RI 9104

Bureau of Mines Report of Investigations/1987

The Character of Five Selected LANDSAT Lineaments in Southwestern Pennsylvania

By Noel N. Moebs and Gary P. Sames

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 9104

The Character of Five Selected LANDSAT Lineaments in Southwestern Pennsylvania

By Noel N. Moebs and Gary P. Sames

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
David S. Brown, Acting Director

Library of Congress Cataloging in Publication Data:

Moebs, Noel N.
The character of five selected LANDSAT lineaments in southwestern Pennsylvania.

(Report of investigations / United States Department of the Interior, Bureau of Mines ; 9104)

Bibliography: p. **24 – 25**.

Supt. of Docs. no.: I 28.23: 9104.

1. Geology – Pennsylvania – Remote sensing. 2. Landsat satellites. 3. Mine roof control. I. Sames, Gary P. II. Title. III. Series: Report of investigations (United States. Bureau of Mines) ; 9104.

TN23.U43 [QE158.S74] 622 s [551.8'028'7] 86-607593

CONTENTS

ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	kHz	kilohertz
deg	degree	μmho/cm	micromhos per centimeter
ft	foot	ohm-m	ohm meter
gpm	gallon per minute	pct	percent
in	inch		

THE CHARACTER OF FIVE SELECTED LANDSAT LINEAMENTS IN SOUTHWESTERN PENNSYLVANIA

By Noel N. Moebs[1] and Gary P. Sames[1]

ABSTRACT

Five LANDSAT lineaments in the coal mining region of southwestern Pennsylvania were investigated by the Bureau of Mines to determine their geologic character, relation to subsurface conditions, and the means of discriminating one from another. The investigation included earth resistivity and very low frequency (VLF) electromagnetic traverses, soil moisture sampling, and a correlation with coal mine roof conditions. The lineaments could not be detected by the methods used, suggesting that they might be a surface phenomenon unrelated to subsurface geologic structures or roof stability in coal mine workings beneath.

[1]Geologist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

The detection of adverse roof conditions in advance of mining could contribute significantly to the safer operation of underground coal mines. The Bureau of Mines has been developing and assessing various methods of determining subsurface mining conditions. One of the more recently developed tools for studying the geologic character of the Earth's surface is imagery of the surface taken from unmanned satellites. The Bureau is just now assessing this emerging technology as a means of obtaining inferences on conditions that can be anticipated in underground coal mining. Depiction of surface features by aerial photography is a long-established practice in many fields, for example, agriculture, geography, and the military. Its use in geology is primarily as a method for mapping rock units and their arrangement at the surface. It is a long-established geologic practice to extend surface features into the subsurface as part of the predictive aspect of the subject.

The use of small-scale LANDSAT imagery derived from LANDSAT 2 multispectral scanner (MSS) data, and high-altitude aerial photography from U2 or similar flights at 40,000 ft altitude and above, has enabled the geologist to delineate major structures and trends that could not be detected by conventional surface mapping or low-altitude aerial photography. In general, LANDSAT and U2 images are more suitable for the detection of regional trends than for the mapping of small fracture traces, which is best accomplished with low-altitude photography.

The analysis or interpretation of LANDSAT imagery is preceded by processing of raw satellite data in which the geometry is corrected and distortions reduced, and by image enhancement to improve the resolution of features in the image. Following these two steps, the image can be enlarged and examined visually by trained personnel or digitized and computer processed to attain a pattern recognition and classification. Depending on the features sought, the programmed computer can select tonal alignments of many types from the processed image and improve upon manual interpretation and judgmental factors. The exploitation of images formed by scanning systems, such as that of LANDSAT, requires an understanding of the manner in which the images were formed. In particular, variations in image geometry caused by mismatches in phase and alignment of pixel arrays must be recognized (1).[2]

The visual process of imagery interpretation is highly subjective, except for very pronounced lineaments. The individual interpretation of identical imagery varies widely; for example, early in this study, three independent experienced analysts defined lineaments at a test site in southwestern Pennsylvania. The analysts submitted largely dissimilar patterns (fig. 1) based on their different experiences, perceptions, and objectives or goals. Wise (2) cautioned against the highly subjective nature of lineaments and the novice analysts who are "happier generating lineaments than analyzing them in a scientific manner."

High-altitude images, in particular, have revealed straight or curvilinear features on the Earth's surface (usually attributed to pronounced contrasts in rock type or vegetation) reflecting actual structural features such as faults or intense jointing. However, the character of most lineaments in the study area in southwestern Pennsylvania is obscure, and their meaning and origins may be diverse. Many lineaments identified from LANDSAT imagery cannot be verified on the ground and can be detected only from the air (3).

Many faults and fracture zones have been discovered or extended by the use of lineaments detected on LANDSAT imagery. Some of these features were barely perceptible on the surface and would have been missed by traditional geologic mapping. Many would have been overlooked during casual examination of the shallow subsurface, such as exposures in coal mines.

---

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

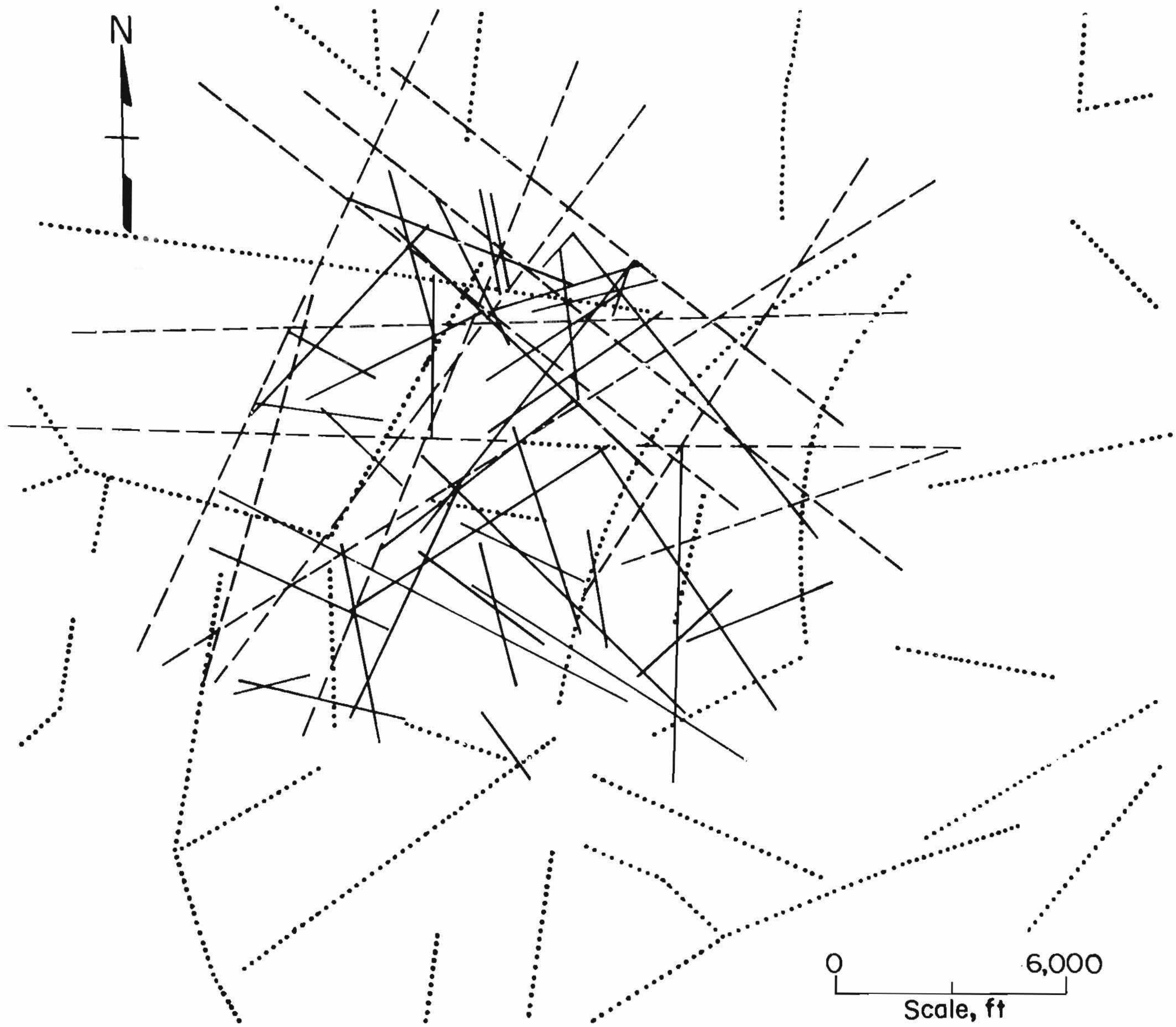


FIGURE 1.—Lineament patterns by three independent analysts. Each analyst is represented by a different line pattern.

In contrast, many lineaments cannot be verified at the surface or correlated with any natural feature, and some can be identified as strictly cultural features and thereby eliminated from further consideration. The northern Appalachian bituminous coal region, site of this study, is a challenging area for the interpretation of LANDSAT imagery because of its soil cover, lack of outcrop, hilly topography, heavy vegetation, extensive cultural development, and sparsity of well-authenticated faults and fracture zones to serve as reference sites.

The previous success in using LANDSAT imagery to locate faults and fracture zones in other regions has encouraged its use in the Appalachian bituminous coal region in hopes of locating adverse ground conditions such as fractured zones in advance of mining. Once located, these zones could be avoided by a revision of mine projections, or special precautions could be exercised during penetration.

Attempts to use LANDSAT lineaments in the study area as an indication of potentially fractured or otherwise unstable and possibly hazardous coal mine roof conditions have led to mixed results and much controversy as to why the attempts have only sometimes been successful. Many factors would have to be thoroughly investigated to resolve this situation. The Bureau conducted some preliminary tests at the surface to help indicate the shallow subsurface geologic character of five interpreted lineaments and determine whether these lineaments could be detected by some rather simple geophysical traverses. Authentic lineaments could thereby be identified and others screened out, since no reliable method has yet been developed to distinguish the actual nature of each linear.

The use of high-altitude images such as LANDSAT for this study, instead of conventional low-altitude aerial photographs, simply follows a practice used in the Appalachian coal regions of starting high for an overview. As LANDSAT lineaments are detected, low-altitude photographs and topographic maps are searched for verification. In this study, 87 pct of lineaments in the area coincided with stream valleys, which generally are not perceived as lineaments on low-altitude aerial photographs. This occurs chiefly because the interpreter examines the LANDSAT image for linear trends of large extent, commonly greater than 10 miles in length, and connects a variety of features (vegetation, soil tone, stream tangents, and topographic relief). This linear association is represented as a lineament. In contrast, on a conventional low-altitude aerial photograph covering 3 to 10 miles on a side, it may be difficult to identify or perceive the individual segments of a lineament derived from satellite imagery, especially if the segments on the low-altitude photograph are subtle features and not strikingly elongated in shape.

This explanation could account for the difficulty encountered in attempting to locate and confirm a LANDSAT lineament on the ground. It also points out the need to verify lineaments in some manner before using them as a basis for subsurface projections and hazard detection.

In this study, three of the five LANDSAT lineaments selected for study were not clearly perceived as lineaments on low-altitude photographs, partly because of the absence of relief and contrast in vegetation. The fourth lineament was easily distinguished on a topographic map because of the high relief of some 250 ft and length of about 2 miles, and on a low-altitude aerial photograph because of the contrast between the wooded hillsides and the cultivated stream valley floor. The fifth lineament was pronounced on every scale of image used.

An "established" LANDSAT lineament in this report simply designates one that was delineated by at least two independent analysts and was field checked to eliminate any cultural features such as roads, pipelines, or power lines that might account for the lineament. The term "lineament" is used for both an image feature and the corresponding locality on the ground. A lineament width of 300 ft was selected to represent lineaments in the illustrations in this report because in the best MSS image a minimum of 300 ft (1 pixel) resolution is actually attainable. It is convenient to use the term "lineament" when the linear feature on the image is greater than 1 mile in length, and "fracture trace" when less than 1 mile. No such distinction is needed in this report because all lineaments examined equaled or exceeded 1 mile in length. The term "linear" is used only as an adjective to denote arrangement in a line or gentle curve.

It is the objective of this report to describe and discuss the results obtained from geophysical measurements, surface observations, and subsurface observations at five interpreted LANDSAT lineaments.

METHOD OF INVESTIGATION

The Bureau selected five sites in southwestern Pennsylvania at which to conduct tests at the surface that might indicate the geologic character of a lineament or serve to distinguish one lineament from another. At each site, a traverse line perpendicular to the central portion of a lineament was positioned to extend several hundred feet on either side of the lineament. Along each traverse, the following three types of surveys were conducted at 50-ft intervals:

1. Ground resistivity.
2. Very low frequency (VLF) electromagnetic fields.
3. Soil moisture.

These methods were selected as economical and appropriate for testing overburden conditions at shallow depths in a rapid and inexpensive manner. Seismic methods were judged slower and more costly. Resistivity sounding, in addition to traversing, was conducted across the lineaments in the study area to determine the depth of weathering and the water table.

An extensive literature review was conducted to identify appropriate surface geophysical techniques for characterizing the geologic conditions at the study sites at relatively shallow depths. Available information indicated that individual techniques such as VLF or resistivity can provide reliable information on the geology near the surface, but have limited capability at depths below 300 ft. For the purpose of detecting lineaments as essentially very shallow subsurface features, or their surface effects, geophysical methods are useful for hypothesis testing. Once a target such as a lineament has been located, geophysical methods can be used to test hypotheses about the nature of the target.

RESISTIVITY

The electrical resistivity method for subsurface studies has proved itself among the most effective means of shallow subsurface investigation. Resistivity is a fundamental property of earth materials and is measured in the field by introducing electrical currents into the ground by means of two electrodes and measuring the potential gradient between the electrodes from which the resistivity can be calculated. By varying the spacing of the electrodes (for sounding purposes) the resistivity at various depths below the surface can be measured, thus detecting the depth to bedrock, water table, or other material. The electrode spacing can be held constant when moving from station to station along a traverse line, thus determining lateral changes at the same depth in the shallow overburden.

The resistivity method is especially suitable for traversing suspected fracture zones because of its sensitivity to variations in moisture content. At the study sites, traversing was the principal method used to test for subsurface anomalies near lineaments. Depth to bedrock was determined by two soundings at each site, one directly over the lineament trace and one near the end of the traverse line. An electrode separation, or "A-space," of two times the determined depth to bedrock was usually chosen for traversing. The Wenner electrode configuration was used for both sounding and traversing.

Since the electrical conduction in rocks is essentially electrolytic, the resistivity of a bedrock formation depends generally on the degree of moisture saturation and the nature of the electrolyte. The degree of saturation varies widely depending on porosity and the presence of joints. The nature of the electrolyte can also vary widely. Within a limited area of study, such as that encompassed by each of the sites in this report, the effects of saturation probably far overshadow those of any variance in the nature of the electrolyte. For an approximation of the conductance of the ground water at each site, well-water samples were analyzed, with results falling within a range of 495 to 1,315 μmho/cm at 25° C. These values compare with 100 to 1,500 μmho/cm for the general range of potable water in the United States, and contrast with 1,360 to 16,560 μmho/cm for highly mineralized groundwater.

The resistivity equipment used in this study consisted of two portable units designed for maximum penetration of either 100 ft for the small unit or 600 ft for the large. In most situations, the 100-ft unit was adequate, because the depth to bedrock seldom exceeded 20 ft and the resistivity traversing was designed to search for anomalous conditions near the bedrock surface where weathering would enhance the resistivity anomaly associated with a fracture zone.

VERY-LOW-FREQUENCY ELECTROMAGNETIC FIELDS

The VLF electromagnetic method of exploration utilizes radio transmissions from a worldwide naval submarine communications network. These transmissions induce secondary electromagnetic fields in and around subsurface conductors such as ore bodies, aquifers, and pipelines. Faults can be detected where rock on one side of the fault is more conductive than that on the other, or where a fault or fracture zone is more or less conductive than adjacent rock.

Reportedly, even individual shear zones or joints filled with wet clay are detectable at shallow depths. Buried pipelines and cables are readily detected. Elevated power transmission lines induce strong signals in the VLF equipment within some 200 ft proximity.

The VLF unit used in this study is simply a portable receiver with two built-in coils, one with a vertical axis and the other horizontal. A null in the signal from the vertical coil is attained by tilting, and the tilt angle is read on an inclinometer. A quadrature (out-of-phase) component of the signal from the horizontal axis is measured by a control knob. The operating frequency of this unit ranges from 15 to 25 kHz.

SOIL MOISTURE

Tonal contrasts on LANDSAT imagery can be attributed to a number of natural factors including vegetation, soil moisture, and soil or rock composition. Lineaments sometimes reflect bedrock fractures, even with a cover of glacial till (4). This is attributed to localized increase in soil moisture and therefore accelerated vegetal growth. A knowldege of soil moisture, and especially saturation, is helpful in interpreting the results of geophysical surveys and might be useful in detecting bedrock fractures, if indeed the assumed relation between fractures and soil moisture is valid. The interpretation of soil moisture levels is difficult because of variables such as topography, vegetation, soil character, seasonal and diurnal changes, and local climatological conditions. The soil samples in this study were collected by augering to a uniform depth of 12 in below the surface before withdrawing the sample. The samples collected from this depth occurred in the B-horizon just beneath the dark-colored A-horizon of organic matter accumulation. Samples from this depth should have been free from diurnal effects, stable in moisture content, and indicative of natural variations. The samples were collected during the growing season of early and late summer, at least 1 week after the last substantial rainfall.

REFERENCE SITE

In the geophysical assessment of lineaments, it is important to use appropriate methods and to have a form of reference with a known geological situation. In order to determine whether resistivity and VLF methods were suitable for detecting fracture-like subsurface structure, a traverse similar to those at the five selected sites was conducted across two mapped, steeply dipping, normal faults in the coal region of western Kentucky. In this region, the nearly horizontal coal measure rocks are similar to those of southwestern Pennsylvania, except for the presence of numerous faults. The fault displacements ranged from 200 to 400 ft. The faults were not detectable on the surface or on either small- or large-scale imagery, chiefly because the lithology is similar on both sides of the faults and intense residual weathering has occurred at depths of 15 to 20 ft in most places. The faults induced no readily apparent contrasts in surface moisture, vegetation, or topography. The faults, however, were detected early in this century through core drilling for coal reserves and, more recently, were accurately mapped during extensive strip mining operations in the area. The fault zones typically are very narrow with little associated disturbance. One exposure in a recently opened strip mine showed a fault zone about 3 in wide filled with a white clay-like gouge and some striations on the walls of the fault, but little evidence of adjacent drag or fracturing.

While faults of this type are virtually unknown in southwestern Pennsylvania, it was suspected that joints, which can give a geophysical response similar to a fault, might occur coincident with some of the lineaments. Any geophysical analogy between the faults and joints would, of course, depend upon factors such as the character of the strata adjacent to the fault or joint and the amount and distribution of weathering and moisture in the zone of the discontinuity. Nonetheless, the interpretation of geophysical measurements on lineaments in southwestern Pennsylvania could be enhanced by experience acquired at other sites in coal mining regions.

The results of the geophysical traverses are summarized in figure 2. The response in the vicinity of each fault is fairly pronounced and asymmetrical. The fault in figure 2*A* is indicated by an abrupt change in resistivity between one side of the fault and the other. The presence of the fault is indicated also by a VLF crossover attributed to a good conductance near the fault zone.

The fault in figure 2*B* is indicated by a gradual and moderate change in resistivity from one side of the fault to the other. The absence of a VLF crossover and the positive quadrature following the in-phase polarity suggests poor conductance within the fault zone.

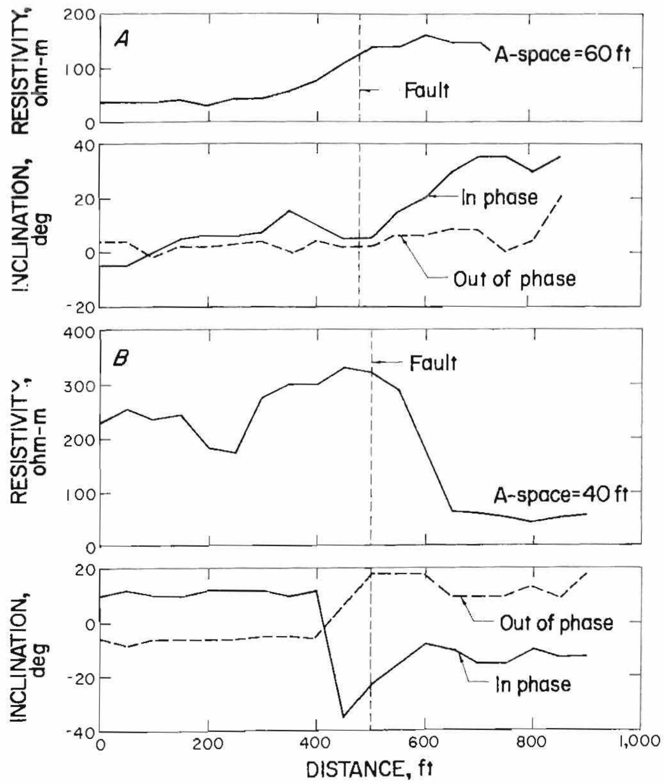


FIGURE 2.—Geophysical profile across faults *A* and *B*.

The above evidence suggests that since these narrow faults, which resemble widened fractures, are detectable by the methods employed, fracture zones commonly assumed to underlie lineaments also should be detectable. As will be discussed later, no such response was obtained from the five lineaments described in this report. Although this does not prove the absence of fractures underlying the lineaments, it offers some basis for doubt as to their existence and must be considered in the overall assessment process.

GEOLOGIC SETTING

The study sites are located in southwestern Pennsylvania, a region of hilly terrain with topographic relief ranging up to 500 ft. This region is a part of the Dunkard Basin, a broad structural depression in the Allegheny Plateau in which several coalbeds were deposited. The Chestnut Ridge anticline, or its northern extension, forms the eastern limits of the study area (fig. 3). Structural dips of rock strata west of the anticline seldom exceed 1°. Cross-strata faults with more than a few feet of displacement are rare, although bedding plane movement may be appreciable. Jointing is common, but not of uniform trend in the region. It is highly developed in valley walls (5-6). The downward extension of any one joint or set of joints is conjectural.

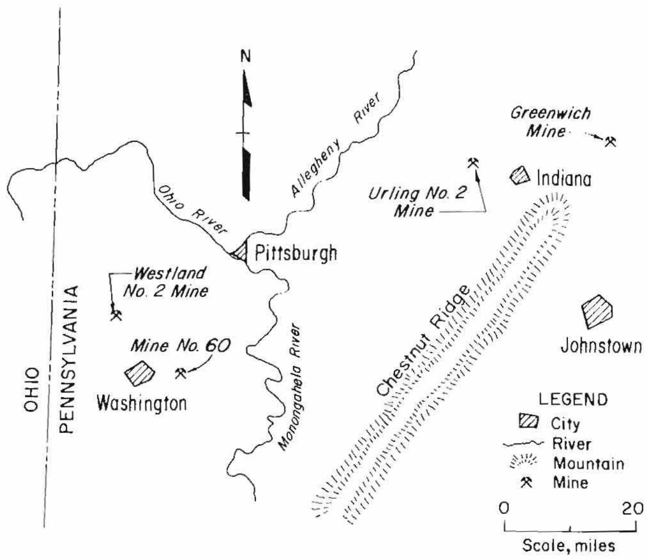


FIGURE 3.—Index map of study area.

The surface is covered chiefly by residual soil or detritus overlain by a veneer of humus, with minor amounts of gravel along streams. Outcrops are rare except in roadcuts or strip mines. While much of the area is cultivated, the hillsides generally are covered with mixed hardwoods. Valley fill seldom exceeds 15 to 20 ft. Near hilltops, the bedrock is seldom more than a few feet below the surface.

The surface drainage of the area consists of a dendritic pattern of streams with little irrefutable evidence of joint control. Occasionally, a straight stream valley occurs, which measures several miles in length, and is difficult to explain without some kind of structural control. Ferguson (5-6) offered strong evidence that jointing develops in valley walls during and after erosion of the valley, although this would not explain an occurrence of joints between valleys. The joint and stream trend relation is not fully understood, but the dendritic pattern of drainage precludes all but local structural control on a small scale.

Ground water in the study area occurs as a water-table aquifer. The term "water-table" is used here to designate the surface below which the overburden is saturated. The water-table aquifer extends from the water table down through the saturated zone to the first aquiclude, or layer of relatively impermeable rock that does not transmit ground water rapidly enough to supply a well or spring. The water table tends to follow topography somewhat, but is deeper beneath hilltops than in valleys, where it lies close to the surface. Deeper confined aquifers occur well below the level of most coal mining, but are of very low yield. They can be highly saline and are of little relevance to this study.

ROCK DEFORMATION BENEATH EROSIONAL VALLEY BOTTOMS

Because lineaments in the study area occasionally are used to infer potential subsurface conditions in coal mines, and because the large majority of the lineaments in the study area coincide with segments of erosional stream valleys, the general geologic character of these valleys is an essential factor in the interpretation of lineaments. The drainage pattern is chiefly dendritic (7) and presumably resulted from some obscure control on the erosion of flat-lying sediments. Genuine linear valleys of several miles in length are rare in the Allegheny Plateau of western Pennsylvania and are suspected of resulting from superimposed streams.

Coalbed continuity beneath valleys in the study area demonstrates the absence of major structural faults, and visual examination of the mine workings seldom reveals more than the normal amount of slickensides or intraformational joints in the roof. Shallow minor structures of recent age, however, probably occur beneath most valley bottoms. For example, work by Ferguson (5-6), Matheson and Thomson (8), Zaruba (9), Wyrick and Borchers (10), and Simmons (11) has demonstrated the plastic deformation, anticlinal flexure, bulging, and jointing that commonly occur beneath many erosional valley bottoms in regions of nearly flat-lying, stratified, sedimentary rock.

These structures seldom are found deeper than 160 ft below the surface, but this probably explains the higher yields of water wells in valleys compared with those on hills, and the higher incidence of mine-water inflow in shallow coal mine workings beneath valleys.

However, the stresses associated with these structures extend much more deeply, resulting in problems with coal mine roof instability (5-6, 12-14). Thus, it may be immaterial to identify a valley in the study area with a lineament when searching for an explanation of coal mine ground-control problems beneath stream valleys, because most valleys are underlain by deformation, which puts the rocks under high stress.

RESULTS OF TRAVERSING

The five selected lineaments were traversed across the trends to test for any evidence of anomalous conditions. The abundance of power lines and buried gas pipelines placed some constraints on attempts to locate traverses in areas free from interference. Problems of accessibility to optimum locations for traverse also were encountered, so the final selection of sites was a compromise affording the best available.

The hilly topography in this region was a minor inconvenience and appeared to have little or no effect on the geophysical or soil moisture value. Pronounced increases in soil moisture occurred only in the vicinity of streams or swamps.

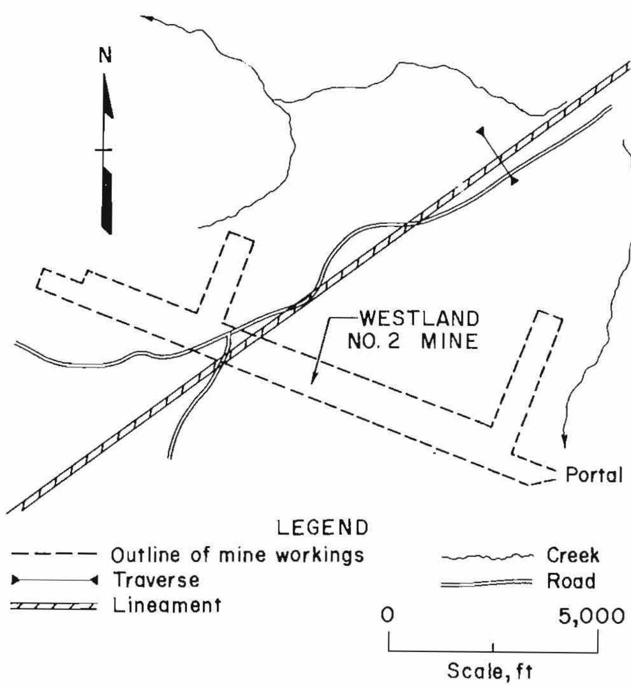


FIGURE 4.—Outline of mine workings and lineament at site 1.

SITE 1: WESTLAND NO. 2 MINE

The LANDSAT lineament site 1 was located at the Westland No. 2 Mine in Washington County, PA, 40 miles west of the Chestnut Ridge anticline (fig. 3). It was 4-1/2 miles long with a strike of N 55° E (fig. 4). The trend of this lineament, with respect to others in the same quadrangle, is shown in figure 5. This lineament followed no discernible topographic or drainage trend. Parts of the lineament coincided with a railroad and a power line. Otherwise, nothing on the surface could be related with the location and trend of this lineament.

Mine workings penetrated a subsurface projection of this lineament in one location and encountered a downward roll in the coalbed (fig. 6), thus raising the possibility that the lineament might be related to a geologic structure. It seems unlikely that a roll-type structure would persist with such a straight trend for over 4 miles, or project vertically through 300 ft of overburden to the

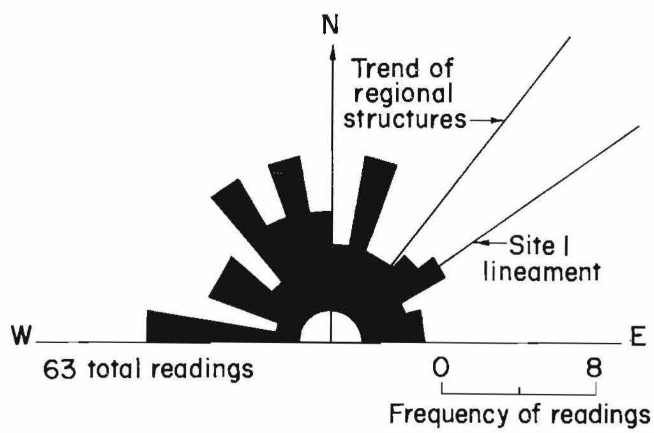


FIGURE 5.—Rose diagram of lineaments at site 1.

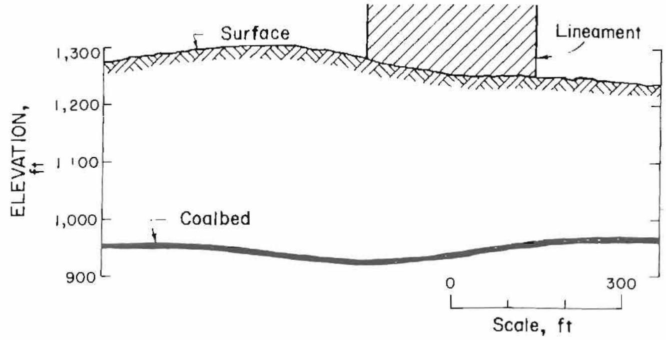


FIGURE 6.—Profile showing lineament and coalbed roll at site 1.

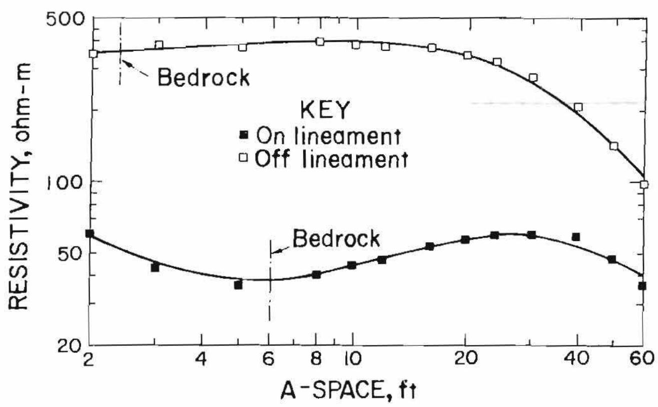


FIGURE 7.—Resistivity sounding at site 1.

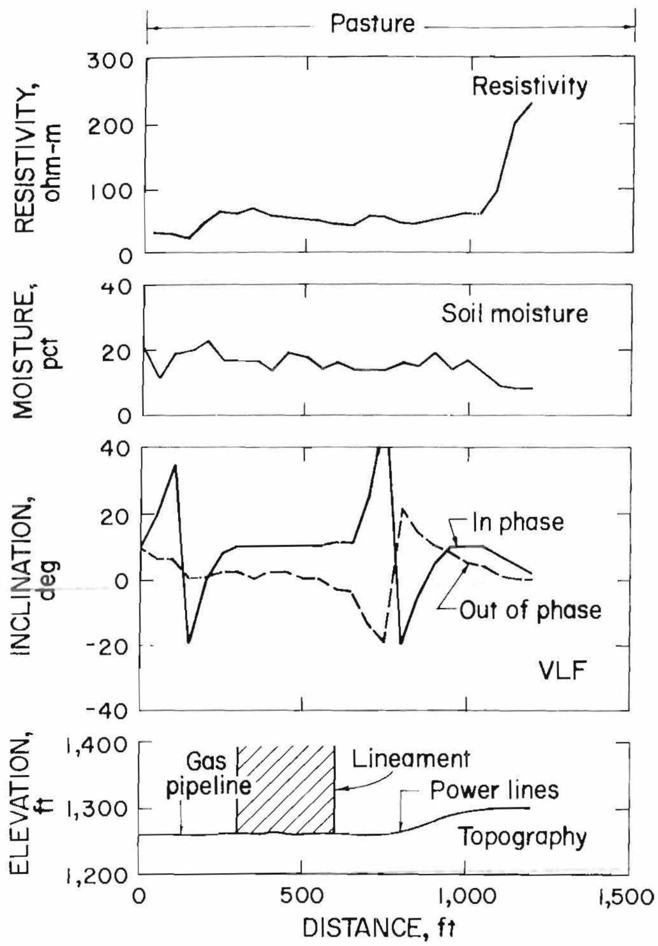


FIGURE 8.—Results of traverses across site 1.

surface. However, resistivity soundings and geophysical traverses of the lineament were conducted to assure that a subsurface structure was not overlooked.

The results of the resistivity soundings are shown in figure 7. The sounding curves show bedrock at 6 ft over the lineament, and at the surface on the ridge at the northern end of the traverse line. The shallow depth to bedrock on the ridge is attributed to a resistant bed of sandstone capping the ridge, while the lineament is located downslope in shale, which has weathered more deeply. The high resistivity on the sandstone ridge and the low resistivity at the lineament downslope in the shale terrane reflect a normal contast consistent with the subsurface conditions.

The results of the traverses conducted across the site 1 lineament are shown in figure 8. It is clear that neither the resistivity, soil moisture, nor VLF detected any anomalous conditions at the portion of the lineament that was traversed. The validity of this lineament was somewhat in doubt since a third interpreter was unable to discern a lineament at this site. It was concluded that, if the lineament actually indicates a subsurface feature at this location, it could not be detected by any of the methods employed in this study.

SITE 2: GREENWICH MINE

The LANDSAT lineament site 2, located at the Greenwich Mine in Indiana County, PA, was situated 3 miles east of the Chestnut Ridge anticline (fig. 3), the nearest major tectonic deformation, although the fold is poorly defined in this area. The lineament was 1 mile in length with a strike of N 40° W (fig. 9). The trend of this lineament, with respect to others in the same quadrangle, is shown in figure 10. This lineament followed

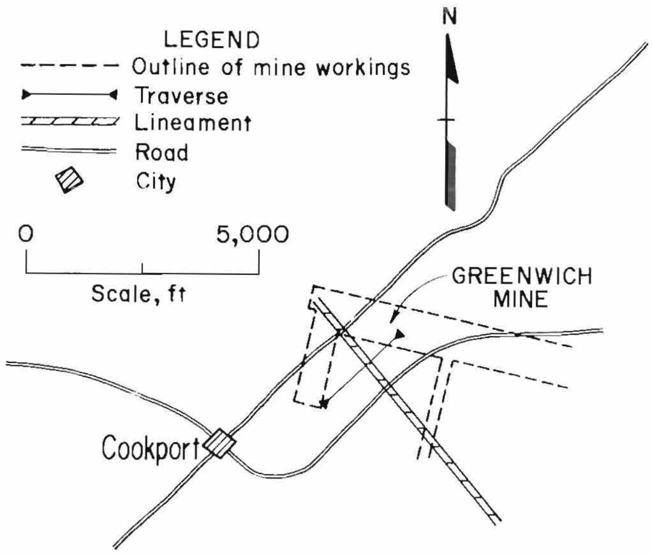


FIGURE 9.—Outline of mine workings and lineament at site 2.

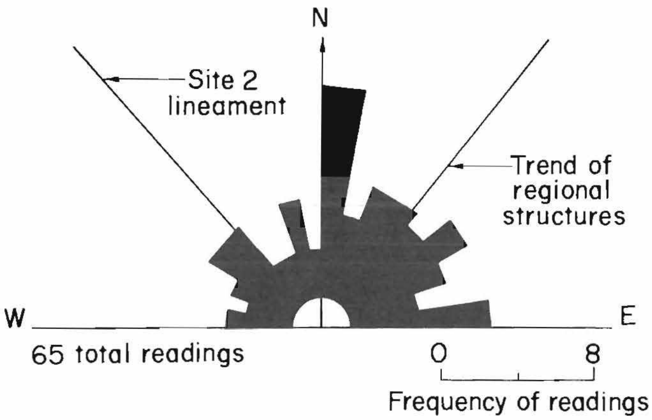


FIGURE 10.—Rose diagram of lineaments at site 2.

the general trend of a small stream and swamp in an area of very little topographic relief. It might be classified by some interpreters as a fracture trace because of its short length, however, it is located in an area of imminent mine development where the results of the traverse might have been a direct bearing on subsurface studies being conducted in the mine.

The subsurface projection of the lineament was penetrated by several sets of mine entries (fig. 11). A large number of clay veins, slickensides, minor rolls, and falls were mapped in the mine roof throughout this section of the mine. None of these features, however, followed any persistent trend or pattern of distribution that could be related to either the lineament or regional structure.

The results of the site 2 resistivity soundings are shown in figure 12. The sounding curves show bedrock at about 4 ft on-lineament, and bedrock at 7 ft in a wooded area about 1,000 ft off-lineament at the southwest end of the traverse line.

The slight contrast in depth to bedrock between on-lineament and off-lineament sites, both located along a nearly level profile in the same strata, probably is of no significance. The somewhat lower resistivity levels on the lineament can be explained by the swampy, poor drainage, and higher soil and bedrock moisture conditions.

The results of the traverses conducted across the site 2 lineament are shown in figure 13. Soil moisture peaks occurred, as anticipated, near a small stream and adjacent swampy zone in the vicinity of the lineament, reflecting the shallow, near-surface water table. The VLF, while showing a very low response of about 4° in the lineament zone because of the near-surface water table, did not show an in-phase crossover from positive to negative tilt angle typically observed when crossing over a conductor. Furthermore, experience shows that a low positive out-of-phase (quadrature) value usually is associated with a surface target such as a swamp, rather than with a deeper conductor. Thus, there is little evidence to support the presence of any anomalous conditions such as fractures or joints in the shallow subsurface beneath the lineament.

SITE 3: URLING NO. 2 MINE, CHEESE RUN

The LANDSAT lineament site 3, located at the Urling No. 2 Mine in Indiana County, PA, was situated 12 miles west of the Chestnut Ridge anticline. The "Cheese Run" lineament was 3-1/2 miles in length and passed through the village of Shelocta. It was curvilinear, but followed a general E-W strike in the area traversed (fig. 14). The trend of this lineament, with respect to others in the same

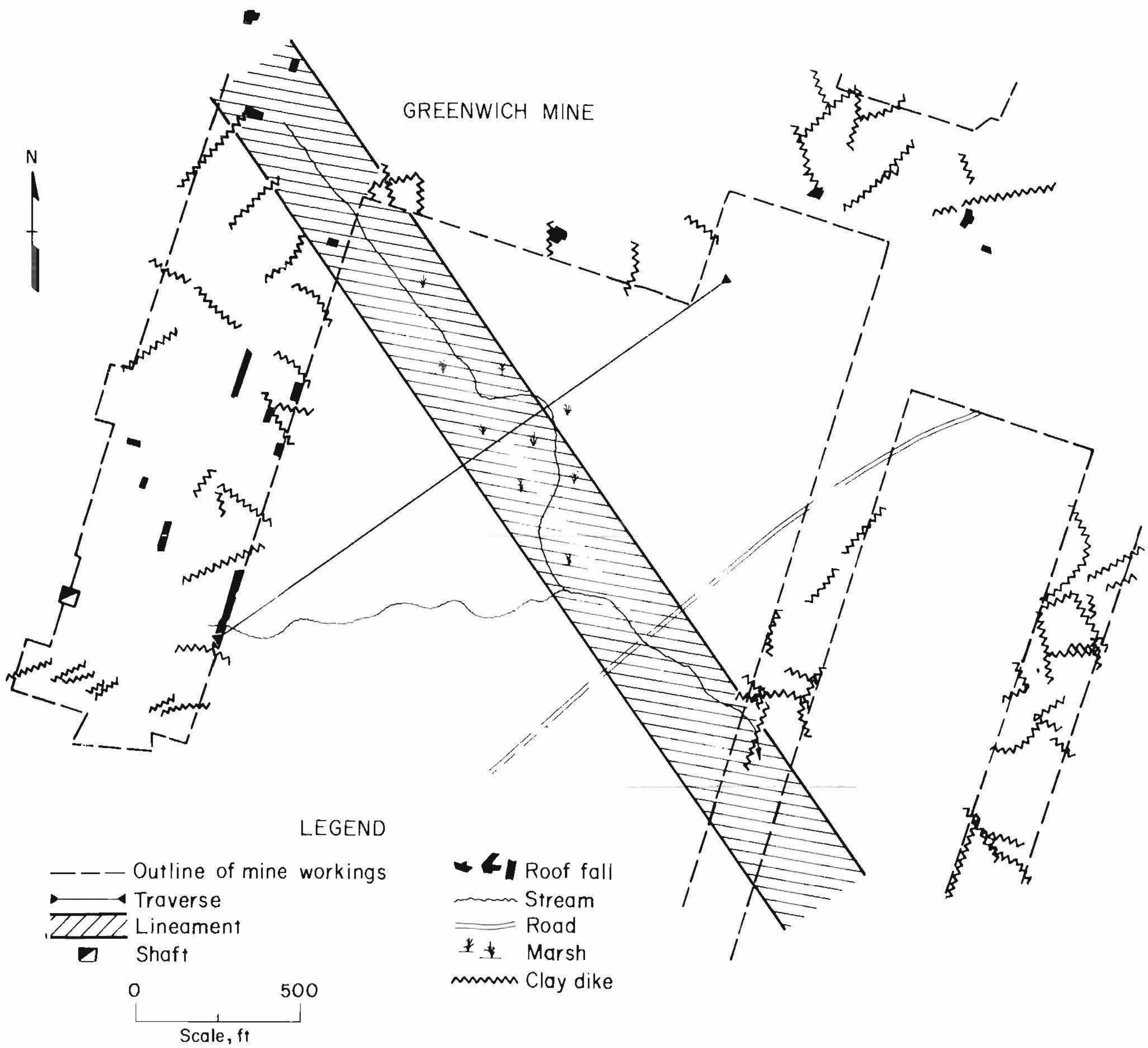


FIGURE 11.—Mine workings and roof structures at site 2 lineament.

quadrangle, is shown in figure 15. The lineament was tangent to short segments of two streams and partly followed the trend of some surface contours. In the area studied, it followed a projected path diagonally across a virtually flat valley floor. This lineament, in particular, seemed to represent a connection of what may be unrelated tonal features on the LANDSAT image. However, in view of the uncertain nature of lineaments and the complex geomorphic history of the region, a traverse across the valley floor was conducted despite the discontinuous elements of the lineament. This site for a traverse fortuitously avoided some of the problems that would have been inherent in conducting geophysical tests in areas of very high relief further along strike of the lineament.

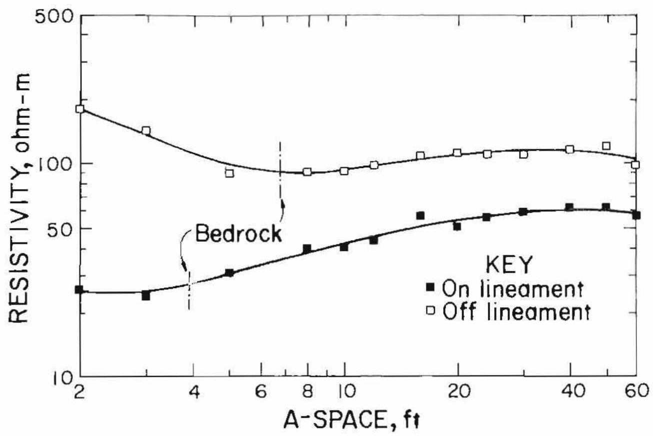


FIGURE 12.—Resistivity sounding at site 2.

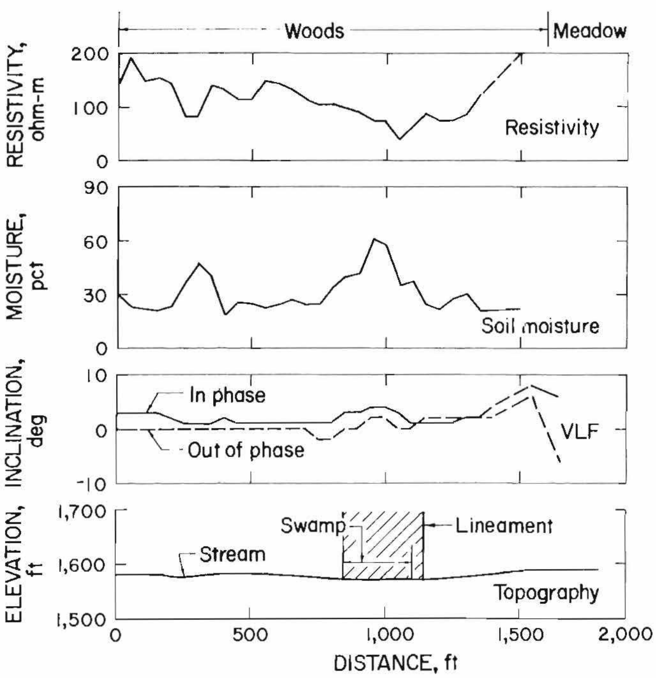


FIGURE 13.—Results of traverses across site 2 lineament.

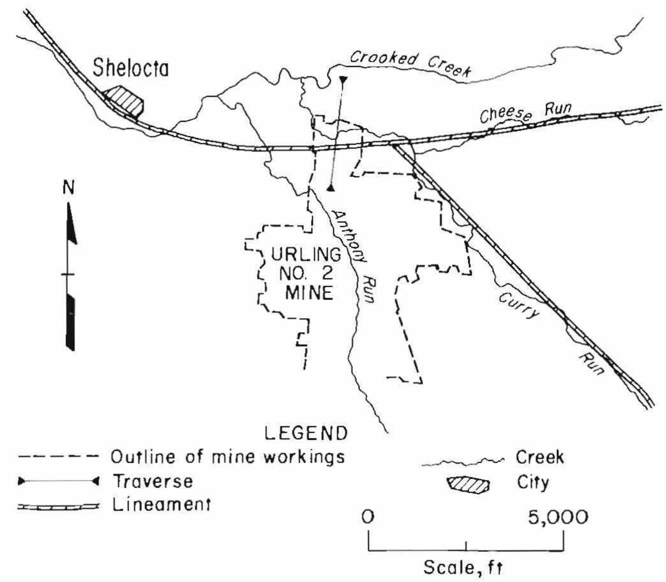


FIGURE 14.—Outline of mine workings and lineament at site 3.

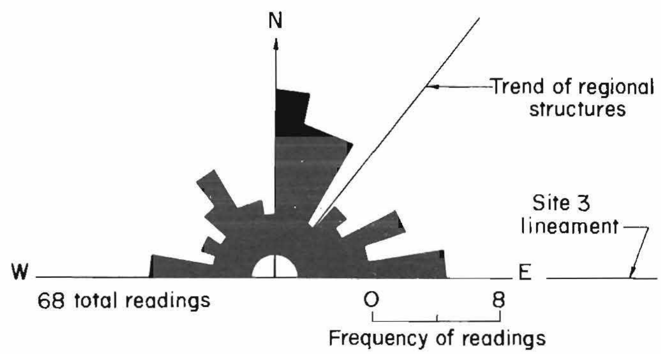


FIGURE 15.—Rose diagram of lineaments at site 3.

A portion of the lineament has been undermined (fig. 16) although the pillars remain intact. The mine workings some 200 ft beneath the lineament were examined to determine whether or not any underground manifestations of the lineament could be discovered. The immediate roof in the mine consisted chiefly of a hard gray silt shale. No geologic structures, other than the normal amount of coal cleat, slickensides, and laminations in the shale, could be detected. Only two roof falls have occurred in this section of the mine, while throughout the adjacent section of the mine to the south (fig. 16), a large number of falls have occurred in a somewhat random pattern. Thus, the best roof conditions occurred in the north section near the lineament.

The results of the site 3 resistivity soundings are shown in figure 17. The sounding curves show the water table on the lineament at 12 ft, and bedrock at

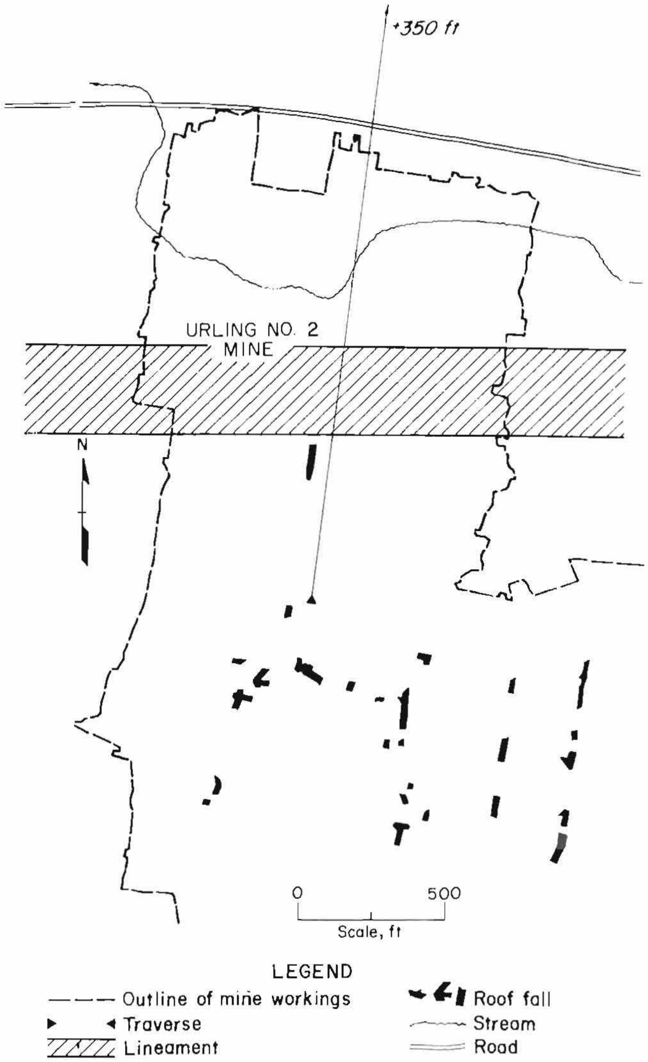


FIGURE 16.—Mine roof falls at site 3 lineament.

20 ft, as confirmed by a nearby drill hole. Off-lineament, 1,000 ft along the profile from the lineament, the soundings show water table at 35 ft and bedrock at 7 ft. This location is higher in elevation than the lineament; thus the depth to water table is greater. In contrast, depth to bedrock is greater on the lineament, largely because of the added depth of valley fill alluvium.

The results of the traverses conducted across the site 3 lineament are shown in figure 18. The VLF gave no response near the lineament. A slight increase in resistivity was recorded, but this was scarcely beyond a normal variation of about 100 ohm-m. Soil moisture indicated a general increase near the stream. It

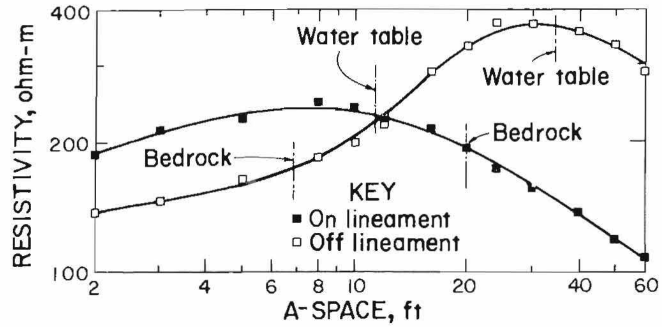


FIGURE 17.—Resistivity sounding at site 3.

was concluded that, if the lineament actually indicated a subsurface feature at this location, it could not be detected by any of the methods employed in this study.

SITE 4: URLING NO. 2 MINE, CURRY RUN

The LANDSAT lineament site 4, located at the Urling No. 2 Mine in Indiana County, PA, was situated 12 miles west of the Chestnut Ridge anticline. It was 2 miles long with a strike of N 45° W, and intersected the site 3 "Cheese Run" lineament (fig. 14). The trend of this lineament, with respect to others in the same quadrangle, is shown in figure 19. This lineament coincides with the well-defined linear Curry Run stream valley. Topographic relief between the narrow cultivated valley floor and the top of the wooded hillsides is over 200 ft (fig. 20). Alluvial material about 20 ft thick covers the valley floor.

Mine workings closely approached this lineament but were stopped to permit the drilling of two test holes beneath the valley floor (fig. 21). The workings at this point were under 250 ft of overburden. The holes were drilled at an angle of +12° to test for roof rock conditions and the presence of water. The holes first penetrated shale at 0 to 20 ft above the coalbed, then sandstone above the shale. Both drill holes produced varying flows of water from the sandstone, the maximum discharge from one hole reaching 370 gpm. A profile summarizing these conditions is shown in figure 22. The drillers reported openings in the sandstone of up to 2 ft wide,

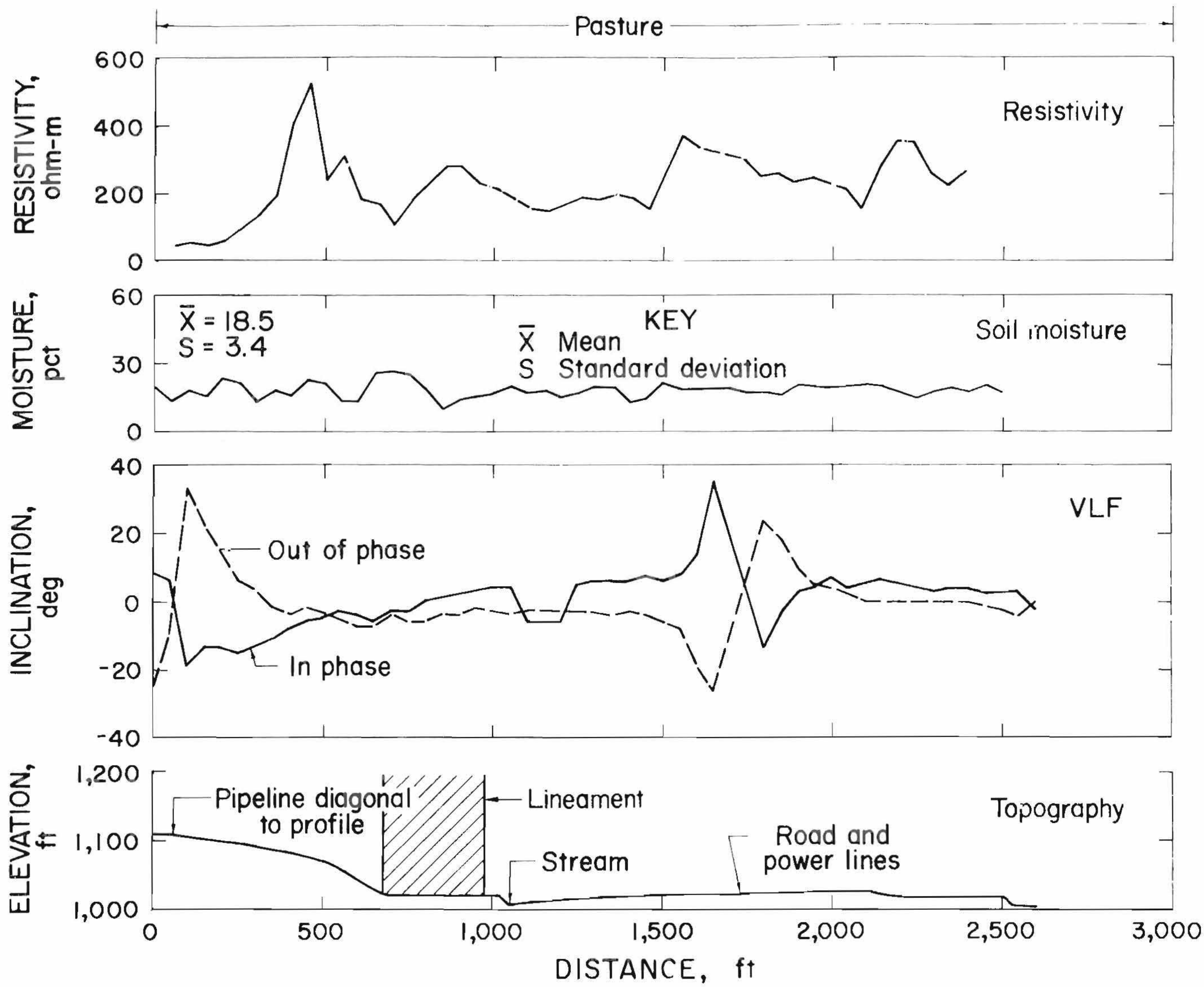


FIGURE 18.—Results of traverses across site 3 lineament.

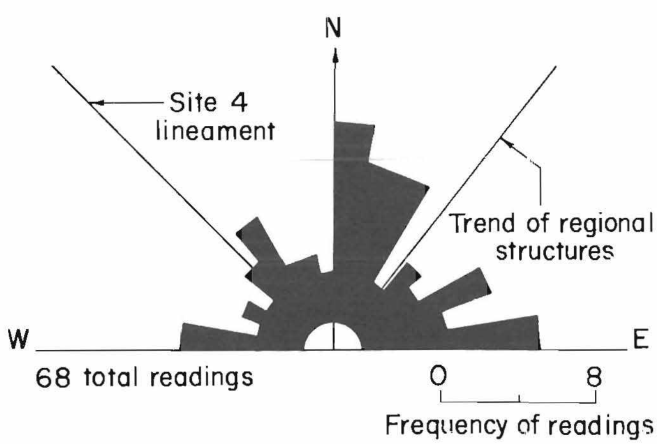
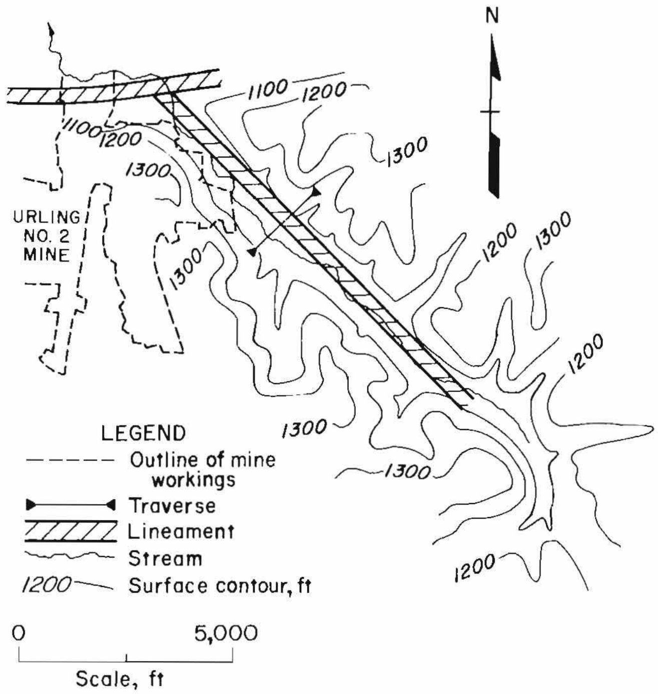


FIGURE 19.—Rose diagram of lineaments at site 4.

indicating separation along bedding or open or clay-filled fractures. This evidence suggests the possibility of a high permeability in the sandstone, and possibly throughout the entire thickness of overburden. This is supported by reports that when heavy inflows of water were encountered in the mine at a roof fall, shallow water wells in the valley located about 1,000 ft laterally from the inflow were affected by a pronounced drop in water level.

While a correlation exists between the surface lineament of Curry Run valley and the evidence of fracturing and water in the mine overburden, the authors interpret this as being entirely a manisfestation of valley stress relief accompanied by valley floor uplift, bed separation, and tension joints. The lineament itself, therefore, is merely a graphic means of representing a straight segment of a stream valley, whose origin is obscure but unlikely to be related to preesixting joints.



,FIGURE 20.—Topography at site 4 lineament.

The results of the site 4 resistivity soundings are shown in figure 23. The sounding curves indicate bedrock at 15 to 18 ft below surface on the lineament in the valley, and bedrock very near the surface on the hillside 1,000 ft east of the lineament. The water table lies 27 ft below surface on the lineament and 60 ft below surface at the off-lineament location, at a higher elevation.

The results of the traverses conducted across the site 4 lineament are shown in

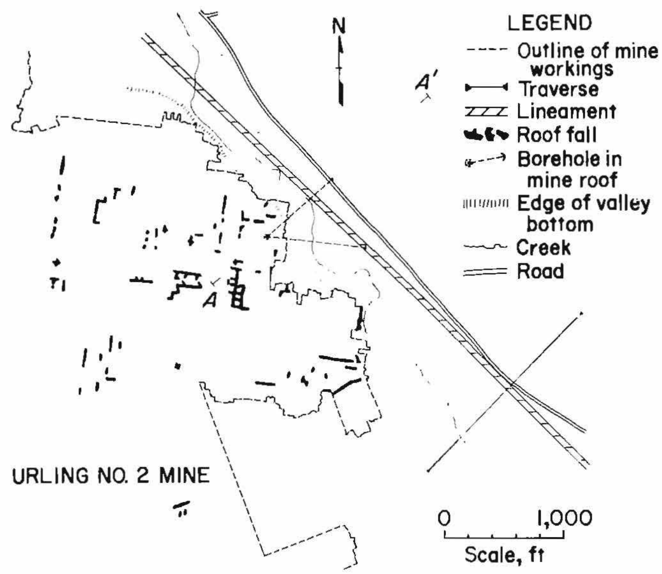


FIGURE 21.—Test hole location at site 4. (The A-A′ section is shown in figure 22.)

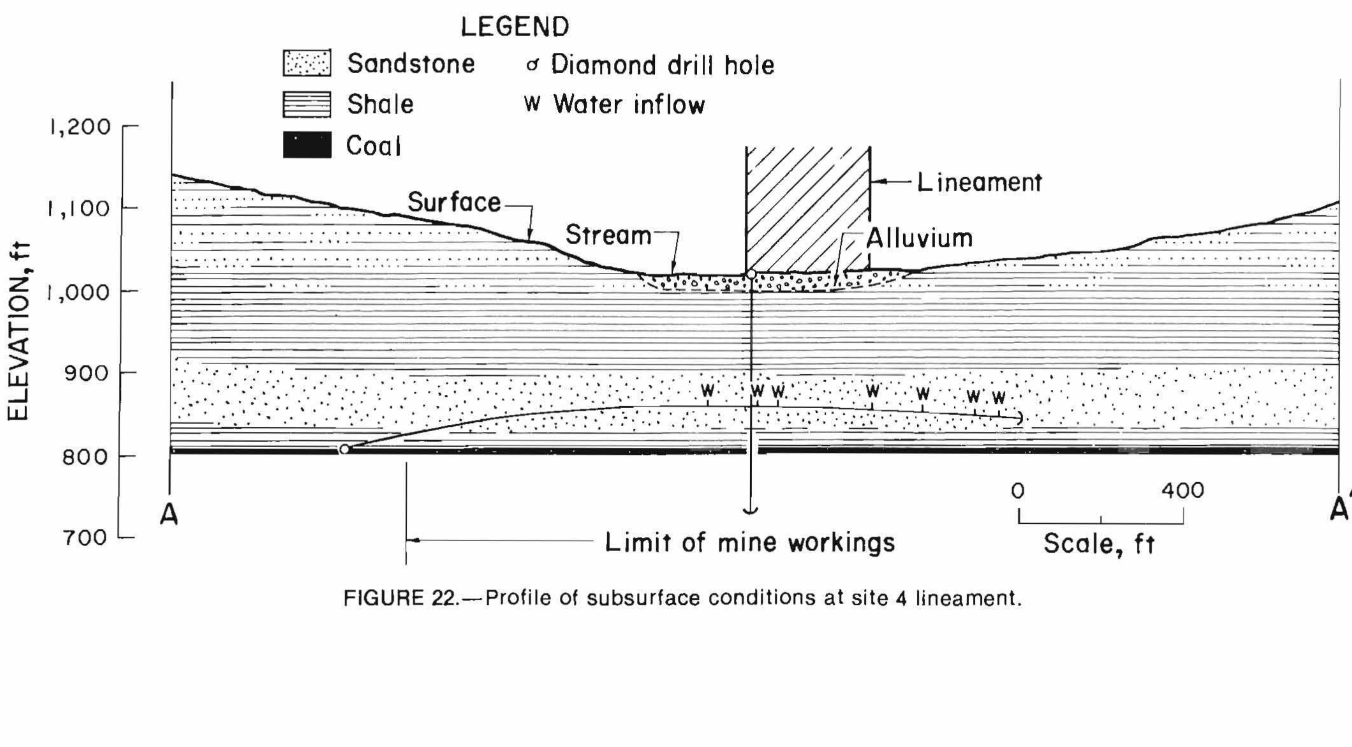


FIGURE 22.—Profile of subsurface conditions at site 4 lineament.

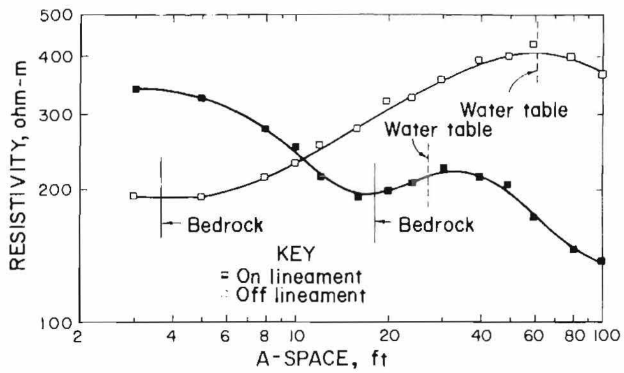


FIGURE 23.—Resistivity sounding at site 4.

figure 24. Neither the resistivity, soil moisture, nor VLF indicated any anomalies that coincided closely with the position of the lineament. Interference from power lines caused a high VLF response close to the lineament, preventing a true reading in the vicinity. Very high resistivity was encountered at 1,800 ft on the traverse, some 250 ft from the lineament, and again at 600 ft on the traverse. Neither of these high resistivities can be satisfactorily explained except by the presence of a highly resistant stratigraphic unit in the slopes on both sides

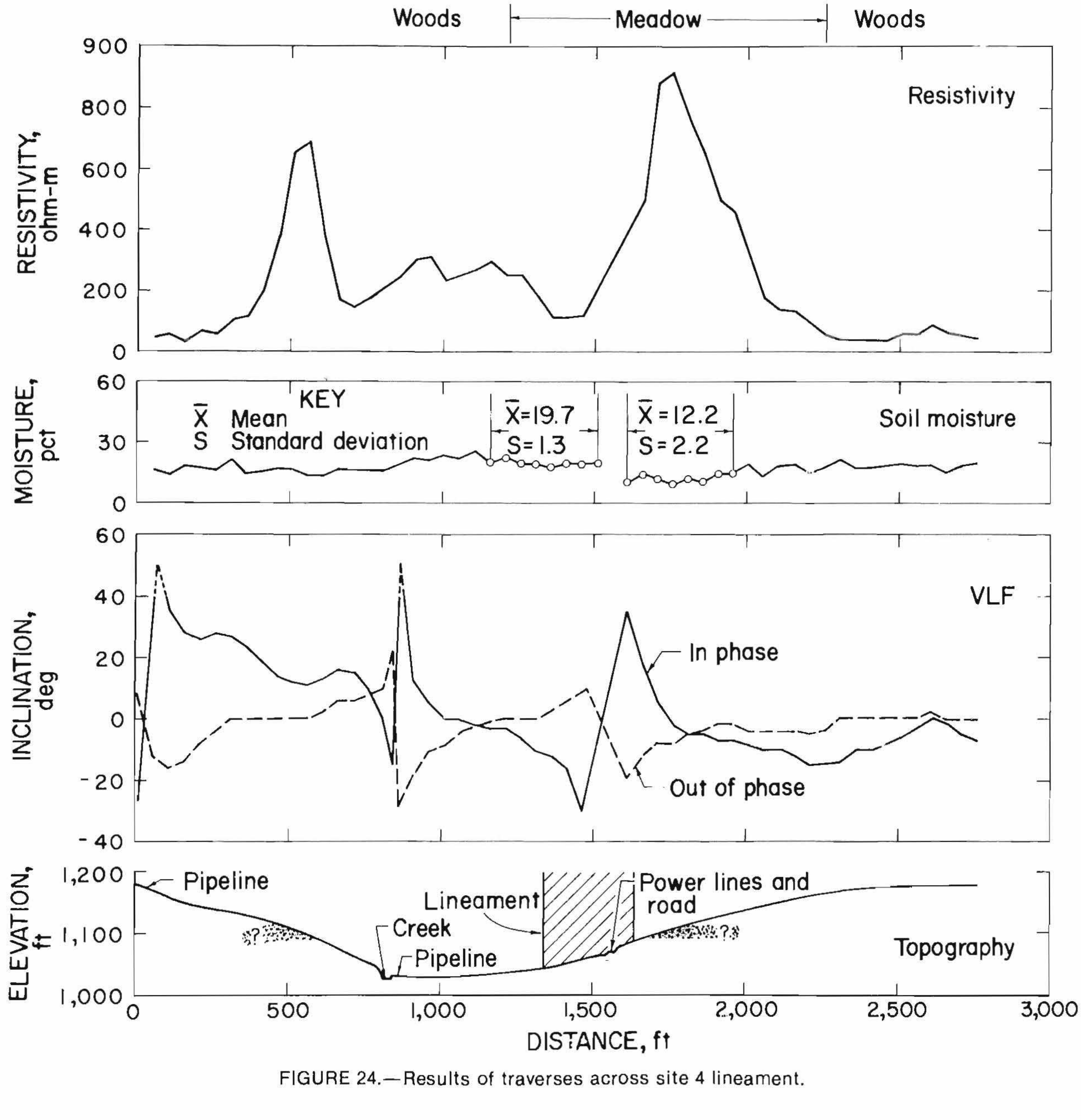


FIGURE 24.—Results of traverses across site 4 lineament.

of the valley. There is little evidence for correlating any of the anomalous responses on the traverse with the presence of the lineament. Possibly, resistivity and VLF methods are limited in their capacity to detect fractures associated with valley rebound and bulging in a very wet subsurface environment.

SITE 5: MINE NO. 60, LITTLE CHARTIERS CREEK

The LANDSAT lineament site 5 was located at the Mine No. 60 in Washington County, PA, 30 miles west of Chestnut Ridge anticline (fig. 3). It was 7 miles long with a N-S strike. The trend of this lineament, with respect to others in the same and adjacent quadrangle, is shown in figure 25. This lineament coincides with the well-defined linear Little Chartiers Creek stream valley (fig. 26) and can be distinguished even without enhancement (fig. 27). Topographic relief between the narrow alluvial-filled valley and the surrounding hills is about 200 ft. The alluvial material was about 12 ft thick at the traverse location.

The origins of landforms and drainage patterns in southwestern Pennsylvania have rarely been explained in detail. In particular, an occasional strongly linear N-S trending stream valley, such as Little Chartiers Creek occurring in the midst of dendritic drainage, raises questions as to its genesis. The absence of any detectable structural control adds to the puzzle. For example, N-S trending joints do not constitute a dominant trend in the Chartiers valley or adjacent quadrangles (15).

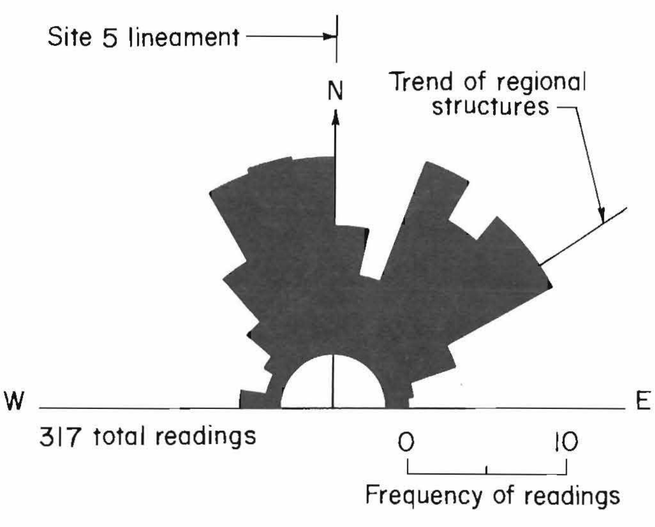


FIGURE 25.—Rose diagram of lineaments at site 5.

Mine workings beneath the Little Chartiers Creek valley encountered some severe roof falls within a zone that lies along the west edge of the valley (fig. 28) under 460 ft of overburden. This zone generally follows the trend of the valley and the 1,025-ft surface contour. Roof falls in this zone were severe but scattered and discontinuous. The character of the falls strongly suggests the so-called snap top or stress-related type of roof failure attributed to stress relief (fig. 29). Roof cutters, or shears, at the intersection of the rib and roof sometimes were present, but not pronounced. Some cutters seemed to occur along the centerline of the roof, which consists of several feet of interbedded claystone, coal, and shale. No joints or water inflow were encountered beneath Little Chartiers Creek valley. The mine operators reported that by using a variation of the stiff-yield pillar design, the driving of entries through the roof fall zone was accomplished with less difficulty than expected, supporting a stress-related cause of roof falls.

Problems with instability in the northern Appalachian region reportedly are more severe beneath N-S trending stream valleys than any other. This suggests that N-S trending lineaments deserve more attention and may be related to an E-W in situ remnant stress.

The results of the site 5 resistivity soundings are shown in figure 30. The sounding curves indicate bedrock at 12 to 15 ft below the surface on the lineament in the valley, confirmed by a drill hole, and bedrock at 7 to 10 ft below the surface on the hillside 600 ft west of the lineament.

The water-table effects could not be distinguished on the sounding curves, but on the lineament the depth to water table is estimated at about 12 ft because of the location in a stream valley and the close proximity of the stream.

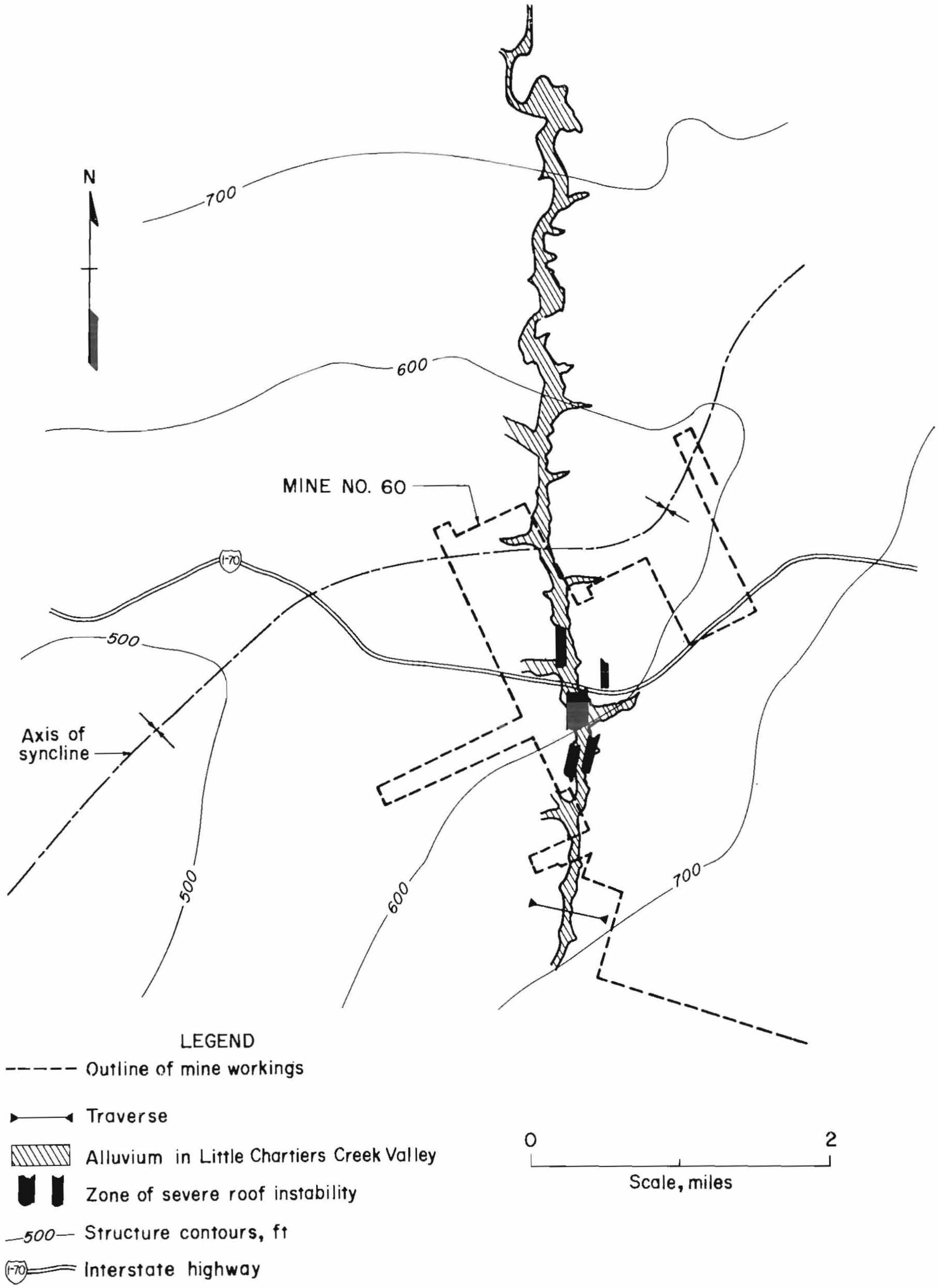


FIGURE 26.—Outline of mine workings and Little Chartiers Creek valley at site 5.

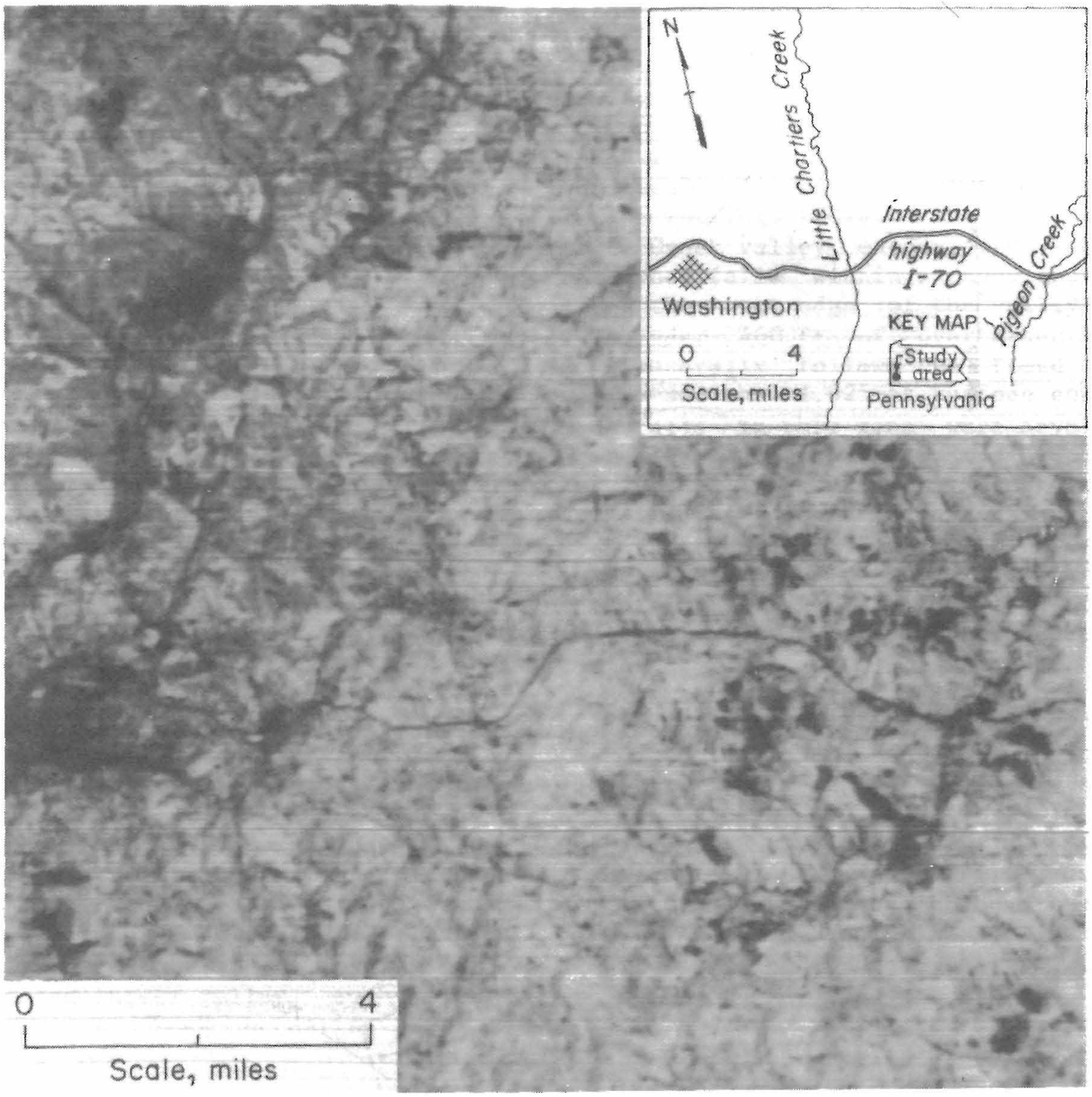


FIGURE 27.—LANDSAT image of site 5 area.

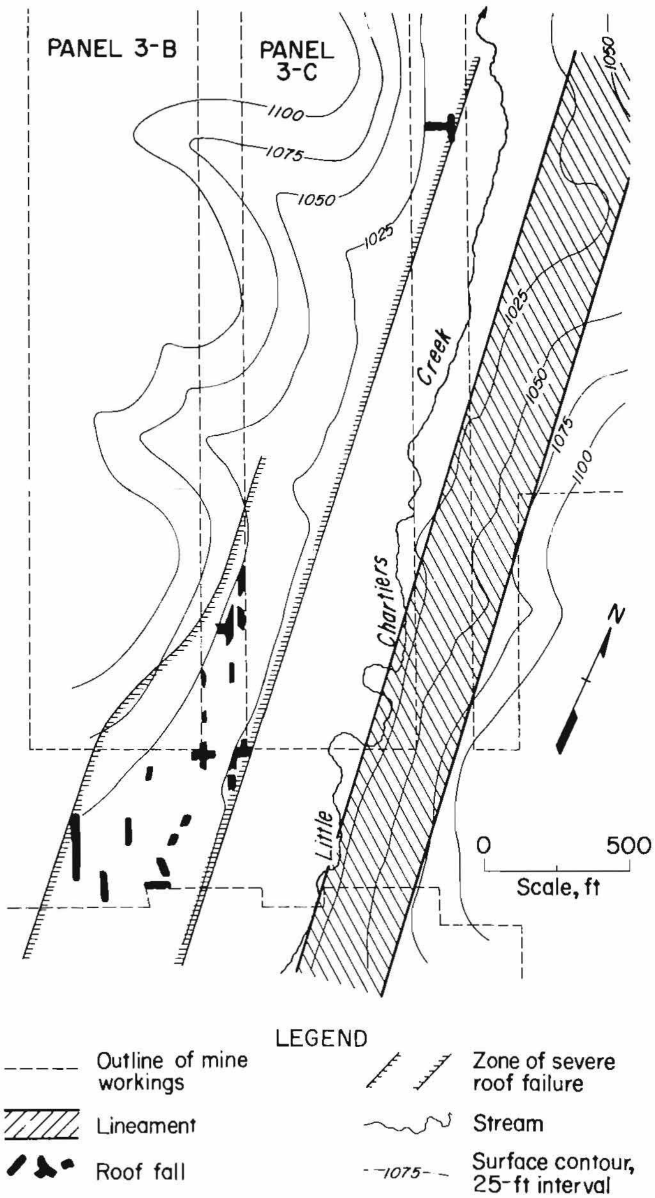


FIGURE 28.—Mine roof falls at site 5 lineament.

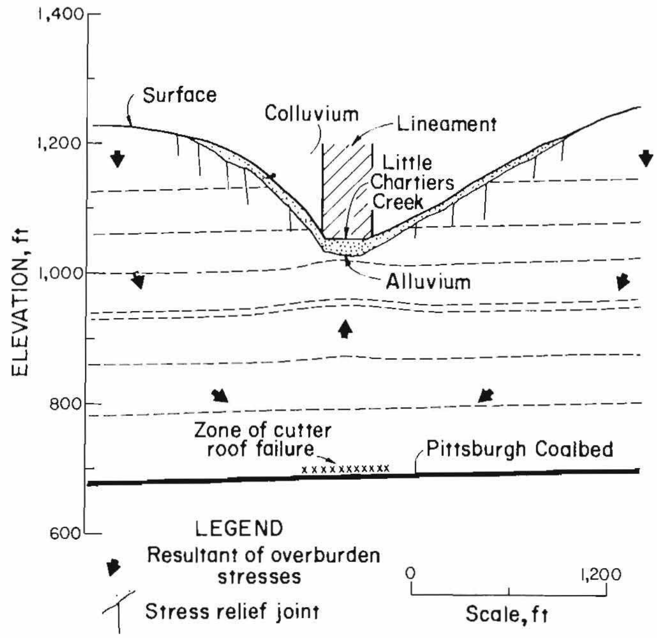


FIGURE 29.—Schematic cross section of Little Chartiers Creek valley.

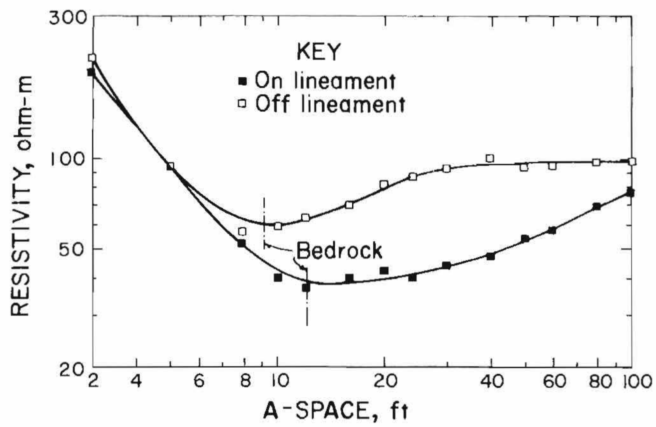


FIGURE 30.—Resistivity sounding at site 5.

The results of the traverse conducted across the site 5 lineament are shown in figure 31. Neither the resistivity nor the VLF showed anomalous readings coinciding with the position of the lineament. A very broad zone of high soil moisture seemed to correspond to the valley and immediate hillsides. A high VLF response some 400 ft away from the lineament was caused by interference from power lines. There is little evidence for correlating any of the measurements on the traverse with effects from the lineament.

DISCUSSION OF RESULTS

Five lineaments in the coal mining region of southwestern Pennsylvania identified on LANDSAT imagery were investigated on the ground in an effort to determine their character and relation to subsurface mining conditions. Similar lineaments have been used with varying degrees of success as indicators of potentially bad roof conditions in underground coal mines. A few of the successful correlations of lineaments with bad roof conditions (Jansky and Valane (16)) have been described in the literature, but the unsuccessful attempts at

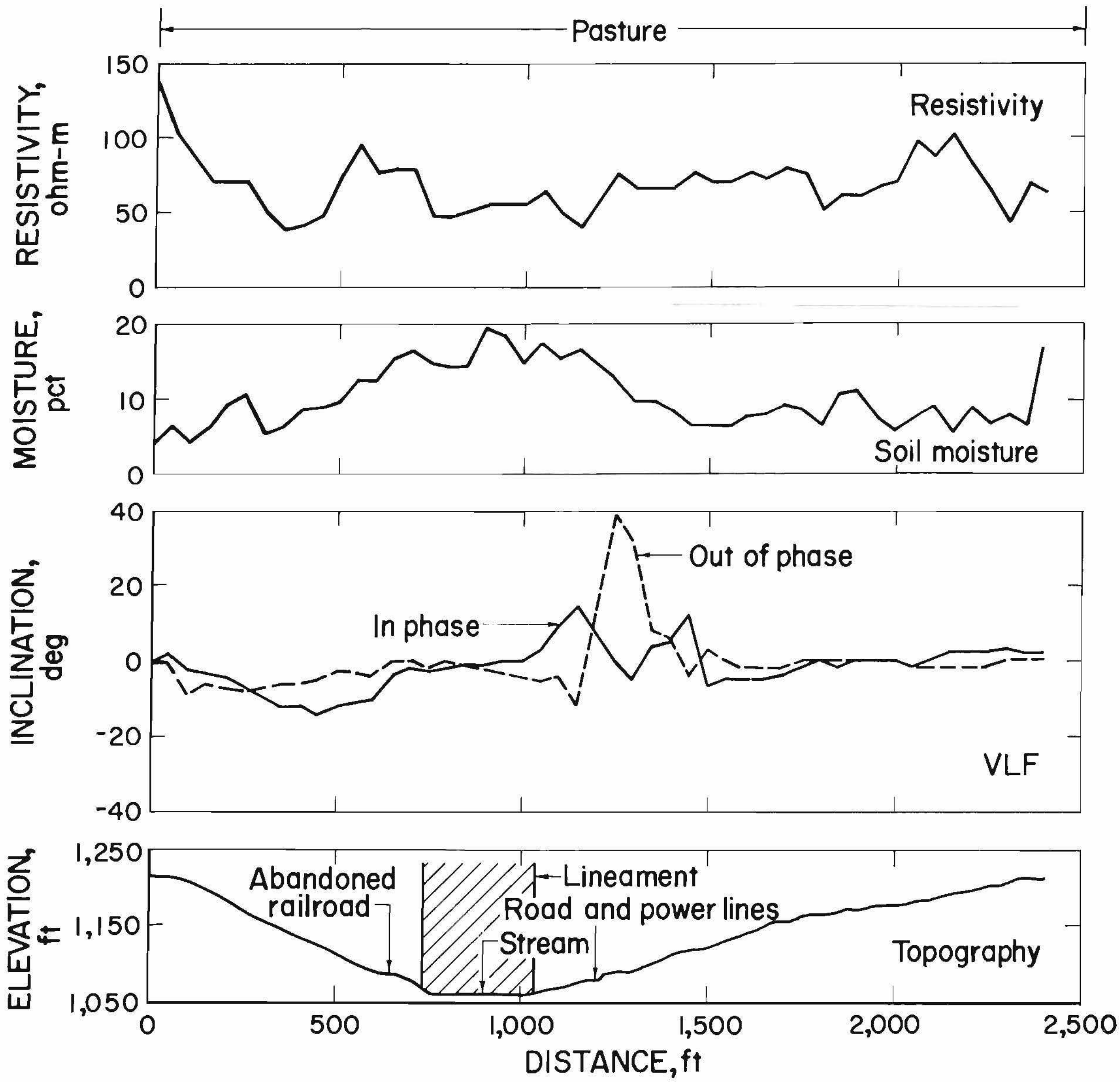


FIGURE 31.—Results of traverses across site 5 lineament.

prediction (Peng and Haddad (17)) go largely unreported, raising questions as to the validity of interpreted lineaments. Similarly, an intensive effort to use lineament analysis in West Virginia to find potential gas fields was unsuccessful, largely because there was no means of evaluating or confirming the interpreted lineaments with resistivity mapping or other geophysical methods (18). Most successful attempts at correlations occurred where the LANDSAT lineament coincided with a linear segment of a stream valley.

These relationships have been attributed to the fracture systems that supposedly controlled drainage, although virtually no supporting evidence has been presented. The authors have yet to discover any clear evidence of an unusually pronounced jointing in mine workings beneath lineaments in this region. Roof instability beneath valleys, however, has been correctly attributed to sediment unloading and valley rebound, resulting in high stresses and minor disturbances of bedrock. Therefore, the presence or absence of a perceived lineament along a valley in this region probably is immaterial. Along similar lines, Rauch, Narotzky, Ragan, and Newton (19), in studying gas-well yield in eastern Kentucky, cite evidence that indicates a gas well must be located directly on an optimum lineament for maximum potential yield. However, it seems unlikely that fracture zones would be truly vertical to gas-well depths of 3,000 ft in the area studied and thus would diverge from the surface location. They (19) suggest instead that these lineaments, which usually are straight segments of streams at least 0.5 miles long, are the result of valley formation followed by stress-relief fracturing to shallow depth.

The geophysical traverses conducted across the five selected lineaments failed to detect any significant anomalous conditions that could be correlated with a lineament or related shallow subsurface fracture zones. Other more sophisticated geophysical techniques, however, might have been capable of detecting the subtle disturbances in bedrock that probably occurred as a result of sediment removal and valley rebound.

The resistivity soundings were conducted to test for contrasts in the subsurface conditions between lineaments and adjacent areas. The sounding curves alone provided little specific information and were difficult to interpret without supporting evidence from drill holes and outcrop. This points out the necessity for a detailed knowledge of geologic conditions when earth-resistivity data are being interpreted. It is suspected that more characteristic breaks in the sounding curves were not obtained because of the obscuring effects of pellicular water in the zone of aeration and the abundance of clay minerals. Despite these limitations in the use of earth resistivity in the areas studied, it can be concluded that no significant contrast in values was detected, since the range in the apparent resistivity of bedrock beneath all five lineaments was 30 to 350 ohm-m, and off-lineament it was 60 to 400 ohm-m. Similarly, depth to bedrock ranged from 3-1/2 to 20 ft on lineaments to 2-1/2 to 9 ft off lineaments, largely accounted for by the thicker valley fill where the lineaments tend to occur.

On the basis of the evidence examined in this study, the lineaments studied are classified as strictly surface phenomena resulting only from perceived linear images or alignments of tonal contrasts. The evidence further indicates that, as previously recognized, roof instability can be anticipated to a depth of at least 600 ft when mining beneath an erosional valley.

The assessment of only five lineaments out of innumerable others in the region was dictated by the usual constraints of time and available work force, and the results cannot be interpreted as being representative of what might be encountered at other sites. It does, however, demonstrate the difficulty of objectively assessing an intangible (impalpable) feature and the diverse parameters that must be considered when searching for the "ground truth" of a lineament in this region. Furthermore, it shows that working on assumptions, such as a correlation between lineaments and fracture or fault zones in bedrock, can lead to false conclusions. Each lineament should be assessed on its individual qualities without preconceived notions. Downs (20) used this approach to investigate a major lineament in the basalt terrane of Idaho. This lineament, approximately 14 miles long, had been mapped, but not confirmed, as a fault. It was investigated using the techniques of vegetation survey, soil profile, earth resistivity, geologic mapping, and trenching. Using these methods, Downs concluded that the lineament was a surface phenomenon only, and not associated with near-surface or deep faulting. Others, including Howard (21), discouraged the indiscriminate use of lineaments as a "black-box" tool and recommended the identification of lineament systems only by experienced personnel and ground-truthing by geomorphic or geophysical evidence.

While attempting an appraisal of LANDSAT lineaments in western Kentucky by geophysical methods, Jackson (22) cautioned as follows:

> "The degree of effectiveness is judgmental, a matter of interpretation; there has been little experience with these kinds of measurements for this purpose ..."

The use of lineament analysis in predicting coal mine roof instability is simply one of many geologic methods available to appropriately trained personnel. Under the proper circumstances, lineaments can provide useful information, but their significance in terms of subsurface conditions must first be established as firmly as possible. As with all technical endeavors, the procedures employed must be theoretically sound, rational, and guided by whatever factual information can be acquired. Even validated lineaments should be used only in conjunction with thoroughly analyzed drill-hole data or other subsurface information to develop a realistic assessment of potential mining conditions.

CONCLUSIONS

This investigation of LANDSAT lineaments at five selected sites in southwestern Pennsylvania leads to the following conclusions:

1. The lineaments are chiefly an expression of topography, some being a connection of discontinuous surface features that are fortuitously in alignment.

2. No anomalous shallow subsurface conditions could be detected in the vicinity of the surface trace of the lineaments using resistivity and VLF geophysical methods.

3. Test drilling at one site indicated a high probability of water inflow along mine entries being extended beneath a valley lineament. The anticipated water inflow and roof instability can be attributed to high lateral stresses and minor bedrock disturbance induced by valley rebound.

4. Until lineaments can be discriminated, screened, or selected on a more scientific basis, extreme caution should be exercised in using them alone as an indication of subsurface conditions.

REFERENCES

1. Grabau, W. E. Pixel Problems. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, MS, Misc. Paper M-76-9, May 1976, 39 pp.; available from BuMines, Pittsburgh Res. Cent., Pittsburgh, PA.

2. Wise, D. U. Linesmanship and the Practice of Linear Geo-art. Geol. Soc. Am. Bull., v. 93, No. 9, Sept. 1982, pp. 886-888.

3. Rabchevsky, G. A., U. P. Boegli, and J. Valdes. Landsat Geologic Reconnaissance of the Washington, D.C. Area Westward to the Appalachians. Photogramm. Eng. and Remote Sens., v. 45, No. AP5, May 1979, pp. 611-621.

4. Wier, C. E., and F. J. Wobber. Application of ERTS-1 Imagery to Fracture Related Mine Safety Hazards in the Coal

Mining Industry (Natl. Aeronaut. and Space Admin. contract NAS5-21795). IN Geol. Surv., Bloomington, IN, Jan. 1973, 43 pp.

5. Ferguson, H. F. Valley Stress Release in the Allegheny Plateau. Assoc. Eng. Geol. Bull., v. 4, No. 1, Jan. 1967, pp. 63-69.

6. _____. Geologic Observations and Geotechnical Effects of Valley Stress Relief in the Allegheny Plateaus. Pres. at Annu. Meet. ASCE, Water Resour. Eng. Meet., Los Angeles, CA, Jan. 22-27, 1974, 31 pp.; available from BuMines, Pittsburgh Res. Cent., Pittsburgh, PA.

7. Fenneman, N. M. Physiography of Eastern United States. McGraw-Hill, 1983, 534 pp.

8. Matheson, D. S., and S. Thomson. Geological Implications of Valley Rebound. Can. J. Earth Sci., v. 10, 1973, pp. 961-978.

9. Zaruba, Q. Bulged Valleys and Their Importance for Foundation of Dams. Paper in Transactions Sixth International Congress on Large Dams. Int. Comm. on Large Dams, World Conf. of Energy, N.Y., v. 4, 1958, pp. 509-515.

10. Wyrick, G. G., and J. W. Borchers. Hydrologic Effects of Stress-Relief Fracturing in an Appalachian Valley. U.S. Geol. Surv. Water-Supply Paper 2177, 1981, 51 pp.

11. Simmons, G. C. Stream Anticlines in Central Kentucky. Art. in Geological Survey Research 1966. U.S. Geol. Surv. Prof. Paper 550-D, 1966, pp. D9-D11.

12. Moebs, N. N., and R. M. Stateham. Geologic Factors in Coal Mine Roof Stability--A Progress Report. BuMines IC 8976, 1984, p. 27.

13. Enever, J., J. Shepherd, and J. Huntington. An Initial Mathematical Modelling Study of the Relationship Between Underground Working Conditions and Overlying Surface Topography With References to the Western Coalfields, N.S.W. CSIRO, Div. of Miner. Phys. Rep. 5, Mount Waverly, Victoria, Australia, 1978, 21 pp.

14. Shepherd, J., and W. Gale. Colliery Roof Stability and the Role of Geology: A Review. Aus. J. Coal Min. Tech. and Res., No. 1, 1982, pp. 47-67.

15. McCulloch, C. M., W. P. Diamond, B. M. Bench, and M. Duel. Selected Geologic Factors Affecting Mining of the Pittsburgh Coalbed. BuMines RI 8093, 1975, 72 pp.

16. Jansky, J. H., and R. F. Valane. Correlation of LANDSAT and Air Photo Linears With Roof Control Problems and Geologic Features. BuMines RI 8777, 1983, 22 pp.

17. Peng, S. S., and M. R. Haddad. A Study of "Linear" as a Tool for Predicting Underground Roof Instability. Dep. Min. Eng., WV Univ., Morgantown, WV, Tech. Rep. 80-7, Jan. 1981, 63 pp.

18. Jackson, P. L., H. L. Wagner, and R. A. Schuchman. Geologic Remote Sensing Over the Cottageville, West Virginia, Gas Field (U.S. Dep. Energy contract DE-AC05-77ET12137, Envir. Res. Inst.). Rep. DOE/ET/12137-T1, Feb. 1979, 96 pp.; available upon request from Claire H. Sink, Morgantown Energy Tech. Cent., Morgantown, WV.

19. Rauch, H. W., K. G. Narotzky, J. Ragan, and D. J. Newton. Effect of Short Lineaments on Gas Well Yield From Devonian Shales in Eastern Kentucky. Paper in Workshop on Remote Sensing/Lineament Applications for Energy Extraction (spons. by U.S. Dep. Energy, Morgantown, WV, Dec. 1-2, 1983). U.S. Dep. Energy, Morgantown, WV, 1983, pp. 632-672.

20. Downs, W. F. An Investigation of the Principal Lineament of the Idaho National Engineering Laboratory (U.S. Dep. Energy contract DE-AC07-76ID01570, EG & G Idaho, Inc.). Rep. EGG-NPR-6676, Oct. 1974, 401 pp.; available upon request from Carl Robertson, ID Oper. Office, Idaho Falls, ID.

21. Howard, J. F. Remote Sensing/Lineament Analysis Applications Workshop--A General Summary. Paper in Workshop on Remote Sensing/Lineament Applications for Energy Extraction (spons. by U.S. Dep. Energy, Morgantown, WV, Dec. 1-2, 1983). U.S. Dep. Energy, Morgantown, WV, 1983, pp. 7-10.

22. Jackson, P. L. Appraisal of LANDSAT Lineaments as Faults in Western Kentucky (U.S. Dep. Energy contract DEAC 2181 MC 16463, Dep. Geol. Sci., Univ. MI, Ann Arbor). Rep. 019277-C, Dec. 1982, 65 pp.

U.S. GOVERNMENT PRINTING OFFICE: 1987 605-017/60067

INT.-BU.OF MINES,PGH.,PA. 28523