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Demonstration of the Enrichment of Medium Quality Gas from GOB Wells Through Interactive Well Operating Practices

Final Report
June - December 1995

S.T. Blackburn
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E.L. Lasseter
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R.A. Mills

December 1995

Work Performed Under Contract No.: DE-AC21-95MC32062

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Black Warrior Methane Corporation
Brookwood, Alabama

MASTER

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December 1995

ABSTRACT

Methane released to the atmosphere during coal mining operations is believed to contribute to global warming and represents a waste of a valuable energy resource. Coal mining in the United States released an estimated 190 to 300 billion cubic feet of methane into the atmosphere in 1990. Commercial production of pipeline-quality gob well methane through wells drilled from the surface into the area above the gob can, if properly implemented, be the most effective means of reducing mine methane emissions. However, much of the gas produced from gob wells is vented because the quality of the gas is highly variable and is often below current natural gas pipeline specifications.

Assessment of upgrading this vented gob gas to pipeline specifications using various gas conversion and enrichment technologies has been shown to be currently economically unattractive. Improved or modified gob well operational techniques may be able to transform the produced gas into pipeline quality at much lower costs, thus providing for attractive economic benefits. Although this process for upgrading the gob gas is currently being used at a few mines in the U.S., there is limited technical understanding of the process nor established methodology of application.

Prior to the initiation of the field-testing required to further understand the operational criteria for upgrading gob well gas, a preliminary evaluation and assessment was performed. An assessment of the methane gas in-place and producible methane resource at the Jim Walter Resources, Inc. No. 4 and No. 5 Mines established a potential 15-year supply of 60 billion cubic feet of mine methane from gob wells, satisfying the resource criteria for the test site. To understand the effect of operating conditions on gob gas quality, gob wells producing pipeline quality (i.e., < 96 percent hydrocarbons) gas at this site will be operated over a wide range of suction pressures. Parameters to be determined will include absolute methane quantity and methane concentration produced through the gob wells; working face, tailgate and bleeder entry methane levels in the mine; and the effect on the economics of production of gob wells at various levels of methane quality. Following this, a field demonstration will be initiated at a mine where commercial gob gas production has not been attempted. The guidelines established during the first phase of the project will be used to design the production program. The economic feasibility of various utilization options will also be tested based upon the information gathered during the first phase.

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EXECUTIVE SUMMARY

Methane released to the atmosphere during coal mining operations is believed to contribute to global warming and represents a waste of a valuable energy resource. Coal mining in the United States released an estimated 190 to 300 billion cubic feet of methane into the atmosphere in 1990. Yet, largely because of inadequate methane capture technology, less than 7 percent of methane released during coal mining is currently recovered for use. Commercial production of mine generated methane through wells drilled vertically from the surface into the area above the gob can, if properly implemented, be the most effective means of reducing mine methane emissions, with current annual capture and utilization of this mine methane emission source estimated at 12 billion cubic feet. However, there is a much larger quantity (26 to 84 billion cubic feet) continuing to be emitted directly into the atmosphere from other gob wells. The primary reason for the venting of this gas from these gob wells is that the quality of the gas is highly variable and is often much below current natural gas pipeline specifications.

Assessment of upgrading this vented gob gas to pipeline specifications using various gas conversion and enrichment technologies has shown to be currently economically unattractive. Improved or modified gob well operational techniques may be able to transform the produced gas into pipeline quality at much lower costs, thus providing for attractive economic benefits. Although this process is currently being used at a limited number of mines, there is limited technical understanding of the process nor established methodology of application. Therefore, this project has as its purpose and overriding objective the *"establishment of the parameters for evaluating the geologic, technical and economic feasibility of natural gas pipeline-quality gob gas production and the development of guidelines and procedures for implementing such a gas-quality improvement operation."*

Prior to the initiation of the field-testing required to meet the project objectives, preliminary evaluation and assessment was performed. An assessment of the methane gas in-place/producible resource at Jim Walter Resources, Inc., No. 4 and No. 5 mines established a potential 15-year supply of mine methane from gob wells at 60 billion cubic feet, satisfying the resource criteria for the test site. The first task of the field project will determine the effect of wide ranges in the operating conditions of selected gob wells on mine methane levels and ventilation requirements. Gob wells producing pipeline quality (i.e., < 96 percent hydrocarbons) methane will be operated over a wide range of suction pressures. Parameters to be determined will include absolute methane and methane concentration produced through the gob wells; working face, tailgate and bleeder entry methane levels; and the effect on economics of production of gob wells at various levels of methane quality. The second phase of the project will be the implementation of a demonstration project at a mine where commercial gob gas production has not been attempted. The mine would be selected based upon whether it has an existing system of gob ventilation, the levels of methane being vented through the gob well system, total methane emissions of the mine, and the proximity of the mine to pipelines or local gas markets. The guideline established during the first phase of the project will be used to design the production program. The economic feasibility of various utilization options will also be tested based upon the information gathered during the first phase.

INTRODUCTION

SCOPE OF PROBLEM

Methane released to the atmosphere during coal mining operations is believed to contribute to global warming and represents a waste of a valuable energy resource. Coal mining in the United States released an estimated 190 to 300 billion cubic feet (Bcf) of methane into the atmosphere in 1990 (EPA, 1993). Based on the current trend of increasing coal production and the mining of deeper, methane-rich coal deposits, methane emissions from coal mines have been forecast to rise to about 260 to 460 Bcf by 2010. Yet, largely because of inadequate methane capture technology, less than 7 percent (13 Bcf) of methane released during coal mining is currently recovered for use. Improved design and technology to lower the costs of methane recovery could make methane recovery economically viable in many more mines, thus providing important environmental and safety benefits, while enhancing the nation's natural gas supply.

Atmospheric concentrations of methane, which is believed to be an important greenhouse gas, have doubled over the past two centuries and continue to rise rapidly. The Clinton Administration, recognizing the potential environmental risks of methane emissions, has developed the Climate Change Action Plan (Clinton, 1993) to control the growth of greenhouse gasses in the atmosphere. The initial Plan looks for voluntary participation by the mining industry for increased methane capture. Should the voluntary actions be inadequate, it is not inconceivable that these environmental initiatives will require the recovery of methane from coal mines in the future, even though the technology to economically recover methane from coal mines has yet to be demonstrated for most mining situations. Thus, a "time window" exists for DOE to assist the mining industry to achieve a successful voluntary effort in coal mine methane capture and use.

STUDY PURPOSE

Commercial production of pipeline-quality mine generated methane through wells drilled vertically from the surface into the area above a mined-out longwall panel (gob) can, if properly implemented, be the most effective means of reducing mine methane emissions to the atmosphere. Currently, about 12 Bcf of methane per year is being collected, compressed, and marketed in the U.S. natural gas pipeline system from gob wells (EPA, 1993). This is possible because the gas that is being produced from these gob wells is of pipeline quality and requires little additional conditioning (primarily dehydration and compression) prior to injection into the pipeline. Importantly, this type of mine methane (i.e. pipeline quality gas) has the highest market value and, accordingly, is the most economically attractive method for use of mine-generated methane.

However, while the quantity of gob gas that is currently being collected is significant, there is a much larger quantity (26 to 84 Bcf) that is being emitted directly into the atmosphere from other gob wells in the U.S. (EPA, 1993). The primary reason for the venting of this gas from these gob wells is that the quality of the gas is highly variable and is often much below current natural gas pipeline specifications. There have been numerous studies performed that have evaluated the potential of upgrading this currently vented gob gas to pipeline specifications using various gas conversion and enrichment technologies (Resource Enterprises, Inc., 1993). However, economic assessment of such conversion/enrichment methods, performed under current natural gas/gas liquids market conditions, has shown marginal or no financial benefit.

An alternative to the "clean-up" of the medium-quality gob gas, which currently is economically unattractive, is to preclude the production of medium-quality gas in favor of producing pipeline-quality natural gas from these medium-quality gob wells. Clearly, if improved or modified well operational techniques could transform the medium-quality produced gas into pipeline-quality gas, then this gob gas could effectively compete in the marketplace with "conventional" natural gas. Therefore, this project has as its purpose and overriding objective *"the establishment of the parameters for evaluating the geologic, technical, and economic feasibility of natural gas pipeline-quality gob gas production and the development of guidelines and procedures for implementing such a gas-quality improvement operation."*

To achieve the goals outlined above, the current project has been divided into two test areas. The first test area of the project will be an extensive test phase conducted by Black Warrior Methane Corp. (BWMC) at mines operated by Jim Walter Resources, Inc. (JWR) to determine the effect of variations in the operating conditions of selected gob wells on mine methane levels and ventilation requirements and gob well gas quality and quantity. Gob wells at this mining operation, which currently produce pipeline quality (i.e., >96 percent hydrocarbons) gas, would be operated over a wide range of suction pressures. Parallel with this, extensive monitoring would be conducted in the mine and at the wells on the surface. The principal parameters to be determined would be 1) methane concentration and absolute methane quantity produced by the gob wells under varying well operating conditions; 2) working face, tailgate, and bleeder entry methane concentrations as a function of the well operating variables; and 3) the effect on project economics of producing gob wells at various levels of methane quality. In addition, the economic feasibility of utilization of the produced gas over a range of qualities less than 96 percent would be tested by evaluating the use of the gas in facilities such as gas-fired turbines, fuel cells, and/or gas enrichment plants.

The second test area of the project would be the implementation of a demonstration project at a mine where commercial, pipeline-quality gob gas production has not been attempted. The mine would be selected based upon, among other factors, whether it has an existing system of gob ventilation, the levels of methane being vented through the gob well system, total methane emissions of the mine, geologic conditions of the mine, and the proximity of the mine to pipelines or local gas markets. The guidelines established during the first part of the project conducted by BWMC would be used to design the production program. The economic feasibility of various utilization options would also be tested based upon the information gathered during this initial effort.

Prior to the initiation of the field-testing described above (currently described as Phase III), significant background research and development will be required. This includes an assessment of the methane gas resource/reserve within the selected test site at the JWR mines and a thorough design and evaluation of the geologic and engineering parameters that influence gas production from a gob well. This report details the initial work (Phase I) of the project which targeted the methane gas resource/recoverable resource issue and the preliminary technology development for field testing implementation.

BACKGROUND AND PREVIOUS WORK

As well documented in the literature (Deul, 1973; Deul, 1986; Stefanko, 1976), methane from coal seams in underground mining environments has been known and documented as a potential hazard ("unwholesome gas") since the late 16th century. Reports early in the 18th century from Great Britain identify the occurrence of methane explosions in what then were termed deep British mines.

In the United States, methane related mining problems were first identified by a report of a mine explosion in the state of Virginia in 1839 (Deul, 1986). According to Deul, methane explosions occurred at irregular intervals until 1875 when an increase in the frequency of explosions was reported. This corresponded to the rapid increase in the growth of the eastern U.S. coal mining industry (required to supply the rapidly expanding base metals and other industry) and the trend toward mining deeper coal horizons.

Similar situations were encountered in the coal mining industry throughout Europe and Asia. Beginning in the early 1900's efforts were put forth by various governments and governmental agencies to mitigate the presence of methane in coal mines. Within the U.S., the formation of the U.S. Bureau of Mines (USBM) in 1910 significantly impacted mine safety through the development and implementation of improved mine ventilation systems, rock dusting procedures, and the use of permissible (safety) explosives, electrical equipment, and cap lamps.

However, even with the adoption of these improved methods and equipment, methane emissions continued to be a source of potential danger. Clearly, supplemental efforts to those described above were required in certain mines, especially the deeper, high gas emission-prone mines. The proposed solution to this problem was the removal of methane prior to mining the coal or venting the methane contained within mined-out coal areas. This process (degasification, firedamp drainage, demethanation) employed various combinations of in-mine and surface relief techniques to remove the methane. The methods employed were initially developed within the European coal mining industry, beginning in earnest during the 1920's and becoming systematic by the early 1950's with the formation by the Council of Organization for European Economic Cooperation of the technical assistance program on the *"drainage and use of methane from coal mines"* (von Schoenfeldt, 1989). Similar programs were also developed in what was then the Soviet-influenced eastern European countries and the republics of the Soviet Union.

Efforts in the United States in methane control were initiated by the USBM in 1964, although industry had already begun a development program of it's own by the early 1950's (Spindler, 1960). However, the work of the USBM did not begin in earnest until the passage in 1969 of the Federal Coal Mine Health and Safety Act, which was quickly enacted following the massive Farmington, West Virginia coal mine disaster. Significant government and industry efforts during the 1970's firmly established the techniques for controlling methane, including the use of in-mine horizontal and cross-measure boreholes, gob wells, and vertical, fracced wells, along with other more conventional methane control methods (i.e. ventilation). As should be expected, much of the USBM work (and that of private industry) built upon the earlier work conducted in other parts of the world (especially Europe), with modifications to these techniques for the unique geologic and mining conditions and operations in the U.S.

However, during this entire period, the effort was directed toward removing the methane from the mine environment (to make the mining operation more safe). Only recently was it realized that 1) the methane that was being recovered by certain techniques could be of value as an added energy source; and 2) the methane that was being captured and emitted to the atmosphere was a potent greenhouse gas. Beginning in the early 1980's, capture and utilization of this gas was realized, primarily through the use of vertical wells in advance of mining and gob wells. In these situations of methane capture and use, all of the gas captured was of high methane concentration (>90 percent) and utilized as a pipeline-grade natural gas.

Although significant quantities of methane were captured and utilized that would otherwise have been emitted, large quantities continued to be emitted to the atmosphere. This gas often has large concentrations of mine air mixed with the methane, ranging from 30 to 90 percent for gas captured by degasification methods and 0 to 1 percent for gas captured by the mine's ventilation air. Clearly, any additional reduction in methane emissions from coal mining requires some type of utilization of this less-than-pipeline-quality gas or alternative techniques for enhancing the quality of the captured gas.

The gas production from gob wells present a unique opportunity for potential increase in the capture and utilization of mine methane. It has been estimated that the quantity of gob gas currently being emitted annually may range from 26 to 84 Bcf (EPA, 1993). One of the primary reasons that this gas is being emitted and not utilized is the variability in the quality of this produced gob gas. The collected and utilized gob gas discussed above is consistently produced at or above natural gas pipeline specifications. Because of this, the collection and use of the gas is relatively simple. However, the variability in quality of the majority of the gob gas produced in the U.S. precludes its simple collection and sale. Conversely, if improvement in the quality of this gob gas were possible, simple collection, compression, and utilization would also be possible.

Historically, the primary purpose of gob wells has been the removal of the mine methane from the gob area created after total extraction of the mined seam of coal. Gob wells were initially introduced to the U.S. mining in the late 1950's but only began to be used after the introduction of the retreating longwall mining method. Beginning in the early 1970's and continuing throughout that decade, numerous mining companies in the U.S. were routinely utilizing gob wells to effectively drain the methane that accumulated in the gob area (Deul, 1986; Thakur, 1971; Aul, 1991; Mills, 1989). This was done to reduce the amount of methane that entered the mine workings, either directly at the working longwall face or through emission into the longwall panel bleeder entries.

While the use of gob wells proved to be an effective technique for the removal of the methane within the gob, little emphasis was placed on maximizing the quality of the produced gob gas. Rather, the effort was to maximize the flow rate of the gas from these wells to further ensure effective removal of the methane from the gob. Initial techniques included the temporary use of blowers on the wells to initiate gas flow from the gob. This was improved upon by the continuous use of the blowers and in some cases the installation of compressors that would effectively increase the vacuum pressure (compressor inlet) on the well and increase flow rate.

Throughout this period it was recognized by numerous authors that the quality of the gas that is produced from these gob wells is highly variable (Maksimovic, 1980; Hagood, 1985; Mills, 1989; REI, 1993). Based on studies by the USBM and others, it was initially concluded that the composition of the gas produced from gob wells was controlled not only by the vacuum pressure applied to the well at the surface, but was also controlled by the location of the well in the gob, the structure of the gob, and the mine's ventilation system (Timko, 1982; Diamond, 1994; Maksimovic, 1980). Nonetheless, the emphasis was placed upon removing the largest amount of methane from the gob area and a simple solution was to apply as much vacuum as was available.

With work performed (beginning in the early 1970's and continuing until present) at the JWR mines in the Warrior basin by JWR and BWMC, it was found that the quality of the produced gas could be controlled through careful application of the vacuum on the wells and coordination with in-mine methane monitoring (Mills, 1989; Hagood, 1985; Stevenson, 1990). From this work it appears that the quantity of methane removed from the gob by a gob well is finite - that is, once a maximum methane flow rate is achieved (at a specified vacuum), additional increase in the vacuum does not increase the quantity of methane removed from the gob. Rather, the increased flow rate due to the further increase in vacuum is made up of additional mine air that has entered the gob either from the working face, headgate or tailgate roadways, or bleeder system.

Therefore, while substantial quantities of methane are currently being emitted from gob wells throughout the U.S. because of less than pipeline quality, there are techniques that can be applied to improve gob well gas quality. Importantly, these techniques can be applied in a manner that does not compromise the mine's ventilation system and may, in fact, supplement and improve the ventilation system. However, these techniques are only currently applied at a limited number of U.S. coal mines.

PROJECT RESULTS AND DISCUSSION

INTRODUCTION

Methane released during the mining of coal has historically been viewed as a safety hazard because of its explosiveness at low concentrations (5 to 15 percent) in air. Because of this, the control of this gas during the mining of coal has been a major concern to mine operators and miners. Recently, however, the potential of certain gases (including methane) released during anthropogenic activity (such as coal mining) to effect global climate has been realized. Accordingly, attention has focused on the emission of methane during the mining of coal and on possible methods to utilize this emission (and thus reduce the quantity emitted into the atmosphere) while still maintaining safe mining operations.

As previously discussed, the possible upgrade of gob gas that is emitted by some (or all) gob wells at coal mines is not only technically possible but also economically probable. The emphasis of this project, to evaluate the potential of improving the quality of this emitted (and wasted) methane, closely aligns itself with these important goals - *maintenance of coal mine safety while reducing emissions of methane to the atmosphere.*

The first step of such an evaluation must include a determination of whether the methane emission source under consideration for quality upgrade will be large enough to perform the required research and development scheduled for the Demonstration Project. Accordingly, an important aspect of the Phase I work included a determination of the size and quality of the gas resource and the potential producibility of this resource. In addition, preliminary analysis of the application of the proposed technology - *the enrichment of medium quality gob gas through improved operating practices* - must also be performed to provide 1) an initial indication of the potential for the demonstration project success; and 2) a foundation for the more detailed design and engineering analysis to be performed during the second phase of the project. This section of the report provides a summary of the work performed during the first phase on these important issues.

TASK 1 - DETERMINATION OF MINE GAS POTENTIAL

Project Location

The site selected for the potential demonstration project is at the Jim Walter Resources Blue Creek No. 4 and No. 5 Mine (JWR No. 4 and JWR No. 5), located in north-central Alabama within eastern Tuscaloosa County, Figures 1, 2, and 3. The JWR No. 4 and No. 5

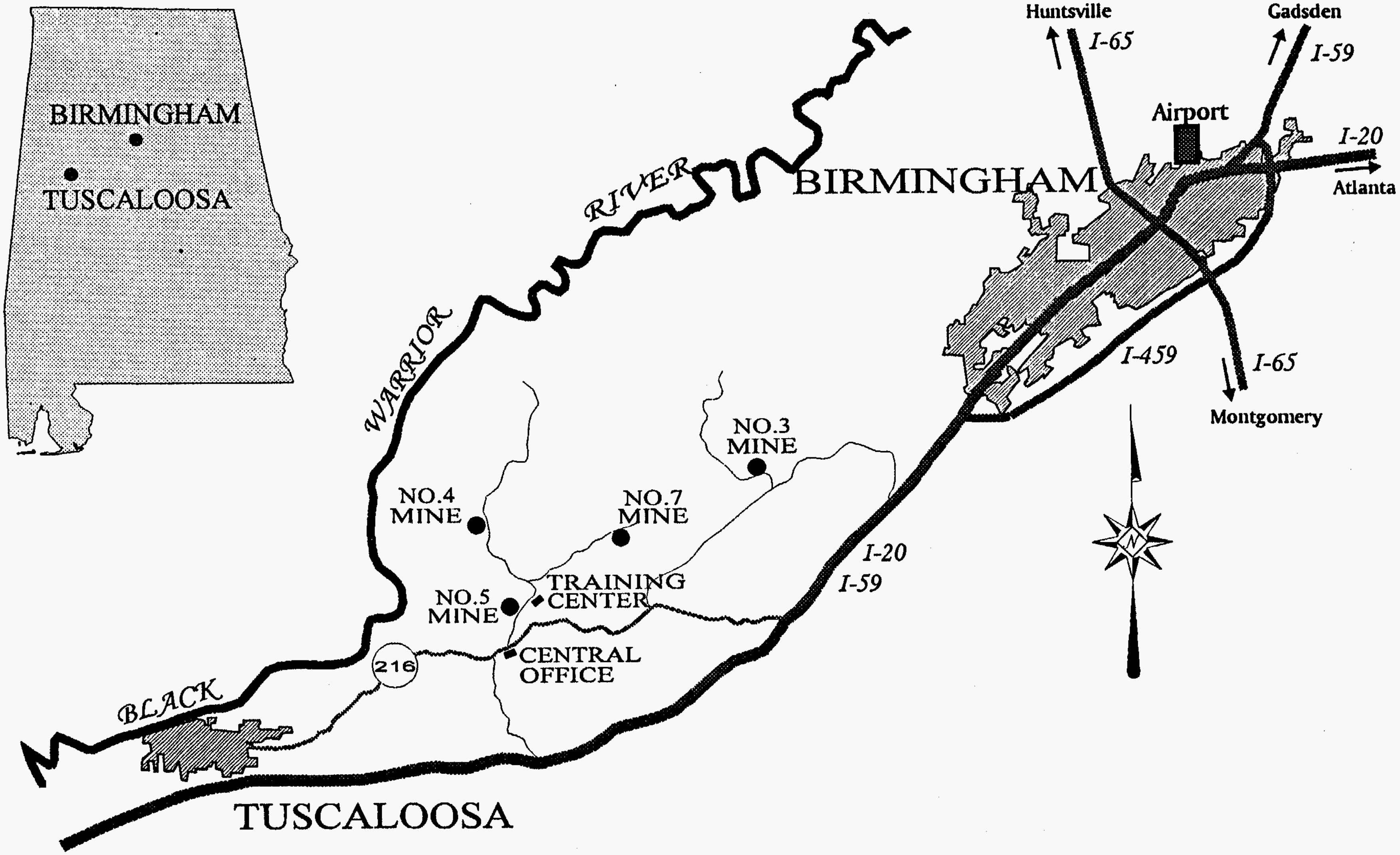

Figure 1 - Location of the Black Warrior Methane Corp./Jim Walter Resources , Inc. Facilities and the Project Site

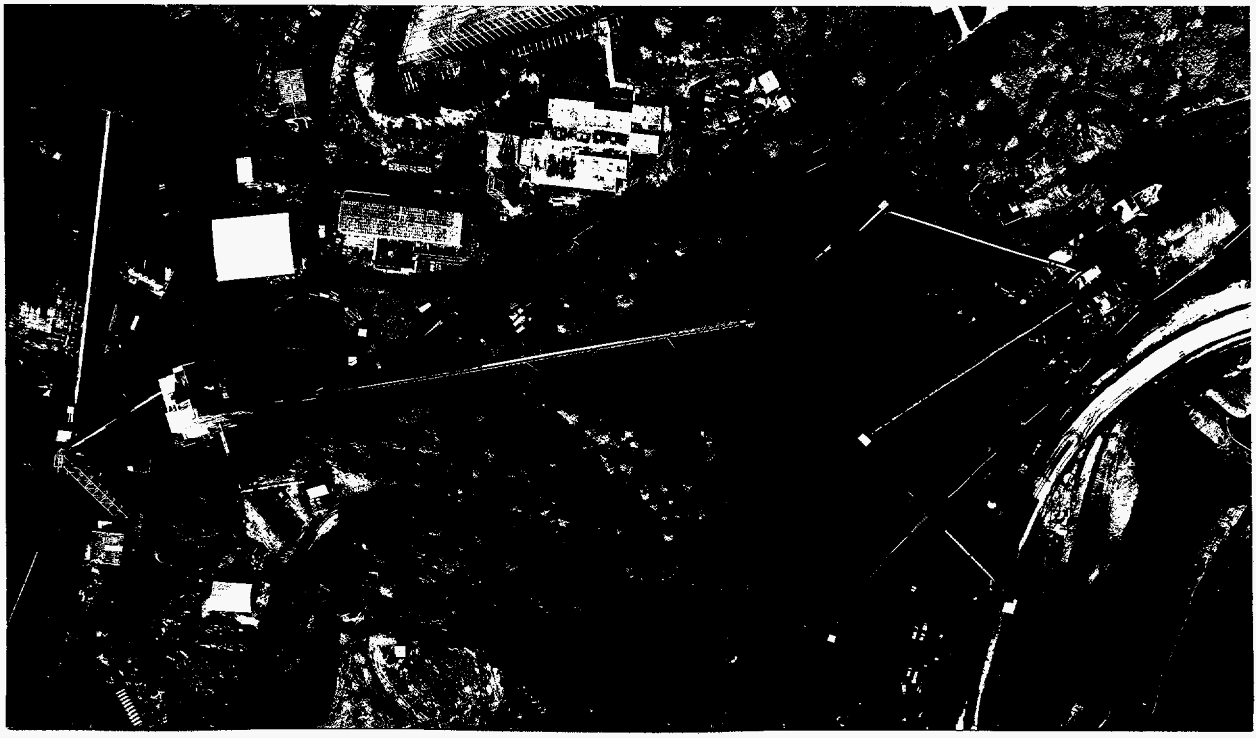

Figure 2 - Aerial view of the JWR No. 4 Mine Showing (from left to right) Mine Shaft, Preparation Plant, Coal Storage Piles, and Thermal Dryer

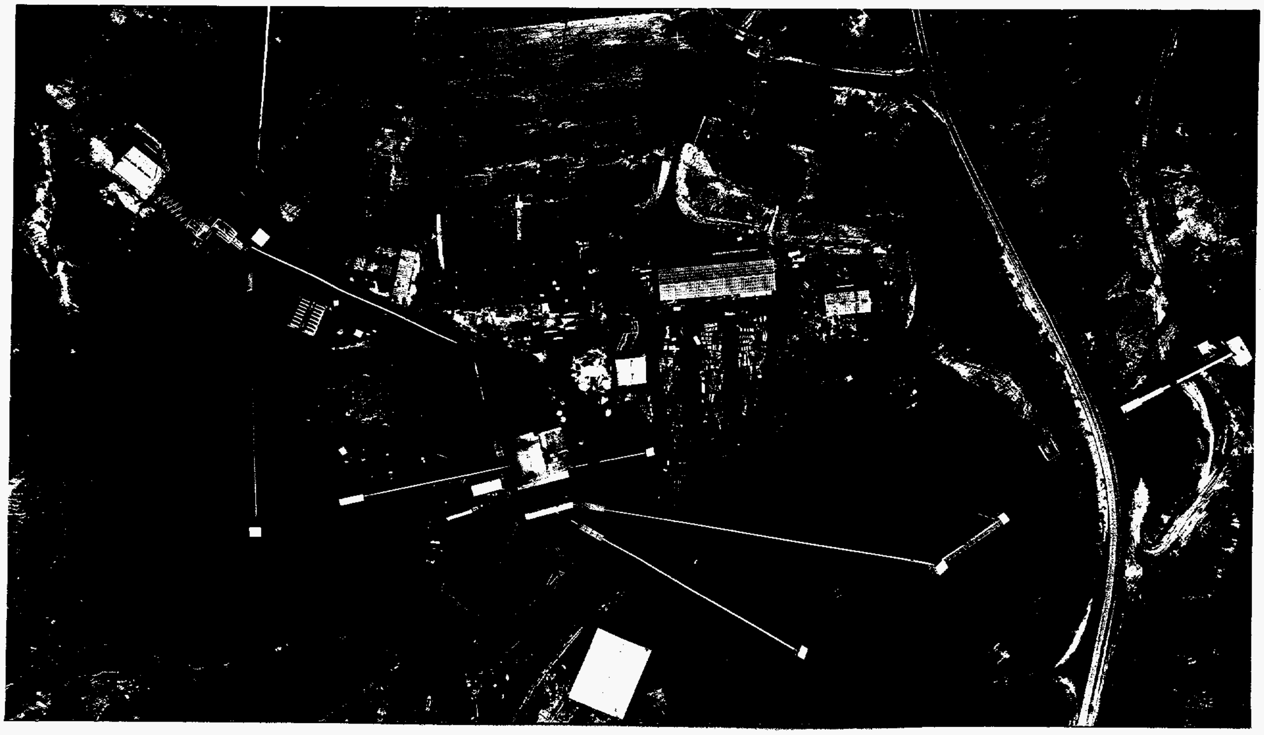

Figure 3 - Aerial View of the JWR No. 5 Mine, Showing (from left to right) Mine Shaft, Preparation Plant, Mine Shaft, and Coal Storage Piles

mines are part of a four-mine underground complex within eastern Tuscaloosa county and western Jefferson county operated by Jim Walter Resources, Inc. Depths of operations in these four mines (JWR No. 3, No. 4, No. 5, and No. 7) range from 1,300 to 2,100 feet, making these mines some of the deepest operating coal mines in the U.S. Adjacent to these mines are other underground coal mines operated by USS Mining Company (Oak Grove Mine) and Drummond Coal Company (Shoal Creek Mine).

The mine site is easily accessible via state highway Route 216 and is 12 miles from the Brookwood/Vance interchange on U.S. Interstate Highway I-59/20. In addition to the well-developed county road system in the area, the mining operations maintain extensive all-weather roads for access to ventilation shafts, mine degasification gob and vertical wells, and other facilities throughout the surface area of the mine.

Topographically, the area is the dissected Appalachian plateau province with an average vertical relief of 50 feet. A more pronounced topographic relief (up to 200 feet) can occur in the vicinity of stream valleys, such as the Davis Creek valley which is located east and north of the JWR No. 4 mine area. The closest major population centers are Birmingham, Alabama (50 miles to the northeast on I-59/20) and Tuscaloosa, Alabama (25 miles to the west-southwest on I-59/20), although numerous towns and villages are present within the mining area. Surface use in the area is composed of timber cutting, surface facilities for underground mining operations, surface (strip) mining, and limited agriculture.

Geologic Setting of the JWR No. 4 and No. 5 Mines

The JWR No. 4 and N. 5 mines are located within and along the eastern edge of the Warrior basin. The Warrior basin is the southernmost of a series of Pennsylvanian-age basins of the Appalachian plateau in the eastern U.S. The basin is principally a triangular wedge of sedimentary rock that is structurally bounded on the east and southeast by steeply dipping strata of the Appalachian orogenic belt and on the southwest by the deeply buried Ouachita structural trend, Figure 4. The northern edge of the basin is stratigraphically defined by the updip limit of Pennsylvanian-age rocks (McFall, 1986).

The easternmost part of the Warrior basin (the area of the project site) is characterized as a structurally complex foreland basin (Pashin, 1991). The eastern margin of the basin is a large thrust structure formed during the Alleghenian orogeny. While extensive folding and faulting of the early Paleozoic strata is more commonly associated with this compressional orogenic event, the eastern Warrior basin is characterized by more broad and low amplitude folds and little evidence of thrust faulting. However, numerous enechelon normal faults are present within this area of the basin, possibly due to tensional pull-apart structures formed during basal decollement in the Alleghenian orogeny (Pashin, 1995), Figure 5.

Within the specific area of the JWR No. 4 and No. 5 mines, the geologic structure consists of a series of northwest-southeast trending normal faults with stratigraphic throws ranging from a

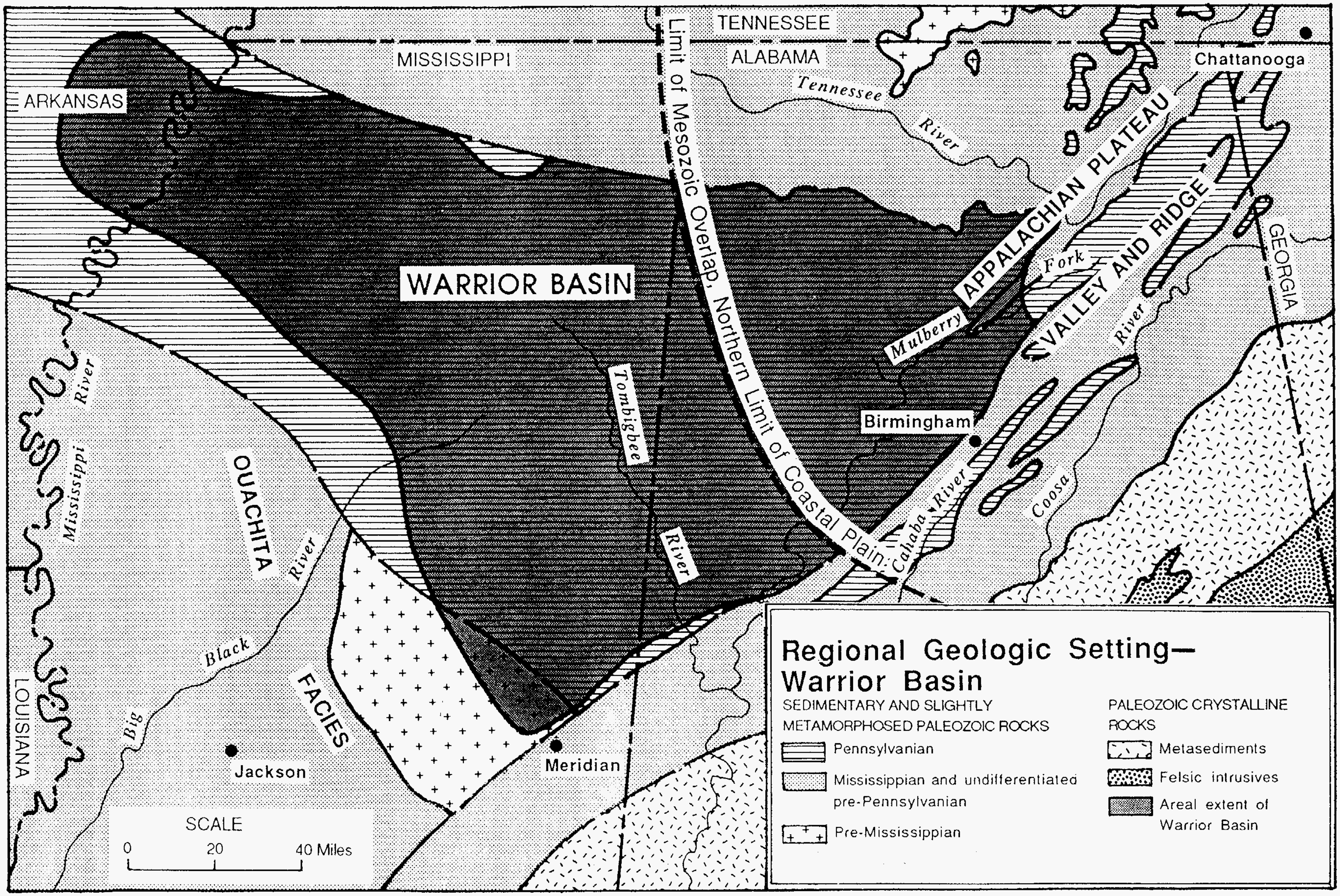

Figure 4 - Geologic Setting of the Warrior Basin

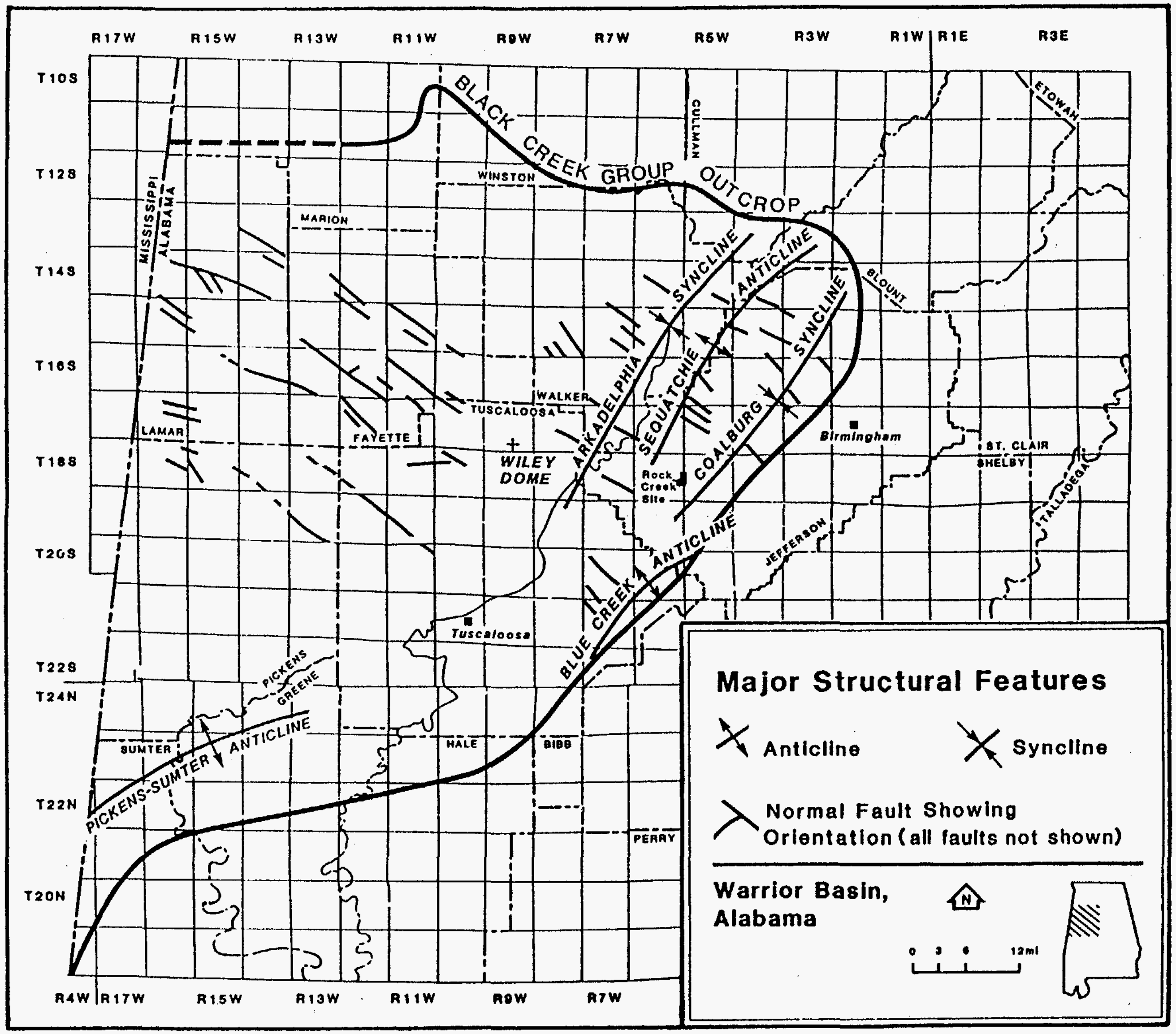

Figure 5 - Major Structural Features of the Eastern Warrior Basin

few feet to over 100 feet, Figure 6. The primary target coal seam (Mary Lee/Blue Creek) dips gently to the west across most of the mine area. Southeast of the JWR No. 5 mine area the structure is dominated by the main Appalachian overthrust, such that the dip of the strata changes rapidly from near horizontal to near vertical.

The coal-bearing strata of the Warrior basin occur in the Lower Pennsylvanian Pottsville formation and consist primarily of sandstone, siltstone, and shale with minor amounts of coal. Repeated sedimentary cycles, each of which correspond to a major coal group, are common throughout the basin (Boyer, 1986). Eight coal groups are present within the eastern portion of the Warrior basin (from oldest to youngest): 1) Black Creek; 2) Mary Lee; 3) Gillespie/Curry; 4) Pratt; 5) Cobb; 6) Gwin; 7) Utley; and 8) Brookwood (McFall 1986; Pashin, 1991; and Pashin, 1995.), Figure 7. Coal groups (which contain the subject coal seams) generally cap the regressive, coarsening-upward sedimentary cycles. The cycles have as much as 350 feet of marine mudstone at the base and typically coarsen upward into sandstone. At the top of each cycle is the interbedded mudstone, sandstone, underclay, and coal that makes up a coal group (Pashin, 1991). Within the Warrior basin the Mary Lee and Blue Creek coal seams of the Mary Lee group are the primary target zones for coal mining. Locally, the Pratt seams within the Pratt Group are also underground mining targets.

The JWR No. 4 and No. 5 mining operations primarily target the Blue Creek coal seam. In addition, the overlying Mary Lee seam is also mined if the rock parting between the two coal seams is too thin and cannot be supported by normal roof control techniques. Coal seams of the other seven coal groups discussed above are present within the mine area, as shown in the typical well stratigraphic section for the mine area, Figures 8 and 9. However, individual coal seams within these groups often are not continuous across the mine area.

Mining Operations at the JWR No. 4 and No. 5 Mines

The mining operations at the JWR No. 4 and No. 5 mines target the Mary Lee/Blue Creek coal seam at a depth ranging from 1,900 to 2,100 feet. Continuous miner sections (there are five sections operating at the JWR No. 4 mine and three operating at the No. 5 mine) develop the mine main entries and sub-main entries and the headgate/tailgate/bleeder entries surrounding the planned longwall panels. The mine mains and sub-mains typically consist of 4 to 6 entries with yield and barrier pillar support systems employed. The mains and sub-mains are designed to effectively create a long-term access/egress route within the mine for ventilation, personnel, and produced coal movement.

Once the continuous miner sections have developed the headgate/tailgate/bleeder entries surrounding planned longwall panels, longwall mining equipment, utilizing ranging-arm rotating drum shearer, armored drag-chain face conveyors, and four-leg shield units for roof support, are installed for longwall mining operations. Longwall panels originally were 600 to 750 feet in width but current operations utilize panel widths of 850 to 950 feet. Panel lengths are dependent upon local mining conditions, especially the numerous high-angle normal faults that are present within the mining area. Typical panel lengths of 5,500 to 6,500 feet are currently employed by the

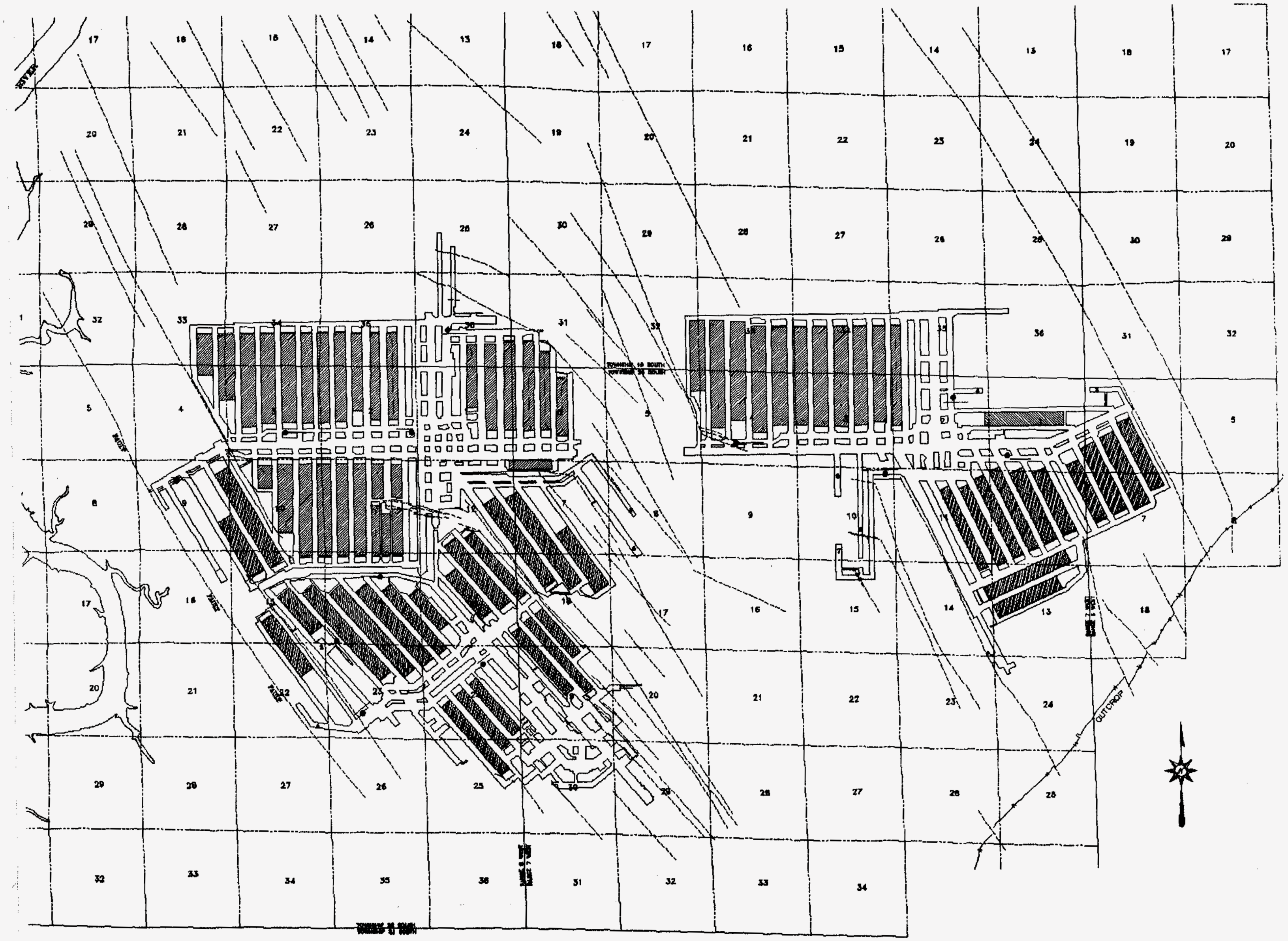

Figure 6 - Structural Features of the JWR Mine Area

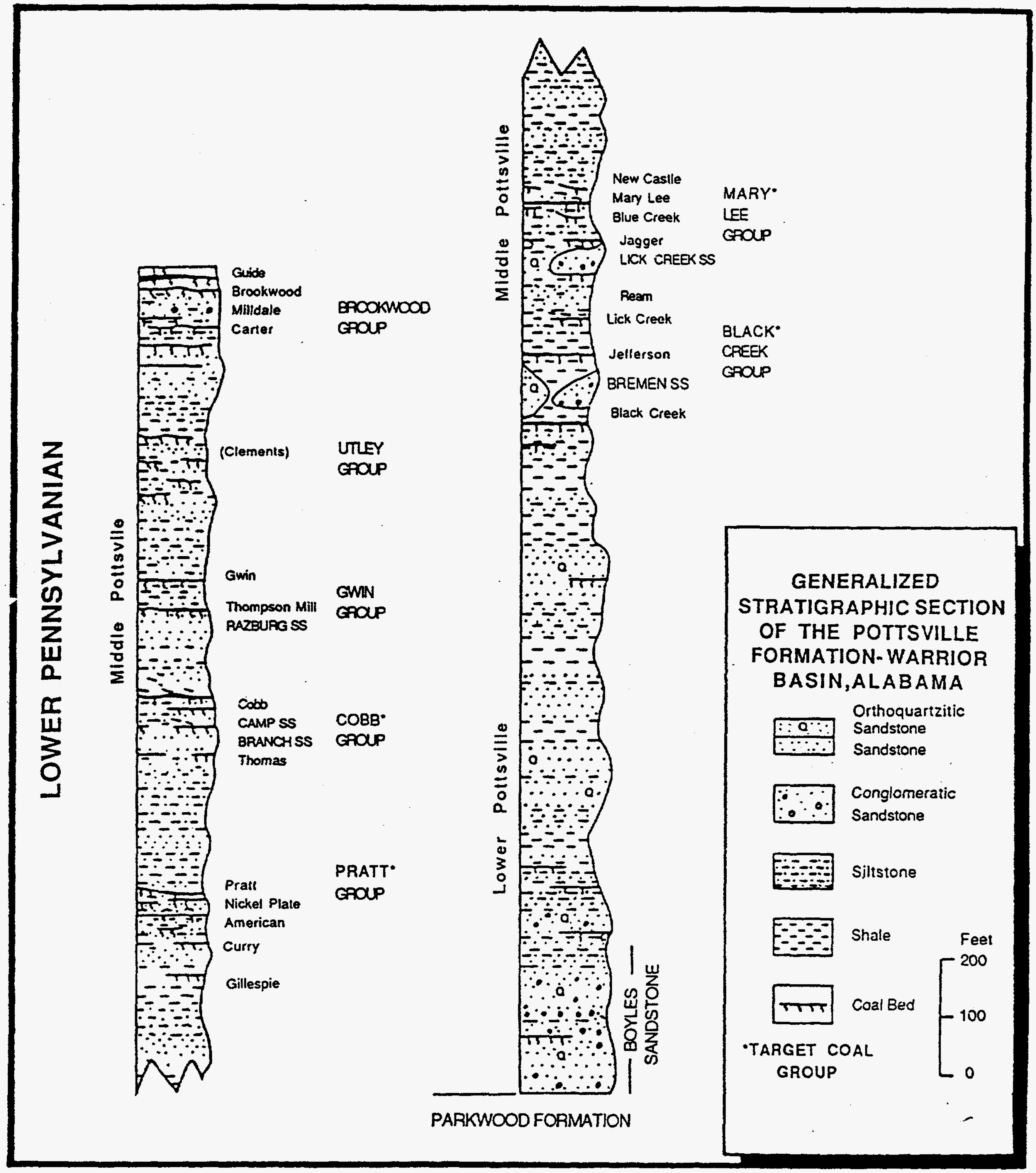

Figure 7 - Generalized Stratigraphic Section for the Eastern Warrior Basin

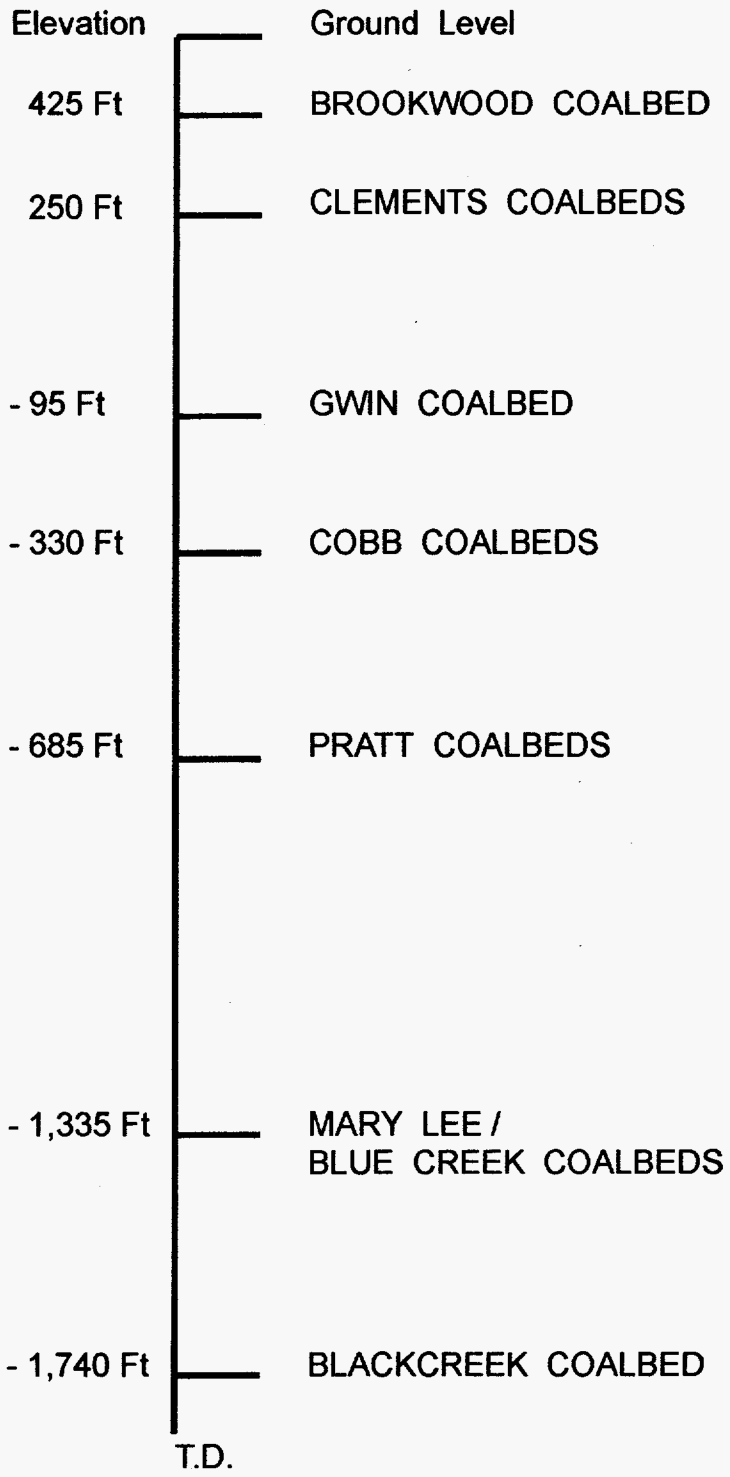

Figure 8 - Generalized Stratigraphic Section for the JWR No. 4 Mine

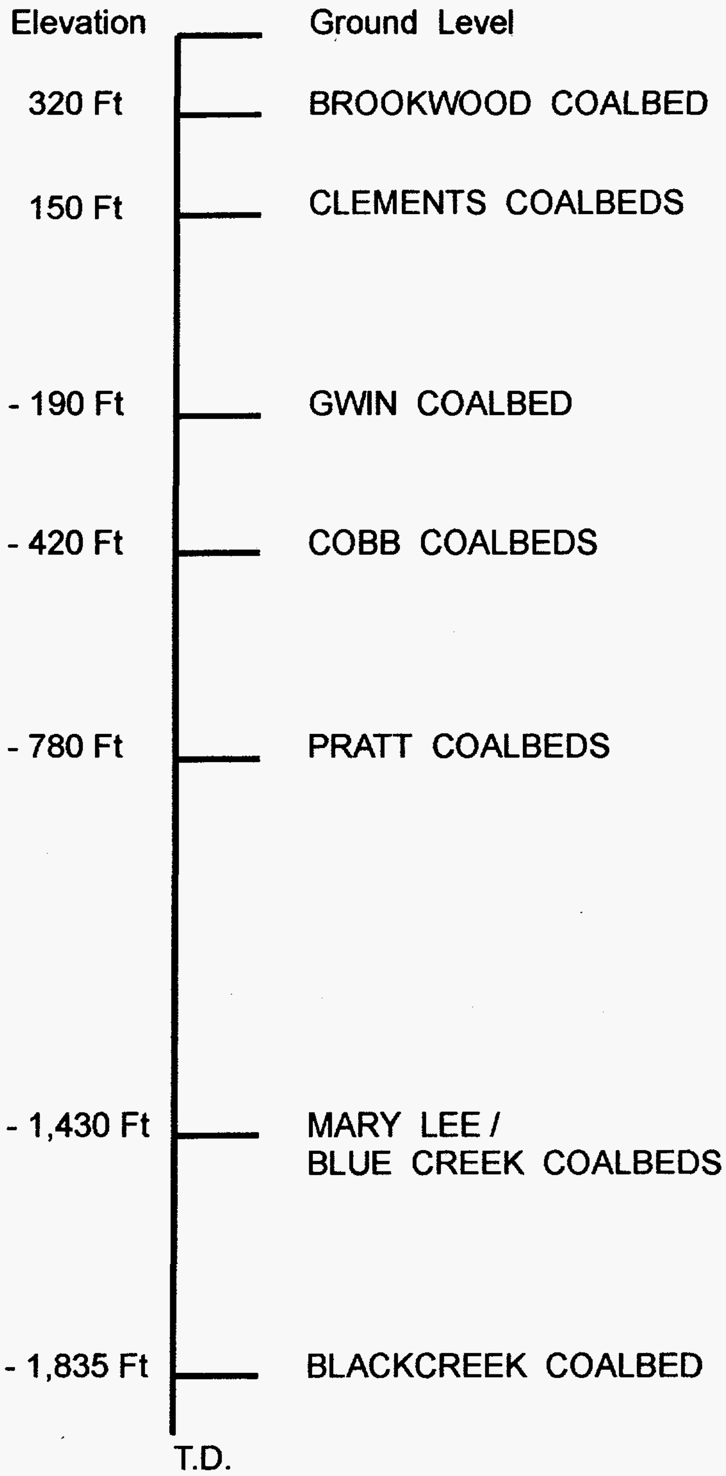

Figure 9 - Generalized Stratigraphic Section for the JWR No. 5 Mine

mining operations. Two longwall units are in operation at the JWR No. 4 mine and one is in operation at the JWR No. 5 mine.

Coal produced from the continuous miner and longwall operations is transported from the working face area via shuttle-car haulage and conveyor systems to underground storage bunkers located near the bottom of the production shafts. Balanced hoisting skips transport the coal from the temporary storage bunkers to the surface, transporting 20 to 25 tons of mined coal per lift (Mills, 1991).

The active portion of Mine No. 4 is illustrated in the mine map of Figure 10. The blackened areas of the map indicate the gob areas of the mined-out longwall panels. Future longwall panels to be mined are represented as the white rectangles in this figure. As shown, future mining (projected through the year 2028) in the JWR No. 4 mine will take place in the western and northern sections of the mine. Similarly, the JWR No. 5 mine is illustrated in Figures 11 and 12. As with Figure 10, mined-out areas are shown as black and future longwall panels are shown as white rectangles. Projected mining will occur at the JWR No. 5 mine through at least 2008.

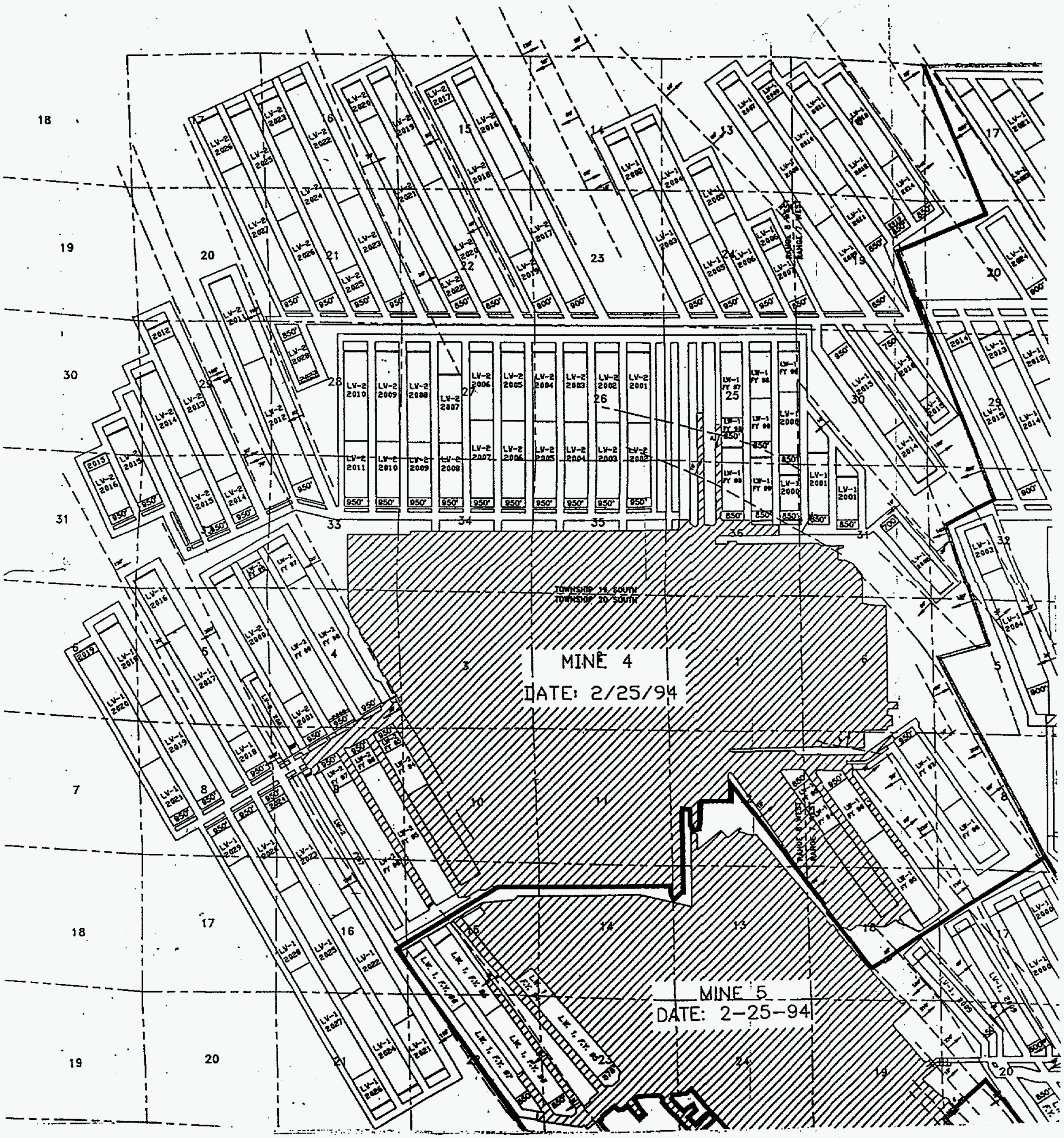

Figure 10 - Mine Map of the JWR No. 4 Mine Showing Mined-Out and Future Mining Area

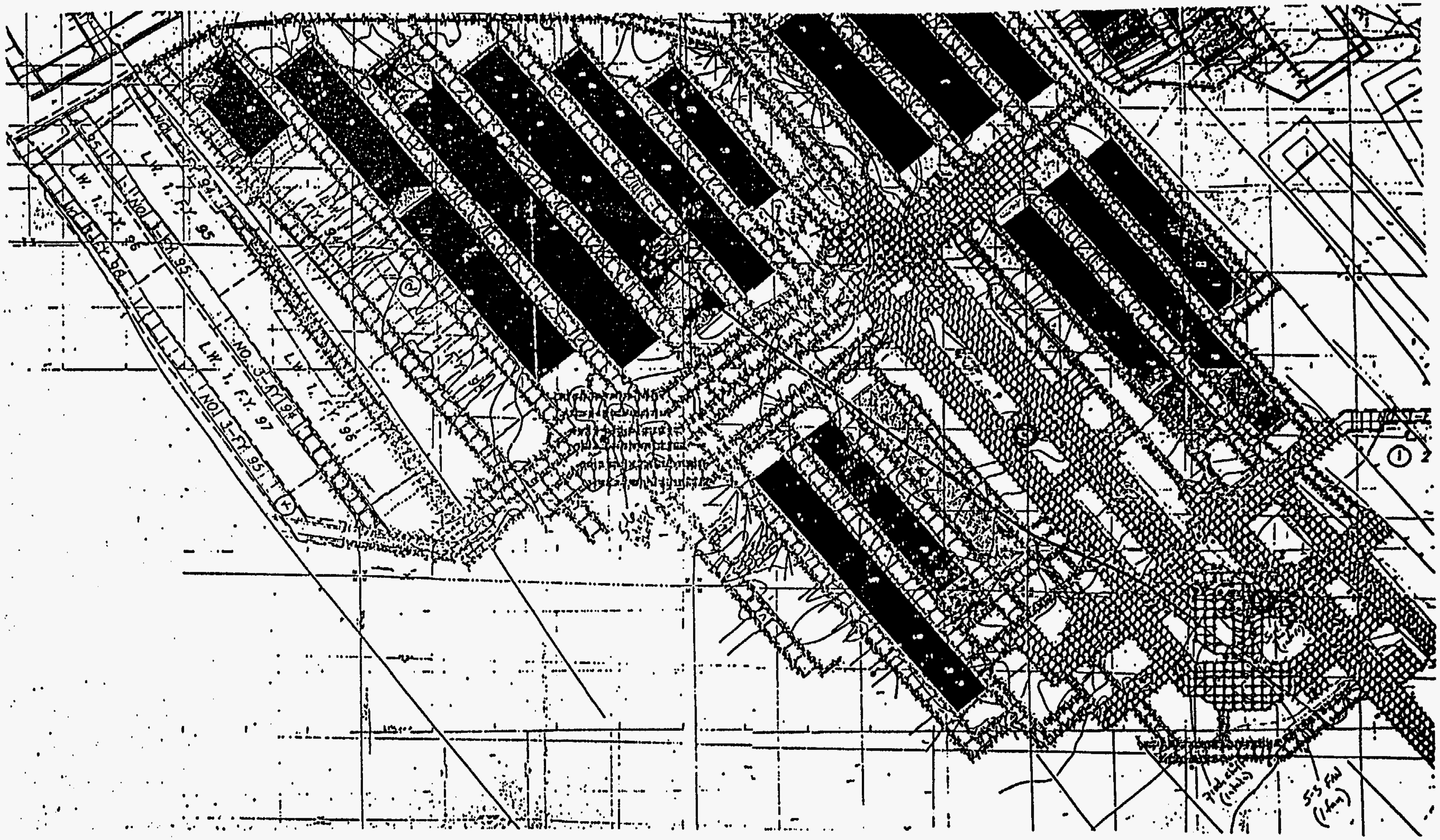

Figure 11 - Mine Map of the Western Section of the JWR No. 5 Mine Showing Mined-Out and Future Mining Areas

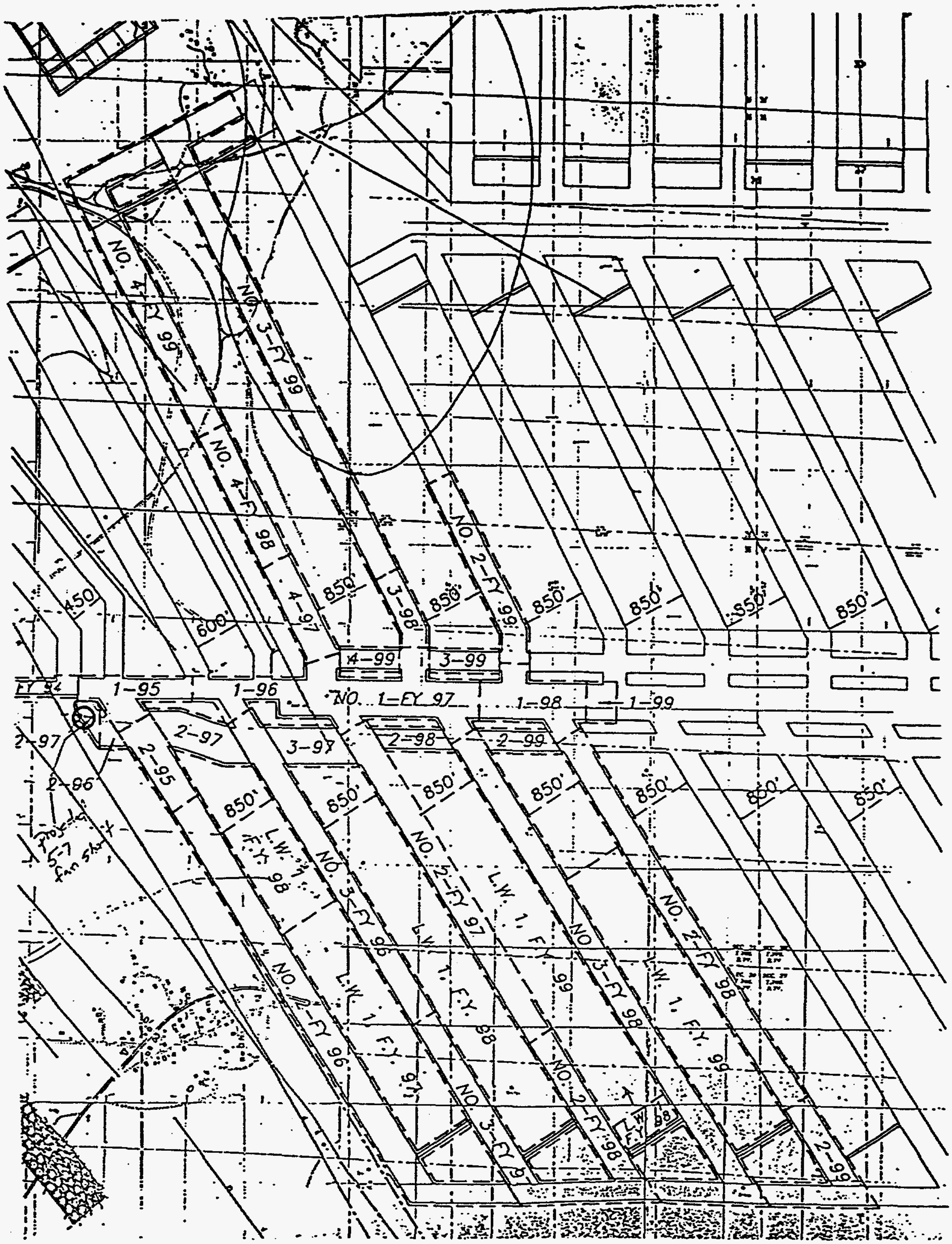

Figure 12 - Mine Map of the Eastern Section of the JWR No. 5 Mine Showing Mined-Out and Future Mining Areas

Mine Ventilation Operations at the JWR No. 4 and No. 5 Mine

The goal of a coal-mine ventilation system is to provide healthy and safe atmospheric conditions for the mine workers. To achieve this goal, the ventilation system must supply an adequate amount of fresh air to dilute toxic, noxious, and explosive gases and dusts to harmless levels while removing them from the mine. In coal mines, the required quantities of air are generally dictated by the amount of fresh air necessary to dilute methane concentrations well below their combustion threshold.

At the JWR No. 4 mine, two exhaust shafts coupled with four intake shafts are used for ventilating the mine, and are located on the mine map shown in Figure 11. At each exhaust shaft, two fans are connected in parallel and provide the means of exhausting air from the mine workings. Each fan is 12 feet in diameter and is powered by a 3500-horsepower electric motor. The south fan shaft produced an average (October 1994 through June 1995) flow of 1,750,000 cubic feet per minute, with an average methane concentration of 0.29 percent. The north shaft delivered an average exhaust of 1,690,000 cubic feet per minute with an average methane concentration of 0.05 percent. Together these fan shafts exhausted an average 3,440,000 cubic feet per minute of air with an average methane concentration of 0.17 percent for an average methane emission rate of 8.6 million cubic feet per day, Figures 13 and 14.

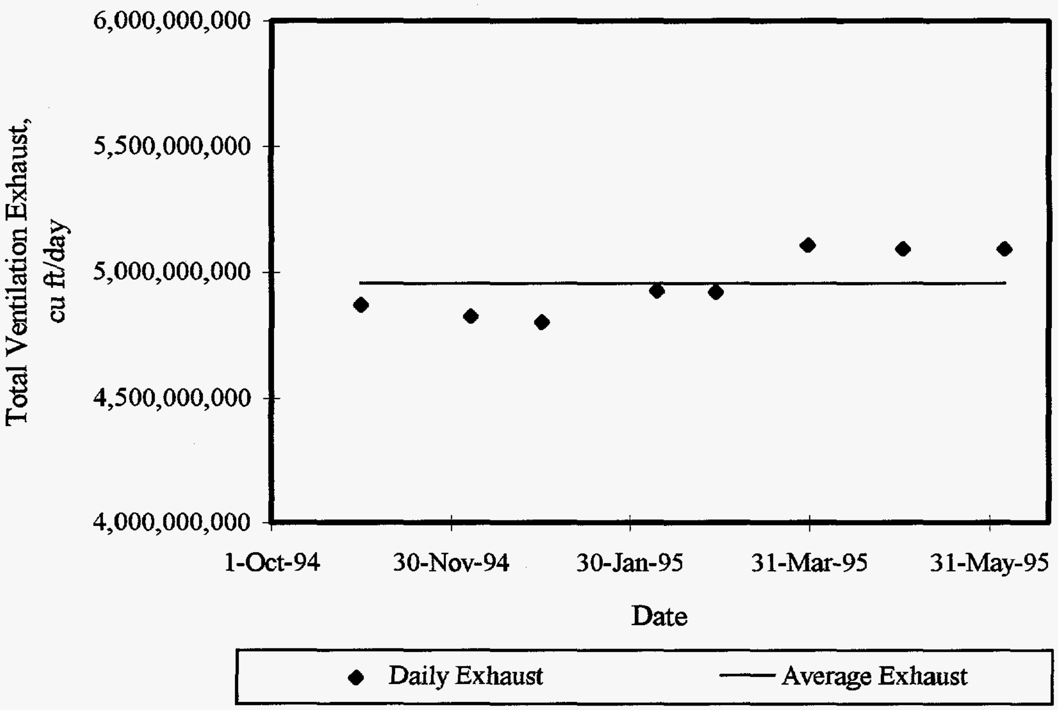

Figure 13 - JWR No. 4 Mine Ventilation Exhaust (October 1994 - June 1995)

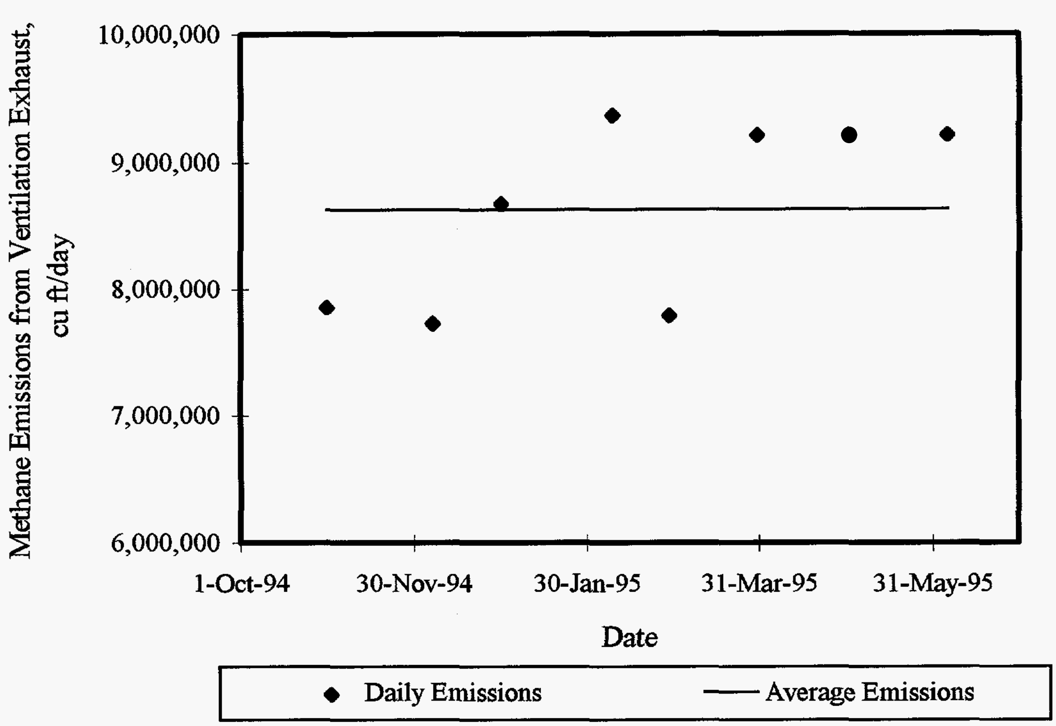

Figure 14 - JWR No. 4 Mine Methane Emissions from Ventilation Exhaust
(October 1994 - June 1995)

The JWR No. 5 mine utilizes three fans, similar in size to the JWR No. 4 mine, with two in parallel located at the north fan shaft and one located at the south fan shaft, Figures 12 and 13. The south fan shaft produced an average (October 1994 through June 1995) flow of 620,000 cubic feet per minute, with an average methane concentration of 0.51 percent. The north shaft delivered an average exhaust of 1,430,000 cubic feet per minute with an average methane concentration of 0.52 percent. Together these fan shafts exhausted an average 2,050,000 cubic feet per minute of air with an average methane concentration of 0.51 percent for an average methane emission rate of 15.2 million cubic feet per day, Figures 15 and 16.

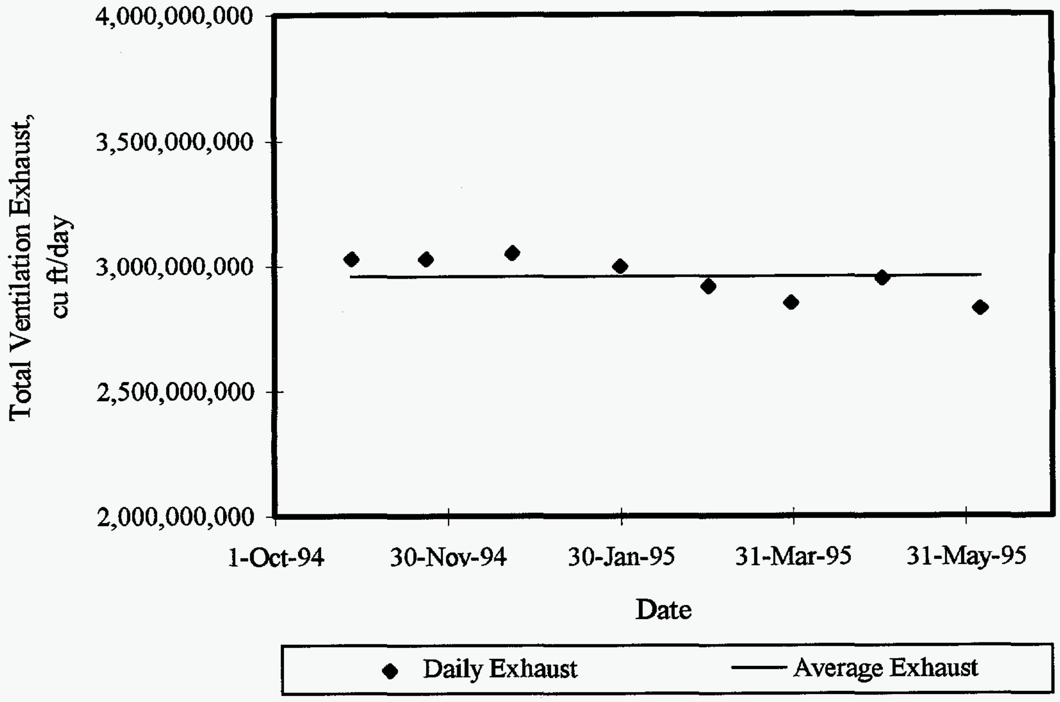

Figure 15 - JWR No. 5 Mine Ventilation Exhaust (October 1994 - June 1995)

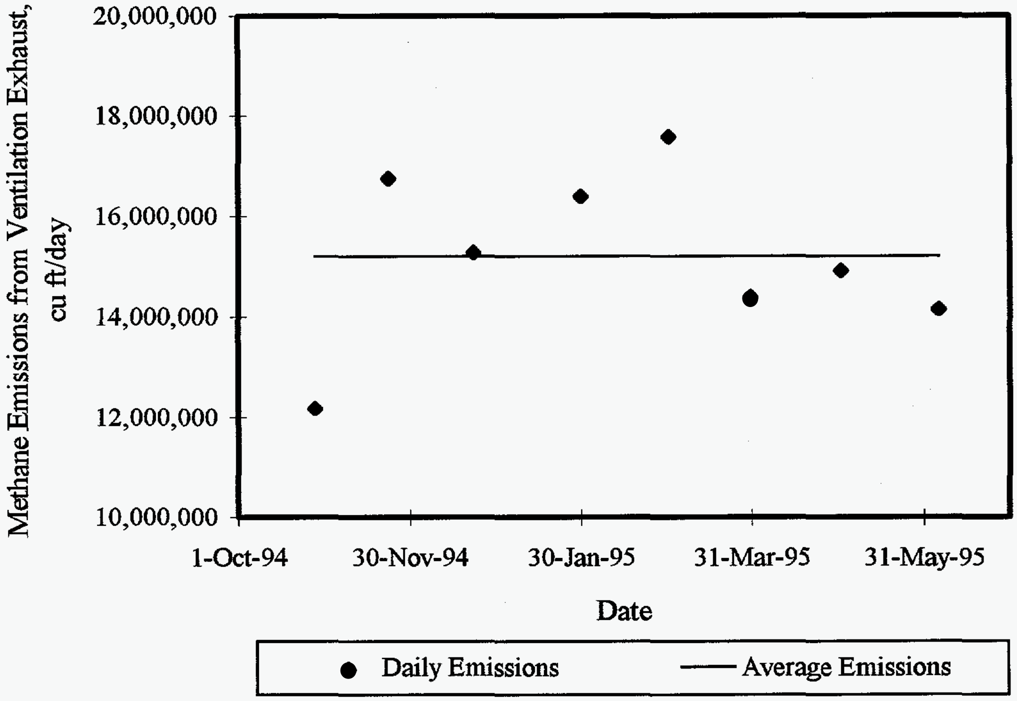

Figure 16 - JWR No. 5 Mine Methane Emissions from Ventilation Exhaust (October 1994 - June 1995)

Mine Degasification Operations at the JWR No. 4 Mine

With the high methane content of the coal seams found at the JWR mines (discussed in more detail later), methane drainage techniques are used to supplement the normal mine ventilation system. These methane drainage systems employ vertical pre-mining wells, in-mine horizontal wells, and gob wells. Each of these systems are described in more detail below.

Vertical, Fracced Pre-Mine Drainage Wells

JWR, along with other mining companies in the Warrior and Appalachian basins, utilize vertical, fracced wells drilled into the unmined coal areas as an effective means of removing the methane from the coal prior to mining. This type of well, drilled and completed in a method similar to conventional natural gas wells, is the primary basis for the large U.S. coalbed methane industry, in which over 6,700 wells were producing 2.2 billion cubic feet of methane per day at the end of 1994.

Vertical, fracced wells (hereafter referred to as vertical wells) at the JWR mines in the Warrior basin initially targeted only the seam that was being mined - the Mary Lee/Blue Creek. However, with improved drilling and completion techniques, current vertical wells target all primary coal gas horizons in the well, including the coal seams of the Black Creek, Mary Lee, Gillespie/Curry, Pratt, and Cobb coal groups. Figure 17 illustrates a typical vertical well that is completed into only one coal zone. As shown in this figure, water that is co-produced with the coalbed methane is pumped from the well through a central tubing string, whereas the gas flows naturally in the annular area between the tubing and the well casing. To enhance the gas flow from the typically lower permeability coal formations, the coal seams are hydraulically stimulated. Current practice utilizes three to four stimulation treatments (one for each of the major coal zones) in each well. Figures 18 and 19 illustrate the surface facilities for vertical wells and show the water pumping, gas separation, and gas metering equipment.

One of the advantages of vertical wells is that the gas produced is unaffected by the mining operations. The gas quality is that found naturally in the coal seam in the JWR mine areas and the gas is principally methane (98 to 99 percent) with minor amounts of nitrogen, carbon dioxide, and other hydrocarbons.

As shown in Figure 20, daily production from the vertical wells in the JWR mining area has slowly increased during the past three years. Increased emphasis by the mining company on vertical well drainage and improved completion practices has led to an increase use of this type of methane recovery. Current production from the 100 vertical wells in the JWR mining area averaged about 10 million cubic feet per day during June 1995, for an average per well daily production of about 100,000 cubic feet. It should be noted, however, that the average daily rate includes new wells still undergoing dewatering (gas production is increasing), wells that are at their peak production, and older wells that have begun their production decline phase.

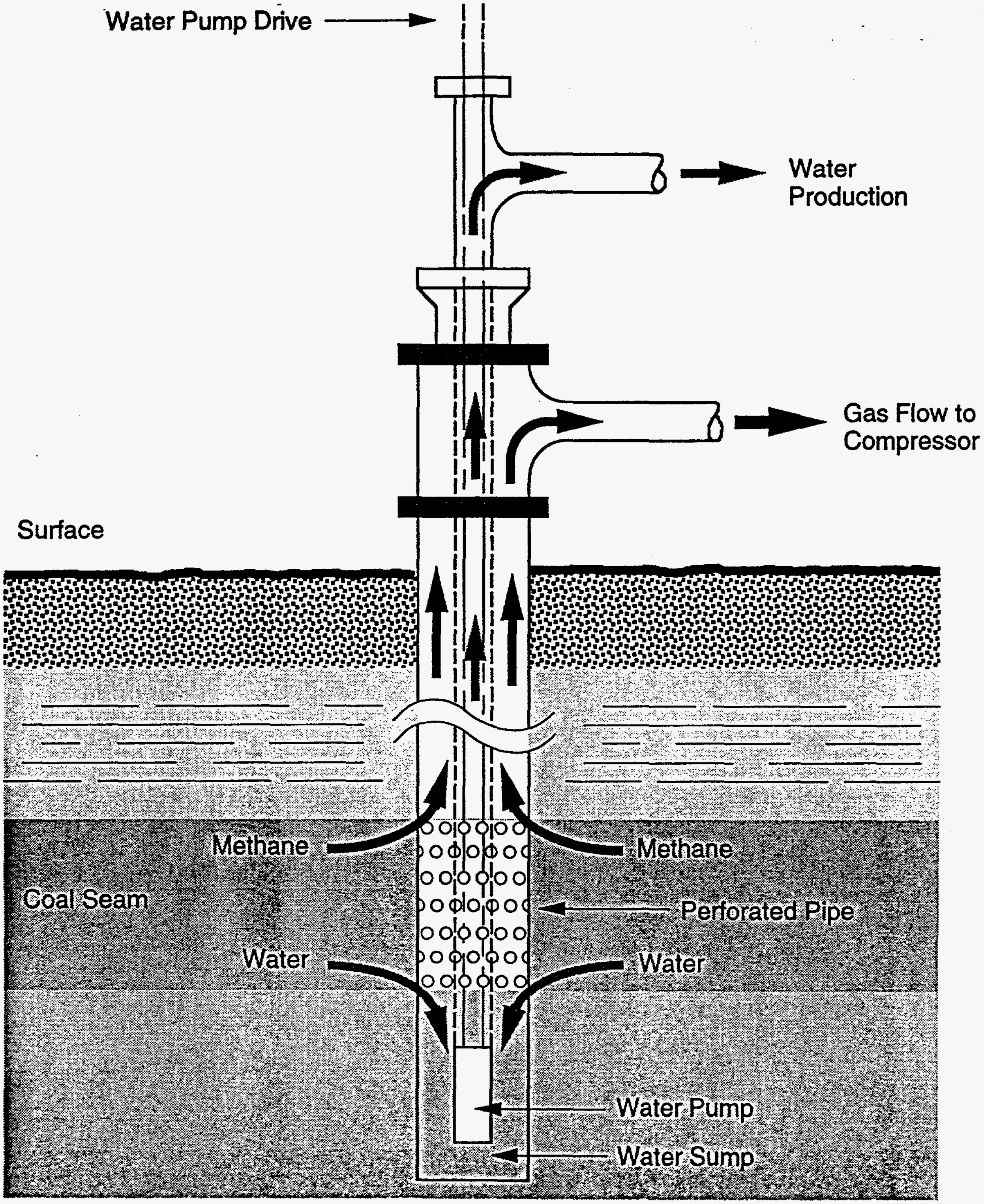

Figure 17 - Schematic Diagram of a Fracced, Vertical Well

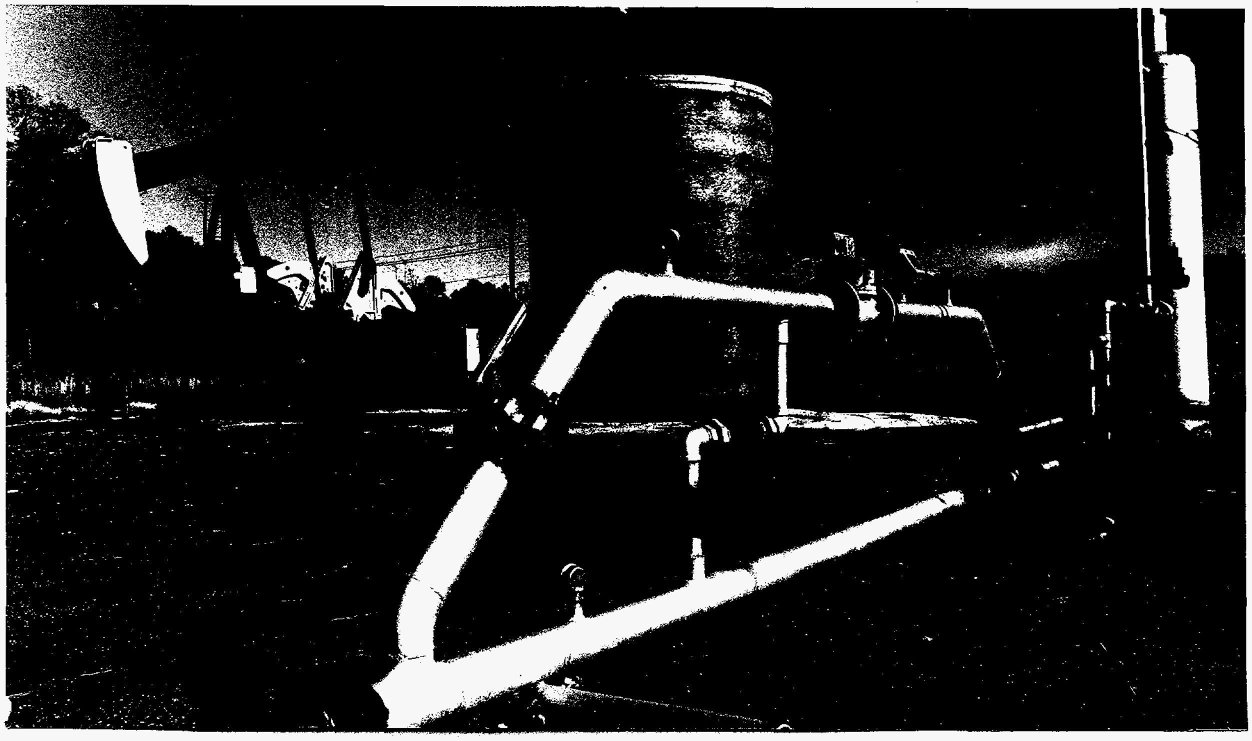

Figure 18 - Surface Facilities for a Vertical Well at the JWR Mines Utilizing a Sucker-Rod Pump Dewatering System

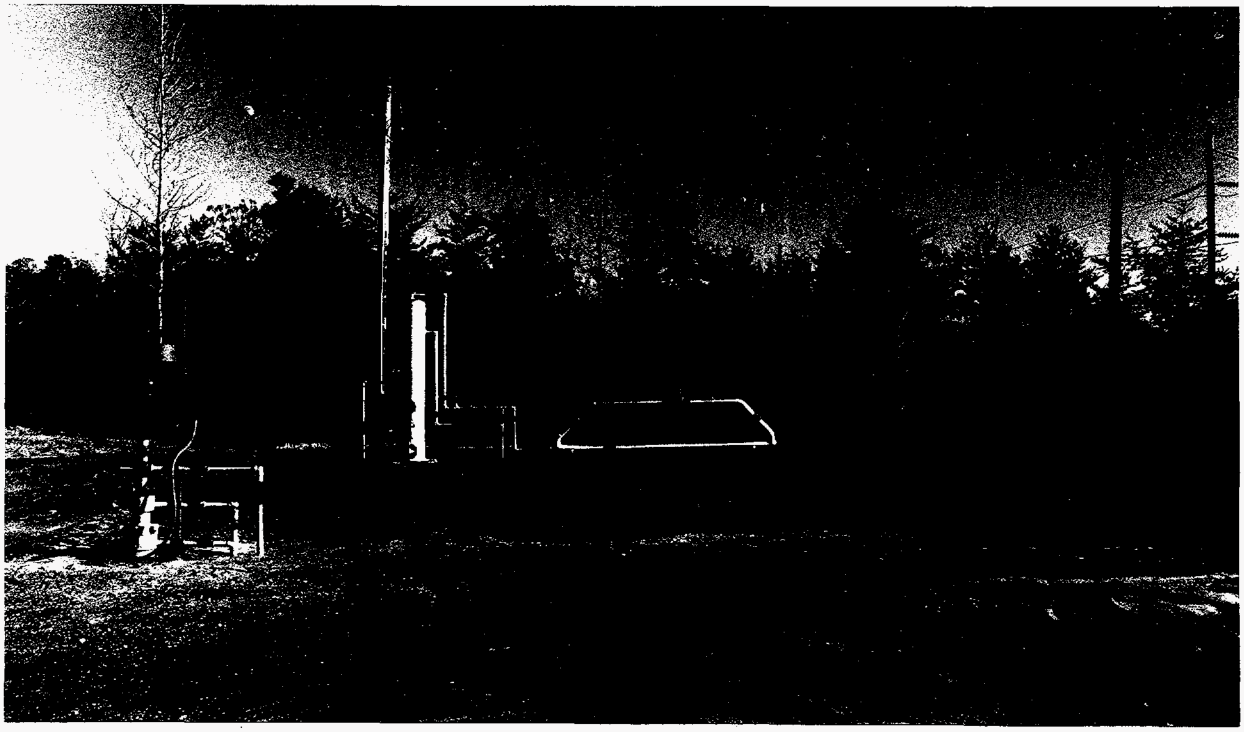

Figure 19 - Surface Facilities for a Vertical Well at the JWR Mines Utilizing a Progressive Cavity Pump Dewatering System

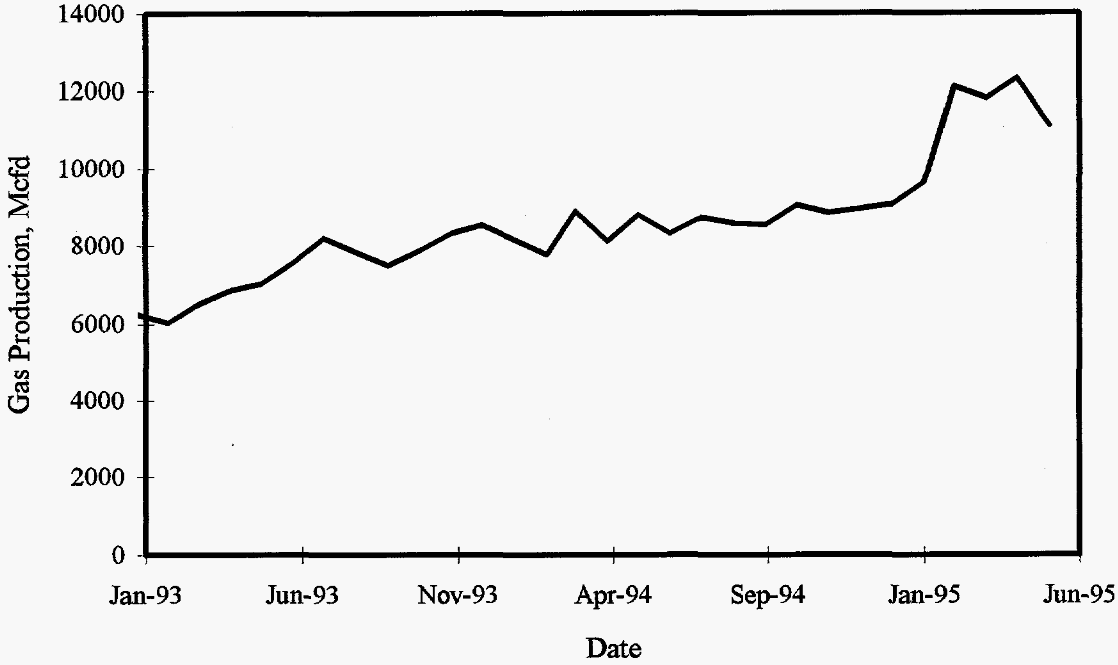

Figure 20 - JWR Mine Area Vertical Well Production History (1993 - 1995)

Horizontal Wells

Horizontal wells have been used in the JWR mines since the late 1970's as an effective means of removing methane from unmined longwall panels. The wells are drilled from the active mine workings (the longwall panel headgate road) across the width of the panel. A typical length for these wells is about 100 feet less than the panel width. These wells are connected to an underground piping system that transports the methane through the mine to a collection point where it is then piped to the surface.

Although an effective method to degasify the mined coal seam immediately prior to its mining, the short production life of these wells causes their total production to be small, when compared to a vertical well. Figure 21 displays the production history for horizontal wells at each of the four JWR mines. As shown in this figure, the production rates can be highly variable, due to changes in mining rates and operations. As can also be seen in Figure 21, there is a general decreasing trend in production rate from the horizontal wells at the four mines. This is due in part to the effect of the pre-mining vertical wells and an emphasis to rely more heavily on these vertical wells to degasify the coal prior to mining. It is anticipated that as future mining occurs, fewer horizontal wells will be required and therefore the production decline should continue.

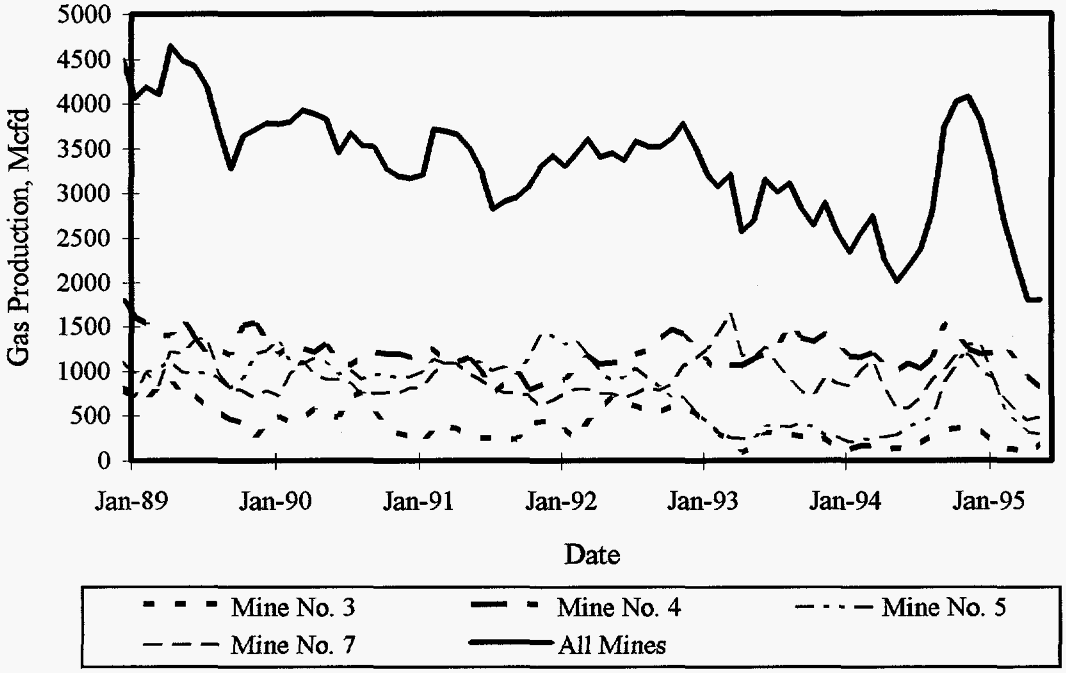

Figure 21 - JWR Area Horizontal Well Production History (1989 - 1995)

Figures 22 and 23 display the horizontal well production from the JWR No. 4 and No. 5 mines, the location of the current project. As can be seen, there is also a general decline in production from horizontal wells due to fewer number of wells being required for methane control and a slowing of mining operations. Of interest is the large increase in production during the latter half of 1994. The rapid increase was due to the installation of numerous wells into a virgin panel followed shortly thereafter by the mining-through (and termination of production) of these wells. This rapid change in production rate from horizontal wells is common and can be expected not only at the JWR mines but at other mines that employ horizontal well degasification.

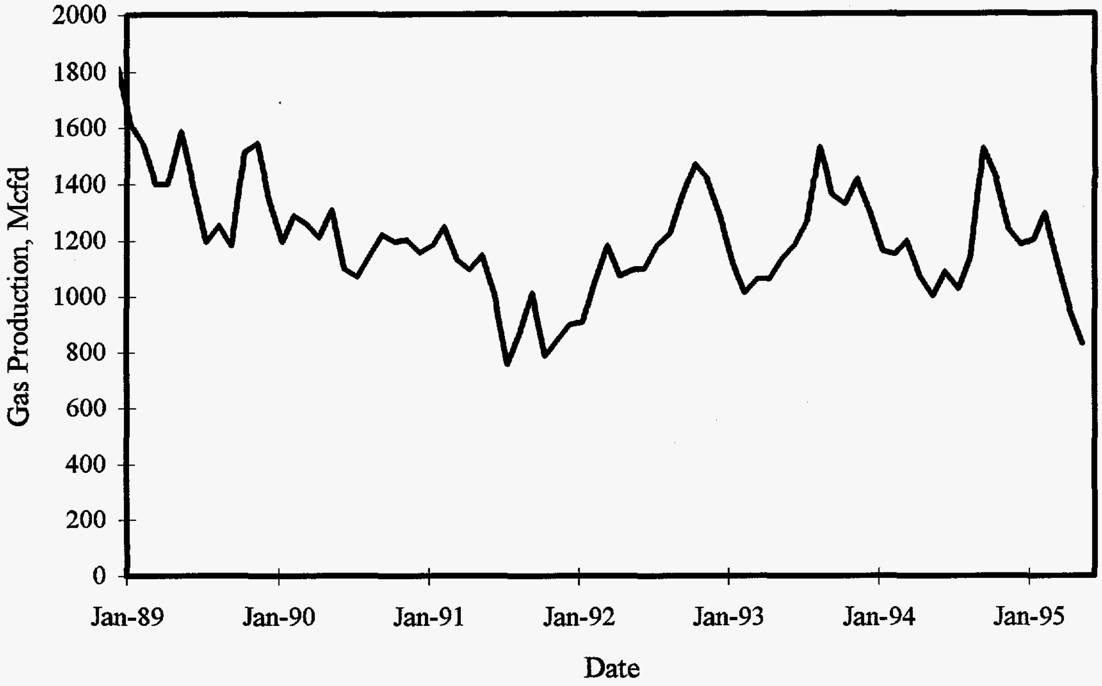

Figure 22 - JWR No. 4 Mine Horizontal Well Production History (1989 - 1995)

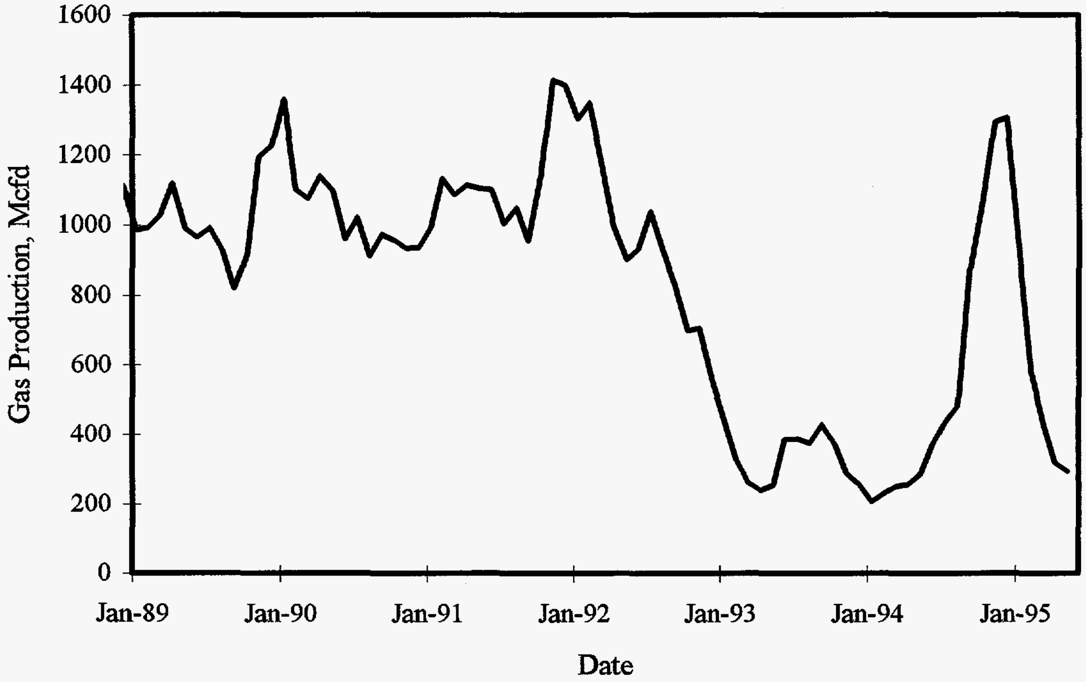

Figure 23 - JWR No. 5 Mine Horizontal Well Production History (1989 - 1995)

Gob Wells

The mine's ventilation system is the primary means of methane control at all of the JWR mines. In addition, gob wells provide an important supplement to the control of methane in the longwall gob areas. Gob wells are drilled from the surface into the area above a planned longwall panel, Figure 24. Following the mining of the coal by the longwall mining operation, the immediate roof fails and collapses into the void behind the mining operation. This collapse creates a lower zone of rock and coal rubble, an intermediate zone of fractured rock and coal, and an upper zone of coal and rock strata with extensive fracturing and bedding plane separation. This zone of disturbed strata (referred to as the gob) has a very high surface area, high permeability, and low reservoir pressure. Because of this, the methane that is contained in the affected coal seams (including some seams below the mined seam which are affected due to stress relief fracturing) flows into the created voids. Without the presence of gob wells, this released methane may enter the active mine workings. However, the gob wells act as low pressure points within the gob such that the methane flows toward and into these wells, thus reducing the flow of the methane into the mine workings.

BWMC and JWR have not only been a leader in the mining industry in the use of gob wells for supplemental methane control during longwall mining, but they have also been at the forefront of the production of pipeline-quality gas from these gob wells. It has been found that insufficient suction (vacuum) of the gob wells does not remove enough methane from the gob area and causes some of the gob methane to flow into the mine workings. If excess suction is placed on the well, the produced gas is a mixture of the methane from the coal seams and the air that is in the underground mine environment. The optimum condition is whereby sufficient suction is placed on the well to prevent the flow of the methane into the mine workings but is not sufficient to draw the mine air into the upper gob area. BWMC and the JWR mines utilize an interactive underground/surface operating system to maximize the methane concentration in the produced gob well gas while preventing methane influx into the mine workings. Figures 25 and 26 illustrate the surface facilities required for the efficient operation of both high and medium production rate gob wells at the JWR Mines.

Figure 27 details the daily production from gob wells in the four JWR mines during the period 1988 through 1995. As shown, total gob well production, while variable, has typically ranged from 20 million to 35 million cubic feet per day during this period. In comparison to the previously displayed production from horizontal and vertical wells, the gob well production is clearly the dominant form of methane capture at the JWR mines. Methane production from the gob wells currently contributes about 68 percent of the total methane produced and captured, while vertical wells contribute about 28 percent followed by horizontal wells at 4 percent.

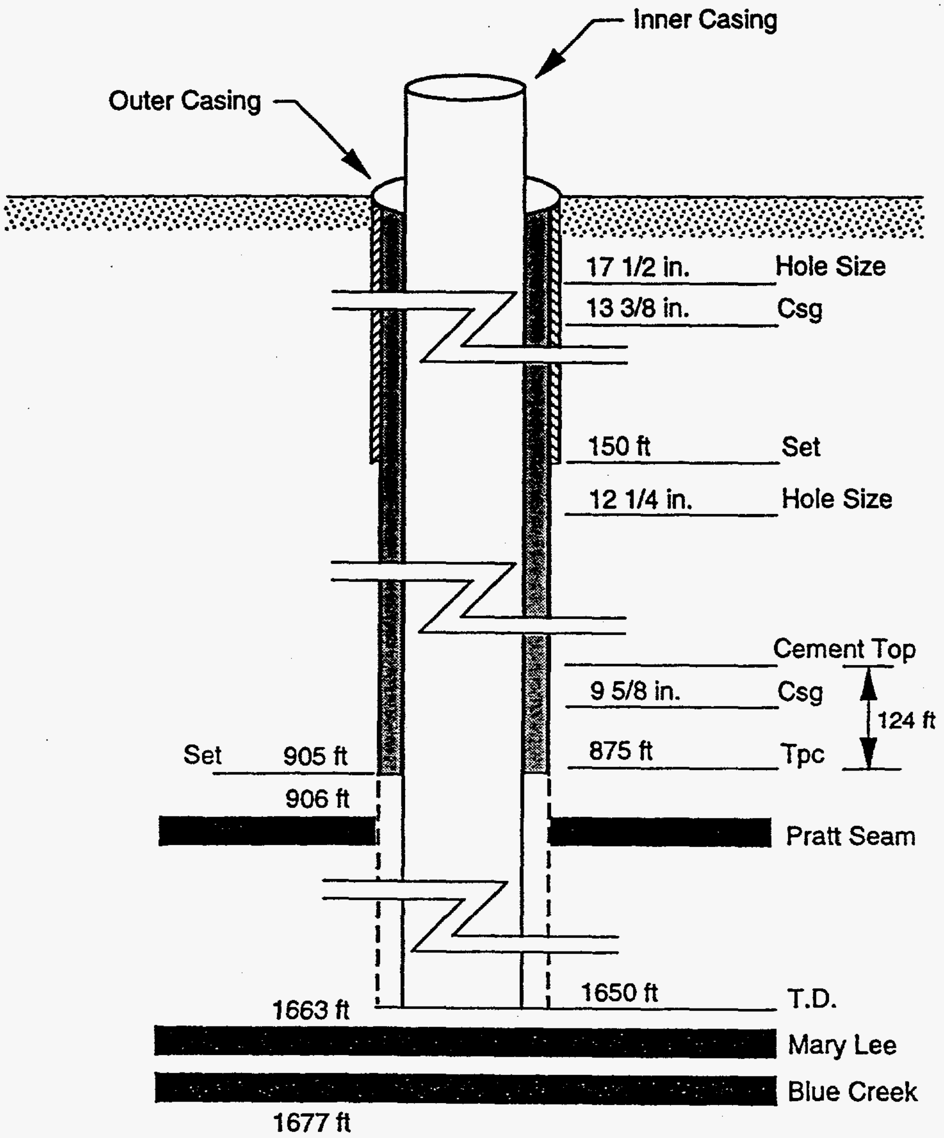

Figure 24 - Schematic Diagram of a Typical Gob Well in the Warrior Basin

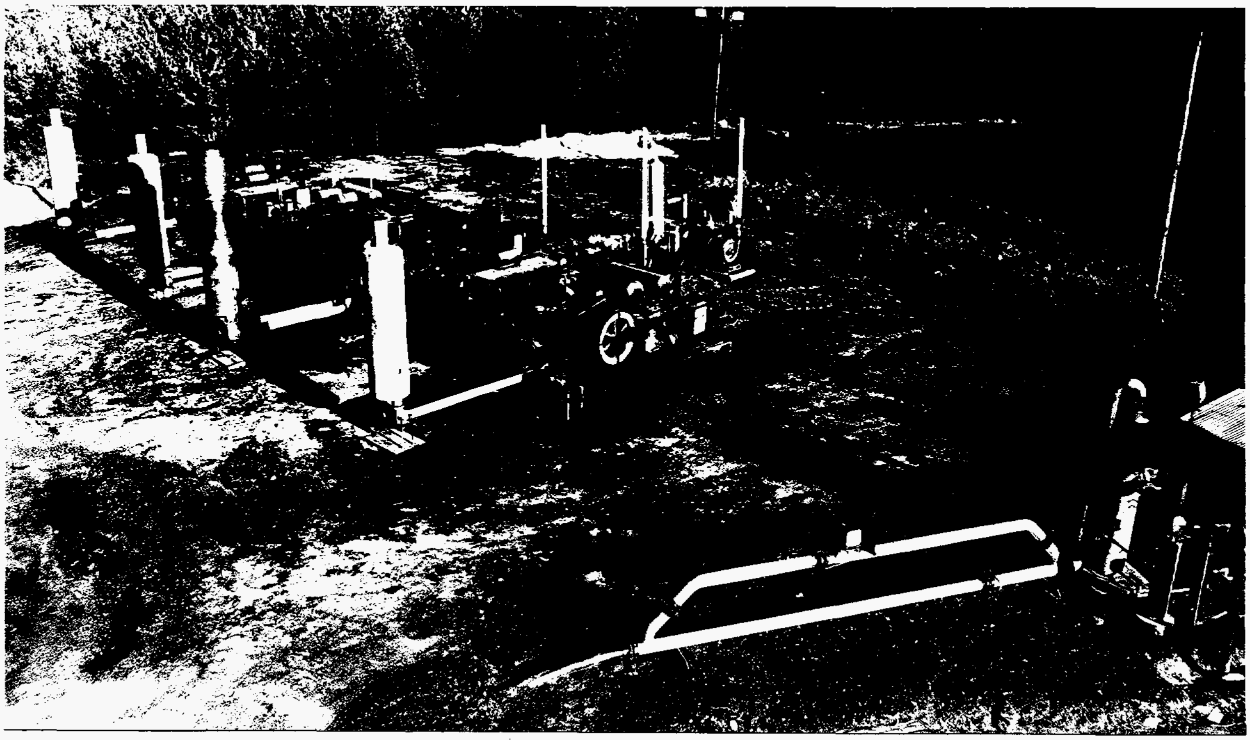

Figure 25 - Surface Facilities for a High Production Rate (2.6 MMcf/day) Gob Well

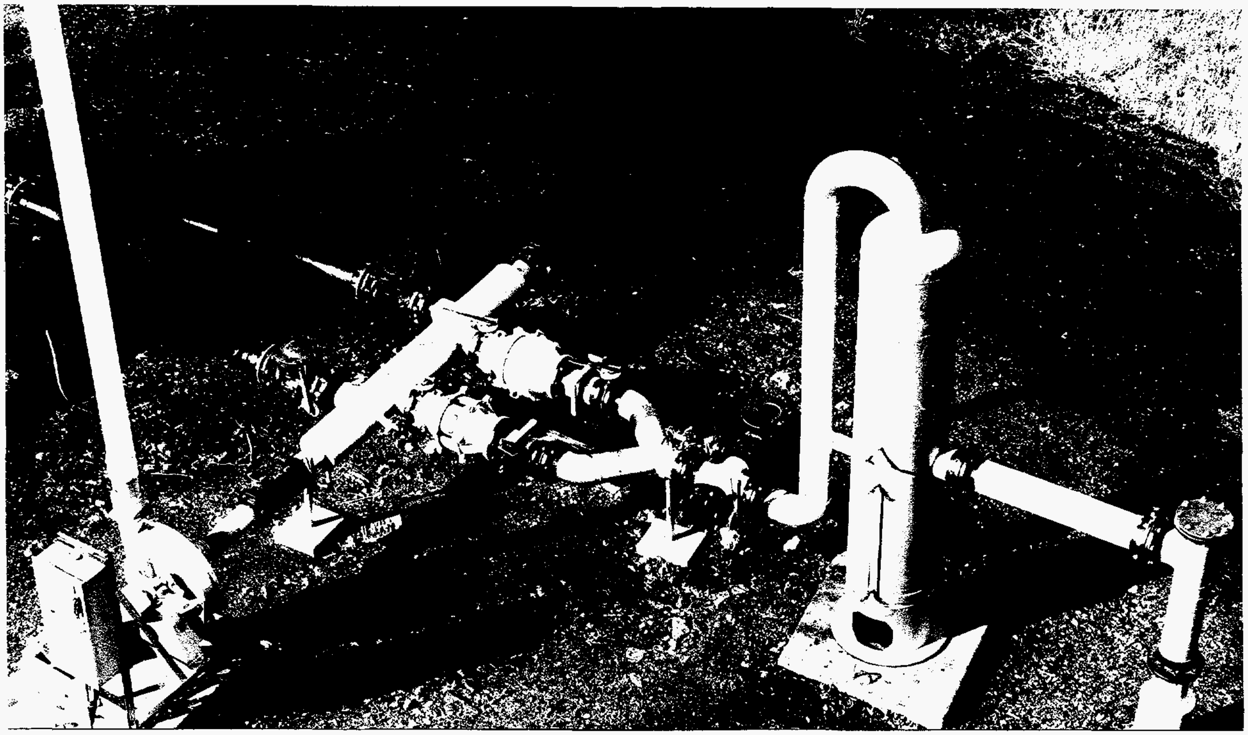

Figure 26 - Surface Facilities for a Medium Production Rate (1.2 MMcf/day) Gob Well

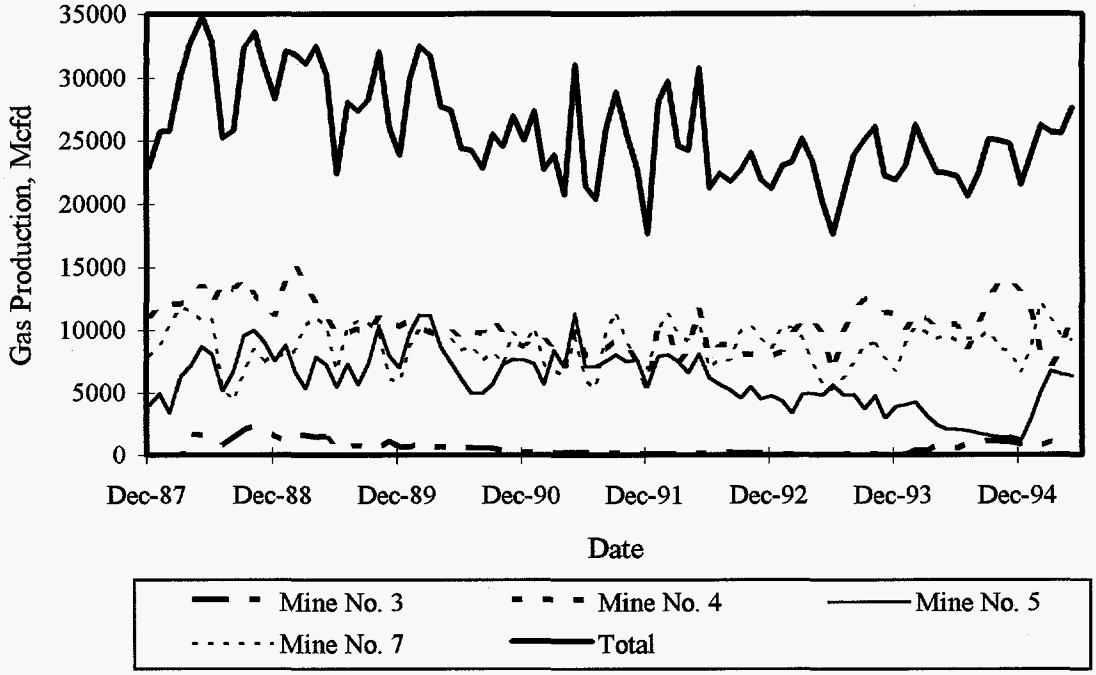

Figure 27 - JWR Area Gob Well Production History (1988 - 1995)

Specific gob well production from the JWR No. 4 and No. 5 mines are shown in Figures 28 and 29. Gob well production for the No. 4 mine has varied during the seven year production period shown from a high of over 15 million cubic feet per day to a low of less than 6 million cubic feet per day.

The gob well production trend at the JWR No. 5 mine is similar to that seen in the horizontal wells in which there was a general decline in production during the period 1991 to 1994 followed by a rapid increase in production to the previous level of about 6 million cubic feet per day. As discussed earlier, the decline was due to a combination of factors, including mining rate and operations. The increase in production observed during 1995 is due the resumption of normal mining operations and the development of new longwall panels (and the concomitant development of new gob wells).

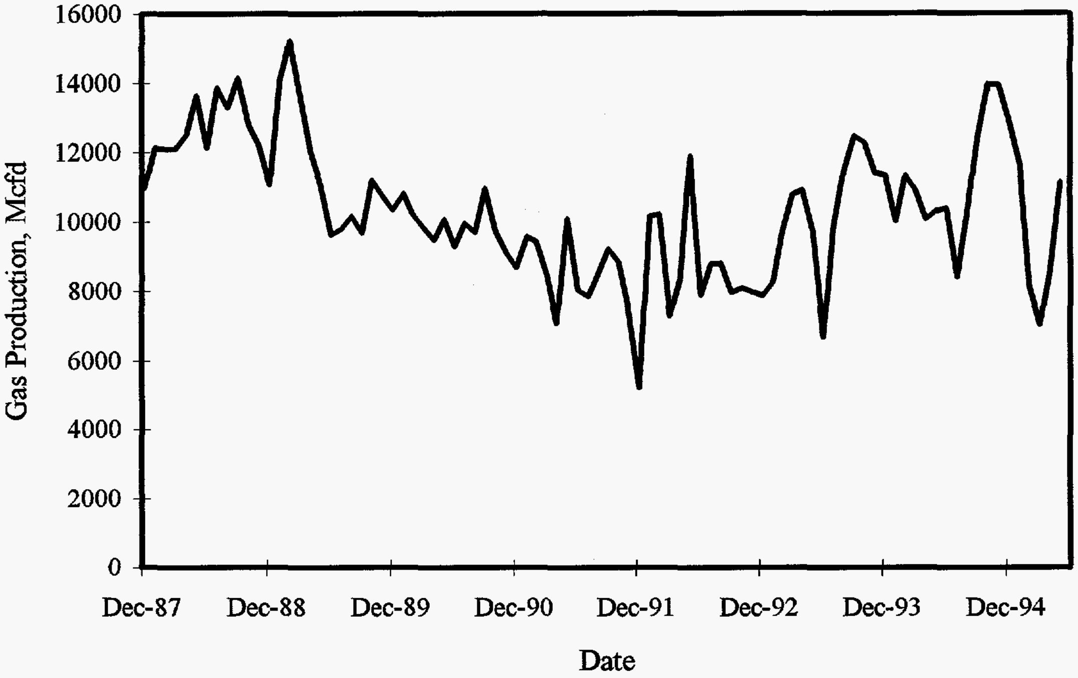

Figure 28 - JWR No. 4 Mine Gob Well Production History (1988 - 1995)

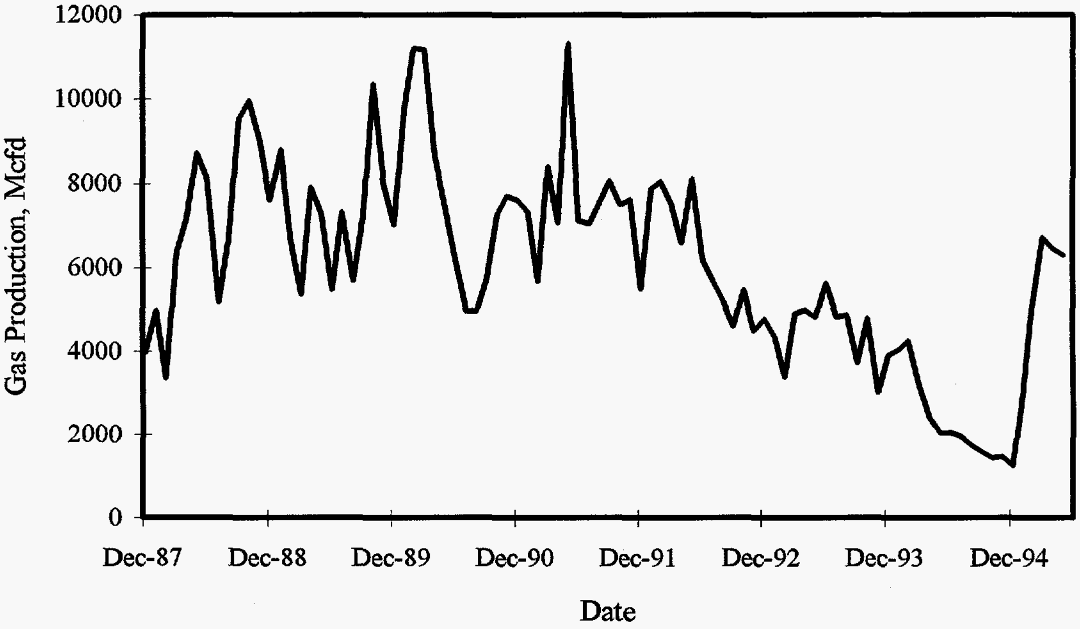

Figure 29 - JWR No. 5 Mine Gob Well Production History (1988 - 1995)

Coal Seam Geologic and Reservoir Conditions at the JWR No. 4 and No. 5 Mine

As discussed previously, the coal seams present within the JWR No. 4 and No. 5 mine areas are Pennsylvanian-age and bituminous in rank. The coal type is typical of that found within the Warrior and Appalachian basins and generally consists of clairain and vitrain with a total vitrinite content of 70 to 75 percent. Ash content is low, typically 5 to 10 percent and is generally described as disseminated to fine laminar mineral matter. Coal rank varies within the JWR mine area, ranging from low volatile bituminous (R_o 1.55) at the JWR No. 3 mine to high-volatile bituminous A (R_o 1.17) at the JWR No. 4 mine.

Within the area of the JWR No. 4 and No. 5 mines, numerous coal seams occur above and below the mined Mary Lee/Blue Creek coal seam. A representative geologic stratigraphic section highlighting the primary coal seams within each mine area are shown in Tables 1 and 2. Coal seams from seven coal groups are present within these stratigraphic sections with a cumulative coal thickness ranging from 24.57 to 35.25 feet. As can be seen, the Mary Lee/Blue Creek coal seams represent 30 to 40 percent of the total coal thickness within the this interval. However, significant coal thickness (and potential gas reservoir) exists above and below this mined interval.

COAL GROUP	COAL SEAM	DEPTH, FT (TOP)	THICKNESS, FT
Utley	Clements	323.50	0.15
	Clements	350.00	1.50
	Subtotal	-	**1.65**
Gwin	Gwin	666.50	0.75
	Subtotal	-	**0.75**
Cobb	Upper Cobb	892.00	0.35
	Upper Cobb	893.00	0.50
	Subtotal	-	**0.85**
Pratt	Pratt	1243.00	1.00
	Pratt	1254.65	0.35
	Pratt	1263.00	0.40
	Pratt	1263.65	0.35
	Pratt	1265.00	1.00
	Nickel Plate	1299.50	0.75
	America	1325.00	1.40
	America	1355.00	0.15
	Subtotal	-	**5.40**
Curry/Gillespie	Curry	1478.50	0.25
	Gillespie	1543.00	0.25
	Subtotal	-	**1.60**
Mary Lee	Marker	1860.00	0.75
	Upper New Castle	1867.50	1.35
	Lower New Castle	1878.00	0.85
	Mary Lee	1916.85	1.61
	Blue Creek	1919.65	4.60
	Subtotal	-	**9.16**
Black Creek	Lick Creek	2126.00	1.15
	Lick Creek	2137.00	0.25
	Jefferson	2235.00	0.15
	Jefferson	2237.00	0.20
	Murphy	2286.50	0.35
	Black Creek	2350.60	3.06
	Subtotal	-	**5.16**
	TOTAL	-	**24.57**

Table 1 - Representative Coal Seam Stratigraphy for the JWR No. 4 Mine - Well S-0545-S

COAL GROUP	COAL SEAM	DEPTH, FT (TOP)	THICKNESS, FT
Utley	Clements	301.00	1.00
	Clements	323.00	1.15
	Clements	432.50	0.25
	Subtotal	-	**2.40**
Gwin	Gwin	726.00	2.30
	Gwin	730.00	0.35
	Thompson Mill	786.50	0.50
	Subtotal	-	**3.15**
Cobb	Upper Cobb	975.00	0.35
	Upper Cobb	978.50	0.35
	Cobb Split	1018.15	0.35
	Cobb Split	1038.00	0.30
	Subtotal	-	**1.35**
Pratt	Pratt	1388.00	1.15
	Pratt	1396.00	0.90
	Pratt	1398.00	0.40
	Pratt	1403.50	1.50
	Nickel Plate	1434.65	0.35
	Nickel Plate	1440.00	1.00
	Nickel Plate	1460.00	1.20
	America	1513.00	1.75
	Subtotal	-	**8.25**
Curry/Gillespie	Curry	1620.00	0.55
	Gillespie	1698.50	0.60
	Gillespie	1707.00	0.45
	Subtotal	-	**1.60**
Mary Lee	Upper New Castle	2072.50	1.50
	Mary Lee	2108.00	2.00
	Blue Creek	2113.75	8.40
	Jagger	2154.50	1.50
	Subtotal	-	**13.40**
Black Creek	Jefferson	2339.00	1.00
	Jefferson	2343.00	0.75
	Jefferson	2367.50	0.50
	Jefferson	2377.00	0.60
	Murphy	2541.75	0.50
	Black Creek	2557.50	1.75
	Subtotal	-	**5.10**
	TOTAL	-	**35.25**

Table 2 - Representative Coal Seam Stratigraphy for the JWR No. 5 Mine - Well S-0518-S

Of particular importance to this project and to the mining operations at the JWR mines is the methane content of the coal. Numerous gas content measurements have been performed on coal core recovered during exploratory drilling. Gas content measurements were made utilizing the U.S. Bureau of Mines Direct Method (Diamond, 1981). Based on the collected gas desorption results, average gas contents were determined for each of the seven coal groups present within the JWR Mine No. 4 and No. 5 areas and are presented below in Table 3.

COAL GROUP	GAS CONTENT, cubic feet per ton
Utley	150
Gwin	300
Cobb	350
Pratt	400
Gillespie/Curry	400
Mary Lee	500
Black Creek	550

Table 3 - Average Coal Seam Gas Content for Seven Coal Groups in the JWR No. 4 and No. 5 Mine Area

Limited measurements of other coal seam reservoir properties exist for the coal seams within the JWR mine area. From tests performed in areas adjacent to this area, it can be extrapolated that the virgin reservoir pressure is near hydrostatic (0.39 to 0.41 psi/ft) and the permeability is in the range of 5 to 20 millidarcy (Schraufnagel, 1991).

Methane Resources for the JWR No. 4 and No. 5 Mine

Using the collected geologic and coal seam reservoir data, preliminary estimates of the gas resource contained in the coal seams within the JWR No. 4 and No. 5 mine area were made. However, it is appropriate to further discuss the reality of estimating coalbed methane resources within an area where active mining is occurring before presenting the summary results.

Gas resource (natural gas, coalbed methane, shale gas, etc.) estimates are an integral part of the conventional natural gas industry. These estimates provide an initial indication of the quantity of gas resource that is present within the rock formations and provide an important input into estimating potential recovery of that gas. The estimation of gas resource is generally a function of void space (porosity) within the rock units, the pressure of the gas within the void space, and specific gas properties of the captured gas. This method is modified slightly for the unique characteristics of gas storage in coal (sorption), but nonetheless it is an attempt to measure the volume of gas that is contained within a certain volume of reservoir rock.

For gas reservoirs (including coal seams) the determination of the quantity of gas that is stored is therefore a straightforward process. However, this assumes that the reservoir has been unaffected by any man-made operation. If the reservoir is disturbed (or example, if part of the reservoir has been produced via producing gas wells) then the determination of gas resource in-place becomes much more difficult. This problem escalates rapidly for coal seams that have been affected by underground mining operations.

In the case of coalbed methane resources present within a mining area, generally three resource types need to be considered. The first type, and often the easiest to determine, is the quantity of gas resource that is present within the coal that is outside of the current influence of the mining activity. This resource could be considered similar to a gas resource in a virgin state because the reservoir properties (primarily reservoir pressure) have not been impacted by the mining operation. Accordingly, the gas resource is estimated using the standard volume relationships described above (i.e. gas content [in cubic feet per ton of coal) x unmined coal resource [tons] = gas resource [cubic feet]).

The second type of gas resource is that which is contained within the unmined coal that is present within the active mining areas. This resource is primarily contained within the unmined pillars in the mining area and in the coal seams above and below the mined seam. While the method of determining the gas resource is the same as that for the unmined virgin coal reservoir areas, the major problem is determining the gas content of the coal in these disturbed areas. It can easily be seen that the gas content of the coal should be lower than that originally in-place. However, there has been little work performed to date to quantify this volume. Importantly, the percentage of gas that remains in this type of coal reservoir will be very dependent upon not only the reservoir properties of the coal (especially permeability, reservoir pressure, and initial gas content) but also will be dependent upon the impact of the mining operation on these properties. Therefore, estimating the gas resource that is in-place within the active mining area is difficult and open to a large degree of uncertainty.

The final type of gas resource that is present is the free gas (and to a lesser degree the sorbed gas) that exists within the gob areas above and below extracted longwall panels. This third type of resource is the most difficult to estimated due to the uncertainty associated with 1) the pore volume within the gob area; 2) the amount of gas that has been lost from the gob area into the mines ventilation system; and 3) the source and quantity of gas that has migrated (or is migrating) into the gob's pore space. Some attempts have been made to estimate the maximum volume of the gas that could originally be contained within a gob, but this has basically been a determination of the amount of gas-in-place in the virgin, unmined coal. Clearly the current amount of gas that is in-place is somewhat less than this and with time this quantity should continue to decrease.

Therefore, to determine the gas resource that is present within the JWR No. 4 and No. 5 mine areas, it was decided to only evaluate the gas resource within the unmined coal areas. The authors recognize that there is a significant quantity of gas present within the other two resource categories, but that limited data precludes any reasonable estimate of this gas volume. However, it should be noted that while estimates of resource volume within these two categories were not determined, the potential reserves (i.e. future recoverable resource) of these can be estimated. These volumes (including the methodology for determination) are presented later in this report.

Using the average gas contents, typical thickness for the coal seams present, and a coal density of 1,800 tons per acre-foot, estimates of gas resource in-place within the JWR No. 4 and No. 5 mine areas were made. Presented in Tables 4 and 5 below are the average gas resource estimates (per square mile of reservoir) by coal group.

COAL GROUP	THICKNESS, ft	GAS CONTENT, cu ft/ton	GAS RESOURCE, billion cu ft/sq mi
Utley	1.65	150	0.285
Gwin	0.75	300	0.259
Cobb	0.85	350	0.343
Pratt	5.40	400	2.488
Gillespie/Curry	1.60	400	0.737
Mary Lee	9.16	500	5.276
Black Creek	5.16	550	3.269
TOTAL	**24.57**	-	**12.657**

Table 4 - Coalbed Methane Resource For the Unmined Areas of the JWR No. 4 Mine

COAL GROUP	THICKNESS, ft	GAS CONTENT, cu ft/ton	GAS RESOURCE, billion cu ft/sq mi
Utley	2.40	150	0.415
Gwin	3.15	300	1.089
Cobb	1.35	350	0.544
Pratt	8.25	400	3.802
Gillespie/Curry	1.60	400	0.737
Mary Lee	13.40	500	7.718
Black Creek	5.10	550	3.231
TOTAL	**35.25**	-	**17.536**

Table 5 - Coalbed Methane Resource For the Unmined Areas of the JWR No. 5 Mine

TASK 2 - EVALUATION OF THE COAL MINE METHANE RESERVES

Potential Methane Reserve Area and Logistics

Potential Reserve Area

The potential coalbed methane reserve area established for this project consists of the area of past, present, and future mining at the JWR No. 4 and No. 5 mine. As seen in Figures 10, 11, and 12, the potential reserve area covers approximately 24 square miles (15,500 acres). This area has been established by JWR as the project site and reserve area, such that all data presented later in this section applies to this total area. Within this 24 square mile area, different types of reserve areas have been developed that correspond to the different methane capture methods (ventilation, vertical wells, horizontal wells, and gob wells).

Area Logistics

As discussed previously, the JWR No. 4 and No. 5 mines are part of a four-mine underground complex within eastern Tuscaloosa county and western Jefferson county operated by Jim Walter Resources, Inc. Because of the extensive underground mining operations in this area, access to the proposed sites for the demonstration project is relatively easily. The mine site is easily accessible via state highway Route 216 and is 12 miles from the Brookwood/Vance interchange on U.S. Interstate Highway I-59/20. In addition to the well-developed state and county road system in the area, the mining operations maintain extensive all-weather roads for access to ventilation shafts, mine degasification gob and vertical wells, and other facilities throughout the surface area of the mine. This existing access should provide the project with ease of movement of equipment and personnel throughout the mine area. In addition to all-weather roads accessing the gob wells and surface facilities, extensive power right-of-ways (including installed transmission service for gob well operation) also exist within the mine area.

Regulatory Considerations in the Methane Reserve Area

The principal regulatory issues which will arise in any project for gob gas production will be those regulations which affect the capture and sale of natural gas. Some states may have regulations which specifically deal with the production of coalbed methane (for example, State Oil and Gas Board of Alabama Administrative Code). In states where there has been no history of coalbed methane production, the rules which will apply may have no special relevance to coalbed methane production. In such a circumstance, the approval of special field rules by the appropriate regulatory body may be a prerequisite to development.

Another regulatory issue which may arise could involve Mine Safety and Health Administration (MSHA) regulations concerning ventilation. As a matter of practice, flame arrestors are installed at all gob wells which are producing at the JWR mines. The reason for this installation is to prevent any gas ignition at the surface from propagating down the well into the mine works. The "Capital Costs" used in the economic evaluations of this report (discussed later) include the cost of these flame arrestors. It may be required or simply considered desirable to install flame arrestors on gob wells developed in other mining areas.

Gas Ownership in the Methane Reserve Area

From the onset of development of coalbed methane, there have been conflicting claims of ownership to the resource (Norvell, 1990). Owners of the mineral interest in coal claim that coalbed methane is included in the ownership of the coal or the right to extract the coal because it was produced from or is contained within the coal. The basis of the claim by owners of the mineral interest in oil and natural gas generally is that coalbed methane is physically and chemically indistinguishable from natural gas. Methane is, in fact, the principal constituent of natural gas, often constituting more than 90 percent of its gaseous fractions. The Federal government takes that latter position - essentially that "gas is gas" - with regard to the extraction of minerals owned by the United States (U.S. Solicitor General, 1981). Finally, in cases where the coal interest and the interest in oil and gas have been severed or separately conveyed, there are occasional claims by the owners of the reserved or residual mineral interest that coalbed methane is not part of either the coal or oil and gas estates.

There have been numerous court cases involving conflicting ownership claims to coalbed methane. Most of these cases have been in Alabama or the Appalachian region (Norvell, 1990). There has also been legislation passed by a few states in attempt to resolve the ownership issues sufficiently to encourage development (Virginia Oil & Gas Act, 1989). A full discussions of these cases and statutes is beyond the scope of this report. However, any person considering the utilization of coalbed methane as outlined in this report must realize that the legal question of ownership of coalbed methane is a threshold issue which must be addressed early in the evaluation of a potential project. The issue may be capable of resolution through legal or administrative means or through the design and operation of the project. If ownership can be resolved, there may arise questions of whether a royalty or other payment due upon severance of a mineral is owed and how such payments may be computed. This is discussed in more detail below.

The origin of the conflicting claims of ownership is the fact that mineral interests have in the past been conveyed without discussion of the ownership of or right to exploit coalbed methane. Generally speaking, this was due to the fact that the economic production of coalbed methane was a relatively recent phenomenon. Therefore the methane contained in the coal or surrounding strata was viewed as, at best, a non-commercial mineral and, at worst, a serious hazard to underground mining. The lack of any indication that coalbed methane was or could become a commercial resource meant that most conveyances or leases of oil and gas or coal were silent or ambiguous with regard to the transfer of or right to develop coalbed methane. When commercial production of coalbed methane was finally attempted and achieved, this potential for conflict led to legal actions being taken in several states. Not only did these actions impede development of the projects involved, but widespread knowledge of the suits served to stifle development in areas where potential conflicts in ownership were readily apparent and not easily resolvable

The potential for conflict should be expected in any situation where the conveyance of the mineral interest in coal does not discuss the beneficial use or commercial sale of coalbed methane by the coal miner. This expectation should be greater in coal basins where oil or conventional natural gas has also been produced. This will be due to the fact that in basins with production of liquid or gaseous hydrocarbons there will be a heightened awareness in the legal community and the general public of the possibilities of revenue from the production of gas.

For any person acquiring mineral interests for the purpose of opening or expanding an underground coal mine, it is imperative that the grant of the new mineral interest conveys the right to the commercial sale or beneficial use of coalbed methane. In the case of the commercial sale of the gas or its conversion to some other marketable product, such as electric power, the computation and allocation of royalties should be addressed through lease clauses which take into account the peculiar problems which occur when gas is produced in conjunction with coal mining. Where the gas is used exclusively on the mine premises with no commercial sale, it may not be unreasonable to expect the mineral owner to convey this right without a royalty requirement. This would be much in the same fashion as the grant to the miner of the right to use for the purpose of facilitating mining and without fee or royalty minerals or resources, such as water or sand and gravel, which may be found on the leasehold. However, if the grantor of the coal does not own the rights to coalbed methane, any use of the coalbed methane by the miner will likely carry with it a royalty obligation.

In the acquisition of the mineral interests or prior to production of methane, serious thought must be given to mechanisms for pooling or unitizing the royalty interests. Otherwise the computation of royalties may become cumbersome or lead to conflicts. This possibility would be most pronounced in the case of utilization of gob gas or gas taken from ventilation outlets. For example, a longwall panel 900 feet wide by 6,000 feet long covers an area of approximately 124 acres. Analysis may indicate that all or most of the gas which might be produced from the panel's gob comes from strata immediately above or below the gob. However, if the miner attempts to limit the allocation of royalty to those mineral owners of the 124 acres overlying the panel, as might be done in the case of coal production, it may provide an open invitation to adjoining mineral owners to assert their claims. Unitizing all or a portion of the mine and pooling production from all gob wells within the unitized area provides the simplest method for dealing with conflicts in advance. Pooling and unitization also have the advantage of being methods which are familiar to the regulatory agencies and courts in states with oil and gas production. BWMC, the company which operates the degasification system for the JWR mines, relies upon the laws and regulations of the State of Alabama and the Alabama Oil and Gas Board regarding the pooling and unitization of mineral interests affected by mine degasification.

The laws and regulations in Alabama regarding pooling and unitization follow generally a model based on oil and gas experience. This model may not be the best guidance with regard to production of either gob gas or utilization of ventilation gas. The Virginia statute may provide a better example of the direction regulation should take for mine gas development and utilization. The Virginia law requires that drilling units follow the mine plan, if there is one, and that well spacing conform to mine operations. This approach makes much more sense than to unitize on the conventional oil and gas model. Oil and gas units generally conform to governmental units, i.e., 40 acre, 80 acre, 160 acre, etc., sized drilling units. It would be the most unlikely happenstance if a mine plan conformed to such units. An example of this is shown in Figure 30, which is taken from a portion of the mine plan for one of the JWR mines. The longwall panels follow fault lines rather than property lines and even when the panels are oriented generally in a north/south direction, the panels cross section lines. Gob wells are located in relation to layout of the panels and the gas production characteristics of the panels. Clearly utilization of governmental units as a basis for unitization in this example would be most cumbersome and could lead to royalty/ownership conflicts.

Potential Future Methane Production at the JWR No. 4 and No. 5 Mines

An important aspect of the proposed project is the confirmation that sufficient feedstock exists for the demonstration of the reduction of methane emissions. While it has been recognized that the coal seams of the Warrior basin contain significant quantities of methane, the potential for recovering this methane is highly variable. Variations in reservoir properties, recovery methods, and duration of production all contribute to this variability.

Within the oil and gas industry, various analytical techniques and methods have been developed for estimating the potential for recovering hydrocarbons from geologic formations (Haynes, 1993). These methods have been modified to account for the unique properties of coal seam gas reservoirs, but nonetheless the basic principles still apply (Mavor, 1991). The analytical solutions provide a means of estimating total recoverable gas and in some cases the rate of recovery. However, the methods of estimating future recovery from coal seams have been primarily applied to the vertical coalbed methane wells not affected by underground mining operations. Little work has been performed in the area of estimating future recovery from other methane capture systems, such as horizontal wells, gob wells, or mine ventilation.

To assess the potential recovery of methane from the JWR No. 4 and No. 5 mine areas, different techniques were applied to each of the four methane capture systems. Results of this assessment are an estimate of the future gas production rate and cumulative gas production for the period 1996 through 2010 (the current planned life of the JWR No. 5 mine).

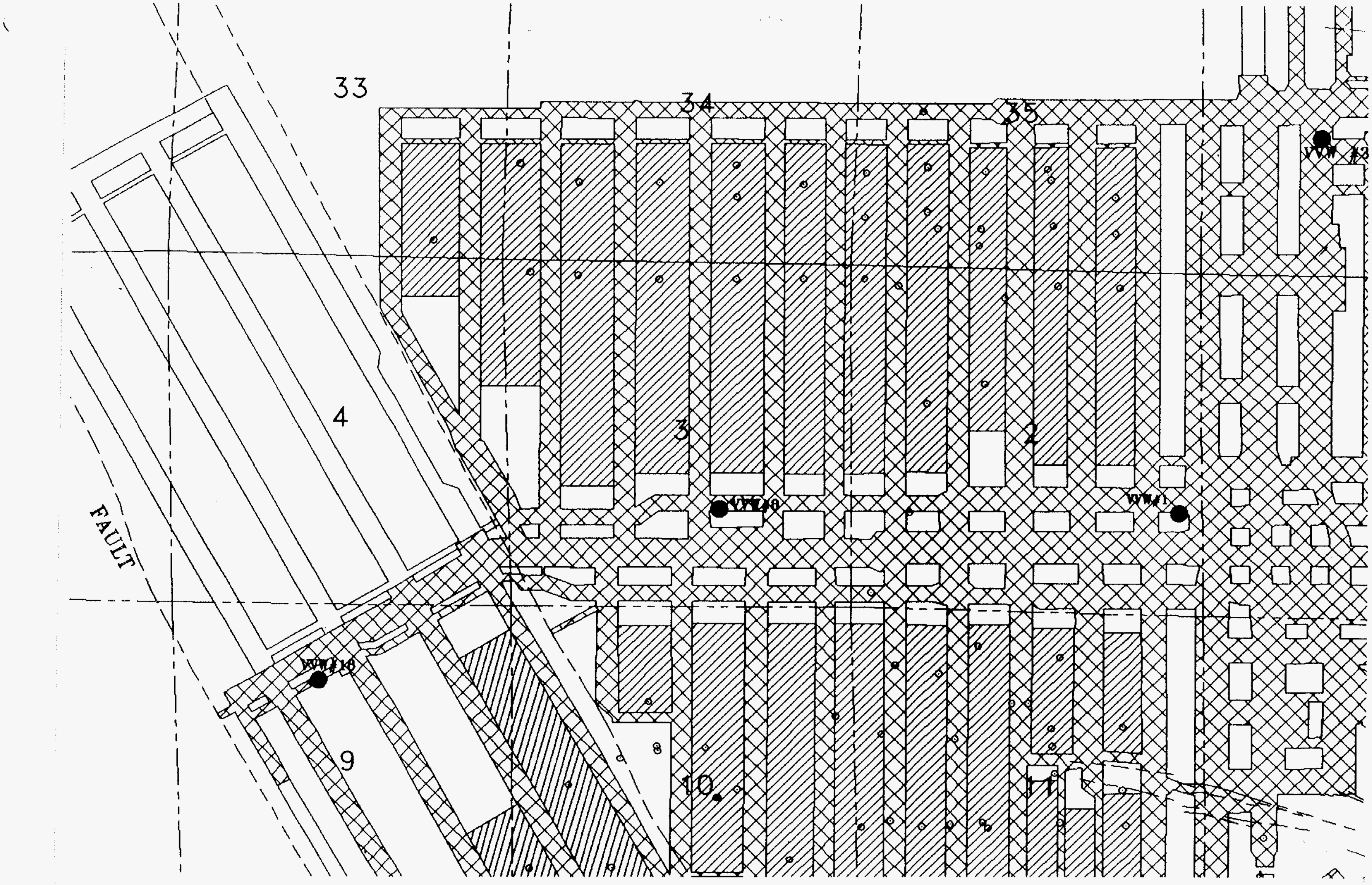

Figure 30 - Comparison of Existing Mine Plans (Longwall Panel Units) and Governmental Section Boundaries

Mine Ventilation System

The potential future production of methane from the JWR No. 4 and No. 5 mine ventilation systems is dependent primarily upon future mining rates and the methane content of the coal that will be mined in the future. Current projections indicate that future mining will proceed at a rate similar to the most recent past. Accordingly, the methane emission rate into the ventilation system should be at a rate similar to that currently encountered. Because of this, it was determined to utilize the current average emission rate as a basis for projecting the future emission rate.

However, current plans also call for an increased use of pre-mining vertical wells within the JWR No. 4 and No. 5 mine areas to recover the methane from the coal. This is expected to lead to a decreased level of gas content in the coal, such that when mining of this coal occurs, reduced methane emissions will be encountered. Projections of future mining areas and vertical well degasification rates indicate that 1) the mine will begin to enter the area of degasification in about five years; and 2) the vertical wells will recover about 50 percent of the methane in-place in about 10 years. Based on this, future projections of methane emissions from the mine were modified to account for the reduced methane content of the coal and the expected reduced methane emission rate.

Figures 31 and 32 display the historic methane emission rates from the JWR No. 4 and No. 5 mines that were used as a basis for estimating the near-term future rate of approximately 8.6 million cubic feet per day (JWR No. 4 mine) and 15.2 million cubic feet per day (JWR No. 5 mine). As shown in the figure, the emission rate begins to decline in about 5 years and continues to decline until the year 2007. Emission rate at this time was estimated to be 50 percent of the original average rate or about 4.3 million cubic feet per day (JWR No. 4 mine) and 7.6 million cubic feet per day (JWR No. 5 mine). The estimated emission rates shown in Figures 32 and 33 result in a cumulative methane emission volume for the 15 year study period of 39.5 billion cubic feet (JWR No. 4 mine) and 63.9 billion cubic feet (JWR No. 5 mine).

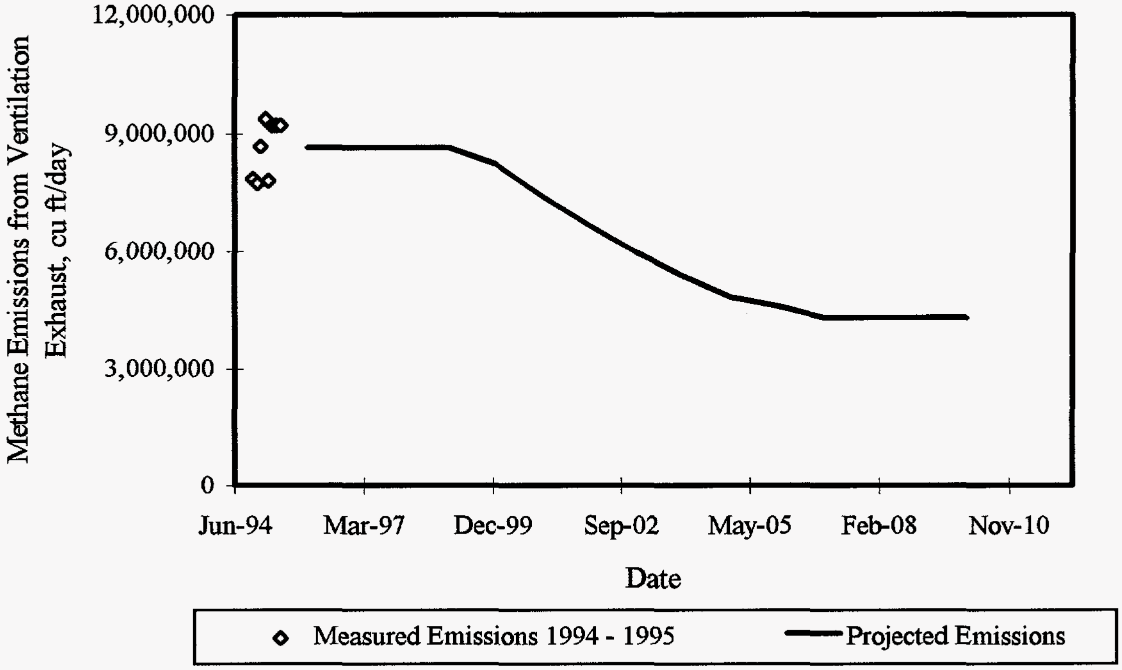

Figure 31 - Projected Future Methane Emissions from Ventilation Exhaust - JWR No. 4 Mine (1996 - 2010)

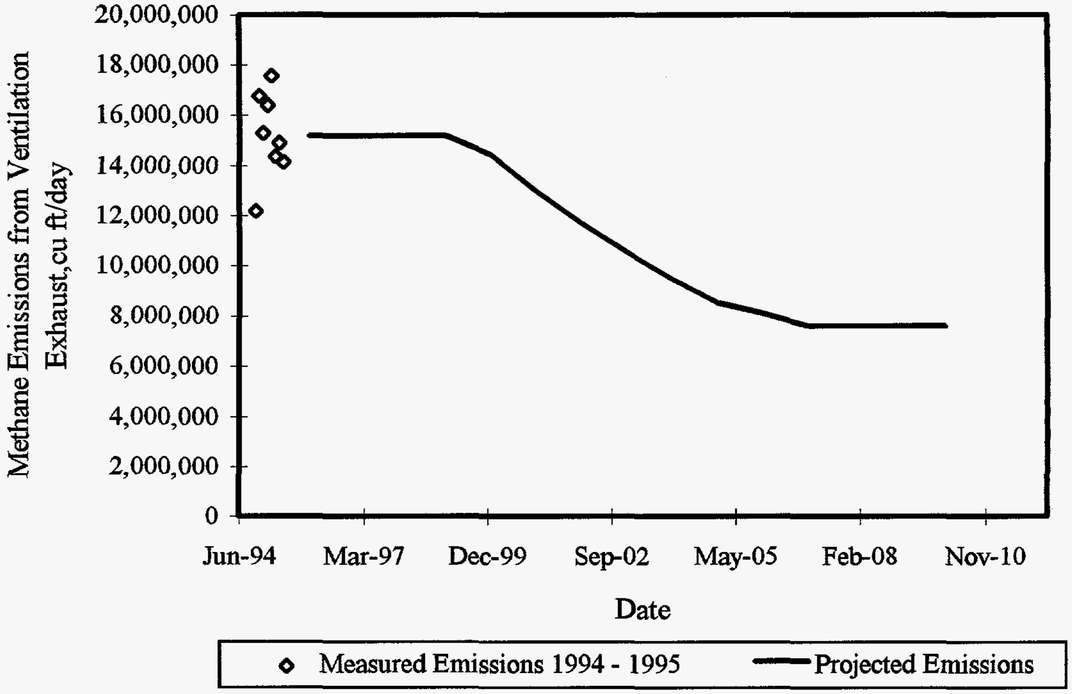

Figure 32 - Projected Future Methane Emissions from Ventilation Exhaust JWR No. 5 Mine (1996 - 2010)

Horizontal Degasification Wells

Future production from horizontal wells in the JWR No. 4 and No. 5 mines was estimated also using past historical performance as a basis for projecting future recovery. As with the mine ventilation methane emissions, the horizontal wells will also be impacted by the effect of the vertical well degasification. In addition, with increased pre-mining degasification from these vertical wells, the need to install horizontal wells in the future will decline. Therefore, it was projected that horizontal well production will begin to decline within the next five years and continue to decline throughout the 15 year study period.

Figures 33 and 34 show the historic methane production rate from the horizontal wells at the JWR No. 4 and No. 5 mines and from this an average initial future production rate of approximately 1.2 million cubic feet per day (JWR No. 4 mine) and 800,000 cubic feet per day (JWR No. 5 mine) was estimated. Because of the effect of vertical well degasification and the reduction in the number of horizontal wells used, the average future production rate was reduced at an average rate of 10 percent per year for the study period, such that by the end of the production projection, horizontal well recovery rate was 300,000 cubic feet per day (JWR No 4 mine) and 200,000 cubic feet per day (JWR No. 5 mine). Cumulative methane recovery for the 15 year period, based on this projection, was estimated at 3.8 billion cubic feet (JWR No. 4 mine) and 2.6 billion cubic feet (JWR No. 5 mine).

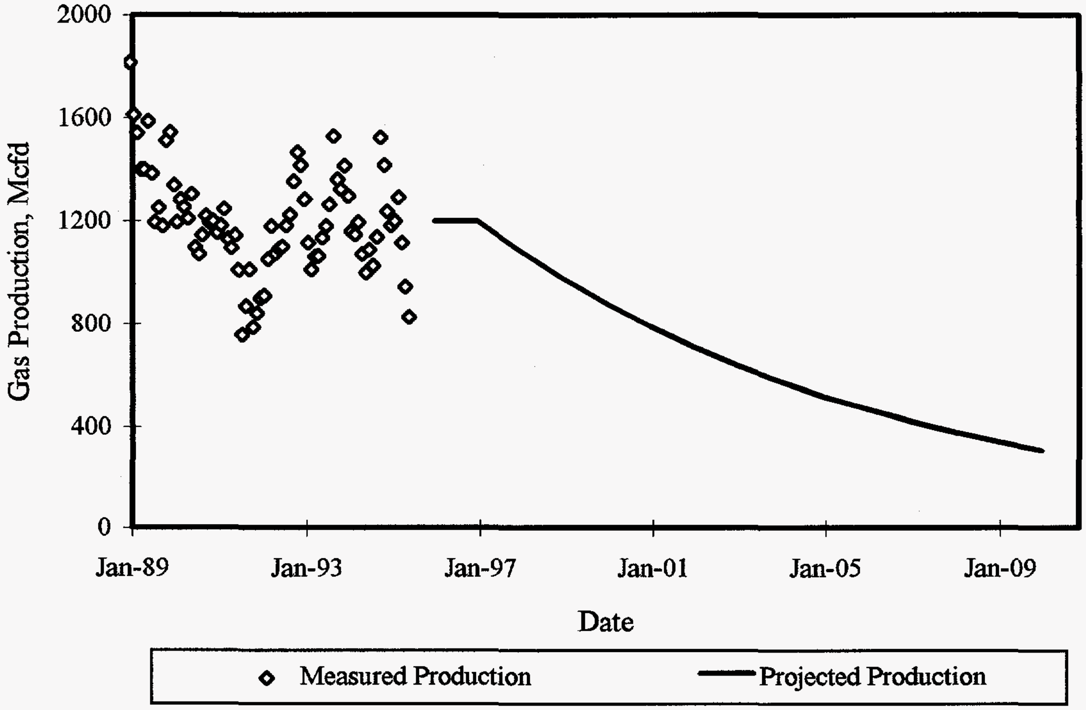

Figure 33 - Projected Future Horizontal Well Production - JWR No. 4 Mine (1996 - 2010)

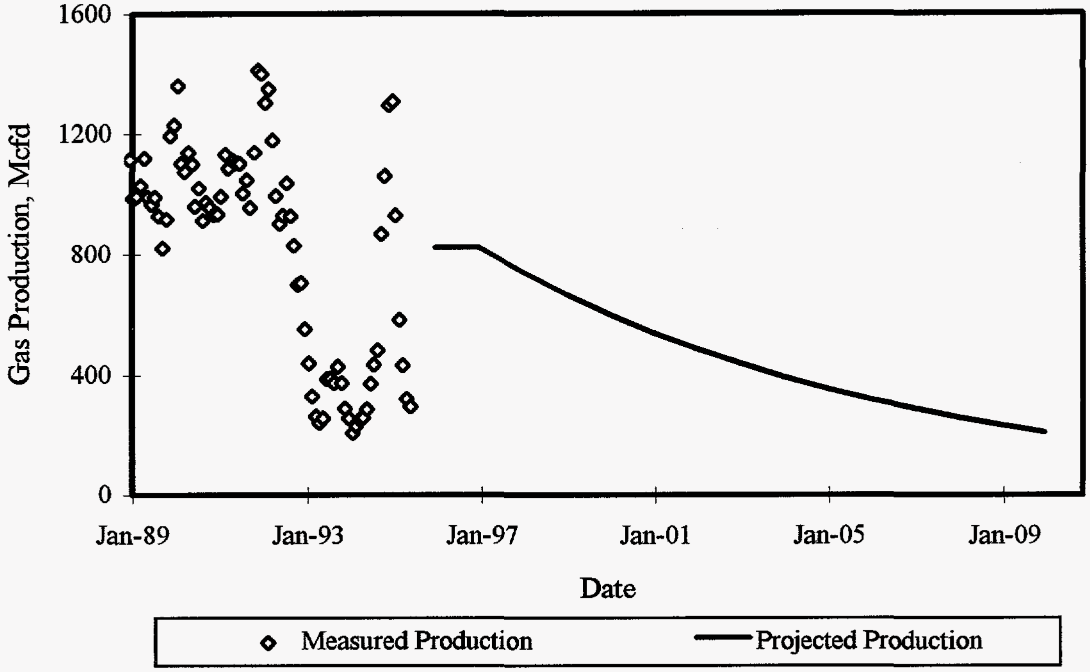

Figure 34 - Projected Future Horizontal Well Production - JWR No. 5 Mine (1996 - 2010)

Gob Wells

Using the methodology employed for the mine ventilation system and horizontal wells, the projection of future production from the planned gob wells was also determined. The planned vertical well degasification will effectively reduce the methane content not only in the mined coal seam (Mary Lee/Blue Creek) but also in the overlying and underlying coal seams. Because of this, it is expected that the future production rate from the planned gob wells will also decrease in the future. As with the mine ventilation system, current plans expect that within the next five years a production rate decline will be observed such that within ten years the production rate from the future gob wells will be 50 percent of the current rate.

As shown in Figures 35 and 36, near-term future production from the gob wells was estimated to be approximately 8.6 million cubic feet per day (JWR No. 4 mine) and 5.1 million cubic feet per day (JWR No. 5 mine). Production rate decline was forecast to begin in 1999 such that by the year 2006 average production rate from the gob wells at the JWR No. 4 and No. 5 mines was estimated at 4.3 and 2.6 million cubic feet per day, respectively. For the 15 year study period, cumulative production from the gob wells was estimated at 37.7 billion cubic feet (JWR No. 4 mine) and 22.2 billion cubic feet (JWR No. 5 mine).

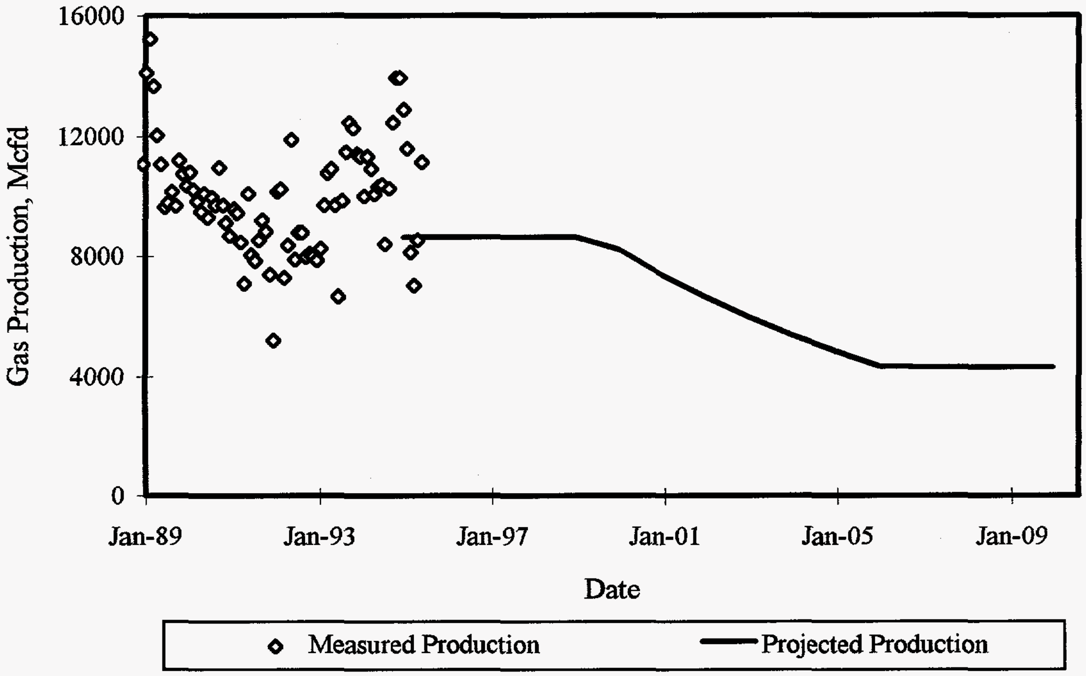

Figure 35 - Projected Future Gob Well Production - JWR No. 4 Mine (1996 - 2010)

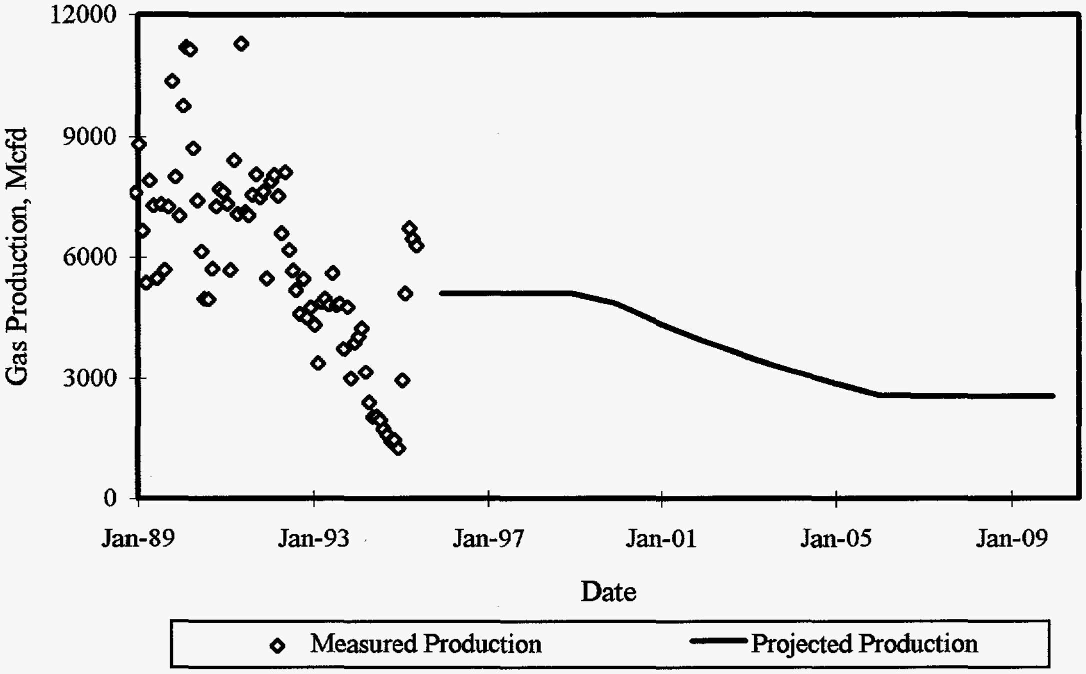

Figure 36 - Projected Future Gob Well Production - JWR No. 5 Mine (1996 - 2010)

Vertical, Fracced Wells

Unlike the future production estimates prepared for the ventilation and horizontal/gob wells, the projection of future production from vertical wells in advance of mining could not rely upon past experience. Recently improved completion practices and additional targeted reservoirs have resulted in higher production rates from these newer wells. Because of this, a different technique was employed for estimating the future production from the planned vertical well program.

Based on recent production data, a typical production type-curve was developed for a single vertical well within the JWR No. 4 and No. 5 mine areas. Figure 37 shows the expected production rate from this single well. As shown, peak production of 300,000 cubic feet per day is expected to occur in the second year of operation followed by a hyperbolic decline leading to a well life of 15 years.

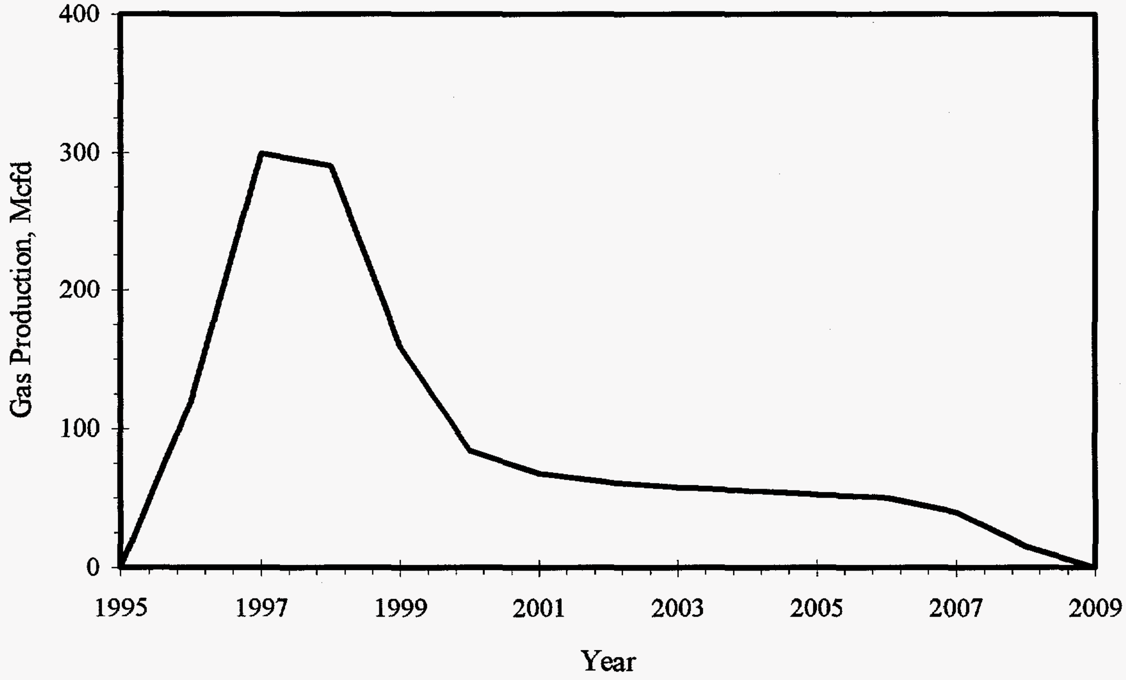

Figure 37 - Projected Future Gas Production from a Single Well - JWR No. 4 and No. 5 Mines

Within the JWR No. 4 mine area, it was projected that at least 150 vertical wells could possibly be drilled. Assuming an installation rate of 25 wells per year for the next six years, 150 wells will be in production by the year 2002. Similarly, 100 vertical wells were projected for the JWR No. 5 mine, with a similar installation rate (25 wells per year). Using the projected single well type-curve and the planned well installation schedule, a projected future production rate from vertical wells was developed, Figures 38 and 39. As shown, production peaks in year 2001 at a rate of approximately 26 million cubic feet per day. Projected cumulative methane production from the planned vertical wells was estimated at 72.3 billion cubic feet.

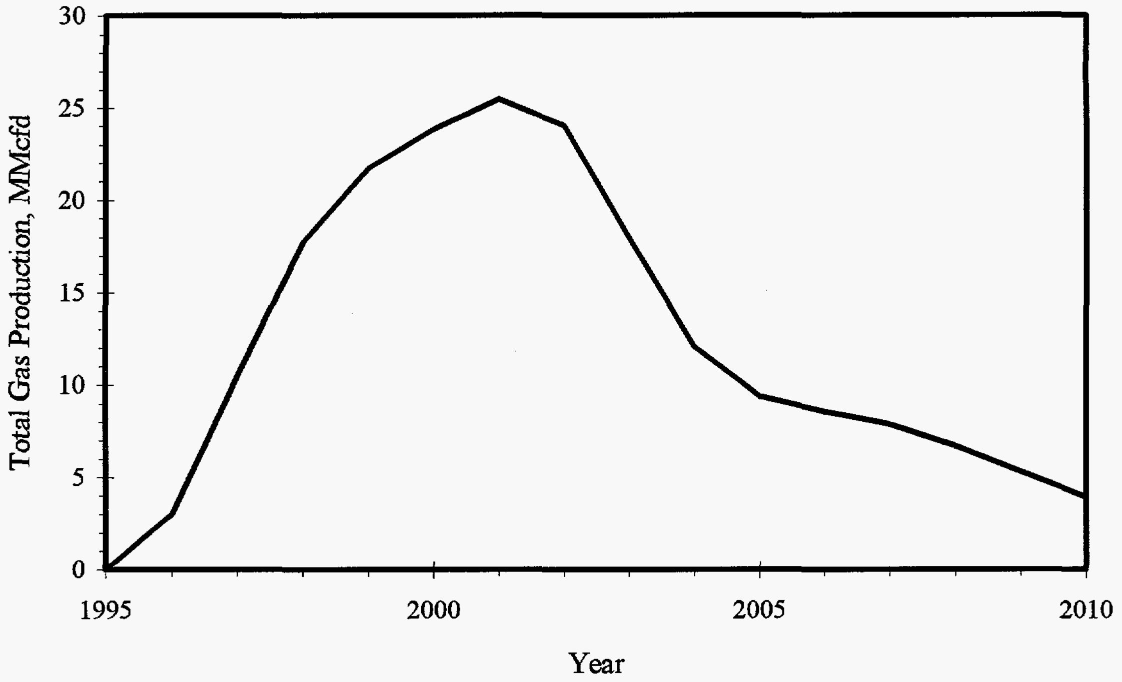

Figure 38 - Projected Future Gas Production from 150 Vertical Wells - JWR No. 4 Mine (1996 - 2010)

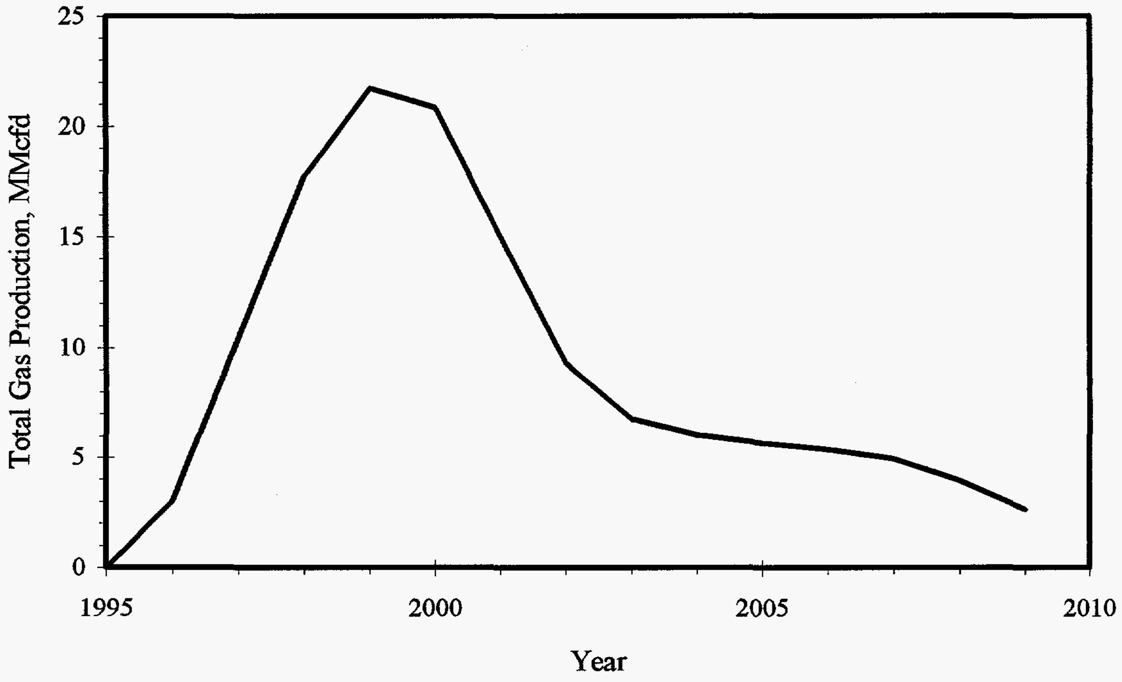

Figure 39 - Projected Future Gas Production from 100 Vertical Wells - JWR No. 5 Mine (1996 - 2010)

Summary

As discussed above, four different flow streams describe the potential future methane production from the JWR No. 4 and No. 5 mine. For the 15 year study period, cumulative methane recovered by these four systems is summarized below in Table 6. This quantity of potential future recoverable methane resources satisfies the required methane feedstock quantity and production period for the proposed field development phase.

RECOVERY SYSTEM	CUMULATIVE RECOVERY, Bcf		
	JWR NO. 4 MINE	**JWR NO. 5 MINE**	**TOTAL JWR NO. 4 & NO. 5 MINES**
Mine Ventilation	39.5	63.9	103.4
Horizontal Wells	3.8	2.6	6.4
Gob Wells	37.7	22.3	60.0
Vertical Wells	72.3	49.2	121.5
TOTAL	**153.3**	**138.0**	**291.3**

Table 6 - Potential Recoverable Resource for the JWR No. 4 and No. 5 Mine Areas

TASK 3 - APPLICATION OF THE TECHNOLOGY OF MEDIUM-QUALITY GOB GAS ENRICHMENT

Introduction

As discussed previously, it has been recognized that the quality of the gas that is produced from gob wells is highly variable and it has initially been concluded that the composition of the gas produced from gob wells was controlled not only by the vacuum pressure applied to the well at the surface, but was also controlled by the location of the well in the gob, the structure of the gob, and the mine's ventilation system. With work performed at the JWR mines in the Warrior basin by JWR and BWMC, it was found that the quality of the produced gas could be controlled through careful application of the vacuum on the wells and coordination with in-mine methane monitoring. From this work it appears that the quantity of methane removed from the gob by a gob well is finite - that is, once a maximum methane flow rate is achieved (at a specified vacuum), additional increases in the vacuum do not increase the quantity of methane removed from the gob. Rather, the increased flow rate due to the further increase in vacuum is made up of additional mine air that has entered the gob either from the working face, headgate or tailgate roadways, or bleeder system.

Therefore, it appears that there may be operational techniques that can be applied to improve gob well gas quality at any coal mine. Importantly, these techniques can be applied in a manner that does not compromise the mine's ventilation system and may, in fact, supplement and improve the ventilation system. However, these techniques are only currently applied at a limited number of U.S. coal mines.

Objectives

The primary goal of the technology application study is the development of a set of standards and procedures to evaluate a mine for its potential to produce pipeline quality gob gas and to install and operate such a system. To achieve this, this phase of the project has been assigned three primary objectives.

The first objective of the project would be the evaluation of the effect of varying operating parameters on gob well performance (especially gas quality). The developed plan will be to install additional monitoring and control devices on existing gob wells and within the mine workings at the JWR No. 4 and/or No. 5 mines to permit a long term and systematic test of the effects of variation in the operating parameters of the wells. These devices would be in addition to those normally called for by operational requirements or mine safety regulations. The purpose would be to measure with a degree of accuracy and to an extent not previously performed, the correlation between changes in methane concentrations in gas produced from a gob well or group of wells and methane emissions in the active mine workings associated with the wells.

A second objective of the field testing, and building upon the results of the first, would be to determine if the increase in suction pressure on a gob well, even though it may result in dilution of the gas below pipeline standards, may nonetheless have economic benefits. As an example, if at a certain suction pressure, a well produced 1 million cubic feet per day (MMcfd) of methane (absolute) with a 96 percent methane concentration in the gas flowstream, could the well at a higher suction pressure produce 1.2 MMcfd of methane (absolute) with an 80 percent methane concentration in the gas flowstream? And if so, would the cost to enrich to pipeline specifications the 1.2 MMcfd of methane at 80 percent concentration be justified by the additional 0.2 MMcfd of marketable methane? Alternatively, would the process be economically justifiable by the additional benefit achieved from the reduced ventilation requirements? If, in the example described, gas enrichment is not viable, would alternative utilization of the gas be economically justifiable - for instance, in gas fired turbines? The economic variables of would be tested across a wide range of operating parameters and with various potential end-uses applications.

The third objective would be the implementation of a demonstration project at a mine where commercial, pipeline-quality gob gas production has not been attempted. The mine would be selected based upon, among other factors, whether it has an existing system of gob well degasification, the levels of methane being vented through the gob well system, total methane emissions of the mine, and the proximity of the mine to pipelines or local gas markets. The guidelines established during the first phase of the project conducted by BWMC would then be used to design the production program. The economic feasibility of various utilization options would also be tested based upon the information gathered during the first phase. This project would also provide the basis for a program to train personnel in the techniques to used in evaluation, installation and operation of gob gas systems. Part of the training program might involve utilization of the equipment installed under the project at the JWR mines. As part of this phase, manuals and procedures would be developed which could then be used by a mine considering the implementation of a commercial gob well system. Included in these would be criteria to determine whether it is preferable to plan a system which produces gas at pipeline standards or to employ one or more of the utilization options demonstrated by a project producing gas at less than pipeline standards.

Conceptual Test Design

To provide a foundation for the design of the required field tests described in the objectives above, it is appropriate to review the status of the current system that is in place at the JWR mines, which produces pipeline-quality gas from gob wells.

Background

JWR began mining coal in the Warrior Basin in the 1970's using the longwall method. The coal seams mined are among the deepest (up to 2,200 feet) in the U.S. and contain significant methane volumes (average 500 cubic feet per ton). Of particular significance is the fact that the mined seam is overlain by numerous coal seams with significant methane content. Mining operations target the 5 to 8 foot thick Mary Lee/Blue Creek coal seam. Following the mining of the coal in a longwall panel, the subsequent collapse of the mine roof causes induced fractures which are believed to propagate through many of the coal seams overlying the mined seam. The amount of gas liberated by the formation of the fractured zone (gob) is significant. As such, a gob well production program can supplement the mine's standard ventilation system and assist in the removal of much of this gob methane. At the JWR mines, BWMC drills three to four gob wells in each panel. The first well is drilled within a few hundred feet of the start line of the panel, with the remaining wells spaced evenly to about the midpoint of the panel. The number and spacing of the wells is based largely on experience.

Each well is connected to a compressor, either at the well site or through a low pressure pipeline. Methane quality is measured at the well indirectly by use of oxygen monitors. This data is continuously acquired at the unmanned remote locations and transmitted to a central control facility. At certain collection facilities, methane concentration is further measured indirectly by use of continuous nitrogen monitors, Figure 40. Finally, the gas is measured directly by physical means for the quality

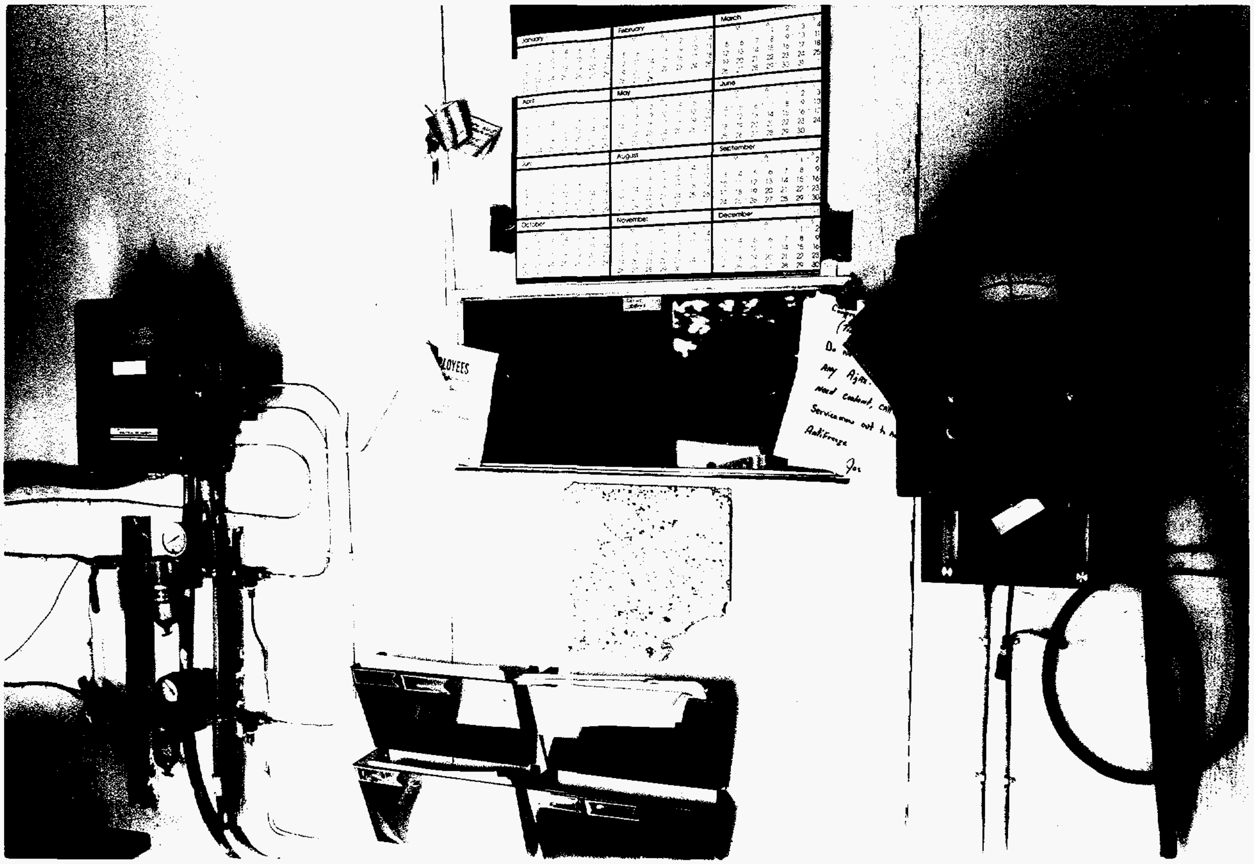

Figure 40 - View of the Oxygen and Nitrogen Monitors at a Gob Well Compression Site

criteria specified in the pipeline sales agreement. Historical data and direct measurements of methane quality provide a statistical baseline for correlating oxygen and nitrogen levels to actual methane concentration with a relatively high degree of accuracy.

BWMC maintains gob gas at pipeline quality by controlling the suction pressure on each well. The data from the remote oxygen and nitrogen sensors provides accurate, real time information on gas quality. Gas flow meters and control devices on gas compressors provide information on gas production levels, Figures 40 and 41. Compressor speed or valve openings are adjusted to maintain gas quality within a narrow range, generally at or above 96 percent methane. An integral part of the gob well program is the close interaction and communication between BWMC's operating personnel and JWR's mining and ventilation personnel. Should circumstances require it, the suction pressure on a well or group of wells can be increased to respond to conditions in the mine. If that results in a decrease in methane quality below 96 percent from the affected wells, the gas may not necessarily be wasted if total gas from the project meets pipeline quality at the sales point. Otherwise, the gas from these wells would be temporarily vented to the atmosphere.

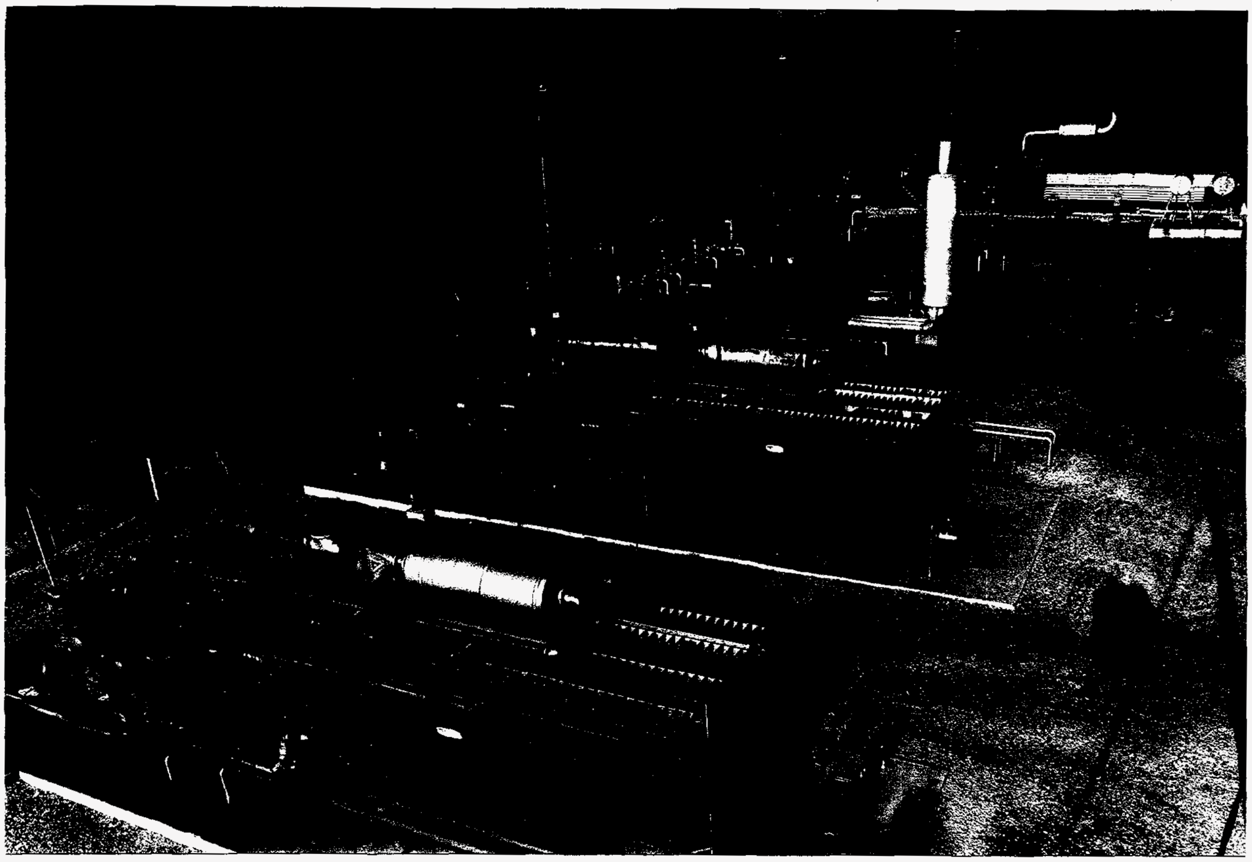

Figure 41 - Compressor Location No. 5 at the JWR Mines

As part of its required mine safety program, JWR regularly monitors methane concentrations in the mining operations. If methane generated in the gob was flowing into the mine works, the effects would be seen primarily at the working face and in the return airways. During the fourteen year period of mining and gob well production, monitoring of methane concentrations by mine safety and ventilation personnel at the working face and in the return airways has indicated that there is no increase in methane concentrations due to maintaining pipeline quality of the methane produced from gob wells. However, no long term, systematic program has been undertaken to conclusively prove these facts or to quantify the effects that variations in the quality of gob gas would have on the economics of the gob wells or reductions in mine ventilation requirements.

However, in contrast to the success achieved by the joint BWMC and JWR operation, a continuing concern frequently voiced by mine operators and engineers is that maintaining high quality in the methane produced through a gob well will, of necessity, result in increased concentrations of methane in the active mine workings. This concern appears to be far more common than not. Overcoming this concern would appear to be a prerequisite to persuading any mining operation which has the potential for commercial gob gas recovery that such a program can be safely and effectively implemented. To our knowledge, there are no texts, manuals or published data, nor any training program which could provide guidance and instruction to a miner wishing to implement commercial gob gas production. One of the primary objectives of this work program will be to develop these tools.

Production of commercial quality gob gas, whether that gas meets pipeline standards or is of sufficient quality that it can be effectively used in alternative applications, may be the single most efficient means of reducing mine emissions of methane. The cost to remove 1,000 cubic feet (Mcf) of methane by ventilation is, in most circumstances, orders of magnitude greater than the cost to produce that gas through a gob well. The methane vented is an environmental concern and, with present technology, of no commercial value. The greatest benefit comes from producing gob gas at pipeline quality. The gas so produced is a fungible commodity, with the marketability and utility of natural gas. If gas cannot be produced at pipeline quality, its marketability and utility are significantly reduced. However, every unit of such gas that can be effectively used, such as in a gas turbine for electric power generation, represents a reduction in mine emissions and revenue to the mine operator.

Test Design

The proposed field testing for the gob wells at the JWR No. 4 and No. 5 mines, as outlined in the objectives, will include the testing of the effect of various vacuum pressures on gas flow rates and gas composition. The selection of wells/panels to be tested will be dependent upon the current mining status at the beginning of the field test phase. However, certain basic concepts can be presented at this time, along with the test schedule/equipment configuration. Importantly, one of the major objectives of the second phase of this program will be the detailed design engineering and test planning/scheduling. Therefore, presented below are the preliminary test design considerations and functions.

As well documented in the literature (Patton, 1995; Diamond, 1994; Diamond, 1993; Trevits, 1988; Goodman, 1986; Hagood, 1985; and others), the flow behavior of gob wells generally is described in the following stages - 1) before undermining of the well by the longwall panel, little if any gas flows from the completed well; 2) following undermining, gas flow increases rapidly, reaching a maximum flow rate often within a few days; 3) gas flow begins a first decline stage that may continue for weeks, months, or years; and 4) gas flow enters a final decline stage in which flow is at a low level, with a slow decline rate.

While gob wells in general may follow the four stages outlined above, it is safe to say that the inconsistency in well performance and the high degree of variability in well performance is a common attribute of gob wells. Wells within a single longwall panel will often display wide variations in flow rate and length of production. At the same time, panel flow rates (the total flow from all gob wells within a single panel) will also display a similar wide variation. Variation in individual well flow performance and panel flow performance has been related to numerous factors, including well location, thickness and methane content of coal seams within the gob, panel location (relative to other panels), depth of the mined seam, geo-mechanical structure of the gob, age of the gob, and well completion practices, to name a few. Accordingly, to be able to fully understand the flow from a gob well (and the effect of well operating practices on that flow), extensive evaluation of the well and the large surrounding mine/reservoir environment will be required.

To accomplish these goals, it will be required to add additional instrumentation at both the surface gob well location and within the mine in areas surrounding the longwall panel(s). Surface instrumentation at the gob well will include the addition of continuous recording, digital 1) gas flow rate meters; 2) oxygen, methane, and nitrogen monitors; 3) pressure and differential pressure gauges; and 4) temperature probes. Additional measurement of operating parameters of the gas compressors or blowers may also be required. In-mine measurement will include continuous recording, digital methanometers, anemometers, and barometers (intrinsically safe and MSHA-approved). In addition atmospheric pressure and humidity measurements would also be continuously recorded on the surface at the well site(s) and at the ventilation fans.

It is envisioned that the initial field test would not include real-time data collection and reduction, but rather data storage at the instruments with data reduction occurring at a later date. It may be necessary, as the program is developed, to include real-time monitoring capability.

An important aspect of the monitoring system is the determination of the flow of methane (and mine ventilation air) within the gob, the adjacent mine entries, and in the gob well. It is envisioned that this will be accomplished through the use of non-toxic, non-flammable tracer gas tests. Extensive work by mining companies and mining research organizations has shown the value in the use of these tracer gases to evaluate flow within the complex environment of a mine ventilation system and gob areas (Timko, 1982; Kennedy, 1987; Thimons, 1974). This work utilized primarily sulfur hexafluoride released within the mine workings or gob wells. Sulfur hexafluoride is a colorless, odorless, chemically and thermally stable gas that can easily be dispersed in air. The advantage of sulfur hexafluoride over other gasses (such as helium or nitrous oxide, which have been used as ventilation tracers) is that only relatively small amounts are required to dope large ventilation airflows (such as those encountered in underground coal mine environments). Sulfur hexafluoride can be accurately measured in concentrations as low as a few parts per trillion by gas chromatography utilizing an electron capture detector (Kennedy, 1987).

The combination of the surface and in-mine flow and concentration measurements coupled with the tracer gas studies will establish not only an understanding of the flow characteristics within the tested gob area(s) but will also provide 1) a basic understanding of the required instrumentation for safe operation of gob wells at pipeline-quality specifications; and 2) the effect of varying gob well suction pressure on methane capture by the well. From this, operational parameters can be established and tested along with the development of procedures for application to gob wells in general.

Important to the planned work is the evaluation of gob well performance under varying geologic conditions. The selection of the JWR no. 4 and No. 5 mine sites provides for a unique opportunity to begin this understanding. While the geologic formations are similar in the two mines, there are important differences, such as depth of mining and total coal seam thickness. Thus, while variation exists, it is limited and it may be discernible by the test methods. It is envisioned that the work at these two locations would provide a foundation that could then be expanded to another mine (or mines) with more diverse geologic conditions.

Ideally, the end product of this research will be the development of a mine/gob well instrumentation system that could effectively monitor operating conditions such that pipeline-quality gas could be produced from a gob well without affecting the mine's normal ventilation system. This could then be the basis for a second-generation system whereby operational actions (i.e. increasing of suction pressure) would be performed using an integrated expert (artificial intelligence) and electro-mechanical system. Such a system has recently been tested with success in mine degasification operations (in-mine gob and horizontal drainage wells) in Japan (Deguchi, 1992).

Market Potential

The potential market in the United States for the conversion of medium-quality gob gas to pipeline-quality gob gas appears to be very large. The U.S. Environmental Protection Agency recently completed a study of the potential for economic utilization of coal mine methane in the U.S. (EPA, 1994). In this study, 74 coal mines were identified as potential candidates for economically capturing and using mine methane emissions. In identifying the potential market for a gob gas enrichment and gathering system, as described in this report, two primary criteria were used. The candidate mines must have as existing gob well degasification program and should have “significant” gob gas emissions. One million cubic feet per day from the mine's gob well degasification system was arbitrarily selected as "significant" for this purpose.

Based on these criteria, there are 22 mines in the U.S. which are candidates for the upgrading and capture of gob well gas. Of these mines, nine are currently capturing gob gas for sale as pipeline-quality gas into the natural gas pipeline system. Of the remaining 13 mines, 11 are located in the northern and central Appalachian basins (West Virginia and Pennsylvania), 1 is located in the Illinois basin (western Kentucky and Illinois), and 1 is located in the Piceance basin (western Colorado). Together, these mines collectively emit an estimated 41.5 MMcf per day of methane from gob wells. If all these mines installed required equipment to maintain pipeline-quality gas and the required gathering systems, the gross revenue from the sale of gas would be about $26 million per year at an average gas price of $1.75 per Mcf. As important, about 10 percent of the current methane emissions from coal mining in the U.S. would be eliminated. In addition, other U.S. coal mines may also be candidates for development of pipeline-quality gob gas systems if favorable economics could be demonstrated. Factors such as gas price, production levels, capital costs, and distance to market would require close analysis of these mines.

Evaluating the potential market for upgrading of medium-quality gob gas outside the U.S. is difficult. There is limited data and no studies similar to the evaluation of U.S. coal mines (EPA, 1994) which separate gob gas methane emission rates from total mine methane emission rates. Additionally, the methods generally employed in overseas mines for removal of gob gas are dissimilar to the gob well method primarily employed in the U.S. and described previously in this report. Whether the methods which are employed can be modified or improved to enrich the produced gas to pipeline-quality would require further analysis. However, if it is assumed that approximately 35 percent of the total mine emissions are from gob wells or similar systems (EPA, 1994), the potential overseas market for the technology described here is quite large. It has been estimated that the nine countries (excluding the U.S.) that emit the most mine methane account for approximately 1,825 Bcf per year (5,000 MMcfd) of methane. If 35 percent of this gas is assumed to be gob gas, the potential international market for the enrichment of medium-quality gob gas would be approximately 639 Bcf per year.

Preliminary Economic Evaluation

The economic analysis presented in this section is based generally upon the experience of BWMC in developing and operating gob wells for the production of pipeline quality methane. An explanation of the "Assumptions" and "Results" line items follows.

Assumptions

The factors for capital costs, depreciation, compression, operating costs, G&A, and pipeline tariffs are based generally on the operations conducted by BWMC at the JWR mines in Alabama. Operating expenses for the production of pipeline quality gob gas are based upon a system of wells, pipelines and compressors designed to gather gas at the wellhead, monitor methane quality by a system of remote monitors at each well and at intermediate gas gathering points, treat and dewater the gas and compress it to a sales pressure of between 500 psi and 750 psi.

- **Capital Costs**. Capital Costs used in this study are shown in Table 7. The cost items included in the table and the value assigned to each are based upon the experience of BWMC in drilling and completing gob wells as described in this report. The Base Case and all cases except Case # 4 assume that the gob gas production system as described in this report is developed at a mine which already employs gob wells as a part of its normal degasification system. The Capital Costs in these cases include only the costs to properly equip an existing well and connect that well to a point of sale or use for the gas. Those cases omit the intangible costs incurred in drilling and completing a well and some of the tangible costs related to drilling and completion. Case # 4 includes all cost which would be incurred in drilling, completing and connecting a gob well. All cases include $10,000 for gas quality monitoring equipment which is in addition to the equipment normally installed at BWMC. Compression costs are based upon leasing compressors. A pipeline tariff is used in lieu of estimated capital costs for a connecting pipeline. Capital Costs, therefore, do not include the cost to install a connecting pipeline or to purchase compressors.

Cost Items	**Capital Costs, $**		
	w/o Gath. Sys.	Gathering System	w/ Gath. Sys.
Intangible	$75,000	$0	$75,000
Tangible			
Surface Equipment	2,000	8,000	10,000
Additional Monitoring Equipment	0	10,000	10,000
Oxygen Analyzer	0	2,400	2,400
Gathering Lines & Fittings	0	4,500	4,500
Equipment Buildings	0	1,800	1,800
Gas Flow Meters	0	2,000	2,000
Flame Arrestor	1,200	0	1,200
Electrical Hook-up	7,000	3,000	10,000
Equipment Installation	1,000	2,000	3,000
Casing & Wellhead	15,100	0	15,100
Subtotal (Tangible & Intangible)	101,300	33,700	135,000
Gathering System & Electrical	0	40,000	40,000
Total Costs	$101,300	$73,700	$175,000

Table 7 - Capital Cost Estimate for a Completed Gob Well and Gathering System

- **Gas Price**. Fuel gas price is based upon present trends in the spot market price of natural gas and is held flat for the life of the analysis.

- **Depreciation**. All tangible costs are capitalized. Depreciation is by the Double Declining Balance method over a seven year life with no salvage value. Intangible drilling costs ("IDC" are expensed in the first year of operation.

- **Gathering Costs**. Gathering Costs include all costs to gather, treat, compress and transport gas to a connecting pipeline that are charged against royalty and severance tax. It is assumed that all compressors for the wells are leased and that the incremental cost of compression is a pro rata allocation of lease payments and maintenance and operating costs for the compressors.

- **Pipeline Tariff**. A Pipeline Tariff is included in the evaluations to account for transportation of the gas through a connecting pipeline from the mine's gathering system to a commercial pipeline or other point of sale or use. The pipeline tariff of $.10/Mcf used in all cases except Case # 3 assumes that the sales point for the gas is relatively close to the mine.

- **Royalty Rate & Severance Tax Rate**. Royalty and severance taxes are based upon the "market value" of natural gas at the wellhead. The rates chosen for each are assumed to be reasonable averages of the rates which would be encountered in areas for which projects as discussed in this proposal would be appropriate. "Market Value" is the gross revenue from gas sales less all post-production operating expenses (in the examples, "Gathering Costs" and "Pipeline Tariff"). The inclusion and method of calculation of royalty and severance tax charges against revenue is not an opinion that the applicability of royalties and severance taxes are determined by the same criteria, or that royalties and severance taxes might be owed for any or all of the cases examined in the economic analysis, or that the method of computation is the only method by which royalties and severance taxes might be fairly and legally calculated.

The authors recognize that the issue of whether royalty or severance tax are due requires the application of different standards. Royalties are payable by contract, generally a document identified as a "mineral lease". While such contracts can be as varied as the skill of the draftsmen and the limits of the law allow, a typical provision might read:

> "As royalty, lessee covenants and agrees . . . to pay lessor on gas and casinghead gas produced from said land (1) when sold by lessee, one-eighth of the net proceeds derived from such sale, or (2) when used by lessee <u>off said land</u> or in the manufacture of gasoline or other products, the market value, at the mouth of the well, of one-eighth of such gas and casinghead gas, lessor's interest, in either case, to bear one-eighth of the cost of compressing, dehydrating and otherwise treating such gas or casinghead gas to render it marketable or usable and one-eighth of the cost of gathering and transporting such gas and casinghead gas from the mouth of the well to the point of sale or use (emphasis added)."

On the other hand, the payment of severance tax is established by law, and is generally payable for any severed mineral sold or used in any beneficial fashion, whether on or off the premises. The possibility that either might be due for gob methane sold or used beneficially by the miner and a sense of fiscal conservatism suggest that both be included in the cost items of the analyses. The inclusion of all costs incurred from the wellhead to the point of sale appears fair and supportable. The exclusion of depreciation on, or a rate of return for, the gathering system or pipeline is not intended as a comment on whether such items can be charged against either royalty or severance tax.

- **Miscellaneous Operating Costs**. This line item covers all lease operating expenses incurred in servicing and maintaining the wells, gathering system and surface facilities which are not charged against royalty or severance tax.

- **G & A**. G & A covers general and administrative costs and is not charged against royalty and severance tax.

- **Gob Well Production Profile**. Gas production rates for all cases are based generally upon the production experience of BWMC. The Base Case through Case # 4 assumes production rates approximately half of the rates experienced by BWMC and would be relevant to mines with fairly high gob gas emissions. Case # 5 uses a gas production rate that is one half of the rate in the Base Case to evaluate economics for mines with relatively low gob gas emissions.

- **Depreciation**. Depreciation is by the Double Declining Balance method over a seven year life with no salvage value. Intangible drilling costs ("IDC") are expensed in the first year of operation.

Results

The results of the analysis under the heading "Results" of the factors described in the "Assumptions" is set out below:

- **Gas Production (Mcf/yr)**. This is computed by taking the appropriate daily production rate from the table in the Gob Well Production Profile and multiplying by 365.

- **Gross Revenue**. Gross revenue is the product of "Gas Production" and the "Gas Price" stated in the "Assumptions".

- **Gathering Costs**. Gathering Costs are the product of "Gas Production" and the "Gathering Costs" factor stated in the "Assumptions".

- **Pipeline Tariff**. Pipeline Tariff is the product of "Gas Production" and the "Pipeline Tariff" factor stated in the "Assumptions".

- **Royalty and Severance Tax**. Royalty and Severance Tax are computed on the net of "Gross Revenue" less "Gathering Costs" and "Pipeline Tariff".

- **Miscellaneous Operating Costs**. Miscellaneous Operating Costs are the product of "Gas Production" and the "Miscellaneous Operating Costs" factor stated in the "Assumptions".

- **G & A**. G & A is the product of "Gas Production" and the "G & A" factor stated in the "Assumptions".

- **Net Production Revenue**. Net Production Revenue is the net of "Gross Revenue" less "Gathering Costs", "Pipeline Tariff", "Royalty & Severance Tax", and "G & A".

- **Depreciation**. Depreciation is by the Double Declining Balance method over a seven year life with no salvage value. Intangible drilling costs ("IDC") are expensed in the first year of operation in Case #4 (Table 11).

- **Taxable Income**. Taxable Income is the net of Net Production Revenue less "Depreciation" and, where appropriate, "Intangible Drilling Costs".

- **Income Tax**. Income Tax is computed at a marginal rate of 34% for Federal and 2% for State taxes.

- **Income after Taxes**. Income after Taxes is the net of "Taxable Income" less "Income Tax".

- **Net Cash Flow and Cumulative Net Cash Flow**. Net Cash Flow and Cumulative Net Cash Flow are the annual and cumulative net of "Income after Taxes" with "Depreciation" recaptured.

- **Net Present Value**. Net Present Value is calculated a discount rate of 10% on the revenue stream for total net cash flow with the first entry as a negative value for "Capital Costs" followed by the annual values for "Net Cash Flow".

- **Internal Rate of Return**. Internal Rate of Return is calculated on "Net Cash Flow".

- **Discounted Net Cash Flow**. Discounted Net Cash Flow is computed on "Net Cash Flow" at a 10% discount rate.

- **Profitability Index**. Profitability Index is "Discounted Net Cash Flow" divided by "Capital Costs".

Analysis of the Cases.

Base Case. The Base Case (Table 9) is based loosely on the experience of BWMC. This case clearly indicates that, under the Assumptions used, collection and sale of gob gas from a mine with high gob gas emissions can be very attractive economically.

Case # 2. Base Case with $2.50/Mcf Gas Price. This case (Table 10) is identical to the Base Case except for gas price. A comparison of this case with the other cases shows that, under the assumptions used in the analysis, economics are most sensitive to gas price. With a gas price of $2.50/Mcf, the economic indicators are substantially improved over the Base Case. This case should be a better example than the Base Case of the economic potential for mines in areas such as the Appalachian Basin where gas prices are usually significantly higher than in the Black Warrior Basin.

Case # 3, Base Case with $.30/Mcf Pipeline Tariff. This case (Table 11) assumes that the mine is more remote form a commercial pipeline or other market for the gas. The tariff is increased to $.30/Mcf. While this tripling of the cost to transport gas to market has a significant effect on the economic indicators, the end result is still a very attractive project.

Case # 4, Capital Costs Include All Well Costs. This case shows is intended to show economics of development at a mine which does not have an existing program of gob well ventilation. This case indicates that such developments will probably require a very close evaluation of economic potential and either high production rates if the local gas price is low or high gas prices if production rates will be low.

Case # 5, Low gas Production and High Gas Price. This case assumes a production rate that is one half the rate used in the Base Case and a gas price of $2.50/Mcf. This case is probably more closely analogous to the situation that will be found with mines in areas such the Appalachian Basin or Illinois Basin where the gob gas production rate may be relatively low but the economics are balanced by a relatively high local gas price.

Table 8 - Economic Evaluation of Gob Gas Enrichment

Base Case

Combined Production Profile for Gob Wells on One Longwall Panel

Reserves (mcf) 960,000

Year of Operation	Production, Mcf per day	Production, Mcf per year	Cumulative Production, Mcf	Cumulative Production, % of Reserves	Decline Rate % of Prior Yr
1	1,709.59	624,000	624,000	65.00%	
2	341.92	124,800	748,800	78.00%	80.00%
3	136.77	49,920	798,720	83.20%	60.00%
4	109.41	39,936	838,656	87.36%	20.00%
5	87.53	31,949	870,605	90.69%	20.00%
6	70.02	25,559	896,164	93.35%	20.00%
7	56.02	20,447	916,611	95.48%	20.00%
8	44.82	16,358	932,969	97.18%	20.00%

Assumptions:	
Cost per well	$73,700
Number of Wells per Panel	3
Capital Costs	$221,100
Gas Price ($/Mcf)	$1.75
Gathering Costs ($/Mcf)	$0.32
Pipeline Tariff ($/Mcf)	$0.10
Royalty Rate	12.5%
Severance Tax Rate	6.0%
Misc. Op'g Costs ($/Mcf)	$0.15
G & A ($/Mcf)	$0.05
Depreciation	7 year, DDB

Results:	1	2	3	4	5	6	7	8
Gas Production (Mcf/yr)	624,000	124,800	49,920	39,936	31,949	25,559	20,447	16,358
Gross Revenue	$1,092,000	$218,400	$87,360	$69,888	$55,910	$44,728	$35,783	$28,626
Gathering Costs	($199,680)	($39,936)	($15,974)	($12,780)	($10,224)	($8,179)	($6,543)	($5,234)
Pipeline Tariff	($62,400)	($12,480)	($4,992)	($3,994)	($3,195)	($2,556)	($2,045)	($1,636)
Royalty & Severance Tax	($153,535)	($30,707)	($12,283)	($9,826)	($7,861)	($6,289)	($5,031)	($4,025)
Misc. Op'g Costs	($93,600)	($18,720)	($7,488)	($5,990)	($4,792)	($3,834)	($3,067)	($2,454)
G & A	($31,200)	($6,240)	($2,496)	($1,997)	($1,597)	($1,278)	($1,022)	($818)
Net Production Revenue	$551,585	$110,317	$44,127	$35,301	$28,241	$22,593	$18,074	$14,459
Depreciation	($63,171)	($45,122)	($32,230)	($23,022)	($16,444)	($11,746)	($8,390)	$0
Taxable Income	$488,413	$65,195	$11,896	$12,280	$11,797	$10,847	$9,685	$14,459
Income Tax (Fed & State)	($175,829)	($23,470)	($4,283)	($4,421)	($4,247)	($3,905)	($3,486)	($5,205)
Income After Taxes	$312,585	$41,724	$7,614	$7,859	$7,550	$6,942	$6,198	$9,254
Net Cash Flow	$375,756	$86,847	$39,844	$30,881	$23,994	$18,688	$14,588	$9,254
Cumulative Net Cash Flow	$375,756	$462,603	$502,447	$533,328	$557,322	$576,010	$590,598	$599,852

Net Present Value **$255,044** **Discounted Net Cash Flow** **$501,648**

Internal Rate of Return **97.43%** **Profitability Index** **2.269**

Table 9 - Economic Evaluation of Gob Gas Enrichment

Case # 2 - Base Case with $2.50/Mcf Gas Price

Assumptions:

Cost per well	$73,700
Number of Wells per Panel	3
Capital Costs	$221,100
Gas Price ($/Mcf)	$2.50
Gathering Costs ($/Mcf)	$0.32
Pipeline Tariff ($/Mcf)	$0.10
Royalty Rate	12.5%
Severance Tax Rate	6.0%
Misc. Op'g Costs ($/Mcf)	$0.15
G & A ($/Mcf)	$0.05
Depreciation	7 year, DDB

Combined Production Profile for Gob Wells on One Longwall Panel

Reserves (mcf) 960,000

Year of Operation	Production, Mcf per day	Production, Mcf per year	Cumulative Production, Mcf	Cumulative Production, % of Reserves	Decline Rate % of Prior Yr
1	1,709.59	624,000	624,000	65.00%	
2	341.92	124,800	748,800	78.00%	80.00%
3	136.77	49,920	798,720	83.20%	60.00%
4	109.41	39,936	838,656	87.36%	20.00%
5	87.53	31,949	870,605	90.69%	20.00%
6	70.02	25,559	896,164	93.35%	20.00%
7	56.02	20,447	916,611	95.48%	20.00%
8	44.82	16,358	932,969	97.18%	20.00%

Results:	1	2	3	4	5	6	7	8
Gas Production (Mcf/yr)	624,000	124,800	49,920	39,936	31,949	25,559	20,447	16,358
Gross Revenue	$1,560,000	$312,000	$124,800	$99,840	$79,872	$63,898	$51,118	$40,894
Gathering Costs	($199,680)	($39,936)	($15,974)	($12,780)	($10,224)	($8,179)	($6,543)	($5,234)
Pipeline Tariff	($62,400)	($12,480)	($4,992)	($3,994)	($3,195)	($2,556)	($2,045)	($1,636)
Royalty & Severance Tax	($240,115)	($48,023)	($19,209)	($15,367)	($12,294)	($9,835)	($7,868)	($6,294)
Misc. Op'g Costs	($93,600)	($18,720)	($7,488)	($5,990)	($4,792)	($3,834)	($3,067)	($2,454)
G & A	($31,200)	($6,240)	($2,496)	($1,997)	($1,597)	($1,278)	($1,022)	($818)
Net Production Revenue	$933,005	$186,601	$74,640	$59,712	$47,770	$38,216	$30,573	$24,458
Depreciation	($63,171)	($45,122)	($32,230)	($23,022)	($16,444)	($11,746)	($8,390)	$0
Taxable Income	$869,833	$141,479	$42,410	$36,691	$31,326	$26,470	$22,183	$24,458
Income Tax (Fed & State)	($313,140)	($50,932)	($15,268)	($13,209)	($11,277)	($9,529)	($7,986)	($8,805)
Income After Taxes	$556,693	$90,546	$27,142	$23,482	$20,049	$16,941	$14,197	$15,653
Net Cash Flow	$619,865	$135,669	$59,373	$46,504	$36,493	$28,687	$22,587	$15,653
Cumulative Net Cash Flow	$619,865	$755,533	$814,906	$861,410	$897,902	$926,589	$949,176	$964,829

Net Present Value	**$535,138**	**Discounted Net Cash Flow**	**$809,751**
Internal Rate of Return	**204.41%**	**Profitability Index**	**3.662**

Table 10 - Economic Evaluation of Gob Gas Enrichment

Case # 3 - Base Case with $0.30/Mcf Pipeline Tariff

Assumptions:

Cost per well	$73,700
Number of Wells per Panel	3
Capital Costs	$221,100
Gas Price ($/Mcf)	$1.75
Gathering Costs ($/Mcf)	$0.32
Pipeline Tariff ($/Mcf)	$0.30
Royalty Rate	12.5%
Severance Tax Rate	6.0%
Misc. Op'g Costs ($/Mcf)	$0.15
G & A ($/Mcf)	$0.05
Depreciation	7 year, DDB

Combined Production Profile for Gob Wells on One Longwall Panel

Reserves (mcf) 960,000

Year of Operation	Production, Mcf per day	Production, Mcf per year	Cumulative Production, Mcf	Cumulative Production, % of Reserves	Decline Rate % of Prior Yr
1	1,709.59	624,000	624,000	65.00%	
2	341.92	124,800	748,800	78.00%	80.00%
3	136.77	49,920	798,720	83.20%	60.00%
4	109.41	39,936	838,656	87.36%	20.00%
5	87.53	31,949	870,605	90.69%	20.00%
6	70.02	25,559	896,164	93.35%	20.00%
7	56.02	20,447	916,611	95.48%	20.00%
8	44.82	16,358	932,969	97.18%	20.00%

Results:	1	2	3	4	5	6	7	8
Gas Production (Mcf/yr)	624,000	124,800	49,920	39,936	31,949	25,559	20,447	16,358
Gross Revenue	$1,092,000	$218,400	$87,360	$69,888	$55,910	$44,728	$35,783	$28,626
Gathering Costs	($199,680)	($39,936)	($15,974)	($12,780)	($10,224)	($8,179)	($6,543)	($5,234)
Pipeline Tariff	($187,200)	($37,440)	($14,976)	($11,981)	($9,585)	($7,668)	($6,134)	($4,907)
Royalty & Severance Tax	($130,447)	($26,089)	($10,436)	($8,349)	($6,679)	($5,343)	($4,274)	($3,420)
Misc. Op'g Costs	($93,600)	($18,720)	($7,488)	($5,990)	($4,792)	($3,834)	($3,067)	($2,454)
G & A	($31,200)	($6,240)	($2,496)	($1,997)	($1,597)	($1,278)	($1,022)	($818)
Net Production Revenue	$449,873	$89,975	$35,990	$28,792	$23,033	$18,427	$14,741	$11,793
Depreciation	($63,171)	($45,122)	($32,230)	($23,022)	($16,444)	($11,746)	($8,390)	$0
Taxable Income	$386,701	$44,852	$3,760	$5,770	$6,589	$6,681	$6,352	$11,793
Income Tax (Fed & State)	($139,212)	($16,147)	($1,353)	($2,077)	($2,372)	($2,405)	($2,287)	($4,246)
Income After Taxes	$247,489	$28,705	$2,406	$3,693	$4,217	$4,276	$4,065	$7,548
Net Cash Flow	$310,660	$73,828	$34,636	$26,715	$20,661	$16,022	$12,455	$7,548
Cumulative Net Cash Flow	$310,660	$384,488	$419,125	$445,839	$466,500	$482,522	$494,977	$502,524

Net Present Value **$180,352** **Discounted Net Cash Flow** **$419,488**

Internal Rate of Return **69.98%** **Profitability Index** **1.897**

Table 11 - Economic Evaluation of Gob Gas Enrichment

Case # 4 - $2.50/Mcf Gas Price and Capital Costs Include All Well Costs

Assumptions:	
Cost per well	$165,000
Number of Wells per Panel	3
Capital Costs	$495,000
Gas Price ($/Mcf)	$2.50
Gathering Costs ($/Mcf)	$0.32
Pipeline Tariff ($/Mcf)	$0.10
Royalty Rate	12.5%
Severance Tax Rate	6.0%
Misc. Op'g Costs ($/Mcf)	$0.15
G & A ($/Mcf)	$0.05
Depreciation	7 year, DDB

Combined Production Profile for Gob Wells on One Longwall Panel

Reserves (mcf) 960,000

Year of Operation	Production, Mcf per day	Production, Mcf per year	Cumulative Production, Mcf	Cumulative Production, % of Reserves	Decline Rate % of Prior Yr
1	1,709.59	624,000	624,000	65.00%	
2	341.92	124,800	748,800	78.00%	80.00%
3	136.77	49,920	798,720	83.20%	60.00%
4	109.41	39,936	838,656	87.36%	20.00%
5	87.53	31,949	870,605	90.69%	20.00%
6	70.02	25,559	896,164	93.35%	20.00%
7	56.02	20,447	916,611	95.48%	20.00%
8	44.82	16,358	932,969	97.18%	20.00%

Results:	1	2	3	4	5	6	7	8
Gas Production (Mcf/yr)	624,000	124,800	49,920	39,936	31,949	25,559	20,447	16,358
Gross Revenue	$1,560,000	$312,000	$124,800	$99,840	$79,872	$63,898	$51,118	$40,894
Gathering Costs	($199,680)	($39,936)	($15,974)	($12,780)	($10,224)	($8,179)	($6,543)	($5,234)
Pipeline Tariff	($62,400)	($12,480)	($4,992)	($3,994)	($3,195)	($2,556)	($2,045)	($1,636)
Royalty & Severance Tax	($240,115)	($48,023)	($19,209)	($15,367)	($12,294)	($9,835)	($7,868)	($6,294)
Misc. Op'g Costs	($93,600)	($18,720)	($7,488)	($5,990)	($4,792)	($3,834)	($3,067)	($2,454)
G & A	($31,200)	($6,240)	($2,496)	($1,997)	($1,597)	($1,278)	($1,022)	($818)
Net Production Revenue	$933,005	$186,601	$74,640	$59,712	$47,770	$38,216	$30,573	$24,458
Depreciation & IDC	($302,143)	($55,102)	($39,359)	($28,113)	($20,081)	($14,344)	($10,245)	$0
Taxable Income	$630,862	$131,499	$35,282	$31,599	$27,689	$23,872	$20,327	$24,458
Income Tax (Fed & State)	($227,110)	($47,340)	($12,701)	($11,376)	($9,968)	($8,594)	($7,318)	($8,805)
Income After Taxes	$403,752	$84,159	$22,580	$20,223	$17,721	$15,278	$13,009	$15,653
Net Cash Flow	$705,895	$139,261	$61,939	$48,337	$37,802	$29,622	$23,255	$15,653
Cumulative Net Cash Flow	$705,895	$845,156	$907,095	$955,431	$993,233	$1,022,855	$1,046,110	$1,061,763

Net Present Value	**$364,357**	**Discounted Net Cash Flow**	**$895,793**
Internal Rate of Return	**67.63%**	**Profitability Index**	**1.810**

Table 12 - Economic Evaluation of Gob Gas Enrichment

Case # 5 -Low Gas Production and $2.50/Mcf Gas Price

Assumptions:

Cost per well	$73,700
Number of Wells per Panel	3
Capital Costs	$221,100
Gas Price ($/Mcf)	$2.50
Gathering Costs ($/Mcf)	$0.32
Pipeline Tariff ($/Mcf)	$0.10
Royalty Rate	12.5%
Severance Tax Rate	6.0%
Misc. Op'g Costs ($/Mcf)	$0.15
G & A ($/Mcf)	$0.05
Depreciation	7 year, DDB

Combined Production Profile for Gob Wells on One Longwall Panel

Reserves (mcf) 480,000

Year of Operation	Production, Mcf per day	Production, Mcf per year	Cumulative Production, Mcf	Cumulative Production, % of Reserves	Decline Rate % of Prior Yr
1	854.79	312,000	312,000	65.00%	
2	170.96	62,400	374,400	78.00%	80.00%
3	68.38	24,960	399,360	83.20%	60.00%
4	54.71	19,968	419,328	87.36%	20.00%
5	43.77	15,974	435,302	90.69%	20.00%
6	35.01	12,780	448,082	93.35%	20.00%
7	28.01	10,224	458,306	95.48%	20.00%
8	22.41	8,179	466,484	97.18%	20.00%

Results:	1	2	3	4	5	6	7	8
Gas Production (Mcf/yr)	312,000	62,400	24,960	19,968	15,974	12,780	10,224	8,179
Gross Revenue	$780,000	$156,000	$62,400	$49,920	$39,936	$31,949	$25,559	$20,447
Gathering Costs	($99,840)	($19,968)	($7,987)	($6,390)	($5,112)	($4,089)	($3,272)	($2,617)
Pipeline Tariff	($31,200)	($6,240)	($2,496)	($1,997)	($1,597)	($1,278)	($1,022)	($818)
Royalty & Severance Tax	($120,058)	($24,012)	($9,605)	($7,684)	($6,147)	($4,918)	($3,934)	($3,147)
Misc. Op'g Costs	($46,800)	($9,360)	($3,744)	($2,995)	($2,396)	($1,917)	($1,534)	($1,227)
G & A	($15,600)	($3,120)	($1,248)	($998)	($799)	($639)	($511)	($409)
Net Production Revenue	$466,502	$93,300	$37,320	$29,856	$23,885	$19,108	$15,286	$12,229
Depreciation	($63,171)	($45,122)	($32,230)	($23,022)	($16,444)	($11,746)	($8,390)	$0
Taxable Income	$403,331	$48,178	$5,090	$6,834	$7,441	$7,362	$6,897	$12,229
Income Tax (Fed & State)	($145,199)	($17,344)	($1,832)	($2,460)	($2,679)	($2,650)	($2,483)	($4,402)
Income After Taxes	$258,132	$30,834	$3,258	$4,374	$4,762	$4,712	$4,414	$7,827
Net Cash Flow	$321,303	$75,956	$35,488	$27,396	$21,206	$16,458	$12,804	$7,827
Cumulative Net Cash Flow	$321,303	$397,260	$432,747	$460,143	$481,349	$497,807	$510,611	$518,437

Net Present Value	**$192,564**	**Discounted Net Cash Flow**	**$432,921**
Internal Rate of Return	**74.41%**	**Profitability Index**	**1.958**

Environmental Benefits of the Technology

The primary beneficial aspect of the proposed project is the capture of methane that otherwise would be emitted to the atmosphere. Methane is believed to have a global warming potential 21 times greater than CO_2 (EPA, 1994). Using the Base Case example described in the above ***Economics*** section, each longwall panel (during the eight-year period of evaluation) would capture over 930 MMcf of methane that would otherwise be emitted to the atmosphere. If it is assumed that all or most of this gas will be used to generate heat or as a substitute for electricity, a further reduction in the greenhouse effect is achieved by the substitution of this captured methane for coal as a fuel for power generation. This is due to the fact that the combustion of methane results in the production of 35 percent less CO_2 than that which would be produced by the combustion of coal for an equivalent amount of heat energy (EPA, 1995).

Any potential harmful environmental effects of the project appear to be minimal, particularly when compared with the benefits of reduced methane emissions to the atmosphere. Compressors used in a project to collect and compress the captured methane will emit a very small quantity of NO_x and SO_x. The operation of these compressors and other equipment and the increased vehicular traffic in the area of the wells may also create an increase in ambient noise which may cause limited inconvenience. However, in all cases these emissions (gaseous and sonic) will be far below the ambient standards established for the area.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Methane released to the atmosphere during coal mining operations is believed to contribute to global warming and represents a waste of a valuable energy resource. Coal mining in the United States released an estimated 190 to 300 billion cubic feet of methane into the atmosphere in 1990. Yet, largely because of inadequate methane capture technology, less than 7 percent of methane released during coal mining is currently recovered for use. Commercial production of mine generated methane through wells drilled vertically from the surface into the area above the gob can, if properly implemented, be the most effective and easiest-achieved means of reducing mine methane emissions.

Assessment of upgrading this vented gob gas to pipeline specifications using various gas conversion and enrichment technologies has shown to be currently economically unattractive. Improved or modified gob well operational techniques may be able to transform the produced medium-quality gob gas into pipeline-quality at much lower costs, thus providing for attractive economic benefits. Therefore, the establishment of the parameters for evaluating the geologic, technical and economic feasibility of natural gas pipeline-quality gob gas production and the development of guidelines and procedures for implementing such a gas-quality improvement operation is critical for the success of this technique.

The preliminary assessment of the methane gas in-place/producible resource at the JWR No. 4 and No. 5 Mines established a very large 15-year supply of mine methane from gob wells (60 billion cubic feet), satisfying the resource criteria for the test site. In addition, the existence of an extensive gob well recovery (and utilization) program further compliments the practical and near-term technology transfer aspects of this project.

Continuation of the project into the next phase (and into the field demonstration phase) will lead to the determination of the effect of wide ranges in the operating conditions of selected gob wells on mine methane levels and ventilation requirements. Parameters to be determined will include absolute methane and methane concentration produced through the gob wells; working face, tailgate and bleeder entry methane levels; and the effect on economics of production of gob wells at various levels of methane quality. Transferring the results of this test work at the JWR mines to a demonstration project at a mine where commercial gob gas production has not been attempted will lead to confirmation of the guidelines established during the field work at JWR. Finally, through the test and demonstration program at the JWR mines and at the potential candidate mine, economic feasibility of various utilization options will be determined. The final results will be not only 1) the confirmation of the applicability of interactive well operating practices to upgrade medium-quality gob gas; but more importantly 2) the capture of previously emitted coal mine methane and the conservation of a valuable national energy source.

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