# Results of coal bed methane drilling, Mylan Park, Monongalia County, West Virginia

By Leslie F. Ruppert, Nick Fedorko, Peter D. Warwick, William C. Grady, Robert D. Crangle, Jr., and James Q. Britton



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## Abstract

The Department of Energy National Energy Technology Laboratory funded drilling of a borehole (39.64378° E , -80.04376 ° N) to evaluate the potential for coal bed methane and carbon dioxide sequestration at Mylan Park, Monongalia County, West Virginia. The drilling commenced on September 23, 2002 and was completed on November 14, 2002. The 2,525 ft deep hole contained 1,483.41 ft of Pennsylvanian coal-bearing strata, 739.67 feet of Mississippian strata, and 301.93 ft. of Devonian strata.

The drill site was located directly over abandoned Pittsburgh and Sewickley coal mines. Coal cores from remaining mine pillars were cut and retrieved for desorption from both mines. In addition, coals were cored and desorbed from the Pittsburgh Roof, Little Pittsburgh, Elk Lick, Brush Creek, Upper Kittanning, Middle Kittanning, Clarion, Upper Mercer, Lower Mercer, and Quakertown coal beds. All coals are Pennsylvanian in age and are high-volatile-A bituminous in

rank. A total of 34.75 ft of coal was desorbed over a maximum period of 662 days, although most of the coal was desorbed for about 275 days.

Measured raw total gas contents ranged from 0.43 standard cubic feet per ton (SCF/ton) for the mined Sewickley coal bed to 130.98 SCF/ton for the Upper Kittanning coal bed. Volumes of residual gas were not measured and these gas volumes should be regarded as minimum volumes.

The amount of oxygen in the gas samples collected from the desorption canisters ranged from 2.55 - 20.13 percent. Methane contents ranged from 0 – 81 percent for intervals of the Sewickley and Clarion coal beds, respectively, suggesting that all of the gas samples were contaminated to some degree by air. Therefore, all gas compositions reported have been normalized to remove the air. With a single exception, the Quakertown coal, the Mylan Park coals are thermogenic in origin with $\delta^{13}c_{1\ \%\ \text{per mil}}$ values ranging from -32.39 to -50.66 and ratios of methane to higher molecular weigh hydrocarbons ranging from 10 to 53. The Quakertown coal bed has a $C^1/C^{2+}$ of 913, suggesting that it contains some microbial gas.

High-pressure carbon dioxide adsorption isotherms were conducted on composite samples of the Upper Kittanning, Middle Kittanning, and Clarion coal beds. Assuming that reservoir pressure in the Mylan Park coals is equivalent to normal hydrostatic pressure, estimated maximum carbon dioxide adsorption pressures range from a low of about 300 pounds per square inch per area in the Clarion coal bed to 500 pounds per square inch for the Upper Kittanning coal bed. Estimated maximum methane adsorption isotherms show that the Upper and Middle Kittanning coal beds are undersaturated in methane while the Clarion is close to saturation.

# Introduction

Personnel in Mylan Park, Monongalia County, West Virginia (fig. 1), requested funding from the Department of Energy's National Energy Technology Laboratory (DOE NETL) to evaluate the potential of using coal bed methane to power the park's electric lights and equipment. NETL responded and provided funding to drill a 2,525 ft core within the park boundaries to evaluate the potential for coal bed methane and carbon dioxide sequestration. Drilling started on September 23, 2002 and was completed on November 14, 2002, running five-day, 12-hour shifts per week. Appendix 1 contains the drillers log for the core and figure 2 depicts a generalized stratigraphic section of the area. The project was managed by William Schuller, EG&G Technical Services, Inc., Morgantown, WV. The West Virginia Geological and Economic Survey (WVGES) coordinated the core drilling, e-logging, and the methane desorption work. The core was drilled by L.J. Hughes & Sons, Summersville, WV. Marshall J. Miller and Associates, Bluefield, Va. e-logged the hole. United States Geological Survey (USGS) personnel conducted all methane desorption work. After desorption was completed, the coal was analyzed in the WVGES lab. In addition, the return fluids and cuttings were logged throughout drilling by Hydrocarbon Well Logging Services, Parkersburg, WV.

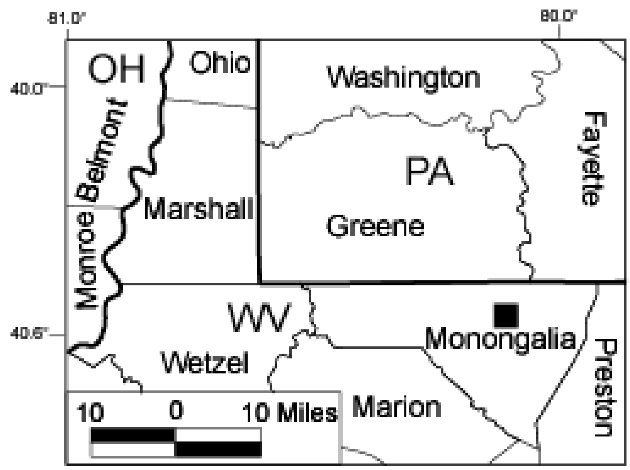


**Figure 1**- Generalized location map of the Mylan Park study area in Monongalia County, WV.

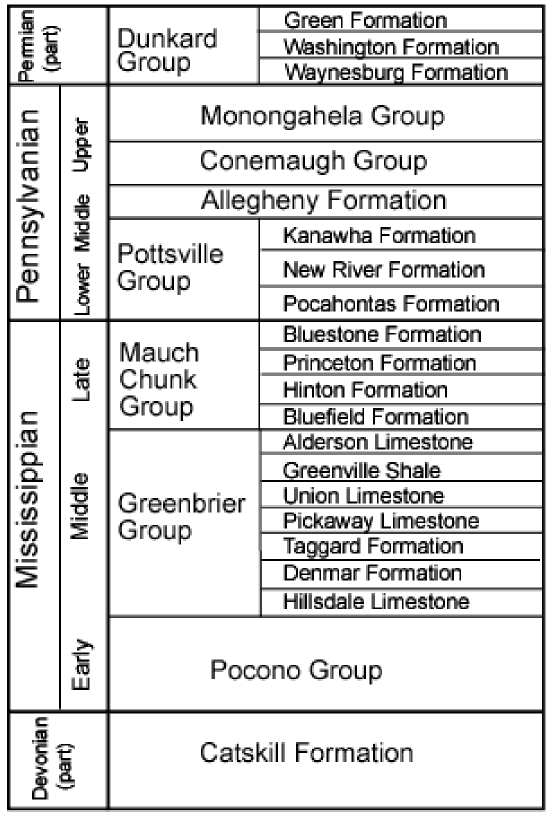


**Figure 2-** Generalized stratigraphic column of the study area (modified from Milici and de Witt, 1988).

# Methods

## *Desorption Methods*

Procedures modified from Stricker and others (2000), Gas Research Institute (1995), and Barker and others (2002) were followed throughout the coring and desorption to measure gas contents of the coals. During coring, both the time that the coal was retrieved off the bottom and the temperature of circulating water was recorded to estimate the amount of lost gas (the volume of gas desorbed between the time the core was retrieved from the bottom and the time that the coal was sealed in a desorption canister) and reservoir temperature, respectively. As soon as the core barrel was recovered at the surface, the core was extracted onto a wooden core holder, quickly described (coal versus rock), and measured. The coal was removed from the wooden core holder in a graduated curved polyvinyl chloride scoop to keep it intact, weighed, and placed in thin (approximately 4 mm) plastic sleeves with holes to maintain the stratigraphic integrity of the coal during desorption. Within 10 - 23 minutes of reaching the surface, intervals of the Sewickley, Redstone, and Pittsburgh coals were placed in 2-ft aluminum canisters and 1-ft PVC canisters; remaining coals were placed in 2-ft PVC canisters (Table 1). All canisters were filled with distilled water, sealed, and placed in water baths kept at reservoir temperature (68 - 70$^{o}$ F) as estimated from the circulating core hole water temperature.

**Table 1-** Coal bed or zone name, depth (ft), and canister number for coals desorbed at Mylan Park.

| Coal Bed/Coal Zone | Depth (ft) | Canister Number |
|---|---|---|
| **Sewickley** | 346.8 - 347.20 | Canister 1: WV-02-CB3-10 |
| | 347.2 - 348.20 | Canister 2: WV-02-B3-1 |
| | 348.2 - 350.20 | Canister 3: WV-02-US4-2 |
| | 350.2 - 352.20 | Canister 4: WV-02-US4-1 |
| **Redstone** | 405.3 - 407.3 | Canister 1:WV-02-US4-5 |
| | 407.3 - 408.0 | Canister 2: WV-02-B3-2 |
| **Pittsburgh Roof** | 426.96 - 427.96 | Canister 1: WV-02-B3-3 |
| | 432.35 - 433.85 | Canister 2: WV-02-B3-5 |
| **Pittsburgh** | 433.85 - 434.35 | Canister 1: WV-02-B3-4 |
| | 434.35 - 436.35 | Canister 2: WV-02-US4-30 |
| | 436.35 - 438.35 | Canister 3: WV-02-US4-14 |
| | 438.35 - 440.35 | Canister 4: WV-02-US4-8 |
| | 440.35 - 442.35 | Canister 5: WV-02-US4-6 |
| **Little Pittsburgh** | 468.5 - 469.25 | Canister 1: WV-02-CB3-2 |
| **Elk Lick** | 659.93 - 660.6 | Canister 1: WV-02-B3-6 |
| **Brush Creek** | 920.4 - 921.1 | Canister 1: WV-02-B3-7 |
| | 921.1 - 921.8 | Canister 2: WV-02-B3-8 |
| **Upper Kittanning** | 1121.7 - 1122.7 | Canister 1: WV-02-B3-9 |
| | 1122.7 - 1123.4 | Canister 2: WV-02-B3-10 |
| **Middle Kittanning** | 1184.1 - 1185.1 | Canister 1: WV-02-B3-11 |
| | 1185.1 - 1185.4 | Canister 2: WV-02-CB3-12 |
| | 1188.0 - 1189.0 | Canister 3: WV-02-B3-12 |
| | 1189.0 - 1190.0 | Canister 4: WV-02-B3-13 |
| | 1190.0 - 1190.45 | Canister 5: WV-02-CB3-11 |
| **Clarion** | 1270.5 - 1271.5 | Canister 1: WV-02-B3-14 |
| | 1271.5 - 1272.35 | Canister 2: WV-02-B3-15 |
| | 1278.7 - 1279.7 | Canister 3: WV-02-B3-16 |
| | 1279.7 - 1280.8 | Canister 4: WV-02-B3-17 |
| **Upper Mercer** | 1324.4 - 1325.15 | Canister 1: WV-02-B3-18 |
| **Lower Mercer** | 1357.5 - 1358.5 | Canister 1: WV-02-B3-19 |
| **Quakertown** | 1465.0 - 1465.6 | Canister 1: WV-02-B3-20 |
| | 1475.6 - 1476.43 | Canister 2: WV-02-B3-21 |

Desorbed gas volumes were initially measured after 10 minutes from the time that the canisters were placed in water baths by opening valves on the canisters and measuring the volumetric displacement of water in a graduated monometer. Ambient air and water bath temperature and atmospheric pressure were recorded during each desorption measurement to correct desorbed gas volumes to standard temperature and pressure (STP). Each canister was measured approximately every ten minutes for the first half hour to hour, and then every 20 to 30 minutes for the first day. Canisters were not monitored overnight, but measured upon reaching the drill site in the morning. After approximately three weeks, the canisters were moved to a laboratory at the U.S. Geological Survey (USGS) where they were measured once a day for two weeks. Over the course of the desorption, the canisters were measured less frequently because less gas was desorbed from the samples. Towards the end of the desorption tests, the canisters were measured bi-monthly. See Appendix 2 for copies of the desorption spreadsheets for all coals.

Lost gas was estimated from curves generated by plotting the cumulative gas volume against the square root of elapsed desorption time for each canister. Diffusion rates of the Mylan Park coals were low, thus lost gas volumes were very low, ranging from approximately 0 for most of the coal intervals to about 20 cc in two of the four Middle Kittanning coal intervals (canisters WV-02-B3-11 and WV-02-B3-11) and one of the two Quakertown coal intervals (canister WV-02-B3-21).

Residual gas was not measured because coal cores were the property of the WVGES, and all of the coal was needed for proximate (Table 2), petrographic, geochemical, and adsorption analyses. Although desorption tests were long term, volumes of residual gas in the coal may be substantial, and reported raw and dry ash free (daf) total gas volumes cited in this report should be regarded as minimum volumes. For example, Diamond and others (1986) report residual gas can average up to 20% of the total gas content. A.K. Markowski (oral commun., 2004) reports that residual gas in cores from Pennsylvania and West Virginia that she has measured can be as high as 35%.

**Table 2-** Selected proximate analyses for the Mylan Park coal beds and coal zones. Abbreviations: ft = feet; % = percent; VolMat = volatile matter; FC = fixed carbon; as rec. = as-received; m-mmf = moist, mineral matter free; Btu = British thermal units.

| Coal Bed/Coal Zone | Depth ft | Moisture % | VolMat % dry | VolMat % as rec. | VolMat % m-mmf | Ash % dry | Ash % as rec. | FC % dry | FC % as rec. | FC % m-mmf | Btu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sewickley | 346.8 - 352.2 | 1.29 | 29.60 | 29.22 | 39.40 | 21.08 | 20.81 | 49.10 | 48.46 | 60.60 | 11,498 |
| Redstone | 405.1 - 408.0 | 0.68 | 28.25 | 28.10 | 48.18 | 27.80 | 27.47 | 43.95 | 43.75 | 51.82 | 10,572 |
| Pittsburgh Roof | 426.96 - 443.85 | 1.63 | 36.55 | 36.34 | 80.21 | 83.05 | 82.18 | 47.39 | 46.96 | 86.94 | 12,231 |
| Pittsburgh | 433.85 - 442.35 | 0.52 | 34.63 | 34.45 | 38.41 | 9.84 | 9.79 | 55.53 | 55.24 | 61.59 | 13,557 |
| Little Pittsburgh | 468.5 - 469.25 | 1.15 | 23.73 | 23.99 | 53.64 | 43.69 | 43.15 | 32.04 | 31.71 | 46.36 | 7,880 |
| Elk Lick | 659.93 - 660.6 | 0.85 | 30.08 | 29.79 | 41.90 | 24.30 | 24.07 | 45.62 | 45.25 | 58.10 | 10,990 |
| Brush Creek | 920.4 - 921.8 | 0.95 | 22.53 | 22.32 | 39.83 | 43.43 | 43.02 | 34.04 | 33.71 | 60.17 | 8,471 |
| Upper Kittanning | 1,121.7 - 1,123,4 | 0.97 | 30.92 | 30.62 | 34.07 | 9.25 | 9.16 | 59.84 | 59.22 | 65.93 | 13,785 |
| Middle Kittanning | 1,184.1 - 1,190.45 | 0.52 | 30.44 | 30.24 | 37.40 | 18.61 | 18.52 | 50.95 | 50.68 | 62.60 | 12,232 |
| Clarion | 1,270.5 - 1,280.8 | 1.01 | 31.05 | 30.74 | 36.21 | 14.22 | 14.12 | 54.69 | 54.14 | 63.79 | 10,735 |
| Upper Mercer | 1,324.4 - 1,325.15 | 0.72 | 24.75 | 24.55 | 32.25 | 10.94 | 10.86 | 60.30 | 59.87 | 67.71 | 13,611 |
| Lower Mercer | 1,357.5 - 1,358.5 | 0.49 | 21.60 | 21.50 | 31.14 | 30.62 | 30.47 | 47.78 | 47.54 | 68.86 | 10,629 |
| Quakertown | 1,465.0 - 1,476.43 | 0.58 | 20.92 | 20.78 | 43.78 | 35.37 | 35.11 | 38.24 | 38.04 | 56.22 | 9,290 |

## *Gas Analyses*

Gas samples were taken intermittently throughout the desorption process, starting within one to two days after the canisters were sealed. Gas volumes were measured in the monometer and samples were collected directly from the monometer with a short (approximately 5 in) piece of plastic tubing and bled into Tedlar bags. The bags were shipped to the DOE-NETL labs for the initial analyses; additional analyses were performed by a commercial laboratory, Isotech Laboratories, Inc..

DOE-NETL labs were able to analyze for the following constituents: CO, $N_2$, $O_2$, $CO_2$, $H_2$, He, methane [$CH_4$ ($C_1$)], ethane ($C_2H_6$ ($C_2$)], ethylene ($C_2H_4$ ($C_2$)], propane [$C_3H_8$ ($C_3$)], isobutene [$iC_4H_{10}$ ($iC_4$)], n-butane [$nC_4H_{10}$ ($nC_4$)], isopentane [$iC_5H_{12}$ ($iC_5$)], 2-methybutane ($C_5$), n-pentane [$nC_5H_{12}$ ($nC_5$)], and 2,2-dimethylbutane ($C_6$), and hexanes ($C_{6+}$). Results for hydrocarbon species were reported in parts per million (ppm) and converted to weight percent for this report.

Isotech Laboratories, Inc. analyzed for $N_2$, $O_2$, Ar, $CO_2$, $H_2$, He, $H_2S$, $C_1$, $C_2$, $C_2H_4$, $C_3$, $iC_4$, $_nC_4$, iC5, $nC_4$,, $C_6$, and $C_{6+}$. In addition, if samples contained sufficient gas, carbon isotopic compositions ($^{13}C/^{12}C$) were analyzed on $C_1$ and $C_2$ to determine gas origin (biogenic versus thermogenic) following Bernard and others (1978) (see Appendix 3).

Use of a short tube to collect gases from the monometer and evacuated gas collection bags did not preclude air contamination in the samples. To remove the air we normalized all of the gas analyses (Appendix 3a) to an air-free basis (Appendix 3b). Examination of the air-free analyses shows significant nitrogen depletion in many of the samples (Appendix 3b) that were run by Isotech Laboratories. The lab reports no systematic errors in the analyses of the Mylan Park samples (S. Pelphrey, oral commun., 2004). We do not have an explanation for the nitrogen depletion. However, it does not affect the accuracy or precision of the hydrocarbon analyses or the ratio of methane to the higher molecular weight hydrocarbons.

## *Adsorption Analyses*

After desorption measurements were completed in December, 2003, the canisters were unsealed and taken to the WVGES laboratory at West Virginia University, Morgantown, WV. The coals were split into representative sub-samples for petrographic, geochemical, and proximate analyses. In addition, splits from all canisters of the Upper Kittanning, Middle Kittanning, and Clarion coal beds were selected for high-pressure carbon dioxide adsorption analyses because they were relatively thick (1.7 -3.95 ft), deep (1,112.7 – 1,270.5 ft, and contained abundant gas [85.45 – 130.98 SCF/ton (ab) (2.67 -4.09 cc/g)] (See sections below.) These analyses were preformed to determine the maximum carbon dioxide sorption capacity in the Mylan Park coals.

Samples for high-pressure carbon dioxide adsorption analyzes were sent to RMB Earth Science Consultants, Ltd. where they were crushed to -60 mesh and placed in an equilibrium moisture bath for 21 days. Isotherm analyses were conducted in a high-pressure volumetric adsorption apparatus at the reservoir temperature of 70$^{o}$ F. A reference cell with a known volume of gas was used to dose 100-gram samples of the Upper Kittanning, Middle Kittanning, and Clarion coals, and the amount of gas adsorbed on equilibrated samples was determined over a series of pressures. See Appendix 4 (RMB Earth Science Consultants, Ltd, 2003) for the adsorption report and Yee and others (1993) for detailed information on gas adsorption theory and analyses.

# Desorption Results and Gas Chemistry by Coal Bed

## *Sewickley coal bed (Mined)*

A 5.4 ft sample of a remaining pillar from an abandoned underground mine of the Sewickley coal bed was cored and retrieved to the surface from a depth of 346.80-352.20 ft at 11:39 hours on 9/27/2002. Eight measurements were taken over three days (fig. 3) until desorption was suspended because the coal did not desorb estimated gas volumes (Appendix 2).

Measured raw total gas content for the coal bed (weighted average) was 0.07 SCF/ton (0.00 c/g). The Sewickley coal bed contained 1.29% moisture and 21.08% ash on a dry basis (db). Because the gas content was so low (fig. 3), ash yields of coals within individual canisters were not determined thus total gas content on a dry, ash-free basis (daf) could not be determined.

**Canister 1 - (**WV-02-CB3-10; 346.80 – 347.20 ft) **-** No gas was desorbed over the three days.
**Canister 2 -** (WV-02-B3-1; 347.20 – 348.20 ft) **-** Only the first measurement recorded the presence of gas. Measured raw total gas content of the coal was 0.40 SCF/ton (0.01 cc/g) (based on the single measurement).
**Canister 3 -** (WV-02-US4-2; 348.20 – 350.20 ft) **-** Only the first and second measurement recorded the presence of gas. Measured raw total gas content of the coal was 0.01 SCF/ton (0.00 cc/g) (based on the two measurements).
**Canister 4 -** (WV-02-US4-1; 350.20 – 352.20 ft) **-** Measured raw total gas content of coal was 0.02 SCF/ton (0.00 cc/g) (based on a single measurement).

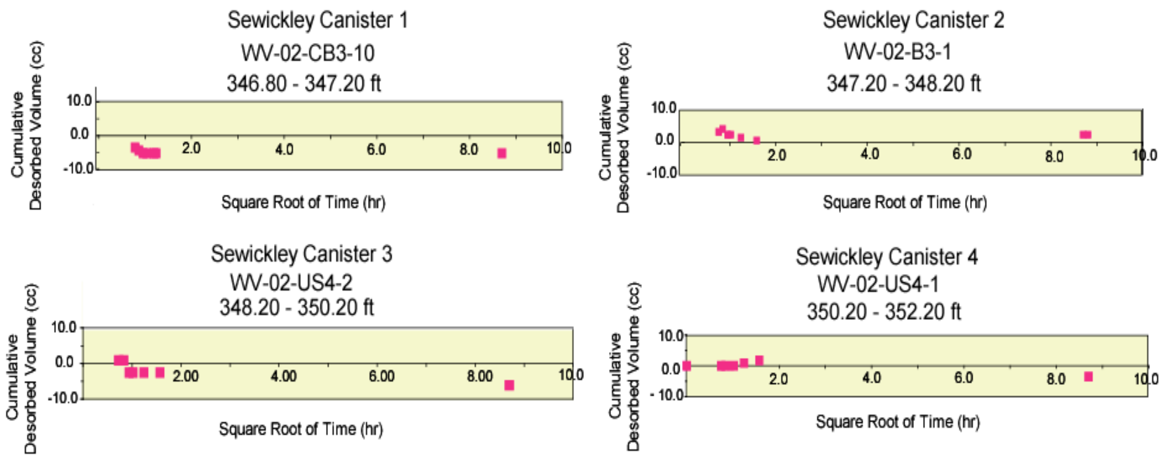


**Figure 3** - Cumulative desorption volume in cubic centimeters per gram (cc/g) of the Sewickley coals against the square root of time in hours. Note the virtual absence of desorbed gas. Canister numbers and coal sample depths are shown. These analyses are not regarded as representative of the Sewickley coal bed where it has not been mined. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Chemistry of the Sewickley Coal Bed

Insufficient gas from the Sewickley canisters was available for chemical analysis.

## *Redstone coal bed*

A 2.7 ft sample the Redstone coal bed was cored and retrieved to the surface from a depth of 405.3 - 408.0 ft at 15:01 hours on 9/30/2002. The measured raw total gas content of the Redstone coal bed (weighted average) at Mylan Park was low, 0.5 SCF/ton (0.02 cc/g), which can be attributed to gas migration due to the mining of the overlying Sewickley coal bed and the underlying Pittsburgh coal bed. Overall, the Redstone coal bed contained 0.68% moisture and ash yield (db) was 27.8%. Because gas contents were low (fig. 4), ash yields of the coal in the individual canisters were not determined and total gas content (daf) could not be determined.

**Canister 1 -** (WV-02-US4-5; 405.3 – 407.3 ft) **-** Twenty seven desorption measurements were taken over 23 days. Measured raw total gas content of the coal was 0.44 SCF/ton (0.01 cc/g).
**Canister 2 -** (WV-02-B3-2; 407.3 – 408 ft) **-** Six desorption measurements were taken on 9/30/2002. Only one measurement detected gas. Measured raw total gas content of the coal in canister 2 was 0.57 SCF/ton (0.02 cc/g), based on the single measurement.

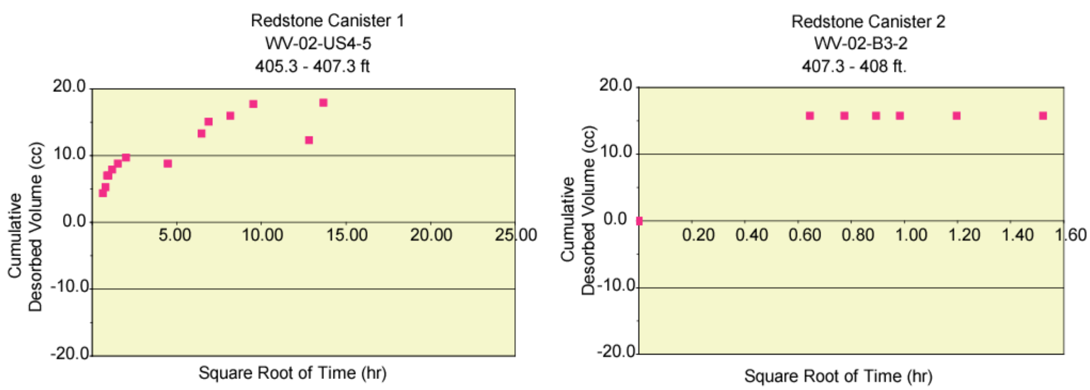


**Figure 4 -** Cumulative desorption volume (cc) of the Redstone coal against the square root of time in hours. Virtually no gas was emitted. Canister numbers and coal sample depths are shown. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Chemistry of the Redstone Coal Bed

Insufficient gas from the Redstone coal canisters was available for analyses.

## *Pittsburgh Roof coals*

Throughout the Northern Appalachian Basin, the Pittsburgh coal bed typically consists of a thick, minable lower bench overlain by a sequence of interbedded shale and thin coal beds, referred to as the roof sequence or interval. A total of 1.9 ft of coal from the 7.29 ft Pittsburgh Roof interval was retrieved from a depth of 426.96 – 433.85 ft at 17:52 on 9/30/2002 and placed into canisters for desorption (fig. 5). The measured raw total gas content of the sampled portion of the Pittsburgh Roof coal bed (weighted average) at Mylan Park was 1.25 SCF/ton (0.04 cc/g). Total gas content (daf) could not be determined because the ash yield of the individual coal in the two canisters was not determined. Overall, the ash yield of the Pittsburgh Roof coals that were desorbed was 83.05% ash (db) and moisture content was 1.63% .

**Canister 1 -** (WV-02-B3-3, 426.96 – 427.96 ft) **-** Thirty desorption measurements were taken from coal in canister 1 over 26 days (fig. 5). Measured raw total gas content of the coal in canister 1 was 1.29 SCF/ton (0.04 cc/g).

**Canister 2 -** (WV-02-B3-5; 432.35 – 433.25 ft) **-** Forty desorption measurements were taken from the coal in canister 2 over 38 days. Measured raw total gas content of the coal in canister 2 was 1.20 SCF/ton (0.04 cc/g).

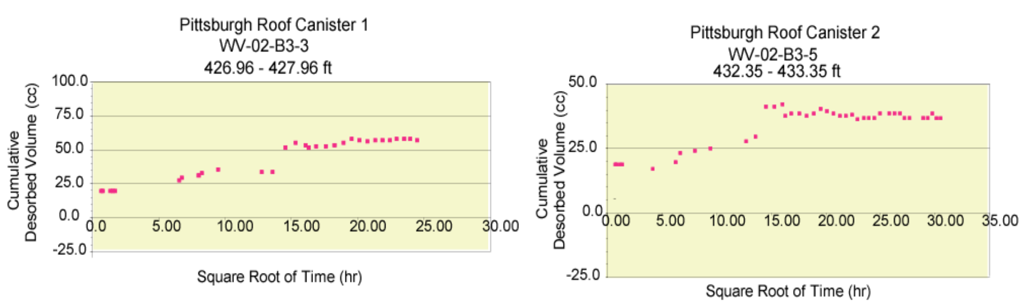


**Figure 5 -** Cumulative desorption volume (cc) for the sampled Pittsburgh Roof coal against the square root of time in hours. Canister numbers and coal sample depths are shown. These analyses are not regarded as representative of the Pittsburgh Roof coals where the underlying Pittsburgh coal bed and the overlying Sewickley coal bed have not been mined. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Chemistry of the Pittsburgh Roof Coal Zone

The underlying Pittsburgh coal bed and the overlying Sewickley coal bed had been mined and air contamination could have occurred in the gas sampling procedure, as the sample was primarily composed of air (Appendix 3a) even after re-normalizing on an air-free basis (Appendix 3b).

## Pittsburgh coal bed (Mined)

A total of 8.75 ft of the lower, minable bench of the Pittsburgh coal from a pillar in an abandoned mine was cored and retrieved to the surface from a depth of 433.85 – 442.35 ft at 17:52 hours on 9/30/2002 and placed in four two-ft long, 4 in diameter aluminum canisters. Desorption measurement were taken over 12 days (fig. 6). The measured raw total gas content of the Pittsburgh coal bed (weighted average) at Mylan Park was 1.0 SCF/ton (0.03 cc/g). Overall moisture content of the coal was 0.52 wt. % and ash yield was 9.84 wt. % (db). Ash yields of coals within the five individual canisters were not determined, thus the total gas content (daf) was not determined.

**Canister 1 -** (WV-02-B3-4; 433.85 – 434.35 ft) **-** Fifteen desorption measurements were taken from the coal in canister 1 over 12 days (fig. 6). Measured raw total gas content of the coal in canister 1 was 0.53 SCF/ton (0.02 cc/g).

**Canister 2** – (WV-02-US4-30; 434.35 – 436.35 ft) **-** Fourteen desorption measurements were taken from the coal in the canister over 12 days. Measured raw total gas content of the coal in canister 2 was 0.29 SCF/ton (0.01 cc/g).

**Canister 3 -** (WV-02-US4-14; 436.35 – 438.35 ft) **-** Fourteen desorption measurements were taken from the coal in the canister over 12 days. Measured raw total gas content of the coal in canister 3 was 0.52 SCF/ton (0.02 cc/g).

**Canister 4 -** (WV-02-US4-8; 438.35 – 440.35 ft) **-** Fourteen desorption measurements were taken from the coal in the canister over 12 days. Measured raw total gas content of the coal in canister 4 was 0.36 SCF/ton (0.01 cc/g).

**Canister 5 -** (WV-02-US4-6; 440.35 – 442.35 ft) **-** Fourteen desorption measurements were taken from the coal in the canister over 12 days. Measured raw total gas content of coal in canister 5 was 0.73 SCF/ton (0.02 cc/g)..

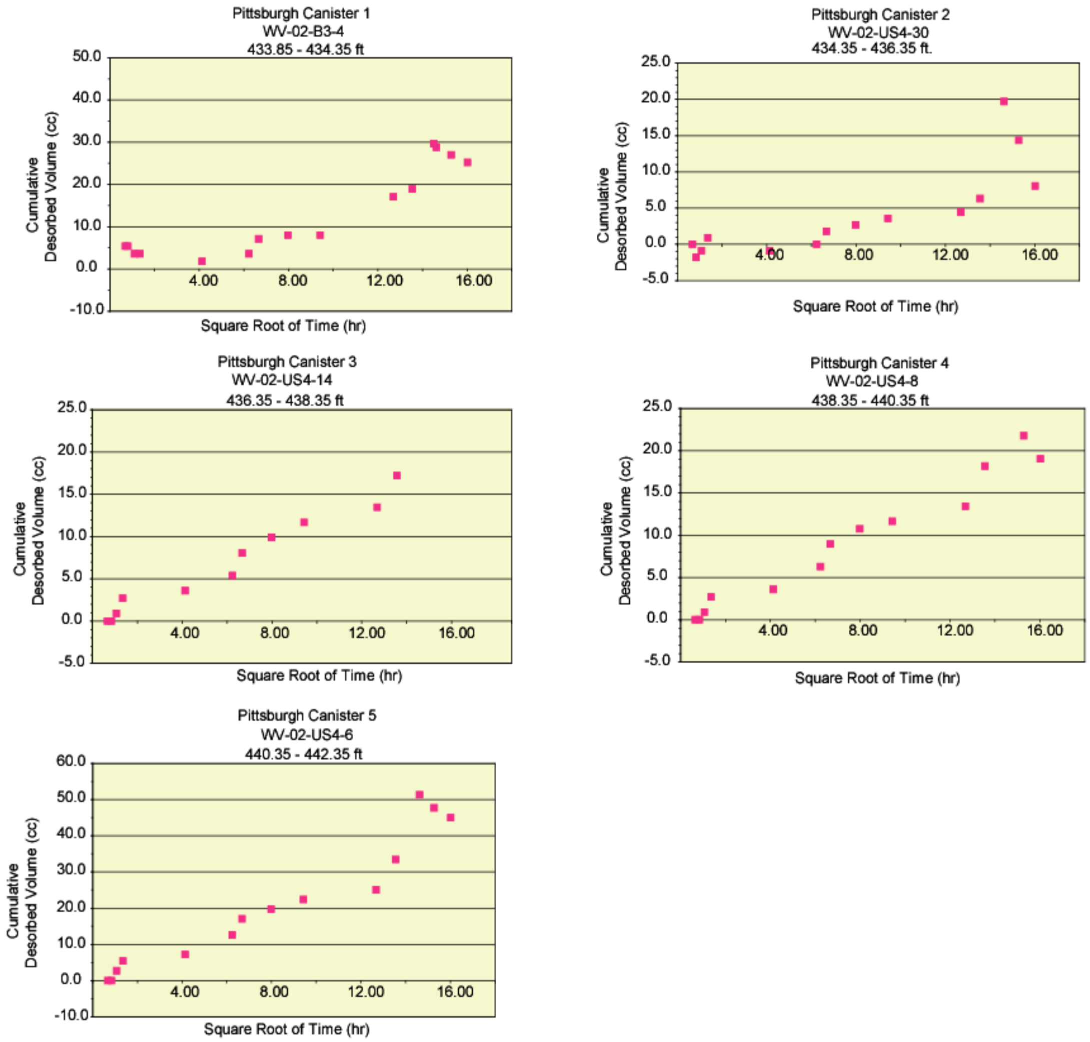


**Figure 6 -** Cumulative desorption volume (cc) for the Pittsburgh coals against the square root of time in hours. No gas was expected as the coal was drilled from a pillar in an abandoned mine. These analyses are not regarded as representative of the Pittsburgh coal bed where it has not been mined. Canister numbers and coal sample depths are shown. Note scale changes. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Chemistry of the Pittsburgh Coal Bed

Because the Pittsburgh coal bed had been mined in this location, there was little desorbed gas and gas from the entire coal bed and all but the top foot of coal was combined and analyzed for gas chemistry. Three gas samples were analyzed (Appendix 3a), recalculated to an air-free basis, and only one (sample number 46862 taken on October 11, 2002), contained substantial amounts of methane (78.7 %) (Appendix 3b).

## *Little Pittsburgh coal bed*

A total of 0.75 ft of coal from the Little Pittsburgh coal bed was cored and retrieved to the surface from a depth of 468.5 – 469.5 ft and placed into a single canister at 13:48 hours for desorption on 10/01/2002. Forty seven desorption measurements were taken over 64 days (fig. 7). Moisture content was 1.15 wt. % and the ash yield of the coal was 24.3% (db). Measured raw total gas content of the coal bed (weighted average) was 13.52 SCF/ton (0.42 cc/g) and total gas content (daf) was 25.44 SCF/ton (0.79 cc/g).

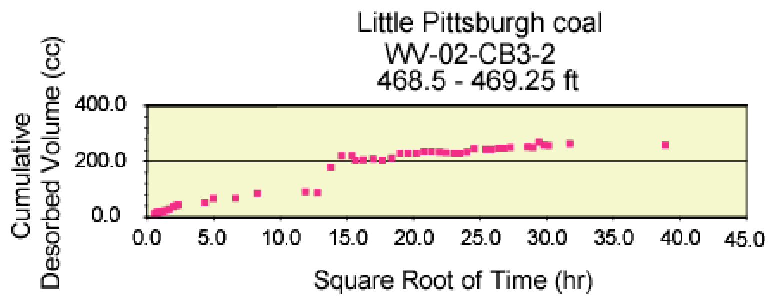


**Figure 7** – (WV-02-CB3-2; 468.5 – 469.25 ft) - Cumulative desorption volume (cc) for the Little Pittsburgh coal plotted against the square root of time in hours. Canister number and coal sample depth is shown. See Appendix 2 for a copy of the desorption sheet from which this graph was derived.

## Gas Chemistry of the Little Pittsburgh Coal Bed

Two gas samples from the Little Pittsburgh coal bed were analyzed and recalculated to an air-free basis. Both samples of coal bed gas were contaminated by air (Appendix 3b) to varying degrees, either through the gas sampling procedure or by interaction with air from mining in the overlying Pittsburgh coal bed. Sample DOE-MP #11 contained 47% methane (Appendix 3b).

## *Elk Lick coal bed*

A total of 0.67 ft of coal from the Elk Lick coal bed was cored and retrieved to the surface from a depth of 659.93 – 660.6 ft and placed into a single canister at 15:20 hours for desorption on 10/02/2002. Ninety four desorption measurements were taken over 431 days and the gas desorption profile shows that gas continued to be released from the coal when the experiment was halted (fig. 8) due to time constraints on completion of the project. This is one of the few coals that contained significant lost gas (60 cc).

Measured raw total gas content of the canister and the coal bed (weighted average) was 62.68 SCF/ton (1.96 cc/g). The moisture content of the coal was 0.85 wt. %, ash yield was 24.3 wt. % (db), and total gas content (daf) was 82.88 SCF/ton (2.59 cc/g).

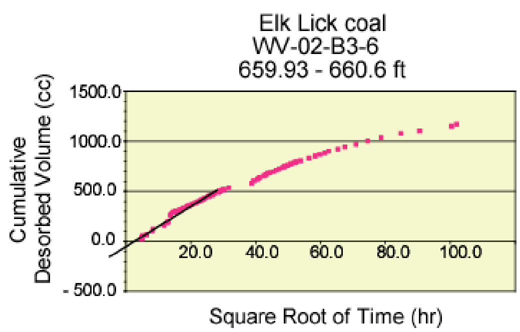


**Figure 8** - (WV-02-B3-6; 659.93 – 660.6 ft) **-** Cumulative desorption volume for the Elk Lick coal against the square root of time. Canister number and coal sample depth is shown. The black, best-fit line was used to estimate lost gas (60 cc/g). See Appendix 2 for a copy of the desorption sheet from which this graph was derived.

## Gas Chemistry of the Elk Lick Coal Bed

Four coal bed gas samples were analyzed for the Elk Lick coal bed and recalculated to an air-free basis. All of the samples have high nitrogen contents and sample 60587 had very low methane content (<1 %). Samples DOE-MP #4, DOE-MP #6, and DOE-MP #12 had methane contents ranging from 82 to 87 percent (Appendix 3b).

## *Brush Creek coal bed*

A total of 1.4 ft of the Brush Creek coal was cored and retrieved to the surface from a depth of 920.4 – 921.8 ft at 17:46 hours on 10/07/2002 and placed in two canisters. Gas continued to be released from the coal when the experiment was halted 425 days later (fig. 9). Overall moisture content of the coal in the two canisters was 0.95 wt. % and ash yield was 43.43 wt. % (db). The total measured raw gas content of the coal bed (weighted average) was 67.38 SCF/ton (2.11 cc/g) on a daf-basis.

**Canister 1 -** (WV-02-B3-7; 920.4 – 921.1 ft) **-** A total of 78 desorption measurements were taken over 425 days. Measured raw total gas content was 40.97 SCF/ton (1.28 cc/g). The ash yield of the coal in the canister was 62.67 percent, and total gas content (daf) was 112.64 SCF/ton (3.52 cc/g).

**Canister 2 -** (WV-02-B3-8; 921.1- 921.8 ft) A total of 83 desorption measurements were taken over 425 days. Measured raw total gas content of the coal in canister 2 was 107.09 SCF/ton (3.35 cc/g). The ash yield of the coal in the canister was 12.34 percent, and total gas content (daf) was 122.14 SCF/ton (3.82 cc/g).

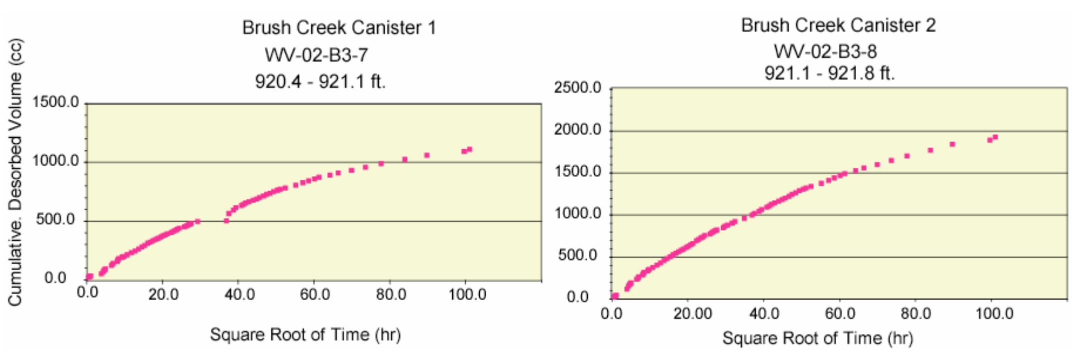


**Figure 9** - Cumulative desorption volume (cc) for the Brush Creek coal against the square root of time in hours. Note the differences in the amount of gas released from the coal in the two cores. Canister 1 contained bony coal and dark grey shale where as canister 2 contained coal. Canister numbers and coal sample depths are shown. There was no estimated lost gas from either canister. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Chemistry of the Brush Creek coal bed

Three coal bed gas samples were analyzed for the Brush Creek coal bed and recalculated to an air-free basis (Appendix 3b). Methane contents of the samples ranged from 84 to 98 percent (Appendix 3b).

## *Upper Kittanning coal bed*

A total of 1.7 ft of the Upper Kittanning coal was cored and retrieved to the surface from a depth of 1,121.7 – 1,123.4 ft at 9:05 hours on 10/09/2002 and placed in two canisters. Eighty two desorption measurements were taken over 424 days (fig 10). The Upper Kittanning coal bed contained 0.97 wt. % moisture, 9.25 wt. % ash (db), a measured total gas content (weighted average) of 130.98 SCF/ton (4.09 cc/g), and a total gas content (daf) of 142.25 SCF/ton (4.45 cc/g).

**Canister 1 -** (WV-02-B3-9; 1,121.7 – 1,122.7 ft) **-** Measured raw total gas content of the coal in the canister was 136.33 SCF/ton ((4.26 cc/g). The ash yield was 6.65 percent, and total gas content (daf) was 146.14 SCF/ton (4.57 cc/g).

**Canister 2 -** (WV-02-B3-10; 1,122.7 – 1,123.4 ft) **-** Measured raw total gas content of the coal in canister 2 was 123.34 SCF/ton (3.85 cc/g). The ash yield was 12.55 percent, and total gas content (daf) was 140.77 SCF/ton (4.40 cc/g).

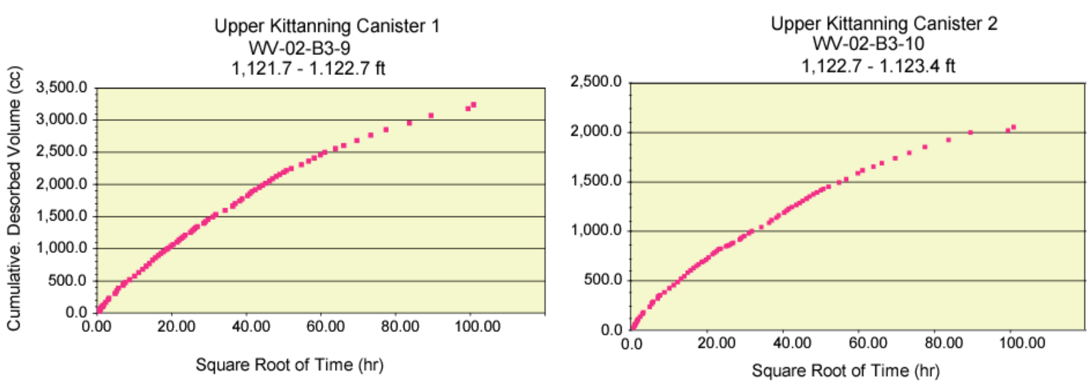


**Figure 10** - Cumulative desorption volume (cc) for the Upper Kittanning coals against the square root of time in hours. Canister numbers and coal sample depths are shown. There was no estimated lost gas in either canister. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Chemistry of the Upper Kittanning coal bed

Four samples of coal bed gas from the Upper Kittanning coal bed were analyzed and recalculated to an air-free basis. Even after correcting for air, nitrogen contents were relatively high, ranging from 4 to almost 10 percent (Appendix 3b). Methane contents for individual canisters (WV-02-B3-9 and WV-02-B3-10) and the cumulative coal bed ranged from 84 to 95 percent (Appendix 3b).

## *Middle Kittanning coal zone*

A total of 3.75 ft of the Middle Kittanning coal was cored and retrieved to the surface from a depth of 1,184.1 – 1,190.45 ft at 13:38 hours on 10/09/2002 and placed in five canisters. Seventy three desorption measurements were taken over 424 days and gas continued to be released from the coal when the experiment was halted due to project time constraints (fig. 11). All but canister 5 had estimated lost gas ranging from 5 - 40 cc. The overall moisture content of the upper and middle splits of the Middle Kittanning coal bed was 0.52 wt. %, ash yield was 18.61 wt. % (db), there was no estimated lost gas, the measured raw total gas content (weighted average) was 113.54 SCF/ton (3.59 cc/g), and the total measured gas content (daf) was 138.94 SCF/ton (4.40 cc/g).

**Canister 1 -** (WV-02-B3-11; 1,184.1 – 1,185.1 ft) **-** Measured raw total gas content of the coal in the canister was 95.36 SCF/ton (2.98 cc/g). The ash yield of the coal in the canister was 21.18 percent, and total gas content (daf) was 121.03 SCF/ton (3.78 cc/g). This canister had 20 cc of estimated lost gas.

**Canister 2 -** (WV-02-CB3-12; 1,185.1 – 1,185.4 ft) **-** Measured raw total gas content of the coal in the canister was 103.42 SCF/ton (3.23 cc/g). The ash yield of the coal in the canister was 29.10 percent and total gas content (daf) was 146.14 SCF/ton (4.57 cc/g). This canister had 20 cc of estimated lost gas.

**Canister 3 -** (WV-02-B3-12; 1,188.0 – 1,189.0 ft) **-** Measured raw total gas content of the coal was 104.81 SCF/ton (3.28 cc/g). The ash yield of the coal in the canister was 29.10 percent, and total gas content (daf) was 139.31 SCF/ton (4.35 cc/g). This canister had 40 cc of estimated lost gas, the second largest amount of lost gas in the Mylan Park samples after the Elk Lick coal.

**Canister 4 -** (WV2-B3-13; 1,189.0 – 1190.0 ft) **-** Measured raw total gas content of the coal was 138.96 SCF/ton (4.34 cc/g). The ash yield of the coal in the canister was 24.73 percent, and total gas content (daf) was 150.78 SCF/ton (4.71 cc/g). This canister had no estimated lost gas.

**Canister 5 -** (WV-02-CB3-11; 1,190.0 – 1,190.45 ft) **-** Measured raw total gas content of the coal was 124.19 SCF/ton (3.88 cc/g). The ash yield of the coal in the canister was 16.34 percent, and total gas content (daf) was 148.61 SCF/ton (4.64 cc/g).

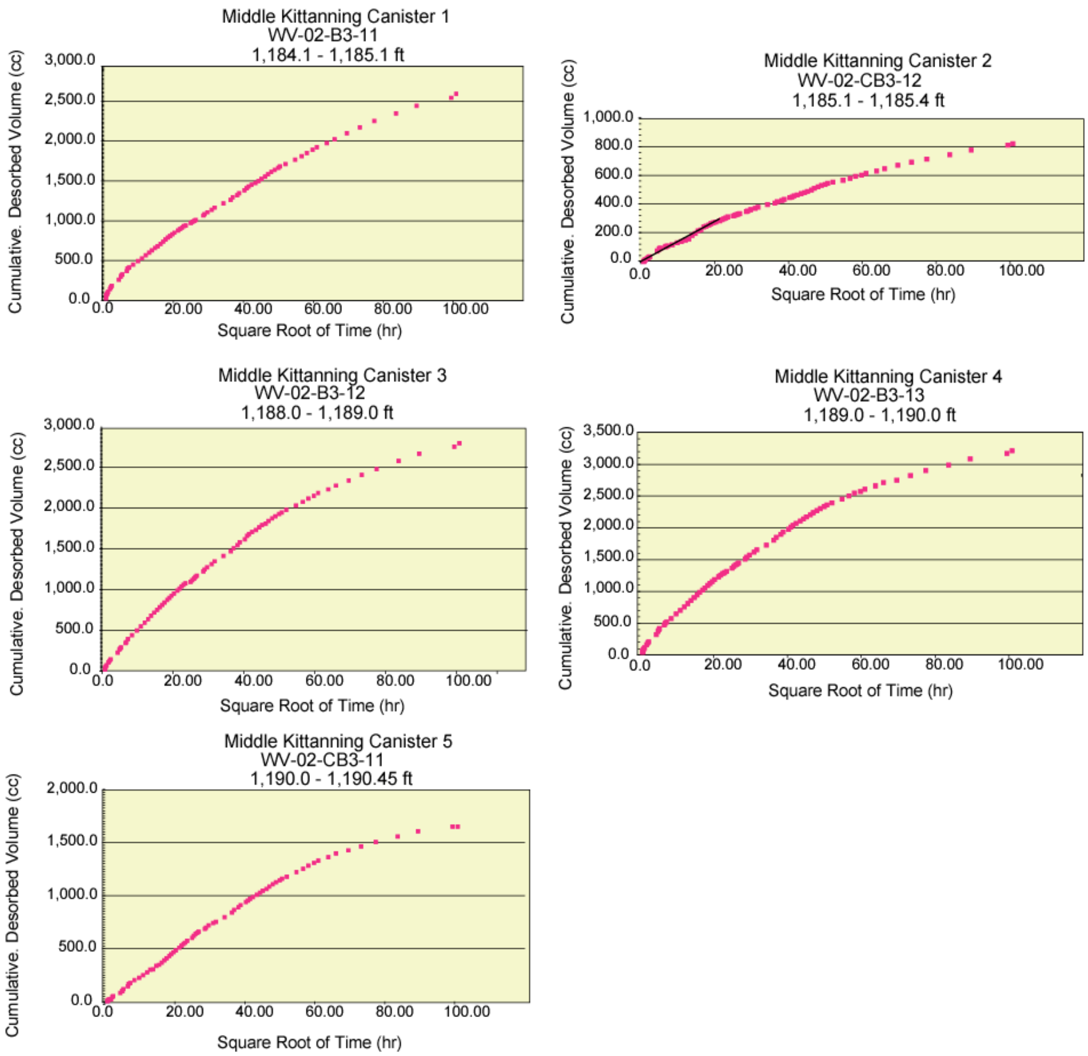


**Figure 11** – Cumulative desorption volume (cc) of the Middle Kittanning coal against the square root of time in hours. Canister numbers and coal sample depths are shown. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Chemistry of the Middle Kittanning Coal Bed

The Middle Kittanning coal bed contains both an upper (1,184.1 – 1,185.4 ft) and a lower (1,188.0 – 1,190.45 ft) split, separated by 2.6 ft of interbedded shale and sandstone parting (Appendix 1). Six coal bed gas samples were analyzed for the upper split and seven coal bed gas samples were analyzed for the lower split. Methane contents of the upper split of the Middle Kittanning coal bed ranged from 68 to 94 percent, on an air-free basis (Appendix 3b). Gas samples of the lower split ranged from 78 to 93 percent, on an air-free basis (Appendix 3b)

## *Clarion coal zone*

A total of 3.95 ft of the Clarion coal was cored and retrieved to the surface from a depth of 1,270.5 – 1,280.8 ft at 8:24 hours on 10/10/2002 and placed in four canisters. Gas continued to be released from canisters 1, 3, and 4 (WV-02-B3-14, WV-02-B3-16, and WV-02-B3-17, respectively) 423 days later (fig. 12) when they were opened. The coal in canister 2 (WV-02-B3-15) continued to desorb small amounts of gas (Appendix 2) until desorption ended 662 days later. Measured raw total gas content for the Clarion coal zone (weighted average) was 85.69 SCF/ton (2.68 cc/g). Moisture content of the Clarion coal was 1.01 wt. %, ash yield was 14.22 (db), and the total gas content (daf) was 124.42 SCF/ton (3.89 cc/g). There was no estimated lost gas for any of the canisters of Clarion coal.

**Canister 1 -** (WV-02-B3-14; 1,270.5 – 1,271.5 ft) **-** Seventy five desorption measurements were taken over 423 days. Measured raw total gas content was 49.14 SCF/ton (1.54 cc/g). The ash yield was 63.69 percent, and total gas content (daf) was 135.58 SCF/ton (4.24 cc/g).

**Canister 2 -** (WV-02-B3-15; 1,271.5 – 1,272.35 ft) **-** Seventy seven desorption measurements were taken over 662 days before gas finished desorbing. Measured raw gas content was 70.52 SCF/ton (2.20 cc/g). Ash yield was 13.73 wt. % and total gas content (daf) was 81.64 SCF/ton (2.55 cc/g).

**Canister 3 -** (WV-02-B3-16; 1,278.7 – 1,279.7 ft) **-** Seventy five desorption measurements were taken over 423 days. Measured raw total gas content was 134.84 SCF/ton (4.21 cc/g). The ash yield was 10.84 percent, and total gas content (daf) was 151.15 SCF/ton (4.72 cc/g).

**Canister 4 -** (WV-02-B3-17; 1,279.7 – 1,280.8 ft) **-** Seventy five desorption measurements were taken over 423 days. Measured raw total gas content was 125.42 SCF/ton (3.92 cc/g). The ash yield of the coal in canister was 17.96 percent, and total gas content (daf) was 152.82 SCF/ton (4.78 cc/g).

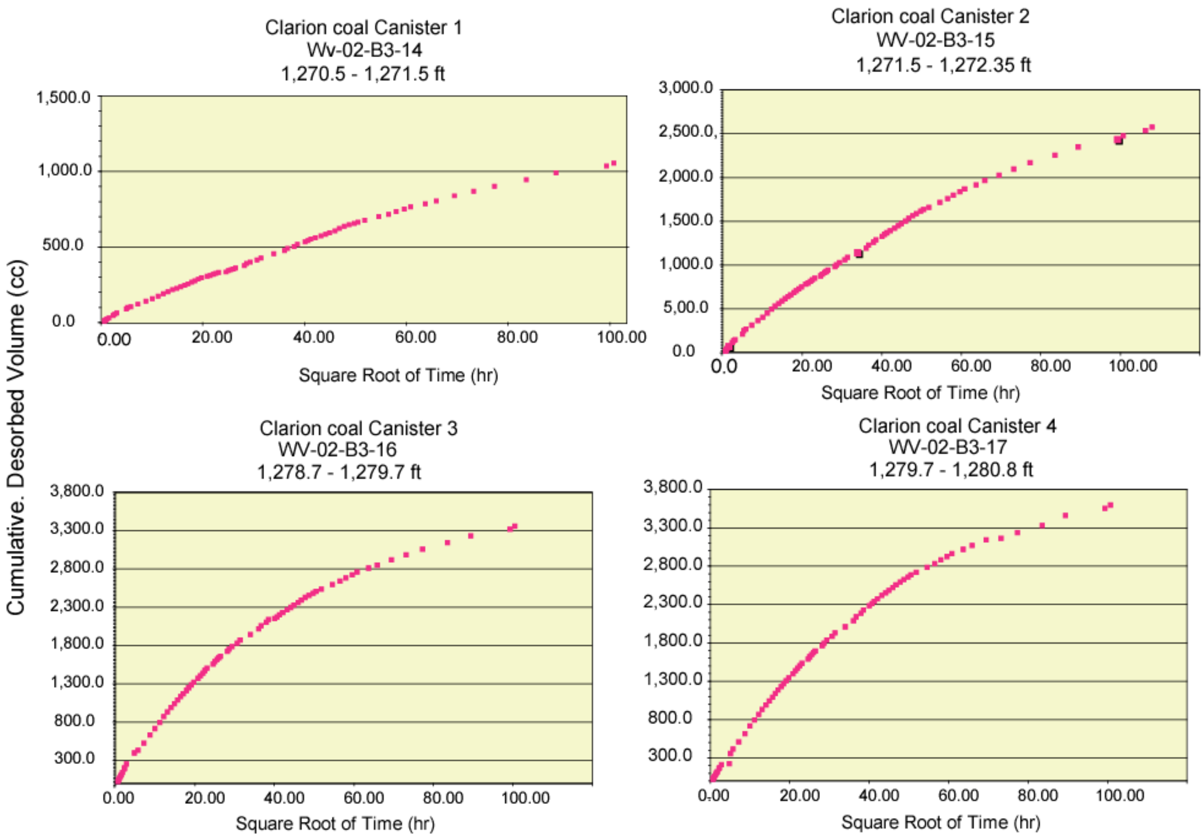


**Figure 12** - Cumulative desorption volume (cc) for the Clarion coals against the square root of time in hours. Canister numbers and coal sample depths are shown. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Chemistry of the Clarion Coal Zone

Like the Middle Kittanning coal bed, the Clarion coal bed also contains both an upper (1,270.5 – 1,272.35 ft) and a lower (1, 278.7 – 1,280.8 ft) split, separated by 6.35 ft of interbedded shale, claystone, mudstone, and sandstone parting (Appendix 1). Four coal bed gas samples were analyzed for the upper split and four coal bed gas samples were analyzed for the lower split. Methane contents the upper split of the Clarion coal ranged from 75 to 94 percent, on an air-free basis (Appendix 3b). Gas samples of the lower split ranged from 81 to 95 percent, on an air-free basis (Appendix 3b)

## *Upper Mercer coal bed*

A total of 0.75 ft of the Upper Mercer coal was cored and retrieved to the surface from a depth of 1,324.4 – 1,325.15 ft at 14:31 hours on 10/10/2002 and placed in a single canister. A total of 71 desorption measurements have been taken over 423 days (fig. 13) and gas continued to be released from the coal when the experiment was halted. There were 10 cc of estimated lost gas.

The measured raw total gas content of the canister and the coal bed was 95.02 SCF/ton (2.97 cc/g). Moisture content was 0.72 wt. %, ash yield was 10.96 wt. %, and total gas content (daf) was 106.67 SCF/ton (3.33 cc/g).

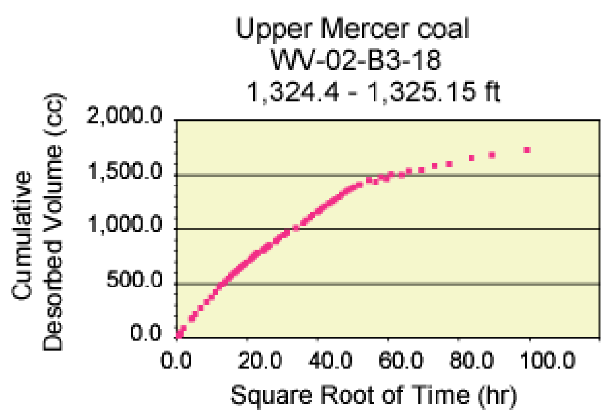


**Figure 13** - Cumulative desorption volume (cc) for the Upper Mercer coal bed against the square root of time in hours. Canister number and coal sample depth is shown. See Appendix 2 for a copy of the desorption sheet from which this graph was derived

## Gas Chemistry of the Upper Mercer Coal Bed

Three samples of Upper Mercer coal bed gas were analyzed (Appendix 3a) and recalculated to an air-free basis (Appendix 3b). Methane contents on an air-free basis ranged from 86 to 93 percent.

## *Lower Mercer coal bed*

A total of 1.0 ft of the Lower Mercer coal was cored and retrieved to the surface from a depth of 1,357.5 – 1,358.5 ft at 17:51 hours on 10/10/2002 and placed in a canister. Eighty six desorption measurements have been taken over 423 days and gas continued to be released from the coal when the experiment was halted (fig. 14). There was no estimated lost gas.

The measured raw total gas content of the canister and the coal bed was 35.27 SCF/ton (1.10 cc/g). Moisture content was 0.49 wt. %, ash yield was 30.62 wt. % (db), and total gas content (daf) was 50.84 SCF/ton (1.59 cc/g).

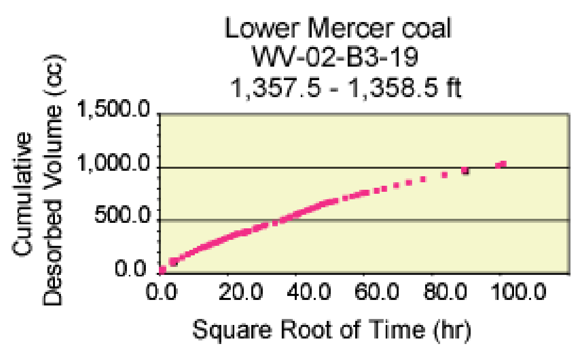


**Figure 14 -** Cumulative desorption volume (cc) for the Lower Mercer coal against the square root of time in hours. Canister number and coal sample depth is shown. The higher ash yield of the Lower Mercer coal bed (30.62 wt. %, db) results in substantially lower gas volumes than the Upper Mercer coal bed with an ash yield of 10.96 wt. %, db. See Appendix 2 for a copy of the desorption sheet from which this graph was derived.

## Gas Chemistry of the Lower Mercer Coal Bed

Three samples of the Lower Mercer coal bed gas were analyzed (Appendix 3a) and recalculated to an air-free basis (Appendix 3b). Methane contents on an air-free basis ranged from 66 to 93 percent (Appendix 3b).

## *Quakertown coal zone*

A total of 1.43 ft of the Quakertown coal zone was cored and retrieved to the surface from a depth of 1,465.0 – 1,476.3 ft at 11:46 hours on 10/15/2002 and placed in two canisters. A total of 71 desorption measurements were taken over 418 days and gas continued to be released from the coal when the experiment was halted (fig. 15). Both canisters of Quakertown coal had estimated lost gas (10 and 20 cc, respectively). Moisture content was 0.58 wt. %, ash yield (db) was 35.37 wt. %, the measured raw total gas content for the Quakertown coal zone (weighted average) was 67.84 SCF/ton (2.12 cc/g), and measured total gas (daf) was 88.17 SCF/ton (2.76 cc/g).

**Canister 1 -** (WV-02-B3-20; 1,465.0 – 1,465.6 ft) The measured raw total gas content was 50.33 SCF/ton (1.57 cc/g). The ash yield was 33.48 percent, and total gas content (daf) was 75.65 SCF/ton (2.36 cc/g). Estimated lost gas for this canister was 10 cc.
**Canister 2 -** (WV-02-B3-21; 1,475.6 – 1,476.43 ft) The measured raw total gas content was 85.90 SCF/ton (2.68 cc/g). The ash yield was 27.74 percent, and total gas content (daf) was 97.62 SCF/ton (3.05 cc/g).

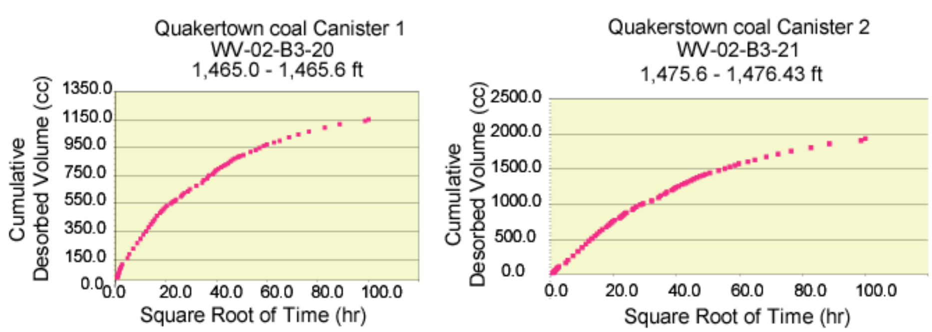


**Figure 15** - Cumulative desorption volume (cc) for the Quakertown coal zone against the square root of time in hours. Canister numbers and coal sample depths are shown. See Appendix 2 for copies of the desorption sheets from which these graphs were derived.

## Gas Analyses of the Quakertown Coal Zone

Three samples of the Quakertown coal zone coal bed gas were analyzed (Appendix 3a) and recalculated to an air-free basis (Appendix 3b). Methane contents for the samples ranged from 86 percent to 99 percent on an air-free basis (Appendix 3b). Two of the gas samples, DOE-MP #23 (canister WV-02-B2-20) and DOE- MP #22 (canister WV-02-B3-21) analyzed by the DOE/NETL laboratory on October 15, 2002, contained high nitrogen contents (10 and 14 percent respectively) after normalizing to an air-free basis (Appendix 3b). In contrast, a composite gas sample (48348, Appendix 3b) taken about two weeks later and analyzed by Isotech Laboratories, Ltd., contained no nitrogen. These differences are currently not explainable with available data.

## Isotope Analyses

Isotopic composition of methane was measured in selected samples throughout the desorption experiment. Samples from the following coal beds were analyzed; Pittsburgh, Brush Creek, Upper Kittanning, Middle Kittanning, Clarion, Upper Mercer, Lower Mercer, and Quakertown (see Appendix 3a, b). Plots of the ratio of methane to the sum of the higher molecular gases ($C_1/C_{2+}$) against $\delta^{13}$ methane show that the methane from all of the coals, with the exception of the Quakertown, is thermogenic. The Quakertown coal plots in the mixing or transitional zone, suggesting that it has been partially oxidized by microbial activity.

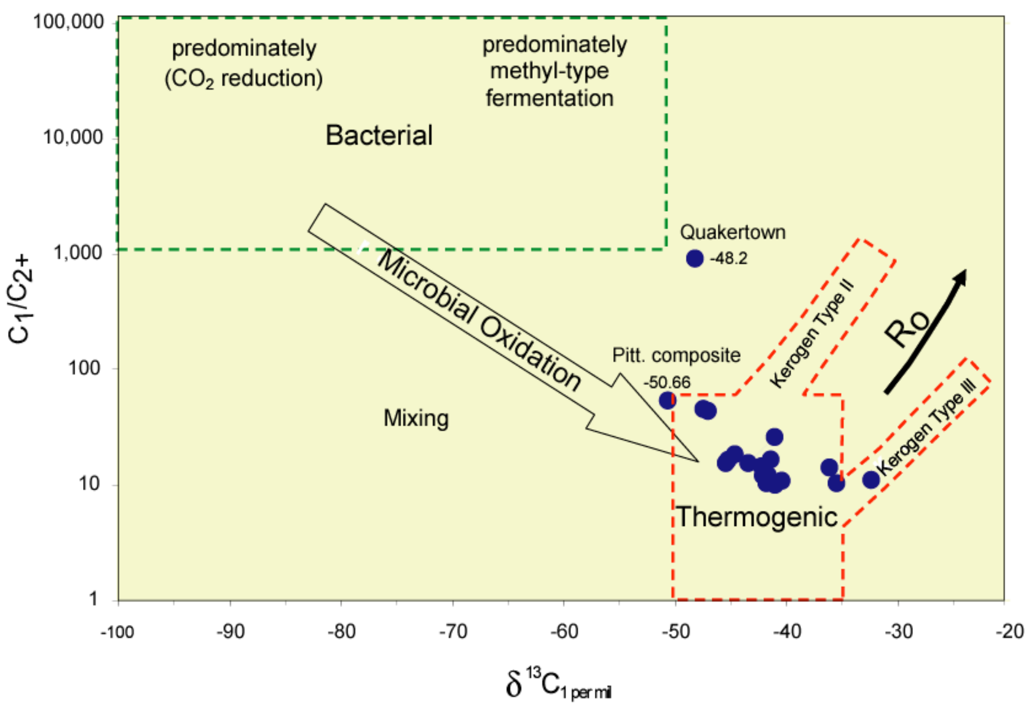


**Figure 16** - Bernard diagram for Mylan Park gas samples (modified from Bernard and others, 1978; Faber and Stahl, 1984; and Whiticar, 1994). The plot of isotopic values of $\delta^{13}$ from methane against the ratio of methane ($C_1$) to the sum of the higher molecular gases ($C_{2+}$) which includes ethane, propane, iso-butane, n-butane, iso-pentane, 2-methybutane, n-pentane, and hexane. Note that the Quakertown coal falls in the mixing zone, suggesting a mixed thermal and biogenic origin of the Quakertown coal gas. All of the other samples are thermogenic in origin. Abbreviations: Pitt. = Pittsburgh; $R_o$ = percent vitrinite reflectance.

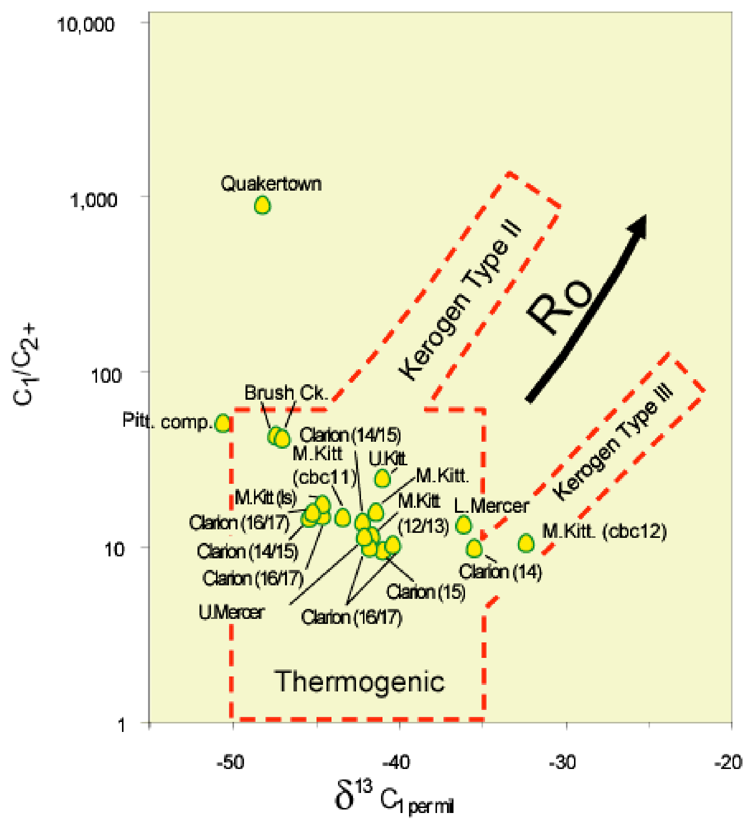


**Figure 17 -** Close-up of the thermogenic sector of the Bernard diagram (fig. 14) showing where entire coal beds (e.g. Brush Creek, Upper Mercer), individual canisters (e.g. Clarion (14), or composite samples of several canister from a single coal bed or coal zone (e.g. Clarion (16/17), Middle Kittanning (12/13)) plot. Abbreviations = $C_1$ = methane; $C_{2+}$ = ethane + propane + iso-butane + n-butane + isopentane + 2-methybutane + n-pentane + hexane; Pitt. Comp = Pittsburgh coal bed composite; Brush Ck. = Brush Creek coal bed; U.Kitt= Upper Kittanning coal bed; M.Kitt. = Middle Kittanning coal bed, U.Mercer = Upper Mercer coal bed, L.Mercer = Lower Mercer coal bed; $R_o$ = percent vitrinite reflectance; cbc12 = canister number cbc12.

## Adsorption Results

High pressure carbon dioxide adsorption isotherms were run on coals from the Upper Kittanning, Middle Kittanning, and Clarion coal zones to determine their maximum carbon dioxide sorption capacity as a function of pressure. Not all of the Clarion coal bed was analyzed for adsorption: coal in canister 15 (1,271.5 – 1,272.35 ft) was not included in the analyses because it was initially mislabeled in the field.

As stated previously, these three coals were chosen for analyses because they were relatively thick (1.7 - 3.95 ft), deep (1,112.7 – 1,270.5 ft, and contained abundant gas [85.69 – 130.98 SCF/ton (daf) (2.68 - 4.09 cc/g)]. Methane adsorption analyses were not performed on the coals because of cost considerations. However, Stanton (2001, unpublished data) and Gluskoter and others (2002) have shown that there is a direct relationship between coal rank and carbon dioxide and methane adsorption (fig. 18). Using the carbon dioxide/methane diagram (fig. 18), we estimate that the Mylan Park high-volatile bituminous A coals can adsorb about twice as much carbon dioxide as methane. This relationship allowed us to estimate the maximum amount of methane that could be adsorbed onto the coals and the degree of methane saturation at reservoir pressures.

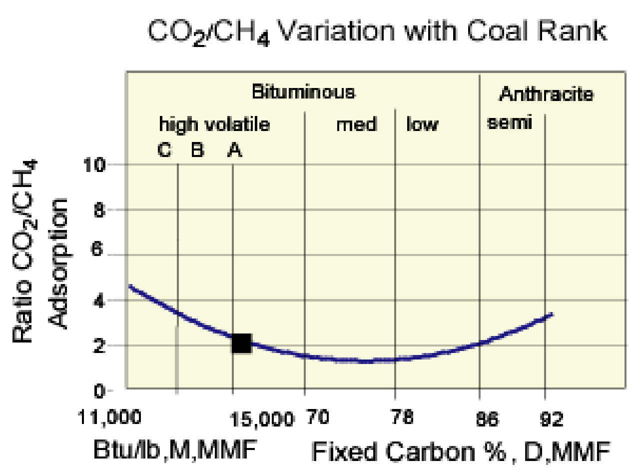


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**Figure 18** - Plot of the relationships between carbon dioxide and methane variation with coal rank. Modified from Gluskoter and others (2002). Based on the high-volatile bituminous A rank of the Mylan Park coals (black square), the plot shows that the estimated carbon dioxide to methane ratio is 2 to 1. Abbreviations: Btu/lb = British thermal units per pound, M = moisture; MMF = mineral matter free; D= dry; $CO_2$ = carbon dioxide; $CH_4$ = methane.

Determination of reservoir pressures was made by assuming that pressure in Mylan Park coals is controlled only by normal hydrostatic pressure. We can then calculate reservoir pressure by multiplying a constant for hydrostatic pressure per foot (0.433) times the depth to the coal. It is important to note that this may be an underestimate of the total pressure.

## Upper Kittanning coal bed

The Upper Kittanning coal bed is calculated to have a hydrostatic pressure of 486 PSIA, based on the bed depth of 1,122.5 ft. This corresponds to a maximum carbon dioxide adsorption of about 500 SCF/ton on an as-received basis (arb) (15.63 cc/g, arb) (fig. 18). On an as received basis, the calculated Langumuir volume is 831.8 SCF/ton (24.45 cc/g), Langmuir pressure is 327.1 PSIA (2.26 MPa), moisture content is 1.84 wt. %, and ash yield is 8.58 wt. %. See Appendix 4 for data on the following basis: (1) dry, ash free; (2) as-received; and (3) ash free, moisture included. Estimated maximum methane adsorption is approximately one half of the maximum carbon dioxide adsorption (fig. 18), which corresponds to approximately 250 SCF/ton (arb) (7.81 cc/g, arb), indicating that the Upper Kittanning coal bed is undersaturated in methane (measured total gas = 130.98 SCF/ton, arb).

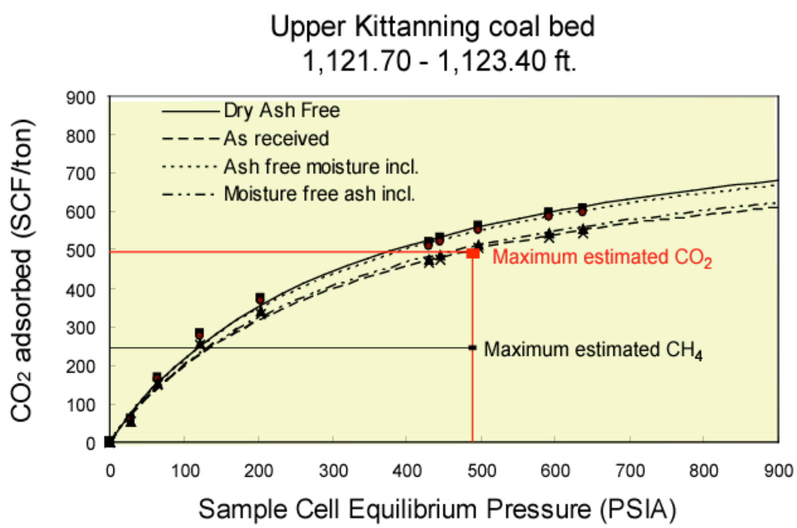


**Figure 19** - Maximum carbon dioxide adsorption (dashed line) and methane (solid line) for the Upper Kittanning coal zone, on an as-received basis. The calculated hydrostatic pressure (486 PSIA) intersects the as-received carbon dioxide isotherm at about 500 SCF/ton (15.63 cc/g), indicating that the maximum amount of carbon dioxide that can be adsorbed to the Upper Kittanning coal is about 500 SCF/ton (15.63 cc/g, arb). The maximum methane adsorption is approximately half of that, or about 250 SCF/ton (arb) (7.81 cc/g, arb). Abbreviations: incl = included; $CO_2$ = carbon dioxide; $CH_4$ = methane; SCF/ton = standard cubic feet per ton; arb = as-received basis; PSIA = pounds per square inch of area.

### *Middle Kittanning coal bed*

The Middle Kittanning coal bed is not as attractive as a repository of carbon dioxide as the Upper Kittanning coal bed. The Middle Kittanning coal bed is calculated to have a hydrostatic pressure of 514 PSIA, based on it's depth of 1,184.1 ft, which corresponds to a maximum carbon dioxide adsorption of about 400 SCF/ton (arb) (12.5 cc/g, arb) (fig. 18). On an as-received basis, the calculated Langumuir volume is 580.0 SCF/ton (17.05 cc/g ), Langmuir pressure is 253.6 PSIA (1.75 MPa), moisture content 1.96 wt. %, and ash yield is 19.91 wt. %. See Appendix 4 for data on the following basis: (1) dry, ash free; (2) as received; and (3) ash free, moisture included. Estimated maximum methane adsorption is approximately one half of the maximum carbon dioxide adsorption (fig. 16), which corresponds to approximately 200 SCF/ton (arb) (6.25 cc/g, arb), indicating that the Upper Kittanning coal bed is also undersaturated in methane (measured total raw gas was 113.54 SCF/ton (3.59 cc/g), arb).

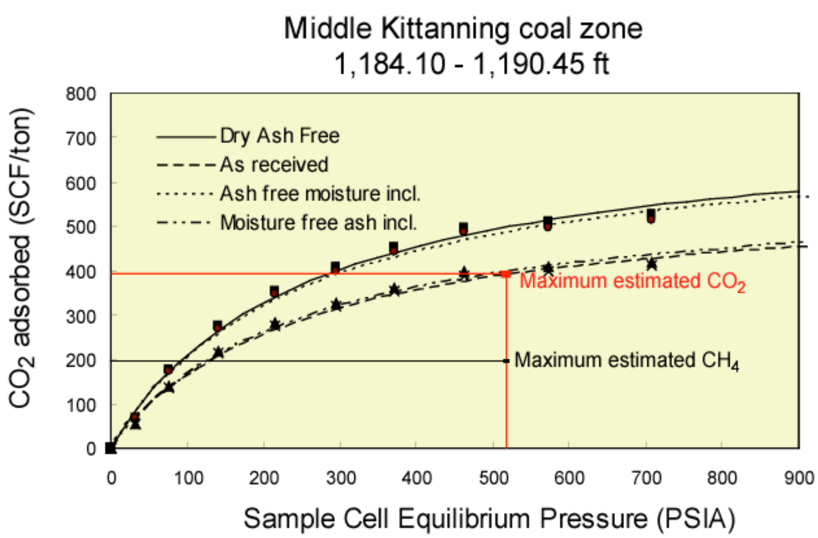


**Figure 20 -** Maximum carbon dioxide adsorption (dashed line) and methane (solid line) for the Middle Kittanning coal zone, on an as-received basis. The calculated hydrostatic pressure (514 PSIA) intersects the as-received carbon dioxide isotherm at about 400 SCF/ton (12.5 cc/g), indicating that the maximum amount of carbon dioxide that can be adsorbed on the Middle Kittanning coal bed is 400 SCF/ton (12.5 cc/g), arb. The maximum methane adsorption is approximately half of that, or about 200 SCF/ton (6.15 cc/g), arb. Abbreviations: incl = included; $CO_2$ = carbon dioxide; $CH_4$ = methane; SCF/ton = standard cubic feet per ton; arb = as- received basis; PSIA = pounds per square inch of area.

## *Clarion Coal Zone*

The Clarion coal zone is calculated to have a hydrostatic pressure of 552 PSIA, based on it's depth of 1,271.5 ft, which corresponds to a maximum carbon dioxide adsorption of about 300 SCF/ton (arb) (9.38 cc/g, arb) (fig. 19). On an as-received basis, the calculated Langumuir volume is 449.4 SCF/ton (17.05 cc/g), Langmuir pressure is 265.9 PSIA (1.75 MPa) , moisture content 1.57 wt. %, and ash yield is 26.57 wt. %. See Appendix 4 for data on the following basis: (1) dry, ash free; (2) as received; and (3) ash free, moisture included. Estimated maximum methane adsorption is approximately one half of the maximum carbon dioxide adsorption (fig. 16), which corresponds to approximately 150 SCF/ton (arb) (6.25 cc/g, arb), indicating that the Clarion coal is undersaturated in methane (measured total gas = 86.69 SCF/ton (3.59 cc/g), arb).

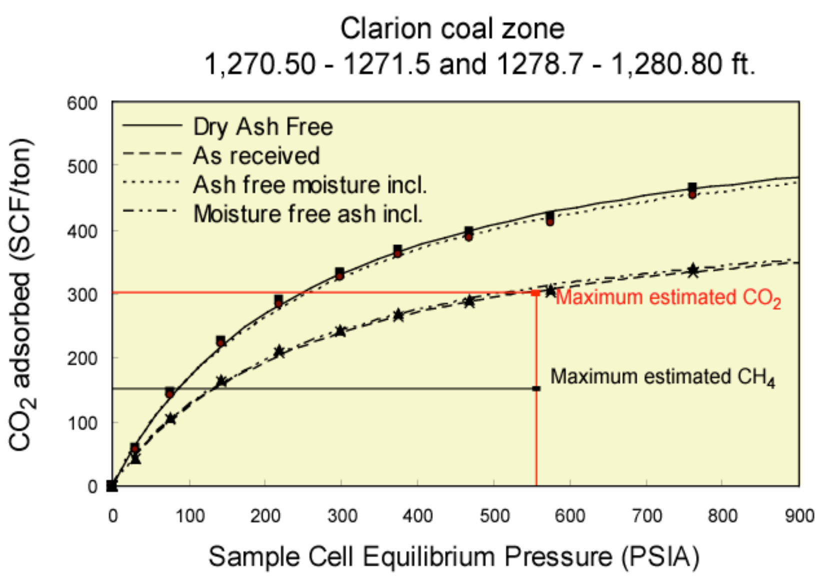


**Figure 21** - Maximum carbon dioxide adsorption (in red) and methane (in black) for the Clarion coal zone, on an as-received basis. The calculated hydrostatic pressure (552 PSIA) intersects the as-received carbon dioxide isotherm at about 300 SCF/ton (9.38 cc/g), which is a measure of the maximum amount of carbon dioxide that can be adsorbed to the Clarion coal. The maximum methane adsorption is approximately half of that, or about 150 SCF/ton (arb) (4.69 cc/g, arb). Abbreviations: incl = included; $CO_2$ = carbon dioxide; PSIA = pounds per square inch of area.

# Conclusions

1- Measured raw total gas contents for the coal beds in Mylan Park, WV, range from 0.07 SCF/ton (0.00 cc/g) for the mined Sewickley coal bed to 130.98 SCF/ton (4.09 cc/g) for the Upper Kittanning coal bed.

2- These values are minimum values because residual gas, which can be significant, was not measured.

3- Gas contents of the coal beds did not increase systematically with depth. All gas contents increased to the depth of the Upper Kittanning coal bed (1,121.70 – 1,123.40 ft) and then decreased to 113.54 SCF/ton (3.59 cc/g) for the Middle Kittanning coal zone, 85.69 SCF/ton (2.68 cc/g) for the Clarion coal zone, 95.02 SCF/ton (2.97 cc/g) for the Upper Mercer coal bed, 35.27 SCF/ton (1.10 cc/g) for the Lower Mercer coal bed, and 67.84 SCF/ton (2.12 cc/g) for the Quakertown coal zone.

4- Gas contents had to be normalized to an air-free basis, despite efforts to prevent air-contamination. Mean methane content of all of the coals was 79.45% (air-free basis).

5- High pressure carbon dioxide adsorption isotherms show that the Upper Kittanning coal bed has the greatest potential for carbon dioxide sequestration out of the three coals beds analyzed (Upper Kittanning, Middle Kittanning, and Clarion). The maximum amount of carbon dioxide that can be absorbed to the Upper Kittanning coal bed is about 500 SCF/ton (15.36 cc/g), arb, at the calculated hydrostatic pressure of 486 PSIA.

6- The coal beds at Mylan Park, WV desorbed slowly which may have implication for slow production rates.

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