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REMOTE SENSING STUDIES IN THE APPALACHIAN PLATEAU FOR APPLICATION TO FOSSIL FUEL EXTRACTION

by

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ABSTRACT

Fractures are an important factor in the production of mineral resources of all types. They are particularly important in the recovery of hydrocarbons from reservoirs of little primary permeability but some secondary fracture permeability. Since direct mapping of subsurface fractures is an extremely time-consuming and expensive task, the determination of the relation of subsurface to surface fractures and features visible on remote sensing imagery could simplify this mapping task. This is particularly important where large reserves currently provide only a marginal economic return, such as the Devonian shale gas of southwestern West Virginia and eastern Kentucky.

One phase of this project is the determination of patterns of photolineaments. Photolineament maps have been produced for several portions of the study area. Both a constant regional pattern and a variable local pattern can be seen on most of these maps. In another phase of the project, the methods frequently employed in photolineament studies were found to be too haphazard for application in the Appalachian Plateau; therefore much of the effort of this project during the past year consisted of development of techniques of photolineament mapping for the specific imagery available and for the terrain of the study area, and development of methods of data analysis employing appropriate statistical techniques.

INTRODUCTION

Much of the world's mineral wealth is produced from natural rock fractures. Most lead and zinc deposits, such as those of the Joplin,

References and illustrations at end of paper.
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Missouri, and Galena, Illinois, deposits are found in crevices which are actually enlarged fractures. In certain areas, the sole source of ground water, another mineral resource, is fractured rock. Water is not the only fluid so produced, of course. Fractures are often conduits through which oil and gas migrate from a source rock to a reservoir rock or to the surface of the earth. In some cases, fractures form the reservoir for these fluids. For example, production of oil from shales of the Niobrara Formation in Colorado and Wyoming is from fractures.[1] Hydrocarbons are obtained from fractures in West Texas cherts and carbonates. In the eastern United States, the Devonian shales of the Appalachian Basin have been estimated to contain as much as 460 quadrillion cubic feet of gas - potentially 200 to 300 years supply.[2] Under present or near future conditions of economics and technology, about 285 trillion cubic feet of this could be extracted, much of it from fractures. Since most of the wells completed in the Devonian shales are marginally profitable, a reduction in exploration costs would affect the recovery figure.

Generally, the fractures in rocks are not positioned at random, nor do they lie in random directions. Numerous studies have been made of natural fractures, or *joints*, which indicate that well-developed systems of fractures are the normal case, even at considerable depths.[3,4,5] These systems are usually developed along several distinct orientations, and vary from place to place in a manner dependent on many factors. A knowledge of the fracture systems, not only for a specific locality but for the region as a whole can aid considerably at various stages of the hydrocarbon recovery process. Knowing the position of concentrations of fractures will allow placement of wells for maximum recovery.[6] There is some indication that drilling a well-defined fracture zone may yield a high-producing well while only a few thousand feet away only a dry hole can be drilled. Second, knowledge of the fracture system orientation will permit the planning of the most efficient drilling pattern for a field.[6] The normal rectangular pattern may not be the best if subsurface fractures are preferentially oriented along one or two directions. Third, the regional fracture pattern can be predictive of the orientation of induced fractures. In secondary recovery procedures which involve pumping fluids down one well to push hydrocarbons out another require a knowledge of subsurface flow directions. In fractures reservoirs, these directions can sometimes be predicted from regional surface fractures.[7]

Fracture systems are also indicative of structural styles; that is, they may be useful for the determination of how rocks have been folded and faulted as well as helping to locate these folds and faults. Since most oil and gas accumulates in a variety of geological traps, and certain types of traps are characteristic of certain types of deformation, the ability to predict the type and location of these traps can aid in the extraction of hydrocarbons.

Thus the study of fracture systems provides the knowledge to locate zones of subsurface fractures for drilling, to predict the orientation of induced fractures during fracturing operations, to determine directions of

subsurface flow for planning well fields and secondary recovery operations, and to locate and define geological traps which may contain hydrocarbon reservoirs.

REMOTE SENSING IN FRACTURE STUDIES

The only direct method of mapping subsurface fractures is through the observation of cores or wellbore fractures. A complete regional survey, therefore, would be extremely expensive and time-consuming since a great many well would need to be drilled. In many cases, those wells would have no other purpose than mapping fractures. Only in such areas where many wells already have been drilled and fracture data obtained would the direct survey method of fracture mapping be feasible economically.

A more practical but still fairly expensive method of delineating at least partly the subsurface fracture system of a given area is to map the surface fracture patterns. This involves placing people in the field with the attendant problems. There may be accessability difficulties, either natural or man-made. Outcrops may scarce and difficult to find. And the method is still fairly time-consuming and expensive.

There exists some evidence that the features known as *photolineaments* may be indicative of surface and subsurface fracture patterns. *Photolineaments* are either continuous linear or curvilinear features or alignments of discrete features which can be seen on aerial photographs or other imagery.[8] Studies of these features have shown that such features mapped from aerial photographs show similar orientation patterns to those of surface and subsurface fractures.[7] In some cases, such methods have been used successfully to explore for hydrocarbons. In general, however, there had been no systematic study made of the methods involved in photolineament mapping and its application to fracture systems. Also there was little information on the effects of such factors as variability in imagery, terrain and operators.

AREA OF STUDY

The area chosen for this study was that of southwestern West Virginia and eastern Kentucky and small adjacent portions of Virginia and Ohio (Fig. 1). There were several reasons for choosing this area:

1) Although remote sensing methods have been used successfully to explore for and develop mineral resources elsewhere, most of this has been in terrains which were either arid or of low relief or both. The Appalachian Plateau area is both rugged topographically and has almost complete vegetative cover. As a result, very little direct observation of the ground and especially the rocks can be done from aerial imagery. Also, the geological structures in most of the area are subdued.

2) This area is at the junction of three distinct geological provinces: a) the Central Appalachians which consist primarily of folded rocks, b) the Southern Appalachians which are primarily deformed through thrust faulting, and c) the Continental Interior with its basement deformation. Not only are these three areas different topographically (see Fig. 2), but they are very different geologically with three very different structural styles which may be distinguishable by different fracture patterns. Each of the three structural styles may have a unique effect on hydrocarbon recovery procedures.

3) Several major structural belts pass through the area. The 38th Parallel Lineament[9] passes through the middle of the area. The Kentucky River Fault Zone, in particular, is a manifestation of this structural lineament. Also, the Rome Trough, a fault belt of the continental basement type which was active in the early Paleozoic, is found in this area.

4) Much of this area is underlain by the gas-bearing Devonian shales. There has been considerable production from these in this particular area and there is much interest in further development at the present time.

5) Various types of remote sensing imagery are available for the area or portions thereof. This includes not only conventional black-and-white mapping photography, but also color-infrared for much of West Virginia, some side-looking radar, and some thermal infra-red as well as satellite images from both LANDSAT (formerly ERTS) and Skylab. This variety allows for the comparison of the effectiveness of the different types of imagery for this type of mapping.

RESULTS AND CURRENT STATUS

This is the second year of this project. Most of the work during this year has been a continuation of the various phases begun in the first year. It has consisted chiefly of further data collection and development of methods of mapping and methods of data analysis. Most of the results to date have been reported in detail elsewhere, so only a brief summary will be given here:

1) Photolineament mapping procedures -

a) Numerous maps have been produced for the study area (for examples, see Fig. 3, 4, and 5). Fig. 5 is an indication of one problem encountered early in the study. The left portion of this figure is a part of a map produced at a scale of 1:5,000,000 while the right half is a reduced version of Fig. 3 which was originally drawn from 1:1,000,000 scale imagery. The differences in the two maps are apparent. This problem was further investigated[8] and it was found that imagery variables were important in determining the character of the resulting map. The most important factor was imagery scale, with image contrast, image density, and image type (i.e., type of sensor) playing lesser, but still important roles.

b) Operator variation was also significant. Each individual picks out different types of features from the imagery. When criteria were set up and clearly understood before mapping, the resulting maps were much more alike than if no such criteria were established.

2) Data analysis procedures. Most of the analysis of photolineament data has been done through visual inspection by past workers. Some conclusions reached by this method may not be valid, at least for certain cases. It was thought that rigorous statistical methods should be employed. For example, it is not clear whether the two rose diagrams in Fig. 6 represent data that are significantly different. An investigation was done of statistical tests[10] to determine those best suited for the photolineament analyses. Most tests are adequate for analysis of all measureable characteristics of photolineaments (and similar types of data) except for the azimuth. Only one test, the Wald-Wolfowitz Runs Test, appears to be satisfactory to compare sets of azimuth data.

3) Relation of photolineaments to geological features.

a) Photolineaments coincide with faults. All the faults in the study area show clearly, and other workers have discovered several new ones by this method.

b) Points which are significant in terms of geological structure occur more frequently near photolineaments than elsewhere. Terminations and deflections of anticlinal axes[11] as well as changes in height of structure and other significant points[12] were plotted in relation to prominent LANDSAT photolineaments and found to be associated. No such analysis has been made for photolineaments derived from other imagery.

c) Joints are oriented either parallel or perpendicular to nearby photolineaments. This is true only if the outcrop which was measured for joints was close to the location of a photolineament. Elsewhere, the joint pattern is much more likely to fit the regional structural pattern. This phase of the work is in a preliminary stage at the present time. It is hoped that the work being done on style elements of joints by Russell L. Wheeler and his students[13] will aid in separating regional and photolineament-associated joints.

4) General photolineament trends. There are four prominent trends in the study area. These are approximately N 75° E, N 12° W, N 40° E, and N 55° W. These trends are also apparently common for joints of the area.[14] Therefore it might be expected that these trends will also be common in subsurface fracture systems.

FURTHER WORK

Some of the detailed photolineament mapping from imagery remains to be done. This is primarily in areas of specific interest or test areas to be done at large scales for comparison with the satellite imagery. The main effort will be field checking and data analysis. It is not yet clear what the ground characteristics of photolineaments are in all but a few cases. Field checking will involve measuring style elements of surface fractures and determining trends of these.

A further phase of the project will be to determine the quantitative effects of photolineaments on hydrocarbon production, particularly from fractured reservoirs.

The final aims of the project are as follows (at least for the study area):

1) State the effects of photolineaments on production of hydrocarbons.
2) Predict sites which are favorable for drilling wells, taking into account both geological structure and fracture systems.
3) Provide information on natural fracture systems to aid in efficient well fields, and derive that information from imagery as the primary source.
4) Predict the orientation of induced fractures produced in fracturing operations.

We hope to be able to provide this kind of information using imagery with only minimal field checking to reduce the costs of such information. Additionally, we hope to develop the techniques to the point where they may be used with confidence by others.

ACKNOWLEDGEMENTS

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REFERENCES

1. Harnett, Richard: "Niobrara Oil Potential", *Earth Science Bulletin* (1968) 1, 37-48.
2. Brooks, Kenneth: "Devonian Shale Gas Study", presented at Devonian Shale Symposium, Columbus, Ohio (1972).
3. Nickelsen, R. P. and V. N. D. Hough: "Jointing in the Appalachian Plateau of Pennsylvania", *Bull. Geol. Soc. Amer.* (1967) 78, 609-629.
4. Parker, J. M.: "Regional Systematic Jointing in Slightly Deformed Sedimentary Rocks", *Bull. Geol. Soc. Amer.* (1942) 58, 381-408.
5. Ver Steeg, Karl: "Jointing in the Coal Beds of Ohio", *Econ. Geol.* (1942) 37, 503-509.
6. Overbey, W. K. Jr., W. K. Sawyer, and B. R. Henniger: "Relationships of Earth Fracture Systems to Productivity of a Gas Storage Reservoir", *U. S. Bureau of Mines Report of Investigations* 7952 (1974), 133 p.
7. Komar, C. A., W. K. Overbey, Jr., R. L. Rough, and W. G. Lambert: "Factors that Predict Fracture Orientation in a Gas Storage Reservoir", *J. Pet. Tech.* (May 1971) 23, 546-550.
8. Werner, Eberhard: "Photolineament Mapping in the Appalachian Plateau and Continental Interior Geological Provinces - A Case Study", *Proc. 5th Remote Sensing of Earth Resources Conf.* (in press).

9. Heyl, Allen V.: "The 38th Parallel Lineament and Its Relation to Ore Deposits", *Econ. Geol.* (1972) 67, 879-894.
10. Werner, Eberhard: "Nonparametric Statistical Methods for Comparison of Orientation Data", Geological Society of America *Abstracts with Programs* (1976) 8, 297.
11. Werner, Eberhard: "Photolineaments Derived from LANDSAT Imagery Related to Structural Map and Field Data from Southern West Virginia", Geological Society of America *Abstracts with Programs* (1976) 8, 297-298.
12. Werner, Eberhard: "The 38th Parallel Lineament in West Virginia", presented at 2nd International Conference on the New Basement Tectonics, Newark, Delaware, 13-17 July 1976.
13. Wheeler, Russell L. and John L. Stubbs, Jr.: "Style Elements of Systematic Joints", presented at 2nd International Conference on the New Basement Tectonics, Newark, Delaware, 13-17 July 1976.
14. Dean, Stuart L. and Byron R. Kulander: "Regional Tectonics, Systematic Fractures, and Photolinears in Southeastern West Virginia", presented at 2nd International Conference on the New Basement Tectonics, Newark, Delaware, 13-17 July 1976.

FIGURES

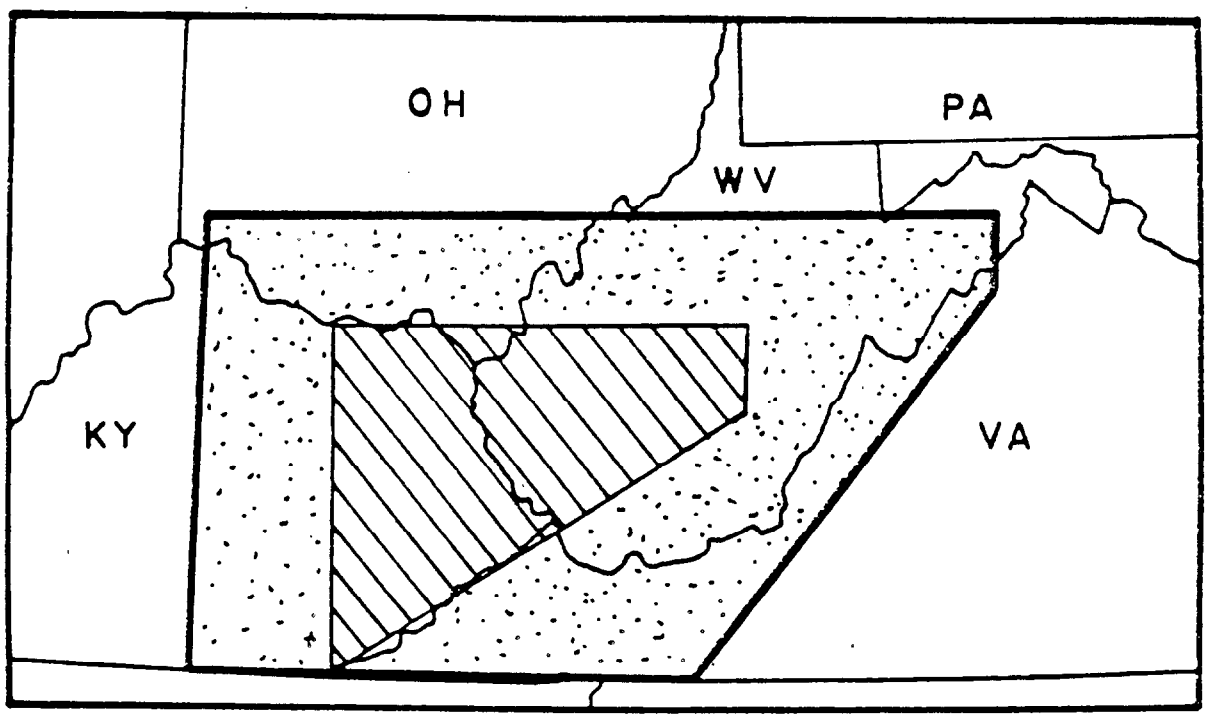

Fig. 1 - Area of study. General regional patterns are mapped in the stippled area with more detailed work in the shaded area.

Fig. 2 - Composite LANDSAT image of approximately the area of Fig. 1. The three geological provinces are clearly discernable. (U. S. Soil Conservation Service)

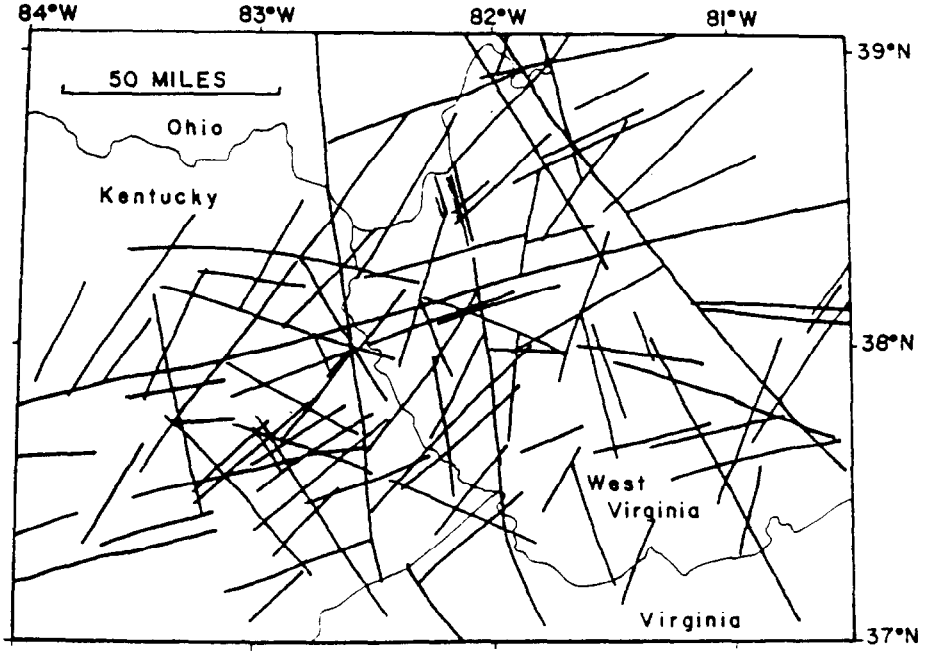

Fig. 3 - A photolineament map produced from the U. S. Soil Conservation Service mosaic of LANDSAT imagery at an original scale of 1:1,000,000. This is but one of several similar but not identical maps produced from the imagery.

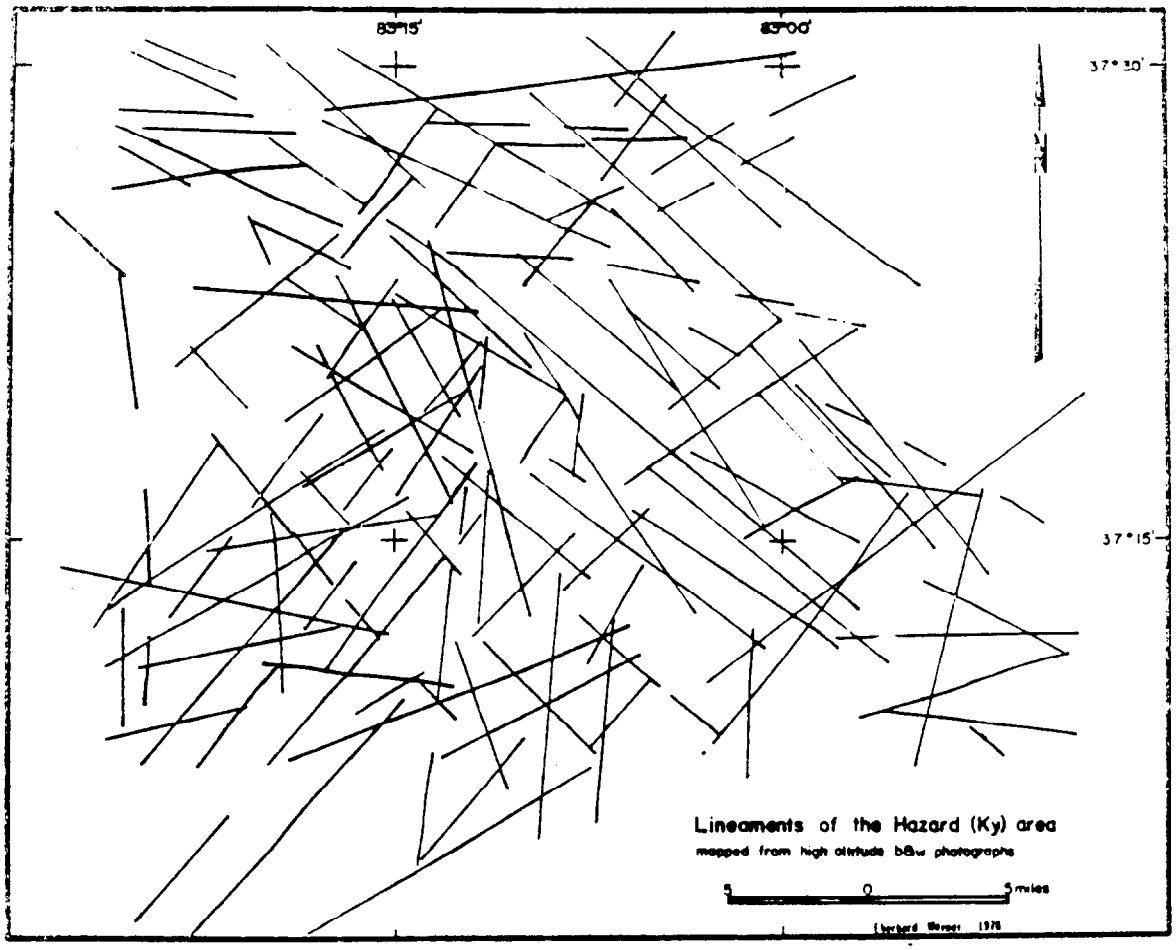

Fig. 4 - Photolineament map of an area near Hazard, Kentucky. Note the difference in character of this map and Fig. 3. This is a detailed map of a very small part of the area of Fig. 3.

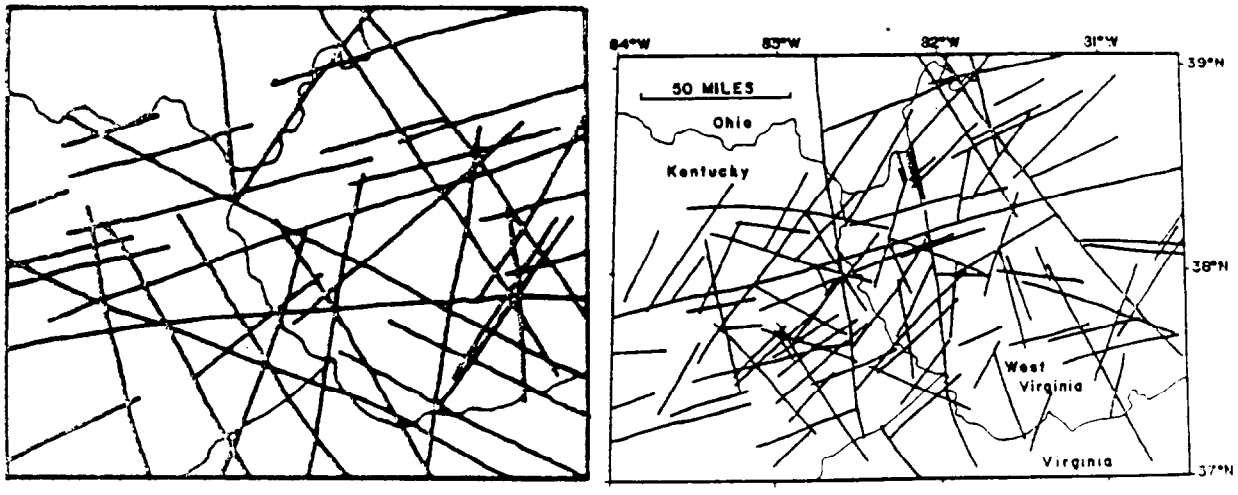

Fig. 5 - Comparison of photolineaments mapped for the same area at two different scales. original was 1:5,000,000 at left, 1:1,000,000 at right.

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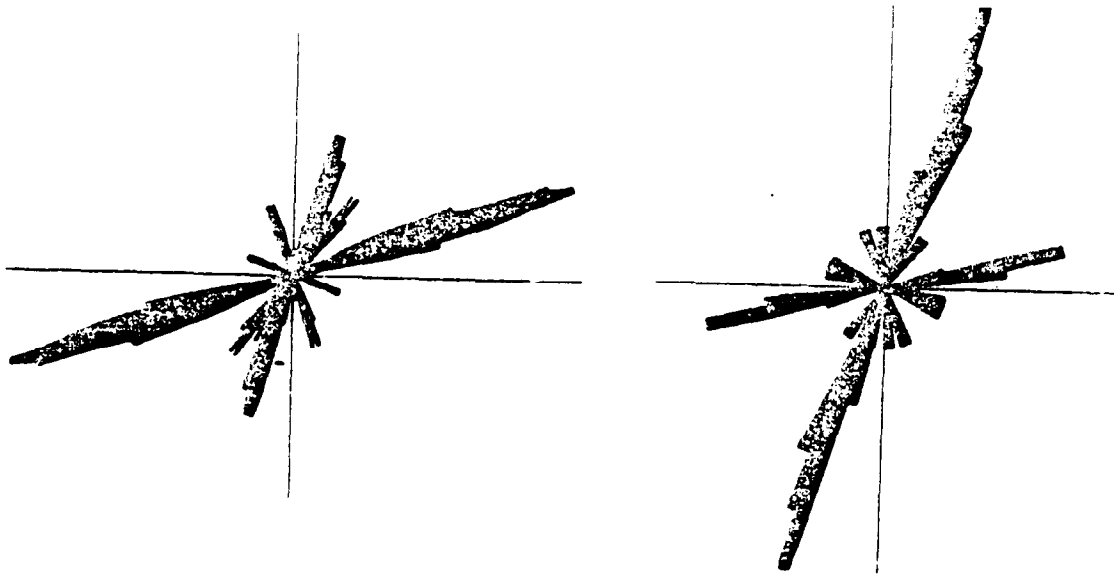

Fig. 6 - Two rose diagrams of photolineaments mapped on two adjacent photographs. Although they appear quite different visually, a statistical test shows them to not differ significantly.