[PS]Manning Canyon Shale in the Northern San Rafael Swell: A Potential Natural Gas Resource Play?*

Steven Schamel[1] and Jeffrey Quick[2]

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Abstract

Across broad areas of northern and west-central Utah, the Upper Mississippian is represented by two interbedded formations, the Manning Canyon Shale and the Great Blue Limestone. The Manning Canyon Shale contains minor carbonates and locally abundant organic matter, whereas the carbonate-rich Great Blue Limestone generally lacks appreciable organic matter and siliciclastic constituents. The Manning Canyon Shale is a regionally significant, potential hydrocarbon source rock. Wells completed in Manning Canyon Shale at the north end of the San Rafael Swell near Price, Utah, have shown enticing, albeit sub-commercial, natural gas flow rates. This study describes core from a vertical well in this area (Carbon Canal 5-12), which was completed in Manning Canyon Shale during early 2008 by Shell E&P Inc. Shortly after completion, testing of this well showed production rates of 78 Mcf/d and 667 Bw/d over a 63-hour period. The produced gas contained 93% methane, 4% ethane, 1.4 % nitrogen, and just 0.5% carbon dioxide, with a heating value of 1,052 BTU/scf. Down-hole fiber optics indicated that most of the flow was from between 9,124 ft to 9,350 ft, roughly corresponding to the lower half of the cored interval. The 546 ft core (8,805-9,351 ft depths) includes the upper two-thirds of the Manning Canyon Shale and 101 ft of the overlying Oquirrh/Round Valley Formation. Nearly 90% of the Manning Canyon part of the core consists of carbonaceous shale and limestone, which is typically silty with laminar features. The remainder is largely non-carbonaceous, nodular and micritic limestone. The inorganic constituents includes sub-equal parts of quartz as silt grains and minor siliceous sponge spicules, carbonate as lime mud, microbioclasts and skeletal debris, and clay. Total organic carbon (TOC) ranges from <1% to >60% and is present as microscopic grains, macroscopic plant parts, and four thin coal beds. Despite abundant TOC, the generation potential (S1+S2) is poor to fair (0.1-6 mg HC/g rock), consistent with the high maturity (dry gas stage) and abundant inertinite (fossil charcoal) indicated by petrographic analyses. Nonetheless, inflated sealed core sample bags suggest that the Manning Canyon Shale retains some quantity of adsorbed natural gas and may have shale-gas reservoir characteristics.

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Summary

Across broad areas of northern and west-central Utah the Upper Mississippian is represented by two interbedded formations, the Manning Canyon Shale and the Great Blue Limestone. The Manning Canyon Shale contains minor carbonates and locally abundant organic matter, whereas the carbonate-rich Great Blue Limestone generally lacks appreciable organic matter and siliciclastic constituents. The Manning Canyon Shale is a regionally significant, potential hydrocarbon source rock. Wells completed in Manning Canyon Shale at the north end of the San Rafael Swell near Price, Utah, have shown enticing, albeit sub-commercial, natural gas flow rates.

This study describes core from a vertical well in this area (Carbon Canal 5-12), which was completed in Manning Canyon Shale during early 2008 by Shell E&P Inc. Shortly after completion, testing of this well showed production rates of 78 Mcf/d and 667 Bw/d over a 63 hour period. The produced gas contained 93% methane, 4% ethane, 1.4 % nitrogen, and just 0.5% carbon dioxide, with a heating value of 1,052 BTU/scf. Down-hole fiber-optics indicated that most of the flow was from between 9124 ft to 9350 ft, roughly corresponding to the lower half of the cored interval. The 546 ft core (8805-9351 ft depths) includes the upper two-thirds of the Manning Canyon Shale and 101 ft of the overlying Oquirrh/Round Valley Formation. Nearly 90% of the Manning Canyon part of the core consists of carbonaceous shale and limestone, which is typically silty with laminar features. The remainder is largely non-carbonaceous, nodular and micritic limestone.

The inorganic constituents includes sub-equal parts of quartz as silt grains and minor siliceous sponge spicules, carbonate as lime mud, microbioclasts and skeletal debris, and clay. Total organic carbon (TOC) ranges from <1% to >60% and is present as microscopic grains, macroscopic plant parts, and four thin coal beds. Despite abundant TOC, the generation potential (S1+S2) is poor to fair (0.1-6 mg HC/g rock), consistent with the high maturity (dry gas stage) and abundant inertinite (fossil charcoal) indicated by petrographic analyses. Nonetheless, inflated sealed core sample bags suggest that the Manning Canyon Shale retains some quantity of adsorbed natural gas and may have shale-gas reservoir characteristics.

Features to Observe in the Carbon Canal 5-12 Core

The dominance of dark carbonaceous limey and silty mudstones with alternating intervals of friable and dense mudstones.

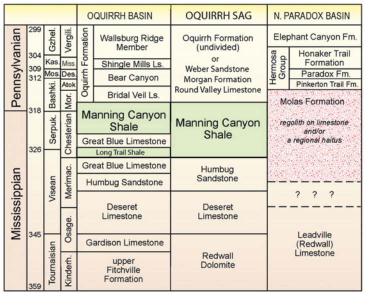
Systematic variations in lithofacies upward through the core, becoming less shaly and organic-rich towards the top.

Repeated "freshing - upward" lithologic cycles in which dark highly carbonaceous mudstone or shale rests with sharp boundary on non- or poorly-carbonaceous lime mudstone. Are these eustatic parasequences, or merely products of migrating mudmounds (keys) and shallow, poorly ventilated lagoons?

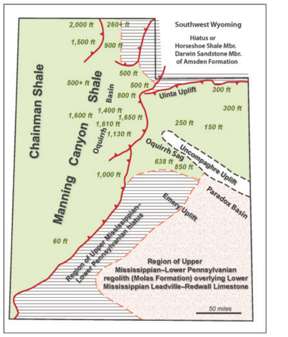
Thin coal beds frequently associated with organic-rich shelly limestone laminae.

Siderite nodules in the lower parts of the core indicating a fresh-water depositional setting.

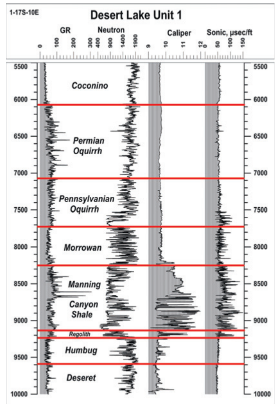
Inflated silver mylar sealed gas canister samples indicating continued desorption of methane from the rock.

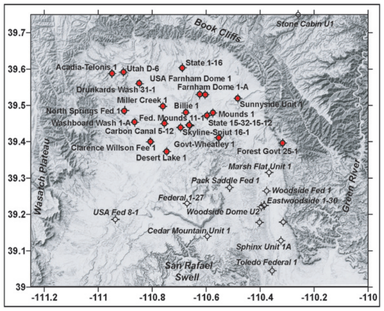


In the Middle Mississippian, the sea was withdrawing from the broad carbonate shelf that had been developed across much of western North America leaving an extensive karst plain from the Four Corners area north through eastern Utah, Colorado, Wyoming and into Montana. In northeast Utah, an embayment remained on the shelf in which marine carbonate and sandstone deposition (Humbug Formation) continued. To the west in central Nevada, the foredeep basin to the Antler orogenic belt had advanced eastward onto the edge of the carbonate shelf, burying it under terrigeneous sediments derived from the thrust belt, the proximal Diamond Peak Conglomerate and the distal Chainman Shale. It was into this setting that the interfingering lithologies of the Manning Canyon Shale and the Great Blue Limestone were deposited. It was also at this time that the Oquirrh Basin and its shelfal extension, the Oquirrh Sag, began to take shape.



The Manning Canyon Shale has a distinctive signature in GR, density, and sonic logs, but especially in the caliper logs due to friable mudstone intervals.

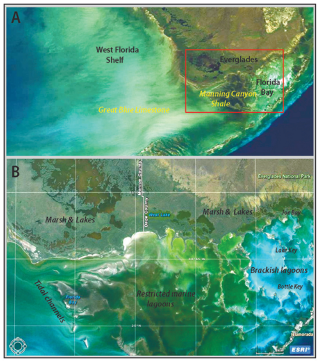


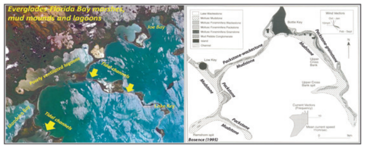


At the north terminus of the San Rafael Swell, wells in which Manning Canyon Shale is present in the section are shown in red.

The Manning Canyon Shale was deposited in a marine to brackish environment that in part included or was in proximity to coastal swamps and marshes. The apparent absence of lateral continuity of stratigraphic markers within the formation suggests a heterogeneous setting in which depositional environments varied laterally over short distances, not just through time. The fresh water marshes of the Everglades and shallow brackish to marine carbonate factory of the Florida Bay might serve as a conceptual model for the depositional setting of the Manning Canyon Shale. The most prominent sedimentary features of the Florida Bay are the mud mounds (mudbanks and mud islands) that form a web of shoals and keys enclosing shallow lagoons. The adjacent West Florida Shelf could be a modern analogue for the depositional setting of the Great Blue Limestone.

Imagine that across a similar shallow unrimmed shelf and near-shore marine to brackish-paludal environment there was a virtually constant rain of loess during the Late Mississippian and Early Pennsylvanian. This was a time of both exposure of large areas of the shelf in western North America, the source of dust, and entry into global icehouse climates that were drier with likely stronger winds. What distinguishes the Manning Canyon Shale from the Great Blue Limestone is the relative amount of silt and clay, as well as terrestrial organic matter. The rocks identified as Great Blue Limestone were those on the carbonate shelf more distant from land, the source of the dust and the plant debris. Deposition of the Manning Canyon Shale "facies" began when large quantities of dust were made available by icehouse-driven climate change across an extensive exposed land surface and ended when large portions of this land surface were flooded by shallow epeiric seas in the Early Pennsylvanian.





Acknowledgements

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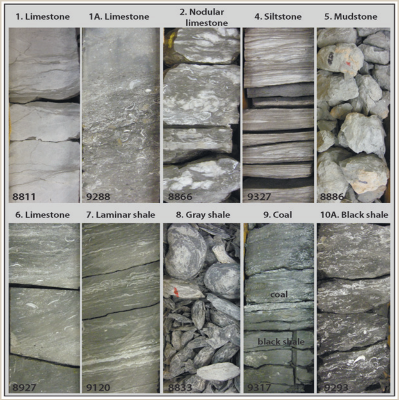
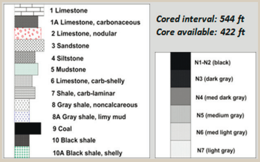
See our Manning Canyon Shale paper in Utah Geological Association Publication 42 (2013)

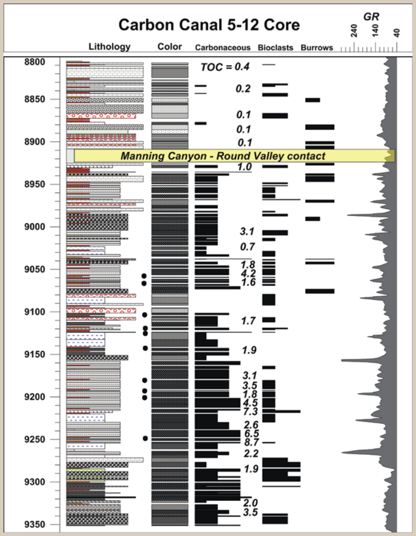
Manning Canyon Shale in the northern San Rafael Swell



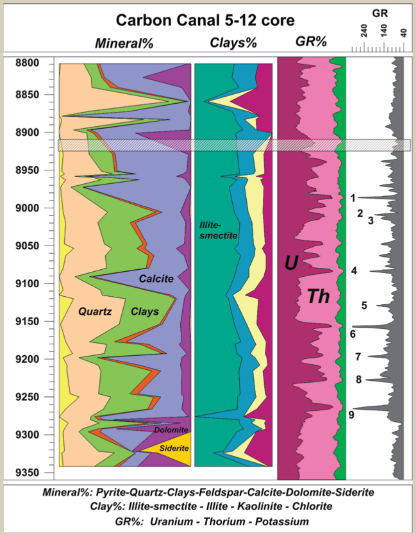


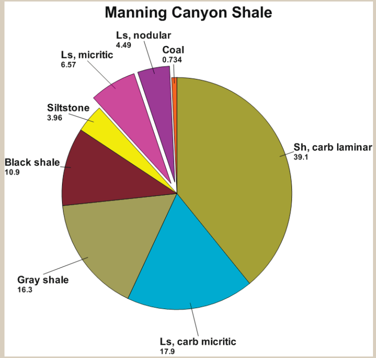
All Manning Canyon Shale lithofacies, except for the 1. Limestone and 2. Nodular limestone, are carbonaceous. The 1A. Limestone is a weakly carbonaceous varient of the 1. Limestone. These three lithofacies commonly form the tops of the depositional cycles.

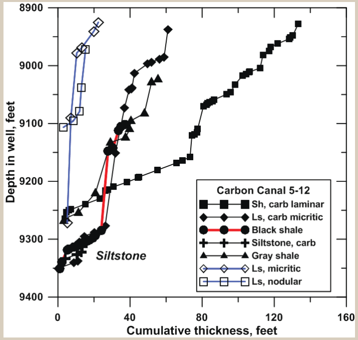
Lithology + Organic Richness



Mineralogy + Spectral Gamma Ray







The Manning Canyon Shale lithologies observed in Carbon Canal 5-12 core fall into two groups, those that are carbonaceous and those that are not.

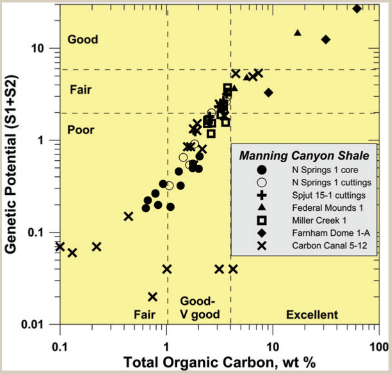
- **Shale, carbonaceous laminar** – thin laminated calcareous shale to weakly laminated argillaceous wackestone and microbioclast packstone including the lithofacies 7 and 6. These lithofacies contain an abundance of disseminated fine-grained to coarse coaly plant fragments. The color is variably grayish black (N2) to dark gray (N3), but organic matter-poor laminae are lighter colored (N4-N5). The laminated shale may enclose thin-shelled pelecyopod or bracheopod fragments strongly aligned with bedding. The weakly laminated limestone variant is normally rich in thin- and thick-shell whole and fragmental skeletal material.
- **Limestone, carbonaceous micritic** – poorly-bedded, dark gray (N3) to grayish black (N2) organic-rich, limy mudstone designated as lithofacies 1A. Distinguished from lithofacies 6 only by the absence of distinct bedding and commonly overlying gradationally lithofacies 6 and/or 7. As with lithofacies 6, this lithology is commonly rich in varied skeletal debris.
- **Gray shale** – structure-less to weakly laminated, carbonaceous shale that is grayish black to dark gray (N2-N3) in color. The rock is a "paper shale" where very organic-rich (lithofacies 8A), but breaks into convex chips (lithofacies 8) when less so. The rock is weakly- to non-calcareous and normally free of skeletal debris.
- **Black shale** – laminar carbonaceous grayish black to black (N2-N1) shale, normally rich in thick- and thin-walled shell fragments. This is the lithofacies 10 and 10A shell-free and shell-rich, respectively. The shale is commonly silty and it may interfinger with siltstone.
- **Siltstone** – characterized by thin-laminated alternations of medium gray (N5) siltstone and dark gray (N3) carbonaceous shale of lithofacies 8. The silt layers are a mix of angular quartz and microbioclast grains.
- **Coal** – faintly bedded on millimeter scale, or unbedded and structureless. Fracture surfaces are concoidal and highly luminous. One of the four coal beds contains a 0.8 cm thick bed of microbioclasts and thin-shelled brachiopod fragments in a black shale matrix. The deepest coal bed (9317.3-9318.3 ft) contains thin laminae rich in clay and pyrite.
- **Limestone, micritic** – limy mudstone (lithofacies 1) that is dark gray to medium dark gray (N3-N4), but poor in or devoid of organic carbon. The rock can be irregularly bedded, or structureless.
- **Limestone, nodular** – irregularly bedded to nodular limy mudstone (lithofacies 2) commonly containing skeletal debris, but poor in or devoid of organic carbon.

The Carbon Canal 5-12 core exhibits two expressions of stratigraphic cyclicity. The most obvious cycling relates to the secular variation in the proportions of siliciclastics versus carbonates as observed in the XRD mineral compositions. There are five relatively thick intervals dominated by siliciclastics separated by thin carbonate-dominate intervals. Given that the Manning Canyon Shale basin was inherently a carbonate environment of deposition into which siliciclastics are deposited, probably transported by wind, the cycles are recording times at which the influx of silt, clay and iron oxides are especially high.

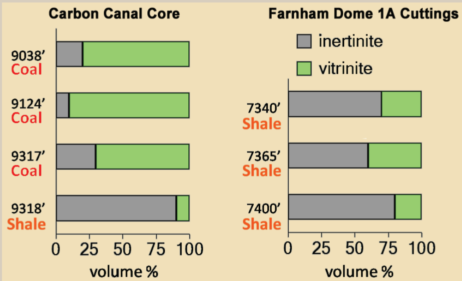
The second type of cyclicity is more subtle and is tied to alternations in the lithofacies described to the left. One reoccurring cycle involves a black or very dark gray carbonaceous lithofacies passing gradually upward into a medium gray, less carbonaceous or non-carbonaceous lithofacies to be overlain abruptly by a black carbonaceous lithofacies. The cycle boundaries clearly mark an upward change from aerobic or dysaerobic to anoxic or anoxic-dysaerobic. From this single core it is not clear if such surfaces can be designated as flooding surfaces or parasequence boundaries. Alternatively, the packets could indicate merely the upward freshening of bottom waters, as within poorly-ventilated lagoons becoming better ventilated.

Graphs above show the relative proportion of lithofacies observed in core, and the vertical distribution of the lithofacies. Note that the 10. Black shale and 4. Siltstone are most common in the lower core and the non-carbonaceous limestone lithofacies are mainly in the upper core.

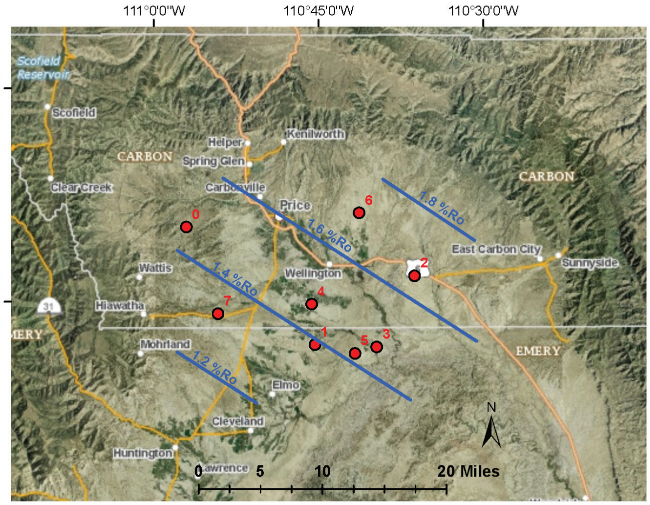
Organic petrography and geochemistry

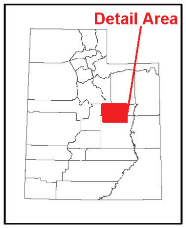


Abundant organic matter but limited hydrocarbon potential for the Manning Canyon Shale as indicated by total organic carbon (TOC wt%) and genetic potential (GP=S1+S2)



Abundant inertinite, and lack of associated vitrinite, can mislead the petrographer and result in erroneously high measured vitrinite reflectance measurements. Vitrinite in coal beds in the Carbon Canal 5-12 core were the key to recognizing the abundance of inertinite





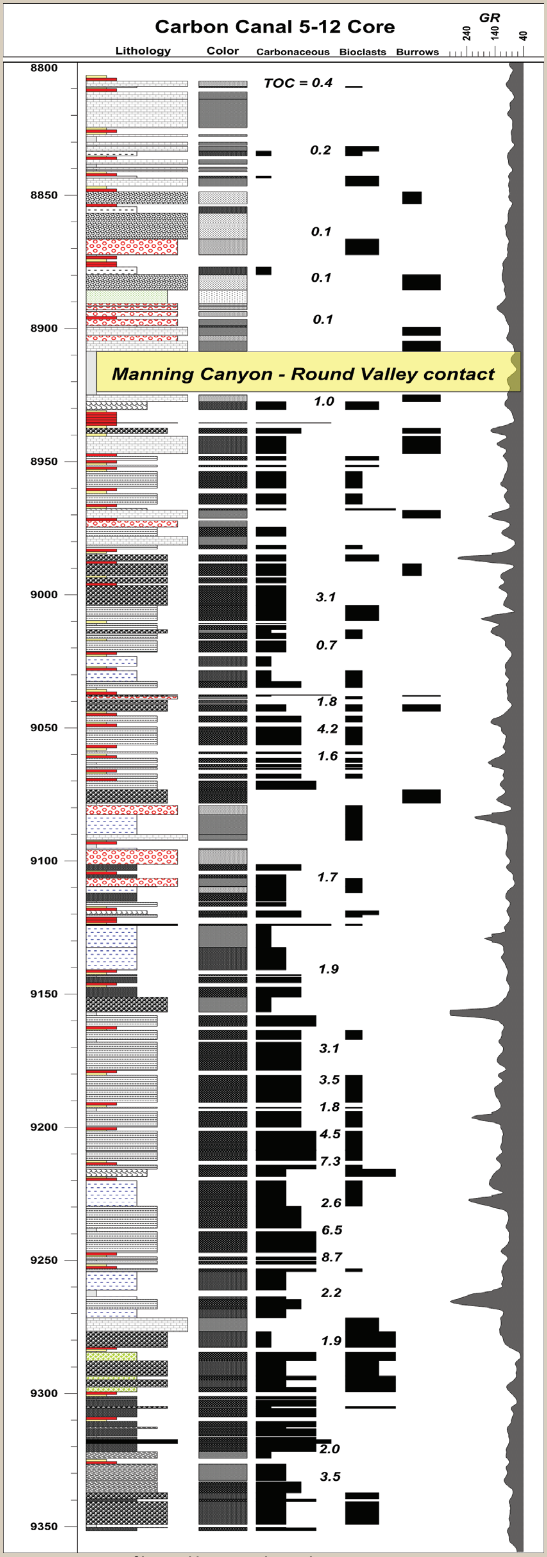
Drill hole with vitrinite reflectance (Ro) measurement

Best-fit Ro trend surface isoline

ID	Drill Hole Name	API	UTME	UTMN	Ro avg
0	Arcadia Telonis 1	4300730093	504251	4381962	1.41
1	Carbon Canal 5-12	4301530709	520963	4366663	1.43
2	Farnham Dome 1-A	4300715395	533892	4375629	1.70
3	Fed Mounds 1	4301510825	528984	4366369	1.45
4	Miller Creek 1	4300711029	520529	4371939	1.35
5	Spjut 15-1	4301530067	526174	4365533	1.38
6	State 1-16	4300730071	526701	4383803	1.73
7	North Springs 1	4300710791	508373	4370693	1.43

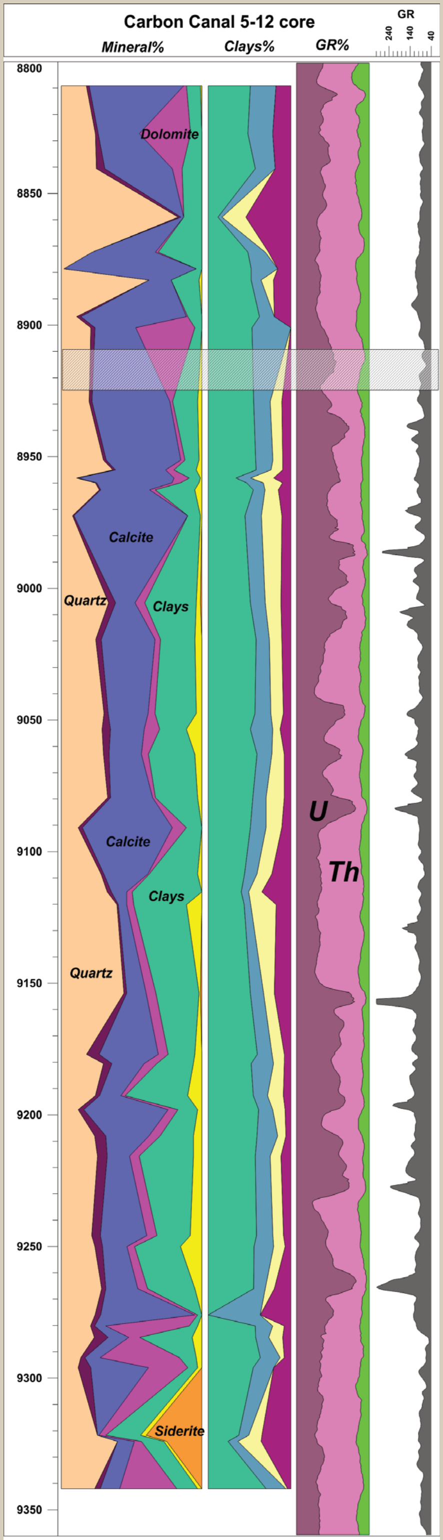
A first-order trend surface of average vitrinite reflectance for eight wells shows increasing maturity of the Manning Canyon Shale towards the northeast. The equation: $Ro=-9.739E\text{-}6UTME+1.4918E\text{-}5UTMN-68.83$, has an adjusted R2 of 0.68, and a standard error of 0.08.

Carbon Canal 5-12 Core Logs



Short red bars: gas desorption test
Short yellow bars: sample removed

Log description by Steven Schamel, GeoX Consulting Inc



Mineral%: Quartz-Feldspar-Calcite-Dolomite-Clays-Pyrite-Siderite
Clay%: Illite-smectite - Illite - Kaolinite - Chlorite
GR%: Uranium - Thorium - Potassium

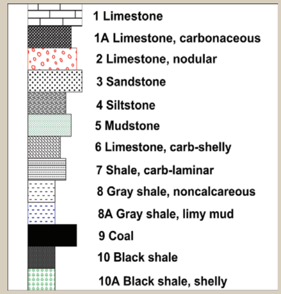
XRD data from Core Lab report for SWEPI, July 2008 (Grover, 2008)

Analytical data - parasequences

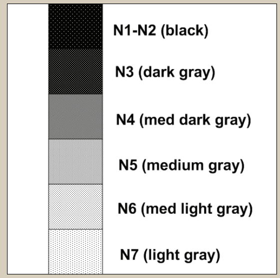
not to scale

From	To	Lithology Keyword		TOC	HI	Ro	Por%	Sg	Thick
8807.1	8809.1	1 Limestone	N5						2.0
8809.1	8809.5	8 Shale	N3	0.06	103				0.4
8811.2	8813.9	1 Limestone	N4						2.7
8813.9	8824.6	1 Limestone	N4						10.7
8827.2	8827.9	1 Limestone	N4						0.7
8830.0	8831.2	1 Limestone	N4						1.2
8831.6	8833.4	1 Limestone	N4						1.8
8833.4	8835.2	8 Shale	N3						1.8
8836.6	8838.3	1 Limestone	N4						1.7
8839.5	8840.2	1 Limestone	N4						0.7
8840.7	8841.1	1 Limestone	N4	0.22	18	1.18	1.8	10.50	0.4
8842.8	8843.5	8 Shale	N3						0.7
8843.5	8846.6	1 Limestone	N4						3.1
8848.7	8853.2	3 Sandstone	N6						4.5
8854.2	8856.7	8 Shale	N3						2.5
8856.7	8866.4	3 Sandstone	N6						9.7
8866.4	8872.3	2 Limestone	N5	0.10	53	1.25	5.6	15.80	5.9
8876.9	8879.8	8 Shale	N3	0.09	12				2.9
8879.8	8885.6	3 Sandstone	N6						5.8
8885.6	8890.6	5 Mudstone	N7						5.0
8890.6	8891.5	2 Limestone	N5						0.9
8891.7	8893.0	2 Limestone	N5				2.1	11.10	1.3
8893.6	8895.5	2 Limestone	N5						1.9
8896.5	8899.0	2 Limestone	N4	0.13	38				2.5
8899.0	8899.5	8 Shale	N3						0.5
8899.5	8902.7	1 Limestone	N4						3.2
8902.7	8904.7	2 Limestone	N5						2.0
8904.7	8908.5	1 Limestone	N4						3.8
8925.0	8927.5	1 Limestone	N5						2.5
8927.5	8930.5	6 Limestone	N3	1.01	1		8.9	79.00	3.0
8935.4	8935.6	9 Coal	N2						0.2
8937.4	8939.5	1A Limestone	N2						2.1
8940.5	8947.0	1 Limestone	N3						6.5
8948.0	8949.5	7 Limestone	N2						1.5
8951.3	8951.9	7 Limestone	N2						0.6
8953.7	8960.0	7 Limestone	N2						6.3
8962.0	8966.0	7 Limestone	N2						4.0
8967.6	8968.3	6 Limestone	N2						0.7
8968.3	8971.3	1 Limestone	N4						3.0
8972.3	8974.6	2 Limestone	N4						2.3
8974.6	8978.1	7 Limestone	N2						3.5
8978.1	8981.3	1 Limestone	N4						3.2
8981.3	8982.8	7 Limestone	N2						1.5
8984.9	8987.4	1A Limestone	N2				4.0	24.60	2.5
8988.4	8992.9	1A Limestone	N2						4.5
8993.5	8995.6	1A Limestone	N2						2.1
8996.6	9004.0	1A Limestone	N2						7.4
9004.0	9009.8	7 Limestone	N2	3.14	1	1.19			5.8
9010.7	9011.0	7 Limestone	N2						0.3
9011.5	9013.1	7 Limestone	N2						1.6
9013.1	9014.4	1A Limestone	N4						1.3
9014.4	9016.5	7 Limestone	N2						2.1
9017.3	9021.5	7 Limestone	N2	0.74	1	1.23			4.2
9023.2	9026.9	8A Shale	N3						3.7
9028.5	9032.5	8A Shale	N3						4.0
9032.5	9034.8	7 Limestone	N2						2.3
9037.5	9037.8	9 Coal	N1						0.3
9037.8	9038.2	1A Limestone	N2						0.4
9038.2	9039.2	2 Limestone	N4						1.0
9039.6	9040.8	1A Limestone	N3						1.2
9041.2	9043.8	1A Limestone	N2						2.6
9045.5	9047.9	7 Limestone	N2	1.80	17	1.23			2.4
9049.5	9056.5	7 Limestone	N2	4.22	1	1.22			7.0
9059.0	9059.8	7 Limestone	N2						0.8
9061.4	9063.0	7 Limestone	N2	1.58	23	1.20	5.6	14.80	1.6
9063.6	9064.7	7 Limestone	N2						1.1
9065.0	9065.6	7 Limestone	N2						0.6
9067.3	9069.0	7 Limestone	N2						1.7
9070.0	9073.2	7 Limestone	N2						3.2
9073.2	9078.3	1A Limestone	N2						5.1
9079.1	9082.6	2 Limestone	N5						3.5
9082.6	9090.1	8A Shale	N4						7.5
9090.1	9092.2	1 Limestone	N4				8.1	23.10	2.1
9095.2	9095.8	8A Shale	N4						0.6
9095.8	9101.3	2 Limestone	N5						5.5
9101.3	9103.5	10 Black shale	N2						2.2
9105.1	9106.5	10 Black shale	N2						1.4
9106.5	9109.5	2 Limestone	N4						3.0
9109.5	9109.7	7 Limestone	N2						0.2
9109.7	9112.0	8A Shale	N5						2.3
9112.0	9115.1	10 Black shale	N2						3.1
9115.5	9117.0	7 Limestone	N2	1.69	28	1.25	7.7	21.70	1.5
9118.7	9120.2	6 Limestone	N2						1.5
9120.2	9121.2	7 Limestone	N2						1.0
9123.7	9124.2	9 Coal	N1						0.5
9124.2	9132.5	8A Shale	N4						8.3
9132.5	9140.9	8A Shale	N3						8.4
9142.6	9143.1	10 Black shale	N2						0.5
9143.5	9145.7	10 Black shale	N2				8.5	8.60	2.2
9147.3	9151.1	10 Black shale	N2						3.8
9151.1	9156.7	1A Limestone	N4						5.6
9158.0	9162.1	7 Limestone	N2						4.1
9163.6	9167.0	7 Limestone	N2						3.4
9168.0	9178.6	7 Limestone	N2	3.13	50	1.26			10.6
9180.4	9190.7	7 Limestone	N2	3.48	33	1.23			10.3
9192.4	9192.9	7 Limestone	N2	1.79	40	1.28	7.6	53.00	0.5
9193.9	9200.0	7 Limestone	N2						6.1
9201.4	9208.9	7 Limestone	N2	4.48	79	1.26	6.1	46.00	7.5
9209.4	9212.5	7 Limestone	N2						3.1
9214.2	9215.7	7 Limestone	N2	7.33	52	1.26	8.3	44.00	1.5
9215.7	9218.5	6 Limestone	N2						2.8
9220.1	9229.7	8A Shale	N2						9.6
9229.7	9237.9	7 Limestone	N2				5.1	37.30	8.2
9239.2	9247.1	7 Limestone	N2						7.9
9248.6	9249.8	7 Limestone	N2						1.2
9250.2	9251.5	7 Limestone	N2	6.47	56	1.59	5.1	32.30	1.3
9253.2	9254.3	7 Limestone	N2						1.1
9254.3	9261.2	8A Shale	N3						6.9
9263.6	9264.6	8A Shale	N3						1.0
9264.6	9268.3	7 Limestone	N2	2.17	28	1.59	5.8	9.80	3.7
9268.3	9271.6	8A Shale	N3						3.3
9271.6	9276.7	1 Limestone	N4						5.1
9276.7	9282.6	1A Limestone	N3						5.9
9284.5	9287.7	10A Black shale	N2	1.93	38	1.62	6.6	33.80	3.2
9287.7	9293.4	1A Limestone	N3						5.7
9293.4	9294.9	10A Black shale	N2						1.5
9294.9	9297.6	1A Limestone	N3						2.7
9297.6	9299.4	10A Black shale	N2						1.8
9301.0	9302.1	10 Black shale	N2				10.5	41.30	1.1
9302.5	9304.8	10 Black shale	N2						2.3
9304.8	9305.6	1A Limestone	N3						0.8
9305.6	9308.8	10 Black shale	N2						3.2
9310.5	9312.6	10 Black shale	N2						2.1
9312.6	9313.2	4 Siltstone	N3						0.6
9313.2	9316.0	10 Black shale	N2				7.2	25.80	2.8
9316.4	9317.3	10 Black shale	N2						0.9
9317.3	9318.8	9 Coal	N2						1.5
9318.8	9321.8	10 Black shale	N2	1.95	55	1.64			3.0
9321.8	9324.3	4 Siltstone	N4						2.5
9326.5	9332.7	4 Siltstone	N4						6.2
9333.1	9337.3	4 Siltstone	N2	3.51	45	1.80	7.0	27.60	4.2
9337.3	9339.6	1A Limestone	N3						2.3
9339.6	9340.6	10 Black shale	N2						1.0
9340.6	9349.2	1A Limestone	N3						8.6
9350.2	9350.4	1A Limestone	N3						0.2
9350.4	9351.5	10 Black shale	N2						1.1

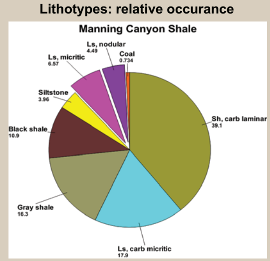
Key to Log Lithotypes



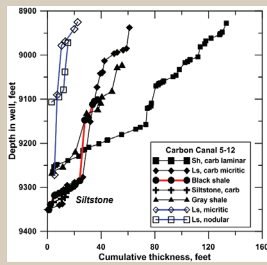
Key to Log Color



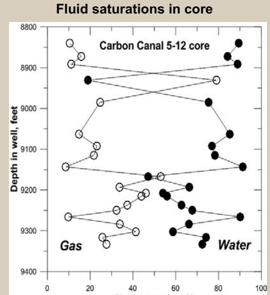
Lithotypes: relative occurance



Lithotypes: cumulative distribution



Fluid saturations in core

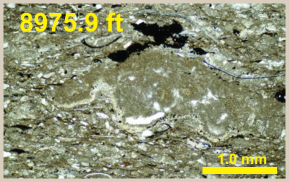


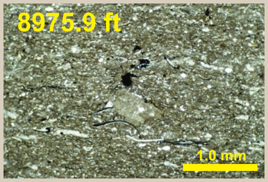
Parasequences: red bars indicate sharp contact of organic rich rock on organic-poor limestone, a possible flooding surface. The orange bars indicate a less clear boundary.

Display prepared July 9, 2011 by
Steven Schamel, GeoX Consulting Inc

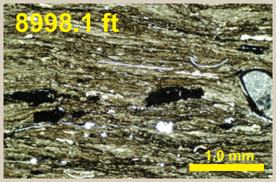
Plate 2

Carbon Canal 5-12 photomicrographs

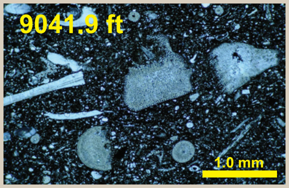


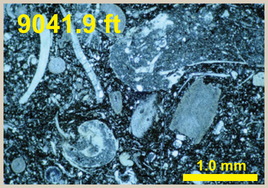


8975.9 ft: silty argillaceous wackestone with abundant lime mud fragments, some encrusted by algae, microbioclasts and shell fragments, including thin-walled pelcypod shell debris. Quartz silt is scattered through the lime mud matrix. Pyrite framboids.

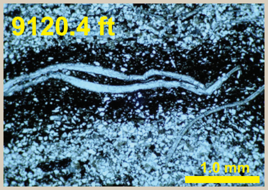


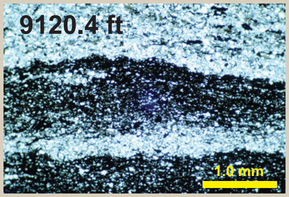
8998.1 ft: Laminated lime mudstone with wispy dark laminations and scattered shell fragments. Secondary white dolomite rhombs.



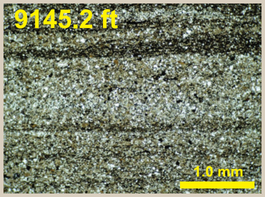


9041.9 ft: Very dark gray wackestone rich in skeletal material, including fragmented bryozoans, crinoids, and thin-walled pelcypods. Lime mud rip-up clasts.

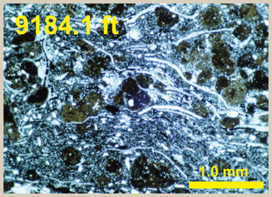




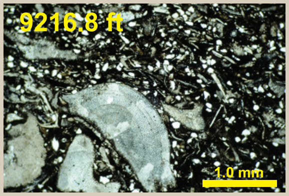
9120.4 ft: Interlaminated calcareous siltstone or silty packstone and silty calcareous shale. Some intervals are rich in thin-walled pelcypod shells.

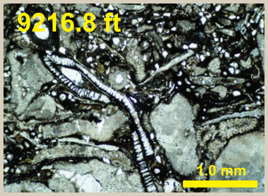


9145.2 ft: Finely laminated silty shale with minor microbioclasts.

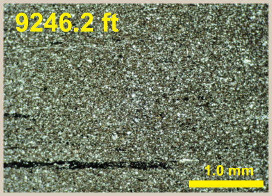


9184.1 ft: Very dark gray wackestone to packstone containing abundant thin-walled pelcypod shell debris and dark reddish brown phosphate nodules up to 0.5 mm in size.

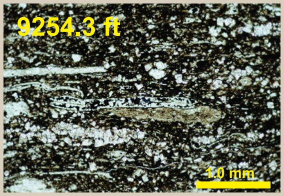




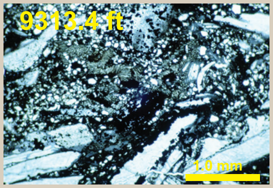
9216.8 ft: Very dark gray phosphatic wackestone rich in highly-abraded and recrystallized crinoid and other skeletal debris together with phosphate nodules.



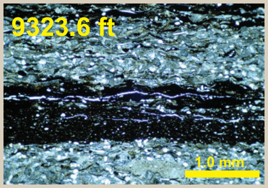
9246.2 ft: Dark gray laminated calcareous silty shale.



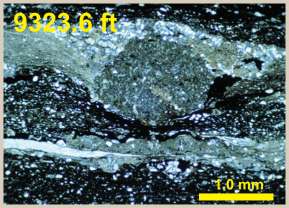
9254.3 ft: Pyritized shell-rich argillaceous wackestone containing reddish brown phosphate nodules.

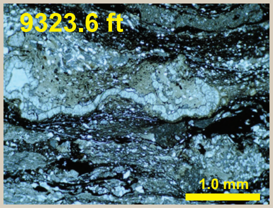


9312.4 ft: Black shale rich in skeletal debris partially pyritized.

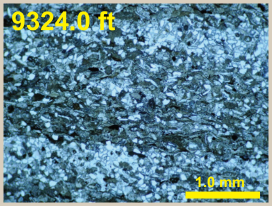


9323.6 ft: Interlaminated calcareous siltstone and organic-rich black shale. The thicker siltstone laminae contain a mix of quartz silt, sit-sized microbioclasts, and plant fragments. Also brown sideritic rip-up clasts, some of which are algae encrusted.

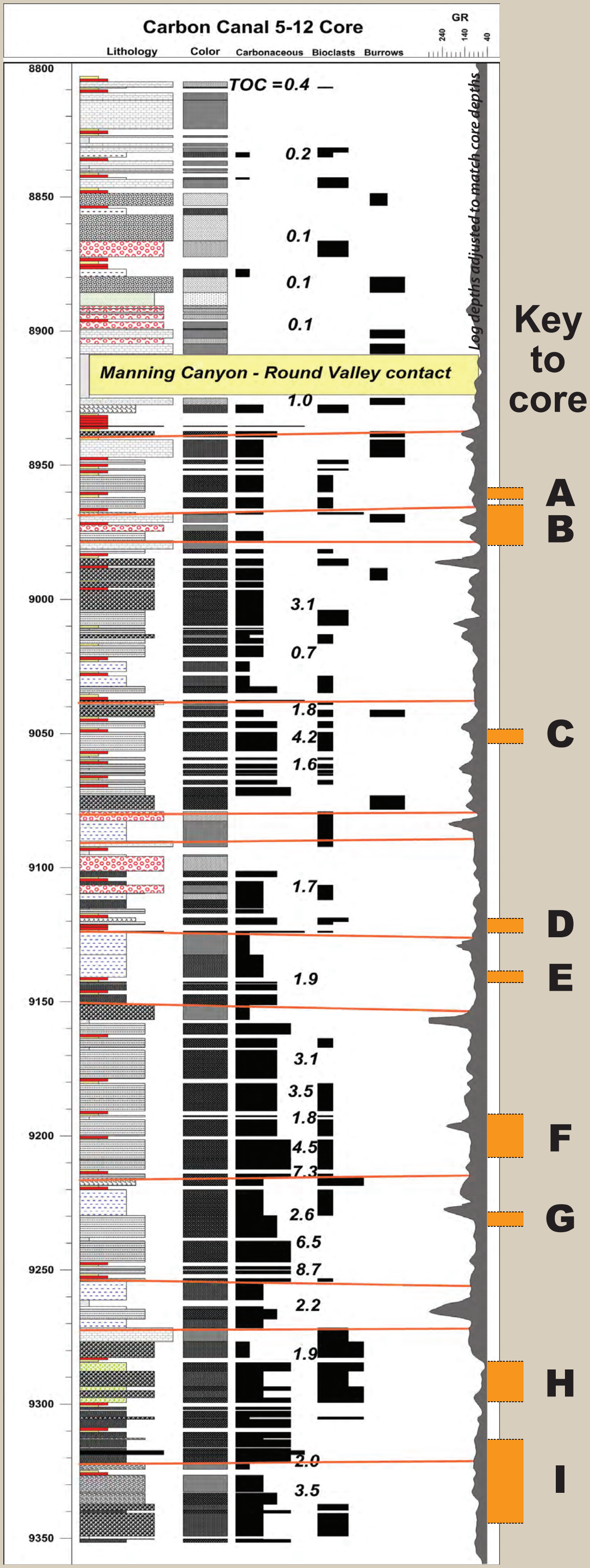




9323.6 ft: Interlaminated calcareous siltstone and organic-rich black shale. The thicker siltstone laminae contain a mix of quartz silt, sit-sized microbioclasts, and plant fragments. Also brown sideritic rip-up clasts, some of which are algae encrusted.



9324.0 ft: Laminated calcareous siltstone rich in silt-sized microbioclasts and containing plant fragments and thin-walled pelcypod shell debris.



Photography by Steven Schamel, GeoX Consulting Inc