Best Practices Guide to Optimizing Multizone Coalbed Natural Gas Well Completions

FINAL REPORT

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Authors

GST/WellDog
John M. Pope, Ph.D.
Arthur R. Toews
Kim Y. Vincent

Black Diamond Energy
Aaron Otteman
Eric Koval

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Submitted by
Gas Sensing Technology Corp./WellDog
1482 Commerce Drive, Suite A
Laramie, Wyoming 82070

Submitted to
Stripper Well Consortium
The Pennsylvania State University
C-211 Coal Utilization Laboratory
University Park, PA 16802-2323

DISCLAIMER

Abstract

The purpose of this study was to illustrate how the challenges encountered when completing coalbed methane wells in multiple formations can be surmounted by deliberate use of reservoir analysis tools.

Multizone completions are attractive options for extending and/or increasing existing production from declining wells via re-entry of additional zones. Determining which available seams should be completed and which should be by-passed is both key to success and difficult to achieve.

Of the 17,000 CBNG wells in the PRB, over 9,600 produce less than 30 mcf/day. While multizone completions could enhance economic gas production, reservoir variability in the PRB has not allowed for broad success. In order to induce increased production from these wells, it is necessary to perform detailed reservoir analysis and identify re-entry zones that contain economic gas.

This study involved mapping the key reservoir properties that determine future production from all seams, using those properties to inform development, producing water and gas from the mapped reservoirs, and correlating the reservoir properties to the resulting production. This final correlation was then used to establish how reservoir testing can inform production success and operator cash flow, particularly when applied to multizone completions.

In the study, WellDog Inc. used its proprietary geochemical reservoir analysis technology to measure critical desorption pressure (CDP), gas content (GC) and gas saturation in several coal seam reservoirs intersected by a dozen coalbed methane (CBM) wells on existing leases in the Powder River Basin (T52N R77W, Sec. 20, Johnson County, Wyoming).

Table of Contents:

Table of Figures

Table of Plates

Table of Tables

1 EXECUTIVE SUMMARY

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The study objectives were:

- Use WellDog's proprietary commercial services to measure CDP, GC, and percent saturation in up to 27 seams, from twelve wells with both single zone and multizone completions.
- Use CDP, GC, and percent saturation to evaluate the production potential of several seams in nine wells. Having the ability to identify a seam with low GC, CDP and high potential for water contribution, a producer can choose to isolate such a seam and reduce water production without sacrificing economic gas production.
- Compare the gas and water production of off-set wells, completed by the PRB industry standard practice of single zone, under-reamed completion method, to the gas and water production of the wells with multizone completion to determine effectiveness in providing enhanced gas production.

The study area was focused on four well pads that straddle the Powder River. Each well pad included three wells that were completed initially in three different coals: the Anderson, the Cook and the Wall seams. Above each of the Anderson and the Cook seams were present up to three stringers of the base coal seams.

WellDog performed 15 tests of isolated coalbed reservoirs in the 12 wells, plus five tests of commingled reservoirs in those wells. 12 of the tests provided data that could be attributed directly to an individual reservoir. Those tests revealed that, contrary to conventional wisdom, the more shallow Cook and Anderson coal seams contained more gas and less water than the deeper Wall seam. In addition, the tests revealed that critical desorption pressure and gas content varied to a surprisingly high extent between coal seams and, within each coal seam, between well pads.

The operator (Black Diamond Energy) was able to produce eight of the wells for a brief period of time. While that production data proved insufficient for correlation with the reservoir data, additional production data from surrounding leases was obtained and used, as well. In general, offset production confirmed the reservoir test results: wells completed in the Anderson seam showed a much lower water/gas production ratio than those completed in the Wall seam.

Without the WellDog technology, the reservoir analysis portion of this study would have required more than $750,000 and up to eight months of field- and lab-work. Using the WellDog technology, it required less than $200,000 and less than two weeks of field- and lab-work.

2 INTRODUCTION

2.1 PROJECT OVERVIEW

2.1.1 Goals and Objectives

The study objectives were:

- Use WellDog's proprietary technology to measure CDP, GC and percent saturation in up to 27 seams, from twelve wells with both single zone and multizone completions.
- Use CDP, GC, and percent saturation to evaluate the production potential of several seams in nine wells. Having the ability to identify a seam with low GC, CDP and high potential for water contribution, a producer can choose to isolate such a seam and reduce water production without sacrificing economic gas production.
- Compare the gas and water production of off-set wells, completed by the PRB industry standard practice of single zone, under-reamed completion method, to the gas and water production of the wells with multizone completion to determine effectiveness in providing enhanced gas production

2.1.2 Work Plan

Spectroscopic reservoir analysis was utilized to determine Critical Desorption Pressure (CDP), Gas Content (GC), and percent saturation on up to 27 seams in twelve of Black Diamond's wells, nine of which were multiseam completions, each with up to three seams identified as potential producing target zones picked from the available gamma ray log. This information was used, along with other reservoir parameters, to compare each coal seam's contribution towards overall water and gas production. By comparing each coal seam directly, Black Diamond was able to identify and isolate seams with negative contributions (i.e. seams with low gas content and high potential for water production), presumable resulting in eventual enhanced gas production and reduced water production.

Four locations, with three wells per location completed in different seams (Fig. 1) were drilled and shut-in during mid-March 2006. Of the twelve CBNG wells drilled, additional seams were targeted for investigation in nine wells to be completed as multizones. Therefore, each of the four well pads had a three well pod – one completed in the "B" coal (the Wall), one completed in the "C" coal (the Cook) and one completed in the "D" coal (the Anderson).

Fig 1. Diagram of the three well pod structure used in the study

The B wells were topset in the Wall coal and were not further completed into other zones. The C wells were topset in the Cook and then, later, completed into the Cook stringers designated “C1” and “C2”. The D wells were topset in the Anderson coal and then, later, completed into the Anderson stringers designated “D1”, “D2” and “D3”.

Tasks performed:

Phase 1:
Drill and complete
Collect data and history match

Phase 2:
Analyze key metrics
Monitor water/gas well production
Publish guide for multizone optimization

2.2 EXPERIMENTAL/METHODOLOGY

2.2.1 Estimation of Critical Desorption Pressure via Raman Spectroscopy

2.2.1.1 Raman spectroscopy

Raman spectroscopy is a well-established laboratory chemical analysis technique. Raman spectroscopy was invented after the discovery of the Raman Effect in 1928, for which Sir Chandrasekhra Venkata Raman won the Nobel Prize in Physics in 1930.

The Raman Effect is when light scatters from a molecule with a slightly changed energy, or color, due to excitation of the molecule’s chemical bonds. The change in energy, or color, is representative of the energy of the bond or bonds that were excited. As a result, observing the colors of light scattered from a material indicates which molecules make up the material. Raman spectroscopy observes these colors by collecting the scattered light and then separating and detecting the colors that make up the light.

A challenge in using Raman spectroscopy is that only one photon in about one million is changed when scattering from a material. The rest of the photons remain unchanged in energy. In order to increase the number of changed photons, researchers have increased the number of incident photons by employing lasers.

One strength of Raman spectroscopy is that water molecules do not change many photons that scatter from it. As a result, in contrast to infrared systems, Raman spectroscopy is not overly sensitive to water — an advantage when analyzing materials in systems such as coalbed reservoirs that contain water.

2.2.1.2 Methodology for estimation of CDP and gas content

In addition to providing chemical fingerprints, Raman spectroscopy allows direct quantification of chemicals. For example, a series of peaks representing increasing amounts of methane dissolved in water are shown in Figure 2a at bottom left. The size of those peaks can be used to build a quantitative calibration between instrument response and methane partial pressure, as shown in the figure at bottom right. As the partial pressure is increased, the instrument response increases linearly.

Through careful instrument design and maintenance, this instrument response can be calibrated to concentration or partial pressure of the methane. As a result, WellDog is able to directly and quantitatively determine partial pressure of methane in coalbed reservoirs.

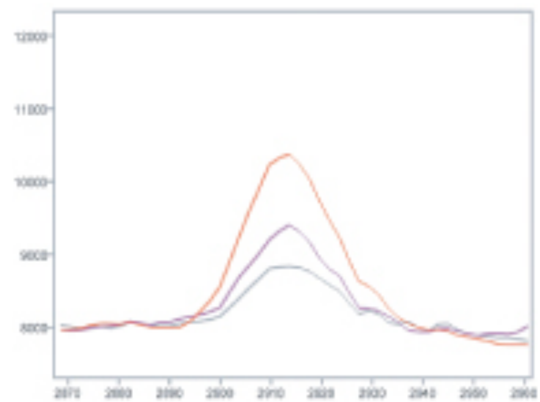


Figure 2a: Raman spectra of increasing amounts of methane dissolved in water. The x-axis shows the color of the photons collected and the y-axis shows the number of photons collected at each color.

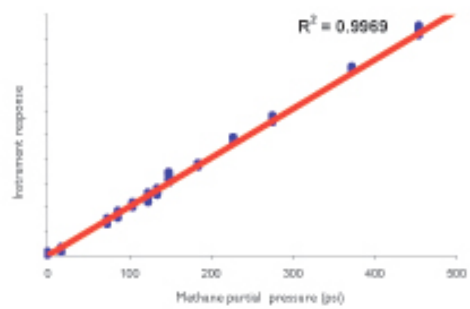


Figure 2b: Correlation of concentration as measured at left with partial pressure of methane, as measured by the pressure of methane gas incident on the sample cell. Indicates instrument response to methane partial pressure.

2.2.2 <u>Estimation of Gas-in-Place</u>

Gas-in-place (GIP) was calculated by creating depth-structure grids in Petra for the top and base of each horizon and then subtracting the base grid from the top grid to arrive at isopach thicknesses for each zone. The isopachs were then used to calculate gas-in-place using the areal extent of Black Diamond Energy's leasehold in Section 20 as a boundary polygon. Gas content parameters were adjusted to represent the average gas content numbers derived from the WellDog tests in each zone and composite zone. An assumption of coal density equal to 1.3 g/cc and a conversion factor of 1767.5 (g/cc to tons/acre-foot) was also incorporated into the gas-in-place calculations. No recovery factor was applied in the GIP calculation.

2.2.3 Estimation of Water in Place

Water-in-place calculations were made using the isopachs created from the top and base depth-structure Petra grids for each zone. Total volume in acre-feet was calculated for each isopach using Black Diamond Energy's leasehold area as a boundary polygon. Matrix and fracture porosity data, extracted from the D.O.E. Powder River Basin Coalbed Methane Development and Produced Water Management Study, was used to calculate a total porosity value for each coal. The water-in-place values are reported in both acre-feet and barrels using a conversion factor of 7758.37 bbls/acre-feet.

2.3 STUDY AREA

2.3.1 CBM Production in the Powder River Basin

2.3.1.1 Drilling & production history

The Powder River Basin, located in northeast Wyoming, and southeast Montana, has been the location of the nation's fastest growing development of coal bed natural gas (CBNG). Production of CBNG, to date, from the tertiary-age Fort Union Formation has been in the east and central portion of the basin, near Gillette, Wyoming, with recent development efforts targeting the deeper basin center. Of the 17,000 CBNG wells in the PRB, over 9,600 produce less than 30 mcf/day. CBNG operators in the PRB are now attempting to implement multizone completions, since they are experiencing a low success rate using the current practice of single-seam completions (while bypassing several thinner seams). While multizone completions should enhance economic gas production, reservoir conditions in the PRB, which tend to be shallow, undersaturated coals of highly variable critical desorption pressure (CDP) and gas content (GC) surrounded by water-bearing aquifers, have not proven suitable for multizone completions. To date, results from multizone completions have not been widely favorable.

It is noted, however, that flexibility and modification of procedures and technologies, specific to the geology and reservoir parameters of the coals in each basin, enabled successful implementation of multizone completions in several other basins. Similarly, modifications will be necessary to successfully implement multizone completions in the PRB. It is our anticipation that with the knowledge and ability to analyze and compare thinner seams potential to produce both gas and water, a producer will be able to identify and isolate zones with low CDP, GC and high water saturation during multizone well completion efforts.

2.3.1.2 Controversy regarding water production

A 2005 report by the Ruckelhaus Institute at the University of Wyoming, entitled "Water Production from Coalbed Methane Development in Wyoming", provides an excellent overview of the social, environmental and political issues created by surface discharge of coalbed methane waters in Wyoming. An excerpt is next:

> In the PRB, CBM water quality generally declines when moving from the

Cheyenne River drainage northwestward to the Belle Fourche, Little Powder, and Powder River drainages. Concerns center on the salinity of the water, usually measured as total dissolved solids (TDS), or electrical conductivity (EC) and sodium adsorption ratio (SAR).

CBM water from the Cheyenne and Belle Fourche drainages is of relatively high quality and is within or close to the TDS water quality limits for human drinking water, and within the EC and SAR limits for irrigation water. CBM waters from the Little Powder, Powder and Tongue River drainages have tested above one or more water quality standards or threshold criteria for TDS (human drinking water or stock water standards), EC (irrigation of sensitive plants), and SAR (irrigation water suitability). Water from CBM wells in the Tongue River drainage has better TDS and EC levels relative to CBM wells in the Powder River drainage, but the SAR levels from CBM wells sampled in the Tongue River drainage are higher than all the wells from the other PRB watersheds.

CBM water may be of good quality at the wellhead but this quality can degrade when water picks up additional solids or salts after discharge to a streambed or storage in a reservoir designed to allow water to infiltrate through the soils. A key water quality issue, not yet fully assessed, is the cumulative effect of numerous CBM water discharges on the overall water quality of basin streams. This leads to one of the most contentious issues in CBM development in Wyoming's PRB: Montana's concern about the potential downstream effects of water quality degradation on rivers flowing north into Montana. Prior to CBM development, samples of Powder River water at the Montana border sometimes exceeded the current EC standard of 2500 microsiemens per centimeter (µs/cm) (Clark et al., 2001). Water quality degradation could potentially affect downstream water uses for agriculture and might also affect Montana's ability to develop its own CBM resources in the northern arm of the PRB. CBM waters sampled from the Powder, Little Powder, and Tongue River drainages exceed Montana's numerical standards for TDS and EC.

The main problem with CBM waters in PRB soil-plant systems is the damaging effects of salts on soil physical condition, particularly on infiltration rates. The TDS, EC and SAR of the water, and soil type, are inter-related in how irrigation water can affect soil permeability and plant growth.

Very little water quality information exists for new CBM development areas outside the PRB, e.g., in southern and southwestern Wyoming. The small amount of information available so far suggests that the quality of CBM water in at least some of these fields will be substantially lower than CBM water in the PRB.

In the eastern part of the PRB where CBM water is generally of good quality, most of it is discharged to surface drainages or to soil (irrigation). In the western part of the PRB, most CBM water goes to evaporation/infiltration ponds or reservoirs. Other management options currently in use include injection, managed irrigation (with additives to mitigate the effects of certain salts in the water), atomization, and treatment by reverse osmosis or ion exchange.

Numerous uses for CBM water have included agriculture, domestic and municipal supplies, and could include commercial and industrial uses as well. The economic feasibility of different options depends on CBM water quality, availability of cost-effective treatments, and location of the CBM gas wells.

Three state regulatory agencies share the main responsibility for regulating CBM development in Wyoming: the State Engineers' Office (SEO), the Department of Environmental Quality (DEQ), and the Oil and Gas Conservation Commission (WOGCC). In addition, the Game and Fish Department recommends measures to mitigate the impact of oil and gas development on wildlife, and the U.S. Department of the Interior, Bureau of Land Management (BLM) oversees the development of federally owned minerals.

CBM development has been regulated in more or less the same way as conventional oil and gas (gas extracted from formations other than coal seams) even though there are major differences in the issues associated with CBM and conventional oil and gas. Agencies are doing their best to make their governing statutes and regulations "fit" CBM, but this strategy has resulted in some regulatory gaps as well as overlapping regulatory responsibility. The CBM industry may need to be regulated as a unique kind of development.

Several lawsuits filed in federal courts have challenged various aspects of CBM development and its associated impacts. There also has been civil litigation by private landowners against both state agencies and individual CBM operators.

The economic impact of CBM water management is influenced by natural gas prices, the amount of water produced per unit of gas, costs for drilling and operating wells, and the water management option chosen by the operator. Additionally, step-changes in regulation over the past half decade have contributed significantly to CBM operating cost and decreases in production.

Despite a number of reports in this vein, a Governor's Task Force dedicated to the issue, and substantial private industry efforts, water production in the PRB remains a critical challenge for operators. Not only do no approved water treatment methods exist, but the sheer volume of the produced water remains largely unmanageable.

2.3.2 <u>Regional Geology</u>

The Powder River Basin (PRB) is a structural, sedimentary, and topographic basin that delineates the Rosebud Creek, Tongue River, Powder River, Cheyenne River, and Belle Fourche River watersheds. The basin is bound on the east by the Black Hills uplift, on the west by the Big Horn uplift and Casper Arch, on the south by the Laramie and Hartville uplifts and, on the north, it is separated from the Williston Basin by the Miles City Arch and the Cedar Creek Anticline (Fig. 3). The basin is a large northwest-southeast trending asymmetric syncline with the synclinal axis on the west side of the basin (Fig. 3). Depths to Precambrian basement reach up to 20,000 feet along this axis. Sediments range in age from lower Paleozoic (Cambrian Flathead Sandstone and equivalents) unconformably overlying Precambrian basement through Mesozoic to Tertiary and Quaternary at the surface. On the eastern side of the basin, sediments dip both shallowly and monoclinally west. On the western side of the basin, sediments dip steeply east off of the hanging wall block of the basement involved fault associated with the uplift of the Big Horn mountain range

Several periods of deposition by marine and fluvial-deltaic processes have occurred within the basin during the Cretaceous and Tertiary periods in response to Laramide (Upper Cretaceous through Eocene orogenic event) exhumation of the basement block comprising the core of the Big Horn mountain range. These Upper Cretaceous and lower Tertiary rocks have a total thickness of up to 8,000 feet (Flores and Bader, 1999). It was during this time that the Paleocene Fort Union and Eocene Wasatch Formations were deposited and it is within these formations that the Powder River Basin coal resource is found.

The Eocene Wasatch Formation occurs at land surface at the basin margins and basin center and is locally covered by Quaternary deposits and/or the Oligocene White River Formation (Flores and Bader, 1999). Most of the coalbeds in the Wasatch Formation are continuous and thin (six feet or less) although, locally, thicker deposits have been found. The Wasatch Formation is unconformably underlain by the Paleocene Fort Union Formation and can be as much as 6,200 feet thick.

The Fort Union Formation outcrops on both the east and west side of the basin. The coalbeds in this formation are dominantly found in the Tongue River Member in the Upper Fort Union (Fig. 4). This member is typically 1,500 to 1,800 feet thick, of which up to a composite 350 feet of coal can be found in various beds. The thickest of the individual coalbeds is over 200 feet.

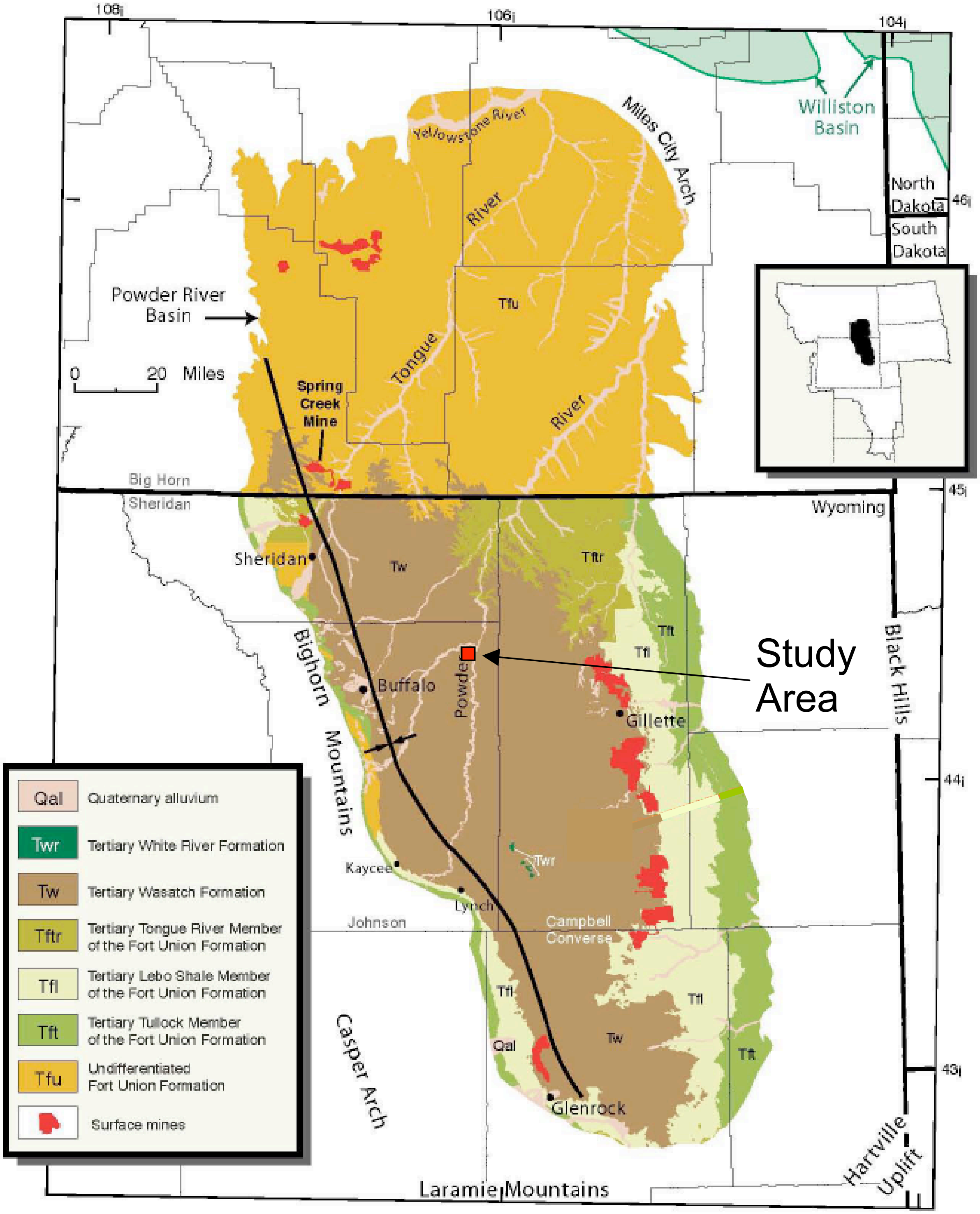
The coalbeds are interspersed with sandstone, conglomerate, siltstone, mudstone, shale, and limited thinly laminated limestone beds. Most coalbed methane (CBM) wells in the Powder River Basin target coals in the Wyodak-Anderson coal zone in the Tongue River Member of the Fort Union Formation. This coal zone is also called the Wyodak or the Anderson, and it can be subdivided further into the Smith, Anderson, Big George, Canyon, and Cook coals (Fig. 4). All of these coalbeds are coalbed methane targets and most are found at depths within 2,500 feet of the surface. The Wall coal is also a viable CBM target and is stratigraphically below the Wyodak-Anderson coal zone (Fig. 4). Due to lateral discontinuity of these coalbeds and the lack of a standardized nomenclature for CBM operators, the target coals for many CBM wells have been mislabeled.

The Wyodak-Anderson coal zone is prominent in the eastern portion of the Powder River Basin and is extensively mined where it outcrops near the City of Gillette. The Wyodak coalbed gets progressively deeper and thicker toward the west, typically ranging from 40 to 185 feet thick.

All of these coals were generally deposited in a fluvial-deltaic environment. However, with increasing subsurface data, the complexity of the environment of deposition is starting to be illuminated. Variations in these coalbeds, both laterally (pinchouts and coalescence) and vertically (thinning and thickening), are common and detailed studies of the anastomosing fluvial channel systems throughout the Fort Union coalbeds have become both increasingly abundant and important due to their control on CBM production.

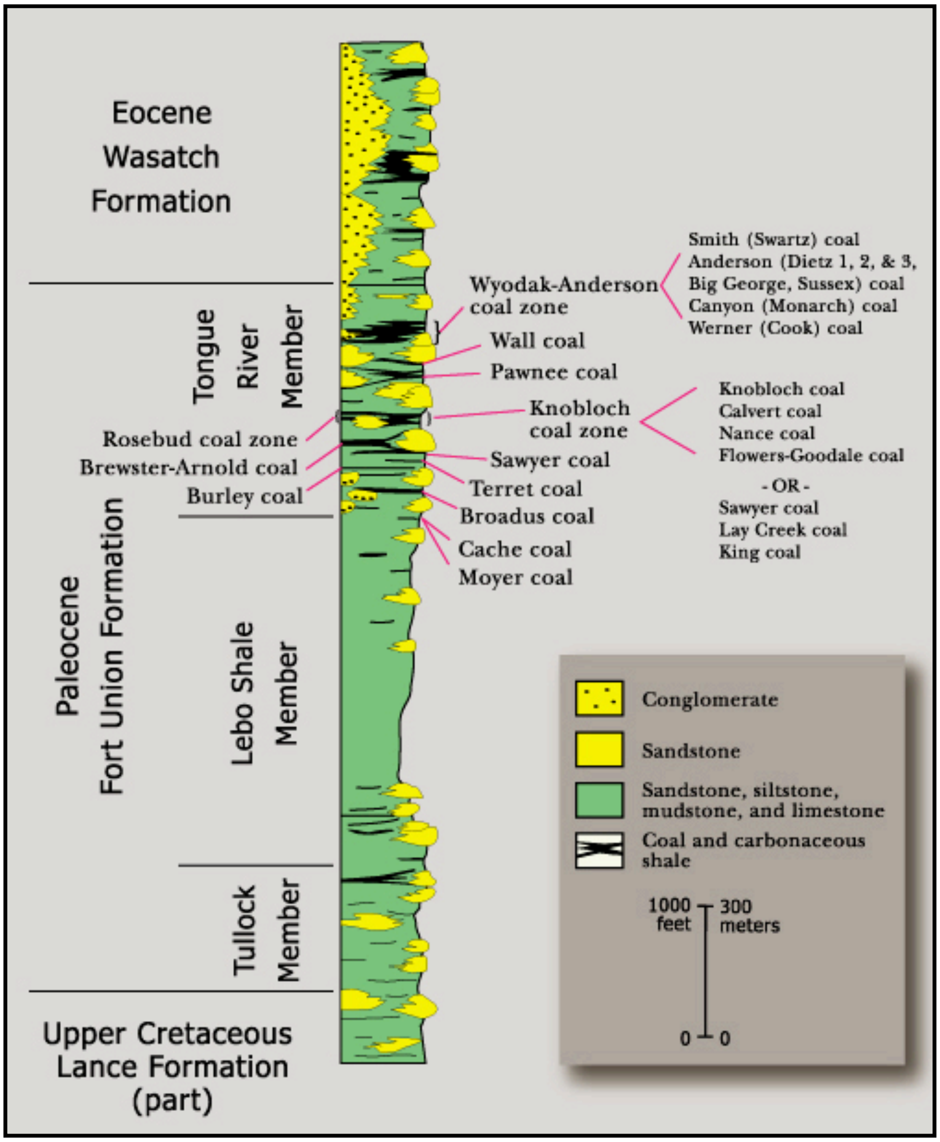
Most of the coal in the Powder River Basin is subbituminous in rank, which is indicative of a low level of maturity. The thermal content of the Fort Union coals found in the Powder River Basin ranges between 7,800 and 9,400 British thermal units per pound (Flores and Bader, 1999). Coal in the Powder River Basin was formed at relatively shallow depths and low temperatures. Consequently, coalbed methane generated in the Powder River Basin coals is biogenic. As a result, coal in the Powder River Basin contains less methane per unit volume than many other coal deposits in other parts of the country. Gas contents from seams in the Wyodak-Anderson zone and Wall coal typically range between 30 and 75 standard cubic feet of methane per ton (scf/ton) of coal compared to 350 scf/ton in other areas. The gas is typically more than 95 percent methane, the remainder being mostly nitrogen and carbon dioxide.

The relatively low gas content of Powder River Basin coal is compensated by the thickness of the coal deposits. Due to the thickness of the PRB coals and the shallow depths, commercial development of coalbed methane has been economical. Total CBM resource estimates in the Powder River Basin range between 12.1 trillion cubic feet (TCF) and 30 TCF (Stricker, et al., 2006).



Modified from Flores and Bader, 1999

Figure 3 - Regional geologic map of Powder River Basin showing study area



Modified from Flores and Bader, 1999

Figure 4 – Schematic illustration of Upper Cretaceous – Lower Tertiary Stratigraphic Section in the PRB

2.3.3 <u>Local Study Area</u>

A map of the study area is shown in Fig. 5. Yellow area is Black Diamond Energy's leasehold. The Powder River runs from bottom right to upper left of the leaseholding. The 22-20 well pod is located on a cliff above the river. The 33-20 well pod is located on the river bank, and the 31-20 and 42-20 well pods are located on a slight hill above the river, opposite from the 22-20.

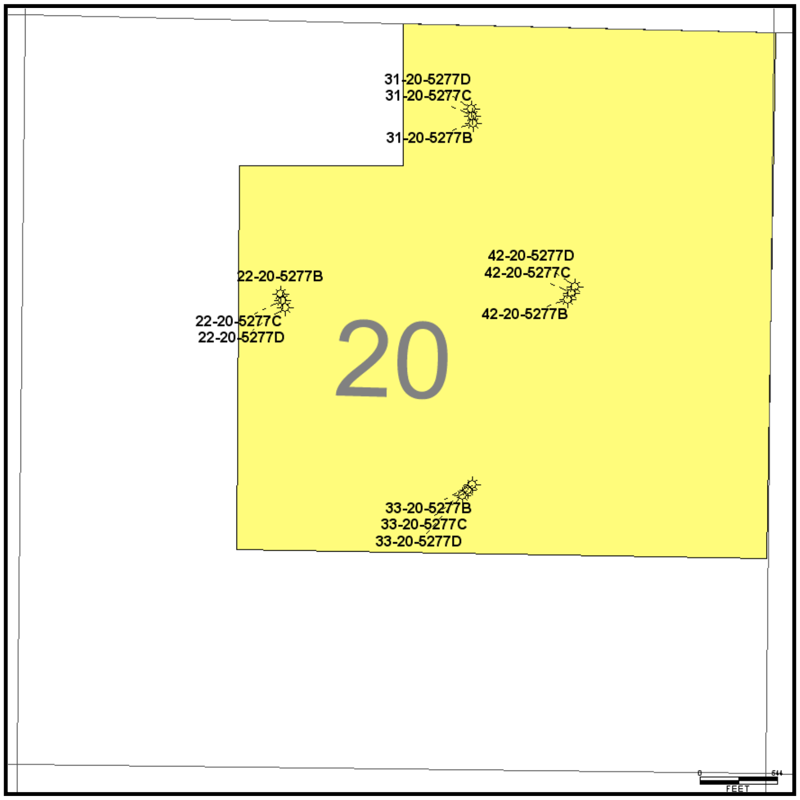


Figure 5 – Map of study area showing study wells in Section 20, T52N, R77W.

Fig. 6 shows a cross section of the wells tested. Details of this figure can be viewed in plate 1.

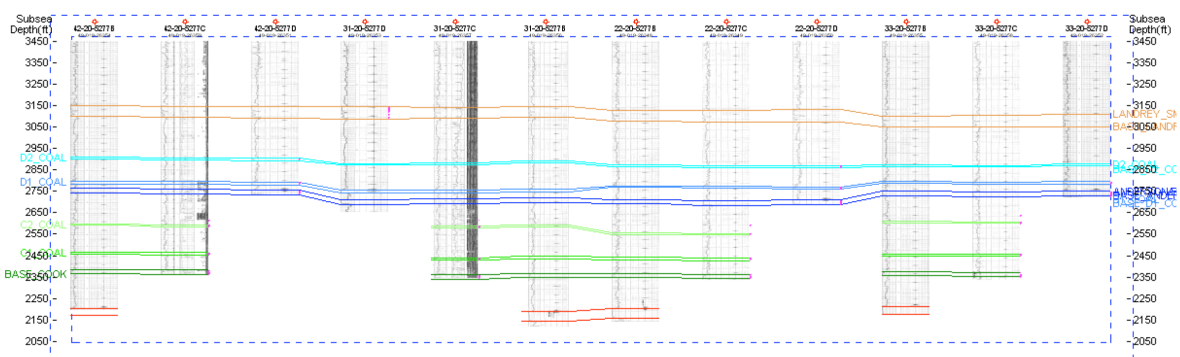


Figure 6 – Cross-section with coal horizon correlations (See Plate 1). Note that given the concerted elevation change in the seams across the study area, it is possible that historical uplift may have caused faulting and thereby facilitated reservoir communication between the tested seams.


N
S
42-20-5277B
49-019-26354
42-20-5277C
49-019-26359
42-20-5277D
49-019-26351
31-20-5277D
49-019-26353
31-20-5277C
49-019-26357
31-20-5277B
49-019-26356
22-20-5277B
49-019-26348
22-20-5277C
49-019-26349
22-20-5277D
49-019-26350
33-20-5277B
49-019-26355
33-20-5277C
49-019-26358
33-20-5277D
49-019-26352
CDP= 204 PSI
GC= 56 SCF/TON
DELTA_P= 117 PSI
D Coals Combined
CDP= 308 PSI
GC= 76 SCF/TON
DELTA_P= 103 PSI
CDP= 275 PSI
GC= 70 SCF/TON
DELTA_P= 173 PSI
CDP= 275 PSI
GC= 70 SCF/TON
DELTA_P= 181 PSI
D Coals Combined
CDP= 291 PSI
GC= 73 SCF/TON
DELTA_P= 138 PSI
CDP= 288 PSI
GC= 72 SCF/TON
DELTA_P= 199 PSI
D Coals Combined
CDP= 272 PSI
GC= 69 SCF/TON
DELTA_P= 163 PSI
CDP= 178 PSI
GC= 50 SCF/TON
DELTA_P= 227 PSI
CDP= 245 PSI
GC= 64 SCF/TON
DELTA_P= 219 PSI
CDP= 272 PSI
GC= 69 SCF/TON
DELTA_P= 266 PSI
C Coals Combined
CDP= 143 PSI
GC= 42 SCF/TON
DELTA_P= 485 PSI
CDP= 278 PSI
GC= 70 SCF/TON
DELTA_P= 313 PSI
C Coals Combined
CDP= 243 PSI
GC= 64 SCF/TON
DELTA_P= 389 PSI
C Coals Combined
CDP= 234 PSI
GC= 62 SCF/TON
DELTA_P= 377 PSI
CDP= 269 PSI
GC= 69 SCF/TON
DELTA_P= 409 PSI
CDP= 239 PSI
GC= 63 SCF/TON
DELTA_P= 388 PSI
CDP= 267 PSI
GC= 68 SCF/TON
DELTA_P= 444 PSI
CDP= 181 PSI
GC= 51 SCF/TON
DELTA_P= 557 PSI
CDP= 213 PSI
GC= 58 SCF/TON
DELTA_P= 540 PSI
CDP= 179 PSI
GC= 50 SCF/TON
DELTA_P= 520 PSI
LANDREY_SMITH
BASE_LANDREY_SMITH
D2_COAL
BASE_D2_COAL
D1_COAL
BASE_D1_COAL
ANDERSON/BIG_GEORGE_(D_COAL)
BASE_ANDERSON/BIG_GEORGE
C2_COAL
BASE_C2_COAL
C1_COAL
BASE_C1_COAL
COOK_(C_COAL)
BASE_COOK
WALL_COAL_(B_COAL)
BASE_WALL_COAL
HS=119
SWC Final Report
PLATE 1 Landrey Well Correlation
LOG CURVES
0 0 GR (GAPI) VERSALOGGER CHANNEL 0
TOPS AND MARKERS
ANDERSON/BIG_GEORGE_(D_COAL)
COOK_(C_COAL)
WALL_COAL_(B_COAL)
LANDREY_SMITH
BASE_COOK
BASE_ANDERSON/BIG_GEORGE
BASE_WALL_COAL
BASE_LANDREY_SMITH
D2_COAL
BASE_D2_COAL
D1_COAL
BASE_D1_COAL
C1_COAL
BASE_C1_COAL
C2_COAL
BASE_C2_COAL
Well Number
UWI
Gamma Ray logs plotted on left side of depth track with casing collar locator and/or cement bond logs plotted on the right side of the depth track. WellDog data from tests on individual and combined zones. Red rectangular boxes on right side of log track indicate perforated intervals.
December 10,2008 10:48 AM

2.3.4 Coal Quality

2.3.4.1 Coal Compositional Parameters

	PRB Wyodak Coal * (59 Analyses)	
	Average	Range
Rank	Lignite/Sub-bituminous	
Fixed Carbon	33.5%	30-41%
Volatile Matter	30.7%	26-33%
Moisture Content	29.8%	23-37%
Ash	6%	3-12%
Heating Value (Btu/lb)	8,224	7,420-9,310

Modified from DOE Study, 2002

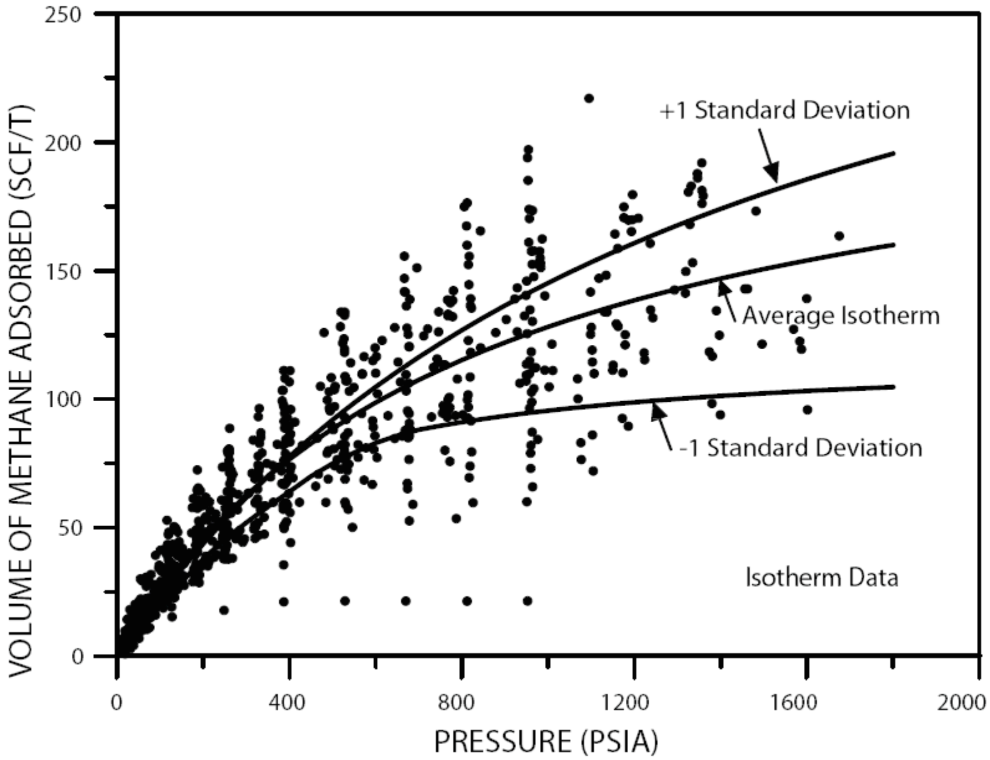
Table 1 – Parameters of Coal Composition

2.3.4.2 Methane Storage Capacity

Within a given coal zone, the total gas storage capacity may vary widely depending upon the ash content and maceral (mineral) composition. Studies have shown that coal zones with relatively higher quantities of inorganic matter and ash contain less gas due to the lower absorbing properties of these constituents. Furthermore, adsorption is also dependent on the woody content of the coal (Stricker, et al., 2006). Powder River basin coals tend to be richer in woody content in the lower portions of the thick coal zones, e.g., the Big George Coal, and more attritus prone in the upper portions of the zone. Consequently, adsorbed gas contents may be vertically differentiated within the same coal bed due to depositional settings partitioning the woody matter from attrital matter. In such conditions, adsorbed gas storage would be higher in the lower portions of the coal zone.

Formation pressure also contributes to the overall storage capacity of a given coal zone. Adsorption is a function of hydrostatic pressure. Coals that are relatively shallow are subject to lower pressures and therefore, with all other reservoir parameters held constant, will have lower storage capacities than their deeper counterparts. However, reservoir studies performed by WellDog indicate that this is rarely true – the historical factors governing methane production from the coal appear to overwhelm any other geologic factors when determining gas content.

Studies have also shown that coal rank plays a significant role in the overall storage capacity of a given coal bed. Lignites in the Williston Basin have a storage capacity of 31 scf/ton while subbituminous coals in the Green River Basin have been shown to have a storage capacity of 173 scf/ton (Stricker, et al., 2006). Thus, burial depth and maturation have a direct impact on the overall storage capacity of a given coal.



Adapted from Stricker, et al., 2006

Figure 7 – Average methane adsorption isotherm of subbituminous coals in the Powder River Basin.

2.3.5 Work Plan

Spectroscopic reservoir analysis was utilized to determine Critical Desorption Pressure (CDP), Gas Content (GC), and percent saturation on up to 27 seams in twelve of Black Diamond's wells, nine of which were multiseam completions, each with up to three seams identified as potential producing target zones picked from the available gamma ray log. This information was used, along with other reservoir parameters, to compare each coal seam's contribution towards overall water and gas production. By comparing each coal seam directly, Black Diamond was able to identify and isolate seams with negative contributions (i.e. seams with low gas content and high potential for water production), which will result in eventual enhanced gas production and reduced water production.

Several reservoir properties, including coal depth, thickness, pressure gradient, along with the measured values for gas content and gas saturation can be used to calculate gas-in-place for each seam. The water production and time to gas production were estimated by calculating the water-in-place, with coal fracture, matrix porosity and permeability estimated by historical matching of off-set well's production. Using WellDog's technology, CDP, GC and gas-in-place information for the coal seams were available within weeks, which is unprecedented. Equally unique is the ability to return post-completion, if isolation of a zone was determined to be beneficial, and again measure CDP. (Retesting is impossible once the well is drilled with alternative testing practices and technologies.) Each zone was considered and evaluated for its potential contribution toward water and gas production. With such a large volume of data available to the producer prior to water production, WellDog and Black Diamond hoped to identify key parameters to be used in economic and production evaluation to assist in multizone completion decision making efforts.

Tasks performed:

Four locations, with three wells per location completed in different seams (Fig. 8) were drilled and shut-in during mid-March 2006. Of the twelve CBNG wells drilled, additional seams were targeted for investigation in nine wells to be completed as multizones. Therefore, each of the four well pads had a three well pod – one completed in the "B" coal (the Wall), one completed in the "C" coal (the Cook) and one completed in the "D" coal (the Anderson).

Fig 8. Diagram of the three well pod structure used in the study

The B wells were topset in the Wall coal and were not further completed into other zones. The C wells were topset in the Cook and then, later, completed into the Cook stringers designated "C1" and "C2". The D wells were topset in the Anderson coal and then, later, completed into the Anderson stringers designated "D1", "D2" and "D3".

Spectroscopic reservoir analysis was conducted on all four wells completed in seam B, three wells completed as multizones in seam C and three wells completed as multizones in seam D. In some cases, the bottom zone, e.g. the D zone, was isolated from higher completions, e.g. the D1 perforation, using a retrievable bridge plug. In this manner, it was possible to test and compare quickly e.g. the D zone to the D1 zone.

This analysis was used to compare each seam's producibility, to identify each as a positive or negative contributor, to decide whether to allow a particular seam to remain in communication with the wellbore, or to isolate it from production.

Phase 1:

<u>Drill and completion procedure:</u>

Black Diamond Energy drilled, cased, and shut in twelve wells to be completed according to the study design. In order to isolate zones for measurement, minor alterations to the standard well completion procedures were necessary. Zones that were to be tested individually were perforated, enhanced, and then allowed to produce sufficient water to ensure optimal reservoir fluid within the wellbore. After the completion of WellDog's survey on the lowest coal interval, a retrievable bridge plug was set and the next interval was perforated, enhanced, produced and measured again by WellDog. This procedure of isolation, production, and testing continued on some of the target seams. In other cases, additional seams were perforated, their fluid was allowed to comingle with that of lower seams, and WellDog tested the mixture.

<u>Data Collection and History Match</u>

WellDog collected all data available from Black Diamond Energy and from the Wyoming Oil and Gas Conservation Commission in order to model and calculate key reservoir parameters and develop baseline gas, water, and time to production values for each of the target seams.

Phase 2:

<u>Key Metrics</u>

WellDog delivered each measured CDP and GC and collaborated with Black Diamond Energy in the consideration of a seam's potential as being positive or negative. Economic and production modeling was used in an effort to design a program to optimize the performance of a multi-zone completion.

<u>Monitor Project Well Performance</u>

The twelve project wells could not be produced in a sustained manner and so their water, gas, and time to production rates were not collected. However, the production of off-set wells was recorded during the two year period.

<u>Develop Guide for Multizone Optimization</u>

The key metrics testing results are in the process of publication. The heterogeneity of producibilities of the seams, as revealed by those key metrics, is an important finding that can assist other basin operators in confronting their multizone production challenges.

As the key metrics can be matched to eventual field performance, further findings will be published.

3 DATA AND RESULTS

3.1 RESULTS OF RAMAN RESERVOIR ANALYSIS

WellDog performed standard Critical Gas Content downhole logs of solution gas during each well test. In these tests, WellDog measures solution gas concentration, as well as reservoir temperature, pressure and salinity. The reservoir properties are used to calculate an appropriate solubility constant for methane in water. The concentration is used, together with that solubility constant, to calculate the partial pressure (or CDP) of methane in the reservoir. That partial pressure is then used, together with an adsorption isotherm for the coal of interest, to calculate a gas content value.

In order to insure that the fluid tested represents the reservoir, WellDog validates the completion/production methods used in the well and then takes hundreds of measurements in the wellbore. When the measurements show a consistent concentration, and the fluid properties are consistent with those known for the reservoir, the analysis is completed.

An example downhole log of solution gas is shown in Figure 9. In this log, the reservoir fluid shows a consistent and substantial amount of methane concentration, indicating that the fluid came from the coalbed reservoir. Above the bubble point in the wellbore, the concentration is reduced due to breakout of the gas from the fluid.

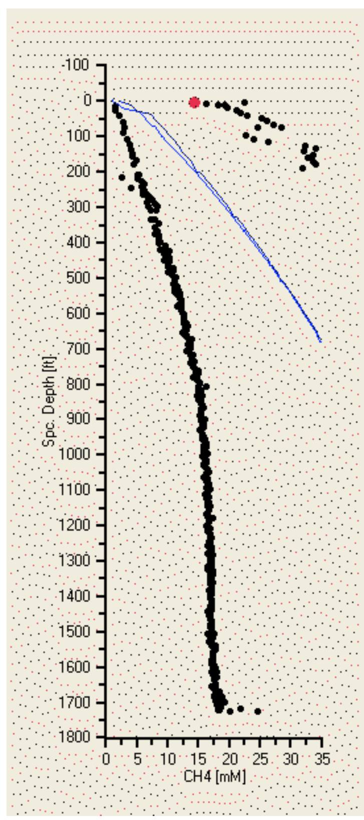


Figure 9 – Example Raman log taken in the Landry 22-20-5277B well on September 28, 2007.

Prior to testing, the seams were enhanced and the enhancement fluids were recovered, according to the following schedule.

Well ID	Enhancement Volume (BBLS of city water)	Water Production After Enhancement (BBLS)
Landrey 31-20-5277C2	720	2190
Landrey 31-20-5277D	742	5355
Landrey 22-20-5277C	703	2138
Landrey 22-20-5277D	710	2699
Landrey 42-20-5277C	600	2945
Landrey 42-20-5277D	750	6365
Landrey 33-20-5277C1	780	4219
Landrey 33-20-5277D	820	3366

Table 2 - Enhancement and fluid recovery volumes.

Measurements were completed in each wellbore, and the following reservoir properties were calculated.

Well ID	Seam	BHP (psia)	CDP (psia)	Gas content	required drawdown	% saturation
Landrey 22-20-5277B	B	753	213	58	540	44%
Landrey 31-20-5277B	B	738	181	51	557	39%
Landrey 33-20-5277B	B	699	179	50	520	40%
Landrey 42-20-5277B	B	711	267	68	444	54%
					0	
Landrey 22-20-5277C	C	678	269	69	409	56%
Landrey 31-20-5277C	C	602	243	64	359	54%
Landrey 33-20-5277C	C	566	234	62	332	53%
Landrey 42-20-5277C	C	591	278	70	313	61%
Landrey 31-20-5277C2	C2	538	272	69	266	64%
Landrey 33-20-5277C1	C1	627	239	63	388	53
Landrey 22-20-5277D	D	487	288	72	199	70%
Landrey 31-20-5277D	Smith	321	204	56	117	71%
Landrey 31-20-5277D	D1	456	275	70	181	71%
Landrey 33-20-5277D	D2	405	178	50	227	55%
Landrey 33-20-5277D	D	464	245	64	219	64%
Landrey 42-20-5277D	D1	448	275	70	173	72%

Table 3 - Well details and measured CDP/GC results for isolated seams

The calculated gas contents are plotted next, grouped by coal seam.

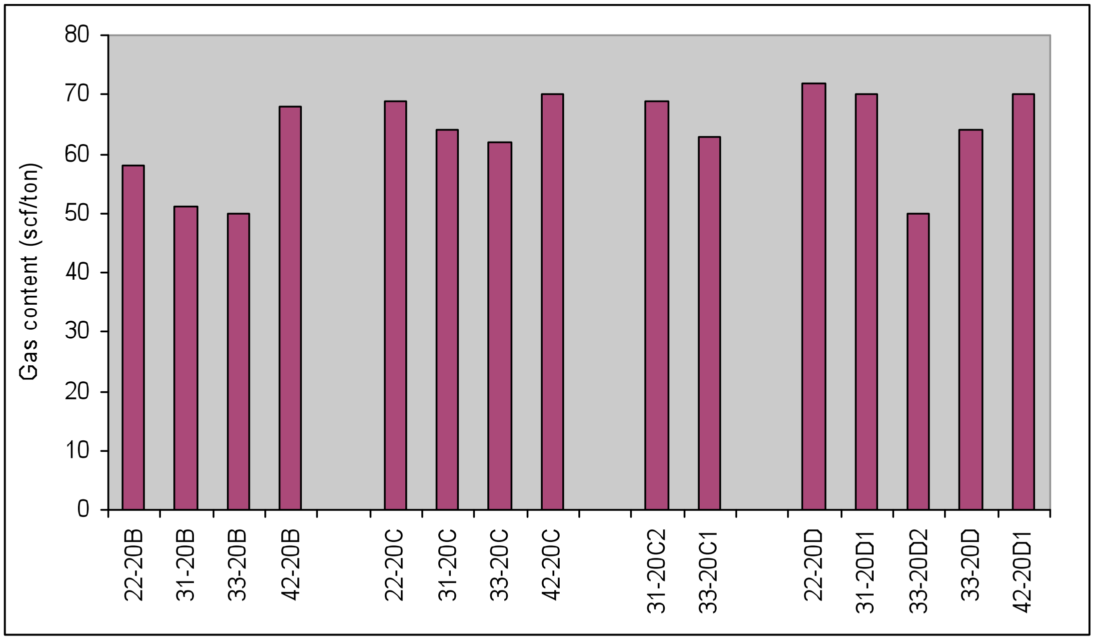


Figure 10 – Plot of gas content by coal seam

The critical desorption pressure and required drawdown (the sum of these is the total reservoir pressure) are likewise plotted by seam next.

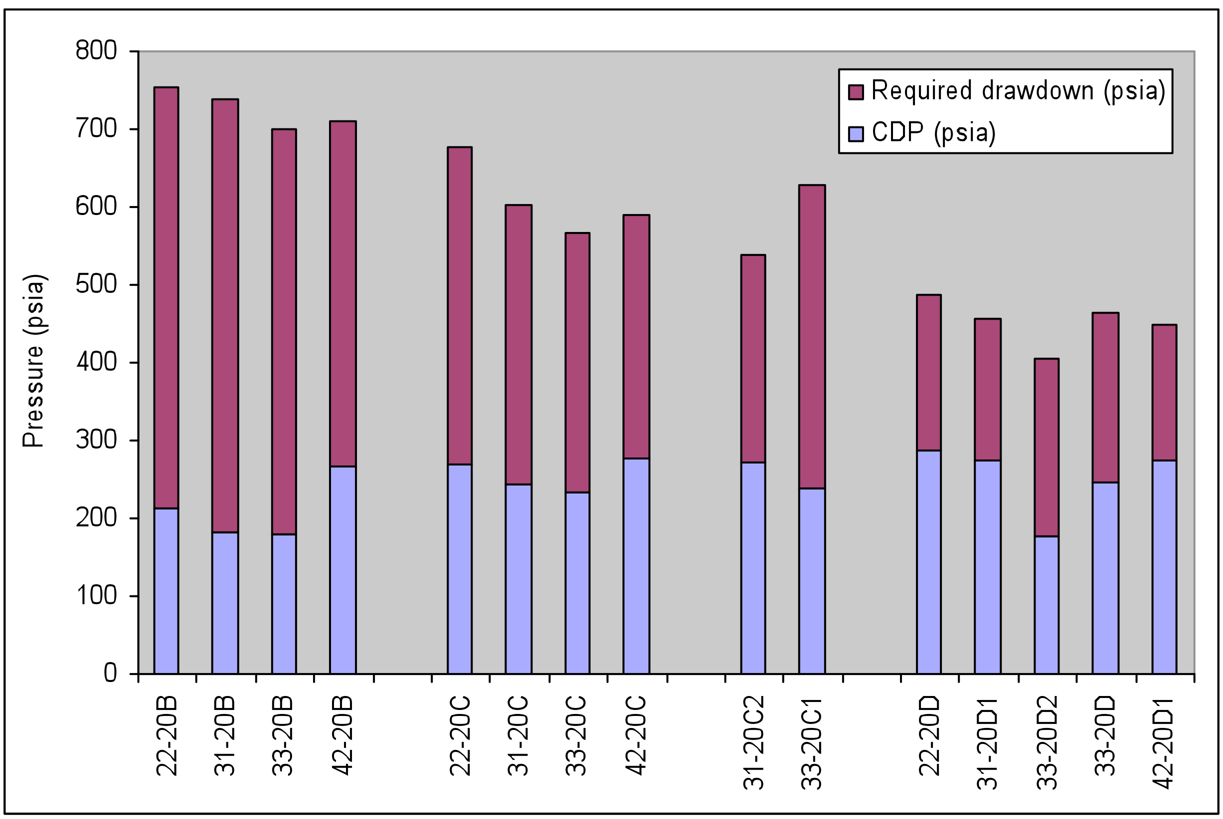


Figure 11 – Plot of critical desorption pressure and required drawdown by coal seam

The gas contents measured are plotted by well pad next.

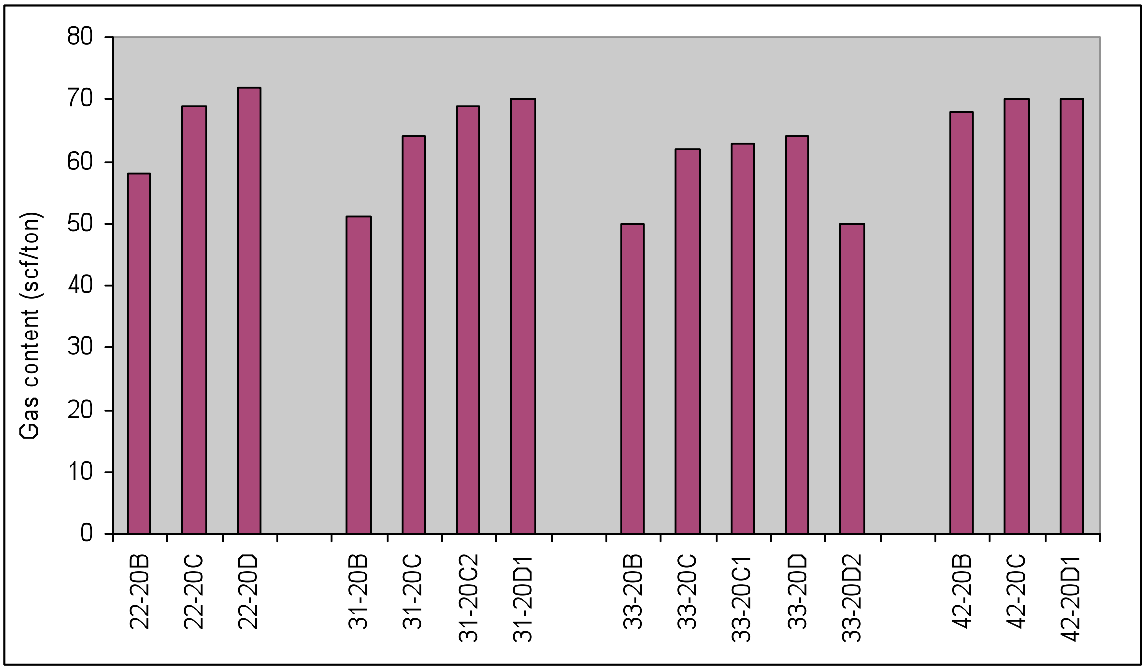


Figure 12 – Plot of gas content by well pad

The critical desorption pressure and required drawdown (the sum of these is the total reservoir pressure) are likewise plotted by well pad next.

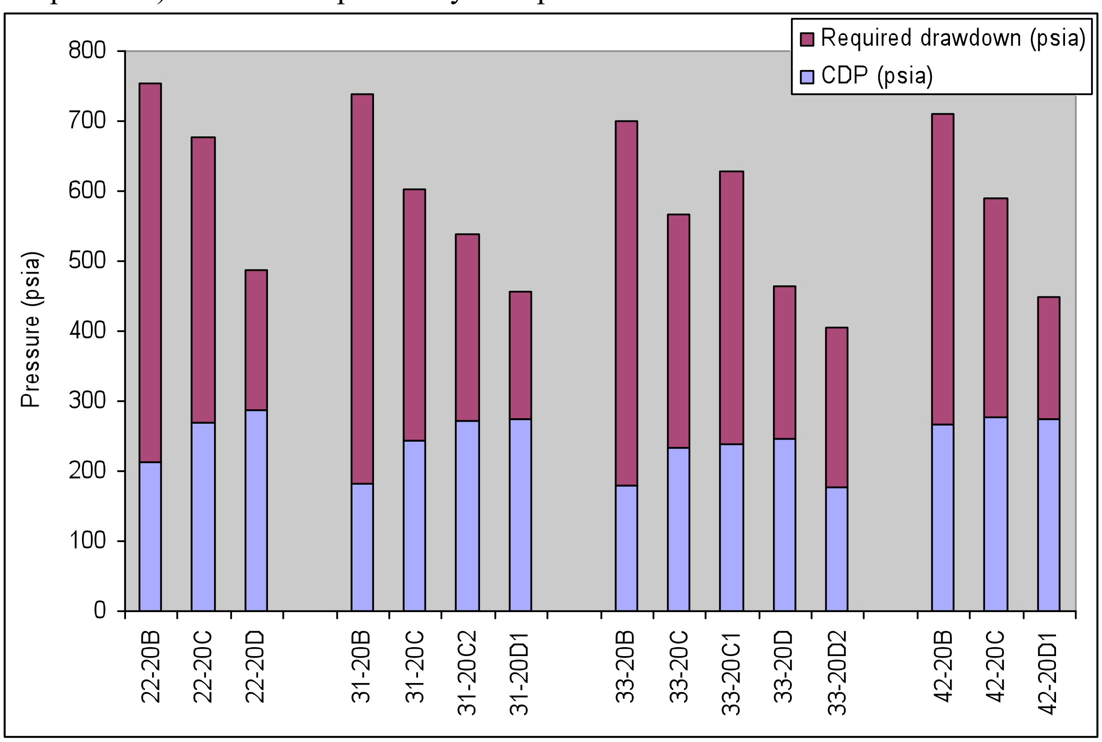


Figure 13 – Plot of critical desorption pressure and required drawdown by well pad

3.2 RESERVOIR VOLUMETRICS

3.2.1 Gas in Place

Gas-in-place for each zone is as follows:

Coal Isopach	Avg. GC (Scf/Ton)	Avg. Thickness (Ft)	GIP (MMCF)
Landrey Smith	56	53.65	2026.91
D2 Coal	50	8.662	292.19
D1 Coal	69	11.2042	521.58
D Coal	67.3	21.6942	985.04
C2 Coal	69	7.7907	362.68
C1 Coal	70	11.5102	543.6
C Coal	66	20.9654	933.56
B Coal	56.75	37.3227	1,429
		Total	**7094.56**
D Coals Combined	72.67	41.5602	2,037.64
C Coals Combined	53	40.2663	1,439.83
		Total	**3,477.47**

Table 4 - Parameters for gas-in-place estimates

3.2.2 Water in Place

The matrix and fracture porosity values used in the calculations as well as the total water-in-place values are summarized in the following table.

Coal Isopach	Avg. Thickness (Ft)	Acre-Feet	Matrix Porosity (%)	Fracture Porosity (%)	Total Porosity (%)	WIP (acre-feet)	WIP (BBLS)
Landrey Smith	53.650	15,752.290	1.100	0.100	1.200	189.027	1,466,545.130
D2 Coal	8.662	2,543.300	1.500	0.200	1.700	43.236	335,441.661
D1 Coal	11.204	3,289.820	1.500	0.200	1.700	55.927	433,901.893
D Coal	21.694	6,369.960	1.500	0.200	1.700	108.289	840,148.612
C2 Coal	7.791	2,287.550	2.400	0.100	2.500	57.189	443,691.482
C1 Coal	11.510	3,379.690	2.400	0.100	2.500	84.492	655,522.138
C Coal	20.965	6,155.940	2.400	0.100	2.500	153.899	1,194,001.505
B Coal	37.323	10,958.840	10.000	1.000	11.000	1,205.472	9,352,500.904
					Total	**1,897.532**	**14,721,753.326**
D Coals Combined	41.560	12,203.080	1.500	0.200	1.700	207.452	1,609,492.166
C Coals Combined	40.266	11,823.170	2.400	2.400	4.800	567.512	4,402,969.317
					Total	**774.965**	**6,012,461.483**

Table 5 - Water-in-place estimates

It should be noted that the volumes reported are static water-in-place values. No recharge or permeability parameters were incorporated into the calculation. Additionally, no adsorbed gas volumes were accounted for in these calculations.

3.3 PRODUCTION HISTORIES

3.3.1 <u>Study Wells</u>

Landrey CBM Well Perforating Detail

Well Name	Well API	Coal Seam	Perf Top (MD)	Perf Bottom (MD)	Perf Footage	Shots/Ft.	Charge	Hole Size	Phase (Degrees)	
31-20-5277C	49-019-26357	C	1490	1500	10	6	23g	0.49	60	3 1/8" Tag
Cook		Add Pay	1483	1487	4	6	23g	0.49	60	3 1/8" Tag
		C1	1403	1413	10	6	23g	0.49	60	3 1/8" Tag
		C2	1255	1262	7	8	23g	0.49	90 & 120	3 1/8" Tag
		Add Pay	1225	1228	3	6	23g	0.49	60	3 1/8" Tag
22-20-5277C	49-019-26349	C	1533	1544	11	8	23g	0.49	90 & 120	3 1/8" Tag
Cook		Add Pay	1526	1529	3	6	23g	0.49	60	3 1/8" Tag
		C1	1449	1459	10	6	23g	0.49	60	3 1/8" Tag
		C2	1334	1340	6	6	23g	0.49	60	3 1/8" Tag
		Add Pay	1294	1297	3	6	23g	0.49	60	3 1/8" Tag
33-20-5277C	49-019-26358	C	1412	1422	10	6	23g	0.49	60	3 1/8" Tag
Cook		Add Pay	1405	1408	3	8	23g	0.49	90 & 120	3 1/8" Tag
		C1	1320	1330	10	6	23g	0.49	60	3 1/8" Tag
		C2	1170	1178	8	6	23g	0.49	60	3 1/8" Tag
		Add Pay	1138	1142	4	6	23g	0.49	60	3 1/8" Tag
42-20-5277C	49-019-26359	C	1421	1431	10	6	23g	0.49	60	3 1/8" Tag
Cook		Add Pay	1413	1417	4	6	23g	0.49	60	3 1/8" Tag
		C1	1332	1342	10	8	23g	0.49	90 & 120	3 1/8" Tag
		C2	1202	1209	7	6	23g	0.49	60	3 1/8" Tag
		Add Pay	1180	1184	4	6	23g	0.49	60	3 1/8" Tag
33-20-5277D	49-019-26352	D2	905	910	5	6	23g	0.49	60	3 1/8" Tag
Anderson		D1	985	994	9	4	23g	0.49	90	3 1/8" Tag
		D	1033	1052	OH	12" Under Ream				
42-20-5277D	49-019-26351	D2	891	899	8	4	23g	0.49	90	3 1/8" Tag
Anderson		D1	1001	1011	10	6	23g	0.49	60	3 1/8" Tag
		D	1044	1057	OH	12" Under Ream				
Note: CIBP Set @ 800'										
31-20-5277D	49-019-26353	Smith Seams	750	754	4	6	23g	0.49	60	3 1/8" Tag
Smith		Smith Seams	734	740	6	6	23g	0.49	60	3 1/8" Tag
		Smith Seams	705	724	19	6	23g	0.49	60	3 1/8" Tag

Table 6 – Summary of key production parameters

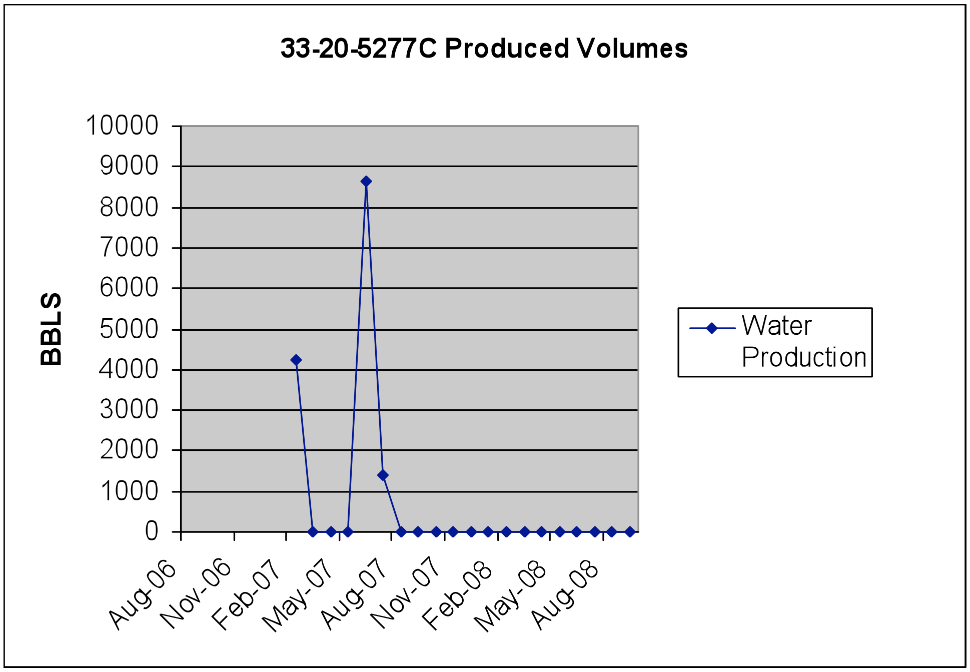


Figure 14 – Production history curve, Well 33-20-5277C.

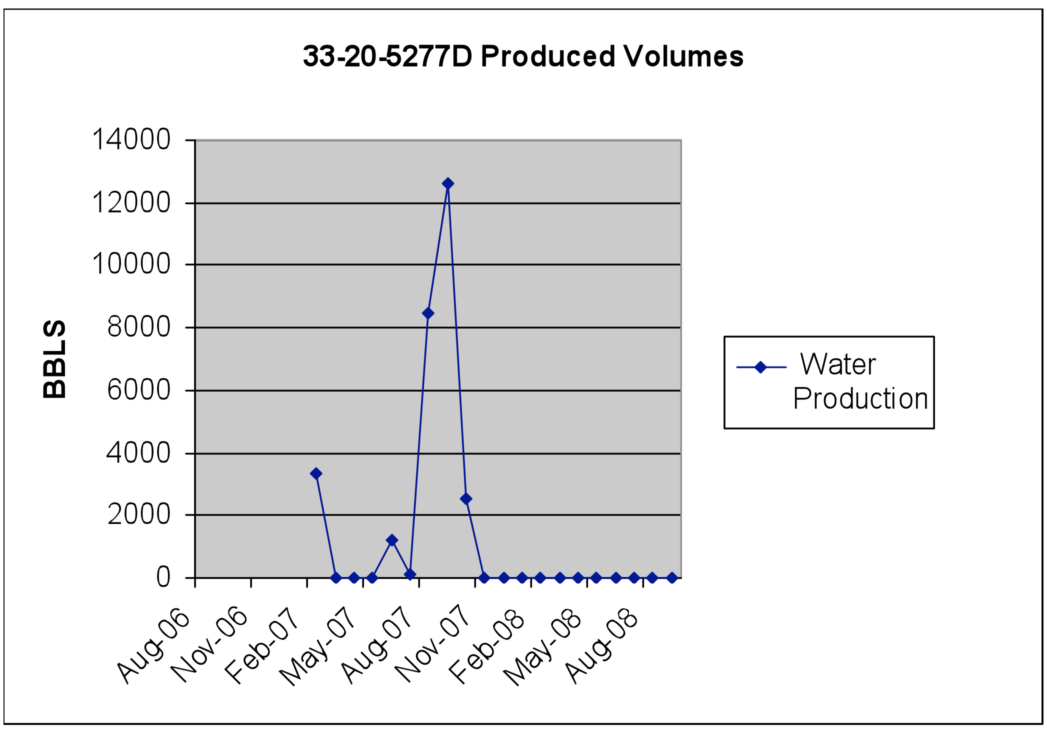


Figure 15 – Production history curves, Well 33-20-5277D.

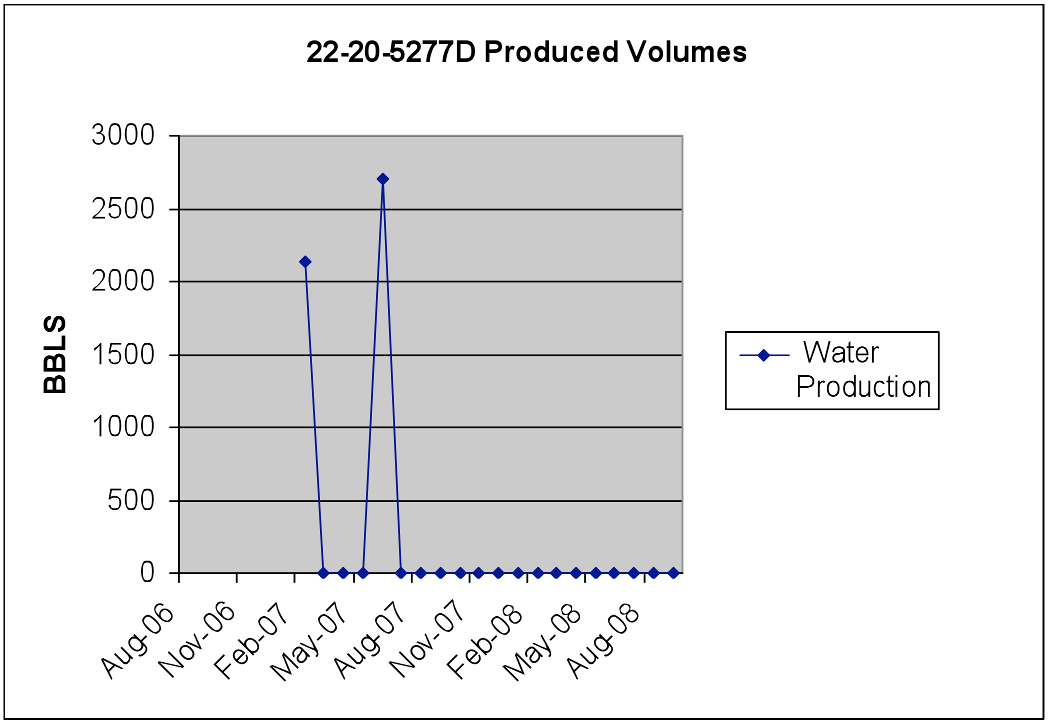


Figure 16 – Production history curves, Well 22-20-5277C.

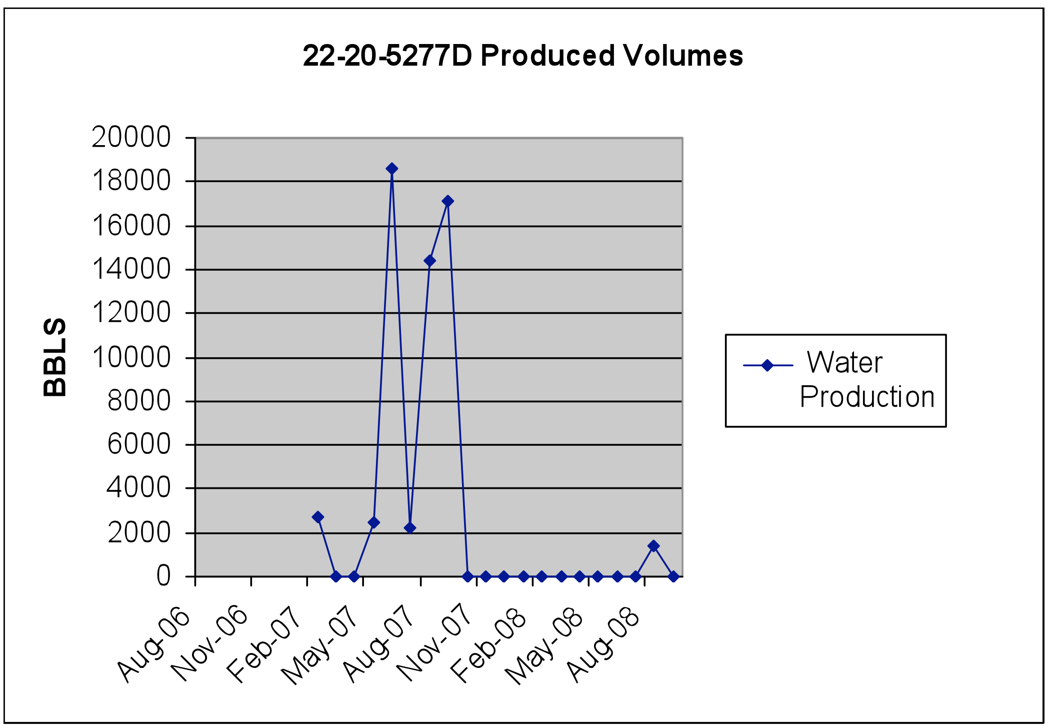


Figure 17 – Production history curves, Well 22-20-5277D.

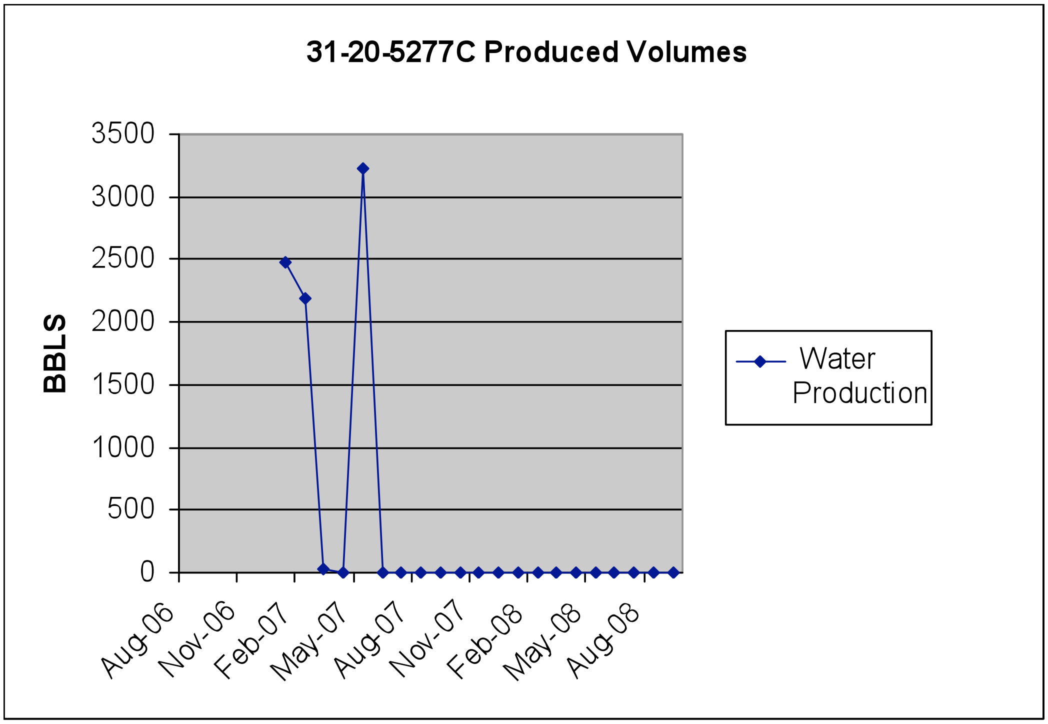


Figure 18 – Production history curves, Well 31-20-5277C.

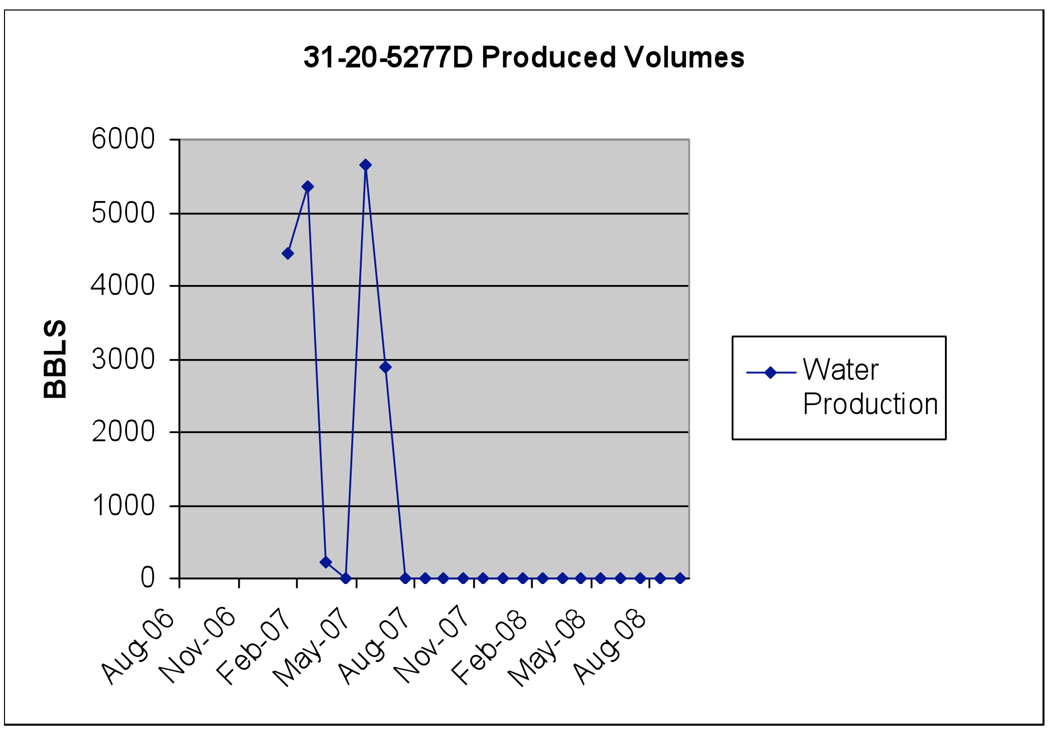


Figure 19 – Production history curves, Well 31-20-5277D.

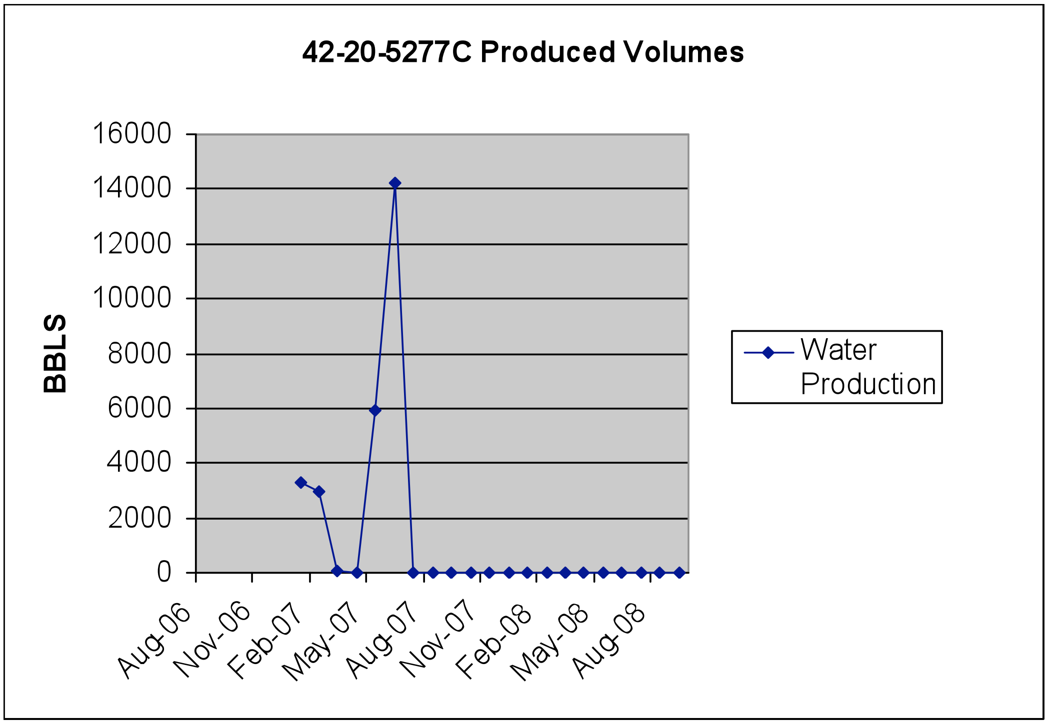


Figure 20 – Production history curves, Well 42-20-5277C.

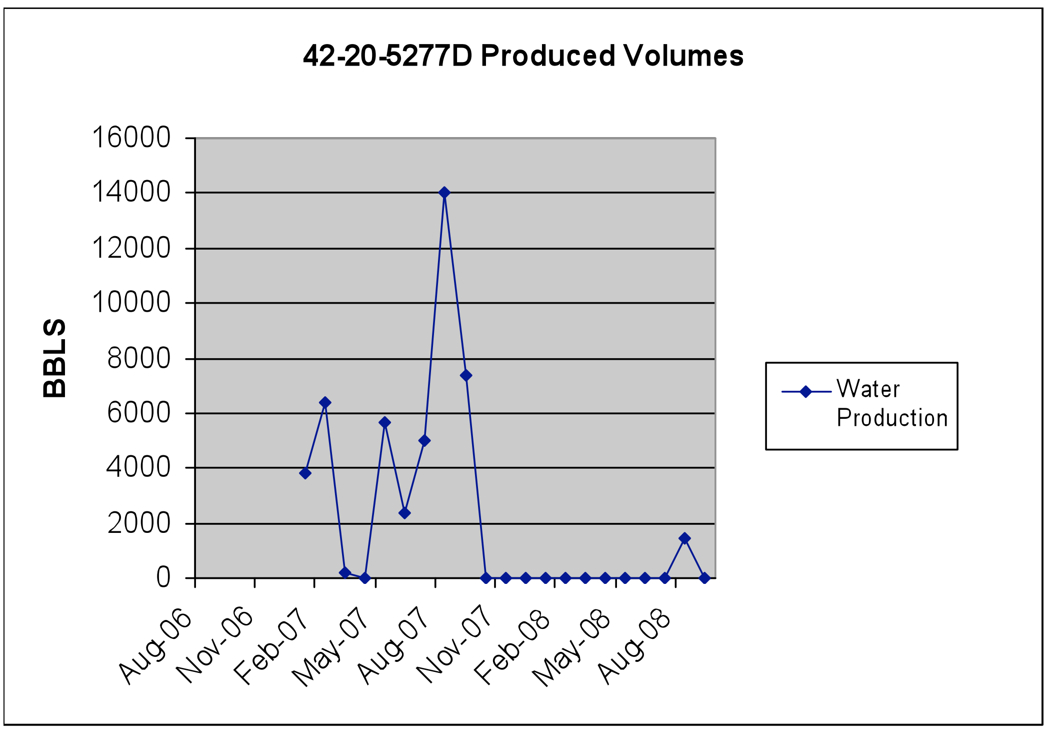


Figure 21 – Production history curves, Well 42-20-5277D.

3.3.2 Offset Wells

Over 280 coal bed methane wells, targeting numerous seams, have been drilled, spud or permitted within T52N, R77W. Of these 280 wells, only 33 have produced reported volumes of gas. The vast majority of production has come from the Anderson Coal seam in Pennaco Energy's wells in Sections and 2 and 3, located approximately 3.3 miles northeast of the study area. In this area, the Anderson Coal seam is roughly 125' structurally higher than the Anderson Seam in the study area. Consequently, the hydrostatic gradient is toward the study area resulting in decreased CDP values and increased differential pressure between the CDP and formation pressure. Ultimately this necessitates greater volumes of produced water and longer dewatering periods for wells south and west of Pennaco's area.

Currently, an estimated 85% of the wells within the Township are not producing water or gas. The following table summarizes production within the township on a by-coal basis:

Company	Total # of wells/coal	Coal	Water Production (BBLS)	Gas Production (MCF)
Pennaco Energy Incorporated	33	Anderson	3,992,914	1,328,187
	2	Pawnee	306,559	
	28	Wall	1,935,762	910
Yates Petroleum Corporation	1	Anderson	100	
Petro-Canada Resources USA, Inc	N/A	No Reported Production from 126 wells		
Lance Oil and Gas Company, Inc	N/A	No Reported Production from 12 wells		

(WOGCC data)

Table 7 – Summary of offset well production results

3.4 PRODUCTION MODELING

3.4.1 Preliminary Modeling Results for Black Diamond C and D Coal Intervals

Two simulations were conducted to compare the dewatering times and the produced water volumes needed to achieve saturated conditions for the C and D coal intervals in the Black Diamond pilot area. The studies used a one-mile square section of reservoir with a confined (no-flow) boundary. Such a boundary occurs when the reservoir is fully developed with multiple patterns of confining wells. The results obtained using this type of boundary would tend to predict the *minimum* dewatering times necessary to achieve critical desorption pressure (CDP) at which point the coal is saturated and will produce methane.

The 12x12-gridded pattern area used in the study is shown in Figure 22 along with the well locations for the offset 80-acre spacings, which are commonly employed in the Powder River Basin. Also shown are the equivalent locations that would be occupied by Black Diamond's 12 pilot wells in the pattern area (well pads 22, 31, 33 and 42).

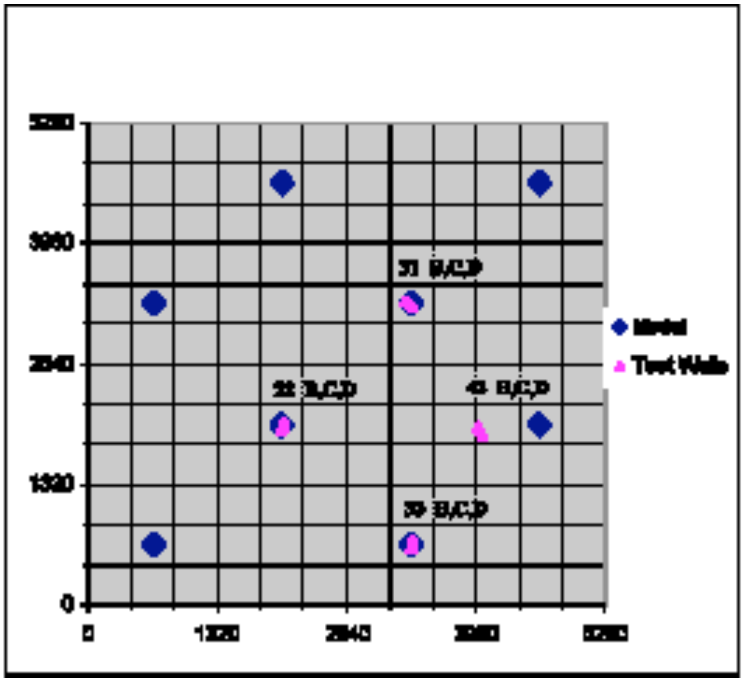


Figure 22 - Areal view of grid pattern used to model dewatering in Black Diamond's pilot area.

The data shown in Table 8 summarizes input data for the models. The descriptions for the C and D coals are similar except for differences in coal thicknesses, CDP and initial pressures. The pressure for the C coal accounted for the over pressuring from the active aquifer recharge. For simplicity and because of the limited data in the area, the coal seams were assumed to be of constant thickness and horizontal. Black Diamond estimated an initial pump rate of 600 bwpd for each of the eight pattern wells as reasonable for the area.

These 2-dimensional, areal simulations did not rigorously account for the active aquifer recharge currently evident in the study area. However, the presence of an aquifer was somewhat addressed by increasing the porosity of the coal to 10%. WellDog has employed this technique with reasonable success in other regions, but it probably does not fully compensate for the potentially strong recharge evident here.

Property	Coal C	Coal D
Model grid spacing, ft	440	440
Coal thickness, ft	34.25	32.33
Porosity, frac. coal volume	0.10	0.10
Permeability, md	200	200
Compressibility, 1/psi	1.E-4	1.E-4
Initial pressure, psia	652	456
CDP, psia	272	259
Initial pump rate, bwpd	600	600
Min. pump pressure, psia	25	25

Table 8 – Parameters used in reservoir simulations

Two-dimensional, areal models were initialized using data shown in Table 8. The coal was modeled as under-saturated so that only water production occurred and no gas-phase methane existed in the coalbed. The eight wells in the pattern area (Figure 22) were placed on production at simulation time 0 at a rate of 600 bwpd, limited by a minimum producing pressure of 25psia. As the simulations proceeded, the average reservoir pressure was monitored until the CDP was reached. Water production rates and all reservoir properties were recorded by the model.

Modeling Results

The results of the simulations of the C and D intervals are summarized in Table 9 and Figures 23 and 24. The results indicate that the D coal interval will dewater in half the time with half the produced volume of water.

Simulation Results	Coal C	Coal D
Dewatering Time, days	134	69
Water produced, Mbblw	643	329
CDP, psia (not calculated)	272	259

Table 9 – Dewatering time and cumulative watering production for coal intervals C and D predicted by modeling.

The fact that the cumulative production curves (Figure 23) for both coal intervals are coincident except for endpoints is not surprising, considering that both seams used identical rock properties and were produced at identical rates. The decreasing reservoir pressure did not limit the production rate until after CDP was reached for both coal intervals. The cumulative dewatering of 643 and 329Mbblw for the C and D coal intervals, respectively, predominantly reflects the differences in initial reservoir pressure.

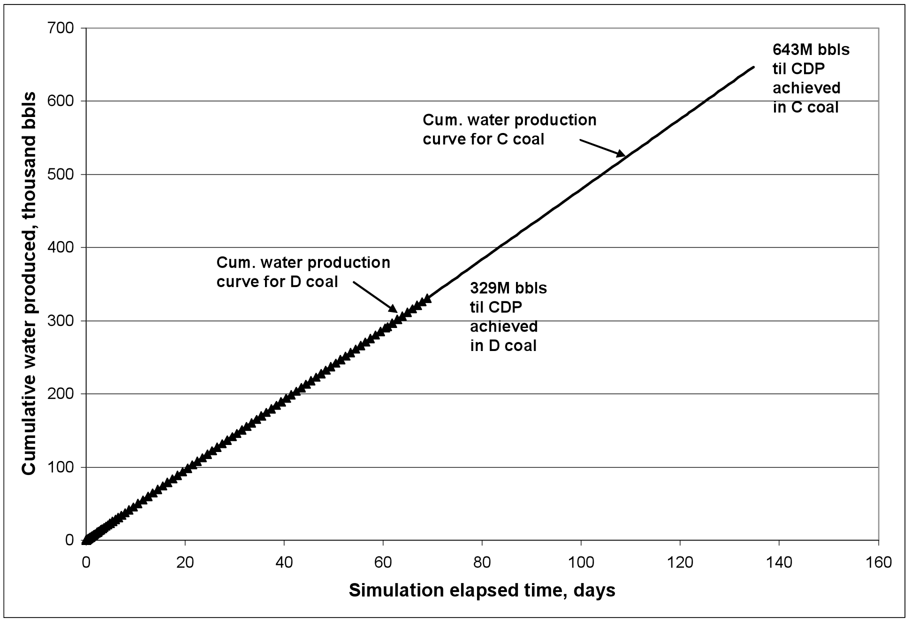


Figure 23 - Predicted cumulative dewatering curves for the C and D coal intervals.

The reservoir pressure responses for the C and D intervals (Figure 24) reflect the differences in initial pressure, but appear to follow nearly parallel paths down to the point of CDP. Again, these responses are expected given the identical rock properties, similar coal seam thicknesses, and identical production rates.

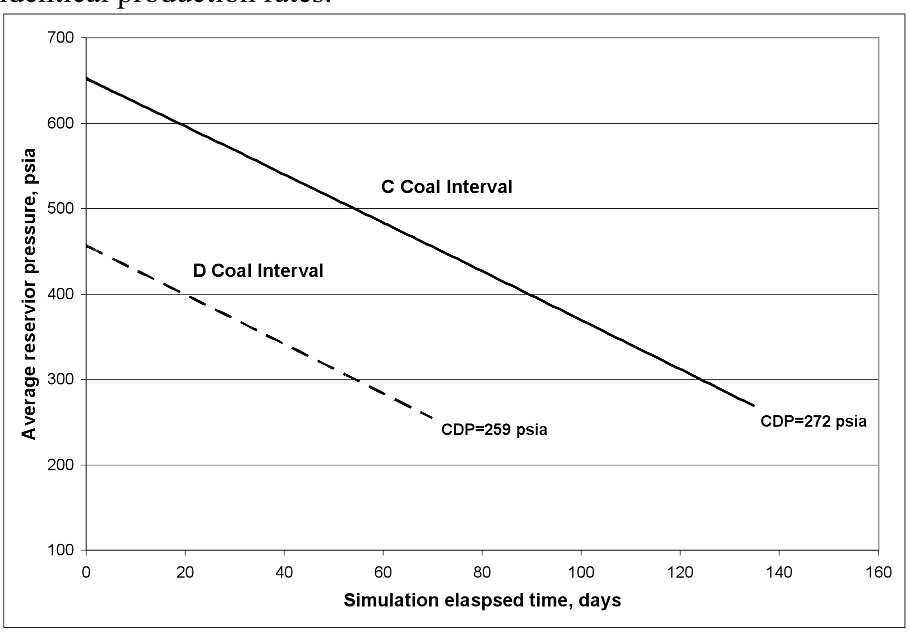


Figure 24 - Predicted cumulative dewatering curves for the C and D coal intervals.

The modeling results confirm Black Diamond's expectations that the shallower D coal interval will reach production earliest in the dewatering process of the coalbed. For a confined pattern development, the predictions indicate that production will occur in half the time with half the volume of produced water. The accuracy of these simulations will improve when actual production data becomes available.

4 DISCUSSION

4.1 INTERPRETATION OF GAS PRODUCTION POTENTIAL

Trends in the reservoir analysis data can be examined to assist in making lucid completion and production decisions. In general, geologists assume that deeper coal seams contain more gas – due to their greater rank/maturity, the higher hydrologic pressures typically available in deep coal seams so that more gas is capped, and general industry experience.

However, in this study the coal seam reservoirs exhibited properties that ran directly against this conventional wisdom. Remarkably, gas content was inversely proportional to seam depth (with one exception, the 33-20D2 reservoir). The deeper Wall coal did not show substantially higher gas content or critical desorption pressure, on average, than the more shallow Anderson coal, as might be expected from normal coalbed reservoir assumptions. In fact, the Wall coal showed lower gas content on average – 57 scf/ton – than either the Cook (66 scf/ton average) or the Anderson (64 scf/ton average) coals.

When this trend is combined with the lower porosity/permeability of the Wall coal, and the higher hydrostatic pressure measured for the deeper Wall coal, the result is that the Wall coal might not be the highest priority completion target in this area. (In fact, the study results convinced the operator not to complete further wells in the B (Wall) seam in this area.) Unfortunately, the thickness of the Wall seam in this area is such that the amount of stranded gas-in-place is substantial – more than any other single seam/stringer tested.

Alternately, the D (Anderson) seam showed both a higher average CDP than the B (Wall) seam and a lower hydrostatic head than either the B (Wall) or C (Cook) seams. As a result, the gas in the D (Anderson) seam was judged the most producible of those evaluated.

Another conventional wisdom involves the belief that thick, continuous coal seams show homogenous, continuous levels of methane gas. This wisdom likewise is belied by the results of this study. For example, the gas content measured in each seam varied substantially across this very small field: from 50 scf/ton to 68 scf/ton for the B (Wall) coal, and even more – from 50 scf/ton to 72 scf/ton – for the D (Anderson) coal.

Surprisingly, CDP and gas content varied substantially even between stringers of the same seam. For example, in the 33-20 well, the gas content of the D seam was 64 scf/ton while the gas content of the D2 stringer was just 50 scf/ton.

4.2 KEY PARAMETERS FOR ECONOMIC AND PRODUCTION EVALUATION

Another way to assess producibility is to calculate the likely water/gas production ratio using gas-in-place and water-in-place models for each seam. Table 10 lists such calculations for the seams tested in the study. Totals for each package of seams is at the bottom.

Coal seam	GIP (MMCF)	WIP (BBLS)	Water/gas (BBLS/MCF)	Gas value ($3/MCF)	Water handling cost ($0.30/BBL)
Smith	2,027	1,466,545	0.72	$ 6,080,730	$ 439,964
D2	292	335,442	1.15	$ 876,570	$ 100,632
D1	522	433,902	0.83	$ 1,564,740	$ 130,171
D	985	840,149	0.85	$ 2,955,120	$ 252,045
C2	363	443,691	1.22	$ 1,088,040	$ 133,107
C1	544	655,522	1.21	$ 1,630,800	$ 196,657
C	934	1,194,002	1.28	$ 2,800,680	$ 358,200
B	1,429	9,352,501	6.54	$ 4,287,000	$ 2,805,750
Total, all seams	7,095	14,721,753	2.08	$ 21,283,680	$ 4,416,526
D Total	2,038	1,609,492	0.79	$ 6,112,920	$ 482,848
C Total	1,440	4,402,969	3.06	$ 4,319,490	$ 1,320,891
B Total	1,429	9,352,501	6.54	$ 4,287,000	$ 2,805,750

Table 10 – Distribution of water and gas volumes and costs throughout the coal seam reservoirs tested

This table highlights the poor producibility of the B (Wall) seam. Multizone wells completed into all zones, as is typical, would show substantial water contributions from the B (Wall) zone. Those contributions would increase the time to gas, increase the water/gas production ratio, and increase water disposal costs for such multizone wells. In fact, the bulk of the total water disposal costs, listed at the right of the table, projected for all the seams originate from the B (Wall) zone.

While production data gathered from the wells tested are insufficient to correlate with the water/gas production predictions, a correlating trend has been observed in offset well production. For example, production by offset wells completed in the D (Anderson) zone by Pennaco/Marathon have shown a combined water/gas production ratio of 3.0 while that for wells completed in the B (Wall) zone have shown a combined water/gas production ratio of 2,127.

5 CONCLUSIONS

The results of the study show that success in multizone completions is determined not by the number of zones completed but instead by the production quality of the zones completed. Avoiding zones that contribute more water than gas under normal production scenarios, like the Wall zone in this area, can result in substantially higher gas production rates and lower water/gas production ratios for multizone completions.

Unfortunately, identifying contributing zones vs. non-contributing zones cannot be done based on depth, geology or volumetric analyses. In this study, the deepest and thickest zone, the Wall, shows both the lowest gas content and the highest water content. Conversely, the Anderson, the shallowest seam analyzed, showed high gas content and low water content, making it an ideal production target.

As is always the case in coalbed methane development, coalbed reservoir heterogeneity is high not only between seams, but across continuous portions of seams. For example, variations of gas content from 50 to 72 scf/ton were observed across the sample area of less than 200 acres. This result demonstrates that more detailed analysis of coalbed methane reservoirs is required in order to increase development success.

6 REFERENCES CITED

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