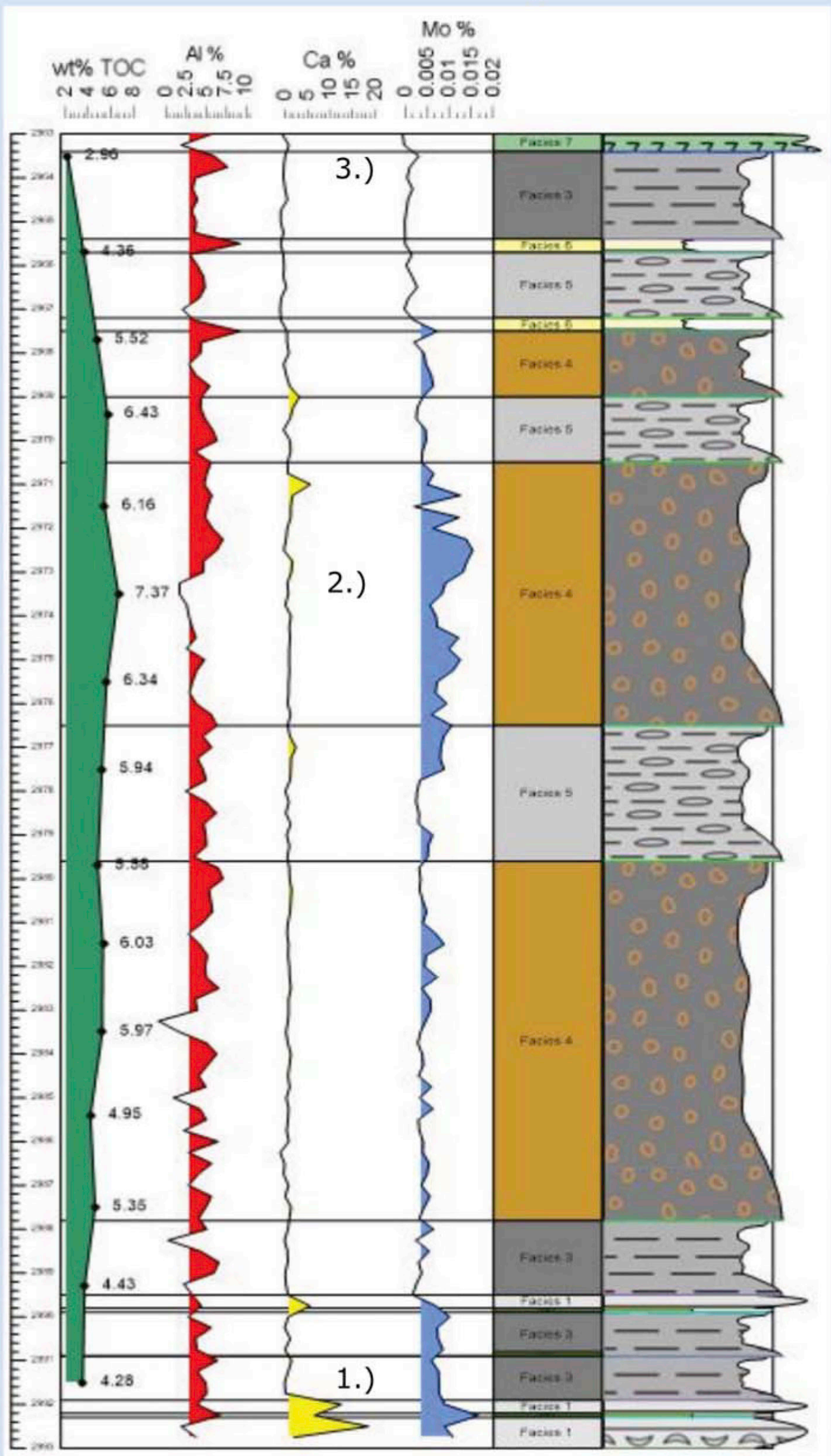
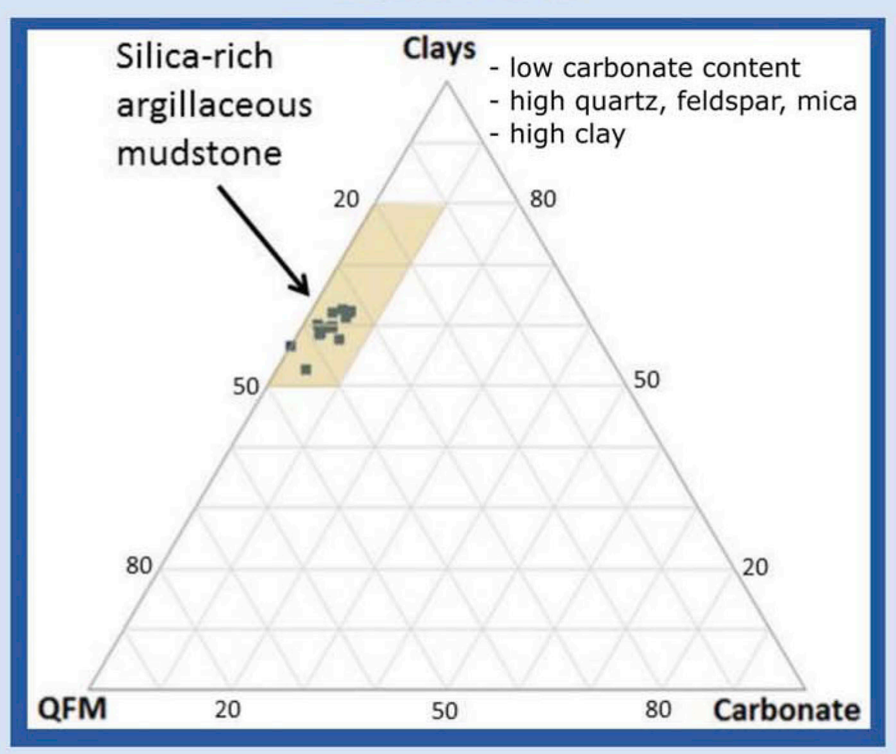
Geochemical Analysis of Depositional Environment

XRF Analysis

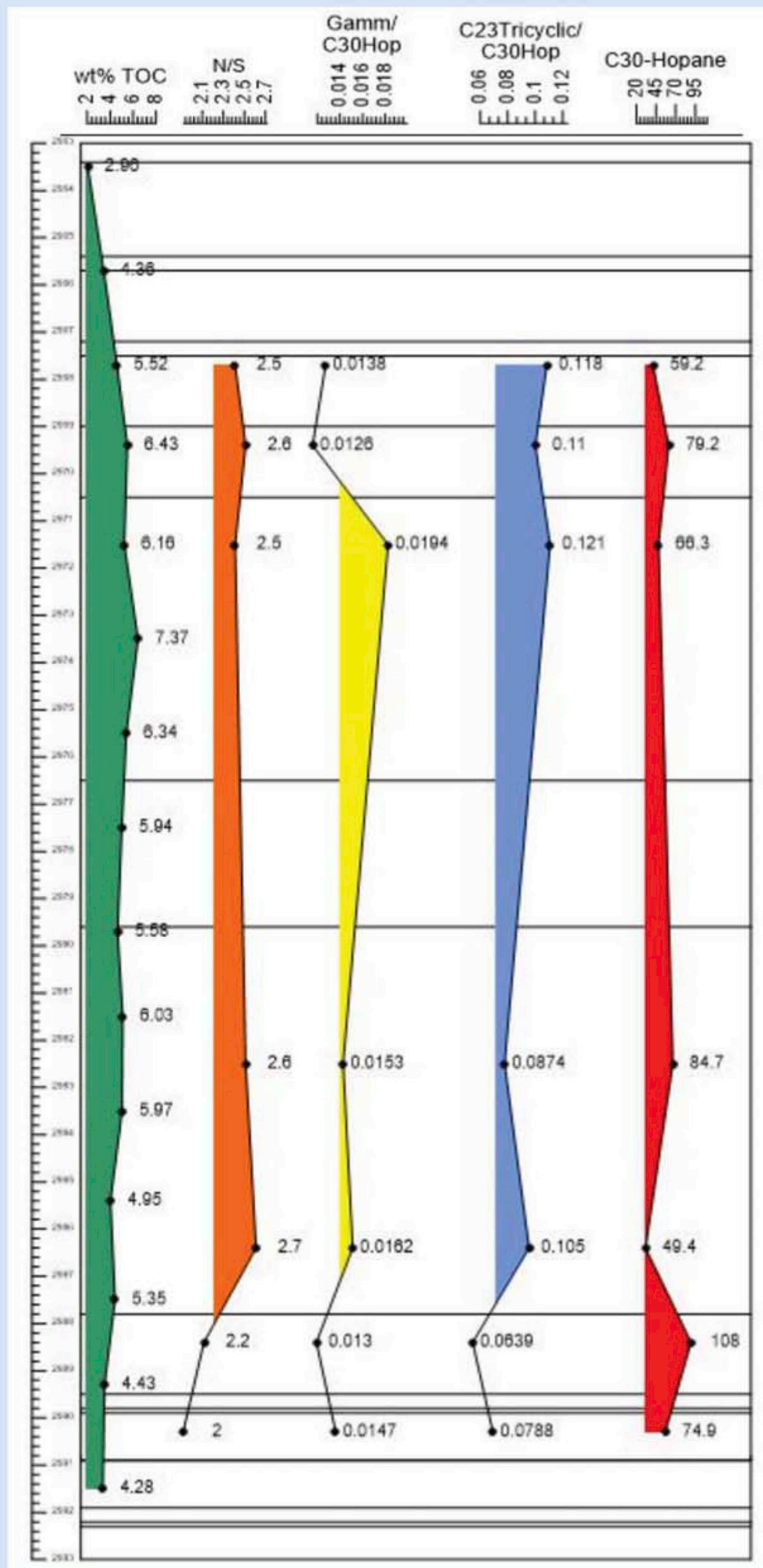


1.) Diagenetic calcite present in facies 1 & 2
2.) Highest TOC associated with highest anoxic indicators (Mo) and lowest detrital indicators (Al)
3.) Lowest TOC associated with lowest anoxic levels (Mo)

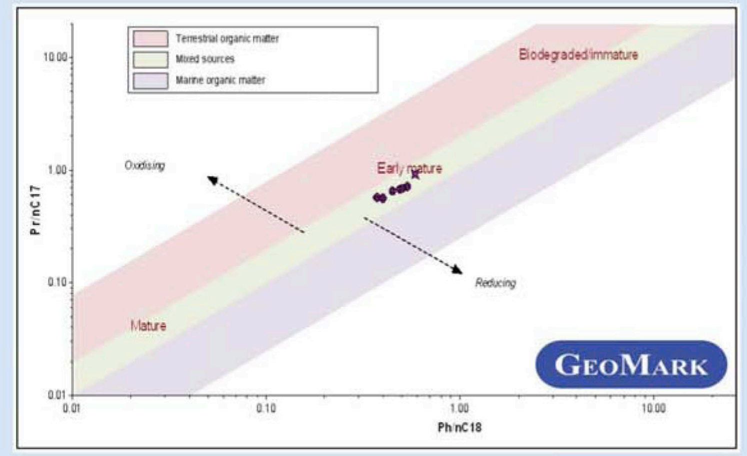
Bulk XRD



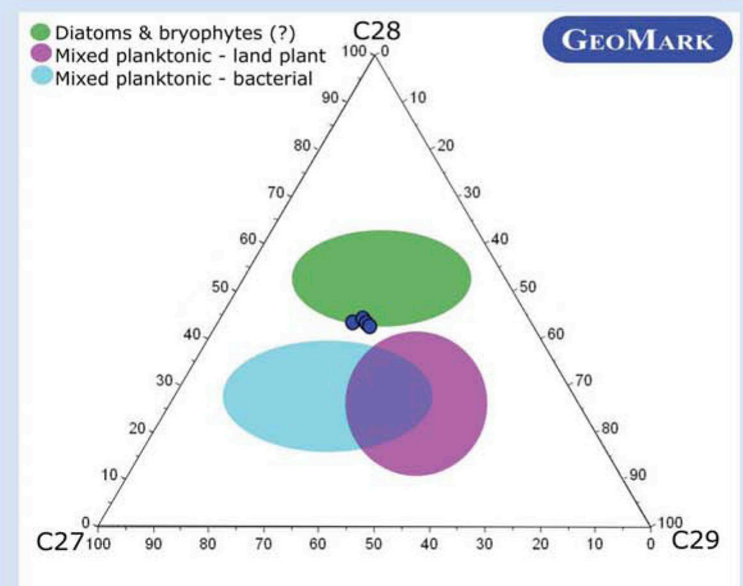
Biomarker Analysis - Bull 42-4 Core



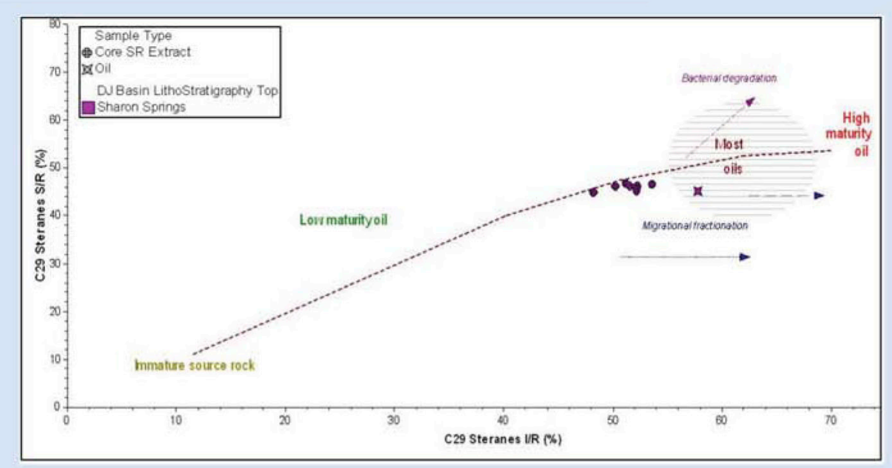
Plot of biomarker analyses with depth. Gammacerane Index inconclusive of water stratification. High C30-Hopane indicative of methylotrophs.



Marine to mixed marine source for organic matter

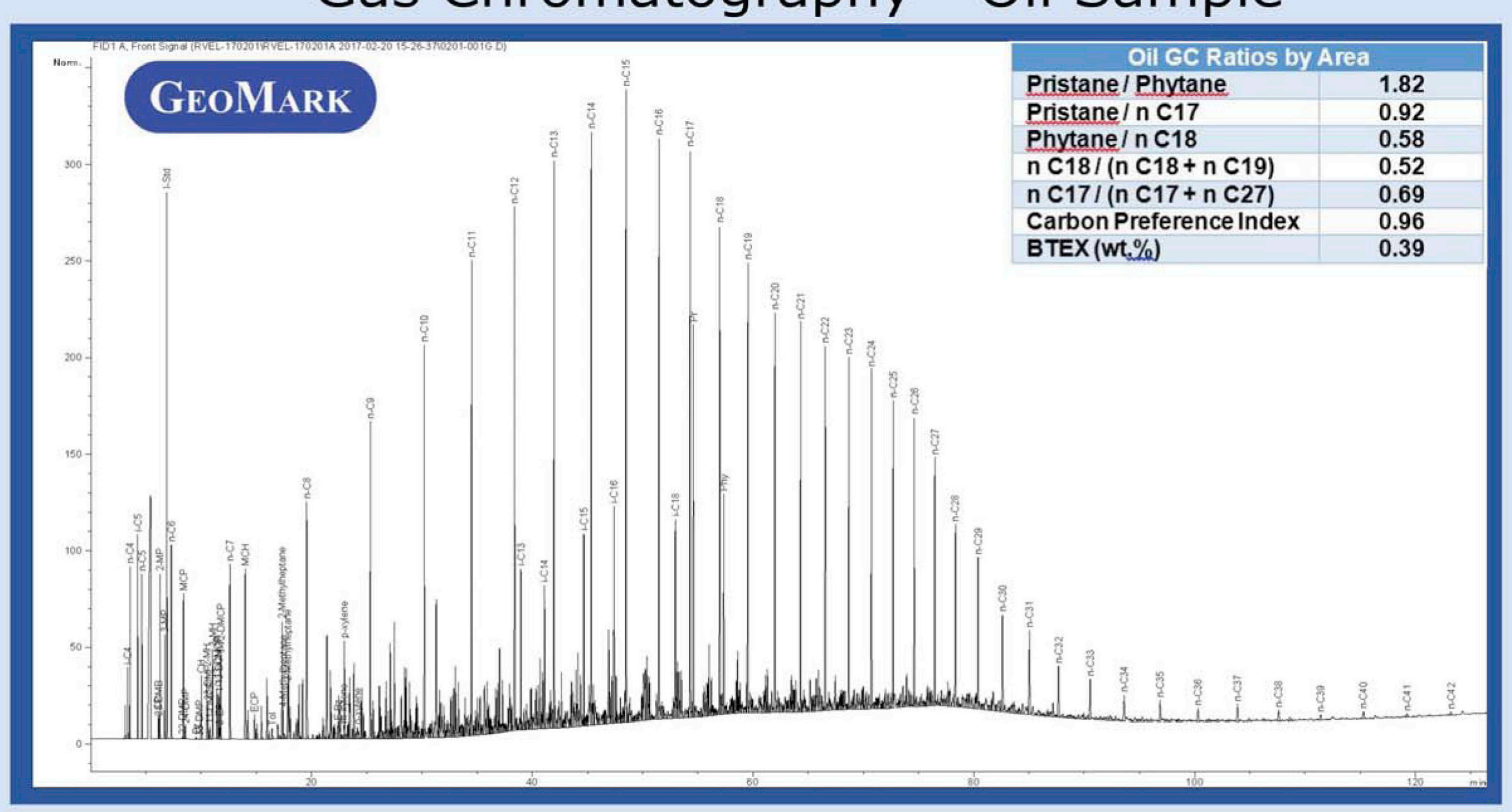


Highest percentage of C28 Steranes. Organic matter likely algal in origin.



Core data shows low maturity while the nearby oil sample indicates an element of migration was present.

Gas Chromatography - Oil Sample



Oil GC Ratios by Area	
Pristane / Phytane	1.82
Pristane / n C17	0.92
Phytane / n C18	0.58
n C18 / (n C18 + n C19)	0.52
n C17 / (n C17 + n C27)	0.69
Carbon Preference Index	0.96
BTEX (wt.%)	0.39

Discussion

Regionally, the Sharon SPrings formation is highly variable. Interpretations of the depositional environment have varied from Griffits (1949) who suggested deposition within deep, quiet waters with conditions that prohibited life, to Leroy and Schieltz (1958) who suggested deposition under "toxic conditions," to clarification by Gautier et al. (1984) who identified euxinic conditions due to the sulfur/carbon ratio and the sulfide sulfur isotopic composition. More recently, it was described by Allred (2017) as the distal toe of prograding clinoforms deposited in oxic environments with reducing conditions below the sediment-water interface. Geochemical and petrographic analysis suggest that the depositional environment is a combination of the two. The rounded, compacted clay flocculates as the mode-of-transport for organic matter combined with the large percentage of detrital matter, bone and shell fragments indicate the presence of bottom water currents and periodic sediment gravity flows. These currents, however, do not preclude the presence of euxinic bottom water conditions.

XRF and thin-section analysis shows that early diagenetic calcite helped prevent compaction and preserve primary texture. Anoxic indicators, such as Molybdenum are seen to be highest where the highest preservation of TOC is present and vice versa, suggesting a good qualitative trend is present. Bulk XRD analysis plots the Sharon Springs as a silica-rich argillaceous mudstone, and thin-section and SEM analysis illustrate a detrital origin for quartz.

Many of the well known biomarkers indicative of paleoenvironment are inconclusive in this small sampling. Biomarker analysis indicates a marine to mixed marine source for the organic matter. C28 steranes dominate with 42-44 wt%. A ternary diagram of the C27, C28 and C29 steranes suggest that the organic matter is primarily algal in origin. While gammacerane is present in the markers, the low values in the Gammacerane Index (Gammacerane/C30-Hopane) is inconclusive on water column stratification. However, the high C30-Hopane values may be indicative of the presence of methylotrophs. The source rocks for this well are on the lower side of maturity and hydrocarbon migration is likely to play a part in accumulation for production. For future work, comparison of biomarkers in less organic-rich Sharon Springs wells could help identify environmental conditions which led to high organic preservation.

Conclusions

- Facies analysis indicates deposition in periods of high energy and comparatively lower energy, though still containing a strong current.
- Rounded clay floccules present in facies deposited under high energy conditions, the facies associated with sediment gravity flow deposits. Rounded shape was preserved due to early diagenetic calcification.
- Elongated clay floccules present in facies deposited under comparatively lower energy conditions, with strong current. The lack of early diagenetic calcification allowed for compaction and elongation of the clay floccules.
- Qualitative XRF curves indicate that highest TOC preservation correspond to highest levels of anoxia/euxinia.
- Biomarker analysis is inconclusive on paleoenvironmental indicators. Organic matter is from a marine to mixed marine source, likely algal in origin. Lower maturity is seen with migration playing a part in hydrocarbon accumulation.

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Acknowledgments

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