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Coalbed Methane Geostatistical Analysis: A Method for Ranking Well Productivity

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ABSTRACT

A study was conducted which demonstrated the use of geostatistical techniques for identifying correlations between geologic parameters and gas production for 38 coalbed methane wells completed in the Blue Creek coal seam of the Oak Grove (U.S. Steel) field in Alabama. Data used in the study consisted of production information for these wells along with geologic information for the area of interest. Results indicated that four geologic parameters showed statistical correlations with gas production: the well elevation (a proxy variable for permeabilty), the number of lineament intersections within 250 feet (76 meters), the thickness of the Blue Creek coal seam, and the length of the nearest lineament. The study suggested that the results obtained for wells in the primary degasification grid could be extrapolated to wells in an adjacent area having lineament orientations similar to the primary grid. A method by which each well could be characterized based upon its production profile (i.e., production versus time relationships) rather than a simple one-number summary, such as 4-year cumulative production, was also identified.

STUDY AREA AND GENERAL GEOLOGY

The area of study was a 38-well coal degasification field in U.S. Steel Corporation's Oak Grove mine located in west-central Alabama (Figure 1), approximately 25 miles (40 kilometers) west of Birmingham. The Oak Grove mine lies within the Warrior coal basin, a synclinal plateau that dips gently to the southwest and is bounded by the Quachita and Appalachian mountain belts[1]. The target of the degasification grid was the Blue Creek coal seam, which varies in thickness from 40 to 70 inches (1.0 to 1.8 meters) and lies at a depth of about 1,100 feet (330 meters) beneath the surface. The major structural features of the area are the Sequatchie and Blue Creek anticlines, which lie to the northwest and south of the study area, respectively. These anticlines divide two contrasting structural provinces[2,3]. To the west of these anticlines the rocks in the Black Warrior basin structural province are generally not deformed, indicating a stable structural setting. Eastward toward the Appalachian structural front, the rocks are folded and thrust-faulted, indicating the presence of intense, compressional-stress forces.

References and illustrations at end of paper.

METHODS AND APPROACH

The study area was divided into two parts; wells inside the primary degasification grid and wells outside the degasification grid. (See Figure 2.) Twenty-three wells inside the degasification grid were the primary wells of interest for the study, although wells outside the grid were also examined.

Lineament and joint data analyzed in the study were obtained from a study conducted by the U.S. Steel Southern Appalachian Field Office[4]. A total of 260 lineaments were identified in the Oak Grove study area. A map showing the location of the lineaments in relation to the gas wells is presented in Figure 3. Several variables relating to these lineaments were investigated. A complete list of independent variables present in the data set is listed in Appendix A.

The dependent variable for this study was gas production. Production data was obtained from U.S. Steel. The gas production profiles (i.e., production versus time plots) were examined for each well within the degasification grid. Construction of these plots was based upon production time, rather than calendar time.

Exploratory data analyses were conducted to screen the data set used in this study for consistency and

accuracy. Scatter plots, histograms, correlation studies, and summary statistics were used for data screening. Problems identified in the data set were examined and corrected when possible. Inconsistent data that could not be verified was eliminated from the data set used for the study. The primary data analyses used in the study consisted of a set of multivariate geostatistical techniques used to examine the effects of geologic variables on gas production. These geostatistical techniques were: (1) principal components analysis, used to establish well categories, and (2) stepwise discriminant analysis, employed to establish key geologic variables, and to develop a classification criteria for predicting production.

RESULTS AND DISCUSSION

Principal components analysis was used to study the patterns of variability in gas production profiles of wells inside the degasification grid. Gas production profiles were characterized by four measurements: gas production during the first, second, third, and fourth years of actual production. The analysis was applied to the gas production data of 22 of the 23 wells inside the degasification grid. One well inside the grid (Well No. 21) had not completed 4 years of production and was eliminated from the analysis. Wells outside the degasification grid were excluded from this analysis since only 2 years of production data were available for those wells. The purpose of the principal components analysis was to develop the fewest number of indices that would explain as much of the total variation in the production data as possible.

The first principal component was the weighted combination of several variables that accounted for the maximum amount of the total variation in production (i.e., summation of individual gas well differences). The second principal component was the weighted combination of the original variables that accounted for the maximum amount of the remaining variation. The second principal component was not correlated with the first principal component. In theory, there may be as many principal components as there are original variables. However, in many practical applications, most of the total variation in the data is usually accounted for by the first few components.

Results of the principal components analysis indicated that most (66 percent) of the variability was accounted for by the first principal component. The second principal component accounted for an additional 24 percent. Since these first two principal components jointly accounted for 90 percent of the total variation in the gas production data, these two components were used exclusively to categorize the wells. The first principal component was interpreted as an index of overall gas production. For example, principal components analysis indicated that Well No. 2 was a high production well (153 MMcf [4.3×10^6 meters^3] 4-year cumulative production), whereas Well No. 19 was a low production well (21 MMcf [5.9×10^5 meters^3] 4-year cumulative production). The second principal component of the production data compared gas production over the first 2 years with the gas production over the third and fourth years. This component indicated whether a well was an "early" or "late" producer. For example, Well No. 14 was classified as an early producer by this index (Figure 4), whereas Well No. 11 was classified as a late producer (Figure 5). The classified wells discussed above were the obvious ones to serve as examples and could have been classified into the designated categories without the use of principal components analysis. However, classification of the other wells would not be that obvious. Classification would become very subjective if done by simply examining the data. Principal components analysis serves as an unbiased technique for objectively identifying natural categories of wells based upon their production histories. The usefulness of this technique increases as the amount of production data increases and the relationships become more complex. In addition, the wells identified within each category may be analyzed to establish why they are considered to be related to each other based upon their production histories.

Based upon the principal component indices, four production categories were identified: (1) low-early production wells, (2) low-late production wells, (3) high-early production wells, and (4) high-late production wells. Each of the 22 wells was placed into one of these production categories.

Discriminant function analyses were then performed to determine if there was a correlation between the production categories and any of the geologic variables in the data set. Four variables were identified as significantly contributing to differences among the four production categories. The variables included the well elevation (a proxy variable), the number of lineament intersections within 250 feet (76 meters), the thickness of the Blue Creek coal seam, and the length of the nearest lineament. By applying these variables, 91 percent of the wells inside the degasification grid were correctly categorized according to the discriminant model. All wells were correctly categorized according to "shape;" however, two of the high producing wells were misclassified as being low production wells. The results indicated that low-late production wells were associated with thicker coal beds, were near more lineament intersections, were in the vicinity of shorter lineaments, and were at higher elevations than high-early producing wells. The results of the discriminant analysis are summarized in Figure 6. The two primary discriminant functions are presented in the figure. The analysis indicated that wells toward the right along the first discriminant function had higher elevations and/or had thicker coal seams on average than wells to the left along that axis. Wells toward the top along the second discriminant function had thicker coal seams, more lineament intersections within 250 feet, and/or near shorter lineaments on average than wells toward the bottom along that axis. The separation of wells belonging to the four production categories is clearly evident in Figure 6. It can also be seen that profile shapes are better separated than overall production. A straight line drawn through this plot could separate the region into an area of predominantly late producers and an area of predominantly early producers. High production wells cannot be separated from low production wells with a straight line.

The percentage of correctly classified wells mentioned above is probably higher than would be observed if the discriminant functions are applied to a set of potential well sites. The number of observations (wells) in this data set was smaller than the number of geologic variables. As a result, if all of the variables were used in the analysis, several different models, each of which could produce 100 percent correct classification rates could be devised. The number of variables was limited to those considered to be geostatistically significant to overcome the "over parameterization" problem. Even though the number of variables was reduced, the results are still better than one would observe in practice for three reasons. First, even though the "best" variables were chosen from a list of available geologic variables, when the number of available variables is large, fairly good results could occur by chance alone. Second, the wells that were reclassified by the discriminant analysis were those used to construct the discriminant model. The best way to validate a discriminant model is to apply it to new observations (i.e., observations not used in constructing the model). Third, the results may be location specific and not general enough to apply to other locations.

Just as in the principal components analysis, the wells outside the degasification grid were excluded from construction of the discriminant model. Because only 2 years of production data was available for these wells, they could not be grouped into one of the four categories and the discriminant model could not be validated by reclassifying wells located outside the degasification grid. However, the discriminant procedures were used to provide a measure of the likelihood that a well would be a "high" or "low" overall producer. This provided a method of indirectly assessing the validity of the discriminant model by examining wells outside the primary degasification grid. The likelihood of one of these wells being a high production well was compared with the 2-year cumulative production for that well. If 2-year cumulative production was a good index of 4-year cumulative production, then a positive relationship between 2-year cumulative production and the likelihood of being a high production well computed from the discriminant model would be expected. The wells outside the degasification, however, did not meet this expectation. (See Figure 7.) An overall negative correlation between the 2-year cumulative production and the likelihood of high production was observed. This suggests, in general, that the discriminant model did not apply to wells located outside the grid.

Figure 7 exhibited an interesting phenomenon. There was a small band of wells in the lower right of the diagram that displayed a positive correlation between the likelihood of high production and the 2-year cumulative production. Most of these wells were located in the south and southeast portions of the study area (refer to Figure 3). The lineament orientations in this area were similar to those within the degasification grid as opposed to those in the eastern portion of the study area. Inspection of the high altitude photography derived lineament map of the study area (Figure 3), revealed that there were two dominant lineament orientations in and around the study area. Within the 23-well degasification grid and to its south, the strike of the dominant lineament trend was to the northwest, possibly related to many northwest oriented normal faults in the area. To the east of the grid, and further into the folded and thrust-faulted structural province, the strike of the dominant lineament trend switched to the northeast, a similar orientation to mapped thrust-faults that are associated with the Appalachian fold belt. This suggests that the results from the primary degasification grid could be extrapolated to nearby wells provided they were located in an area with a similar geological environment.

Although several relationships were found between lineaments and gas production for this study area, it should be noted the relationships may have been different if the lineaments had been mapped by another company. Results of a study done by Pratt and others[5] indicated that mappers often disagree about lineament placement, length, and orientation. Any "effects" of lineaments that are established by principal components and discriminant analyses may be dependent upon who mapped the lineaments and how they mapped them, as opposed to true lineament affects. For this reason, the relationships between lineaments and production that are discussed in this report should be used with caution.

REFERENCES

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5. Pratt, H. R., E. H. Robey, and R. A. Wojewodka, "Eastern Gas Shales Geostatistical Lineament Analysis - Final Report," work performed under contract to the U.S. Department of Energy, Morgantown Energy Technology Center, Morgantown, West Virginia, December 1985.

APPENDIX A

List of Independent Variables Present in the Data Set

- Thickness of the Blue Creek Coal, Feet.
- Distance from the Well to the Nearest Lineament, Feet.
- Distance from the Well to the Nearest Intersection of Lineaments, Feet.

- Elevation of the Well Above Reference Well US30-9-30, Feet.
- Density of Joints with Orientations of 10-30, 40-50, 285-295, and 335-355 Degrees.
- Length of the Lineament Nearest to the Well, Feet.
- Number of Lineament Intersections Within 250 and 500 Feet of the Well.
- Number of Lineaments Within 250 and 500 Feet of the Well.
- Orientation of the Lineament Nearest to the Well, Degrees.
- Total Length of all Lineaments Within 250 and 500 Feet of the Well, Feet.

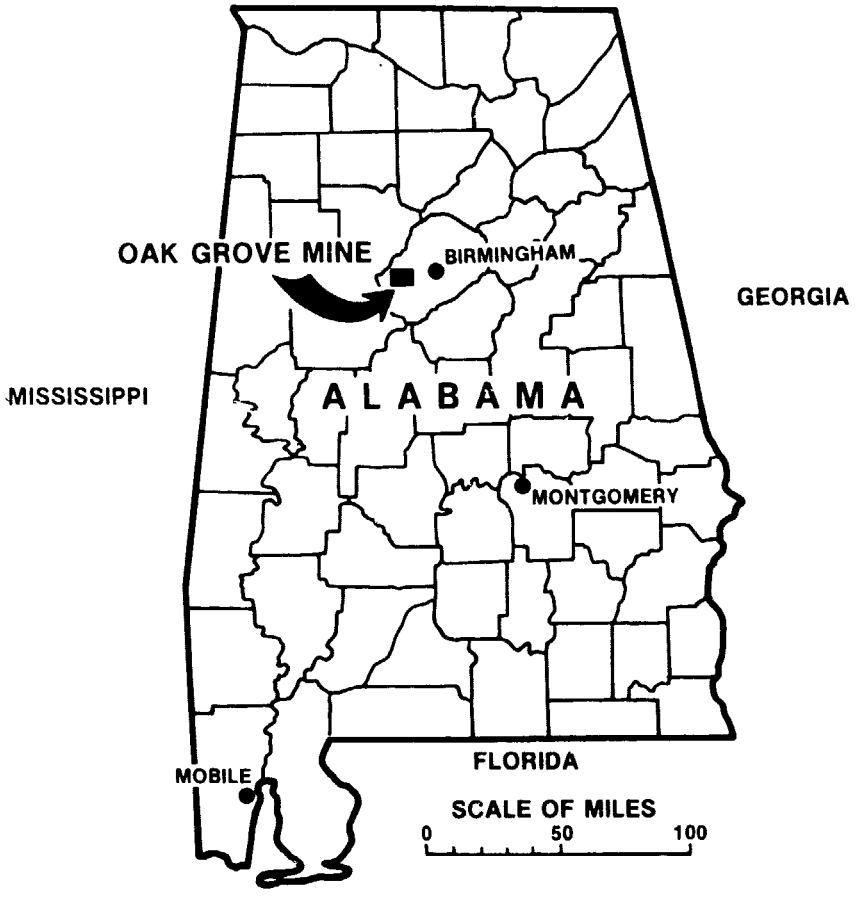

Fig. 1—Location of Oak Grove study area.

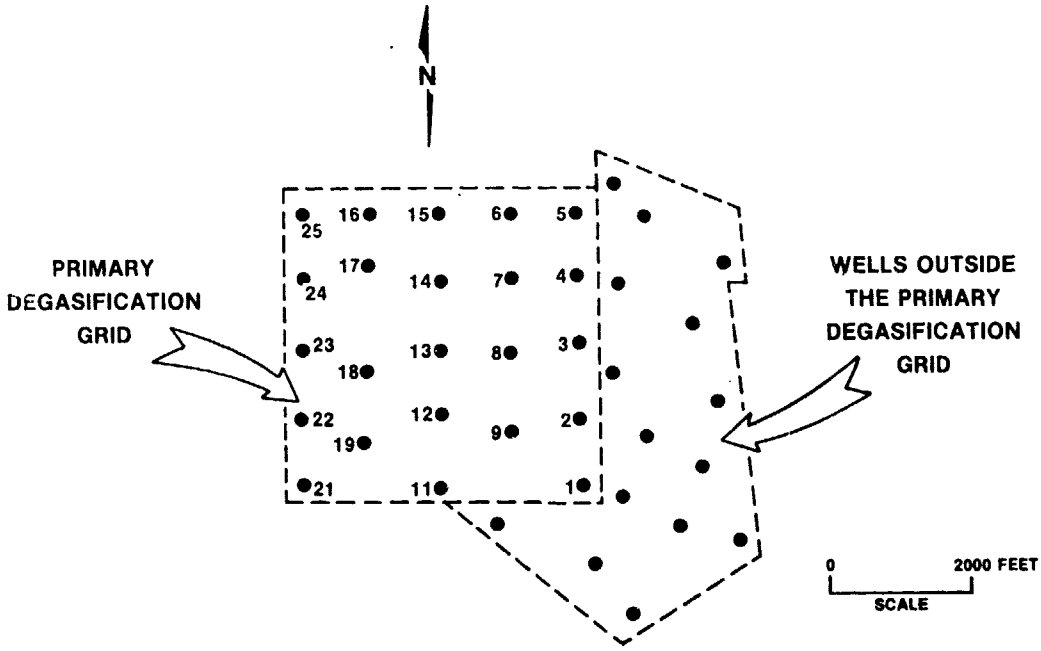

Fig. 2—Location of gas wells in the Oak Grove degasification field.

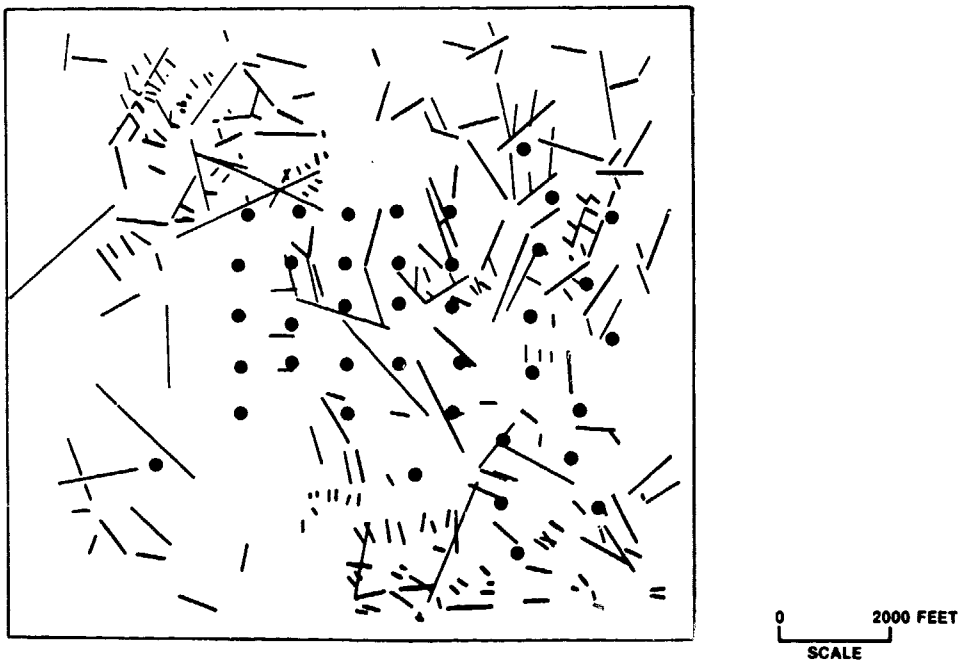

Fig. 3—High-altitude lineaments mapped in the Oak Grove field.

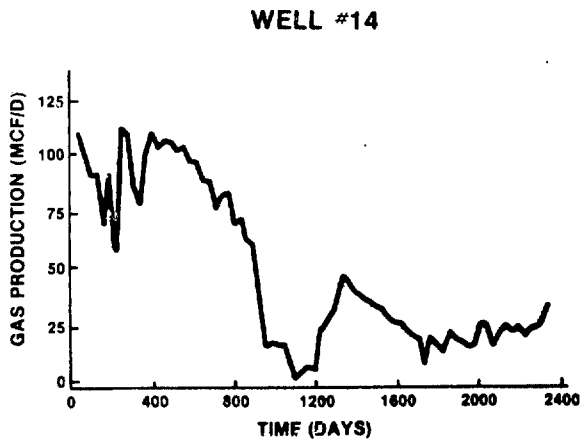

Fig. 4—Gas production of Well 14 vs. time.

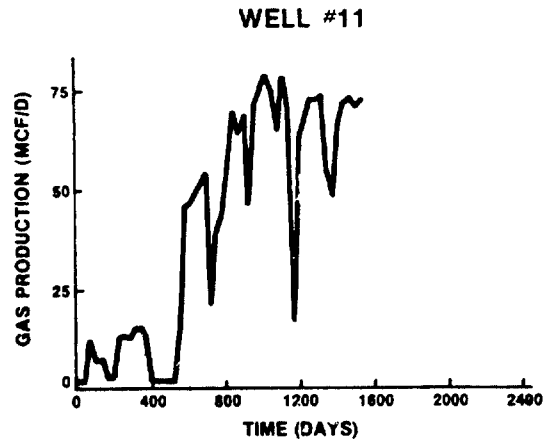

Fig. 5—Gas production of Well 11 vs. time.

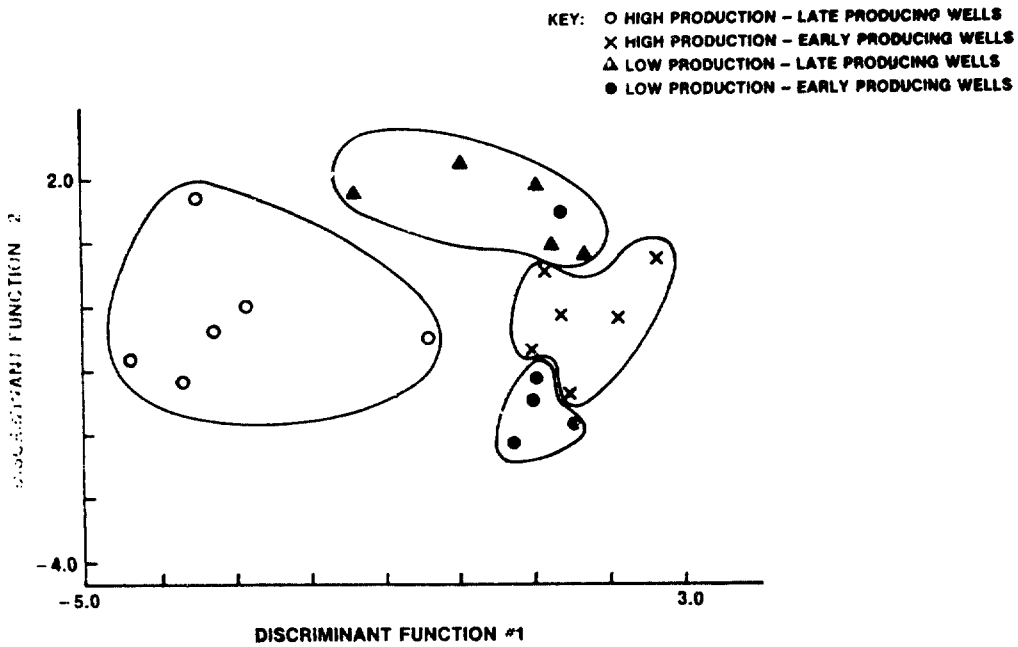

Fig. 6—Separation of well groups in discriminant space.

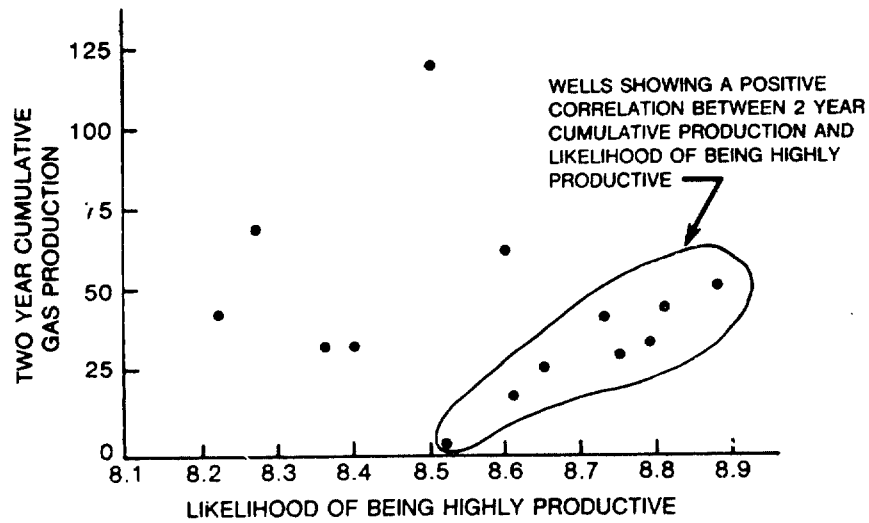

Fig 7—Results of the discriminant analysis for wells outside the degasification grid.