CO_2 Sequestration Potential Of Texas Low-Rank Coals

Quarterly Technical Progress Report

Reporting Period Start Date: July 1, 2003
Reporting Period End Date: September 30, 2003

By:

Duane A. McVay
Walter B. Ayers, Jr.
Jerry L. Jensen

October 2003

DE-FC26-02NT41588

Texas Engineering Experiment Station
3000 TAMU
332 Wisenbaker Engineering Research Center
College Station, Texas 77843-3000

DISCLAIMER

ABSTRACT

The objectives of this project are to evaluate the feasibility of carbon dioxide (CO_2) sequestration in Texas low-rank coals and to determine the potential for enhanced coalbed methane (CBM) recovery as an added benefit of sequestration. The main objective for this reporting period was to further characterize the three areas selected as potential CO_2 sequestration sites.

Well-log data are critical for defining depth, thickness, number, and grouping of coal seams at the proposed sequestration sites. Thus, we purchased 12 hardcopy well logs (in addition to 15 well logs obtained during previous quarter) from a commercial source and digitized them to make coal-occurrence maps and cross sections. Detailed correlation of coal zones is important for reservoir analysis and modeling. Thus, we correlated and mapped Wilcox Group subdivisions – the Hooper, Simsboro and Calvert Bluff formations, as well as the coal-bearing intervals of the Yegua and Jackson formations in well logs. To assess cleat properties and describe coal characteristics, we made field trips to Big Brown and Martin Lake coal mines.

This quarter we also received CO_2 and methane sorption analyses of the Sandow Mine samples, and we are assessing the results. GEM, a compositional simulator developed by the Computer Modeling Group (CMG), was selected for performing the CO_2 sequestration and enhanced CBM modeling tasks for this project. This software was used to conduct preliminary CO_2 sequestration and methane production simulations in a 5-spot injection pattern. We are continuing to pursue a cooperative agreement with Anadarko Petroleum, which has already acquired significant relevant data near one of our potential sequestration sites.

TABLE OF CONTENTS

INTRODUCTION

The overall objectives of this project are to determine the feasibility of CO_2 sequestration in Texas low-rank coals and the potential for enhanced coalbed methane (CBM) recovery as an added benefit of sequestration. The main objectives for this reporting period were to further characterize the three areas selected as potential test sites.

Characterization of the three areas selected for CO_2 sequestration is crucial for accurately evaluating the technical and economic feasibility of CO_2 sequestration and enhanced coalbed methane production. As part of the coal characterization, description of the properties of natural fractures is required for planning exploration and development, owing to fracture influence on CO_2 injection and methane production. Fresh coal samples are needed from the regions of interest in order to effectively characterize the coal. Well log data are critical in defining depth, thickness and number of coal seams at the proposed sequestration areas. Activities during this reporting period included acquisition and analysis of these types of data.

EXPERIMENTAL

Three surface coal samples obtained from the Sandow mine area were sent to TerraTek Laboratories in Salt Lake City, Utah, to determine methane and CO_2 adsorption isotherms. The samples obtained had been exposed by overburden removal for less than 24 hours. Other supporting laboratory tests run included proximate analysis, coal petrography and vitrinite reflectance. For some analyses, the coals must be at equilibrium moisture content, which may take as much as a month to accomplish. Results of the sorption isotherm tests are shown in Figs. 1a and 1b. The methane sorption isotherms are plotted against the USGS samples obtained from Panola County, Texas (Warwick *et al*, 2000) in Fig. 1a.

The ratio of CO_2 adsorption to that of methane adsorption decreases from an initial value of 8.85 as the pressure increases until, at a pressure of 700 psi, the value drops to approximately 8 (fig. 1c). This suggests that, as the reservoir pressure increases, the amount of CO_2 adsorbed will decrease in proportion to the amount of methane produced.

RESULTS AND DISCUSSION

Coal Properties at Outcrops and Mines

Fractures occur in nearly all coal beds. Knowledge of the coal natural fracture properties is essential for planning both CO_2 injection and methane production. Coal permeability depends on the abundance, aperture, and connectivity of natural fractures, and commonly, the fracture orientation imposes flow anisotropy. Therefore, we are describing coal fracture characteristics at outcrop and in mines in east-central Texas. During the last quarter we described the Jackson coal outcrop at Lake Somerville and Wilcox coal exposures at Sandow surface mine. This quarter we continued this task in Big Brown and Martin Lake surface mines.

We described upper Wilcox Group lignite in two Big Brown pits located about 0.7 miles apart. In the first pit the face cleat orientations averaged N80°E, and butt cleat trends averaged N0ºE. Fractures are not uniformly spaced, and they terminate within bedding intervals. Face cleat spacing measured at highwalls ranged between 1.4 and 13.8 inches. At the second stop, the face cleat orientations ranged from N65ºE to N85ºE, and the distances between the face cleats ranged between 2.8 and 6.7 inches. The orientations of the butt cleats ranged from N0ºE to N30ºE. The distances between the butt cleats ranged between 2.8 and 7.6 inches (Table 1 and Figs. 2 and 3).

At the Martin Lake mine, we described two Wilcox pits approximately 3.6 miles apart. In both pits, the face cleat trends averaged N80°E and the butt cleat trend was N02ºE. Face cleat spacings measured at highwalls ranged between 2 and 8.7 inches and butt cleat spacings ranged between 4.3 and 10.2 inches (Table 1 and Figs. 4 and 5).

Figure 6 shows the rose diagrams of face and butt cleats that quantify the distribution of the fracture orientations. The rose diagrams illustrate close mean orientation in all four field trip locations. In general, the fracture traces show northeast (NE) face cleat orientation and northwest (NW) butt cleat orientation.

As stated in the last quarterly report, the orientation of face cleats at the Lake Somerville outcrop and Sandow Mine is consistent with the dominant fracture strike (N65ºE) in the Austin Chalk of the Giddings field of Washington and Austin counties in Central Texas. The orientations of the face cleats (N65-80°E) in the Big Brown and Martin Lake mines are within the range of regional and local fracture orientation (Figs. 6 and 7).

We were unable to collect coal samples for CO_2 and methane sorption analyses at the Big Brown and Martin Lake surface mines because of prohibitions set forth by the mine operators.

Analysis of Well Logs

To determine the potential for CO_2 sequestration, detailed coal description is required for each of the 3 proposed areas. We purchased 12 hardcopy well logs from a commercial source and digitized them (in addition to 15 well logs obtained during the previous quarter) to make coal-occurrence maps and cross sections. These well logs include gamma-ray, self-potential, resistivity, sonic, and density curves.

We interpreted coal occurrences in the logs. Also, we correlated and mapped the coal bearing formations (Wilcox Group subdivisions, the Hooper, Simsboro and Culvert Bluff formations, as well as coal zones in the Yegua and Jackson formations) for correlation of individual coal seams. The next steps are refining the correlations of the coal occurrences within individual formations, constructing isopleth maps (number of coal seams) and fence diagrams for each site, and combining the results with existing available coal occurrence maps. Then, we will define net coal thickness and coal reservoir volumetrics for each of the 3 proposed sequestration areas. This information will be used to build models for reservoir simulation. Figure 8 shows Wilcox Group coal occurrences in two well logs from Grimes and Fayette counties.

Selection of a Simulation Package

Upon completion of the reservoir characterization phase of the project, reservoir simulation will be used to determine the feasibility of CO_2 sequestration and enhanced coalbed recovery from Texas coals. Simulators that were developed primarily for the CBM production process have many features allowing for a proper characterization of coalbed reservoirs. Some of these features are:

- Dual-porosity system
- Pure gas diffusion and adsorption in the coal matrix
- Coal shrinkage due to gas desorption

However, if CO_2 sequestration is to be modeled, more features than those listed above need to be available to properly characterize the process and to accurately predict the amounts of CO_2 sequestered and the amounts of methane produced (Law *et al*, 2002). These additional features are:

- Mixed-gas diffusion
- Mixed-gas adsorption
- Ability to model coal swelling due to adsorption
- Non-isothermal effects of gas injection

Considering all of these required features, GEM, a numerical compositional simulator developed by the Computer Modeling Group (CMG) Ltd. was selected to perform simulation studies. GEM has the capability to model mixed-gas diffusion and mixed-gas adsorption for 3 or more gas components using a dual-porosity approach. It can also model stress-dependent permeability and porosity arising out of matrix shrinkage and swelling due to the opposing phenomena of methane desorption and CO_2 adsorption.

Simulation Studies

Preliminary simulation studies were conducted using properties for Texas low-rank coals obtained from literature (Warwick *et al*, 2000). The most likely coal properties from the literature (Table 2) were used to simulate and analyze coalbed methane reservoir behavior under CO_2 sequestration and methane production.

For performing simulation studies, one quarter of a 5-spot pattern was modeled (Fig. 9). The next step was to determine realistic injection and production rates and volumes for Texas Gulf Coast lignites. To accomplish this, the base-case data set was used to perform a series of simulations. Both injector and producer begin operation at the start of simulation. The producer is primarily rate-constrained to operate at 3 MMscf/d and secondarily pressure-constrained to operate at 40 psi. The effective constraint is the pressure constraint. Likewise, the injector is primarily rate-constrained to operate at 1 MMscf/d and secondarily pressure-constrained to operate at 2,000 psi. In the case of the injection well, the rate constraint is the effective constraint. Simulation ends when CO_2 is 5% of the production stream. Wells were assumed to be on a spacing of 80 acres per well. A single-layer 11x11 grid was used.

Fig. 10 shows the CO_2 injection rate and bottomhole pressure in the injection well for the base case. Fig. 11 shows the methane production rate, bottom hole pressure in the producing well, and water production rate for the base case.

Fig. 11 shows that a slug of gas is produced very early in the life of the well. When the well is turned on, the pressure in the wellbore immediately drops to the minimum allowable flowing pressure, 40 psi, and the water in the cleats immediately surrounding the wellbore is produced. Before this water can be replaced with water from deeper in the formation, the cleats fill with methane desorbed from the coal immediately surrounding the wellbore. This methane is quickly displaced by water from deeper in the formation, which limits the permeability to methane. Thus, methane production falls off until enough water has been produced to lower the pressure sufficiently to allow methane to desorb and force the water from the cleats.

These figures show that CO_2 injection is maintained at 1 MMscf/D per well for almost 5 years before it breaks through at the producing well. Methane production peaks at about 130 Mscf/D per well at about 2 years and declines to about 100 Mscf/D at the time of CO_2 breakthrough. These simulations were for a coal thickness of 10 ft. Areas with greater thickness will be able to sequester CO_2 for longer time periods and produce larger volumes of coalbed methane.

Data Acquisition

Last quarter we initiated discussions with Anadarko Petroleum Corporation, which is active in conventional oil and gas production in the areas of our selected sites and is interested in pursuing a cooperative study. Anadarko has provided us with a list of coalbed reservoir data they have collected from 5 wells near one of our proposed CO_2 sequestration areas. These data are more abundant than the data we had proposed to acquire by drilling our own core holes and, since they were obtained at greater depths, they are more relevant. Thus, during the summer we began reviewing opportunities for cooperative research and began working on a cooperative agreement. These discussions have been delayed due to organizational restructuring within Anadarko. Although the delays have put us a little behind schedule, we believe the project will be best served by working with Anadarko, given the amount and quality of data already acquired, and we are still pursuing a cooperative agreement.

CONCLUSIONS

1. Face cleat orientations measured in mines are consistent with regional fracture patterns in the Austin Chalk, a fractured hydrocarbon-bearing unit that underlies Tertiary age coals. Butt cleats in these coals are orthogonal to face cleats.
2. Face and butt cleat spacings in Wilcox coals at all field sites (Sandow Mine, Big Brown and Martin Lake) are between 2 and 10 inches.
3. CMG Ltd's compositional simulation package GEM was found to be adequate for modeling CO_2 sequestration and enhanced CBM recovery in coal beds.
4. Preliminary modeling results appear to support the technical viability of CO_2 sequestration and enhanced CBM recovery in Texas low-rank coal beds. A more in-depth analysis will be performed when further coal characterization is completed.

REFERENCES

Baumgardner R.W. Jr., 1987, Landsat-Based Lineament Analysis, East Texas Basin and Sabine Uplift Area, The University of Texas at Austin, Bureau of Economic Geology, Report of Investigation No. 167, 26 pages.

Hovorka S.D., 1998, Facies and diagenesis of the Austin Chalk and controls on fracture intensity - a case study from North-Central Texas: The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 98-2, 47 pages.

H.S. Law et al., 2002, Numerical Simulator Comparison Study for Enhanced Coalbed Methane Recovery Processes, Part I: Pure Carbon Dioxide Injection, paper SPE 75669 presented at the 2002 SPE Gas Technology Symposium, Calgary, Alberta, 30 April-2 May.

Warwick, P.D., Barker, C.E., SanFilipo, J.R., and Morris, L.E.: 2000, Preliminary Results from Coal-Bed Methane Drilling in Panola County, Texas, U.S. Geological Survey Open-File Report 00-048, U.S. Department of the Interior.

Table 1. Orientation and Spacing of Coal Cleats in Big Brown and Martin Lake

Big Brown : Upper Wilcox							
Seam thickness --8 ft **STOP-1: Location: N31°49.059' W 96°05.286'** **Altitude: 188 ft**				**Seam thickness --7 ft** **STOP-2: Location: N31°49.489' W 96°04.820'** **Altitude: 222 ft**			
Fracture orientation				Fracture orientation			
Face Cleat	Distance between face cleats	Butt Cleat	Distance between butt cleats	Face Cleat	Distance between face cleats	Butt Cleat	Distance between butt cleats
N80°E	13.8inch	N0°E	7.9inch	N65°E	2.8inch	N10°E	7.5inch
N85°E	1.4inch	N0°E	1.4inch	N70°E	6.7inch	N20°E	2.8inch
N78°E		N0°E		N75°E	6.7inch	N30°E	
				N85°E		N0°E	
Martin Lake : Upper Wilcox							
Seam thickness --6 ft **STOP-1: Location: N32°15.160' W 94°31.534'** **Altitude: 270 ft**				**Seam thickness --8 ft** **STOP-2: Location: N32°12.989' W 94°33.983'** **Altitude:**			
Fracture orientation				Fracture orientation			
Face Cleat	Distance between face cleats	Butt Cleat	Distance between butt cleats	Face Cleat	Distance between face cleats	Butt Cleat	Distance between butt cleats
N80°E	4.3inch	N05°E	10.2inch	N80°E	8.7inch	N05°E	7.1inch
N80°E		N0°E		N80°E	6.7inch	N0°E	4.33inch
N80°E		N0°E		N78°E	2.0inch	N0°E	

Table 2: Coal reservoir properties used in preliminary reservoir modeling.

Coal Seam Thickness	10 feet
Depth	2000 feet
Fracture/Cleat Spacings	2.5 inch
Fracture Porosity	0.005
Fracture Absolute Permeability	**5 md**
Fracture Compressibility	100e-6 1/psi
Water Density	61.8 lb/ft^3
Water Viscosity	0.6 cp
Water Compressibility	8.7e-8 1/psi
Coal Density	**80 lb/ft^3**
V_L, CO_2	**800 scf/ton**
V_L, CH_4	**80 scf/ton**
P_L, CO_2	**400 psi**
P_L, CH_4	400 psi
Diffusion Time	**1 day**
Initial Reservoir Pressure	**1000 psi**
Initial Water Saturation	100%
Initial Composition of Gas in Reservoir	100% CH_4
Initial Coal Gas Content	100% saturated

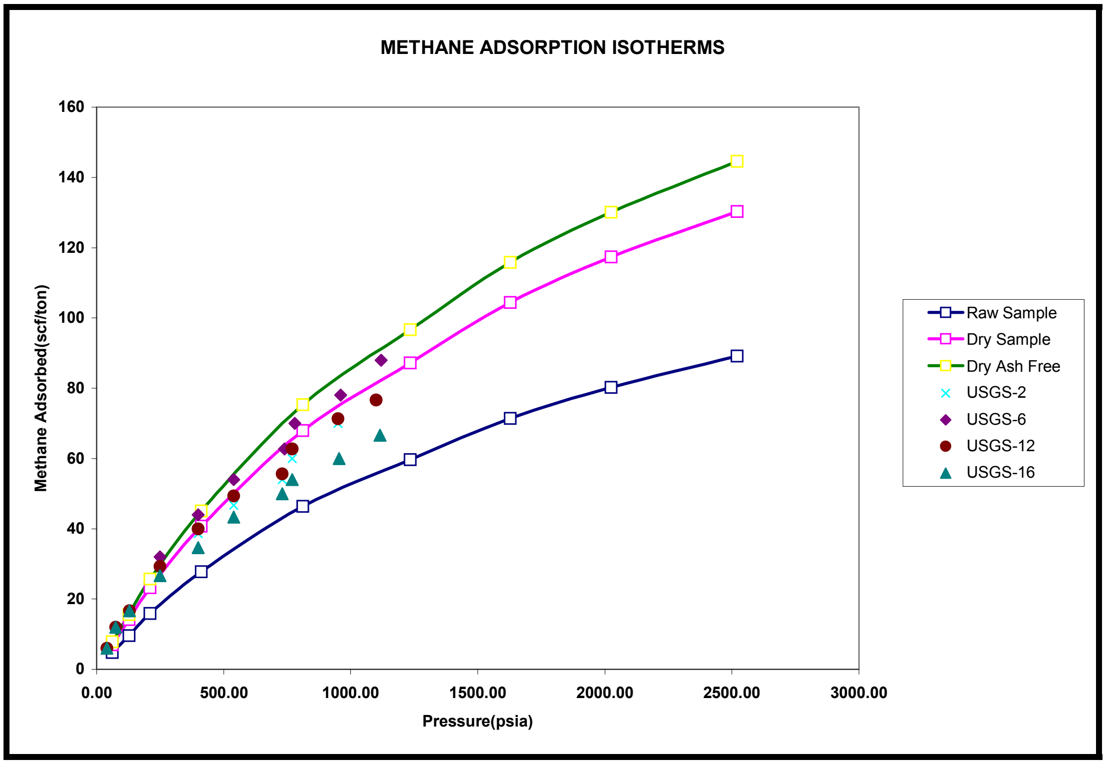

Fig. 1a: Plot of methane isotherms comparing sample from the Sandow mine with the USGS samples.

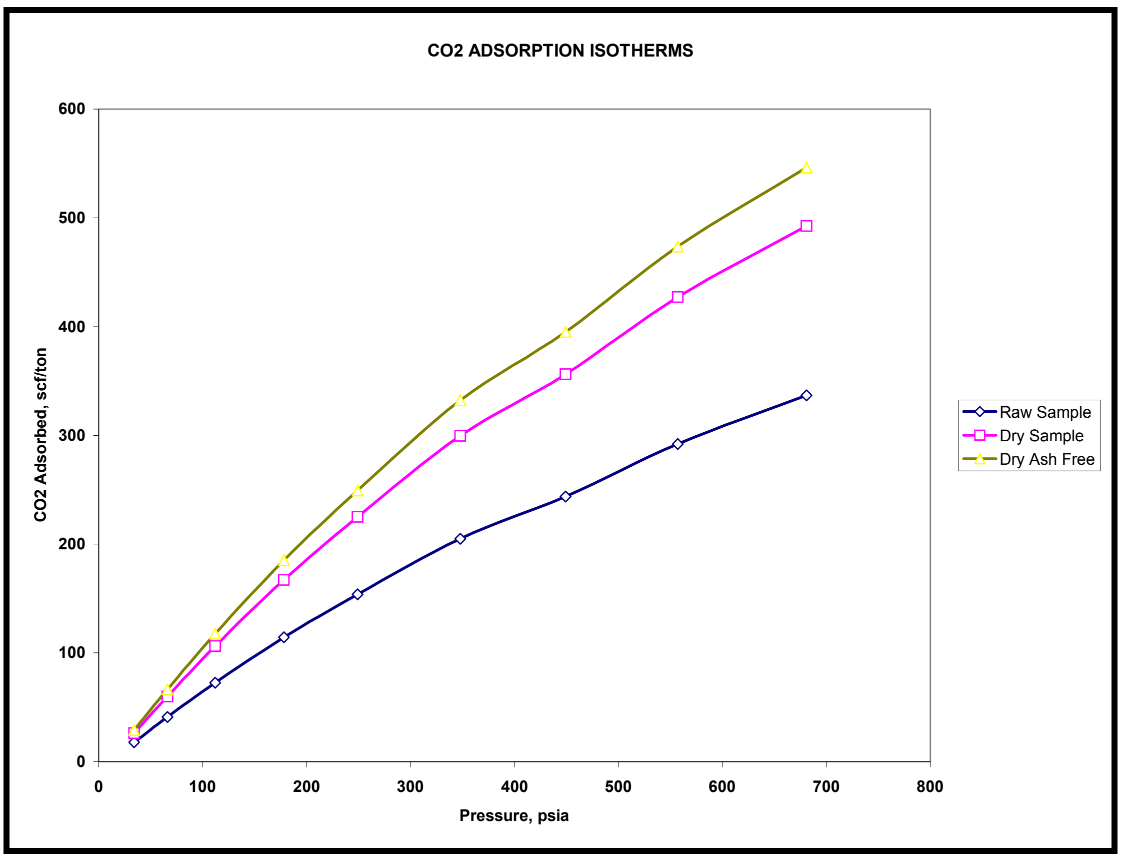

Fig. 1b: CO_2 adsorption isotherms from the Sandow surface mine sample.

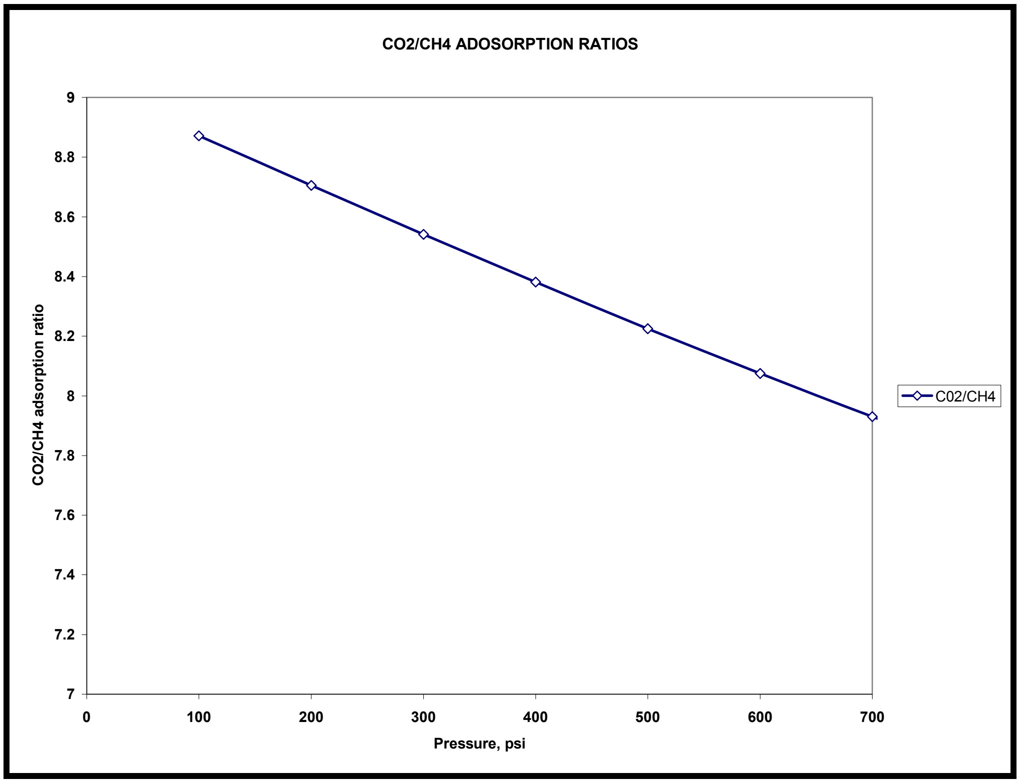

Fig. 1c: Variation of CO_2/CH_4 adsorption ratios with pressure.

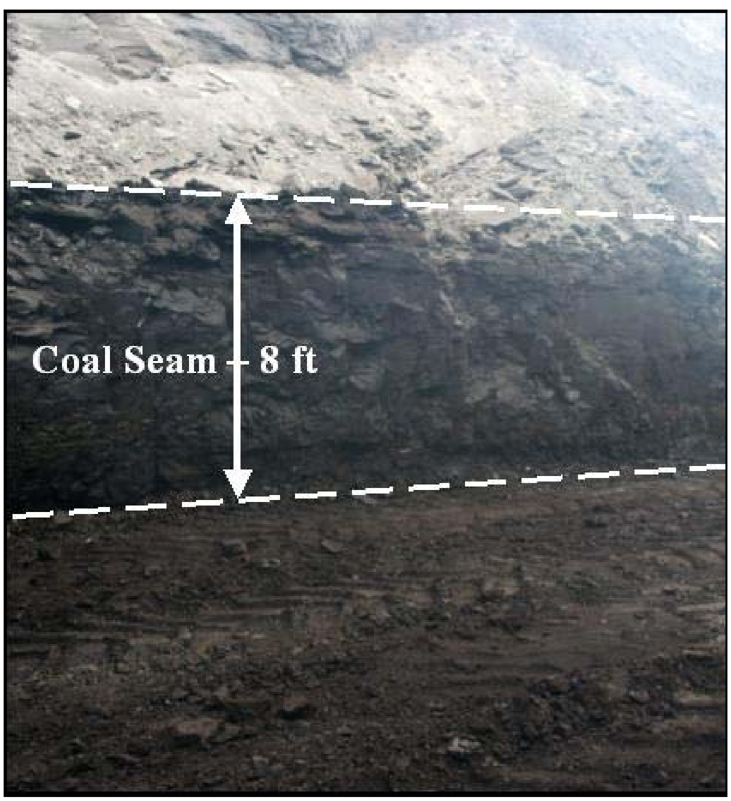

Fig. 2. Big Brown coal seam.

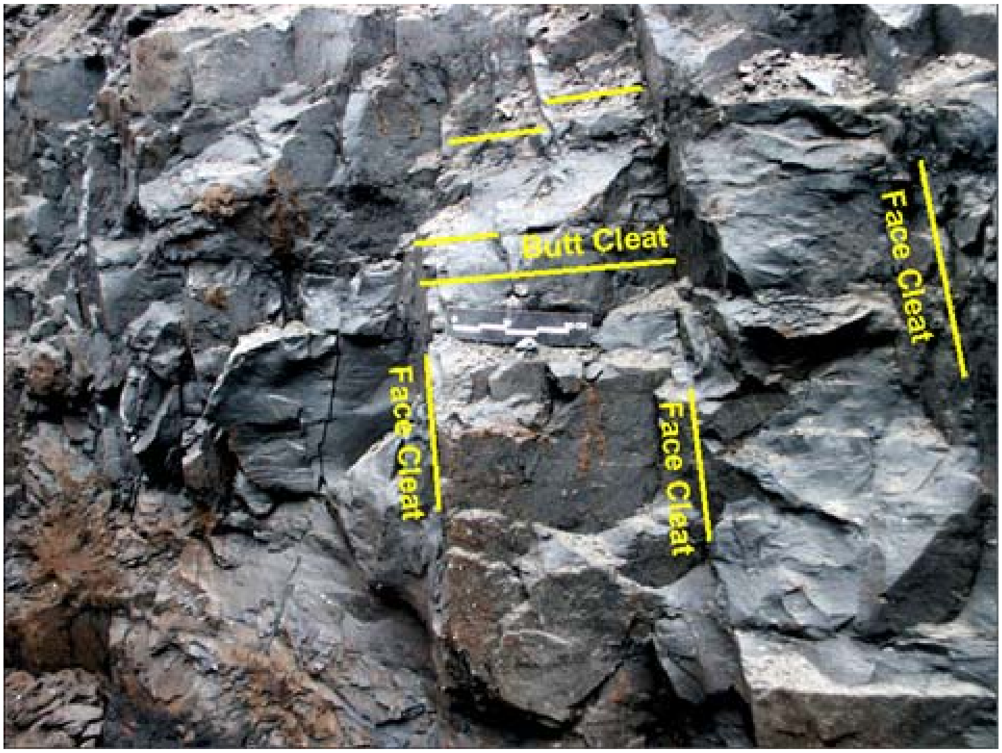

Fig. 3. Big Brown coal cleat.

Fig. 4. Martin Lake coal seam.

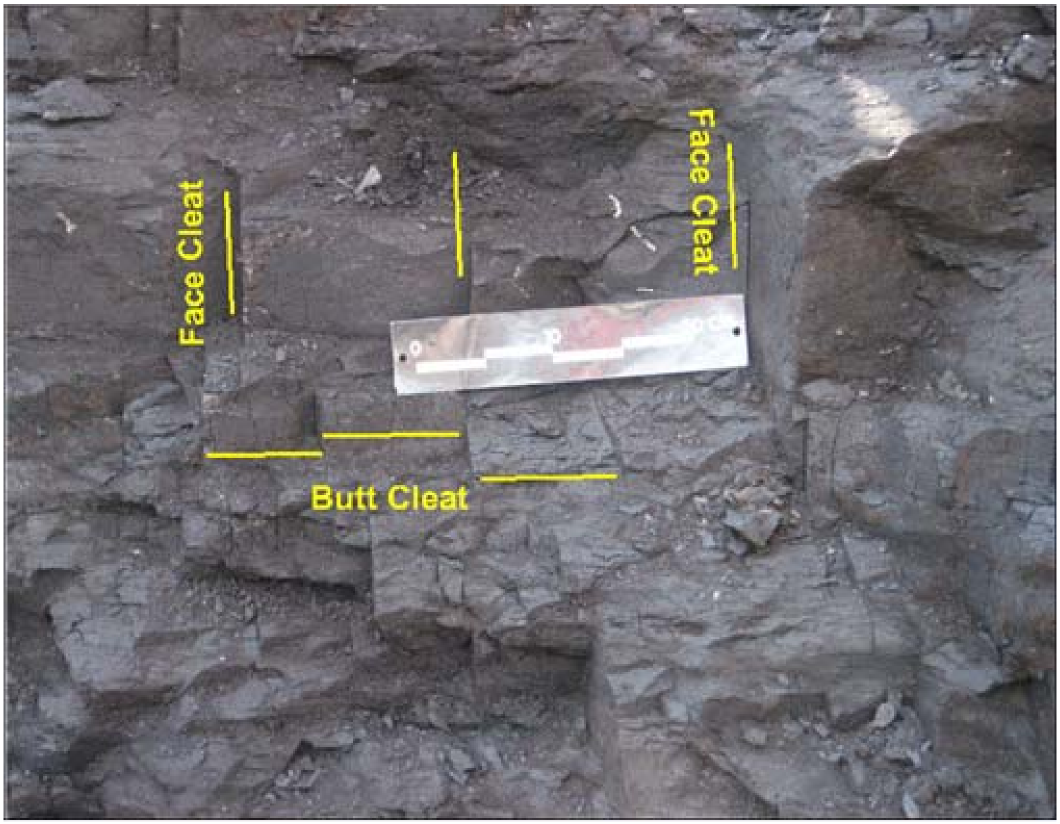

Fig. 5. Martin Lake coal cleats.

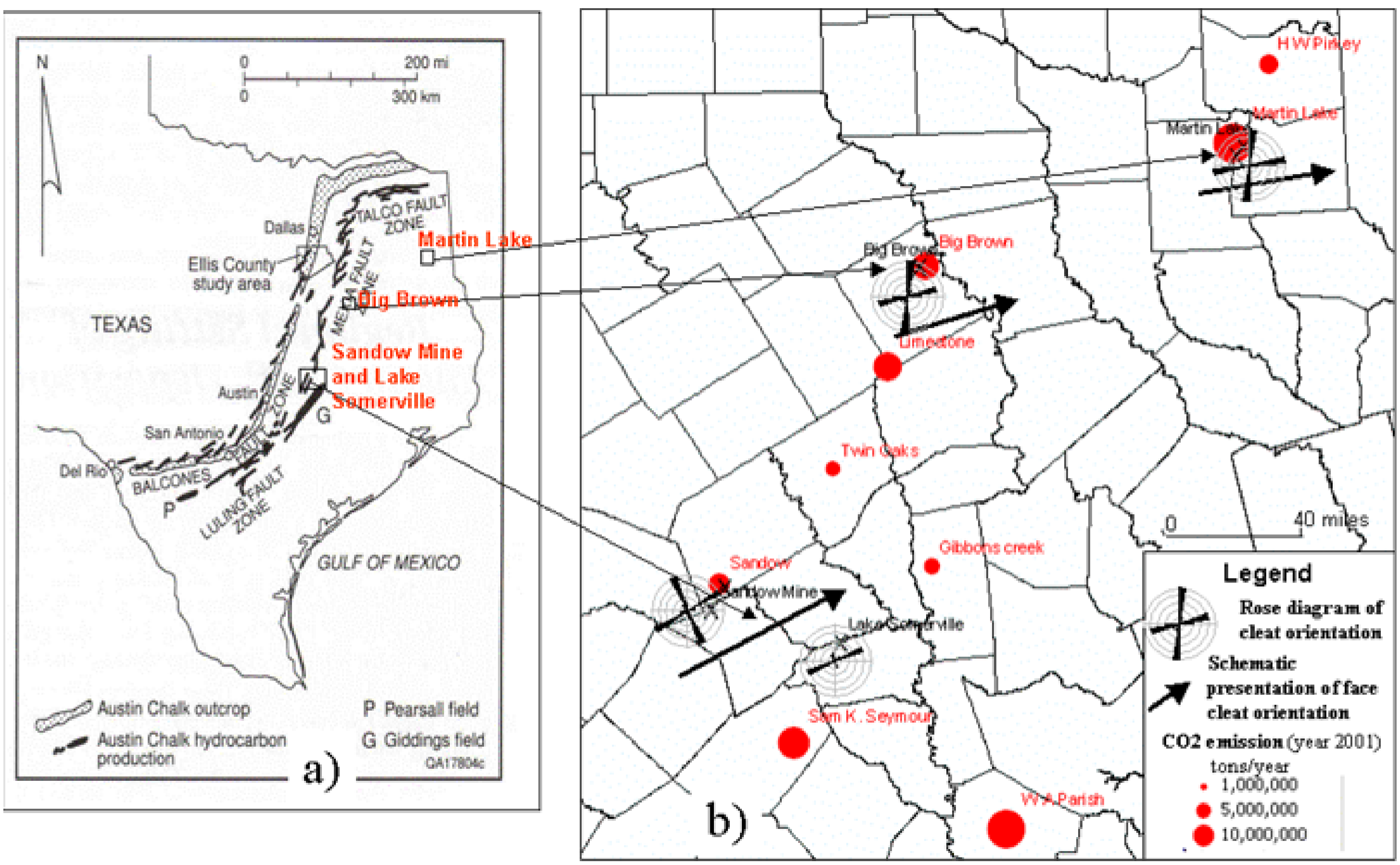

Fig. 6. a) Location of the Austin Chalk Outcrop; major hydrocarbon-producing fields; Balcones, Luling, Mexia, and Talco Fault Zones; and the Ellis County study area. From Hovorka (1998) after Collins and others (1992). b) Rose diagrams and schematic presentation of cleat trends in each field sites. Rosettes are in 10º interval.

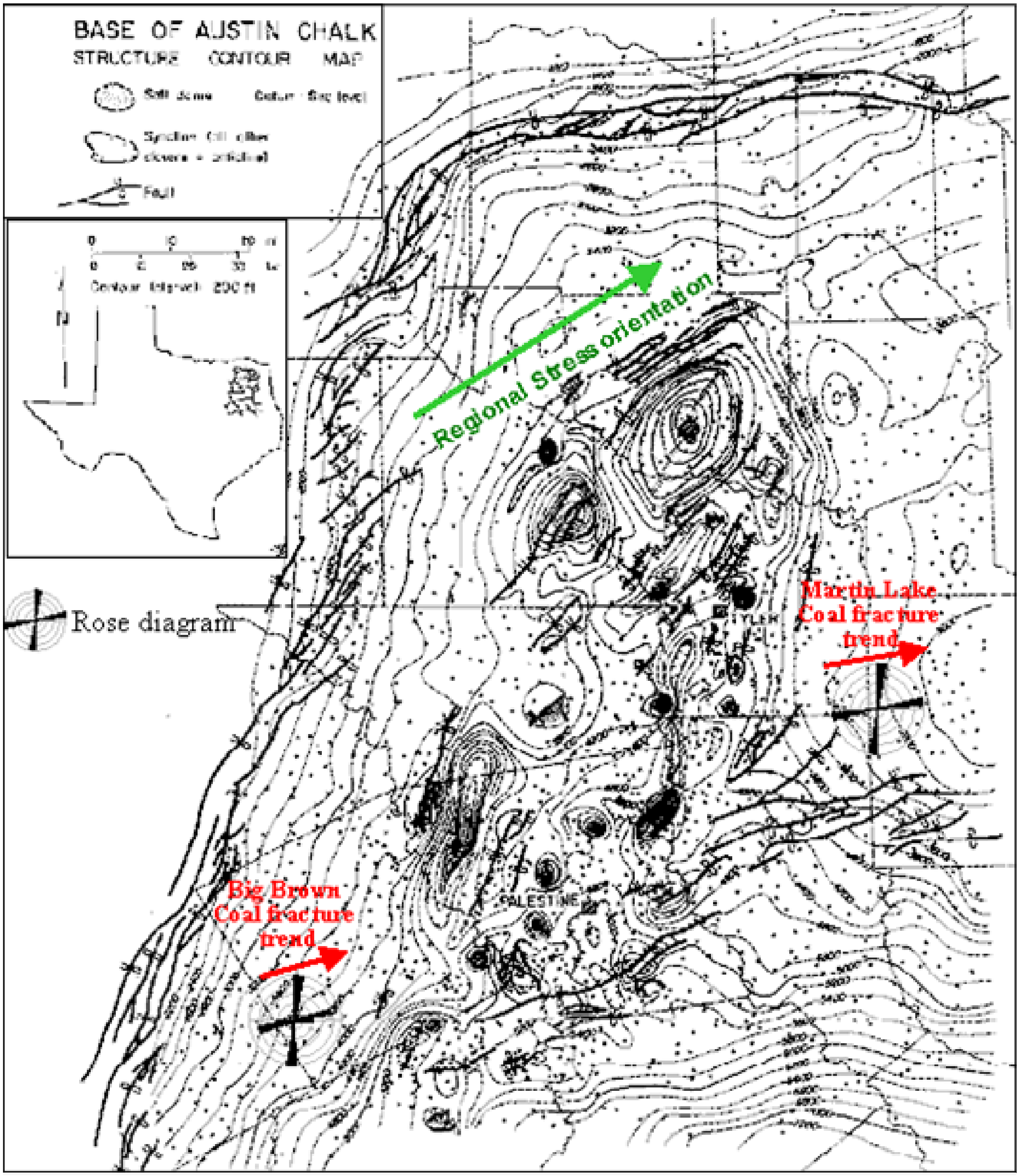

Fig. 7. Big Brown and Martin Lake schematic fracture orientation overlain on structure contour map, base of Austin Chalk, East Texas Basin.

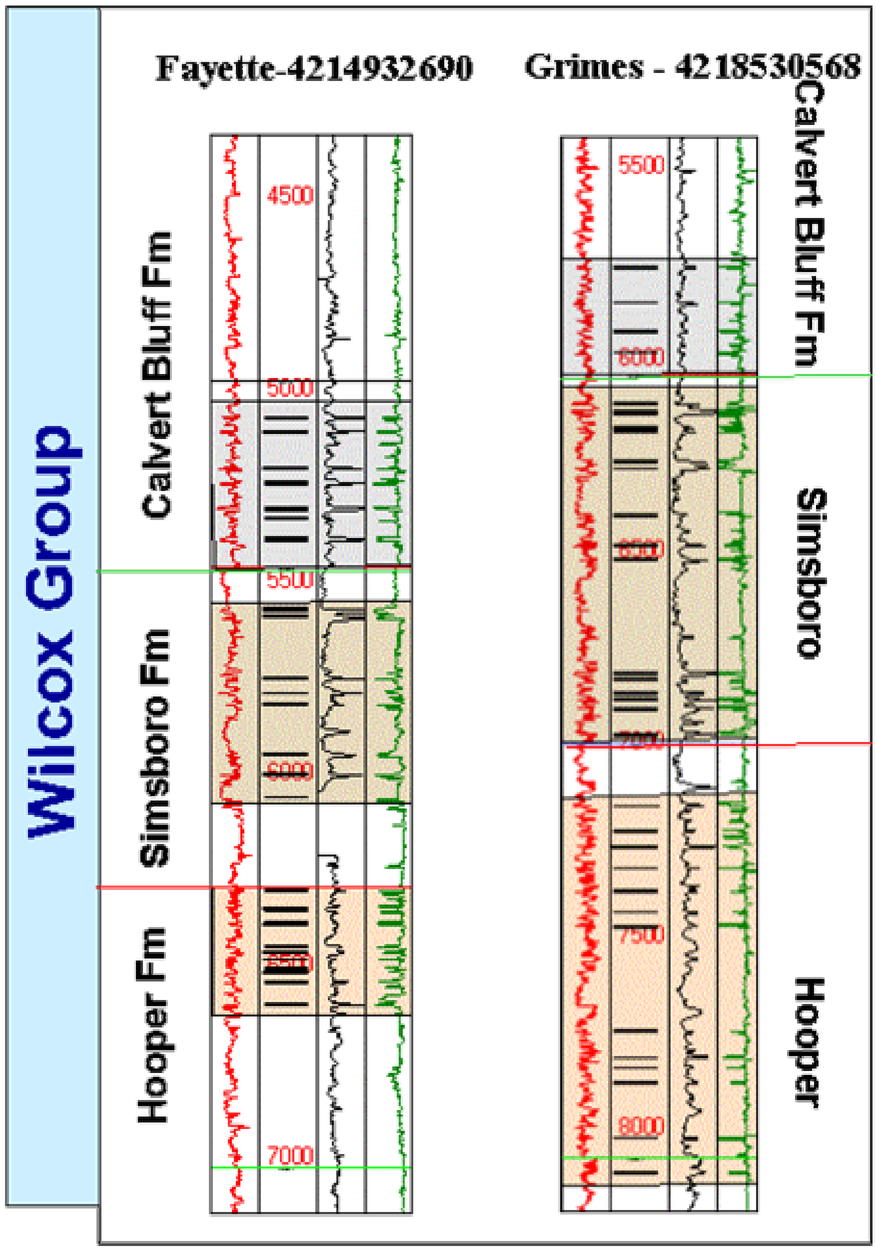

Fig. 8. Lignite occurrence in 2 wells in Fayette and Grimes counties. Note different vertical scales. Red curve is GR (0-150 API, increase from left to right), black -deep resistivity (0 to 5 OHMM, increases from left to right), and green -density porosity (-0.15 to 1 V/V, increasing from right to left). Coal seams are shown as black lines in depth track. Colored filled areas denote coal-bearing zones within each formation. Coal occurs in the lower part of Calvert Bluff (CB), and in the Simsboro and upper Hooper Formations.

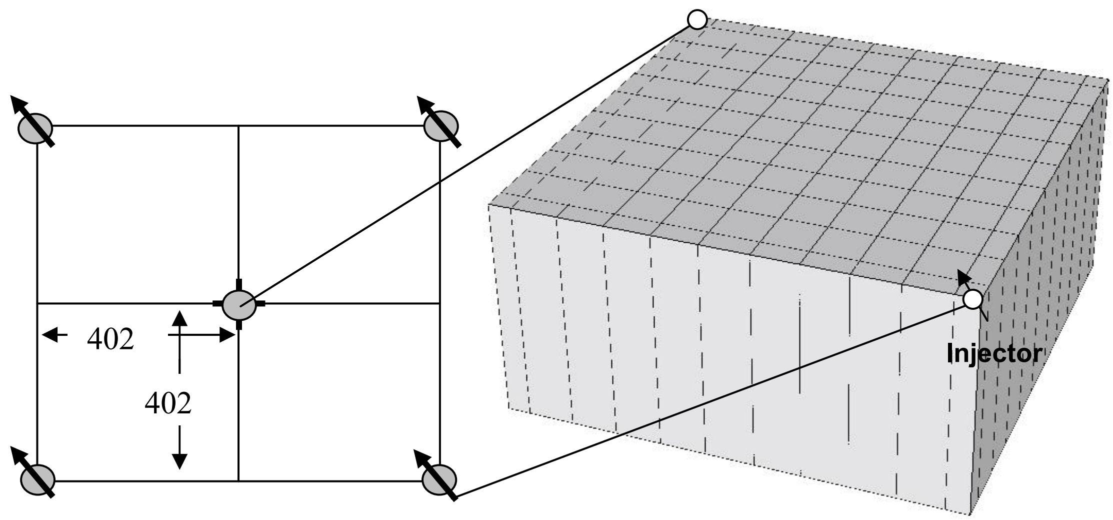

Fig. 9: One-quarter 5-spot reservoir simulation model.

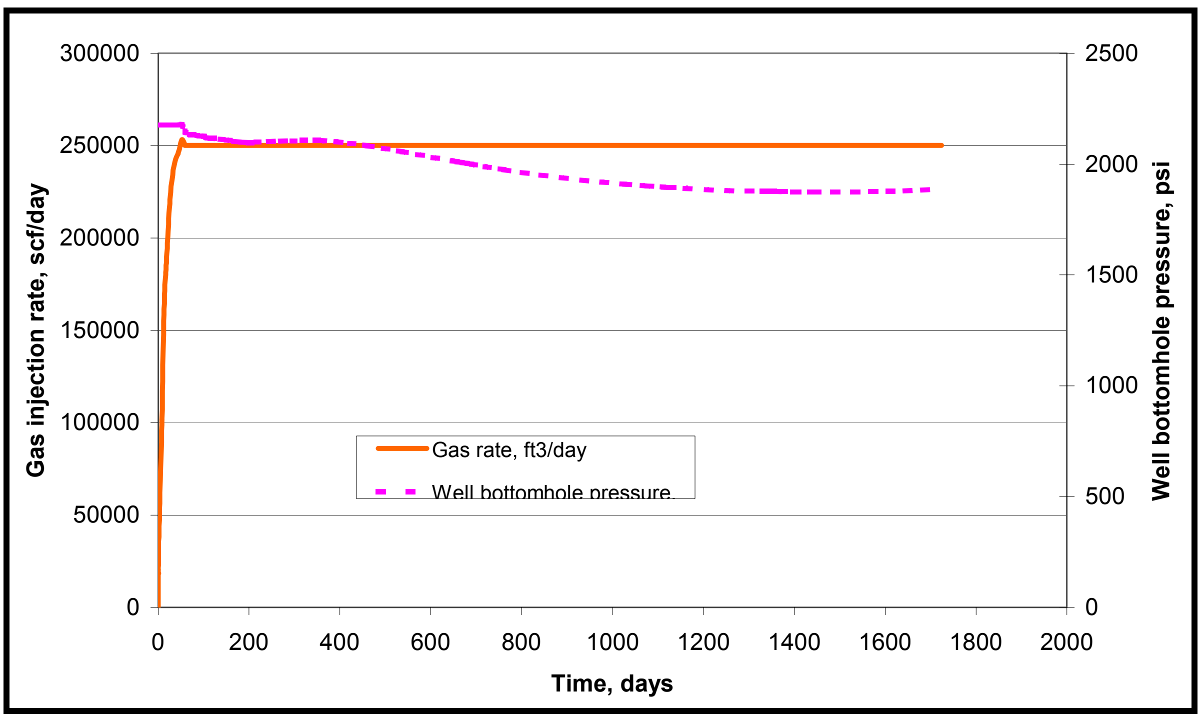

Fig. 10: CO_2 injection rate and bottom hole pressure for the injection well. Rates are for ¼ well.

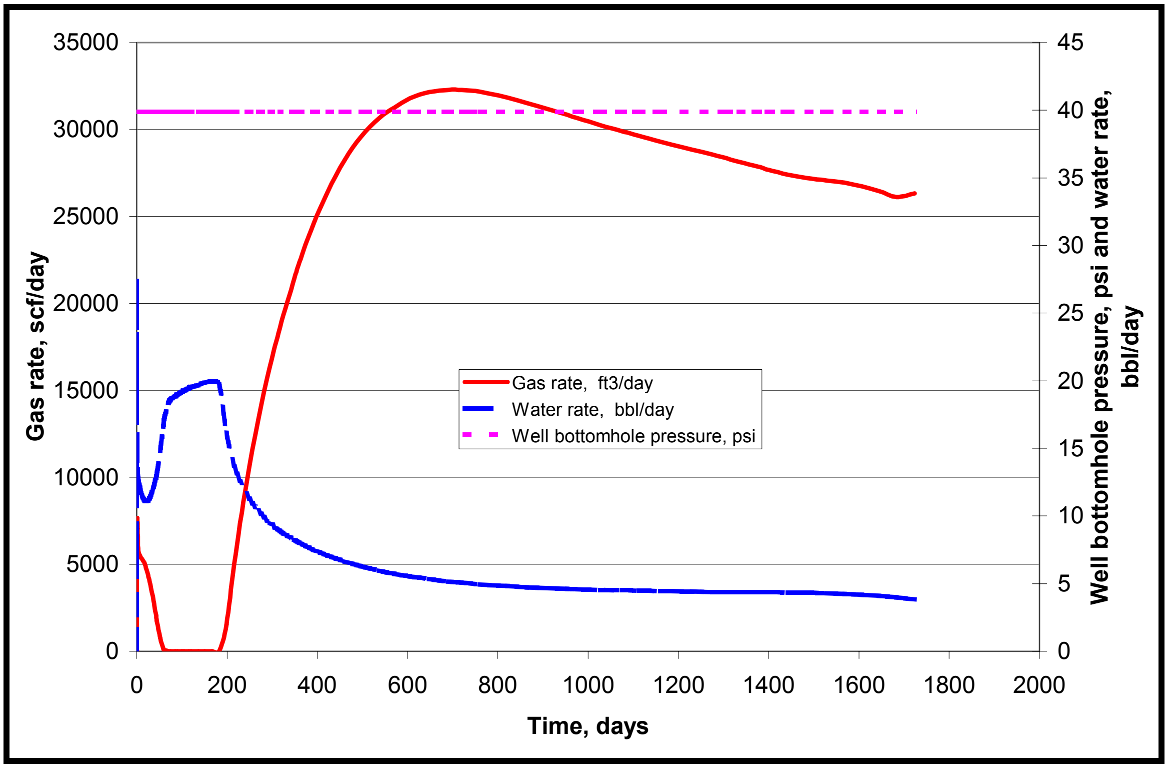

Fig. 11: Methane production rate, water production rate and bottom hole pressure for the production well. Rates are for ¼ well.