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Structure of Cedar Cove and Peterson Coalbed Methane Fields and Correlation to Gas and Water Production

M. R. McIntyre, University of Alabama; R. H. Groshong, Jr., University of Alabama; J. C. Pashin, Geological Survey of Alabama; Hongwei Yin, University of Alabama

ABSTRACT

Map-scale structure significantly controls the distribution of gas and water production in Cedar Cove and Peterson coalbed methane fields. While exceptional gas producers are generally exceptional water producers, many wells that produce exceptional amounts of water produce limited amounts of gas. Faults segment the reservoir into blocks with different production characteristics. Gas production can be enhanced near faults, particularly ones forming half grabens and with maximum displacements of less than 100 feet (37m). Gas production is limited in areas of very little map-scale structure and in the two complex full grabens systems found at the southern and northern ends of Cedar Cove field.

INTRODUCTION

The relationship between the productivity of coalbed methane wells and map-scale structure is the focus of this paper. The Black Warrior basin, and the coalbed methane fields therein, has long been used to study the relationship between geology and methane production (Ellard, et al., 1992; Sparks, et al., 1993; Pashin, et al., 1995; Smith, 1995; Pashin and Hinkle, 1997; Cox 2002). An adequate gas resource must be present and producible for economic production. Gas is adsorbed onto coal and held there by the hydrostatic pressure. The production of gas normally requires a reduction in pressure by the production of the formation water. Both methane and water production is possible only if transmissive fractures are present, as coal has essentially no permeability. Geologic history, stratigraphy, hydrology, and map-scale geologic structures potentially influence to the abundance, continuity, and openness of fractures in the reservoir. Completion techniques also may be related to production. Productivity of wells in the Black Warrior basin ranges widely small distances, and this variability is ostensibly the product of geologic heterogeneity (Pashin, 1998).

Wells are developed on an 80-acre spacing and are completed by hydraulic fracturing in multiple coal zones (Lambert, et al., 1987; Spafford and Saulsberry, 1993). Lambert and others (1987) and Sparks and others (1993) found that drilling and completion techniques were not a major factor in production variability. Differences in production of more than an order of magnitude in wells that have undergone similar completions can be seen in closely spaced wells (Malone, et al., 1987). Controls on production vary locally, as indicated by the lack of documented production interference between wells (Ellard, et al., 1992).

Little significant control of the variability of methane production can be attributed to stratigraphic-related factors, such as coal thickness (Pashin, et al., 1991; Pashin and Hinkle, 1997). Coal composition and thermal maturity control the amount of gas in place, which represents the available resource. A minimum maturity of $R_0 = 0.7$ is required for major thremogenic methane formation. Regionally the most productive wells have high gas in place and produce from shallow depths within the mature area of the basin (Bodden, 1997). However local variations in the amount of gas in place exert little control over production variability (Sparks, et al., 1993; Bodden, 1997)

Direct measurements show that the coal beds are the most permeable units within the upper Pottsville Formation (Ellard, et al., 1992). However, coal has essentially no matrix permeability to water. This indicates that there are open fractures to enhance fluid flow (Sawyer, et al., 1987; Sparks, et al., 1993; Pashin and Hinkle, 1997). Low-volatile bituminous coal shows maximum coal cleat development (McFall, et al., 1986; Pashin, et al., 1999; Bodden, 1997). Parallel to the open cleat direction would be the most permeable direction. Because coal is a relatively soft material, the openness of the cleat could be a function of in-situ stress, which is related to depth of burial and tectonic stress (Sparks, et al., 1993). The fracture closure pressure, measured before stimulation, is equal to the magnitude of the least principal stress. Where closure pressure is lower, permeability should be greater. Sparks and others (1993) found a correlation between early production and closure pressure and suggested that the in-situ stress was related to the map-scale structure.

One significant factor in gas production can be hydrology (Pashin et al., 1991; Ellard, et al., 1992). Along the uplifted southeastern edge of the basin, where the Pottsville is exposed, the basin water is recharged. A potentiometric high along the basin edge and plumes of fresh water that extend northwest from the basin edge indicate the recharge area. The water pressure in part of the recharge area in Cedar Cove field cannot be reduced sufficiently to produce much gas (Sparks, et al., 1992, Pashin and Groshong, 1998).

While the relationship is not clearly defined, map-scale structures have been proposed as significant factors in controlling production (Pashin, et al., 1991; Ellard, et al., 1992; Sparks, et al., 1993; Pashin, et al., 1995; Pashin and Groshong, 1998). Although the relationship was not specified, bed dip has been indicated as a controlling factor (Malone, et al., 1987). Pashin and others (Pashin, et al., 1991; Pashin and Hinkle, 1997) indicated that enhanced natural fracturing near faults might be expected to lead to enhanced production in fault zones, but Sparks et al. (1993) found that fault zones are not as productive as the blocks between faults. Although structure is clearly implicated as having significant control on well productivity, the exact nature of the control still has to be determined.

This research investigates the relationship between map-scale structure and production in Cedar Cove and Peterson fields. This area has been previously researched by Ellard et al. (1992), Sparks et al. (1993), and Pashin and Groshong (1998). The fields have been completely remapped in a high-resolution three-dimensional structural model with new wells included.

GEOLOGIC SETTING

The Black Warrior Basin is a late Paleozoic foreland basin formed by the north and northeast verging Appalachian-Ouachita fold-thrust belt (Thomas, 1988). In the basin, strata dip gently southwestward (1-2°) and thicken to the southeast in the coalbed methane fields. The Appalachian thrust front forms the southeastern margin of the basin, where strata dip steeply and may be overturned. Within the basin numerous northwest-trending normal faults form horst, graben, and half graben structures (Figure 1). The majority of the faults dip southwest. Most of the faults in the coalbed methane producing region have displacements of 400 feet (146 m) or less. A thin-skinned detachment is predicted in the lower part of the Pottsville Formation (Pashin, et al., 1995). Within the coalbed-methane fields, at least two faults penetrate deep into the basement, the major southwest dipping fault in Robinson's Bend field and the major northeast dipping fault in Moundville field (Figure 1). These faults have stratigraphic separations exceeding 1,000 feet (300m). The faults in Cedar Cove field are assumed to be thin-skinned based on displacement measurements. The southernmost, northeast-dipping fault in Cedar Cove may be basement-involved.

The coal bed methane reservoirs are in the upper Pottsville Formation (Early Pennsylvanian). Coal groups (McCalley, 1900) or zones (Gastoldo, et al., 1993, Pashin, et al., 2003) have been named based on stratigraphic clusters of coal beds. The entire upper Pottsville can be divided into depositional cycles, each containing a coal zone of one to seven coal beds, each of which is generally traceable throughout the study area (Pashin, et al., 1991; Pashin, 1998; Gastoldo, et al., 1993). The cycle names (Figure 2) are those in common usage in the basin (Pashin, 1998).

The peak maximum daily production of methane and the peak maximum daily production of water are the production variables used in this paper. These values were obtained by dividing the peak monthly production values, provided by the State Oil and Gas Board of Alabama, by 30. Previous authors have used the production rates for certain dates or certain times since the beginning of production. Desorption time is a controlling factor for initial production (Sawyer, et al., 1987) and desorption rates are quite variable (Bodden, 1997). Low rank coals generally desorb slower than higher rank coals (Bodden, 1997), perhaps due to poorer development of cleat at lower rank. How rapidly water pressure drops also exerts control on the rate of methane production. We reason that peak values are the most closely related to the transmissivity of the coal. Cedar Cove and Peterson fields have been producing long enough so that the peak months can be readily identified.

METHODS

A structural model of Cedar Cove and Peterson fields was constructed using data from the 664 well logs available in the fields. From these logs the depth of the tops of up to eleven depositional cycles and any fault cuts found were recorded. The logs generally available for these wells are neutron-density, gamma, resistivity, and caliper. The gamma and neutron density logs are most useful for correlation; caliper logs can aid in the location of a fault cut. Cycle bounding flooding surfaces were interpreted at the first high-gamma peak at the base of a thick clay section. Where significant (greater than 20 feet of missing section) changes in thickness in a cycle are observed, a fault cut was assumed. By correlating up and down the section, the position of the fault within the section can be determined. Generally this procedure does not give one a unique fault position, but rather a range of 10 – 100 feet (3.6–37 m). The center of the range is picked as the position of the fault cut. Where a borehole breakout, as seen on the caliper log, is not at a coal bed, the fault is placed at that elevation.

The structural model was built from the well log data in 3Dmove software using several general principles. Locally beds maintain nearly constant thickness. A general thickening to the south and southeast can be seen, but within a mile (1.9 km) only very small changes in cycle thickness, other than at fault cuts, is seen. Dips of bedding are generally less than 5°. Mapping the cycle tops will produce a surface with very low dip and even where the surface crosses an unmapped fault, dips remain fairly low (10-20°). The hangingwall and footwall cycle boundaries were projected along dip into a fault to produce fault cutoff maps. The result is validated if cycle thickness remains constant as the fault is approached.

Faults were assumed to trend northwest–southeast and dip approximately 60°, unless direct evidence indicated otherwise. Many studies, including information from surface mapping, coal mines, and seismic lines, support the general trend of normal faults in the coalbed methane fairway as northwest-southeast. Most faults clearly strike northwest-southeast, several strike southwest-northeast. Only two faults large enough to be mapped lacked sufficient evidence to uniquely determine the strike independent of the northwest assumption. Fault planes were not allowed to cut unfaulted wells and were required to honor all fault cuts. Faults were originally assumed to be planar and straight, however, in order to honor all points in the final interpretation, several faults are slightly curved. Faults were extrapolated up to 600 feet (218 m) above sea level to make them high enough to cut all cycle tops and, generally, be above ground surface; they were extended down to 3000 feet (1091 m) below sea level, so that they would cut the mapped horizons and extend approximately to elevation of the intra-Pottsville detachment.

RESULTS

Structural Model

The structural model of Cedar Cove and Peterson fields shows the major structures of the fields (Figure 3 and 5). The structure is dominated by two complex graben systems, one in the northeast and the other in the southwest parts of Cedar Cove Field (A and B in Figure 5). An oblique, three-dimensional view of part of the southwestern graben is shown in Figure 4. Between these two major graben systems there are many faults of smaller displacement and extent. Along the southeastern edge of Cedar Cove field, the Pottsville strata dip up to 20° under the frontal thrust of the Appalachians (‘C’ in figure 5). Outside of this area of upturned bedding, the dips are generally less than 10° and away from faults dips average 2-4°.

The major graben systems consist of several larger faults, with smaller faults transferring displacement between them. Several faults change strike along the trend direction, possibly indicating the breach of an accommodation zone (Ferrill, et al., 1999). Individual faults within the graben may strike up to 45° from the general northwest-southeast trend. The large faults in these graben systems have over 100 feet (37 m) of displacement. The largest displacement in Cedar Cove field is in the southern graben system (B in Figure 5) and is in excess of 500 feet (182 m). Throughout Cedar Cove and Peterson fields, faults are scattered about, commonly within a couple of miles (4 km) of each other (for example area D, Figure 5). Most of these faults form half grabens, although there are two full grabens, which have smaller displacements (less than 100 feet (37 m)) than the graben systems. There are two areas of relatively little deformation in western Cedar Cove/ southern Peterson and in central portion of the southeastern edge of Cedar Cove (areas E and F in Figure 5).

The faults dip between 50° and 75°. Fault displacement generally dies out laterally from the center to the ends. Displacement does not decrease symmetrically on either side of the maximum and fault length is not consistent on the different map horizons. Displacement does not decrease smoothly where faults are very close together; where two faults interact, displacement often changes abruptly. Footwall uplift is seen on some of the faults, but the majority of the displacement is in the hangingwall.

Along the southeastern edge of the Cedar Cove Field, many wells cut a large, southeast-dipping thrust fault, which places Cambrian-Ordovician carbonates over the Pennsylvanian age Pottsville Formation. This is the frontal thrust of the Appalachian fold and thrust belt. In these and adjacent wells there is an apparent thickening of the section caused by dip. The Pottsville horizons dip northwest up to 20° under the thrust fault.

STRUCTURAL CONTROLS ON PRODUCTIVITY

The magnitude scales for mapping water and gas production are based on the range of maximum daily production. The levels are defined at the 25th (160 bbl/d), 50th (350 bbl/d), 75th (740 bbl/d), and 95th (1640 bbl/d) percentiles for water (Pashin, et al., 2003). The gas production scale uses the 33rd (100 Mcf/d), 75th (300 Mcf/d), and 95th (600 Mcf/d) percentiles.

Structure has been shown in other studies to have some control on production of gas and water in the Black Warrior Basin coal-bed methane fields (Pashin, et al., 1991; Ellard et al., 1992; Sparks et al., 1993; Pashin and Groshong, 1998; Cox, 2002;Groshong et al, this volume.). This study also finds that structure controls production, however, finds some differences in the effects of structure from these other studies. To investigate the correlation of structure and production, peak daily gas and water production values were mapped on to the structural model (Figures 6 and 7). In general, faults compartmentalize the fields, and can increase fluid transmissivity. Half grabens and small displacement full grabens generally have better gas production than the large full graben systems at the northern and southern end of Cedar Cove and the areas of little deformation in western Cedar Cove and southern Peterson Field (areas A, B, E, and F, Figure 5). In previous studies, full grabens were not good gas producers (Pashin, et al., 1995; Pashin and Groshong, 1998; Cox, 2002; Groshong, et al., 2003), however, in this area some of the best production is in and around a small graben. Some faulted wells in an area of moderate to high gas production are exceptional producers while others limited production (figure 8). Highly productive gas wells are generally highly productive water wells; however, the reverse is not true. The production of gas and water follows some general trends related to the structural trends in Cedar Cove and Peterson fields.

The southeastern edge of the field contains a syncline that separates the southeast dip of the Black Warrior basin from the northwest dip of the Birmingham anticlinorium. In the syncline, gas production is limited and water production is high. This relationship has been hypothesized as being caused by high recharge rates and an inability to effectively dewater the coal beds (Ellard et al., 1992; Sparks et al 1993). The high water production agrees with the theory that water pressure is too high for economic gas production but the researchers (Ellard et al., 1992) also cite a water production high in the up-turned beds, which is not seen in this study. In fact, in the steep southeastern limb of the syncline, water production is generally moderate to low; gas production in the limb is also low.

Gas production (Figure 6) in areas of high deformation (A and B, Figure 5) is also limited. The average well, in the major grabens, does not produce over 100 Mcf/d; however, several wells produce between 100-300 Mcf/d. Areas far from faults (>2 miles (3.8 km)) (i.e. E and F, Figure 5) tend to be borderline average, in terms of gas production, and low water producers, as well. Areas where bedding dips between 4° and 7° and are within two miles of a fault are the best producing.

Several exceptional gas producing areas (>600 Mcf/d) are found in Cedar Cove field. These tend to be near faults (within a 1.5 miles (2.9 km), measured on the top Mary Lee horizon) and in the immediate footwall of half grabens below the Pratt cycle top. These patches of high gas production tend to be closer to the end of a fault than the point of maximum displacement. They contain two or more wells with exceptional gas production and may be partially separated by a well with limited or average gas production. Some of the patches are in a larger area of highly productive (300-600 Mcf/d) wells; others are surrounded by wells, which produced 100-300 Mcf/d at their maximum. In general these patches do not cross faults, when mapped on the top of the Mary Lee cycle, and often contain wells that are only in the footwall. Several trends of above average gas production (300-600 Mcf/d), and a couple of exceptional wells, do not appear to be related to mappable faults.

In addition to patches of several highly productive to exceptional gas wells, there are approximately twenty wells that produce significantly higher amounts of gas than the surrounding wells. Of these wells, four cut through a mapped fault. The fault cuts range stratigraphically from the Gwin down to the Mary Lee cycles. The vertical separation measured on the well log ranges from 30 to 240 feet (10–87 m). Individual high-producing wells are within a mile (1.9 km) of a fault (measured on the top of the Mary Lee cycle), however most are in the area of minor faulting where faults tend to be no more than 3 miles (5.7 km) apart. These isolated, exceptionally productive wells do not contain more coal than average, nor have any other distinguishing feature. Why these twenty wells are better producers than the neighboring wells is an issue for further study.

Water production (Figure 7) in high-deformation areas A and B is highly variable, suggesting that the faults contribute to transmissivity in some areas and decrease it in others. Faults are generally barriers to flow. Throughout the Cedar Cove and Peterson fields, the water production is variable, indicating strong compartmentalization. Water production shows no preference for the hangingwall or footwall blocks but is generally higher in faulted areas than in the unfaulted areas in western Cedar Cove and southern Peterson fields, and along the central southeastern edge of Cedar Cove (E and F, Figure 5).

Sparks and others (1993) found that closure pressure (Figure 9) and early gas production were related in northern Cedar Cove and Peterson fields. They found that areas of lower closure pressure were more productive. While areas of exceptional production found in the current study do tend to correlate to the areas of lower closure pressure, there is still substantial local variability, which is not explained by the closure pressure map. Closure pressure may have more effect on early production than on peak production.

A direct correlation between water and gas production is difficult to find (Figure 10). High gas production correlates with high water production, however, many wells fall well below this maximum. The maximum gas produced by a well for a given water production rate increases with water production; but most wells produce over a wide range for a given water production. In 37 wells, which produced over 1,600 bbl/day of water, approximately 50% produced at less than average gas levels while nearly 20% produced over 600 Mcf/d of gas. Wells below 30 bbl/d water generally do not produce average amounts of gas (22 out of 23 wells). In the total well population, 33% of all wells produced less than 100 Mcf/d at their maximums, approximately 40% of wells produced between 100-300 Mcf/d, 20% produced 300-600Mcf/d, and 5% produced over 600Mcf/d.

CONCLUSIONS

Production in Cedar Cove field is related to the major structures in the field. Some high and low production trends are related to the major structural features. The synclinal trough adjacent to the Birmingham anticlinorium is an area of exceptional water production and limited gas production. Sparks et al. (1993) and Pashin and Groshong (1998) have suggested that this may be due to an inability to depressurize the coals by dewatering. The major graben systems in the northeastern and southern portions of Cedar Cove mark the limits of the area of above average gas production. In the graben systems and beyond to the edges of the study area, gas production is low (<150 Mcf/d) and water production is variable. The relatively large area without faults and low dip (<4°) in western Cedar Cove has low gas and water production. The grabens and the unfaulted region indicate that both too much deformation and too little deformation reduce the potential for gas production, while high deformation (grabens) can mean exceptional water production.

Half grabens, on the other hand, appear to provide the correct amount of deformation for patches of average to exceptional gas production to exist. Water production changes dramatically across many faults in the area. The lack of communication between the footwall and hangingwall is less apparent in gas production, although, it is compartmentalized by the faults to some degree. The patches of highly productive gas wells are within a mile (1.9 km) of the fault trace, as measured on the top of the Mary Lee cycle. These patches often include wells in the footwall and wells that cut the fault. Individual wells that are good producers are within a mile (1.9 km) of a fault (as measured on the Mary Lee horizon), several of these wells contain fault cuts, which range in depth from the Gwin cycle to the Mary Lee. These wells do not appear to have any distinguishing characteristic. The results of this study are in partial agreement with Cox (2002), one difference being while Cox (2002) and Groshong, et al. (this volume) found that the hangingwalls of the half grabens were the most productive areas, this study finds that footwalls of isolated half grabens and small grabens can be equally good gas producing areas. There is little direct correlation between water and gas production in a well. While highly productive gas wells are invariably highly productive water wells, the reverse is not true.

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REFERENCES

Bodden W.R. III, 1997: Coalbed Methane Production and Desorption Testing in the Black Warrior Basin of Alabama: Ph.D. Dissertation, Columbia, University of South Carolina, 237p.

Cox M.H., 2002: Relationship Between Fracture Transmissivity and Structure in Coalbed Methane Fields of the Eastern Black Warrior Basin, Alabama: M.S. Thesis, Tuscaloosa, University of Alabama, 95 p.

Ellard J.S., Roark R.P., and Ayers W.B., Jr., 1992: “Geological Controls on Coalbed Methane Production: An Example from the Pottsville Formation (Pennsylvanian Age), Black Warrior Basin, Alabama, U.S.A.”, Symposium On Coalbed Methane Research And Development In Australia, Townsville, James Cook University, p. 45-61.

Ferrill D.A., Stamatakos J.A., and Sims D.W., 1999, “Normal Fault Corrugations: Implications for Fault Growth and Seismicity of Active Normal Faults”: Journal of Structural Geology, V. 21, 1027-1038

Gastoldo R.A., Demko T.M., and Liu Y., 1993: ”Application of Sequence and Genetic Stratigraphic Concepts to Carboniferous Coal-Bearing Strata: An Example from the Black Warrior Basin, USA”: Geologische Rundshau, V. 82, p. 212-226.

Groshong R.H., Jr., Cox M.H., Pashin J.C., and McIntyre M.R., 2003: “Relationship Between Gas and Water Production and Structure in Southeastern Deerlick Creek Coalbed Methane Field, Black Warrior Basin, Alabama” paper 0306, Proceedings of the 2003 International Coalbed Methane Symposium, Tuscaloosa, Alabama, in press.

Lambert S.W., Niederhofer J.D., and Reeves S.R., 1987: “Multiple Coal Seam Completion Experience in the Deerlick Creek Field, Black warrior Basin, Alabama”, paper 8721, Proceedings of the 1987 International Coalbed Methane Symposium, Tuscaloosa, Alabama, p. 81-82.

Malone P.G., Briscoe F.H., and Camp B.S., 1987: “A study of Coalbed Methane Production Trends as Related to Geological Features”, paper 8762, Proceedings of the 1987 International Coalbed Methane Symposium, Tuscaloosa, Alabama, p. 293.

McCalley H., 1900: Report on the Warrior coal basin: Tuscaloosa, Alabama, Geological Survey Special Report 10, 327 p.

McFall, K.S., Wicks, D.E., and Kuuskraa, V.A., 1986: A Geological Assessment Of Natural Gas From Coal Seams In The Warrior Basin, Alabama - Topical Report (September 1985-September 1986): Washington, D.C., Lewin and Associates, Gas Research Institute contract no. 5084-214-1066, 80p.

Pashin, J.C., 1998: “Stratigraphy and structure pf coalbed methane reservoirs in the United States: an overview”, International Journal of Coal Geology, v. 35, p. 207-238.

Pashin J.C. and Groshong R.H., Jr., 1998: “Structural control of coalbed methane production in Alabama”, International Journal of Coal Geology, v. 38, p. 89-113.

Pashin J.C., Groshong R.H., Jr., and Wang S., 1995: “Thin Skinned Structures Influence Gas Production in Alabama Coalbed Methane Fields, Tuscaloosa, Alabama”, paper 9508, Intergas ’95, Tuscaloosa, Alabama, p. 15-32.

Pashin J.C. and Hinkle F., 1997: Coalbed Methane in Alabama: Tuscaloosa, Alabama Geological Survey Circular 192, 71 p.

Pashin, J.C., Carroll, R.E., Hatch, J.R., and Goldhaber, M.B., 1999: “Mechanical and thermal control of cleating and shearing in coal: examples from the Alabama coalbed methane fields, USA”, in Mastalerz, M., Glikson, M., and Golding, S., eds., Coalbed Methane: Scientific, Environmental., and Economic Evaluation: Dordrecht, Netherlands, Kluwer Academic Publishers, p. 305-327.

Pashin, J.C., Carroll, R.E., Groshong, R.H, Jr., Raymond, D.E., McIntyre, M. and Payton, J.W., 2003: “Geologic Screening Criteria for Sequestration of CO2 in Coal: Quantifying Potential of the Black Warrior Coalbed Methane Fairway, Alabama”, Annual Technical Progress Report, U.S. Department of Energy, National Energy Technology Laboratory, contract DE-FC-00NT40927, 190 p.

Pashin, J.C., Ward, W.E., II, Winston, R.B., Chandler, R.V., Bolin, D.E., Richter, K.E., Osborne, W.E., and Sarnecki, J.C., 1991:Regional Analysis of the Black Creek-Cobb Coalbed-Methane Target Interval., Black Warrior Basin, Alabama: Tuscaloosa, Alabama Geological Survey Circular 145, 127 p.

Sawyer W.K., Zuber M.D., Kuuskraa V.A., and Horner D.M., 1987: “A Field Derived Inflow Performance Relationship for Coalbed Gas Wells in the Black Warrior basin”, paper 8744, Proceeding of the 1987 International Coalbed Methane Symposium, Tuscaloosa, Alabama, p. 207-215.

Smith J., 1995: Normal Faults in Holt and Peterson Coalbed Methane Fields, Black Warrior Basin, Alabama; M.S. Thesis, Tuscaloosa, university of Alabama, 76p.

Spafford S.D and Saulsberry J.L., 1993: “Field verification of Fracture Height Growth Associated with a Restricted Access Completion”, paper 9375, Proceedings of the 1993 International Coalbed Methane Symposium, Tuscaloosa, Alabama, p. 139-144.

Sparks D.P., Lambert S.W., and McLendon T.H., 1993: “Coalbed Gas Well Flow Performance Controls, Cedar Cove Area, Warrior Basin, U.S.A.”, paper 9376, Proceedings of the 1993 International Coalbed Methane Symposium, Tuscaloosa, Alabama, p.529-547

Thomas W.A., 1998: “The Black Warrior Basin, in Sloss L.L., ed., Sedimentary Cover-North American Craton: Geological Society of America, The Geology of North America, v. D-2, p. 471-492.

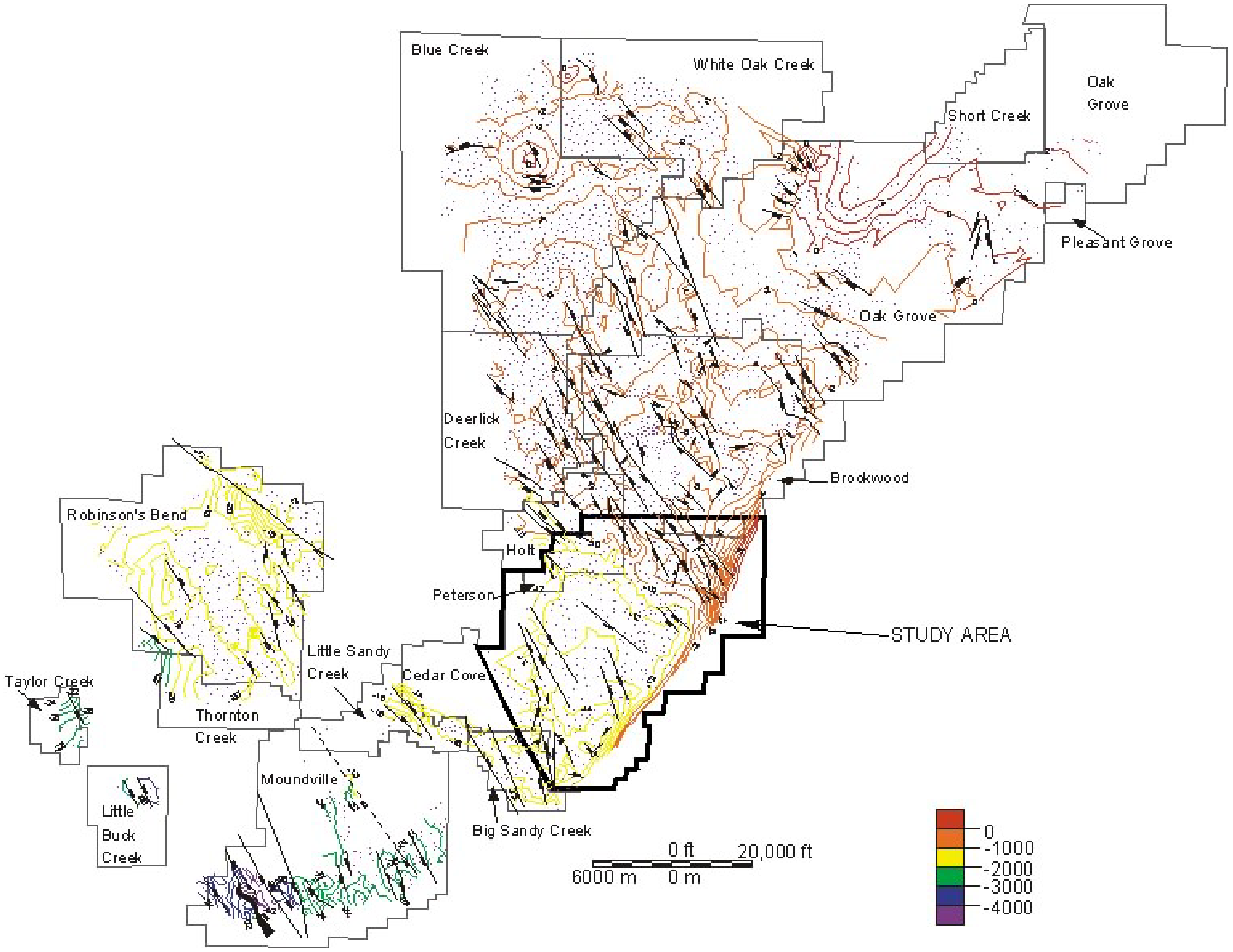

Figure 1. Geological Setting and location of Cedar Cove and Peterson Coalbed Methane Degasification Fields. Structure contour map of the top of the Pratt cycle. Contour interval is 100 feet (approx. 30m), labeled in 200 foot (74m) intervals (elevation X 100 ft), every fifth line accented.

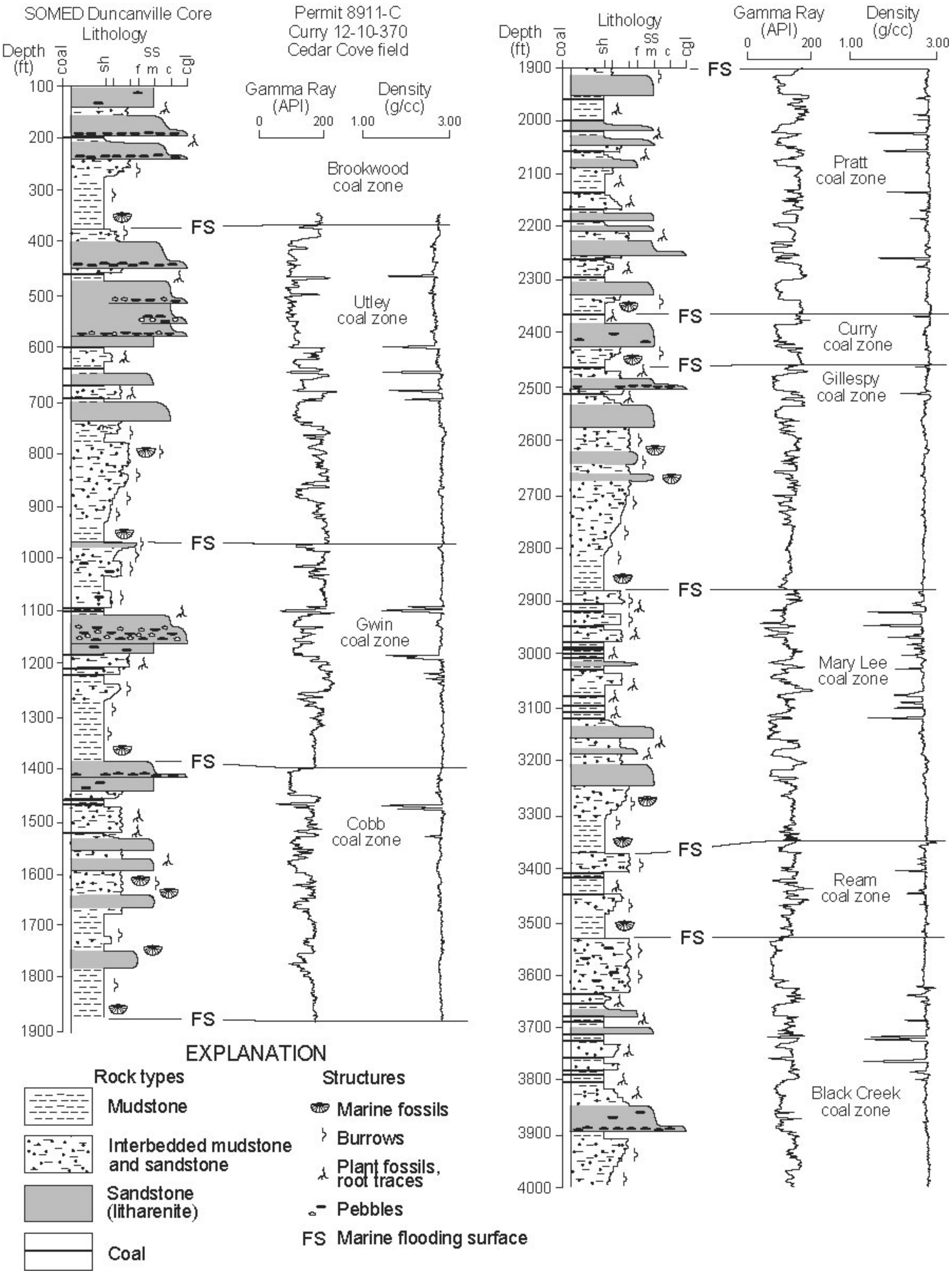

Figure 2. Typical core, gamma, and density logs for Cedar Cove. (Modified from Pashin and Hinkle, 1997)

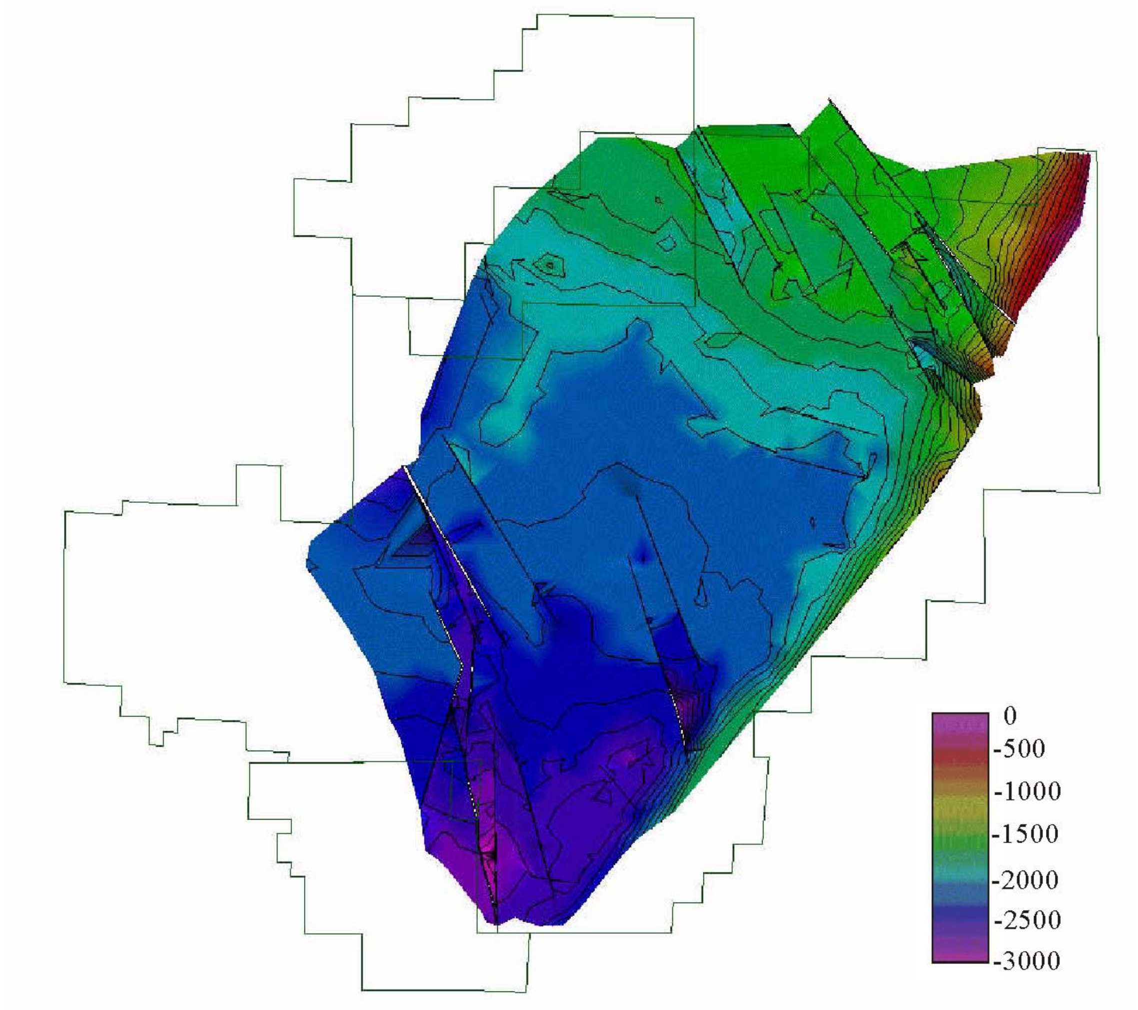

Figure 3. Structure contour map of Cedar Cove and Peterson fields on the top of the Mary Lee cycle. Contour Interval is 100 feet (37 m).

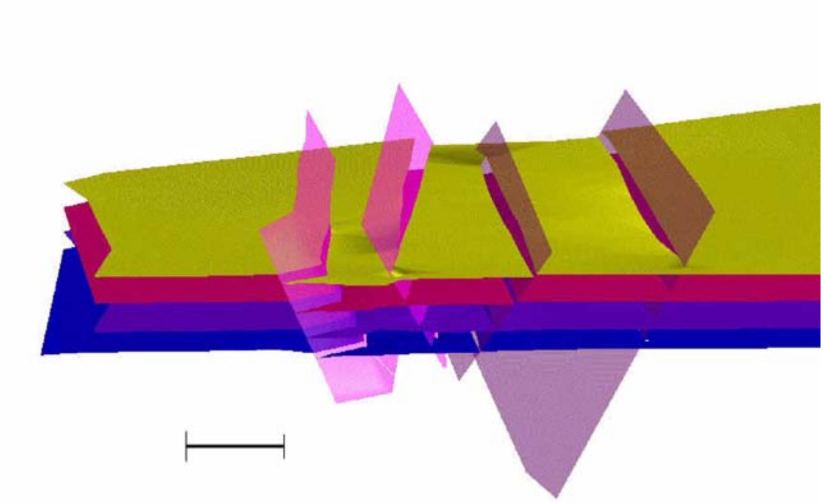

Figure 4. Oblique view of the southwestern graben. Cycle tops shown are the Gwin, Pratt, Mary Lee, and Black Creek (top to bottom), purple inclined planes are faults. Bar is 1 km long, no vertical exaggeration.

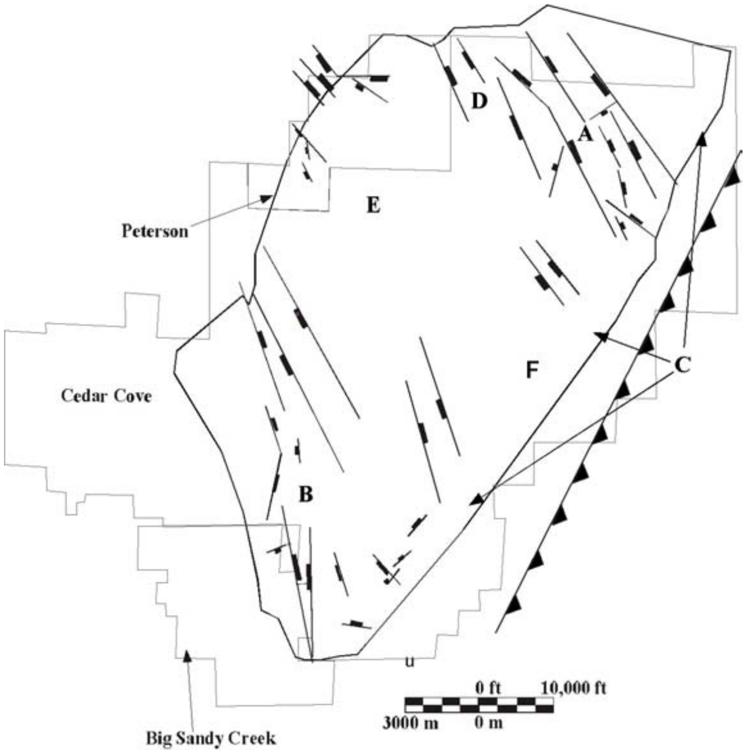

Figure 5. Map of Cedar Cove field at the top of the Mary Lee cycle, showing all mapped faults (symbols on hangingwall). Letters indicate general location of areas discussed in text.

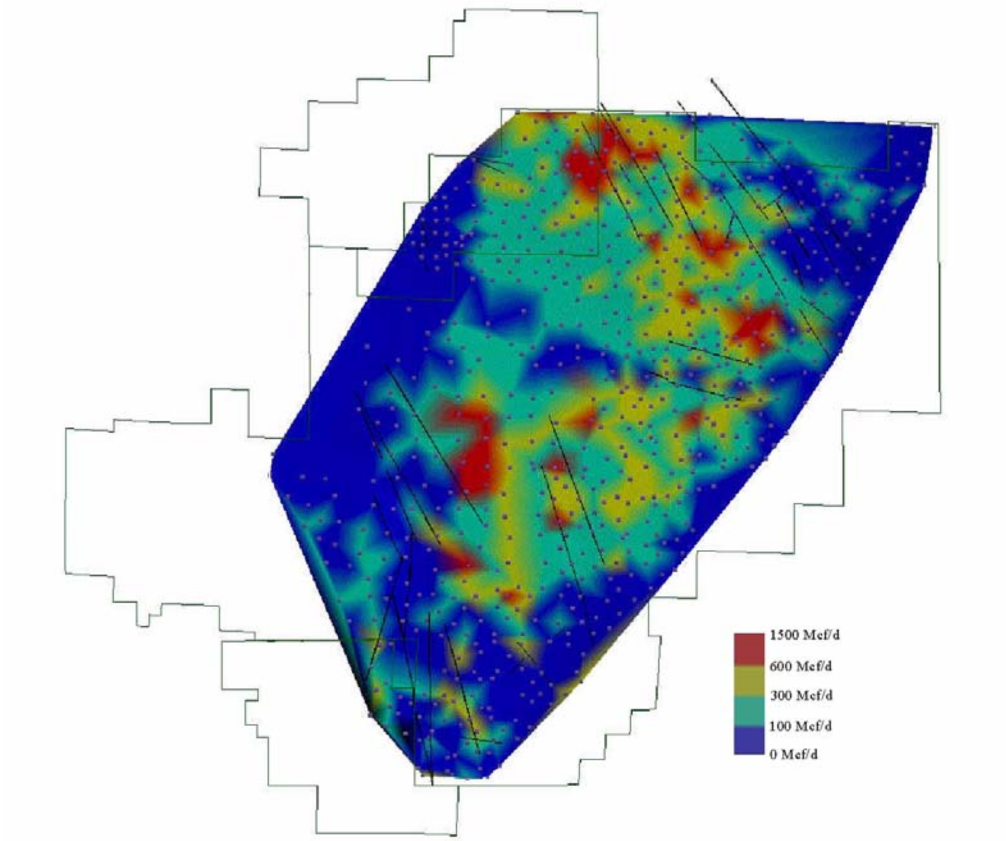

Figure 6. Maximum daily gas production (Mcf/d). Mapped on the Mary Lee cycle top and ignoring faults. Black lines indicate fault traces.

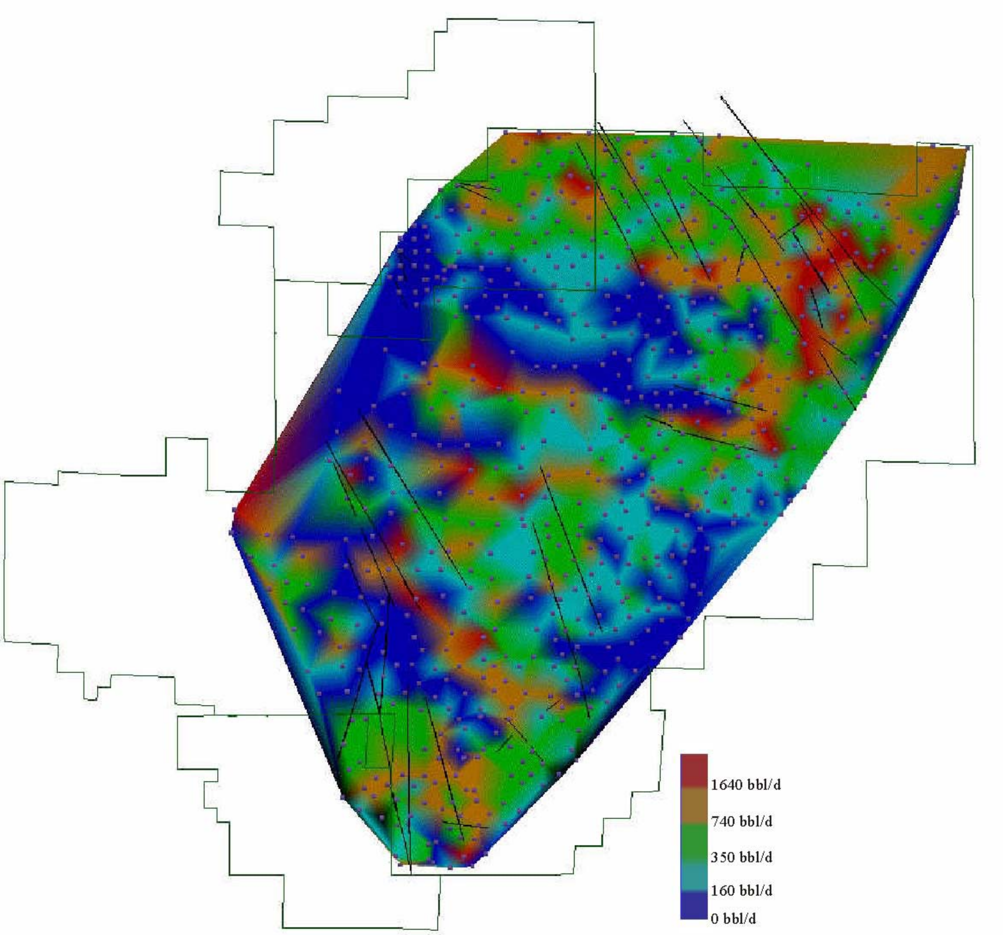

Figure 7. Maximum daily water production (bbl/d). Mapped on the top of the Mary Lee cycle, ignoring faults. Black lines indicate fault traces.

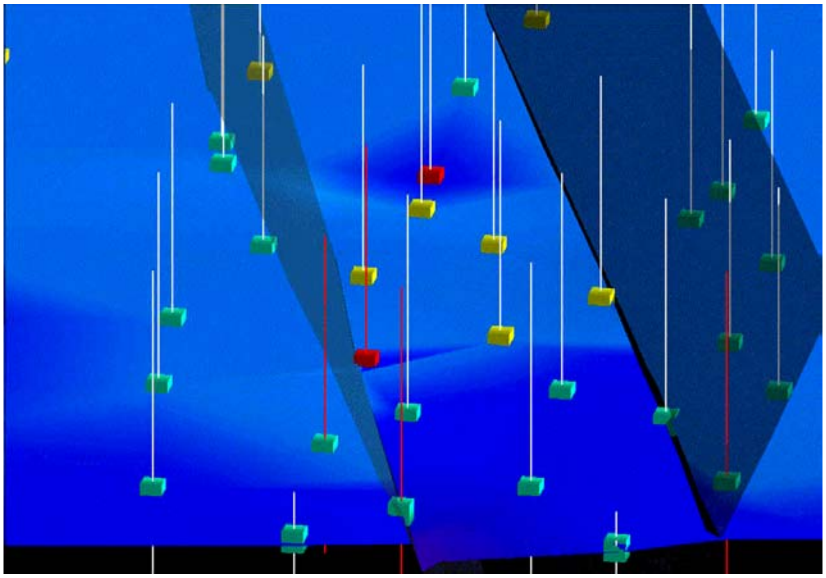

Figure 8. Oblique View of a graben with average to exceptional gas production. Top of the Mary Lee cycle colored for elevation. Data points shown as blocks, colored by gas production (same scale as in Figure 6). Faulted wells colored red, unfaulted wells colored light gray.

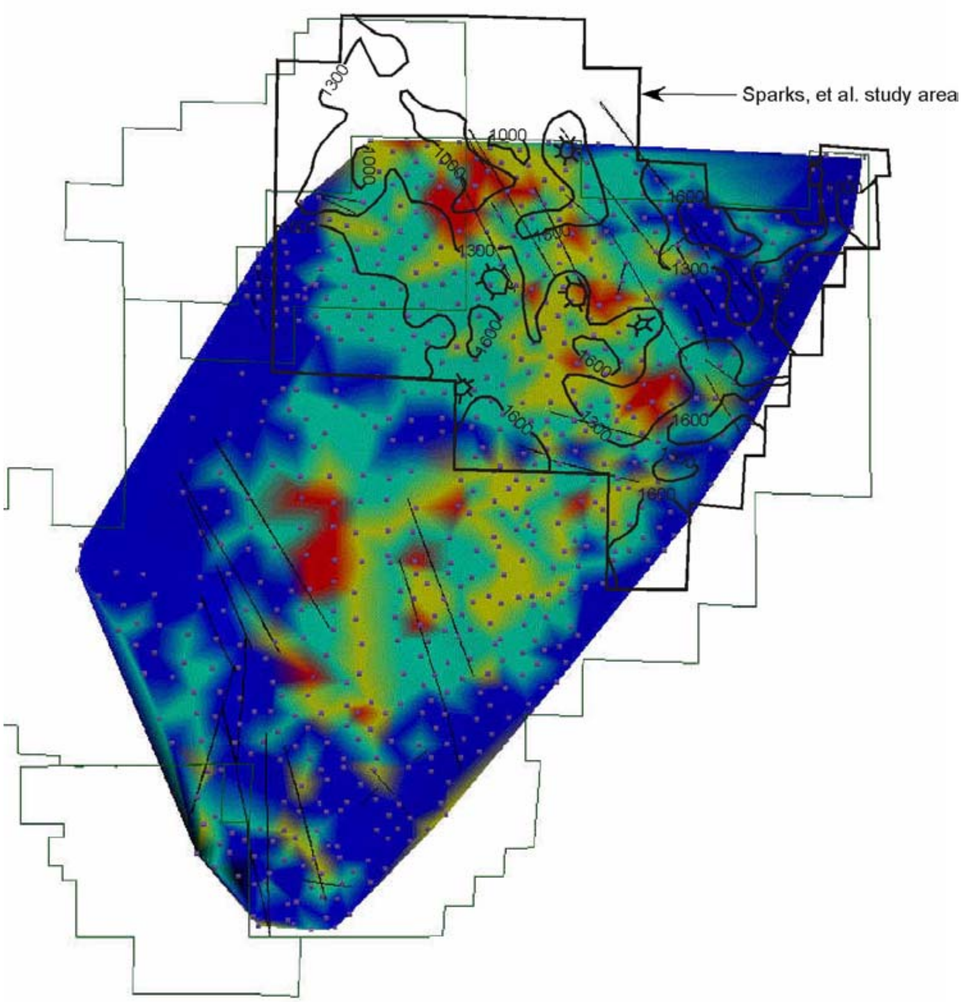

Figure 9. Maximum daily gas production with closure pressure overlay. Maximum daily gas production as in Figure 5. Closure pressure contours in PSIG, hachured on down gradient side (modified from Sparks et al., 1993).

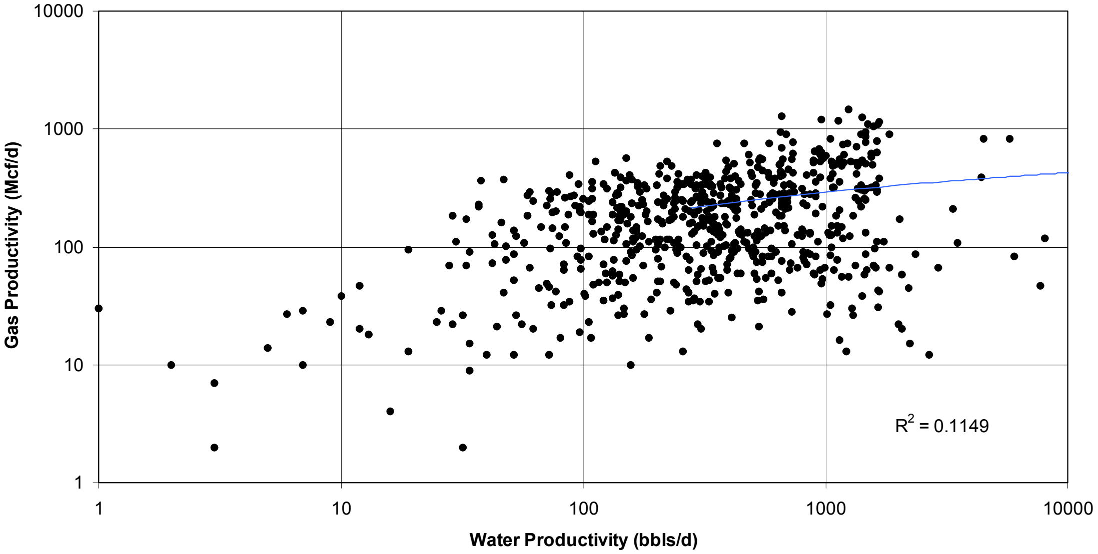

Figure 10. Gas production vs. water production. Blue line is the logarithmic trend line, R2 = 0.1149.