

ANALYSIS OF CHEROKEE GROUP CORE SAMPLES FOR GAS CONTENT
-- LAYNE-CHRISTENSEN #13-28 BEURSKENS;
SW SW 28-T.31S.-R.16E., MONTGOMERY COUNTY, KANSAS

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SUMMARY

Thirteen three-inch diameter core samples from the Pennsylvanian Cherokee Group were collected from the Layne-Christensen #13-28 Beurskens well, SW SW 28-T.31S.-R.16E., Montgomery County, KS from April 7 to April 9, 2003. The following as-received gas contents were measured, based on the dry weight of the sample:

- 677.8' to 678.8' (Excello Shale) (21.6 scf/ton)
- 681.5' to 682.4' (Excello Shale) (16.1 scf/ton)
- 682.4' to 683.2' (Mulky coal) (154.9 scf/ton)
- 706.0' to 707.0' (Iron Post coal) (135.6 scf/ton)
- 731.5' to 732.2' (Croweburg coal) (118.5 scf/ton)
- 772.0' to 773.0' (Mineral coal) (148.6 scf/ton)
- 838.3' to 839.1' (Tebo coal) (119.0 scf/ton)
- 847.0' to 848.0' (Weir-Pittsburg coal) (135.9 scf/ton)
- 848.0' to 849.0' (Weir-Pittsburg coal) (139.5 scf/ton)
- 888.2' to 889.2' (Bluejacket coal) (72.9 scf/ton)
- 1003.7' to 1004.7' (Rowe coal) (215.3 scf/ton)
- 1053.7' to 1054.7' (Riverton coal) (120.9 scf/ton)
- 1054.7' to 1055.7' (Riverton coal) (125.3 scf/ton)

Analyses of five desorbed coal gases indicate that these are dry gases, ranging from 1035 to 1057 BTU/scf. Nitrogen is the major non-combustible component gas. Carbon dioxide contents range from 0.7% to 1.7%. Isotopic analysis indicate the gas is mixed thermogenic and biogenic in origin.

Based on gas content, density, and thickness measurements, the gas-in-place estimates for the respective units are:

<i>unit</i>	<i>gas per acre (thousand cubic ft)</i>
Excello Shale	307.6
Mulky	254.0
Iron Post	311.6
Croweburg	131.5
Mineral	506.7
Tebo	238.5
Weir-Pittsburg	466.0
Bluejacket	131.1
Rowe	444.4
Riverton	533.9

BACKGROUND

The Layne-Christensen #13-28 Beurskens well; SW SW 28-T.31S.-R.16E., in Montgomery County, KS was selected for desorption tests in association with an on-going coalbed-gas

research project at the Kansas Geological Survey. The samples (3-inch-diameter cores) were gathered from April 7, 2003 to April 9, 2003 by K. David Newell and Donghong Pei of the Kansas Geological Survey, with assistance by Jim Stegeman of Colt Energy. Samples were obtained by wireline coring on a rig owned by Layne-Christensen, Canada.

Bottom-hole times (i.e., the time the core sample was lifted from the bottom of the hole) and canistering times (i.e., the time the sample was placed in the desorption canister) were noted in order to determine lost gas and start of desorption. Approximate wet weight of the sample was determined by subtraction of the weight of the empty canister from the weight of the canister with the sample in it. After the sample was removed from the canister, it was weighed again before air-drying, then weighed after drying. The weight loss is noted in the desorption table (Table 1).

Temperature baths for the desorption canisters were on site, with temperatures at 75 °F for the Mineral coal and shallower samples. Samples deeper than the Mineral coal were desorbed at 80° F. The canistered samples were transported to the laboratory at the Kansas Geological Survey in Lawrence, KS after their collection at the wellsite and desorption measurements were continued at these temperatures. Desorption measurements were periodically made until the canisters produced no more gas upon testing for at least two successive measurements.

DESORPTION MEASUREMENTS

The equipment and method for measuring desorption gas is that prescribed by McLennan and others (1995). The volumetric displacement apparatus is a set of connected dispensing burettes, one of which measures the gas evolved from the desorption canister. The other burette compensates for the compression that occurs when the desorbed gas displaces the water in the measuring burette. This compensation is performed by adjusting the cylinders so that their water levels are identical, then figuring the amount of gas that evolved by simply reading the difference in water level using the volumetric scale on the side of the burette.

Some of the canisters utilized for this study (i.e., canisters with the prefix "Mer") were obtained from PEL-I-CANS (by J.R. Levine) in Richardson, TX. These canisters are approximately 11.2 inches high (28.5 cm), 3.8 inches (9.7 cm) in diameter, and enclose a volume of approximately 127 cubic inches (2082 cm³). The rest of the canisters utilized for this study were obtained from SSD, Inc. in Grand Junction, CO. On average, these canisters are approximately 12.5 inches high (32 cm), 3 1/2 inches (9 cm) in diameter, and enclose a volume of approximately 150 cubic inches (2450 cm³). The desorbed gas that collected in the desorption canisters was periodically released into the volumetric displacement apparatus and measured as a function of time, temperature and atmospheric pressure.

The time and atmospheric pressure were measured in the field using a portable weather station (model BA928) marketed by Oregon Scientific (Tualatin, OR). The atmospheric pressure was displayed in millibars on this instrument, however, this measurement was not the actual barometric pressure, but rather an altitude-compensated barometric pressure automatically converted to a sea-level-equivalent pressure. In order to translate this measurement to actual

atmospheric pressure, a regression correlation was determined over several weeks by comparing readings from the Oregon Scientific instrument to that from a pressure transducer in the Petrophysics Laboratory in the Kansas Geological Survey in Lawrence, Kansas (Figure 1). The regression equation shown graphically in Figure 1 was entered into a spreadsheet and was used to automatically convert the millibar measurement to barometric pressure in psi.

A spreadsheet program written by K.D. Newell (Kansas Geological Survey) was used to convert all gas volumes at standard temperature and pressure. Conversion of gas volumes to standard temperature and pressure was by application of the perfect-gas equation, obtainable from basic college chemistry texts:

$$n = PV/RT$$

where n is moles of gas, T is degrees Kelvin (i.e., absolute temperature), V is in liters, and R is the universal gas constant, which has a numerical value depending on the units in which it is measured (for example, in the metric system $R = 0.0820$ liter atmosphere per degree mole). The number of moles of gas (i.e., the value n) is constant in a volumetric conversion, therefore the conversion equation, derived from the ideal gas equation, is:

$$(P_{\text{stp}} V_{\text{stp}})/(RT_{\text{stp}}) = (P_{\text{rig}} V_{\text{rig}})/(RT_{\text{rig}})$$

Customarily, standard temperature and pressure for gas volumetric measurements in the oil industry are 60 °F and 14.7 psi (see Dake, 1978, p. 13), therefore P_{stp} , V_{stp} , and T_{stp} , respectively, are pressure, volume, and temperature at standard temperature and pressure, where standard temperature is degrees Rankine ($^{\circ}\text{R} = 460 + ^{\circ}\text{F}$). P_{rig} , V_{rig} , and T_{rig} , respectively, are ambient pressure, volume, and temperature measurements taken at the rig site or in the desorption laboratory.

The universal gas constant R drops out as this equation is simplified and the determination of V_{stp} becomes:

$$V_{\text{stp}} = (T_{\text{stp}}/T_{\text{rig}}) (P_{\text{rig}}/P_{\text{stp}}) V_{\text{rig}}$$

The conversion calculations in the spreadsheet were carried out in the English metric system, as this is the customary measure system used in American coal and oil industry. V is therefore converted to cubic feet; P is psia; T is °R.

The desorbed gas was summed over the time period for which the coal samples evolved all of their gas.

Lost gas (i.e., the gas lost from the sample from the time it was drilled, brought to the surface, to the time it was canistered) was determined using the direct method (Kissel and others, 1975; also see McLennan and others, 1995, p. 6.1-6.14) in which the cumulative gas evolved is plotted against the square root of elapsed time. Time zero is assumed to be the instant the core sample is lifted from the bottom of the hole. Characteristically, the cumulative gas evolved from the sample, when plotted against the square root of time, is linear for a short period after the sample

reaches ambient pressure conditions, therefore lost gas is determined by a line projected back to time zero. The period of linearity generally is about two hours for core samples.

LITHOLOGIC ANALYSIS

Upon removal from the canisters, the cores were washed of drilling mud, and air-dried for several days. After drying, the cores were weighed again to obtain a dry-weight based gas content.

DATA PRESENTATION

Data and analyses accompanying this report are presented in the following order: 1) data tables for the desorption analyses, 2) lost-gas graphs, 3) desorption graphs for individual samples, and 4) desorption graph for all samples at a common scale, 5) gas chemistry diagrams, and 6) reserve diagrams.

Data Tables of the Desorption Analyses (Table 1)

These are the basic data used for lost-gas analysis and determination of total gas desorbed from the core samples. Basic temperature, volume, and barometric measurements are listed at left. Farther to the right, these are converted to standard temperature, pressure, and volumes. The volumes are cumulatively summed, and converted to scf/ton based on the total weight of coal and dark shale in the sample. At the right of the table, the time of the measurements are listed and converted to hours (and square root of hours) since the sample was drilled.

Lost-Gas Graphs (Figures 2-14)

Gas lost prior to the canistering of the sample was estimated by extrapolation of the first few data points after the sample was canistered. The linear characteristic of the initial desorption measurements was usually lost within the first two hours after canistering, thus data are presented in the lost-gas graphs for only up to 9 hours after canistering. Lost-gas volumes derived from this analysis are incorporated in the data tables described above.

Desorption Graphs (Figures 15-26)

Desorption graphs for individual samples are presented in Figures 15-24. A summary graph showing all the samples at a common scale is presented in Figure 25. A second summary graph (Figure 26) expresses the desorption in terms of percentage of the total gas desorbed with time. Sorption times (the time it takes for 63.2% of the gas from a sample to desorb) are derived from this latter figure.

Gas Chemistry (Figure 27-28)

Gas isotopic chemistry is compared to similar analyses on other nearby coalbed gases, with respect to the local stratigraphy (Figure 27). The crossplot of chemistry and location of samples is shown in Figure 28.

Reserve Estimate (Figure 29)

Gas reserves are calculated based on desorption data, and crossplotted with sorption time, which is a semi-quantitative indicator of production rates.

Appendix 1

These are photocopies of the results of the Luman's Laboratories proximate analyses.

RESULTS and DISCUSSION

The following as-received gas contents are calculated, based on dry weight of the sample:

- 677.8' to 678.8' (Excello Shale) (21.6 scf/ton)
- 681.5' to 682.4' (Excello Shale) (16.1 scf/ton)
- 682.4' to 683.2' (Mulky coal) (154.9 scf/ton)
- 706.0' to 707.0' (Iron Post coal) (135.6 scf/ton)
- 731.5' to 732.2' (Croweburg coal) (118.5 scf/ton)
- 772.0' to 773.0' (Mineral coal) (148.6 scf/ton)
- 838.3' to 839.1' (Tebo coal) (119.0 scf/ton)
- 847.0' to 848.0' (Weir-Pittsburg coal) (135.9 scf/ton)
- 848.0' to 849.0' (Weir-Pittsburg coal) (139.5 scf/ton)
- 888.2' to 889.2' (Bluejacket coal) (72.9 scf/ton)
- 1003.7' to 1004.7' (Rowe coal) (215.3 scf/ton)
- 1053.7' to 1054.7' (Riverton coal) (120.9 scf/ton)
- 1054.7' to 1055.7' (Riverton coal) (125.3 scf/ton)

Proximate analyses were made for ten selected samples . The core was cut down its vertical axis and half was preserved for future analyses. The proximate analyses were performed on the following samples by Luman's Laboratory (see Appendix 1):

Luman's Lab proximate analysis:

<i>unit</i>	<i>depth</i>	<i>moisture</i>	<i>ash</i>	<i>moisture-free ash</i>
Excello Shale	681.5'	3.24%	82.89%	85.66%
Mulky	682.4'	2.04%	16.89%	17.24%
Iron Post	706.0'	1.97%	6.39%	6.52%
Croweburg	731.5'	1.51%	14.60%	14.83%
Mineral	772.0'	1.12%	13.27%	13.42%
Tebo	838.3'	1.29%	23.52%	23.83%
Weir-Pittsburg	847.0'	1.34%	7.44%	7.54%
Weir-Pittsburg	848.0'	2.05%	9.81%	10.01%
Bluejacket	888.2'	1.47%	22.83%	23.17%
Rowe	1003.7'	1.67%	18.14%	18.45%
Riverton	1053.7'	3.04%	18.95%	19.55%
Riverton	1054.7'	1.46%	14.87%	15.09%

According to the BTU/lb. (dry, ash-free) determinations, all the samples can be classified as high-volatile A bituminous coal. The dry, ash-free heating value of the Excello Shale sample, at 20,091 BTU/lb., is somewhat enigmatic. Nevertheless, this characteristic of giving a rather

inflated calculation for this particular unit appears to be consistent, for a nearby well (the Layne-Christensen #1 Pierce well in sec. 16-T.31S.-R.17E.; also in Montgomery County) also yielded a high value for this measurement. These are the first two ashing measurements of the Excello Shale that has been brought to the attention of the Kansas Geological Survey, so the spatial extent of this behavior or its cause is not yet known. A possible explanation is that the Excello may contain considerable amount of oil, which may serve to increase its apparent heat content.

Using the equation from McLennan and others (1995):

$$G_c = G_{pc} (1 - a_d)$$

where:

G_c = gas content, scf/ton

G_{pc} = "pure coal", gas content, scf/ton

a_d = dry ash content, weight fraction

the gas content of the samples converts to:

<i>unit</i>	<i>depth</i>	<i>moisture-free ash</i>	<i>G_c</i>	<i>G_{pc}</i>
Excello Shale	677.8'	85.66%	21.6 scf/ton	150.6 scf/ton
Excello Shale	681.5'	85.66%	16.1 scf/ton	112.3 scf/ton
Mulky	682.4'	17.24%	154.9 scf/ton	187.2 scf/ton
Iron Post	706.0'	6.52%	135.6 scf/ton	145.1 scf/ton
Croweburg	731.5'	14.83%	118.5 scf/ton	139.1 scf/ton
Mineral	772.0'	13.42%	148.6 scf/ton	171.6 scf/ton
Tebo	838.3'	23.83%	119.0 scf/ton	156.2 scf/ton
Weir-Pittsburg	847.0'	7.54%	135.9 scf/ton	147.0 scf/ton
Weir-Pittsburg	848.0'	10.01%	139.5 scf/ton	155.0 scf/ton
Bluejacket	888.2'	23.17%	72.9 scf/ton	94.9 scf/ton
Rowe	1003.7'	18.45%	215.3 scf/ton	264.0 scf/ton
Riverton	1053.7'	19.55%	120.9 scf/ton	150.3 scf/ton
Riverton	1054.7'	15.09%	125.3 scf/ton	147.6 scf/ton

Samples were also tested for their density. Dried samples were weighed and immersed in water in a beaker filled to its brim. With placing the sample in the beaker, the displaced water was spilled from the beaker and subsequently weighed. The volume of the sample is thus easily converted to volume using 1 gram/cc for the density of the water. The following density measurements were calculated:

<i>unit</i>	<i>depth</i>	<i>density and uncertainty</i>
Excello Shale	677.8'	2.20 g/cc ± 0.05
Excello Shale	681.5'	2.38 g/cc ± 0.06
Mulky	682.4'	1.34 g/cc ± 0.01
Iron Post	706.0'	1.30 g/cc ± 0.05
Croweburg	731.5'	1.36 g/cc ± 0.02
Mineral	772.0'	1.32 g/cc ± 0.05

Tebo	838.3'	1.34 g/cc ± 0.05
Weir-Pittsburg	847.0'	1.27 g/cc ± 0.03
Weir-Pittsburg	848.0'	1.35 g/cc ± 0.01
Bluejacket	888.2'	1.47 g/cc ± 0.03
Rowe	1003.7'	1.38 g/cc ± 0.01
Riverton	1053.7'	1.43 g/cc ± 0.01
Riverton	1054.7'	1.46 g/cc ± 0.05

Compositional and isotopic chemistry were performed on five gas samples. These analyses are in Appendix II and were performed by Isotech Laboratories in Champaign, IL.

Isotopic Analyses

Analysis	Mulky (682.4')	Mineral (777.0')	Weir-Pitt (847.0')	Rowe (1003.7')	Riverton (1054.7')
$\delta^{13}\text{CO}_2$	3.12	3.79	-0.75	-3.42	-8.23
$\delta^{13}\text{C}_{\text{methane}}$	-60.08	-64.58	-55.05	-60.46	-65.26
$\delta\text{DC}_{\text{methane}}$	-227.5	-221.6	-214.5	-212.5	-222.7

Chemical Analyses (as reported; red = hydrocarbons; blue = non hydrocarbons, green = oxygen)

Component (%)	Mulky	Mineral	Weir-Pitt	Rowe	Riverton
Methane	94.21	94.83	94.38	95.47	92.93
Ethane	1.18	0.77	0.90	1.12	0.99
Propane	0.43	0.26	0.56	0.048	0.82
n-Butane	0.13	0.078	0.21	0.0025	0.19
iso-Butane	0.036	0.021	0.048	0.0055	0.065
n-Pentane	0.018	0.012	0.026	0.0000	0.023
iso-Pentane	0.013	0.0085	0.0210	0.0000	0.022
Hexane+	0.0092	0.0072	0.015	0.0011	0.013
Nitrogen	1.84	1.91	2.61	2.47	3.50
Oxygen	0.41	0.51	0.30	0.073	0.15
Argon	0.034	0.037	0.035	0.025	0.042
Hydrogen	0.025	0.094	0.0072	0.11	0.0
Carbon Dioxide	1.66	1.46	0.89	0.67	1.26
Helium	0	0	0.0019	0	0

Chemical Analyses (recalculated after removing atmospheric contamination; red = hydrocarbons; blue = non hydrocarbons)

Component (%)¹	Mulky	Mineral	Weir-Pitt	Rowe	Riverton
Methane	96.09	97.20	95.75	95.81	93.59
Ethane	1.20	0.79	0.91	1.12	1.00
Propane	0.44	0.27	0.57	0.048	0.83
n-Butane	0.13	0.080	0.21	0.0025	0.19
iso-Butane	0.037	0.022	0.049	0.0055	0.065
n-Pentane	0.018	0.012	0.026	0.0000	0.023
iso-Pentane	0.013	0.0087	0.0213	0.0000	0.022

Hexane+	0.0094	0.0074	0.015	0.0011	0.013
Nitrogen	0.32	0.01	1.51	2.27	2.96
Argon	0.016	0.015	0.022	0.022	0.036
Hydrogen	0.025	0.096	0.0073	0.11	0.0
Carbon Dioxide	1.69	1.50	0.90	0.67	1.27
Helium	0	0	0.0019	0	0

¹atmospheric component (based on oxygen content) subtracted from the analysis, with components recalculated to 100%

Other Isotech Data

	Mulky	Mineral	Weir-Pitt	Rowe	Riverton
Specific Gravity	0.593	0.587	0.590	0.577	0.599

Summary

	Mulky	Mineral	Weir-Pitt	Rowe	Riverton
Calculated BTU	1057	1054	1056	1035	1041
Total % non-HCs	2.05	1.62	2.45	3.01	4.27
HC Wetness (%)	1.89	1.21	1.85	1.22	2.23

Plotting of the isotopes and gas wetness (Figure 28) indicates that the gas is of mixed biogenic and thermogenic origin. Although isotopically the gases are mostly biogenic, the hydrocarbon wetness indicates some thermogenic influence.

An estimate of gas reserves per acre for the coals and shales tested can be made using thickness, density, and gas content data:

<i>unit</i>	<i>thickness</i> ¹ (ft)	<i>coal/shale per acre</i>		<i>gas per acre</i> (thousand cubic ft) ⁴
		(ft ³) ²	(ton) ³	
Excello Shale	5.2	226,512	16,191	307.6 ⁵
Mulky	0.9	39,204	1,640	254.0
Iron Post	1.3	56,628	2,298	311.6
Croweburg	0.6	26,136	1,110	131.5
Mineral	1.9	82,764	3,410	506.7
Tebo	1.1	47,916	2,004	238.5
Weir-Pittsburg	1.9	82,764	3,384	466.0 ⁶
Bluejacket	0.9	39,204	1,799	131.1
Rowe	1.1	47,916	2,064	444.4
Riverton	2.2	95,832	4,337	533.9 ⁷

¹thicknesses (ft) from Rolland Yoakum, Layne Energy (personal communication, 2005)

²thickness (ft) X 43,560 ft²/acre

³ft³ coal or shale per acre X density (g/cm³) X (1/ 907,168 g/ton) X 28,317 cm³/ft³

⁴tons coal or shale per acre X gas content (ft³/ton)

⁵averaged density (2.29 g/cm³) and gas content (19.0 ft³/ton) used

⁶averaged density (1.31 g/cm³) and gas content (137.7 ft³/ton) used

⁷averaged density (1.45 g/cm³) and gas content (123.1 ft³/ton) used

Sorption times (time required to desorb 63.2% of the total gas content) for the samples are as follows (see Figure 26):

<i>unit</i>	<i>depth</i>	<i>sorption time (days)</i>
Excello Shale	677.8'	182.6
Excello Shale	681.5'	17.7
Mulky	682.4'	12.8
Iron Post	706.0'	63.5
Croweburg	731.5'	16.3
Mineral	772.0'	36.7
Tebo	838.3'	23.4
Weir-Pittsburg	847.0'	27.6
Weir-Pittsburg	848.0'	20.3
Bluejacket	888.2'	42.8
Rowe	1003.7'	10.1
Riverton	1053.7'	13.0
Riverton	1054.7'	10.6

The large span for desorption time for the Excello Shale is puzzling. A possible explanation is that the sample from 681.5' was giving off gas so slowly that its full gas desorption was not realized before it was decanistered. Its sorption time may therefore be drastically underestimated, and its gas content may be more like that of the Excello Shale sample taken above it (i.e., 21.6 scf/ton as opposed to 16.1 scf/ton).

A reserves versus sorption time diagram is shown in Figure 29.

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FIGURES, TABLES, and APPENDICES

FIGURE 1. Correlation of field barometer to Petrophysics Lab pressure transducer.

TABLE 1. Desorption measurements for samples.

FIGURE 2. Lost-gas graph for 677.8' to 678.8' (Excello Shale).

FIGURE 3. Lost-gas graph for 681.5' to 682.4' (Excello Shale).

FIGURE 4. Lost-gas graph for 682.4' to 683.2' (Mulky coal).

FIGURE 5. Lost-gas graph for 706.0' to 707.0' (Iron Post coal).

FIGURE 6. Lost-gas graph for 731.5' to 732.2' (Croweburg coal).

FIGURE 7. Lost-gas graph for 772.0' to 773.0' (Mineral coal).

FIGURE 8. Lost-gas graph for 838.3' to 839.1' (Tebo coal).

FIGURE 9. Lost-gas graph for 847.0' to 848.0' (Weir-Pittsburg coal).

FIGURE 10. Lost-gas graph for 848.0' to 849.0' (Weir-Pittsburg coal).

FIGURE 11. Lost-gas graph for 888.2' to 889.2' (Bluejacket coal).

FIGURE 12. Lost-gas graph for 1003.7' to 1004.7' (Rowe coal).

FIGURE 13. Lost-gas graph for 1053.7' to 1054.7' (Riverton coal).

FIGURE 14. Lost-gas graph for 1054.7' to 1055.7' (Riverton coal).

FIGURE 15. Desorption graph for Excello Shale.

FIGURE 16. Desorption graph for Mulky coal.

FIGURE 17. Desorption graph for Iron Post coal.

FIGURE 18. Desorption graph for Croweburg coal.

FIGURE 19. Desorption graph for Mineral coal.

FIGURE 20. Desorption graph for Tebo coal.

FIGURE 21. Desorption graph for Weir-Pittsburg coal.

FIGURE 22. Desorption graph for Bluejacket coal.

FIGURE 23. Desorption graph for Rowe coal.

FIGURE 24. Desorption graph for Riverton coal.

FIGURE 25. Desorption graph for all samples

FIGURE 26. Sorption Times for all samples.

FIGURE 27. Gas chemistry of individual well samples

FIGURE 28. Gas chemistry of samples compared to other nearby samples.

FIGURE 29. Reserves and sorption times for all units.

APPENDIX I. Proximate analyses of samples by Luman's Laboratories, Chetopa, KS.