CO_2 Sequestration Potential Of Texas Low-Rank Coals

Quarterly Technical Progress Report

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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 primary objectives for this reporting period were to construct a coal geological model for reservoir analysis and to continue modeling studies of CO_2 sequestration performance in coalbed methane reservoirs under various operational conditions.

Detailed correlation of coal zones is important for reservoir analysis and modeling. Therefore, we interpreted and created isopleth maps of coal occurrences, and correlated individual coal seams within the coal bearing subdivisions of the Wilcox Group – the Hooper, Simsboro and Calvert Bluff formations.

Preliminary modeling studies were run to determine if gravity effects would affect the performance of CO_2 sequestration in coalbed methane reservoirs. Results indicated that gravity could adversely affect sweep efficiency and, thus, volumes of CO_2 sequestered and methane produced in thick, vertically continuous coals. Preliminary modeling studies were also run to determine the effect of injection gas composition on sequestration in low-rank coalbeds. Injected gas composition was varied from pure CO_2 to pure N_2, and results show that increasing N_2 content degrades CO_2 sequestration and methane production performance.

We have reached a Data Exchange Agreement with Anadarko Petroleum Corporation. We are currently incorporating the Anadarko data into our work, and expect these data to greatly enhance the accuracy and value of our studies.

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INTRODUCTION

The 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 (1) establish the geological framework for reservoir modeling using well-log cross sections and coal occurrence maps, and (2) conduct preliminary modeling studies to evaluate the importance of gravity effects and injected gas composition on CO_2 sequestration in coalbed methane reservoirs. An additional objective was to continue pursuing cooperative agreements with operating companies interested in Texas coalbed gas production and CO_2 sequestration potential.

EXPERIMENTAL

None.

RESULTS AND DISCUSSION

Coal Reservoir Framework

Determination of the number of coal beds, cumulative and individual coal bed thickness, and lateral extent of coal beds or coal-bearing zones is critical to reservoir characterization and evaluation of the potential for CO_2 sequestration and enhanced coalbed methane production. In this reporting period, well log data were used to make cross sections and to revise regional coal-occurrence maps to establish the coal reservoir framework at two proposed CO_2 sequestration sites in Wilcox Group coals of East Texas.

The types of well logs used to evaluate the coal reservoir framework included density, natural gamma-ray, acoustic, resistivity (ILD or RT and LLS or RXO), and caliper logs. The suite of logs available for interpretation varied greatly among the wells. The density log is the preferred tool for coal identification. In coal beds, density, acoustic velocity, and gamma ray log responses are commonly low, whereas resistivity values are high.

We identified coal occurrences in the well logs and correlated coal beds and/or coal-bearing zones among wells at the proposed Sam Seymour (Site 1) and Gibbons Creek (Site 2) locations (Fig. 1). At both sites, the coals occur in the Hooper, Simsboro, and Calvert Bluff Formations of the Wilcox Group (Paleocene-Eocene age). Two cross sections were made for each of the two sites (Fig. 1). In general, thickness of the individual Wilcox formations increases southeastward into the Gulf of Mexico basin (Figs. 2 - 8). At both sites, the Calvert Bluff (lower part), Simsboro, and Hooper (upper) formations are coal-bearing. Because coals in the Simsboro Formation are interbedded with numerous, thick, laterally continuous, water-bearing sandstones, we consider this formation less viable for CO_2 sequestration and enhanced coalbed gas production. The upper Hooper Formation and the lower part of the Calvert Bluff Formation contain much less sandstone, and they have more continuous and correlatable coals than does the Simsboro Formation.

Coal zones or packages are correlatable on a regional scale. At least two of the coal beds in both the Hooper and the Calvert Bluff Formations at both sequestration sites can be correlated for 6 to 10 mi (10 to 17 km). However, correlation of most individual coal beds is difficult and equivocal because of the discontinuous character of coal (peat) deposits that formed in fluvial (Simsboro and Calvert Bluff) and delta plain settings (Hooper) (Ayers and Lewis, 1985). These depositional environments of the coals may limit the lateral extent of individual coal beds to a few miles. Coal beds tend to split and pinch out toward channel-fill sand complexes or, in other settings, individual, thin coal beds merge into one thicker bed. Commonly, it is impossible to determine which individual coal beds are correlatable and are in hydraulic communication. To characterize the coalbed reservoir framework at Sites 1 and 2, we correlated coal-bearing zones and, where possible, individual coal beds (Figs. 3, 5, 7 and 8).

Isopleth maps show the number of coal beds greater than 2 ft thick in each formation and will be used to build models for reservoir simulation. We constructed isopleth maps for each site and incorporated the results with existing available coal occurrence maps of Calvert Bluff and Hooper formations (Figs. 9 - 12).

The thickness of the coal beds affects the volumes of CO_2 that can be sequestered and the volumes of methane that may be produced from a given area or well. Also, production techniques are easier and less expensive to implement in thick coal beds than in thin coal beds. Therefore, only coal in beds greater than or equal to 2 ft thick are included in our reservoir characterization model. The data available for coal thickness determinations were oil and gas well logs. The quality and resolution of the well log data are poor in some wells, which makes it difficult to determine accurate thicknesses of coal seams. Tables 1a and 1b summarize the thicknesses of correlatable coal seams for Sites 1 and 2, respectively. On average, there are six coal beds with average cumulative thickness of 20 ft (6.1 m) in each formation at sequestration Sites 1 and 2.

Preliminary Modeling Studies: Gravity Effects

Preliminary simulation studies were conducted using the properties for shallow Texas low rank coals obtained from literature (Warwick *et al*, 2000). Table 2 shows the average coal properties used for the modeling studies.

To determine whether gravity effects would significantly affect performance of coalbed methane reservoirs during CO_2 sequestration, we conducted a modeling study of a 5-spot pattern. Two 10-layer reservoir models were constructed. One had vertical communication, representing a scenario with thick coals with vertical continuity. The other had no vertical communication between the layers, representing a coal with interbedded shales or multiple thin coal seams. The results of the modeling study are shown in Figs. 13-17. Figs. 13-16 show colorfill maps of various reservoir properties at breakthrough, i.e., when the produced gas composition reaches 5% mole fraction CO_2. Fig. 17 contains several plots comparing performance of the two cases.

The results indicate that gravity can have significant effects on performance of coalbed methane reservoirs during CO_2 injection. For the case with vertical communication, the results indicate that CO_2 preferentially sweeps upper portions of the reservoir; methane recovered from the lower layers is incomplete. In addition, not all the water in the fracture system is swept from the lower layers.

For the model with no vertical communication, the volume swept by CO_2 for all the layers is the same. More of the water in the fracture system and more of the methane in both the coal and fracture system is produced.

These results indicate that CO_2 sequestration and enhanced coalbed methane production may be adversely affected by gravity in thick, vertically communicating coals. This is a preliminary study that considers only gravity effects and does not consider the possibility that thin, heterogeneous coals may be less continuous laterally.

Preliminary Modeling Studies: Effects of Injected Gas Composition

In this study we analyzed coalbed methane reservoir behavior under varying injection gas compositions. For the simulation studies, one quarter of a 5-spot pattern was modeled in a single-layer model. Injection gas compositions were varied from pure CO_2 to pure N_2. The results are shown in Figs. 18-21. Figs. 18-20 show colorfill maps of various reservoir properties at breakthrough. Breakthrough was defined as the time when the produced gas stream reached more than either 5% N_2 or 5% CO_2 by mole fraction. Fig. 21 shows two plots comparing performance of the various cases.

With increasing N_2 mole fractions in the injected gas, methane production decreases and breakthrough occurs earlier than with pure CO_2 injection. Low rank coals adsorb CO_2 efficiently and rapidly. The effects of N_2 in the injected gas are to reduce the partial pressure of methane and aid in its desorption from the coal, but this effect is not as significant as the adsorption of CO_2 and simultaneous displacement of methane. Consequently, lower recoveries of methane are predicted with increasing nitrogen composition in the injected gas. In cases where the injected gas stream contains N_2, breakthrough time is reached due to the presence of more than 5% mole fraction N_2 in the produced gas. As a result, CO_2 does not sweep the entire reservoir and does not reach the producer. Consequently, since the CO_2 adsorption-CH_4 desorption process is more efficient, lower CH_4 production is forecasted.

Data Exchange Agreement

We recently signed a Data Exchange Agreement with Anadarko Petroleum Corporation. Anadarko has evaluated the deep coals in several wells in the vicinity of Sites 1 and 2. We have received desorption, adsorption, and gas analysis reports and other data from three Anadarko wells, and will provide Anadarko with data in our possession as well as results of reservoir characterization and modeling studies. We are currently incorporating the Anadarko data into our work. We expect these data to greatly enhance the accuracy and value of our studies, because the data are from coals at depths comparable to those at the potential CO_2 sequestration sites.

CONCLUSIONS

1. Multiple coal beds greater than 2 ft (0.6 m) thick occur in zones or intervals in the lower Calvert Bluff, Simsboro, and Hooper Formations of the Wilcox Group at proposed CO_2 sequestration Sites 1 and 2.
2. The upper Hooper and the lower Calvert Bluff Formation coal-bearing intervals are most viable for CO_2 sequestration and enhanced coalbed gas production. Coal beds occur in the Simsboro Formations but are less prospective, because they are interbedded with thick, water-bearing sandstones.
3. On average, there are six coal beds with average cumulative thickness of 20 ft (6.1 m) in each formation at sequestration Sites 1 and 2.
4. At least two of the coal beds in both the Hooper and the Calvert Bluff Formations at both sequestration sites can be correlated for 6 to 10 mi (10 to 17 km).
5. Preliminary modeling indicates that gravity effects can be significant in the sequestration of CO_2 and production of methane from coalbed methane reservoirs.
6. Injected gas composition affects breakthrough times and amount of methane produced. Greater CO_2 mole fractions in the injected gas stream increase methane recovery from the coal beds

References

Ayers, W.B., and Lewis, A.H., 1985, The Wilcox Group and Carrizo Sand (Paleogene) in East-Central Texas: Depositional Systems and Deep-Basin Lignite, Bureau of Economic Geology, The University of Texas at Austin.

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 1a. Thickness of correlatable coal beds and total number of coal seams > 2 ft thick at Site 1.

SITE 1			4214932690	4214932786	4214932883	4214932790	4214932832	4214932877
Reliability category based on log quality and scale			good	good	poor	poor	good	poor
Calvert Bluff	Coal Thickness (ft)	**1**	2.0	4.0	4.0	3.0	2.8	4.0
		2	2.2	2.5	3.0	2.0	2.6	3.0
		3	3.2	4.2			4.6	4.0
		4	3.2	6.5	4.0	4.0	7.0	4.0
		5	6.0	6.5	4.0	4.0	4.0	5.0
		6		4.0	5.0	4.0	5.0	4.0
		7	5.2	3.4			1.6	3.0
Total number of coal			**8**	**12**	**11**	**5**	**16**	**14**
Simsboro	Coal Thickness (ft)	**1**	7.0	7.0	4.0	5.0	4.0	
		2	4.0	8.0			5.0	4.0
		3	2.2	3.2	3.0	3.0	6.0	3.2
		4	4.0	2.0			3.4	3.0
		5	2.1	4.0	4.0	4.0	2.5	4.0
		6	7.5	4.0	4.0	5.0	3.2	
		7	3.0	2.4				
Total number of coal			**9**	**11**	**5**	**8**	**9**	**4**
Hooper	Coal Thick ness (ft)	**1**	2.2	10.0	5.0	4.0	4.0	3.0
		2	2.0	2.0				
		3	2.0	3.2	3.0	3.0		
		4	2.0	2.0		2.0		
		5	2.2	2.5	3.0	3.0		
Total number of coal			**11**	**10**	**3**	**8**	**6**	**3**

Table 1b. Thickness of correlatable coal beds and total number of coal seams > 2 ft thick at Site 2.

SITE 2			4204131541	4204131673	4218530389	4218530275	4204131757	4218530483	4218530525	4218530568
Reliability category based on log quality and scale			poor	poor	poor	poor	good	good	poor	good
Calvert Bluff	Coal Thisckness ((ft)	**1**	2.0		2.0	2.0				
		2	3.0	4.0	3.0	3.0	3.5	3.0		
		3	6.0		3.0	2.0			4.0	3.5
		4	4.0	6.0		2.0	4.0	4.0	3.0	3.0
		5	4.0	6.0			5.0	4.0	5.0	2.0
Total number of coal			**7**	**5**	**8**	**8**	**4**	**7**	**5**	**6**
Simsboro	Coal Thickness, (ft)	**1**		4.0	2.0	2.0	3.0	2.0	3.0	5.0
		2		2.0	2.0	3.0			3.0	3.0
		3	4.0		3.5	3.0		4.0		4.0
		4	3.0		3.0	2.0	3.0	5.0	4.0	5.4
		5	5.0		2.6			4.0		5.0
		6	4.0	5.0			5.0	4.0		5.0
Total number of coal			**5**	**3**	**7**	**5**	**3**	**17**	**9**	**17**
Hooper	Coal Thickness (ft)	**1**	6.0	5.0			4.0	3.0	4.0	5.0
		2		4.0	3.5		5.0	2.0		4.0
		3	5.0	2.0	3.0		3.5			4.0
		4	4.0	3.0	3.0		3.0	2.4	3.5	4.0
		5	4.0	3.0	3.0		4.0			2.0
		6		5.0			4.0	4.0		2.0
Total number of coal			**6**	**9**	**6**	**1**	**11**	**5**	**2**	**14**

Table 2. Reservoir Coal Properties Used for the Modeling Study.

Coal Seam Thickness	3 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

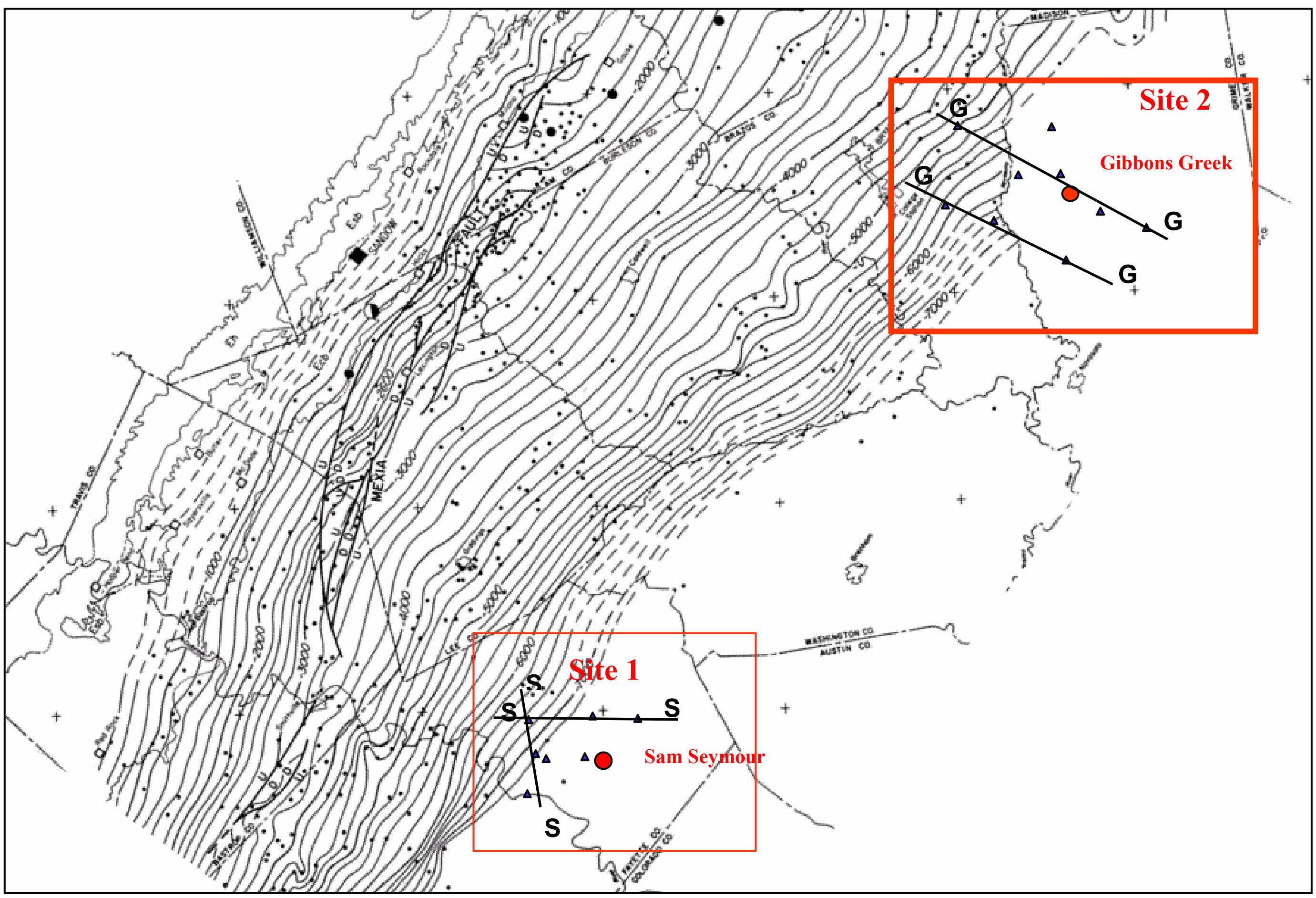

Fig. 1. Structure of base of Wilcox Group and correlation lines in proposed sequestration area (Sites 1 and 2). Red circles are proposed sequestration sites. Wells used to modify the regional maps are shown as triangles (Modified from Ayers and Lewis, 1985)

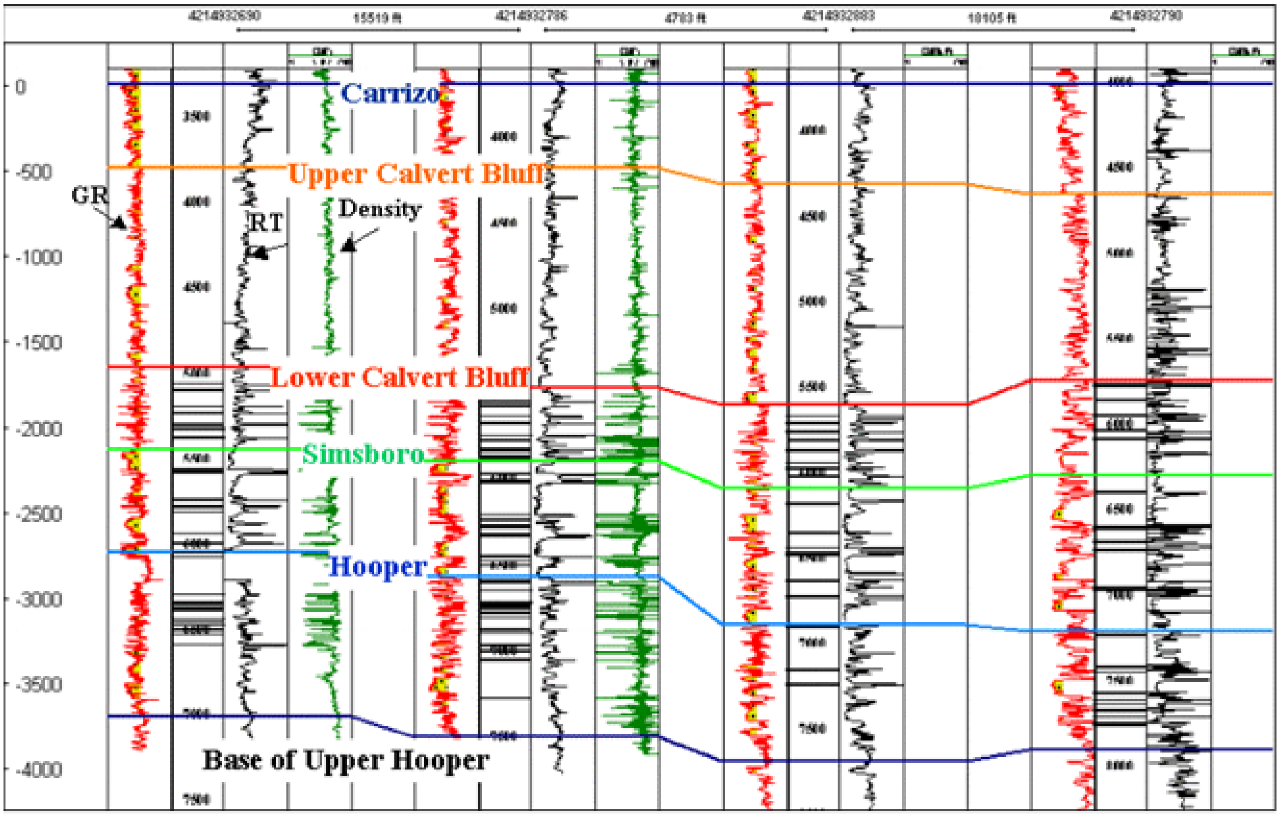

Fig. 2. Stratigraphic cross section S1-S1' (Fig. 1) showing subdivisions of Wilcox Group and coal occurrences (datum top of Carrizo Sandstone).

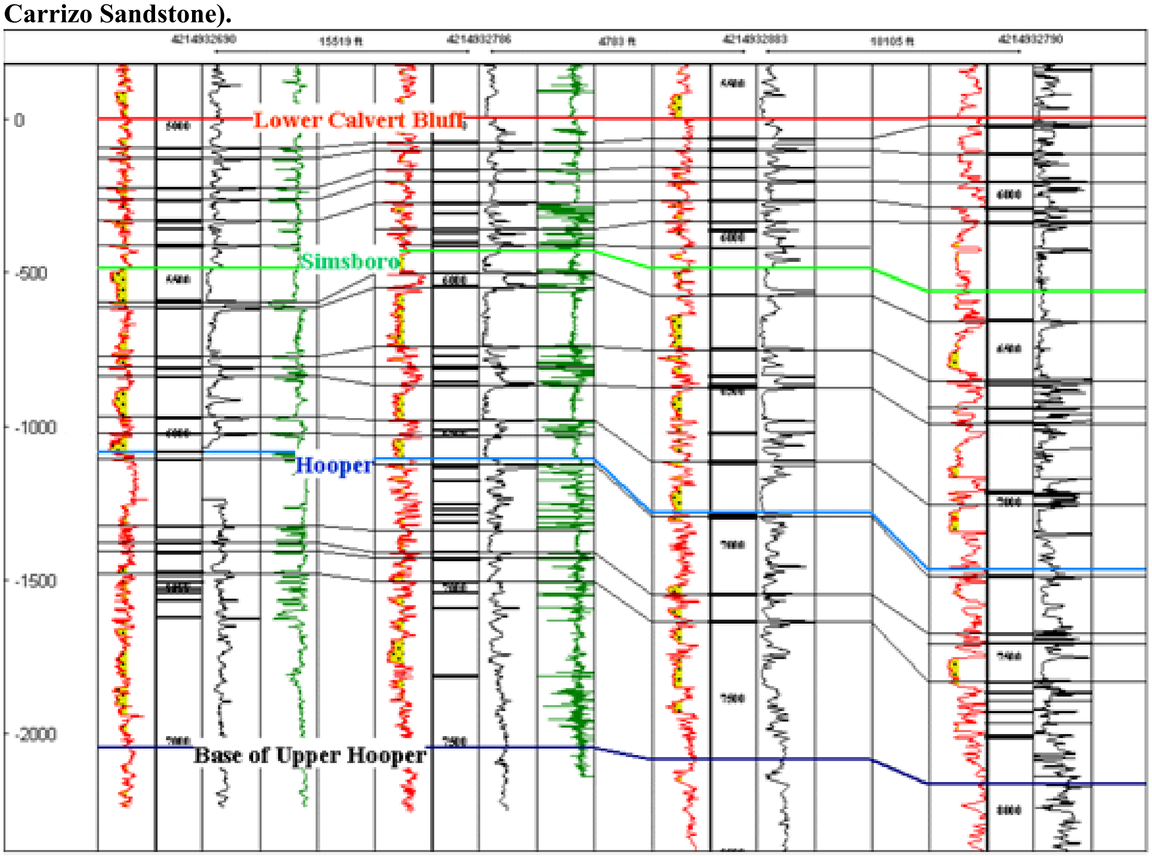

Fig. 3. Stratigraphic cross section S1-S1' (Fig. 1) showing correlation of individual coal seams. (datum top of Lower Calvert Bluff Formation).

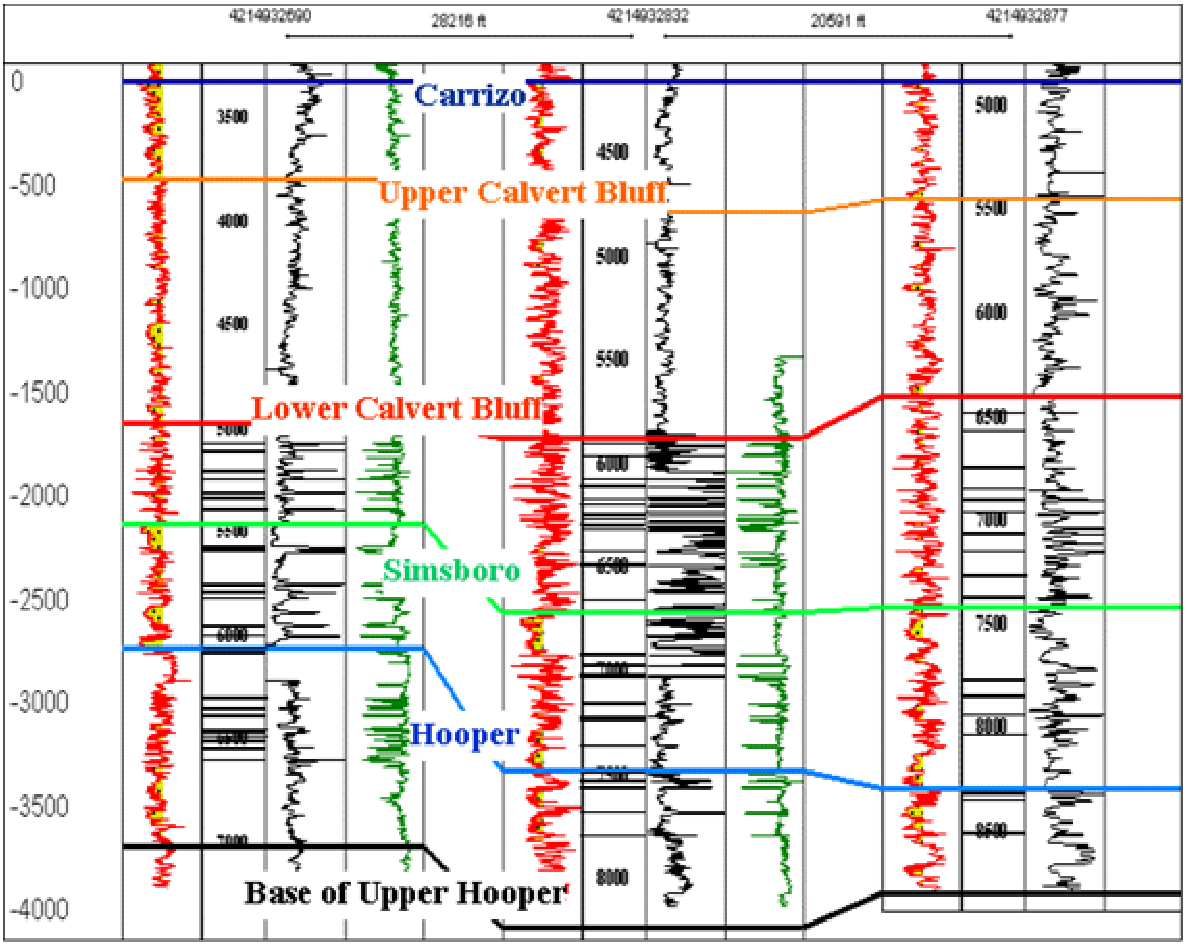

Fig. 4. Stratigraphic cross section S2-S2' (Fig. 1) showing subdivisions of Wilcox Group and coal seam occurrences (datum top of Carrizo Sandstone).

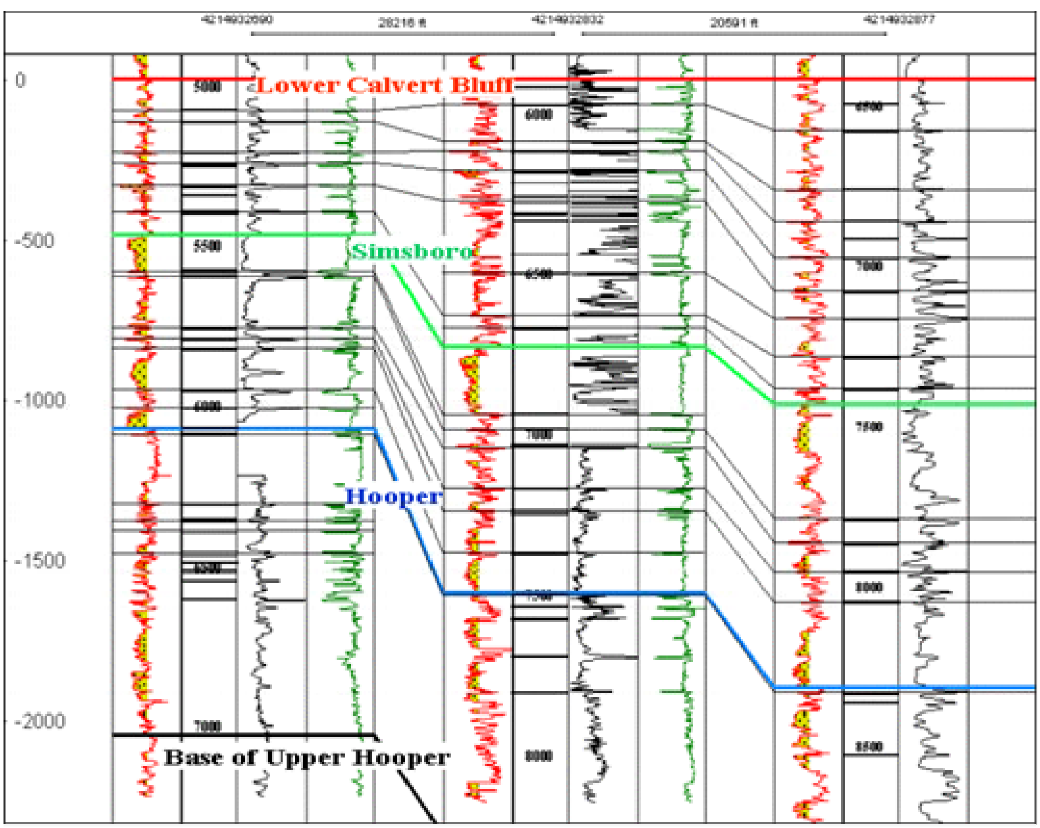

Fig. 5. Stratigraphic cross section S2-S2' (Fig. 1) showing correlation of individual coal seams (datum is top of Lower Calvert Bluff Formation).

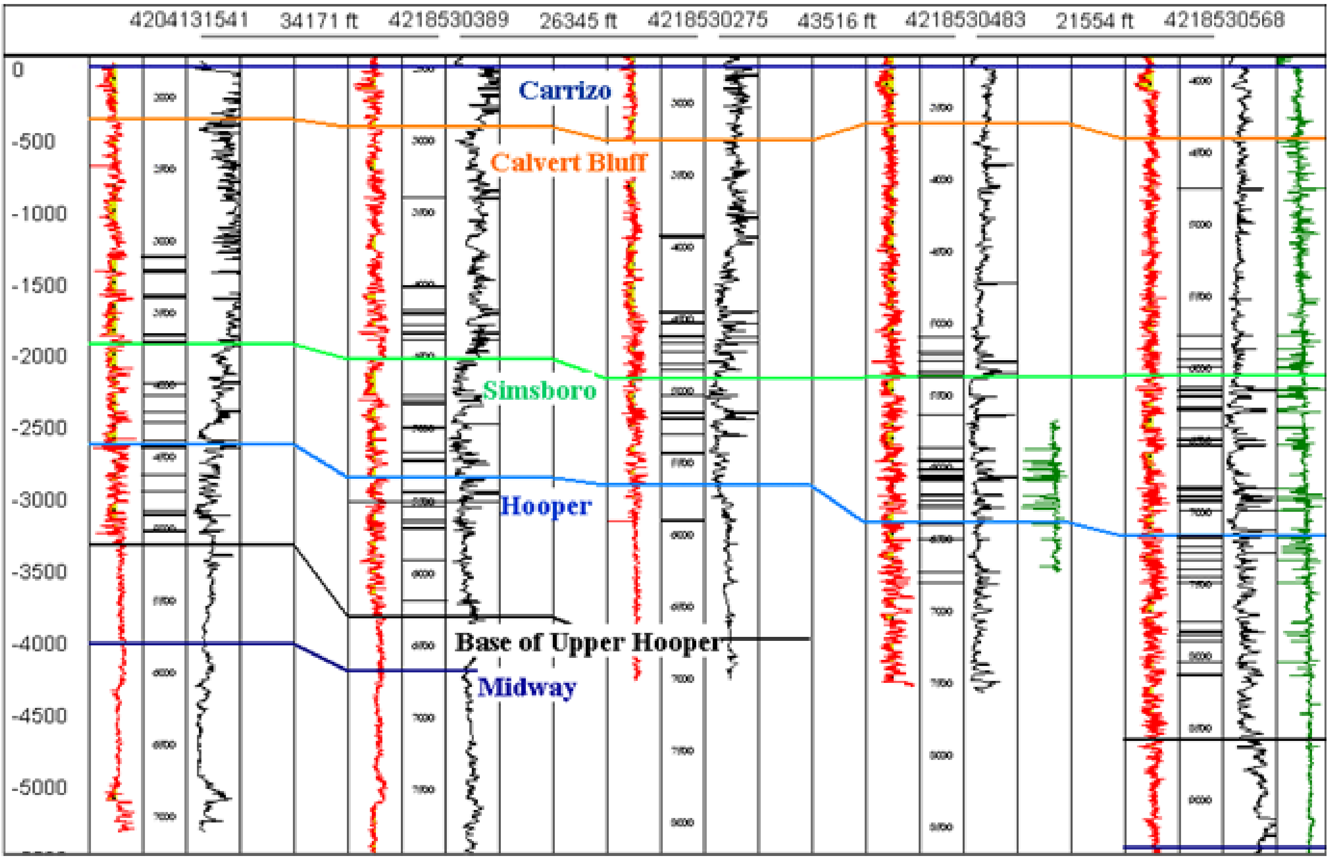

Fig. 6. Northwest to southeast stratigraphic cross section G1-G1' (Fig. 1) showing subdivisions of Wilcox formation and coal seams. (datum is top of Carrizo Sandstone).

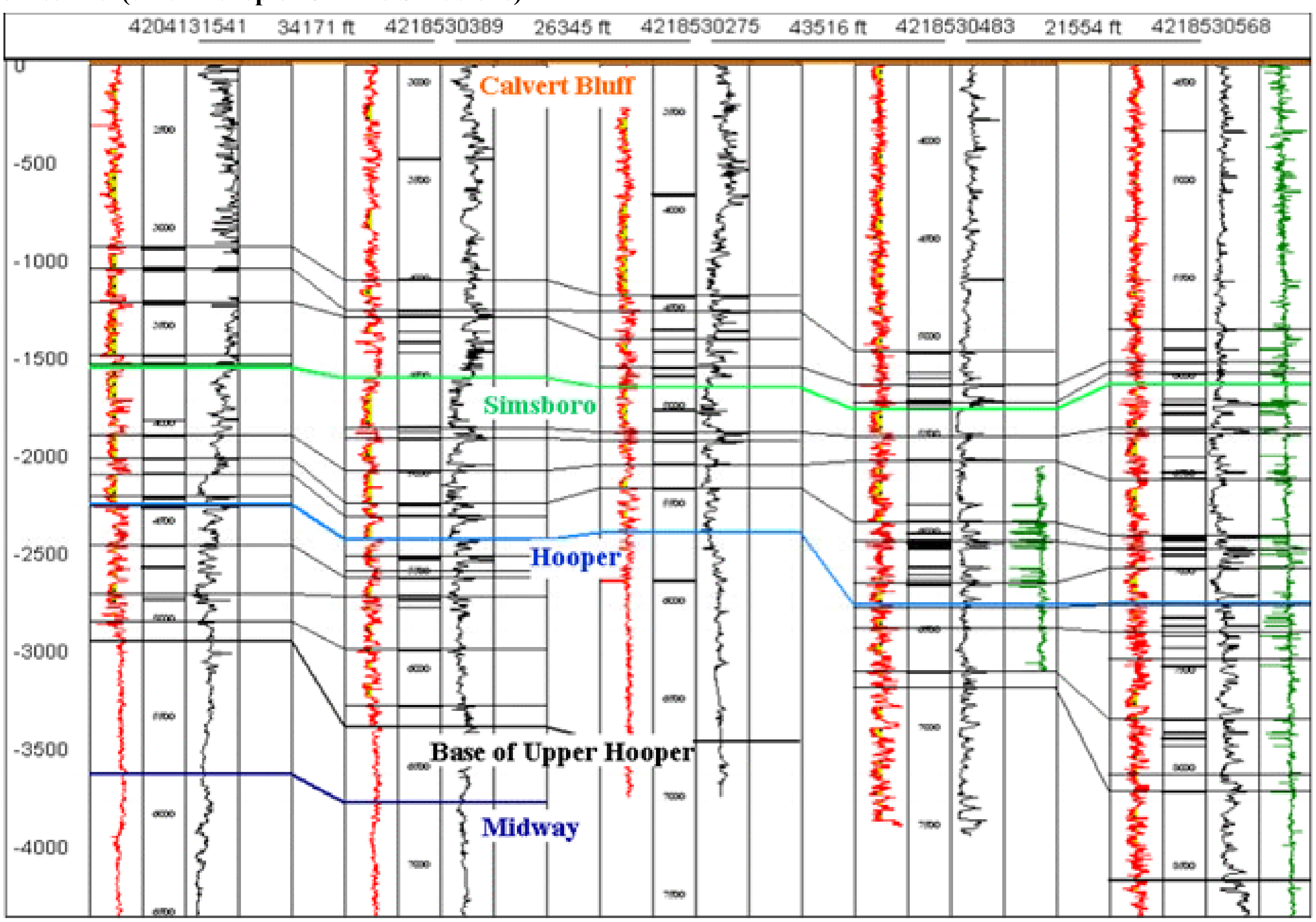

Fig. 7. Stratigraphic cross section G1-G1' (Fig. 1) showing correlation of individual coal seams. (datum is top of Calvert Bluff Formation).

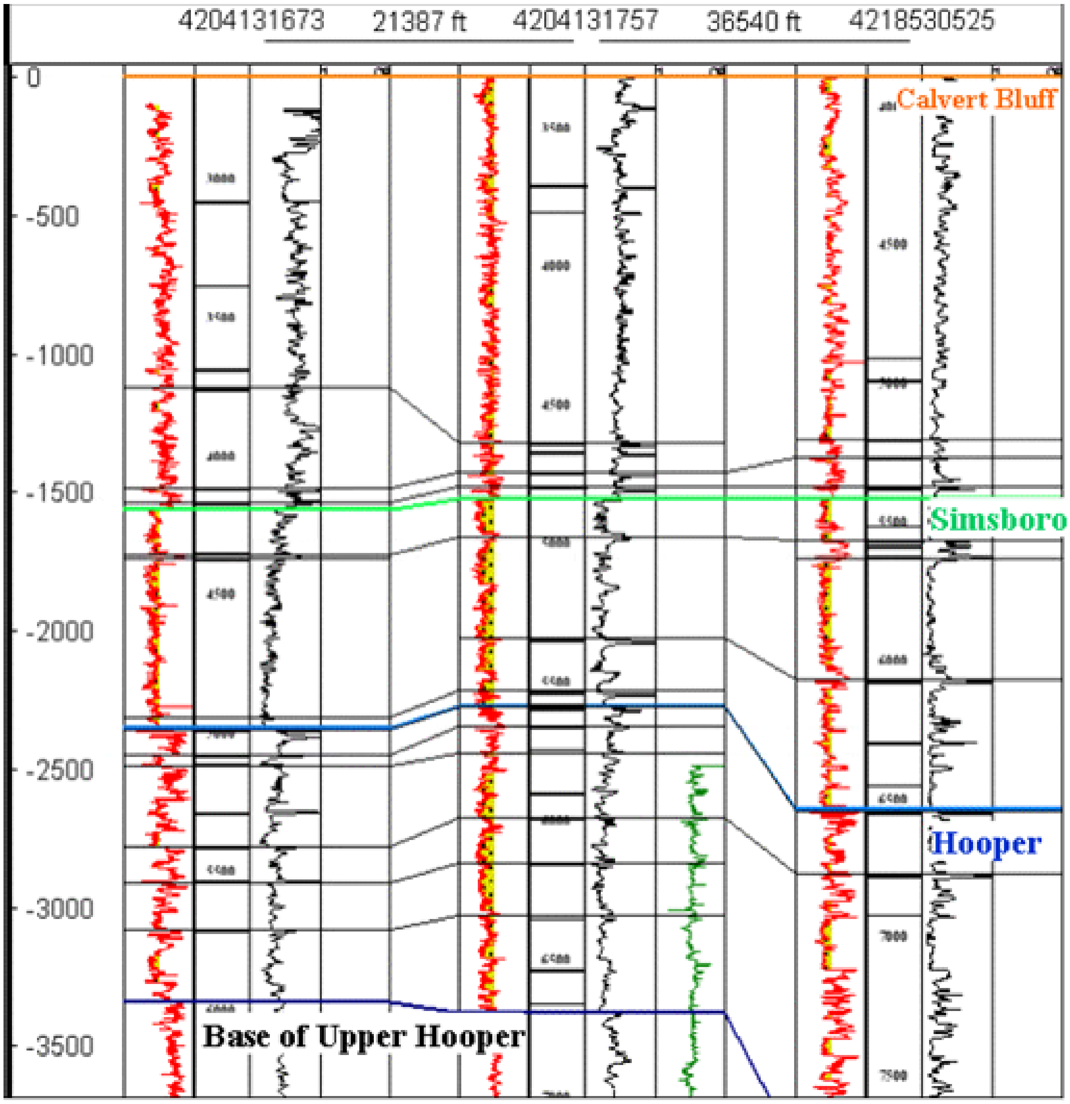

Fig. 8. Stratigraphic cross section G2-G2' (Fig. 1) showing correlation of individual coal seams. (datum is top of Calvert Bluff Formation).

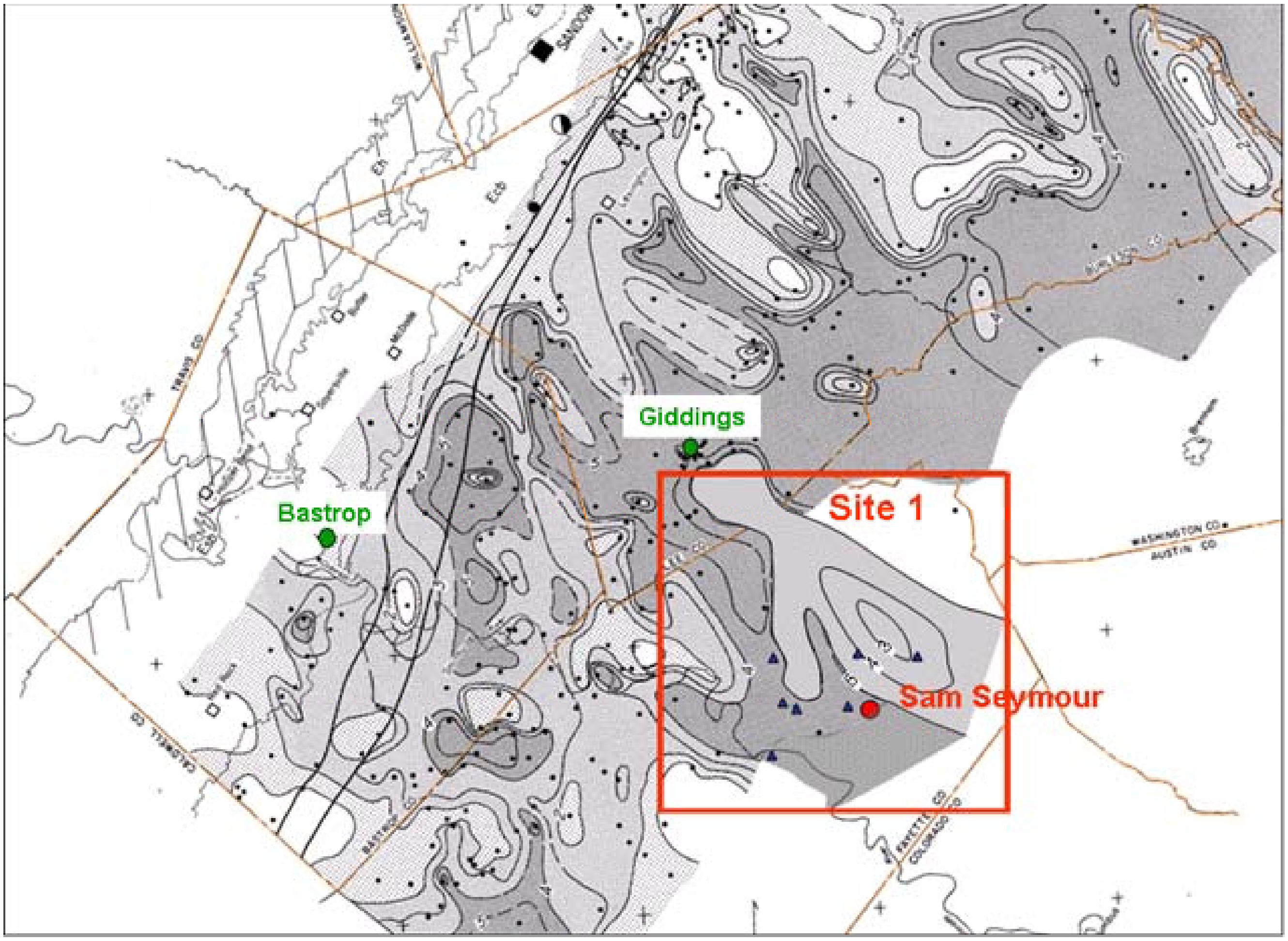

Fig. 9. Hooper isopleth map of Site 1 and adjacent areas. Wells used to modify the regional map are shown as triangles (modified from Ayers and Lewis, 1985).

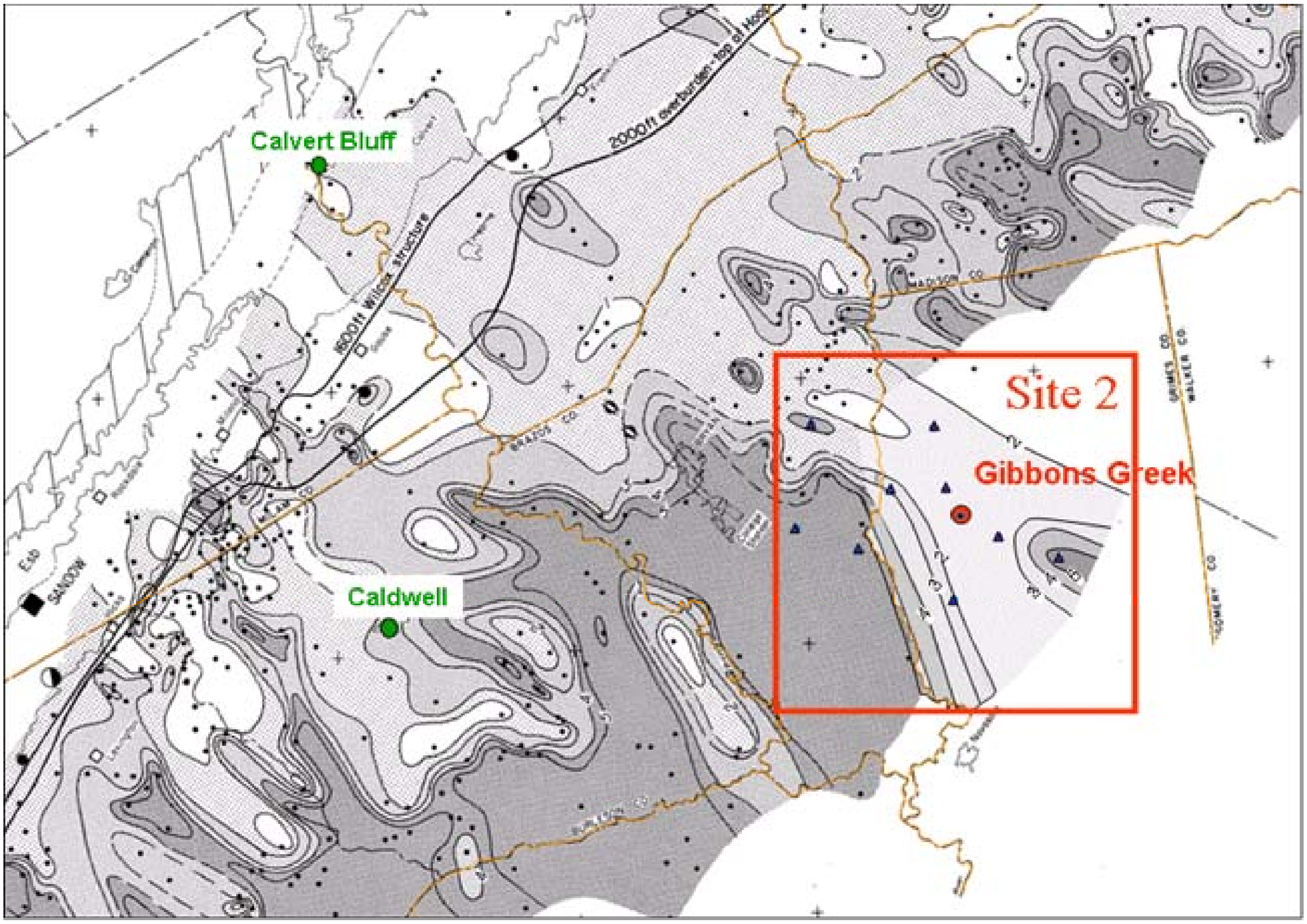

Fig. 10. Hooper isopleth map for Site 2 and adjacent areas. Wells used to modify the regional map are shown as triangles (modified from Ayers and Lewis, 1985).

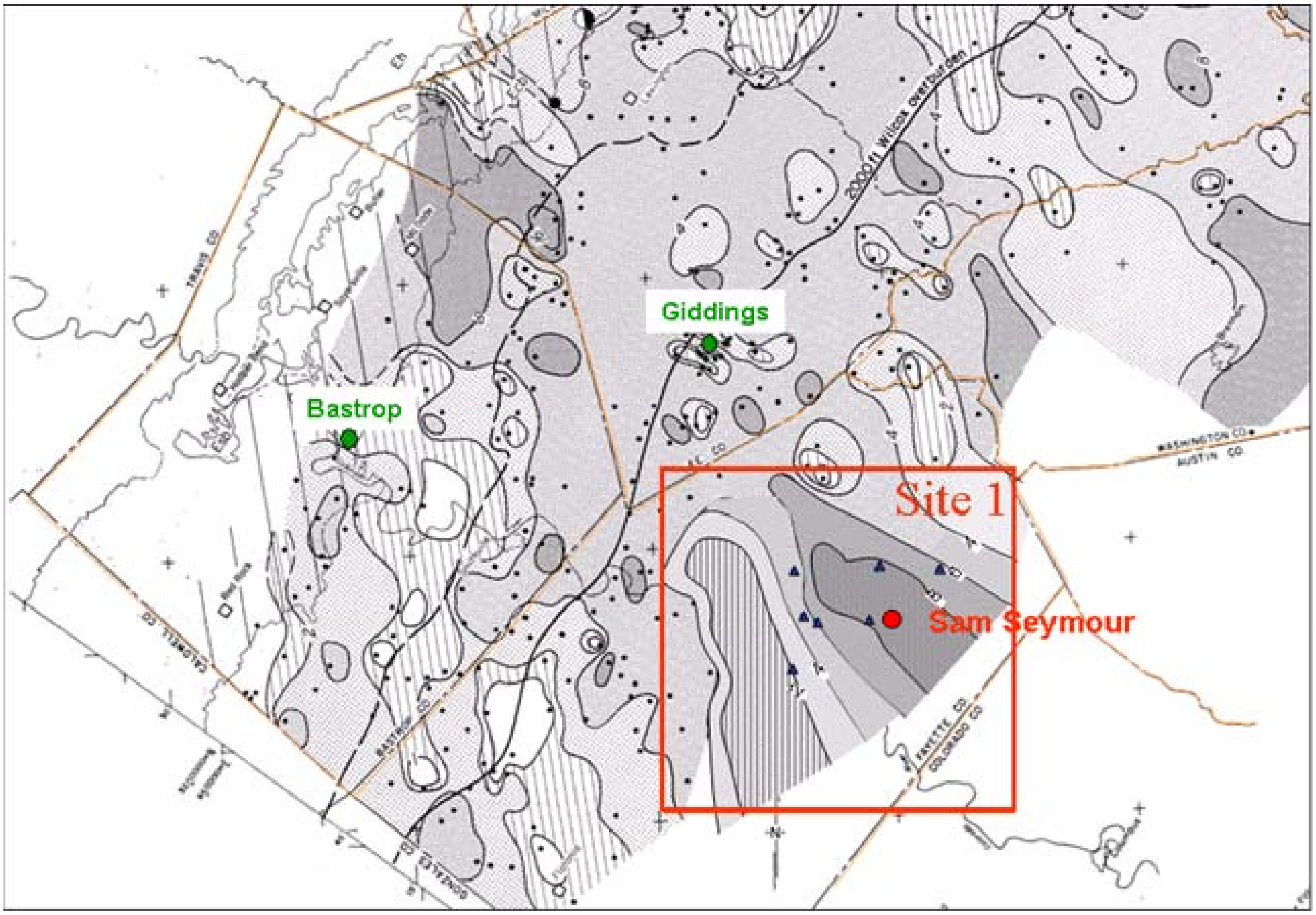

Fig. 11. Calvert Bluff isopleth map in Site 1 and adjacent areas. Wells used to modify the regional map are shown as triangles (modified from Ayers and Lewis, 1985).

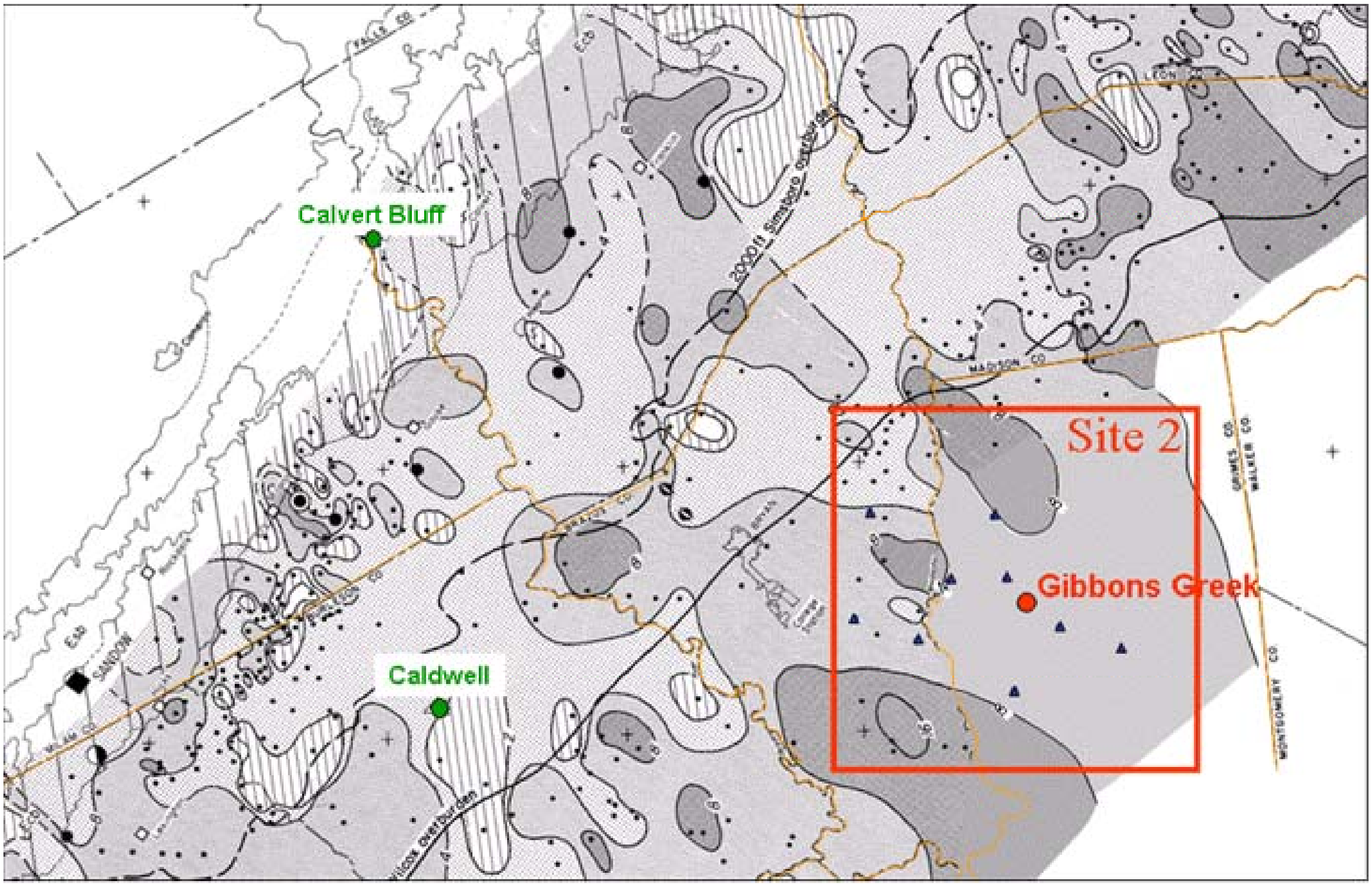

Fig. 12. Calvert Bluff isopleth map of Site 2 and adjacent areas. Wells used to modify the regional map are shown as triangles (modified from Ayers and Lewis, 1985).

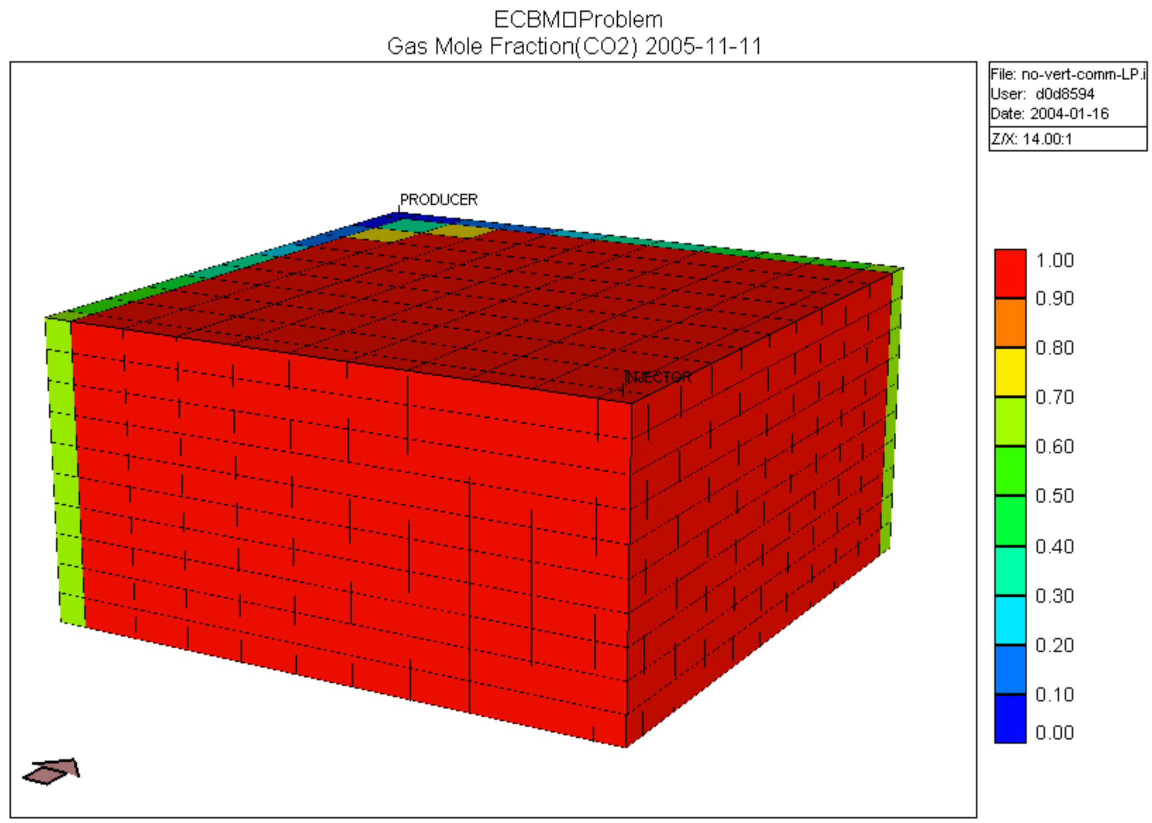

Fig. 13a. CO_2 Mole Fraction at Breakthrough-No Vertical Communication.

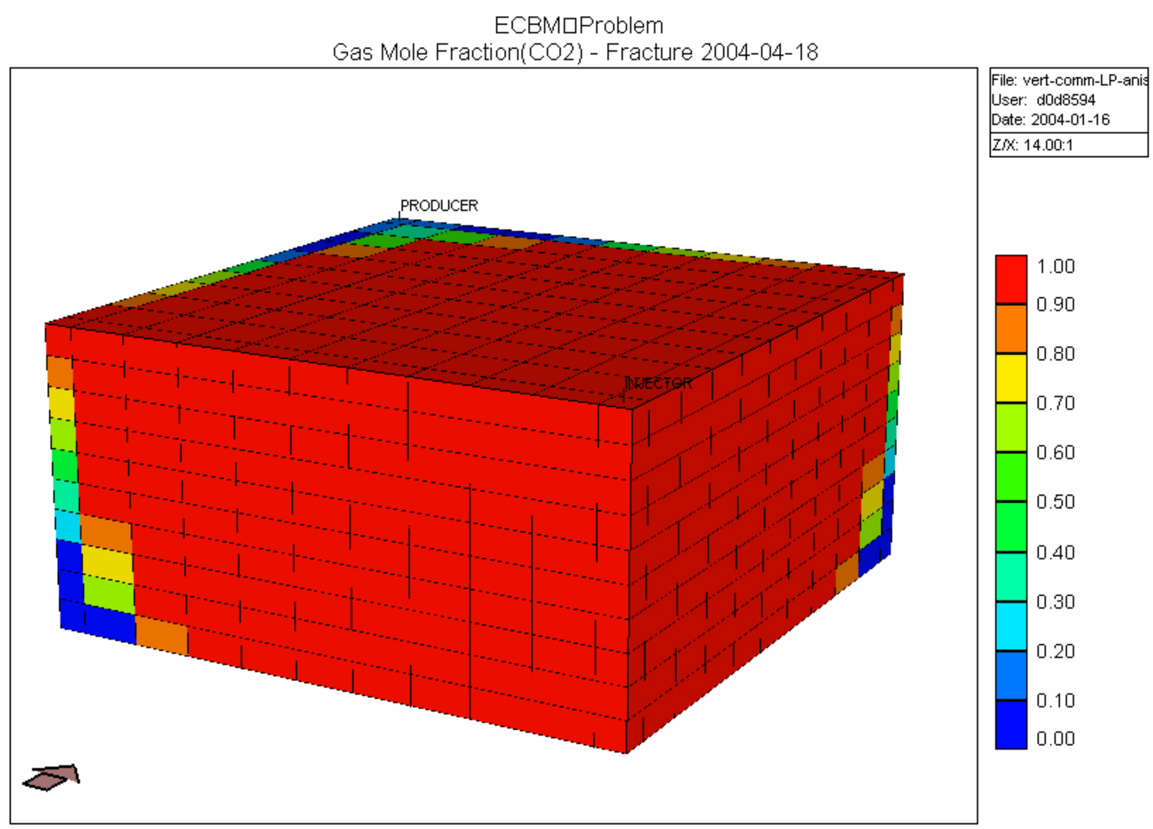

Fig. 13b. CO_2 Mole Fraction at Breakthrough -With Vertical Communication.

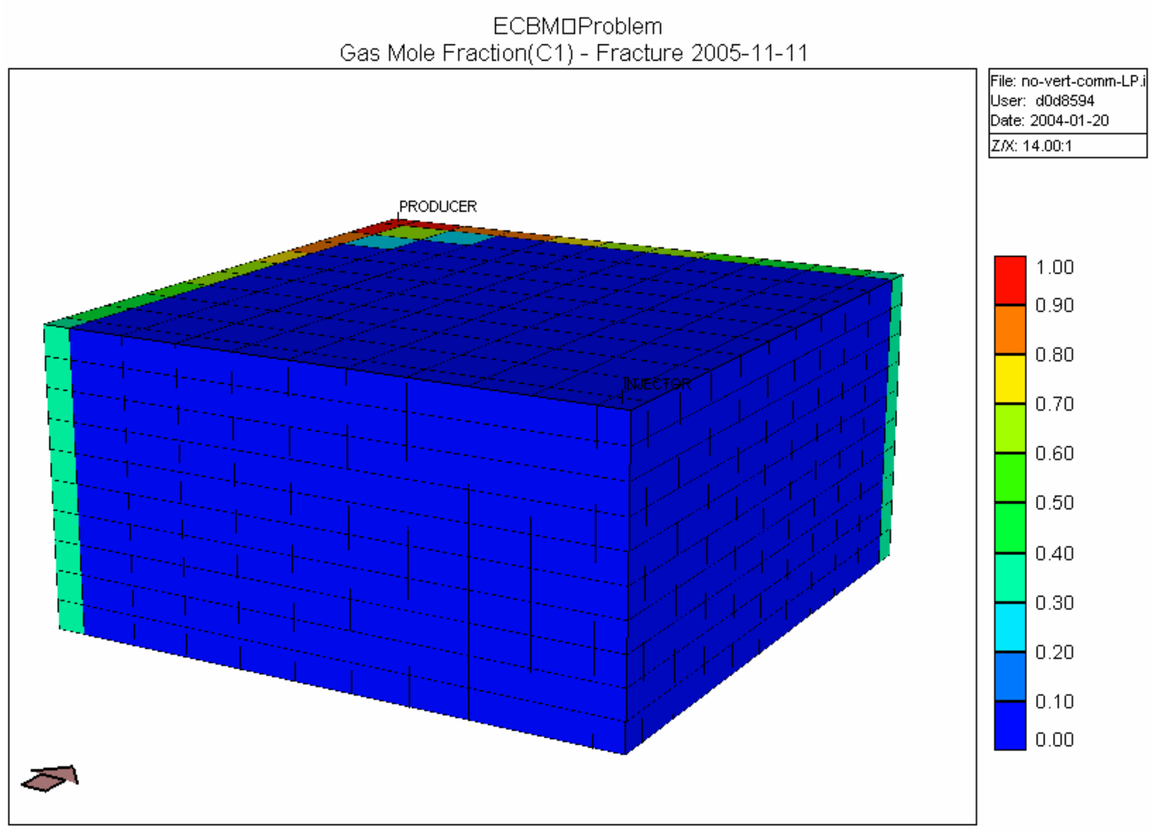

Fig. 14a. CH4 Mole Fraction at Breakthrough, No Vertical Communication.

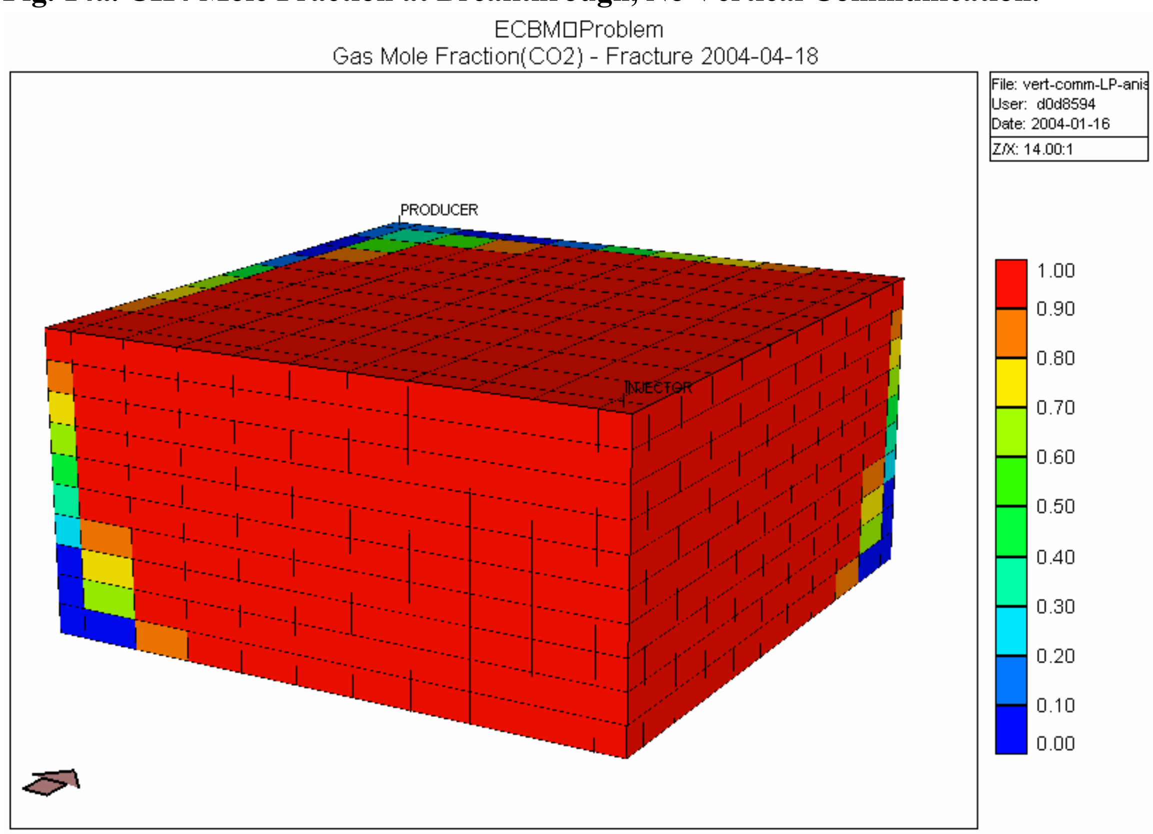

Fig. 14b. CH4 Mole Fraction at Breakthrough, With Vertical Communication.

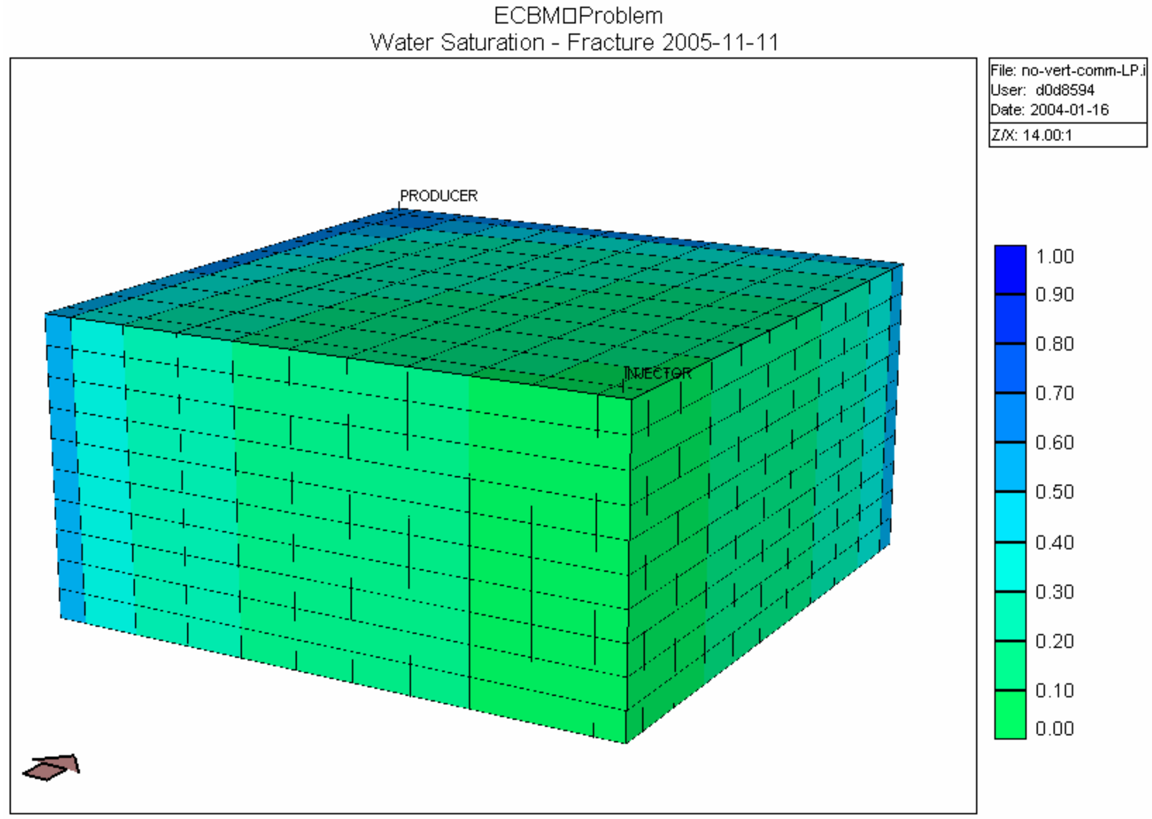

Fig. 15a. Water Saturation Profile at Breakthrough, No Vertical Communication.

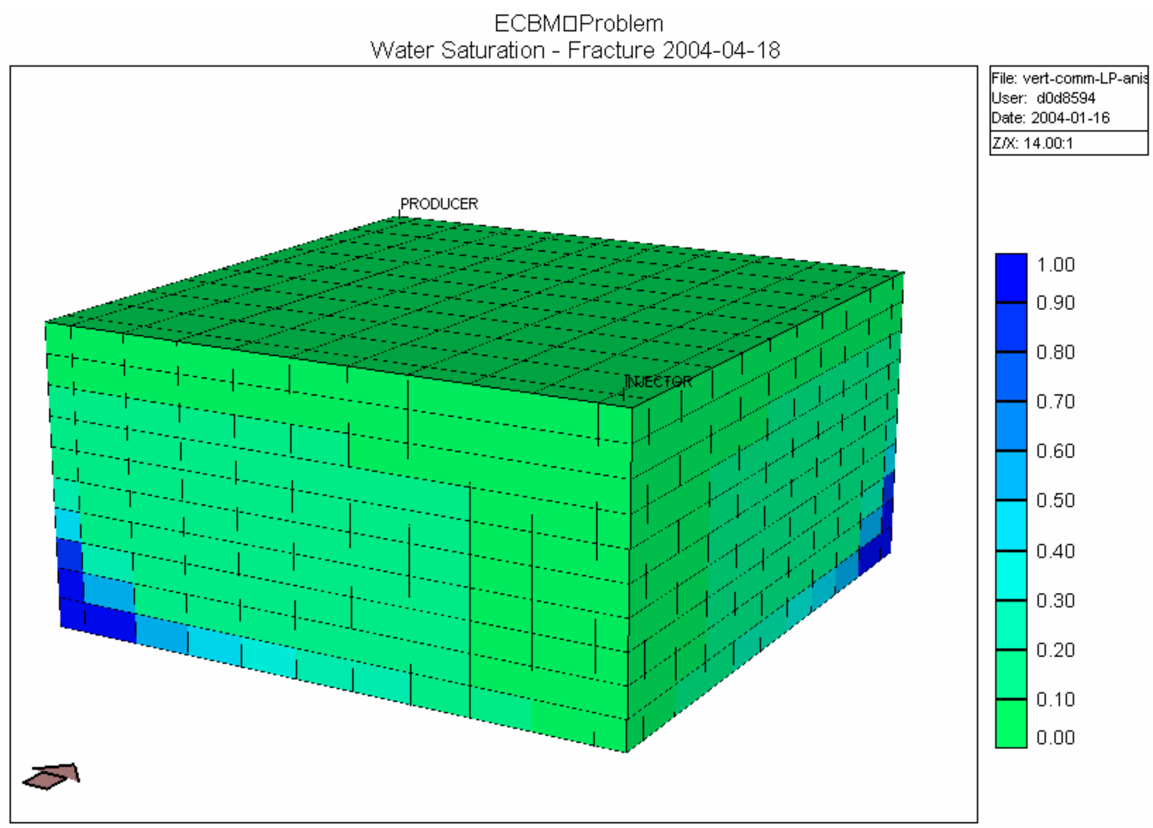

Fig. 15b. Water Saturation Profile at Breakthrough, With Vertical Communication.

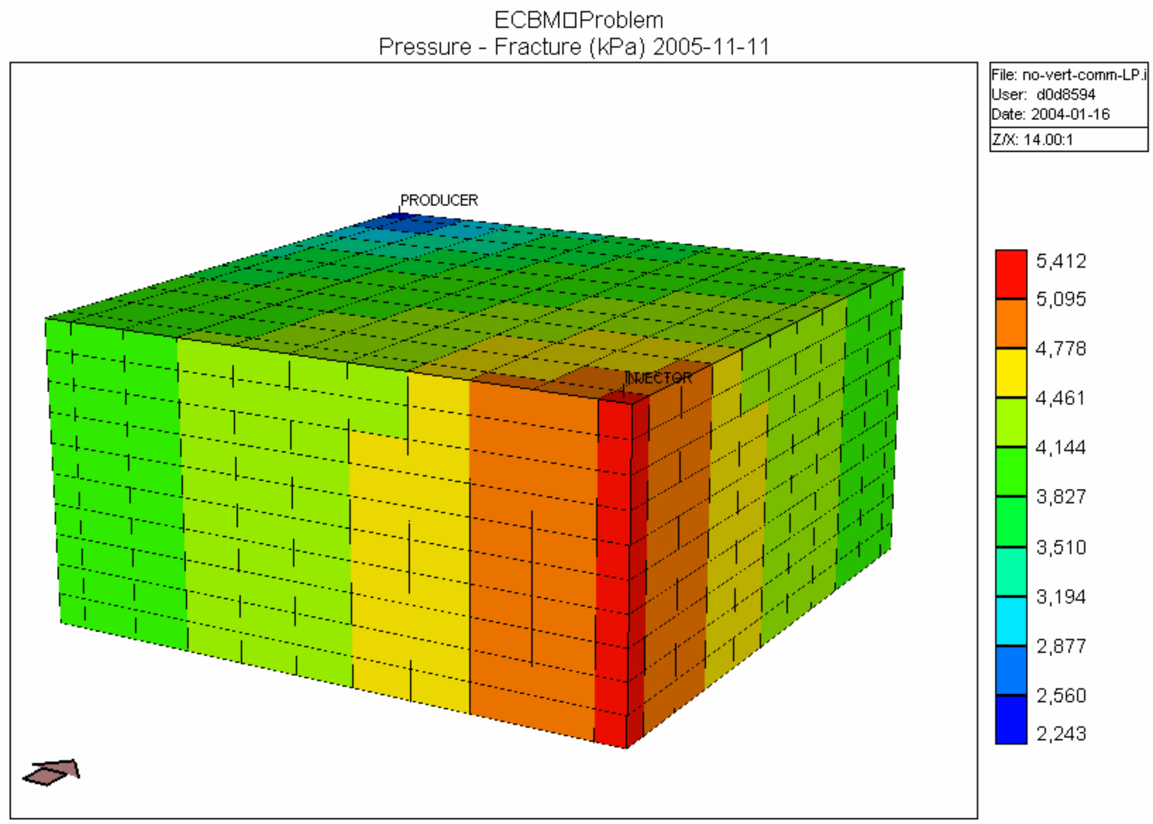

Fig. 16a. Pressure Profile at Breakthrough, No Vertical Communication.

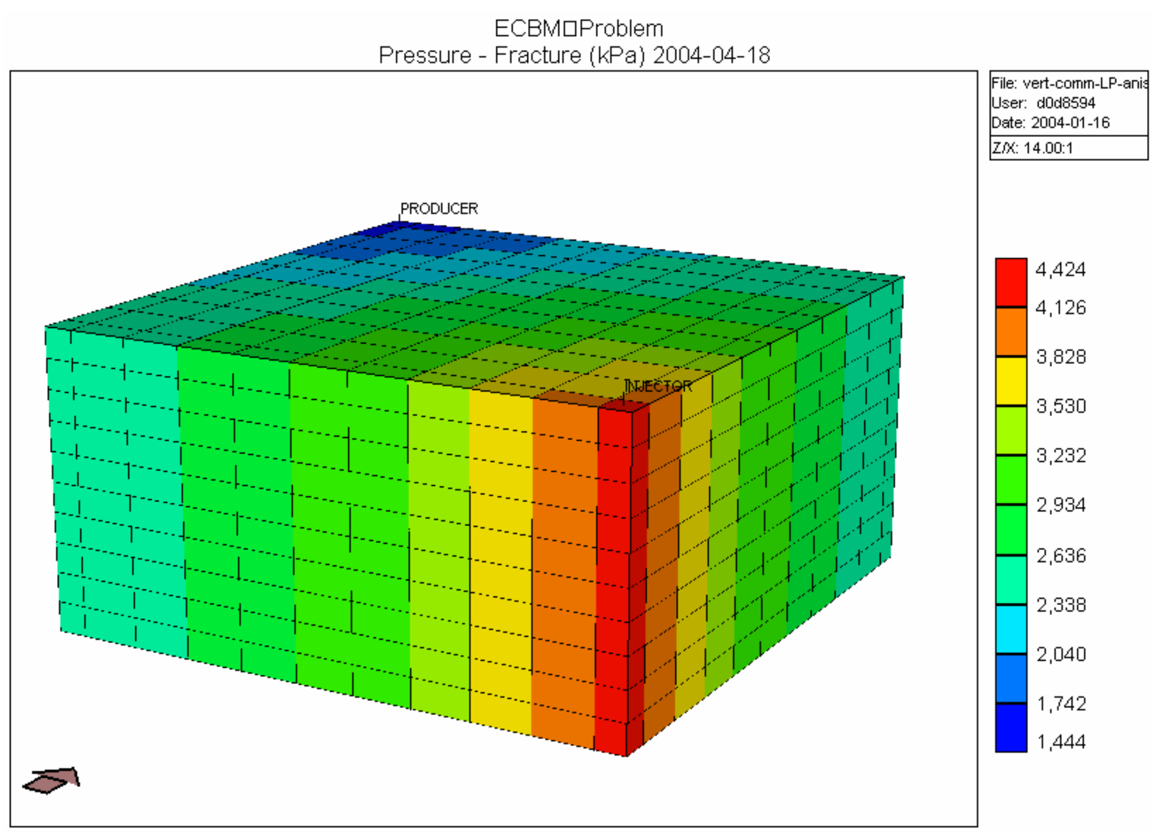

Fig. 16b. Pressure Profile at Breakthrough, With Vertical Communication.

Fig. 17a

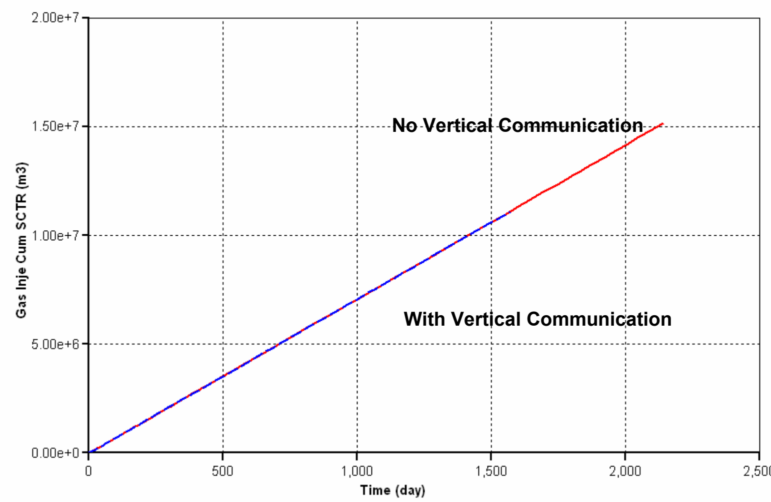

Fig. 17b.

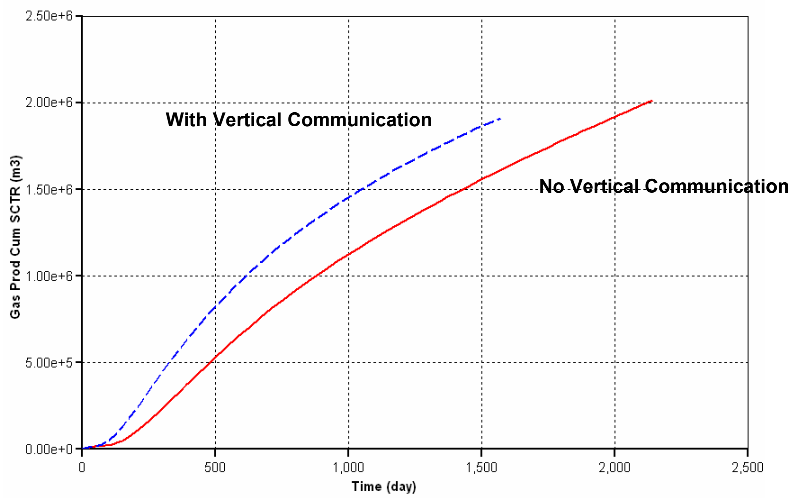

Fig. 17c.

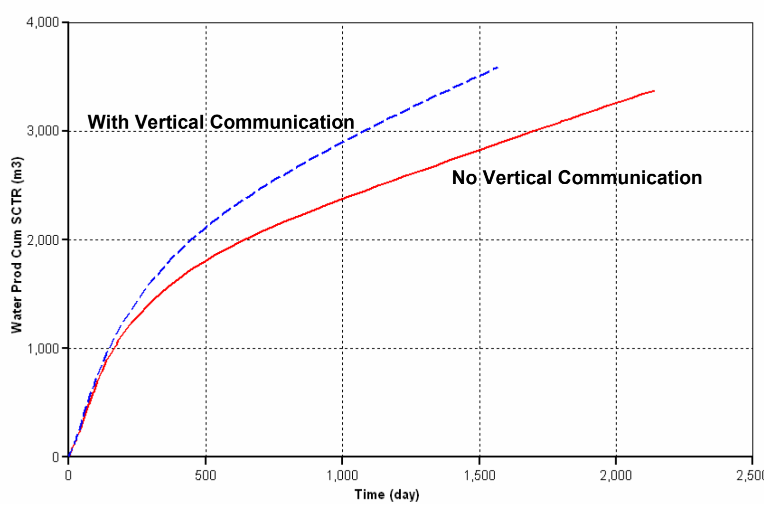

Fig. 17. Comparison of Reservoir Performance, a) Cumulative Injected Gas Volumes, b) Cumulative Produced Gas Volumes, and c) Cumulative Produced Water

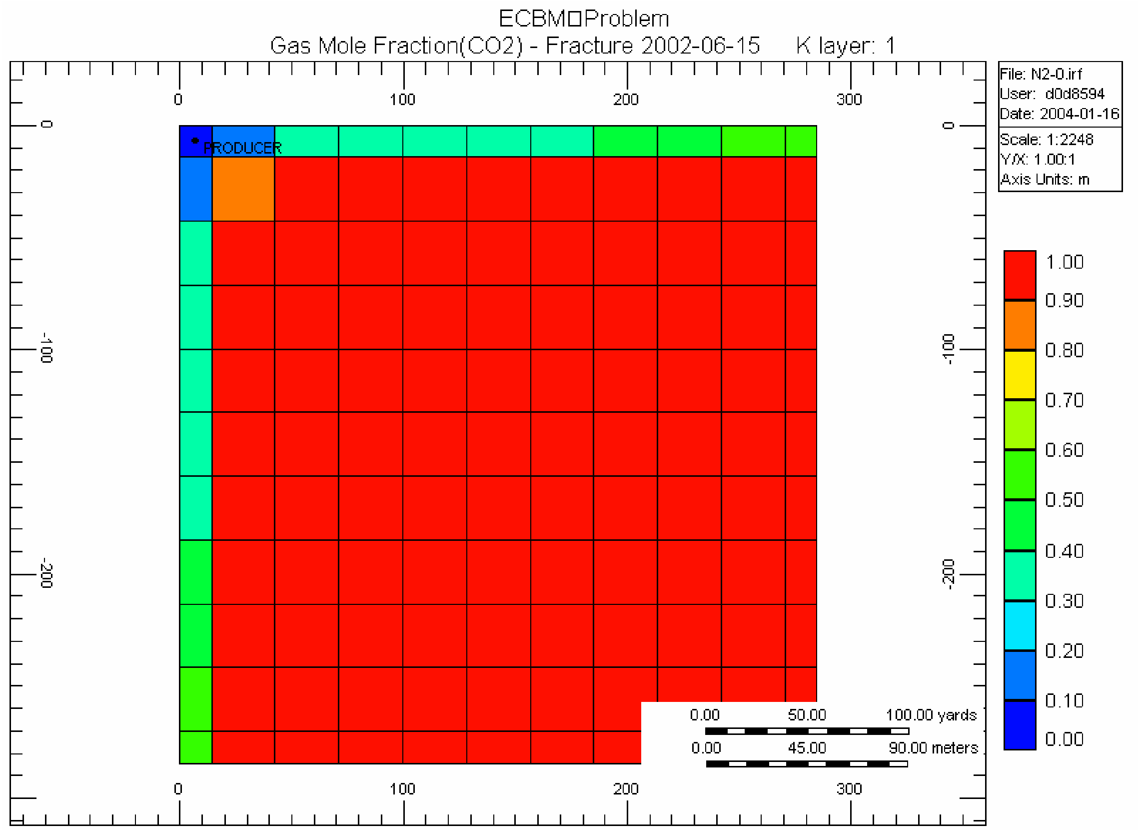

Fig. 18a. CO_2 Mole Fraction at Breakthrough With Pure CO_2 Injection

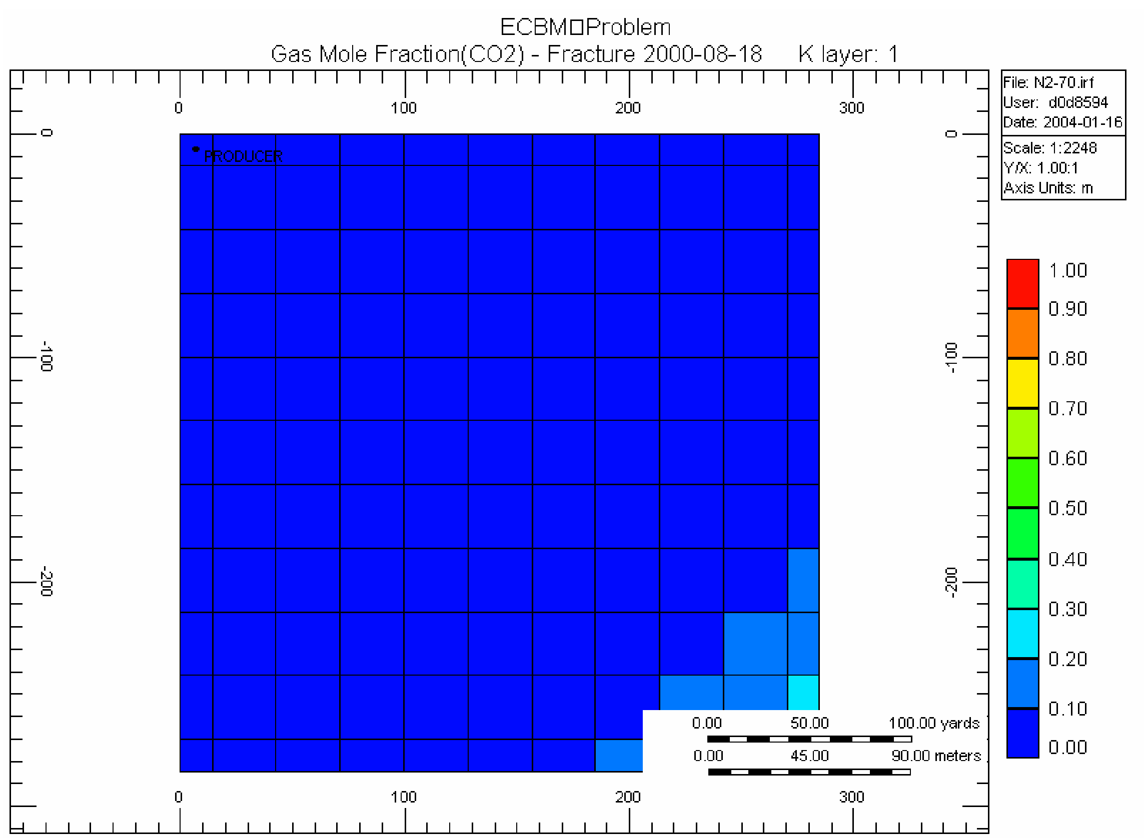

Fig. 18b. CO_2 Mole Fraction at Breakthrough With 80% N2, 20% CO_2 Injected.

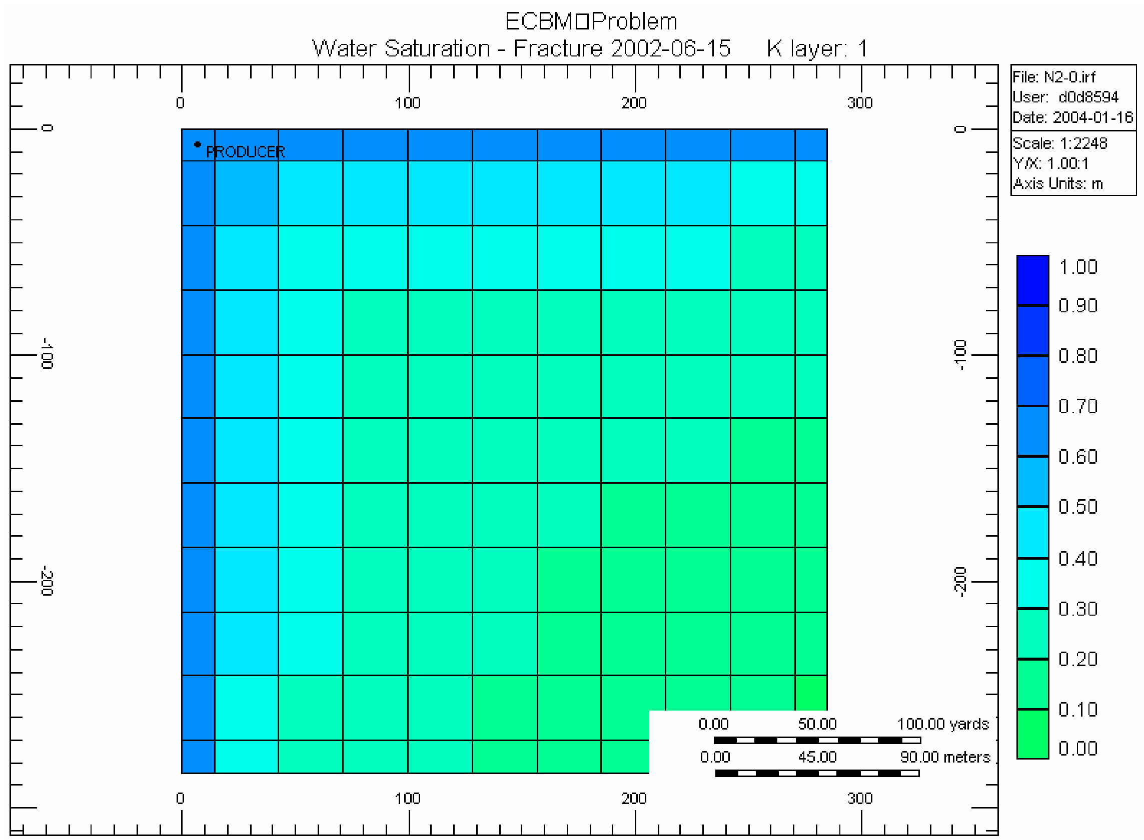

Fig 19a. Water Saturation Profile at Breakthrough With Pure CO2 Injection.

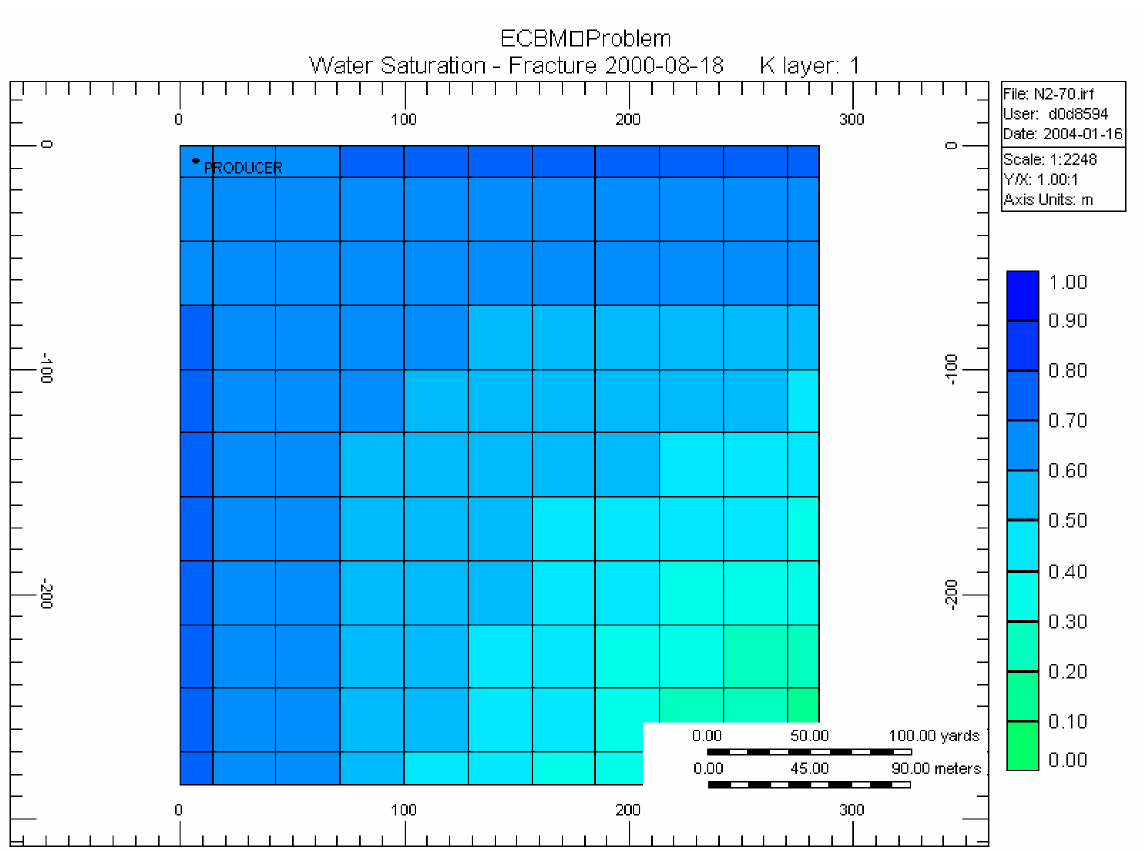

Fig 19b. Water Saturation Profile at Breakthrough With 80% N2, 20% CO_2 Injection.

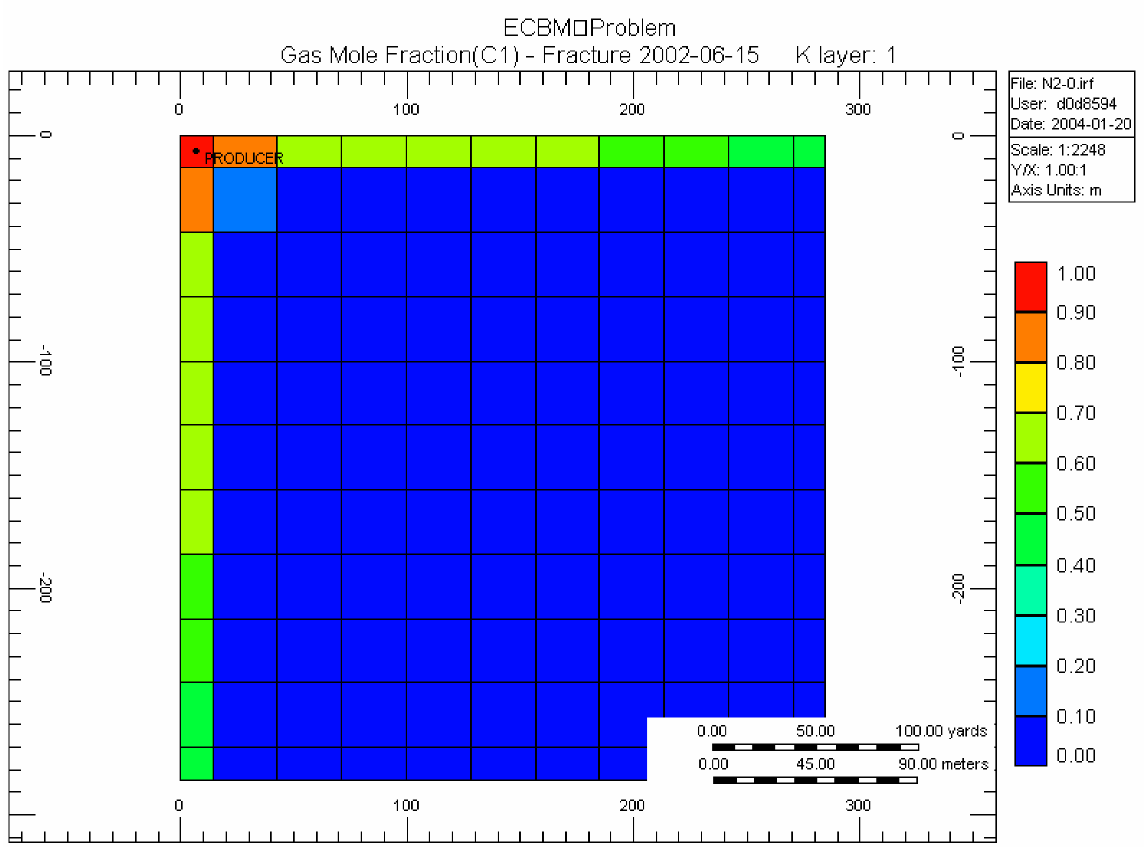

Fig. 20a. C1 Mole Fraction at Breakthrough With Pure CO_2 Injection.

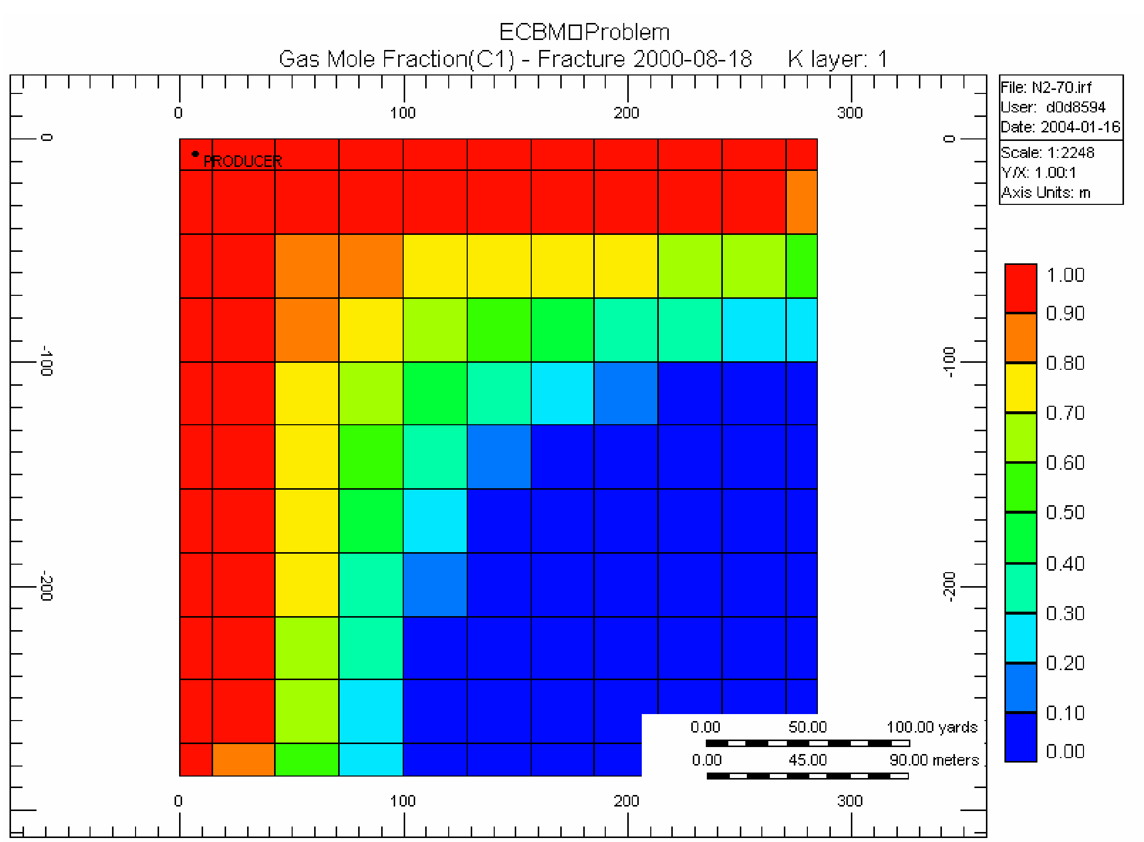

Fig. 20b. C1 Mole Fraction at Breakthrough with 80% N_2, 20% CO_2 Injection.

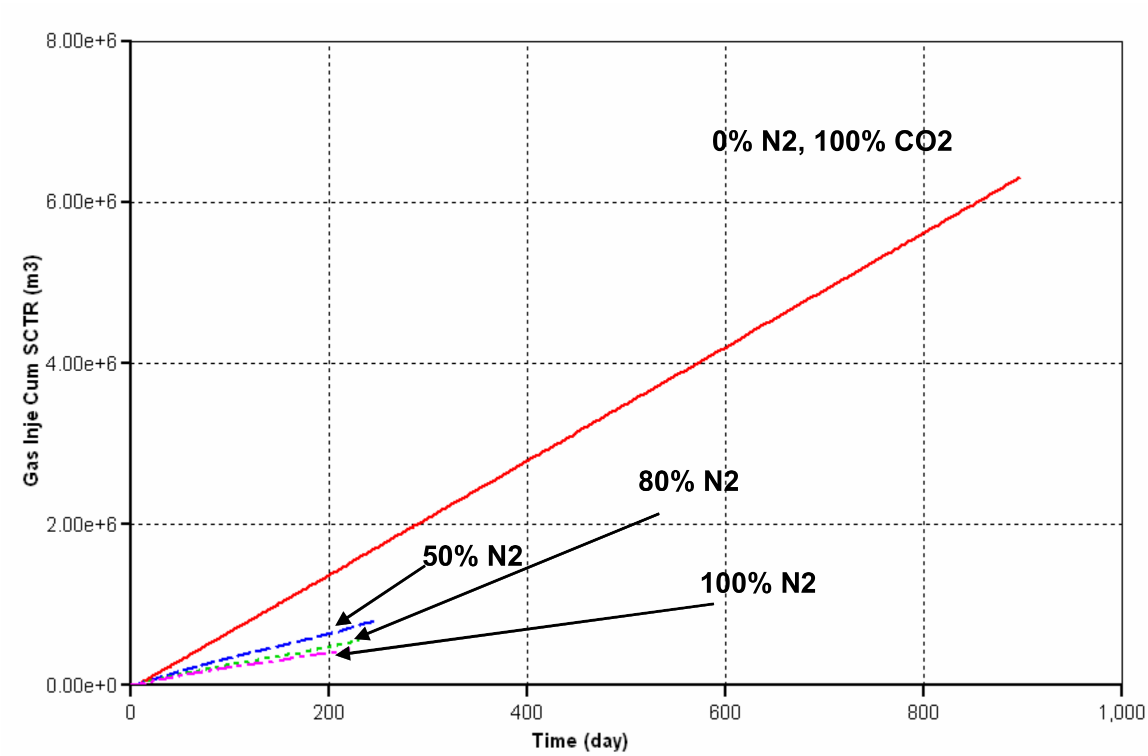

Fig. 21a. Comparison of Injected Gas Volumes.

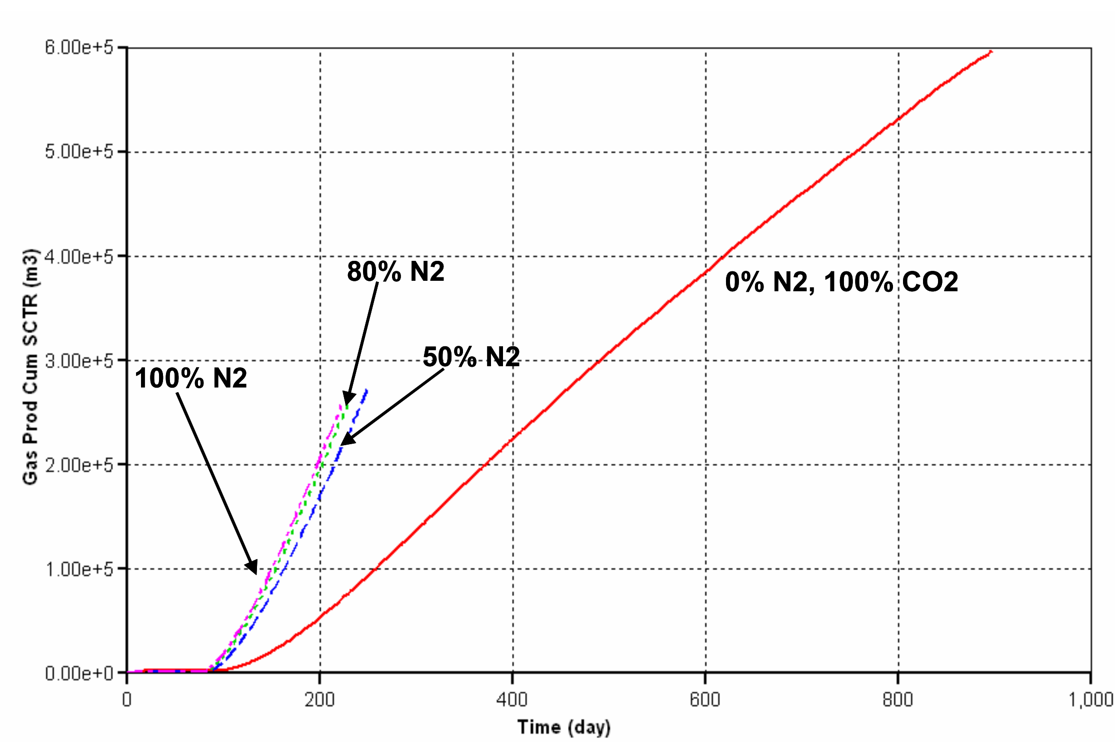

Fig. 21b. Comparison of Produced Methane Volumes.