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Fractal Interrelationship in Field and Seismic Data

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Third Quarterly Technical Report - Contract No. DE-FG21-95MC32158

(21 Sep. 1995 to 21 Dec. 1995)

TITLE: Fractal Interrelationship in Field and Seismic Data

BY

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STATUS - BY TASK

Task 1 - Analysis of contour irregularities

Background

Contour irregularities traced over both study areas in the pervious quarter were scanned into the computer and digitized at a 30 meter interval. Patterns mapped in both the Granny Creek and Middle Mountain field areas are presented in Figures 1 and 2 respectively. One of the hypotheses of this research project is that contour irregularities must be controlled by a combination of sedimentation features, lithologic variation, and local structure and fracture distribution.

As noted previously, the Granny Creek area experienced persistent fault activity throughout the Paleozoic along the underlying east margin fault of the Rome trough. The tectonic development of the area is represented by a combination of extensional and compressional styles of deformation. However, based on historical records derived from seismic data, only very minor reactivation of basement structures would be expected during the Middle Pennsylvanian. Structures associated with the Late Paleozoic Allegheny orogeny are also very subtle. Structural controls on these patterns is expected to be negligible or at the threshold of detectability in the area.

Conversely, in the Valley and Ridge, the record of Alleghany deformation is significant. Structural relief of formations exposed at the surface across the Middle Mountain syncline and Elkhorn Mountain anticlines reaches more than 3000 feet in some areas; intense folding and fracturing is observed; and significant plunge of major structures occurs across the area. The influence of structure on contour patterns is visually pronounced across both the major and minor structural features of the area.

The "box counting" method of fractal analysis was employed to analyze these patterns. The data obtained using this procedure consists of the number of boxes of a certain size that are occupied by segments of the pattern. The counting is done for boxes of varying size and the resulting plots are analyzed to determine if a fractal interrelationship exists. Log-log plots of the number of occupied boxes versus box size are shown in Figures 3 for Areas 1 through 3 along the Middle Mountain Syncline.

Surprisingly, the box-counting technique reveals no quantitative differences between areas with patterns that are visually quite different from one another. The patterns appear to be "space filling", that is, with the exception of the smaller boxes, all boxes tend to be occupied. The region of Figure 3 noted as he "Random Regime" corresponds to the space filling response of the pattern. D in this case is 2, i.e., for all practical purposes are 2-dimensional over the range of from 150 meters to over 4000 meters. Regimes noted as "fractal" in Figure 3 reveal the tendency for boxes to be increasingly unoccupied at smaller scale. D decreases quite rapidly, and the impression is that the actual fractal region of the data has been missed.

The results suggest that the overall patterns, which differ visually from one another, are not separable through box counting. The same result was obtained in the Granny Creek area. Additional examination of these patterns is under consideration. For example, box counting of smaller features in the pattern may be undertaken or the data sets may be resampled at smaller sample intervals in hopes of more accurately defining the fractal regime with box sizes smaller than 30 m.

However, further work is this area will not be undertaken until the fractal characteristics of topographic contours has been determined. Alignments of contour irregularities that are so distinctly different in appearance are associated with contour patterns that are equally distinct. Individual contours are far from space filling, and represent another approach that should be tested.

Task 2 - Analyze fractal characteristics of bed-length and structural relief

Completed. See our second quarterly report and topical report titled "*some pitfalls in the fractal characterization of folds*". Major issues associated with this task have been resolved and no future work is planned.

Task 3- Field work and topographic analysis

Analysis of the fractal characteristics of topographic relief has been completed in both study areas. Significant variations of fractal dimension were observed along the length of the Middle Mountain syncline. Geological explanations of these variations is complicated due to the presence of both stratigraphic and structural variability along the axis of the syncline. However, the observed increase of fractal dimension occurs abruptly and remains high through areas of significant lithologic variability. This observation supports a structural origin for the fractal dimension variations. The drop in fractal dimension south of the CSD on the other hand is associated with a major stratigraphic boundary. The contributions of structural and stratigraphic variability, in this case, cannot be separated.

Location and photographing of fractured rock outcrop, also part of this task, is planned for the winter and spring months. The general time-frame for this work is to have data available for analysis during the coming summer.

Task 4 and 5 - Seismic analysis.

Work proposed under this task has been completed. Fractal dimensions were computed for major reflection events observed in vibroseis data across the Granny Creek field in Clay Co. West Virginia. The results of this analysis reveal the presence of systematic variations of fractal dimension from the basement to shallow stratigraphic levels. These variations are summarized in Figure 4 for lines which cross the faulted East Margin of the Trough. Fractal dimension increases abruptly from the basement to the Cambrian Rutledge Ls. The fractal dimension of reflection events from the Cambrian through Lower Devonian intervals remains nearly constant at approximately 1.35. The fractal dimension increases abruptly to 1.48 between the Devonian Onondaga Limestone and Huron shales. The higher fractal dimension implies that the Huron and shallower Greenbrier reflectors are rougher. Seismic interpretations of the area suggest that the Devonian shales are detached (Wilson et al. 1993, Wilson and Zheng 1994). Additional structures developed above the decollement may cause the higher fractal dimension of the Huron and shallower Greenbrier reflectors. Two lines located primarily east of the East margin reveal an increase in fractal dimension between the basement and sediment reflection events. Fractal dimensions are generally higher in these two lines than in those across the margin, but no increase is observed between the Onondaga and Huron and Greenbrier events.

Tasks 4 and 5 are largely complete, but the origins and statistical significance of changes in fractal dimension observed in the area require further analysis. Fractal dimensions will be computed for windowed segments the Onondaga, Huron, and Greenbrier reflections in an attempt to better define structural interrelationships within and between lines.

Future Work

- The most promising result obtained thus far are those reported under ***Tasks 4 and 5.*** If further tests continue to support the observation that increased fractal dimension reflects the presence of detached structure, the analytical techniques employed here may be of use in the routine evaluation of seismic data to locate subtle traps. The observations may allow one to predict the variation of fractal dimension within a subsurface fracture network based on seismic observation of resolvable structural parameters. Such predictions would provide a working hypothesis, which could be modified within the context of available subsurface data. During the next quarter we will consider possible efforts that could be undertaken to broaden the scope and practical applications of research initiated under this contract.

- During the coming quarter we will also submit an abstract for presentation at the next Annual Meeting of the American Geophysical Union.

REFERENCES

Wilson, T., Shumaker, R., and Zheng, L., 1993, Sequential Development of Structural Heterogeneity and its Relationship to Oil Production: Granny Creek, West Virginia: in Virginia Division of Mineral Resouorces Special Publication 132 - Studies in Eastern Energy and the Environment, Edited by A. Shultz, and E. Rader, p 20-25.

Wilson, T. H., and Zheng, L., 1994, Field Scale Heterogeneity Interpreted from Seismic Studies: Task 2B of Measuring and Predicting Reservoir Heterogeneity in Complex Deposystems: in U. S. Department of Energy Final Contract Report, (reference no. DOE/BC/14657-15, DE94000129), Bartlesville Project Office, Bartlesville, Oklahoma, p.20-26, Figures 26-45.

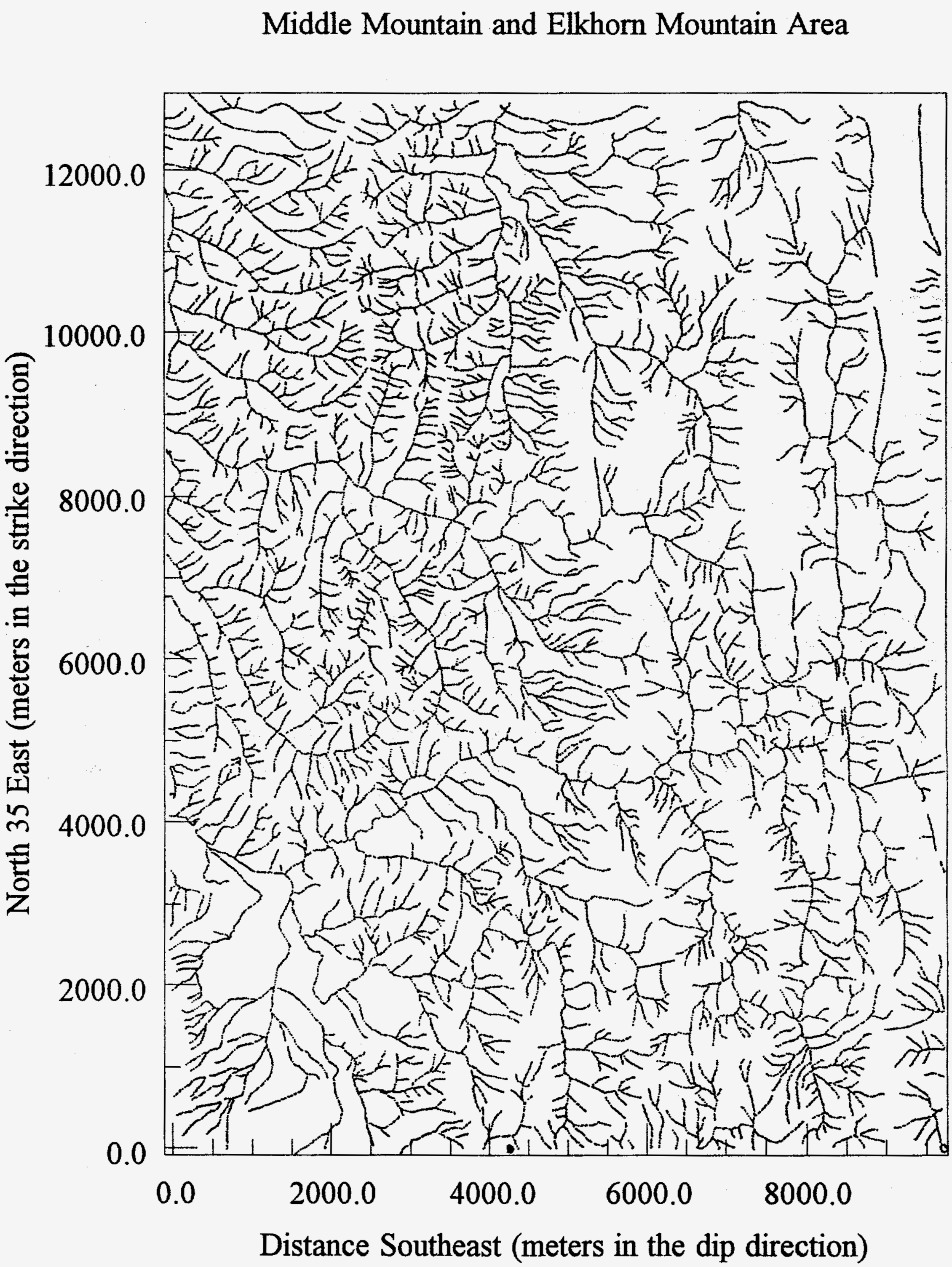


Figure 1: Alignments of contour irregularities traced from 7^1/2 minute quadrangles over the Middle Mountain and Elkhorn Mountain areas of the Valley and Ridge study area.

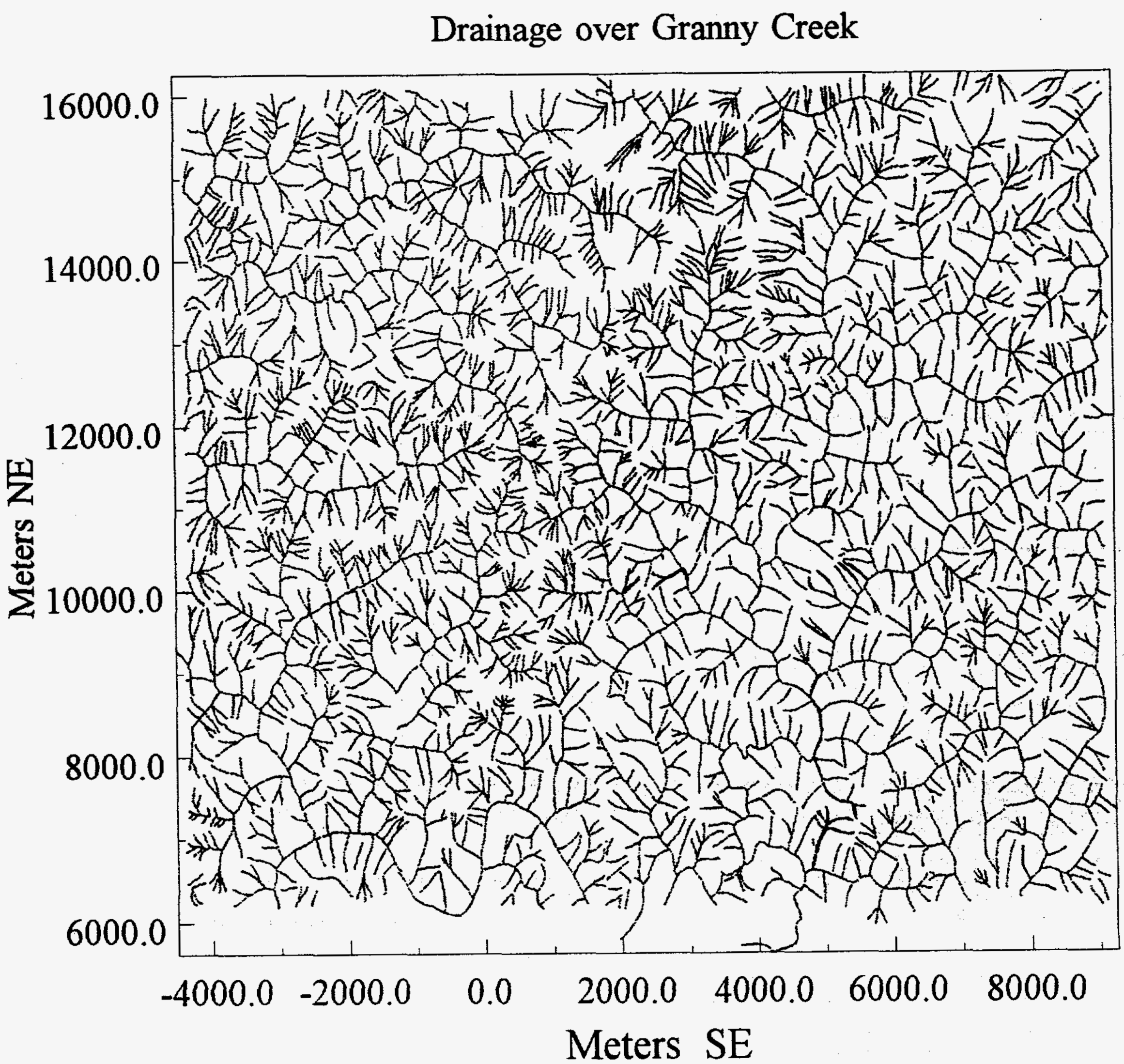
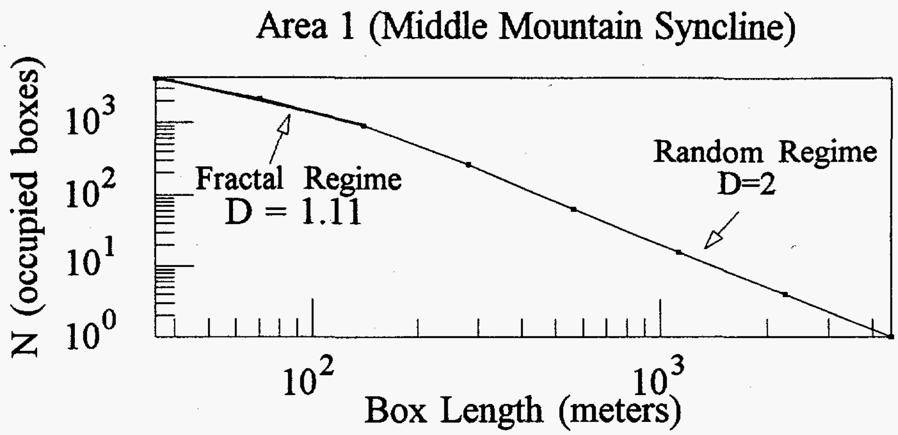
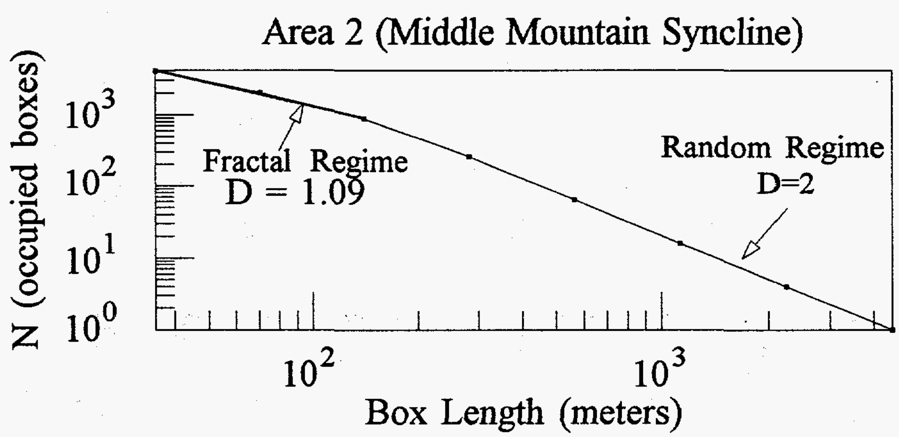


Figure 2: Alignments of contour irregularities traced from $7^{1/2}$ minute quadrangles over the Granny Creek study area in western West Virginia.





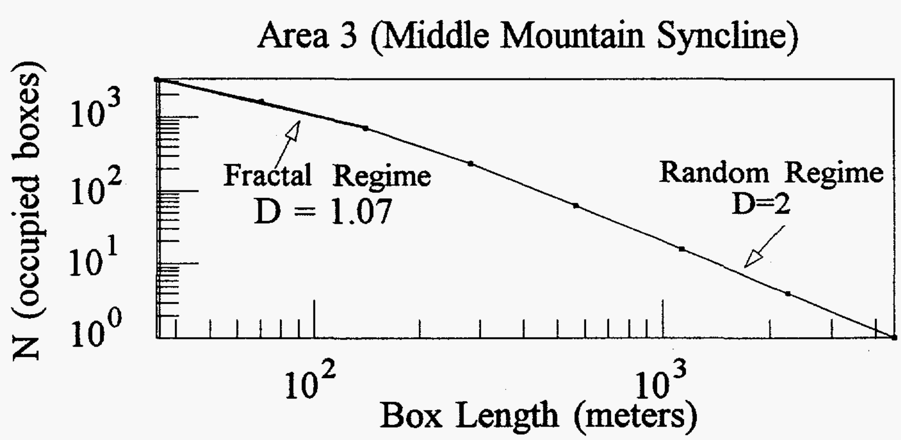


Figure 3: The results of box counting are illustrated for three areas from the Valley and Ridge study area. The random regime generally extends from about 4500 m to 150 m and reflects the tendency for all boxes to be occupied (D=2). The fractal regime may be misnamed. In this region D drops rapidly and approaches 1 suggesting that the fractal characteristics of the pattern are not being measured or may not exist.

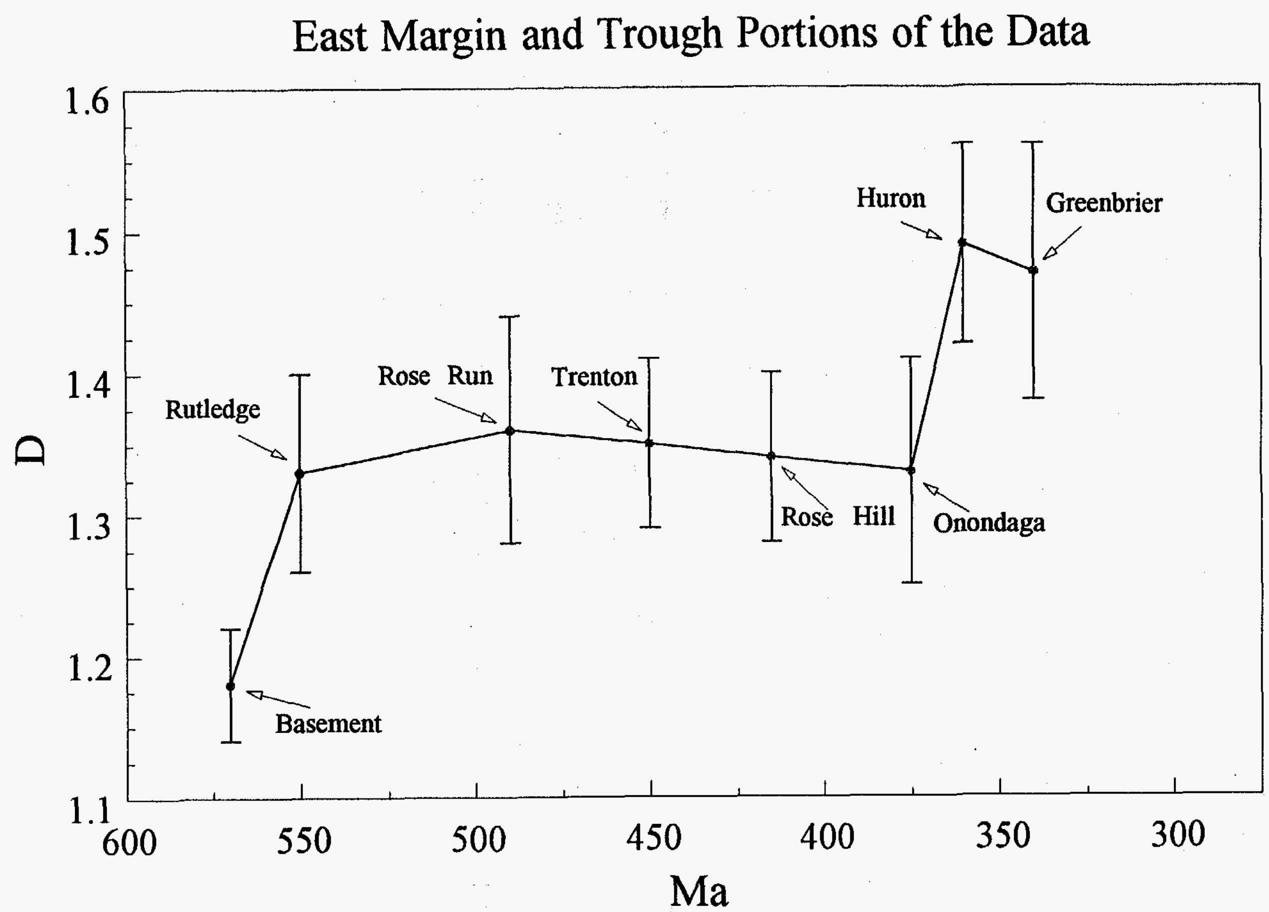


Figure 4: Variation of fractal dimension is plotted for numerous reflection events observed in seismic data across the Granny Creek field in Clay Co. WV. This plot shows variations of D for computed along lines which cross the faulted east margin of the Rome Trough. The error bars shown in the plot span two time the standard deviation of the measured values (N=4).

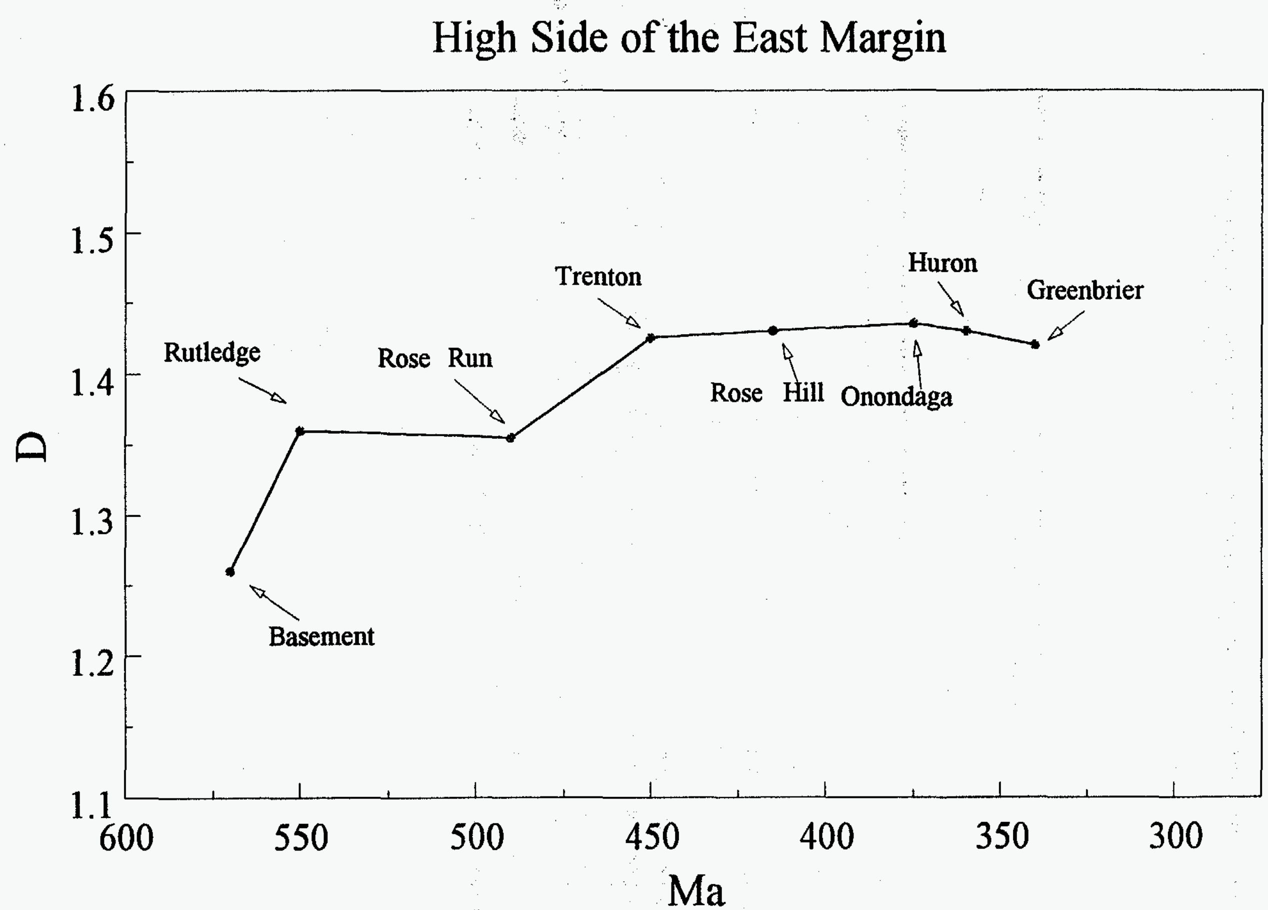


Figure 5: Variations of fractal dimension are plotted for two lines which lie on the high side of the east margin of the Rome Trough.