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INTERRELATIONSHIPS OF PHOTOLINEAMENTS, GEOLOGICAL STRUCTURES, AND FRACTURE PRODUCTION OF NATURAL GAS IN THE APPALACHIAN PLATEAU OF WEST VIRGINIA

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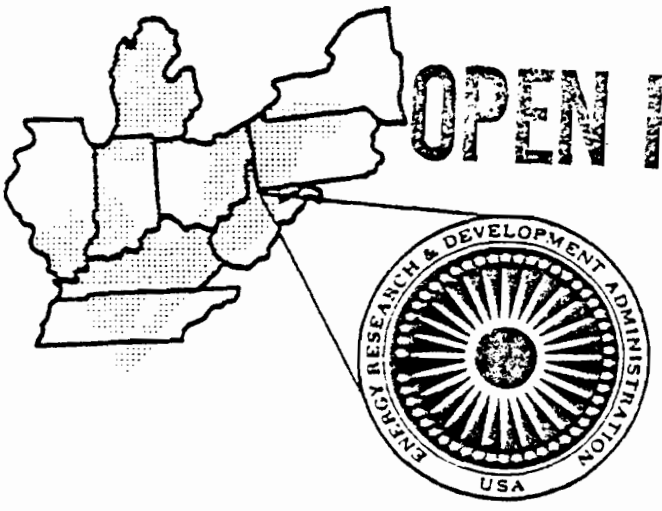

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INTERRELATIONSHIPS OF PHOTOLINEAMENTS, GEOLOGICAL STRUCTURES, AND FRACTURE PRODUCTION OF NATURAL GAS IN THE APPALACHIAN PLATEAU OF WEST VIRGINIA

by

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ABSTRACT

Natural gas production from the Devonian black shales of the Appalachian Basin is mainly from fracture permeability. Wells which intersect many natural or induced fractures are expected to be better producers than wells intersecting few or no fractures. Natural fracture zones often appear as photolineaments on various types of remote sensing imagery. In some areas, photolineaments have been demonstrated to be loci of improved production of hydrocarbons. Photolineaments are also often related to surface and subsurface fractures and stress fields. The various relationships of all these features in the Devonian shale gas production areas of western West Virginia were investigated during this project. Photolineaments were mapped from satellite and aircraft imagery; surface fractures were measured at outcrops; subsurface fractures were measured on cores; and natural gas initial open flow data were obtained from driller's logs. Fractures were found to relate to the primary directions of nearby photolineaments; however, there was considerable scatter in this data. Wells of high initial open flows are usually found between rather than on or near photolineaments.

INTRODUCTION

A significant fraction of all hydrocarbon production is from wells which either have intersected natural fractures or which have had fractures artificially produced in them. Such production comes from formations which, although "tight", have considerable hydrocarbons trapped in intergranular porosity. These formations have such low intergranular permeability that hydrocarbons, even natural gas, can only be produced economically from fractures. The Middle and Upper Devonian black shales of the Appalachian Basin which underlie the Plateau and eastern Continental physiographic provinces are excellent examples of the fractured hydrocarbon reservoir. It has been estimated that as much as 460 quadrillion cubic feet of gas - potentially 200 to 300 years supply - may be in these shales; of this, about 285 trillion cubic feet could be extracted under expectable conditions of technology and economics [1]. Since most of the wells are presently only marginally profitable, any exploration technique which decreases the ratio of low- to high-producing wells would increase the ultimate recovery.

The aim of the present project is to ultimately develop a technique for planning wells which uses low-cost remote sensing methods. Mapping of fractures and use of such maps in planning well fields has been a routine procedure in many areas. Normally photolineaments are mapped from air photos, satellite imagery, and any other type of imagery available. *Photolineaments* are continuous linear or curvilinear features or alignments of discrete features which can be detected on aerial photographs or other imagery [2]. Such procedures have been found to be of significant aid in some arid terrains such as those of northern Africa or southwestern Asia. In the United States, photolineament mapping has been successfully used as an exploration tool by Columbia Gas in their Haysi Field in western Virginia and southeastern Kentucky. Here it was found that for wells producing from the rather tight Berea siltstones, those wells drilled on or near photolineaments produced at about

twice the rate of the other wells [3]. The potential usefulness of the photolineament mapping procedures in fractured reservoirs is not restricted specifically to siting of wells. A relationship has been demonstrated among the orientation patterns of photolineaments, surface fractures, subsurface fractures, and regional stress fields [4]. Thus, even if specific siting cannot be done, the techniques can still be used for predicting induced fracture orientations in various stimulation procedures.

METHOD OF STUDY

Regional photolineaments were mapped from satellite imagery at scales of 1:1,000,000 and 1:5,000,000. Local patterns were mapped at various scales, but most commonly at 1:250,000 (the standard scale of the Eastern Gas Shales Project). Surface fractures (joints) were measured on outcrops in selected areas; orientation patterns were plotted; and preferred orientation directions determined. Subsurface data are scarce, and only that data derived from a core in Jackson County, West Virginia, was used in this study (published in [5], p. 16-17). Initial open flow figures were obtained from driller's logs on file with the West Virginia Geological and Economic Survey.

The area chosen for this study consists of portions of West Virginia and eastern Kentucky with small adjacent portions of Virginia and Ohio also included (figure 1). The reasons for choosing this area have been outlined previously [6]. Briefly, this area is of interest for two chief reasons: it is geologically or topographically different from other areas where remote sensing methods have been applied in the past; and it is underlain by the Devonian gas shales. Two areas of West Virginia were chosen for detailed study: 1) the Jackson-Mason County area, which contains the Cottageville (Mount Alto) Gas Field and has been the scene of intensive investigations by personnel of the Morgantown Energy Research Center of ERDA and others; 2) Wayne County, which has passing through it several major photolineaments associated with the 38th Parallel Lineament and also has available a considerable amount of initial open flow data for Devonian shale gas wells.

RESULTS AND CURRENT STATUS

This is the third and final year of this project. A full discussion of this project will be available in the final contract report and only a summary will be presented here. Results of previous years have already been reported [6]; only brief summaries of the current year will be given here.

Data Analysis Procedures

One of the major tasks of this project has been the evaluation and development of procedures and research tools. Among these are the statistical techniques used to test the similarity or dissimilarity of sets of orientation data. Last year it was discovered that the Wald-Wolfowitz Runs Test could be used to compare orientation data distributions. Subsequently, other tests were evaluated and one, Kuiper's modification of the Kolmogorov-Smirnov Test [7] was adopted for use in some of the statistical analyses. A computer program to plot orientation diagrams and to provide the statistical analyses of the data distributions was completed. Additionally, a general mapping computer program to aid in the analysis of the various types of data utilized by this project was completed. A discussion of the characteristics of these programs is beyond the scope of this report, but they will be fully described in the contract final report.

Relationship of Photolineaments to Geological Features

This year's effort in terms of this phase of the project consisted of collecting data on joints and comparing this with large-scale photolineament maps. Measurements of orientation and other properties of fractures in outcrops are the primary field data utilized in this project. A relationship between orientation of fractures in surface outcrops and fractures in subsurface hydrocarbon reservoirs has been established for some areas [8]. There is also a relationship between surface fractures and photolineaments in some areas [9, 10]. In the final report of this contract, there will be a more extensive discussion of these relationships; only a brief example of problems encountered and results obtained will be given here.

Problems encountered. In Jackson County (figure 1 shows location), the surface rocks are of the Permo-Pennsylvanian Dunkard Group which is primarily a deltaic sequence consisting of gray and red mudstones, siltstones, and channel and bar sandstones. The most prevalent rocks in outcrop are

the sandstones. There are several reasons why fractures measured on these sandstones may not be reliable indicators of regional fracture patterns. The sandstones tend to be relatively small patches surrounded by the mudstones. This leads to two conditions. First, regional fractures may not be propagated through the mudstones into the sandstones. Thus, fractures seen in the sandstones may well be due to fracturing of a brittle mass only poorly supported by the surrounding, rather weak mudstones and breaking up under its own weight. Second, the irregular shapes of the sandstone bodies can cause refraction of a propagating fracture and so change its orientation by twisting the propagating wave front about an axis parallel to the direction of propagation. In this case, although the fractures are related to regional fracture patterns, the directions found tend to differ from that pattern.

The effects of these problems are partially reduced by a regional analysis employing several thousand measurements. With this quantity of data, errors introduced by factors active in small areas are eliminated or greatly attenuated. In any case, however, any analysis done cannot depend on a *small* error margin.

Results. Figure 2 shows the most important preferred orientations at outcrops in the general area of the Cottageville Gas Field. Figure 3 is a summary of the more prominent photolineaments of the same area as the joint measurements. A comparison of figures 2 and 3 shows that several of the trends are coincident. The major preferred directions on both diagrams are approximately the same. There is, however, clearly not complete agreement between the two patterns. Assuming a relationship between the two types of features, the disagreement between the two sets of orientations could be caused by either 1) the distortions of joint directions by sand lenses as outlined above, or 2) a difference in reaction of the short (joints) and long (photolineaments) features to regional stresses which may have varied in direction. There is, however, too much coincidence of the orientations of the two sets of data for it to be ignored entirely. Thus, it appears that the photolineament maps may serve to at least partially predict surface outcrop fracture directions.

Predicting subsurface fracture orientation from photolineaments is less certain. It is difficult to evaluate this relationship mainly because of the lack of data. However, in the vicinity of the core from which the subsurface orientation measurements were taken is one outcrop site. The relationship between the two sets of orientation measurements is not clear-cut, but at least one of the major directions of the surface outcrop matches the chief subsurface fracture orientation. From this meager evidence, one may postulate a relationship between surface and subsurface fractures, and indirectly between subsurface fractures and photolineaments. Such a relationship needs extensive testing, however, before it can be applied as a predictive tool. The additional step of predicting subsurface fractures induced during stimulation of wells is even less certain because of additional restrictions placed on their formation by conditions under which they form.

Relationship of Initial Open Flows and Photolineaments

A considerable amount of raw data has been gathered. About 400 wells in Wayne County and 160 wells in the Jackson-Mason County area were found which included gas yield data for the Devonian shales. Most of the data is after-shot initial open flows although some natural open flows and underway gas tests were also found.

Problems encountered. Both the photolineament and the gas initial open flow data presented problems. The gas production figures were derived from driller's logs on file with the West Virginia Geological and Economic Survey. The information on such logs is of variable quality. Often it difficult to determine the source formation of the gas produced. It is possible also that some of the gas ascribed to the Devonian shale may come from another formation. Despite attempts to eliminate errors of this nature, it is possible that some errors nevertheless remain in the data.

Photolineament mapping presents many problems. Affecting the analysis most is the choice of imagery type and scale which in turn affects the type of photolineament mapped. If too large a scale is chosen, the map which results will have have far too many lines for usefulness in most cases. Almost any point would be on or near a photolineament and any kind of analysis depending on relative locations would probably be meaningless. (This type of map is not totally useless, however, since orientation patterns can still be obtained from it.) In this particular study, for example, it would be useless to have a map on which the photolineaments are closer together than the wells. In such a case, all wells would be "near" photolineaments.

It is also apparent that photolineaments mapped from different scales (and types) of imagery do not necessarily represent the same type of features. Literature reports of the width of the influ-

ence zone of photolineaments range from 40 feet to 1 mile. Most of this difference is probably due to imagery scale choices which result in photolineament maps which preferentially depict certain types of photolineaments. There is, however, no evidence that the influence zone width of photolineaments is always related to imagery scale. Thus, any test made for the relationship of proximity of a well to a photolineament and hydrocarbon production will have the uncertainty related to influence zone width.

Results. Test analyses were done for Wayne County and for the Jackson-Mason County area. The photolineament maps for both areas (figures 4, 5, 6, and 7) were prepared in a similar manner. Individual maps were produced for each of the types of imagery available (8 maps for Jackson-Mason, 4 maps for Wayne). These were then superimposed and those photolineaments which appeared on two or more maps were extracted and are shown on figures 4-7. Superimposed on these photolineament maps are the before- and after-shot open flow data.

The results for Wayne County seem to indicate that the natural open flows are less on or near photolineaments. After-shot open flows are not clearly related to photolineaments. Although some of the wells with high after-shot flows do fall on or near the photolineaments, even more fall between them. There are no high natural open flows on or near photolineaments (except possibly for one case).

The picture for the Jackson-Mason County area is similar. An additional photolineament map was produced from imagery at a scale of 1:65,000 for the Cottageville Gas Field because of the close spacing and generally higher yields of those wells. The results were no different than those above. The wells with high initial open flows were not near photolineaments.

These results are not entirely unexpected in light of the probable characteristics of the features represented by photolineaments. Such features are generally zones of undetermined (but ranging at least from 40 feet to 1 mile) width in which the rocks differ from those around them, and in particular, where the rocks are more fractured than the surrounding rock. If no secondary mineralization has caused sealing of the fractures, such zones should be much more permeable than the country rock. However, since photolineaments, by the fact that they can be seen on aerial imagery, must represent conditions at the surface of the earth, and if these conditions (i.e., fracturing) exist to the depth of the gas reservoir, then it is entirely reasonable that the gas has been vented to the surface through the fracture permeability. The only conditions under which one might expect better production due to such fracture zones would be if they were very well sealed above the gas reservoir.

Thus, it appears that the locations of photolineaments are poor choices for gas wells in the area investigated. Several possible explanations exist for the apparent discrepancy of findings of this study and that referenced for the Haysi Field [3]. First, the lithologies of the producing formations are different. The producing horizon in the Haysi Field is the Berea siltsone; the producing horizon in western West Virginia is the Devonian shale. The two rock types behave differently under stresses which produce fracturing. Second, the Haysi Field is located in an area of Appalachian thin-skinned tectonics, where the areas of this study are probably not.

CONCLUSION

Photolineament maps may be used to predict surface fracture orientations, and indirectly may also be useful to predict subsurface fracture orientations. Both of these relationships must be further tested, particularly in areas of different lithologies and different tectonic histories. Natural open flows of gas wells in the study area appear to be low on photolineaments, with high open flows occurring only between photolineaments. High values of after-shot open flows appear to be more uniformly distributed. Chances of good wells appear to be slightly enhanced by avoiding locations near photolineaments seen on small-scale imagery.

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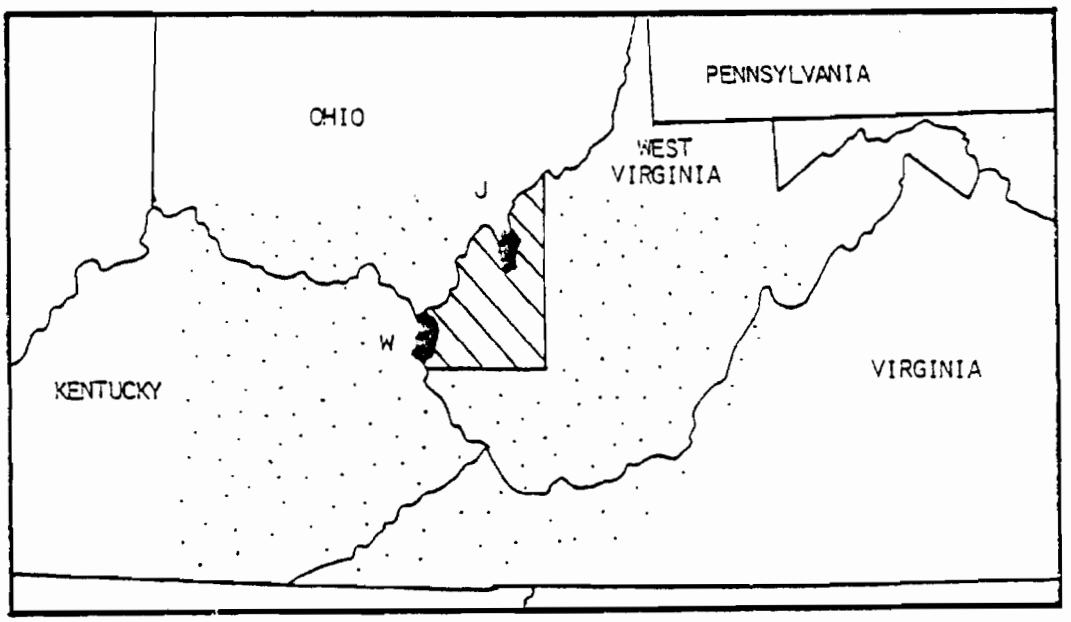

Figure 1. Area of study. The overall photolineament study covers the area shown in stipple pattern. The area of West Virginia underlain by the Devonian gas shales is approximated by the shaded area. J - Jackson County, W - Wayne County.

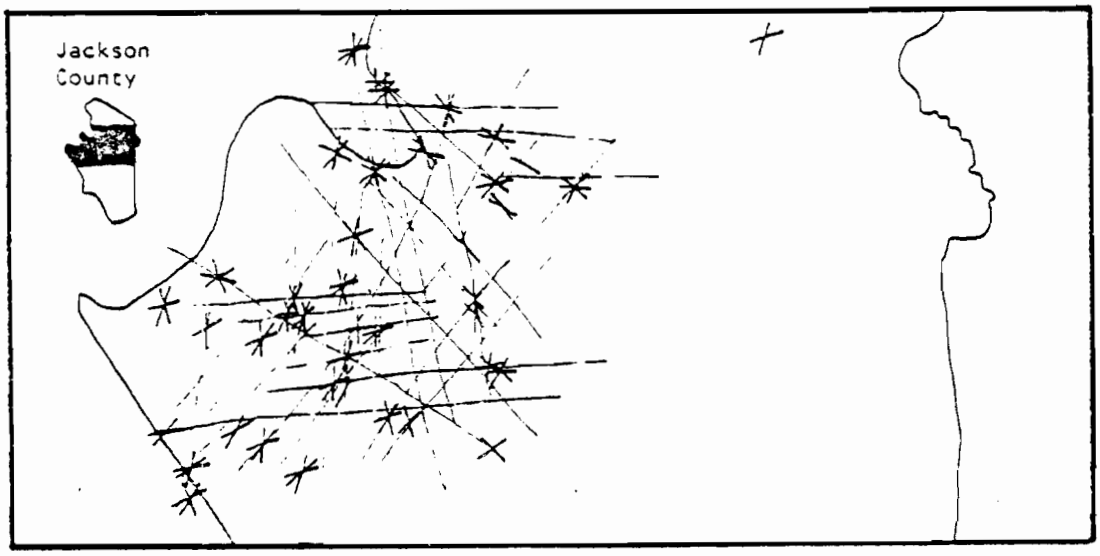

Figure 2. Joint patterns in part of Jackson County, West Virginia. The rosettes indicate the orientation peaks at individual outcrops. Light lines are interpolations of these directions between outcrops and are probably indicative of the regional trends.

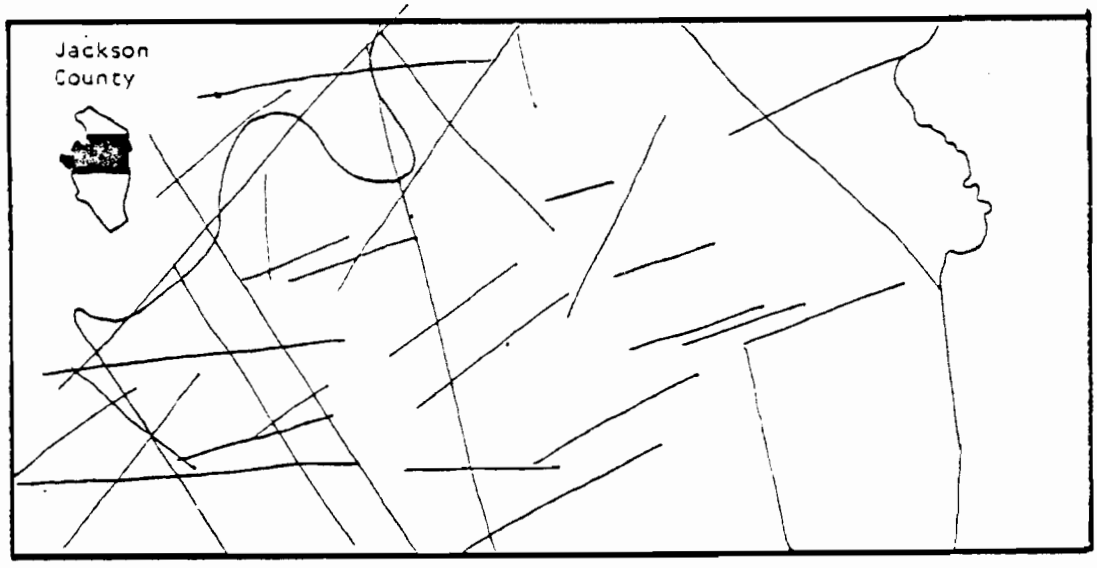

Figure 3. Major photolineaments in the portion of Jackson County for which joint data is shown in figure 2. Photolineaments are derived from LANDSAT, Skylab, and high-altitude aircraft imagery. Photolineaments shown are visible on two or more of the eight images used.

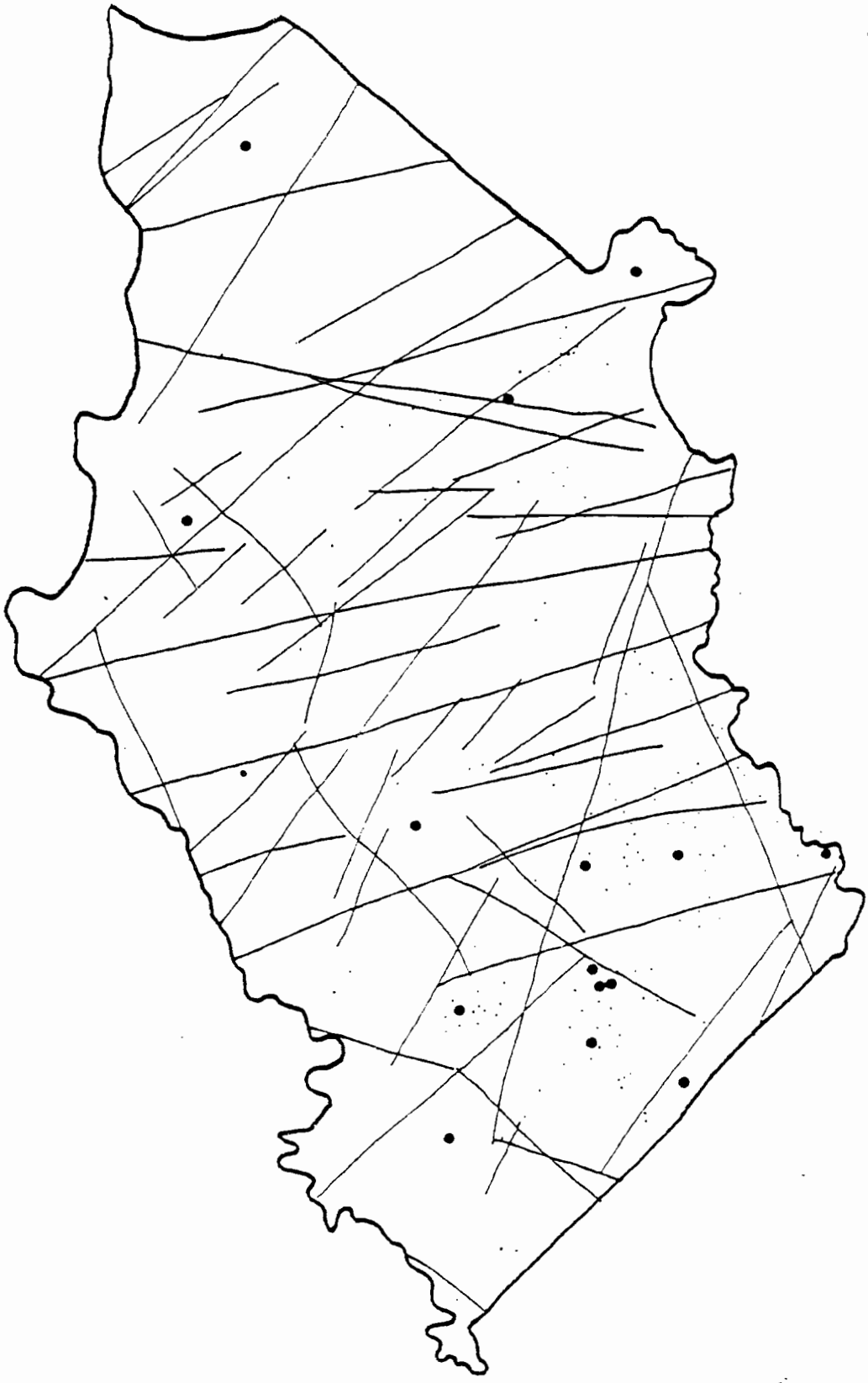

Figure 4. Map of Wayne County, West Virginia showing major photolineaments (those visible on two or more of the four images used) and natural initial open flows of gas wells. Small dots indicate relatively poor wells, large dots relatively good wells.

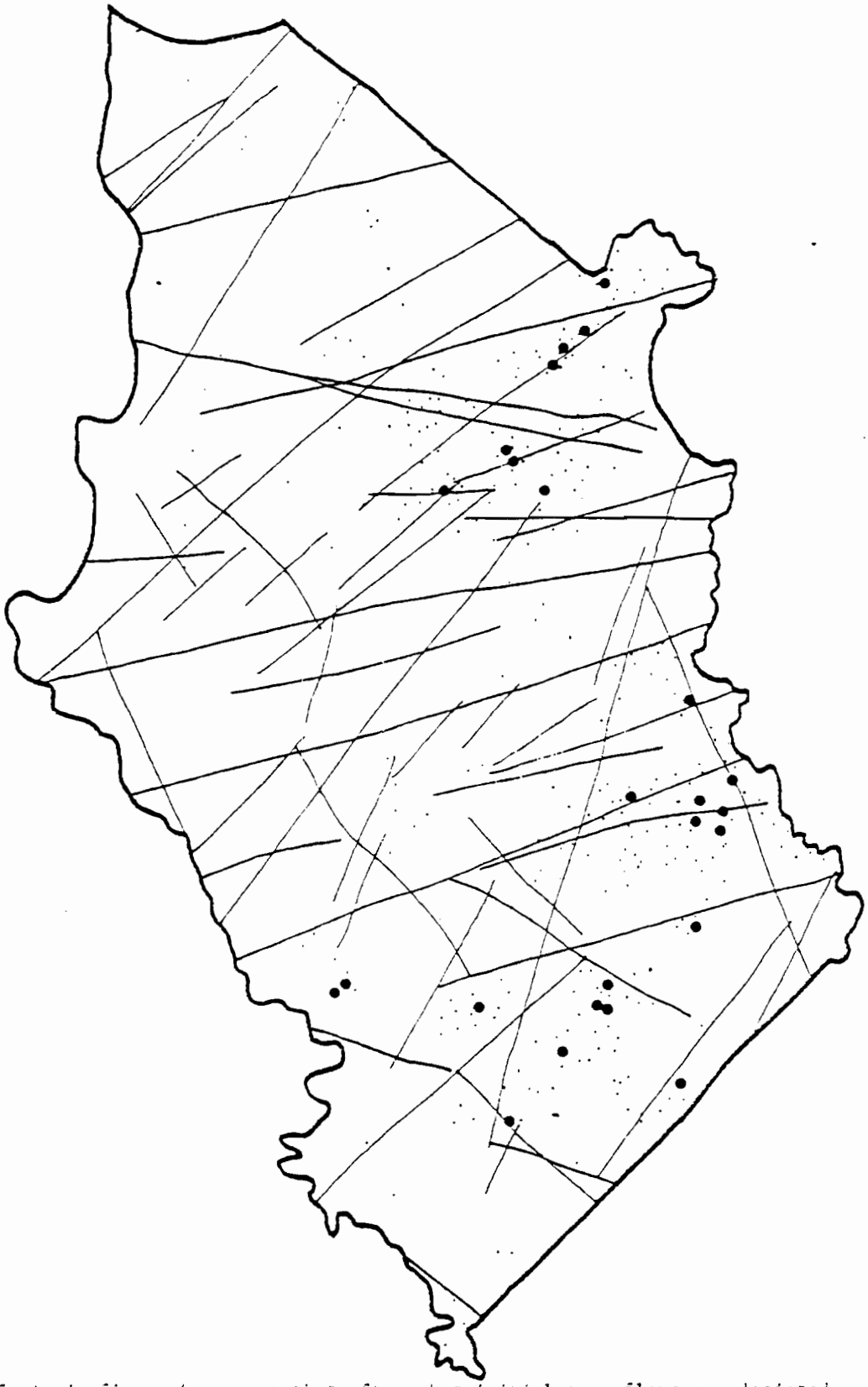

Figure 5. As in figure 4, except that after-shot initial open flows are depicted.

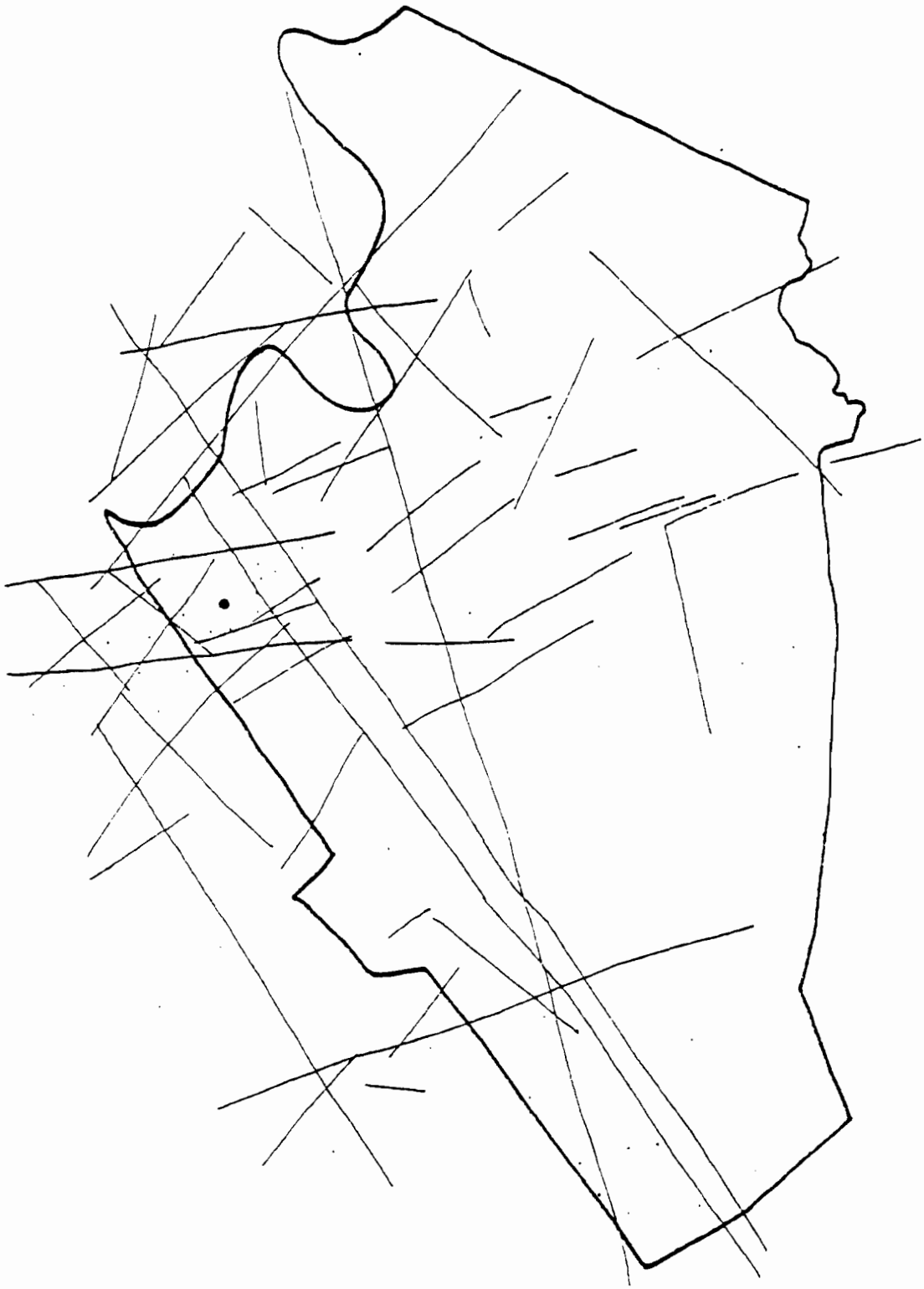

Figure 6. Map of Jackson County and a portion of Mason County, West Virginia, showing major photolineaments (those visible on two or more of the eight images used) and natural open flow of gas wells. Large dots indicate good wells, small dots relatively poor wells.

Figure 7. As in figure 6, except that after-shot initial production is depicted.