[PS]Porosity, Permeability, and Pore Characterization of the Triassic Cumnock Formation: A Continuous Gas Assessment Unit, Sanford Sub-Basin, Deep River Basin, Lee County, North Carolina, USA*

Jeffrey C. Reid[1], Michael C. McGlue[2], and Geoffrey S. Ellis[3]

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Abstract

The Upper Triassic (Carnian) Deep River Basin is a continuous gas assessment unit (AU) and a total petroleum system. The source rocks (Cumnock Formation) are grey and black freshwater shales with thin basal coals. The Cumnock Formation was deposited in a lacustrine rift near the paleo-equator after the onset of the breakup of Pangea. The Deep River Basin Continuous Gas AU has an estimated mean gas content of 1,660 BCFG and an estimated mean natural gas liquids content of 83 MMBNGL (USGS Fact Sheet 2012-3075). In order to better characterize the potential for shale gas reservoirs in the Sanford sub-basin of the AU, twenty samples were analyzed from continuous core hole USBM DH2 (CH-C-1-45) between the depths of 1,047 and 1,178 feet. This zone is a candidate "sweet spot" for the Cumnock Formation. Fifteen additional samples (between the depths of 2,407 and 2,428 feet) were analyzed from the V.R. Groce #1 core (API 32-095-00009) located near the sub-basin center, where alluvial fan facies thin the Cumnock Formation and its coals. The majority of samples from both cores are laminated to massive, chlorite- and illite-rich mudrocks with variable carbonate and tektosilicate content and organic carbon concentrations ranging up to 6.4 weight percent. Mercury injection capillary pressure data were obtained to characterize porosity and permeability in the Cumnock Formation. A maximum pressure of 60,000 psia provided a pore aperture frequency distribution down to 0.00036 microns diameter. These data will ultimately be complimented by pore characterization using scanning electron microscopy and ion beam milled samples. The average Cumnock Formation porosity in the "sweet spot" (drill hole CH-C-1-45) is 2.28%; the minimum is 0.44%, the maximum is 6.43%, and the standard deviation is 1.46%. The average permeability in the "sweet spot" (drill hole CH-C-1-45) is 1.75 x 10^{-5} md. The minimum is 0.090 x 10^{-5}md, the maximum is 7.11 x 10^{-5} md, and the standard deviation is 1.77 x 10^{-5} mg. Porosity near the basin center (V.R. Groce #1) is 1.58%; the minimum is 0.24%; the maximum is 3.74%, and the standard deviation is 1.03%. Average permeability near the basin center is 1.61 x 10^{-5} md; the minimum is 0.05 x 10^{-5} md, the maximum is 6.68 x 10^{-5} md, and the standard deviation is 1.99 x 10^{-5} md. In conjunction with a growing database of mineralogy and organic geochemistry, these data provide the most robust assessment available of pore space in the Cumnock Formation.

Porosity, permeability, and pore characterization of the Triassic Cumnock Formation: A continuous gas assessment unit, Sanford sub-basin, Deep River basin, Lee County, North Carolina, USA

by Jeffrey C. Reid*, Michael M. McGlue**, and Geoffrey S. Ellis***

* North Carolina Geological Survey, **University of Kentucky, Lexington, and ***U.S. Geological Survey, Denver, CO

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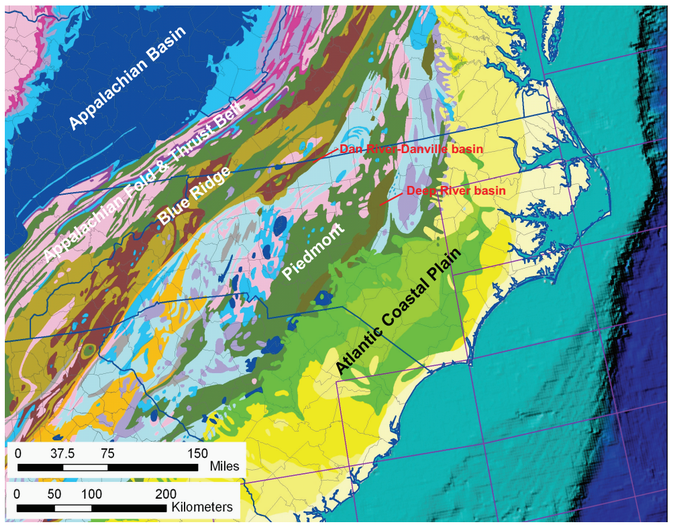
The Upper Triassic (Carnian) Deep River basin is a continuous gas assessment unit (AU) and a total petroleum system. The source rocks (Cumnock Formation) are grey and black freshwater shales with thin basal coals. The Cumnock Formation was deposited in a lacustrine rift near the paleo-equator after the onset of the breakup of Pangea. The Deep River basin Continuous Gas AU has an estimated mean gas content of 1,660 BCFG and an estimated mean natural gas liquids content of 83 MMBNGL (USGS Fact Sheet 2012 - 3075).

In order to better characterize the potential for shale gas reservoirs in the Sanford sub-basin of the AU, twenty samples were analyzed from continuous core hole USBM DH2 (CH-C-1-45) between the depths of 1,047 and 1,178 feet. This zone is a candidate "sweet spot" for the Cumnock Formation. Fifteen additional samples (between the depths of 2,407 and 2,428 feet) were analyzed from the V.R. Groce #1 core (API 32-095-00009) located near the sub-basin center, where alluvial fan facies thin the Cumnock Formation and its coals. The majority of samples from both cores are laminated to massive, chlorite- and illite-rich mudrocks with variable carbonate and tektosilicate content and organic carbon concentrations ranging up to 6.4 weight percent. Mercury injection capillary pressure data were obtained to characterize porosity and permeability in the Cumnock Formation. A maximum pressure of 60,000 psia provided a pore aperture frequency distribution down to 0.00036 microns diameter. These data will ultimately be complimented by pore characterization using scanning electron microscopy and ion beam milled samples.

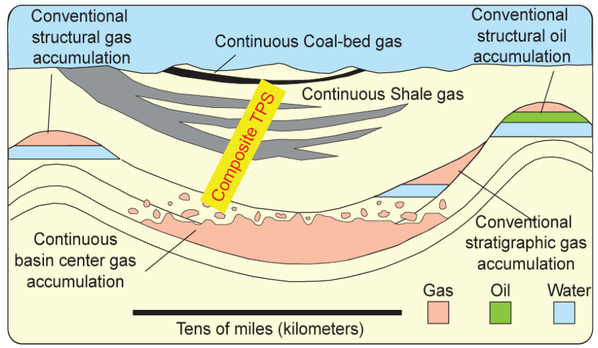
The average Cumnock Formation porosity in the "sweet spot" (drill hole CH-C-1-45) is 2.28%; the minimum is 0.44%, the maximum is 6.43%, and the standard deviation is 1.46%. The average permeability in the "sweet spot" (drill hole CH-C-1-45) is 1.75 x 10-5 md. The minimum is 0.090 x 10-5 md, the maximum is 7.11 x 10-5 md, and the standard deviation is 1.77 x 10-5. Porosity near the basin center (V.R. Groce #1) is 1.58%; the minimum is 0.24%; the maximum is 3.74%, and the standard deviation is 1.03%. Average permeability near the basin center is 1.61 x 10-5 md; the minimum is 0.05 x 10-5md, the maximum is 6.68 x 10-5 md, and the standard deviation is 1.99 x 10-5 md. In conjunction with a growing database of mineralogy and organic geochemistry, these data provide the most robust assessment available of pore space in the Cumnock Formation.



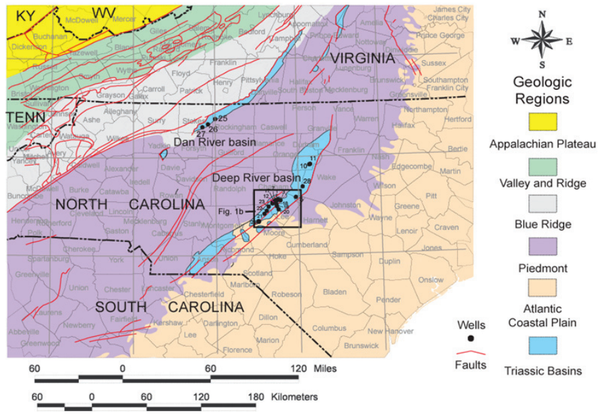
The geology of eastern North Carolina consists of a relatively thin to increasingly thick veneer of coastal plain sediments and sedimentary rocks of the Atlantic Coastal Plain, which range in age from Upper Jurassic(?) to Recent. These strata overlie a complex folded and faulted geology of metaigneous and metasedimentary rocks of Early Paleozoic to Late Proterozoic age, which in turn are punctuated in places by narrow Late Triassic(?) to Early Jurassic(?) rift basins. The stratigraphic geology of the Atlantic Coastal Plain section is composed of Mesozoic and Cenozoic siliciclastic and carbonate sedimentary rocks. This coastal plain has a relatively simple structural geology, with few faults and structures, other than those associated with the rift basins.

Identified and possible Triassic - Jurassic rift basins are not present in easternmost North Carolina based on drilling, seismic, and potential fields geophysical information. A hypothesized and undrilled Triassic-Jurassic rift basin (Cumberland-Marlboro basin) may be present beneath a thin coastal plain veneer. The basin is recognized by a large aeromagnetic low located parallel to, and seaward of the Deep River basin. (modified and adapted from Schruben and others, 1998).

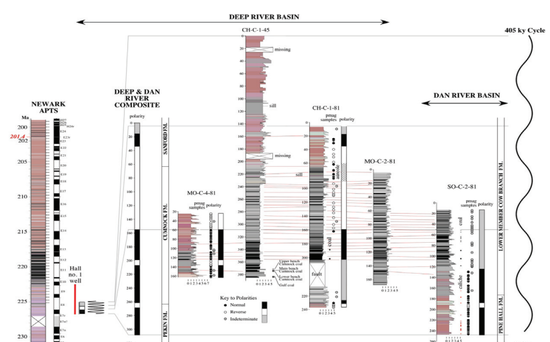
PANEL #1 - Overview and setting

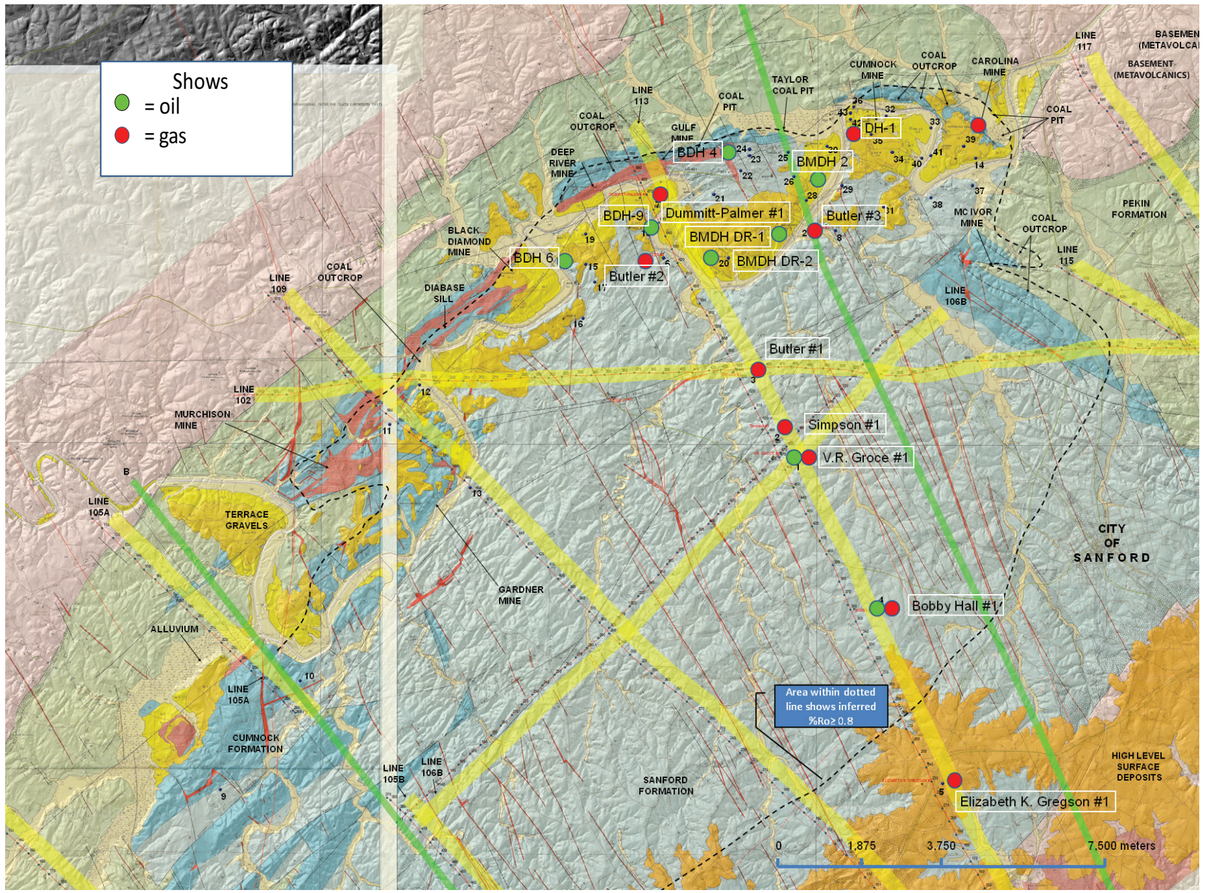


Geologic setting of continuous gas and oil accumulations relative to discrete accumulations in structural or stratigraphic traps (modified and adapted from Schmoker and others, 1995).The elements of a total petroleum system (TPS) shown in this diagram are present in both the Deep River and Dan River-Danville basins.



Location of the Deep River basin composite TPS (central North Carolina) and the Dan River-Danville basin composite TPS (north central North Carolina and south central Virginia). From Reid and Milici, 2008. The box in the central part of the Deep River basin is the location of the Sanford sub-basin. The Wadesboro sub-basin is located southwest of the Sanford sub-basin, and the Durham sub-basin is located northeast of the Sanford sub-basin.





Map showing the location of the V.R. Groce #1 well and the USBM DH2 drill hole in the Sanford sub-basin, Deep River basin. Yellow lines denote vintage 2D seismic lines. Green lines are cross section lines in Reinemund. Unlabled map area that is pink or uncolored is metavolcanic Paleozoic bedrock (adapted from Reid and others, 2010).

Left -- Shows the correlation of drill hole CH-C-1-45 (USBM DH2) with cores from the Sanford sub-basin of the Deep River basin and the Dan River-Danville basin. Correlation prepared by P.E. Olson using magnetic polarities (adapted from Fig. 26 in Reid and others, 2011).

Note: Please be sure to visit the companion poster in this session, "Unconventional reservoir potential of rift-lake mudrocks:Preliminary results from the Newark, Deep River, and Central Lake Malawi basins," by M.M. McGlue, G.S. Ellis, J.C. Reid, S. Peng, and T. Zhang. That poster's control id is 1841013.

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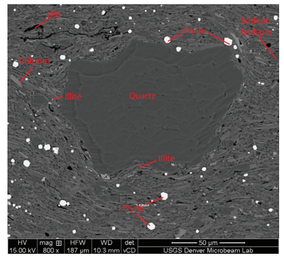
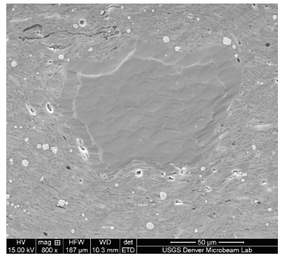
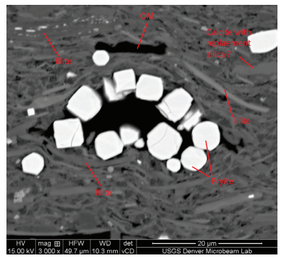
V.R. Groce #1 (32-105-00001) -- LE-OT-01-74

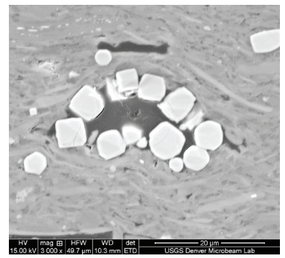


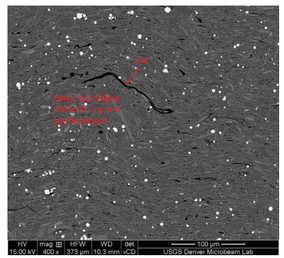
V.R. Groce #1, depth 2,407 feet. Field of view shows abundant clay, organic matter (OM) stringers, pyrite, and quartz grain.



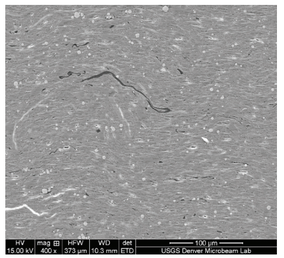


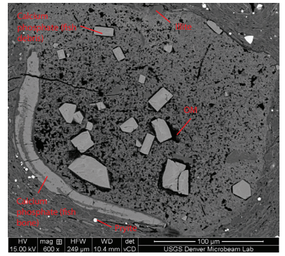
V.R. Groce #1, depth 2,407 feet. Field of view shows pyrite replacing organic matter (OM), with some evidence of organic matter porosity. Also present are illite; calcite may be replaced by silica.



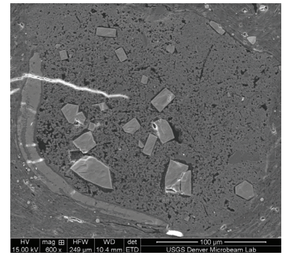


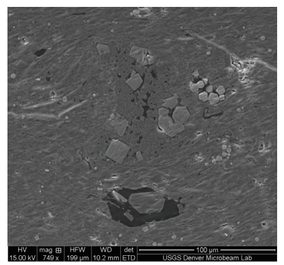
V.R. Groce #1, depth 2,407 feet. Field of view shows abundant clay, pyrite, organic material (OM) as wavy stringers, and pyrite.



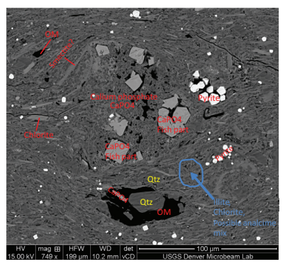


V.R. Groce #1, depth 2,407 feet. Field of view shows collophane nodule (CaPO4) with fish bones, organic matter (OM), pyrite, occluded clay, and intergranular pores.

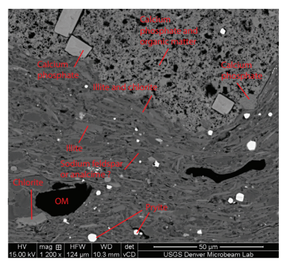




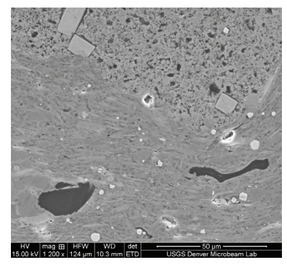
V.R. Groce #1, depth 2,407 feet. Field of view shows organic matter (OM), sodium feldspar, illite, chlorite, and pyrite.

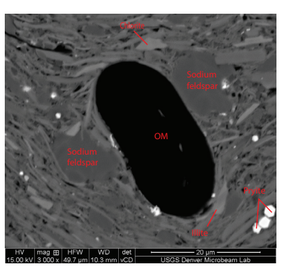


V.R. Groce #1, depth 2,407 feet. Field of view shows quartz, organic matter (OM), pyrite, clays (illite and chlorite) and phosphate (nodule and fish parts); analcime may be present (area of blue circle). Smectite ? may also be present in the field of view.

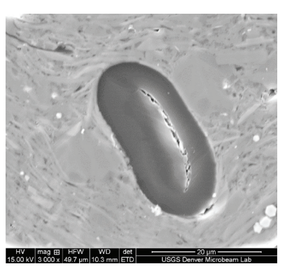


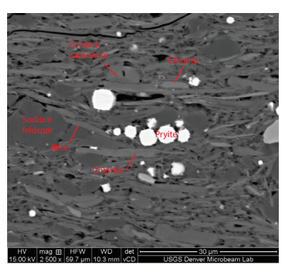
V.R. Groce #1, depth 2,407 feet. Field of view shows abundant clay (illite and chlorite), organic matter (OM) stringers, sodium feldspar (or possible analcime ?), pyrite, and a collophane phosphate nodule.



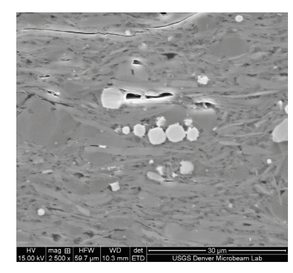


V.R. Groce #1, depth 2,407 feet. Field of view shows organic matter (OM), sodium feldspar, illite, chlorite, and pyrite.



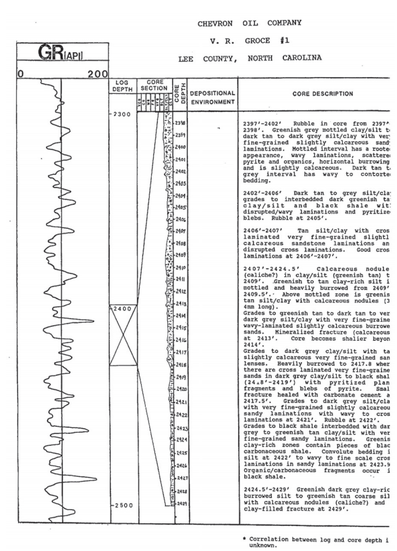


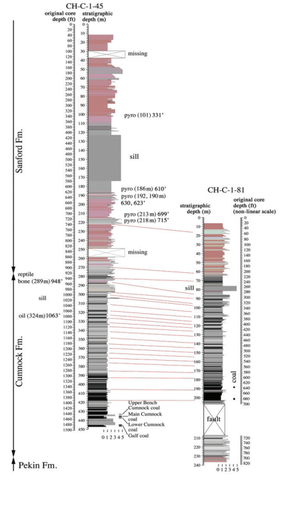
V.R. Groce #1, depth 2,407 feet. Field of view shows intergranular pores associated with clay minerals (illite and chlorite), pyrite, sodium feldspar and calcium carbonate. The intergranular pore are at contacts with rigid grains.



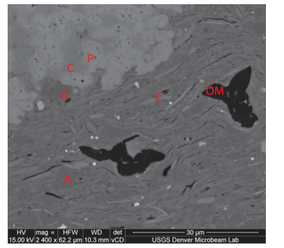
Summary of the V.R. Groce #1, depth 2,407 feet: 1) laminae appear wavy/convolute, 2) intergranular pores associated with clays are the most common pore type (1-5um in diameter), 3) quartz and feldspar are more common in the silt-size fraction in this sample as compared with the USBM DH2 sample, 4) the pyrite content is noticeably higher in this sample than the USBM DH2 sample - there is some porosity along the contact between these grains and clays (illite and chlorite). Analcime also appreares to be present. 5) Organic porosity is noticeably lower than the USBM DH2 samples, and is present in only rare instances, and 6) collophane phosphate nodules are common - some up to 600 um in diameter; some intergranular pores are present as in USBM DH2. 6) Organic matter (OM) is often wavy.

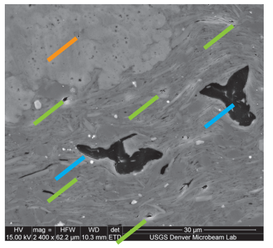
PANEL #2 - Reservoir characterization data



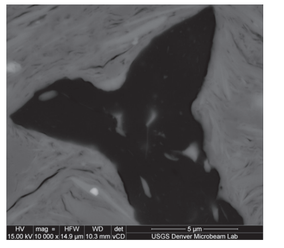


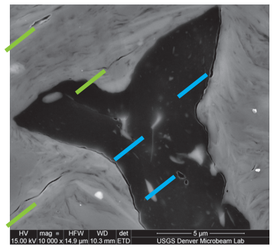
USBM DH2 (CH-C-1-45)





USBM DH2, depth 1,163 feet. The sample has 2.3% TOC and 6.4% Hg porosity. The sample is a chlorite/illite mudrock with prominent phosphate "complexes" that can exceed 200 um in diameter. Pore types are variable. Intergranular porosity (green arrows) associated with Mg-chlorite (C) is common; this can also occur at boundaries between chlorite and quartz (Q) or feldspar (A). Intergranular porosity associated with phosphate complexes is also common and seemingly important (orange arrows). Organic porosity occurs both within and along the margins of organic matter (OM; blue arrows) - this pore type is not pervasive but it is present.

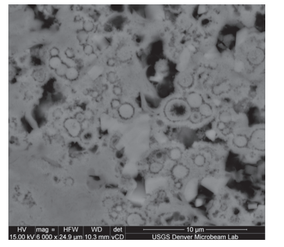


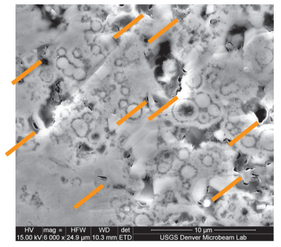


USBM DH2, depth 1,163 feet. Evidence of "organic porosity". The sample has 2.3% TOC and 6.4% Hg porosity.

(Left) - Backscatter electron image; organic matter (om) is black. Clays have typical platy appearance; chlorite is the lighter shade of gray.

(Right) - Secondary electron image; pores marked by arrows - these are of variable size (nanometer range is typical). Gray fleck in organic matter (om) are occluded clay.





USBM DH2, depth 1,163 feet.

(Left) - Backscatter electron image; organic matter (om) is black. Clays have typical platy appearance; phosphates have a variable habit.

(Right) - Secondary electron image; pores marked by arrows - these are of variable size (nanometer to ~2 microns).

Adjacent (left): Drill core from intervals of the V.R. Groce #1 well (above left) and the USBM DH2 (CH-C-1-45). See hole locations on previous panel.

Porosity, permeability, and pore characterization of the Triassic Cumnock Formation: A continuous gas assessment unit, Sanford sub-basin, Deep River basin, Lee County, North Carolina, USA

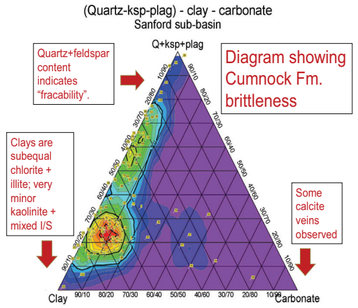
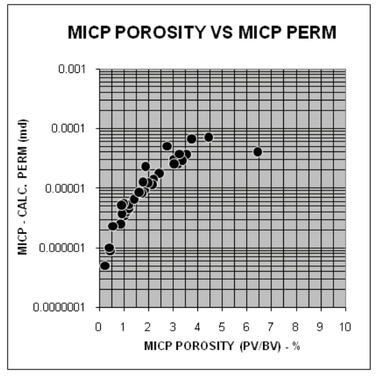
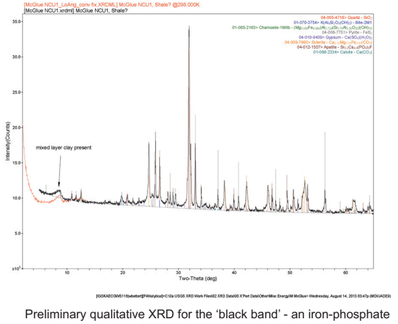


Diagram showing 'brittleness' of the Cumnock Formation to help access 'fracability' based on whole rock XRD mineralogy of 75 samples from multiple core holes. Known are: clays (chlorite, kaolinite, illite and mixed layer illite/smectite), carbonates (calcite, iron-bearing dolomite, siderite), major minerals (quartz, k-spar, plagioclase) and trace minerals (pyrite, gypsum, anhydrite,carphosiderite, analcime, and hematite).

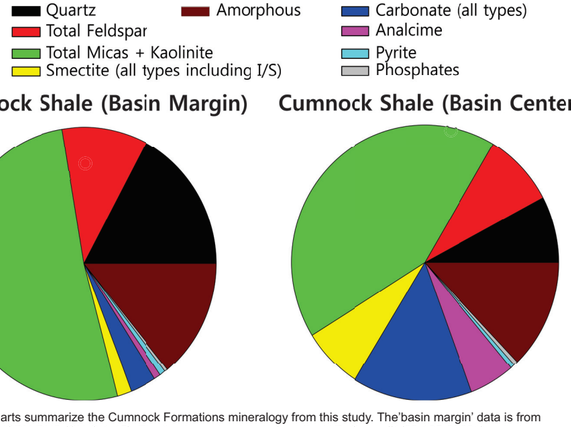


Plot showing the relationship between MICP porosity vs. MICP permeability for the coal core USBM DH2 (CH-C-1-45) and the V.R. Groce #1 well (API 32-095-00009), Cumnock Formation, SSB. Thirty-five samples are represented in this plot.

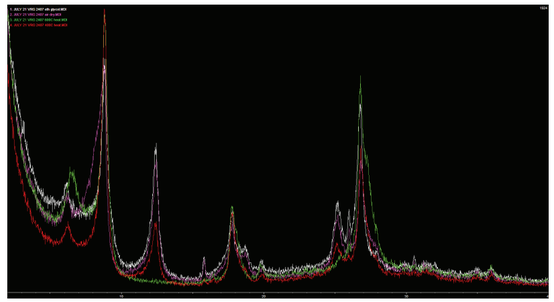
Basin	Formation	Well	Depth	TOC	HI	OI	S1+S2	Tmax	S1	S2	PI	Hg MICP
		Name	(ft)	(wt.%)								porosity %
DR/Sanford	Cumnock	V.R. Groce #1	2407	3.67	222	11	9.30	425	1.17	8.13	0.13	1.21
DR/Sanford	Cumnock	V.R. Groce #1	2414	0.08	25	151	0.07	0	0.05	0.02	0.71	0.56
DR/Sanford	Cumnock	V.R. Groce #1	2415	0.17	24	12	0.09	0	0.05	0.04	0.56	0.99
DR/Sanford	Cumnock	V.R. Groce #1	2417	1.73	150	13	3.22	438	0.63	2.59	0.20	1.42
DR/Sanford	Cumnock	V.R. Groce #1	2418	1.12	124	18	2.11	444	0.72	1.39	0.34	0.93
DR/Sanford	Cumnock	V.R. Groce #1	2419	3.24	182	15	7.58	442	1.68	5.90	0.22	1.99
DR/Sanford	Cumnock	V.R. Groce #1	2420	1.92	113	25	3.51	440	1.34	2.17	0.38	3.26
DR/Sanford	Cumnock	V.R. Groce #1	2421	0.29	17	27	0.13	0	0.08	0.05	0.62	0.24
DR/Sanford	Cumnock	V.R. Groce #1	2422	1.29	94	17	1.67	438	0.46	1.21	0.28	0.41
DR/Sanford	Cumnock	V.R. Groce #1	2423	0.1	379	19	0.46	548	0.07	0.39	0.15	0.90
DR/Sanford	Cumnock	V.R. Groce #1	2424	0.88	201	2	2.19	438	0.43	1.76	0.20	1.61
DR/Sanford	Cumnock	V.R. Groce #1	2425	4.13	151	7	7.17	442	0.94	6.23	0.13	1.78
DR/Sanford	Cumnock	V.R. Groce #1	2426	0.13	627	164	1.00	548	0.16	0.84	0.16	2.75
DR/Sanford	Cumnock	V.R. Groce #1	2427	0.31	610	48	2.25	368	0.36	1.89	0.16	3.74
DR/Sanford	Cumnock	V.R. Groce #1	2428	0.16	772	25	1.53	365	0.28	1.25	0.18	1.88
DR/Sanford	Cumnock	USBM-2	1039	0.35	26	26	0.14	0	0.05	0.09	0.36	
DR/Sanford	Cumnock	USBM-2	1041	2.81	254	11	8.76	441	1.63	7.13	0.19	
DR/Sanford	Cumnock	USBM-2	1045	0.23	159	9	0.38	457	0.01	0.37	0.03	
DR/Sanford	Cumnock	USBM-2	1046	0.25	45	20	0.16	0	0.05	0.11	0.31	
DR/Sanford	Cumnock	USBM-2	1047	0.69	103	38	1.42	434	0.71	0.71	0.50	0.44
DR/Sanford	Cumnock	USBM-2	1050	0.2	41	10	0.12	0	0.04	0.08	0.33	1.85
DR/Sanford	Cumnock	USBM-2	1066	0.51	42	38	0.36	0	0.15	0.21	0.42	4.44
DR/Sanford	Cumnock	USBM-2	1067	4.26	327	19	17.03	429	3.08	13.95	0.18	3.03
DR/Sanford	Cumnock	USBM-2	1071.3	3.24	198	14	8.07	437	1.65	6.42	0.20	3.53
DR/Sanford	Cumnock	USBM-2	1075	0.23	17	69	0.11	0	0.07	0.04	0.64	1.73
DR/Sanford	Cumnock	USBM-2	1077	0.17	30	126	0.12	0	0.07	0.05	0.58	
DR/Sanford	Cumnock	USBM-2	1078.5	0.23	49	49	0.16	0	0.05	0.11	0.31	1.16
DR/Sanford	Cumnock	USBM-2	1080	0.26	39	73	0.15	0	0.05	0.10	0.33	
DR/Sanford	Cumnock	USBM-2	1081	0.46	53	31	0.32	438	0.08	0.24	0.25	
DR/Sanford	Cumnock	USBM-2	1143	1.75	133	10	3.02	435	0.69	2.33	0.23	1.27
DR/Sanford	Cumnock	USBM-2	1144	3.65	212	15	10.44	437	2.71	7.73	0.26	3.18
DR/Sanford	Cumnock	USBM-2	1145	4.12	219	16	11.39	441	2.35	9.04	0.21	3.38
DR/Sanford	Cumnock	USBM-2	1145.5	6.42	351	10	26.18	442	3.67	22.51	0.14	2.20
DR/Sanford	Cumnock	USBM-2	1146	1.72	139	27	3.37	436	0.98	2.39	0.29	2.15
DR/Sanford	Cumnock	USBM-2	1147	0.96	187	18	2.33	434	0.54	1.79	0.23	3.05
DR/Sanford	Cumnock	USBM-2	1148	0.9	147	8	1.50	434	0.18	1.32	0.12	1.14
DR/Sanford	Cumnock	USBM-2	1148.5	0.37	65	3	0.29	437	0.05	0.24	0.17	
DR/Sanford	Cumnock	USBM-2	1149	0.37	52	16	0.25	0	0.06	0.19	0.24	1.09
DR/Sanford	Cumnock	USBM-2	1150	0.25	45	16	0.15	0	0.04	0.11	0.27	1.18
DR/Sanford	Cumnock	USBM-2	1162	1.02	114	24	1.50	439	0.34	1.16	0.23	0.88
DR/Sanford	Cumnock	USBM-2	1163	2.3	438	8	6.21	216	1.24	4.97	0.20	
DR/Sanford	Cumnock	USBM-2	1164	1.95	161	22	3.98	443	0.85	3.13	0.21	6.43
DR/Sanford	Cumnock	USBM-2	1165	1.79	433	13	4.29	177	1.12	3.17	0.26	
DR/Sanford	Cumnock	USBM-2	1165.5	0.67	438	21	0.58	60	0.18	0.40	0.31	2.44
DR/Sanford	Cumnock	USBM-2	1166	1.19	433	17	2.20	136	0.58	1.62	0.26	
DR/Sanford	Cumnock	USBM-2	1168	0.23	22	87	0.22	0	0.17	0.05	0.77	
DR/Sanford	Cumnock	USBM-2	1171	0.23	0	92	0.08	4	0.07	0.01	0.88	1.03
DR/Sanford	Cumnock	USBM-2	1178	0.67	442	31	0.47	42	0.19	0.28	0.40	



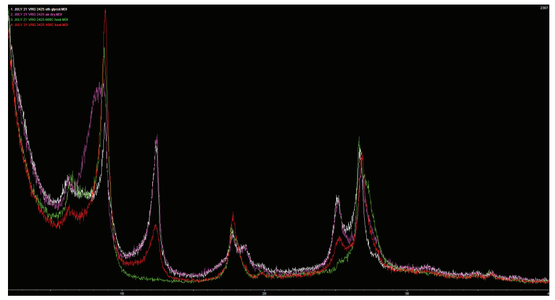
Preliminary qualitative XRD for the 'black band' - an iron-phosphate unit found below the Cumnock coals. This shows typical clay types. Chlorite/illite dominates but there is some mixed layer clay also.



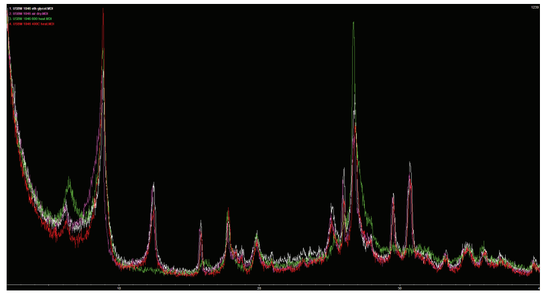
The pie charts summarize the Cumnock Formations mineralogy from this study. The'basin margin' data is from core hole USBM DH2 (CH-C-1-45). The 'basin center data is from the V.R. Groce #1(32-105-00001) well also known as LE-OT-01-74 from the N.C. Geological Survey's well records.



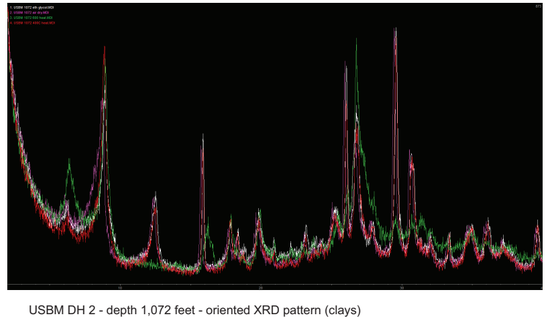
V. R. Groce #1 - depth 2,407 feet - oriented XRD pattern (clays)



V. R. Groce #1 - depth 2,425 feet - oriented XRD pattern (clays)



USBM DH 2 - depth 1,046 feet - oriented XRD pattern (clays)



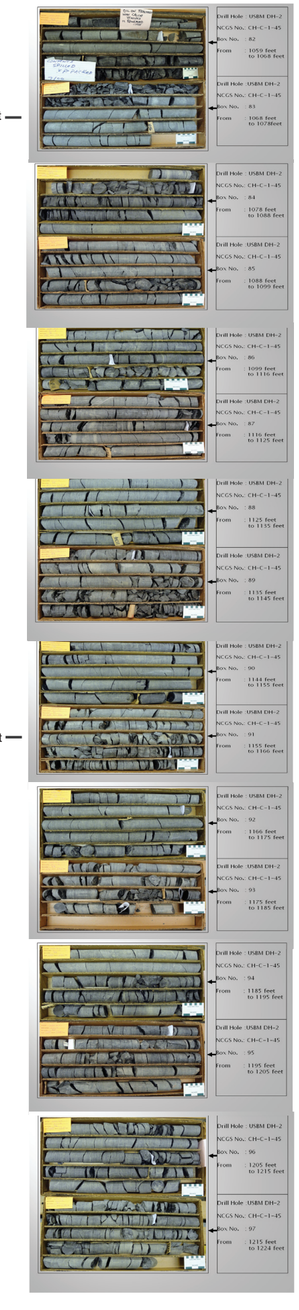
USBM DH 2 - depth 1,072 feet - oriented XRD pattern (clays)

V.R. Groce #1 (32-105-00001) LE-OT-01-74

Depth: 2,407 feet

USBM DH2 (CH-C-1-45)

Depth: 1,072 feet



Depth: 1,163 feet

The clays in the V.R. Groce #1 (top two - left) gray silty interval at a depth of 2,407 feet consists primarily of illite and chlorite. The average total clay is about 53%.

Several samples of the clayey siltstones have higher quartz and feldspar abundance. These are not found in the USBM DH2 (CH-C-1-45) core hole (bottom two - below).

Core intervals from the two drill holes used in this study. Core is placed in the boxes from left to right, then the next row begins, etc.

PANEL #3 - Reservoir characterization data