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EXTRACTION OF GEOLOGICAL LINEAMENTS FROM LANDSAT IMAGERY BY USING LOCAL VARIANCE AND GRADIENT TREND

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ABSTRACT

A method for computer extraction of geological lineaments from LANDSAT images is presented. The variance thresholded map of each image is separated into eight gradient direction maps, where basic linear segments are determined each of which is based on the principal eigen vector of a cluster of pixels whose gradient direction is orthogonal to its orientation. A special linking algorithm operates on the basic linear segments to give a candidate lineament segment. The method has been experimented on LANDSAT images of a small region southwest to Pittsburgh. The preliminary result is encouraging and further work for improvement is suggested.

I. INTRODUCTION

Interpretation of lineaments from LANDSAT images has significant applications to geological studies. They may reflect structural features as surface manifestation of possible fractures and faults, and may be used to aid in the placement of geological measurements for exploration of petroleum/gas and mineral resources.[1-4] Lineaments are usually situated in a highly textured image background. Some lineaments appear rather prominent while others subtle; their visual interpretation is often quite subjective.[5] Linear enhancement and computer-aided extraction of lineaments have been studied by Podwysocki, et al.[6] and Chavez, et al.[7] A technique for digital enhancement by combining principal component analysis with multispectral classification was developed by Fontanel, et al.[8] and applied by Hilali, et al.[9] The performance of algorithms of linear, semilinear, and nonlinear detectors was examined, and an algorithm for iterative enhancement of linear features was developed by Vanderbrug.[10] Match filters were used by Ehrich in preprocessing for automatic extraction of lineament segments which were then linked by means of dynamic programming.[11] Recently, Jackson, et al. conducted an extensive study by various methods on computer enhancement of interpretative lineaments in the remotely sensed images of Cottageville, West Virginia, and developed a method of gradient filtering for enhancement of directional trends.[12,13] All of these studies have been directed towards providing an improved capability of computer-aided interpretation of geological lineaments. This paper intends to present our progress in this area.

Lineaments are line-like features in a terrain. Along a lineament, the transverse changes in gray value persist, but its edge characteristics may vary. Hence, it must be perceived both locally and globally. Three characteristics of a lineament are noted: (1) within its small neighborhood, one side shows darker shade while the other side is brighter; (2) the variance of grayness in its small neighborhood is often large to account for the change in grayness across the lineament; and (3) the pixels along a lineament mostly have more or less the same gradient direction, although their directions may be reversed at some places, and their trend must continue for a significant length. These features are incorporated in our lineament model for algorithm development.

II. DETECTION OF BASIC LINEAR SEGMENTS

Each of the multispectral images under consideration is preprocessed first by level slicing to stretch its gray range to 256 levels. Consider a small nxn window (for example, n = 3) centered around each pixel (i,j), and compute its mean gray level $\bar{g}_{ij}$ and its variance σ_{ij} within the window. These local statistics may be used for contrast enhancement and noise filtering.[14] By choosing an appropriate threshold value σ_t of the local variance, a region of high nonhomogeneity is segmented by locating those pixels whose local variance σ_{ij} is greater than σ_t. Within such a variance thresholded map, the narrow region around a lineament segment is expected to lie. The local variance parameter has also been used in processing SEASAT SAR images for classifying statistically homogeneous subregions in the polar ice region.[15] From the pool of pixels in the variance thresholded map, their gradient directions are examined for possible trends of lineament segments.

For those pixels which exist in the variance thresholded map, their Sobel gradients are evaluated. Each of these pixels, (i,j), and its 3x3 neighbors in the image are convolved by operators H_1 and H_2 to give the horizontal and vertical differences $S_1(i,j)$ and $S_2(i,j)$ respectively. Both the magnitude and direction of the Sobel gradient S(i,j) are computed. The gradient direction is quantized into eight direction numbers (0,1,2,.....,7), with 0 direction pointing to the east and 1 direction pointing to the northeast, etc. Each pixel in the variance thresholded map may then be labeled by its direction code. Eight gradient direction maps are then separated, each of which represents those pixels whose gradient directions are all coded by the same number q, (q = 0,1,2,....,7). Search is then attempted in each direction map to obtain pixels forming possible linear segments with a direction orthogonal to the gradient direction of the map.

Consider a square window of mxm pixels (m = 32 in this study) in a direction map with direction q. Examine the number and distribution of pixels in the window, and evaluate eigen values (λ_1 and λ_2) and eigen vectors ($\underline{e}_1$ and $\underline{e}_2$) of this cluster of pixels. If there exists a single cluster of contiguous pixels which are aligned linearly with a direction orthogonal to the gradient direction q, these pixels naturally form a segment of a possible lineament. If a cluster of sufficient number of pixels, not necessarily contiguous, is significantly elongated, the principal eigen vector $\underline{e}_1$ passing through the cluster center may be an adequate representation of a linear segment. Let N be the number of pixels in the cluster in a window, and $r = \lambda_1/\lambda_2$ be the ratio of eigen values of the cluster. If N and r are greater then their respective threshold values N_t and r_t, and furthermore, if the direction of its principal eigen vector is orthogonal to the gradient direction within ±22.5° tolerance, this eigen vector extending between two sides of the square window, as shown in Figure 1, is accepted as a basic linear segment whose orientation is now not restricted to a quantized direction. The use of the cluster eigen vector permits us to detect a possible lineament segment even when it is interrupted in the middle as long as the gradient directions of the pixels are consistent so as to provide a lineament trend.

This process is repeated in all successive windows in a given direction map and for all directions to detect all basic linear segments in an image. It should be noted that any two successive windows are overlapped 50% either horizontally or vertically in order to take care of the cases where a cluster may be split by a window into two small parts below the threshold size.

III. LINKING OF BASIC LINEAR SEGMENTS

The process of linking basic linear segments should be viewed as a means of approximation. It is not often to find two basic linear segments which are precisely aligned or which can be connected from end to end. Thus, the linking of two neighboring segments is achieved by connecting their respective cluster centers to provide a piecewise linear approximation.

For a basic linear segment L_k in "window k", search is made to link it with another basic linear segment, if exists, in one of its three neighboring windows. Depending upon whether the orientation of L_k is closer to the vertical, horizontal, or diagonal direction, the three neighboring windows are specified by "window k+1", "window k+2" and "window k+3" as shown in Figure 2 (a),

(b) and (c); and they are searched in that order. If a basic linear segment L_{k+1} exists in "window k+1" and if the difference in orientation between L_k and L_{k+1} is less than 45^o, they are allowed to be linked together by connecting their respective cluster centers C_k and C_{k+1} as illustrated in Figure 3. Otherwise, their directions are inconsistent, so L_{k+1} should not be linked to L_k. If there is no basic linear segment, in "windows k+1, k+2 and k+3", which can be connected to L_k, the next set of three windows should be searched as indicated by "window k+4", "window k+5" and "window k+6" in Figure 2 (d), (e) and (f). If the search is successful, the current linking process can be continued forward; otherwise, the process stops at L_k and a new linking effort will start at another window. As shown in Figure 3, the successful linking of a series of basic linear segments provides an extended piecewise linear structure following a trend which is orthogonal to the average gradient direction of the pixels on the line. In this way, candidate lineaments are extracted from those pixels having the similar gradient direction and being not too far separated even though not contiguous.

IV. EXPERIMENTAL RESULTS

A portion of LANDSAT-1 image of a region southwest to Pittsburgh has been experimented by the above-described method. The images from four spectral bands are shown in Figure 4 (a), (b), (c) and (d). Each image is of 512 x 1024 size. A lineament map in this region as viewed by two geologists is shown in Figure 5. A total of 20 lineaments were mapped.

Only one half on each image consisting of 512 x 512 pixels was processed at a time; the results were then combined. The variance threshold σ_t for each image was chosen as that value of σ such that the upper 10% under the variance histogram was covered for $\sigma > \sigma_t$. In the detection of basic linear segments, two sets of threshold parameters N_t and r_t were used. If $N > N_t = 32$, then $r>r_t=1.5$. If $32 \geq N>16$, then $r>r_t=8$. The length of the basic linear segments varied between 16 pixels to 32 pixels, corresponding to the actual length of approximately 1 to 2 km.

The processing results obtained for the images of all 4 spectral bands are shown in Figure 6 (a), (b), (c) and (d). Combining these results, 13 segments of lineaments were extracted by this method. Many spurious short linear segments were found, which were not true lineament segments.

V. DISCUSSIONS

It is apparent that the experimental result gave a considerable amount of error in the automatic detection of lineaments. A close examination suggested several problems for further consideration. Long lineaments were not fully tracted by computer processing because the thresholded variance maps failed to provide sufficient regions for extraction of basic linear segments. A more refined preprocessing should be performed in order to improve the detection accuracy. A larger window (for example, 64x64 pixels) and separate cluster seeking may be preferred for more reliable identification of basic linear segments. A more global trend search should be further developed to identify the possible alignment of several linear segments which are separated far apart. Some of the spurious short segments may then be discarded as they individually do not fit into a longer trend. These aspects are being presently investigated for further improvement.

VI. REFERENCES

1. Smith, W.L., ed., "Remote-Sensing Applications for Mineral Exploration," Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa., 1977.

2. Sabins, F.F., Jr.,"Remote Sensings: Principles and Interpretation," W.H. Freeman and Co., San Francisco, Ca., 1978.

3. Werner, E., "Application of Remote Sensing Studies to the Interpretation of Fracture Systems and Structural Styles in the Plateau Regions of Eastern Kentucky, Southwestern Virginia and Southwestern West Virginia for Application to Fossil Fuel Extraction Processes," Final Report, UGR File No. 040, DOE Morgantown Energy Technology Center, December 1977.

4. Goetz, A.F.H. and L.C. Rowan. "Geologic Remote Sensing," Science, Vol. 211, pp. 781-791, 20 February 1981.

5. Siegal, B.S. and N.M.Short, "significance of Operator Variation and the Angle of Illumination in Lineament Analysis on Synoptic Images," Modern Geology, Vol. 6, pp.75-85, 1977.

6. Podwysocki, M.H., J.G. Moik and W.C. Shoup, "Quantification of Geologic Lineaments by Manual and Machine Processing Techniques," Proc. NASA Earth Resources Survey Symposium, Houston, Tx, Vol. I-B, pp. 885-903, June 1975.

7. Chavez, P.S., Jr., G.L. Berlin and A.V. Acosta, "Computer Processing of LANDSAT MSS Digistal Data for Linear Enhancements," Proc. 2nd Annual W.T. Pecora Memorial Symposium, Mapping with Remote Sensing Data, Sioux Falls, S.D., pp. 235-250, October 1976.

8. Fontanel, A., C. Blanchet and C. Lallemand, "Enhancement of LANDSAT Imaginery by Combination of Multispectral Classification and Principal Component Analysis," Proc. NASA Earth Resourcws Survey Symposium, Houston, Tx, Vol. I-B, pp. 991-1012 June 1975.

9. Hilali, E., A. Demnati, J.C. Rivereau and B. Soulhol, "Contribution Des Images LANDSAT A La Prospection Geologique Dans Les Regions De La Mediterranee Occidentale," Proc. International Conference on Earth Observations from Space and Management of Planetary Resources, Toulouse, France, European Space Agency SP-134, pp. 133-140, May 1978.

10. Vanderbrug, G.J., "Line Detection in Satellite Imagery," IEEE Trans. on Geoscience Electronics, Vol. GE-14, No. 1, pp. 37-44, January 1976.

11. Enrich, R.W., "Detection of Global Edges in Textured Images," IEEE Trans. on Computers, Vol. C-26, No. 6, pp. 589-603, June 1977.

12. Jackson, P.L., H.L. Wagner and R.A. Schuchman, "Geologic Remote Sensing Over The Cottageville, West Virginia, Gas Field," Final Report No. 130700-13-F, Environmental Research Institute of Michigan, Ann Arbor, Mich. February 1979.

13. Wagner, W.L. and P.L., Jackson, "Feature Enhancement Using Digital Shaded Relief Processing Techniques," Proc. 13th International Symposium on Remote Sensing of the Environment, Ann Arbor, Mich., pp. 1721-1725, 1979.

14. Lee, J.S., "Digital Image Processing by Use of Local Statistics," Proc. IEEE Conference on Pattern Recognition and Image Processing, Chicago, IL, pp. 55-61, 1978.

15. Tang, G.Y., "Classification of SEASAT-1 SAR Images of Polar Ice Regions," presented at the IEEE Workshop on Digital Signal and Waveform Analysis, Miami Beach, FL, December 5, 1980.

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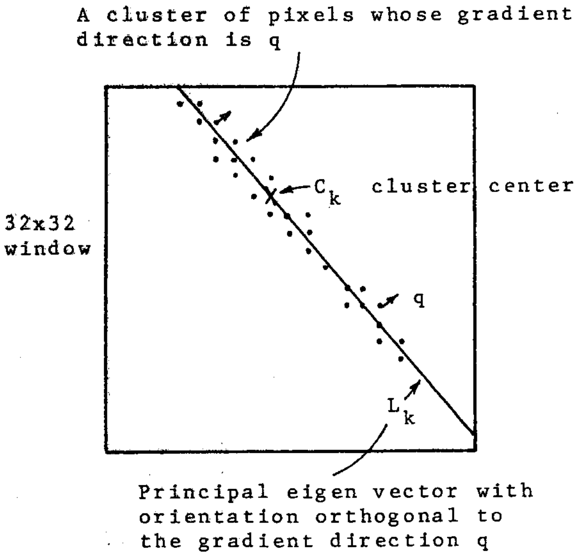


Figure 1 - Basic linear segment determined by the principal eigen vector of a cluster of pixels in a gradient direction map.

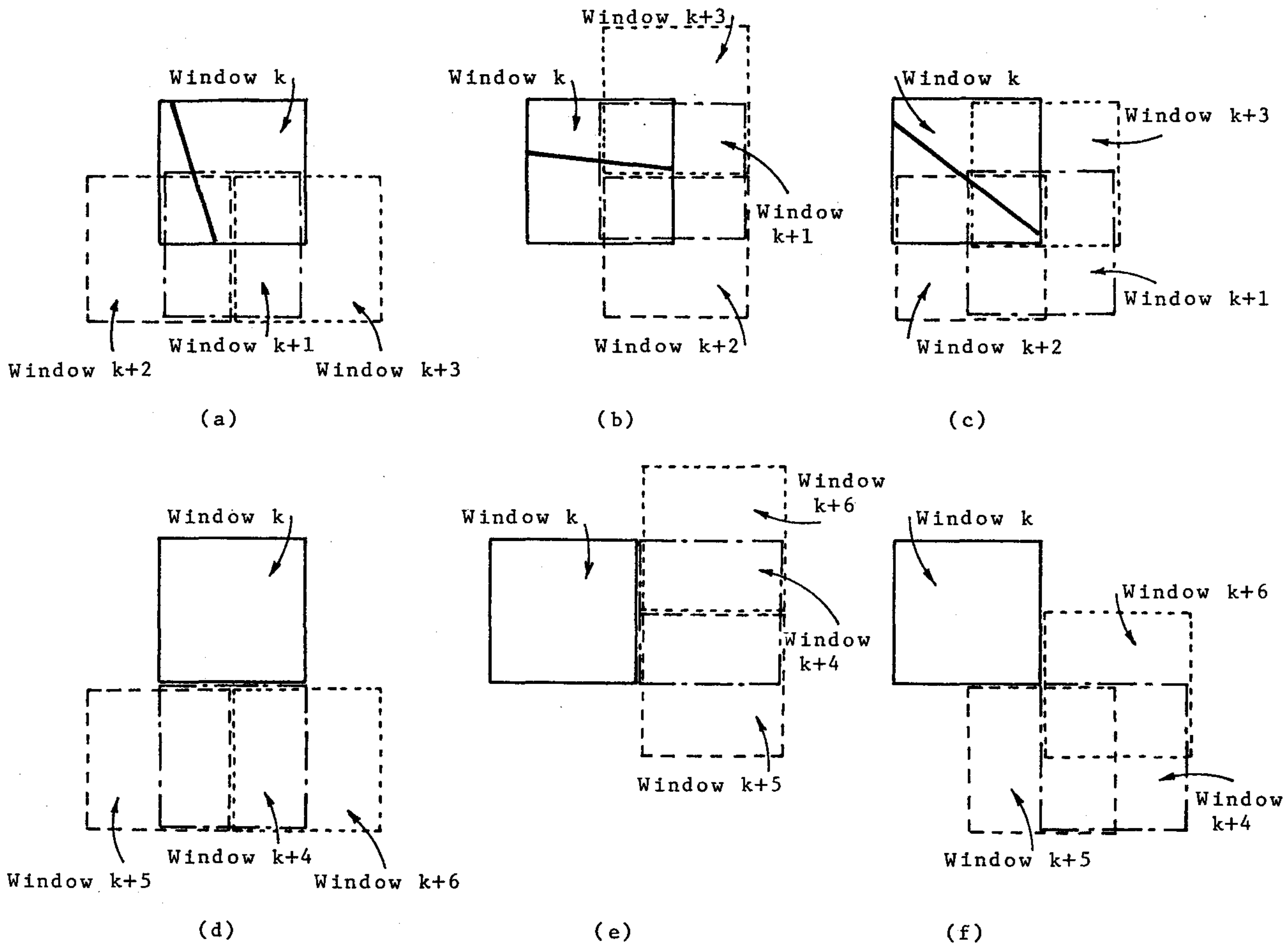


Figure 2 - Neighbouring windows of "window k" specified in search for connection of basic linear segments.

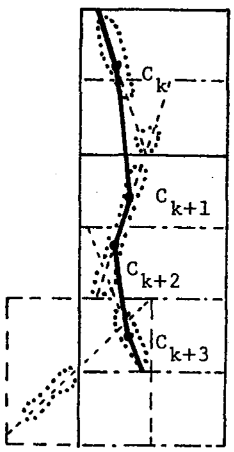
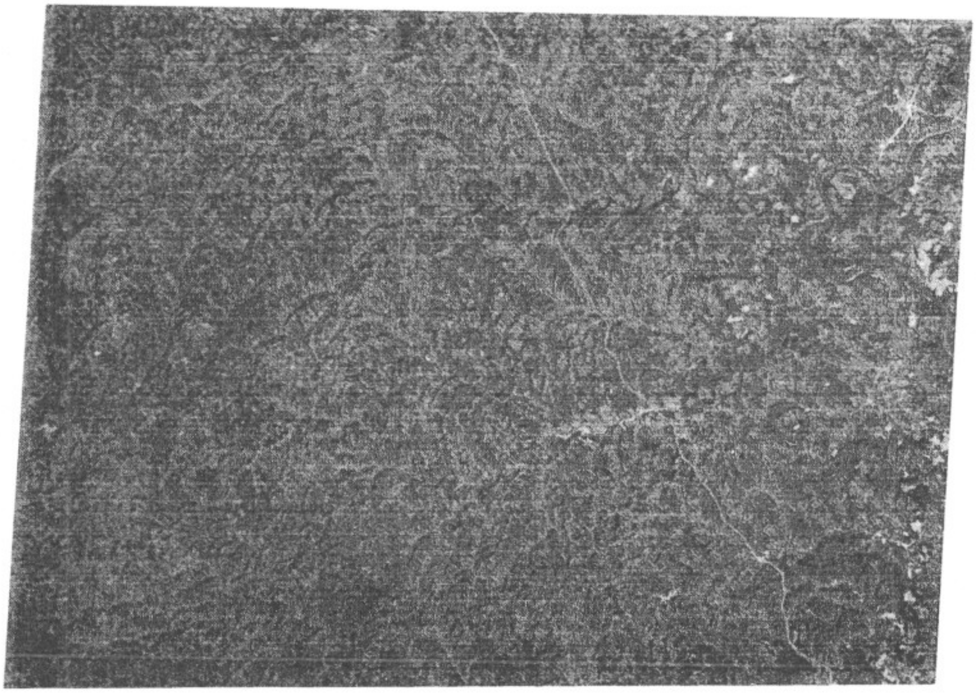
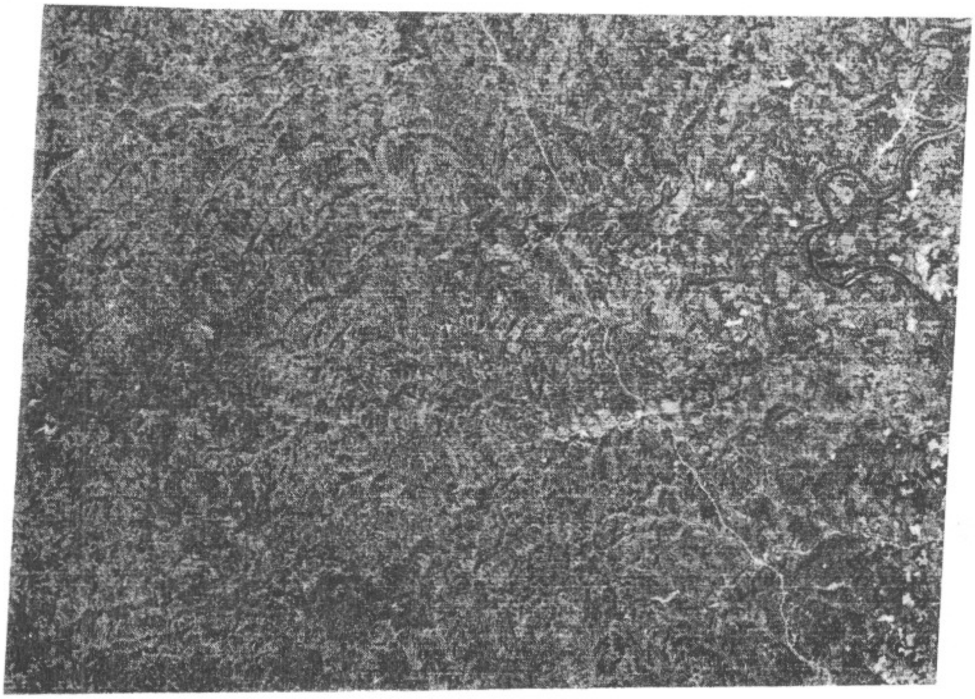


Figure 3 - Linking a series of basic linear segments

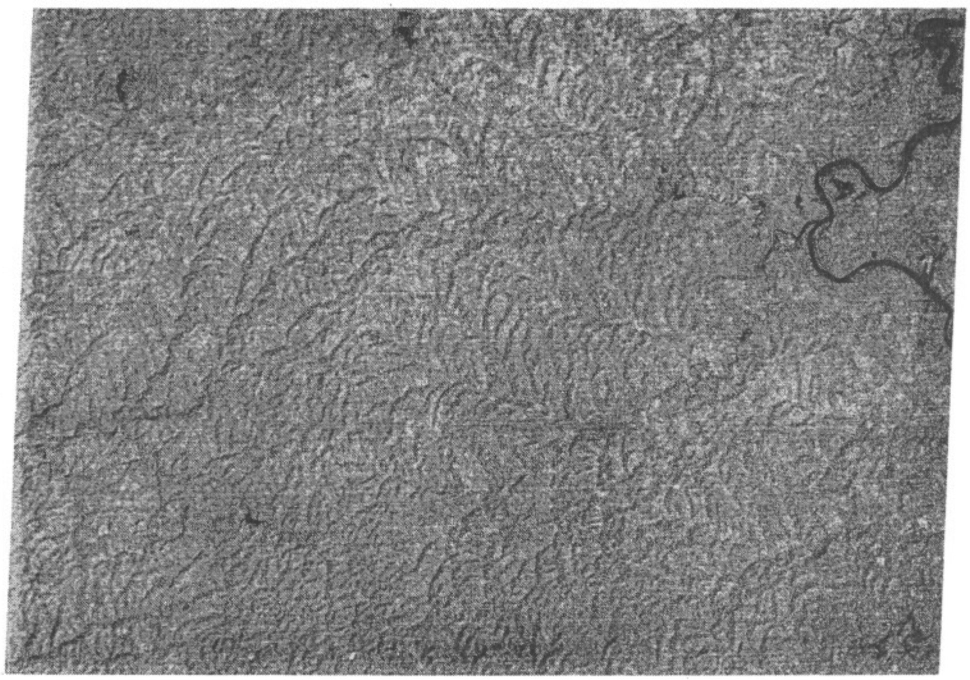


(a) Band 4

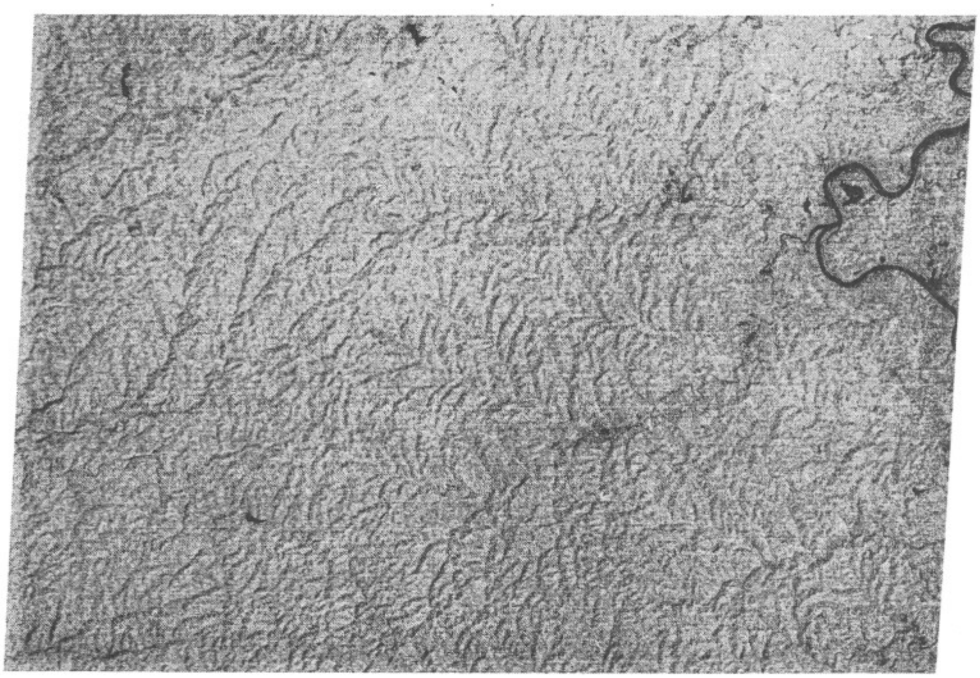


(b) Band 5

Figure 4 - LANDSAT-1 images of a region southwest to Pittsburgh, PA.



(c) Band 6



(d) Band 7

Figure 4 - (Continued)

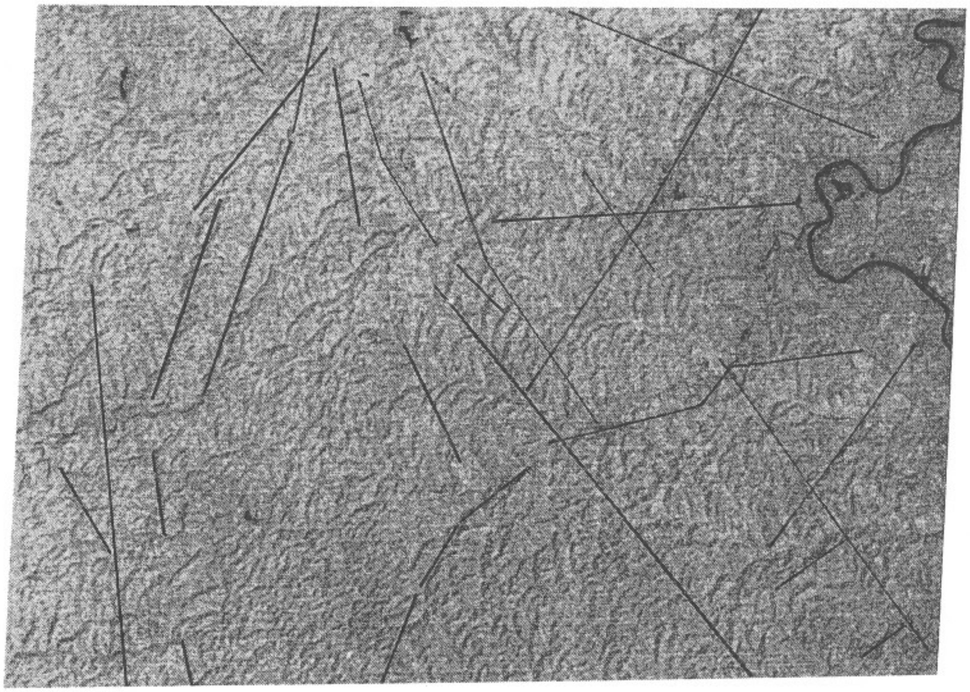
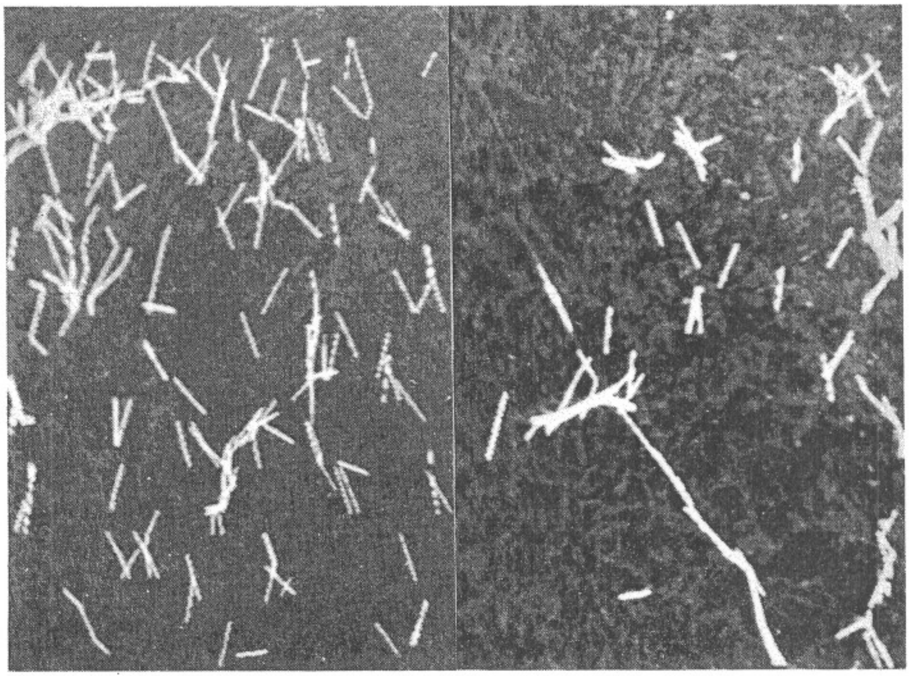
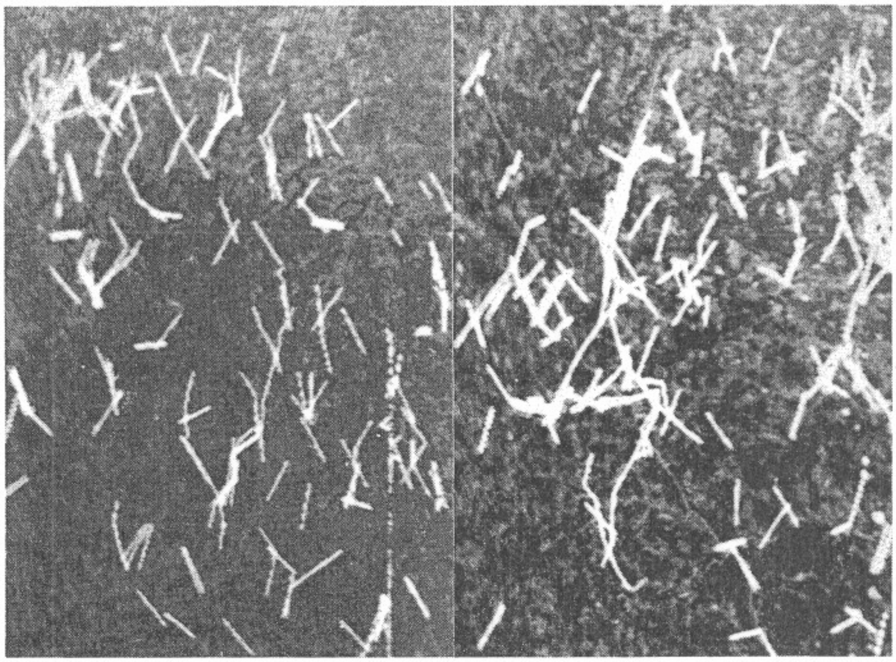


Figure 5 - A lineament map determined by two geologists for a region defined in Figure 4.

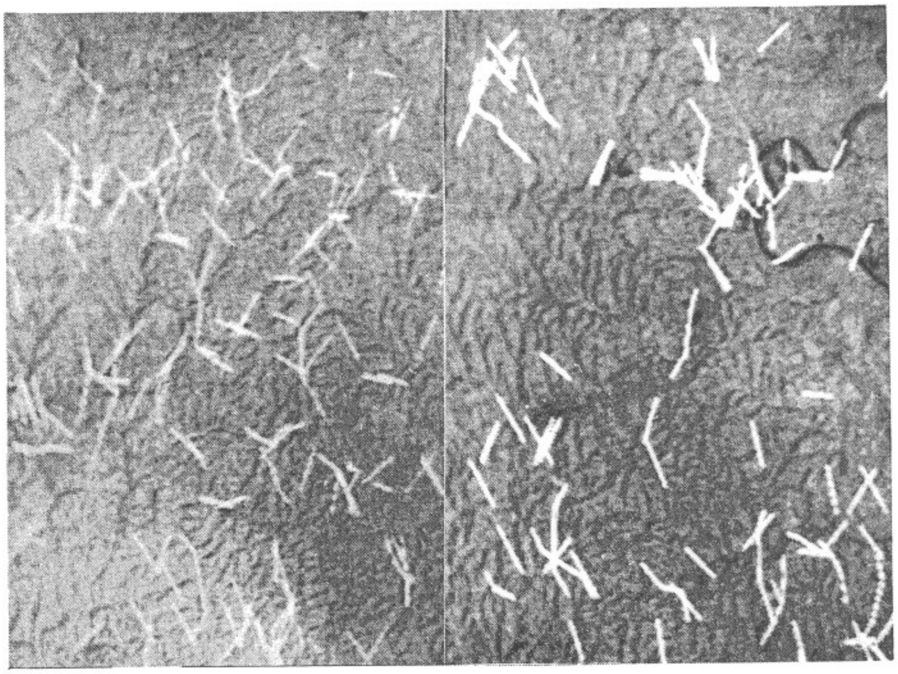


(a) Band 4

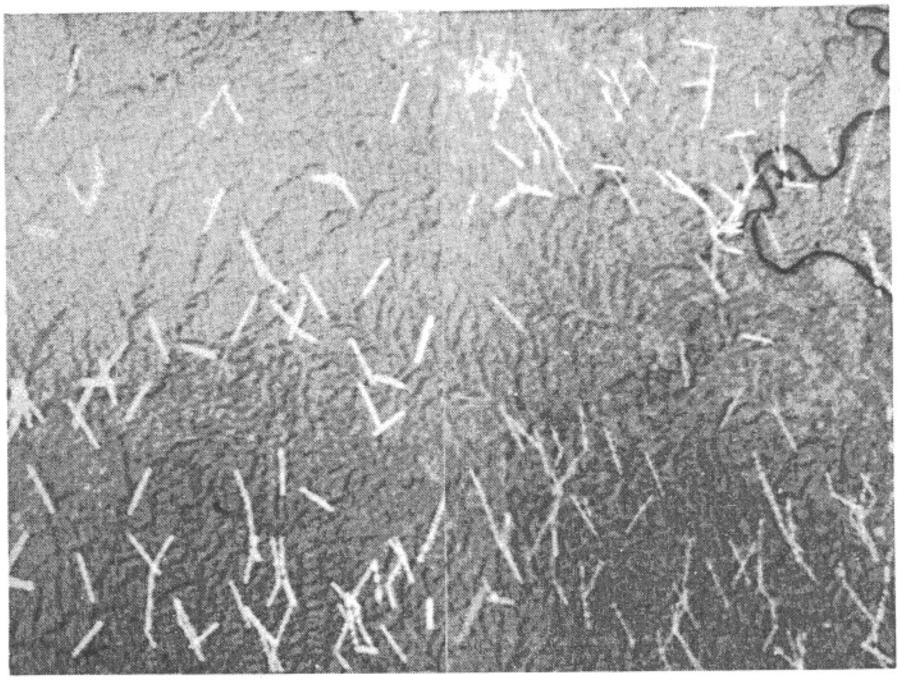


(b) Band 5

Figure 6 - Lineaments extracted by computer processing.



(c) Band 6



(d) Band 7

Figure 6 - (Continued)

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