Paper G 19

RELATIONSHIP OF ROOF FALLS IN UNDERGROUND COAL MINES TO FRACTURES MAPPED ON ERTS-1 IMAGERY

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ABSTRACT

ERTS imagery is of unique value for mapping of certain fractures that are not identifiable on aircraft imagery. Because color infrared and ERTS imagery complement each other both sources of data were used to map fractures in western Indiana and eastern Illinois. In the Kings Station Mine, Gibson County, Indiana, most roof falls reported had occurred in areas where mapped fractures were closely spaced and intersecting. Using this information as a basis for extrapolation, roof fall hazard maps were prepared for other mine sites. Various coal resources programs related to energy and environment also were conducted.

INTRODUCTION

The purpose of this project is to relate lineaments on imagery to fractures in bedrock, which are related to frequency and location of roof falls in underground coal mines. Hazardous areas of potentially frequent roof falls can then be predicted. The importance of such an application is emphasized by the current energy crisis.

Coal production today represents a vital national resource, which, with the shortage of petroleum products, has taken on increased importance. The need for greatly expanded coal production can most readily be fulfilled by increased surface, or strip, mining. However, expanding strip mine production is complicated by limited strippable reserves, the drastic disturbance of the landscape, and the national concern for the environment. Regardless of the pros and cons of this environmental conflict, it is certain that there will be an increase in underground coal mining operations.

Underground mining is generally more complicated than surface mining and the hazards to the miners are greater. About 75 percent of all coal mining fatalities occurred in underground mines. The U.S. Bureau of Mines identifies roof falls as the number one killer in coal mining. More than 40 percent of the fatalities in underground mining are the direct result of roof falls and wall collapse. Any method or technique which will provide greater safety to the miners is desirable and this is the prime objective of this ERTS experiment.

The area studied is the Indiana coal field that lies on the east side of the Eastern Interior Coal Basin (also called the Illinois Basin), the center of which is in southeastern Illinois. This is both a structural and a sedimentary basin and the coal bearing rocks in Indiana dip to the west and southwest toward the center of the basin at an average rate of 25 feet per mile. Coal deposits in Indiana occur in 25 counties in the southwestern part of the state and underlie an area of about 6,500 square miles (Figure 1).

There are eight major mineable coals interbedded with some 1500 feet of shale, sandstone, underclay, limestone, and at least 25 thin coals. The rocks are covered by a foot to more than 100 feet of glacial drift, loess, alluvium, and residual soil.

Coal reserves in Indiana are estimated to be slightly more than 33,000 million tons. Most of this will be mined by underground methods. About 2,000 million tons of this is considered recoverable by current strip mining methods, and 15,000 million tons by present underground mining methods.

OBJECTIVES

The primary objectives of this project are to:

1. evaluate the utility of ERTS and aircraft imagery for fracture mapping,
2. map fractures in the coal mining area in southwestern Indiana,
3. demonstrate the extent which fractures coincide with known roof falls, and
4. predict and delimit hazardous areas for underground mining.

Related objectives of the Indiana coal resources program include:

- Surface mined lands inventory and monitoring: A prototype national mined lands map series is being prepared in response to state and national (S425 and HR 5988) legislation.

- Subsidence in underground mined areas: Graphic products showing zones of subsidence that may be spatially related to fracture systems are being planned.

- Refuse bank and slurry pond inventory: Maps and tabulations to assist in setting a fair tax on coal produced; data to be used by the Indiana State Legislature.

- Energy related data acquisition: Various production statistics for surface mining will be made available to State offices in response to the energy crisis.

UTILITY OF ERTS DATA FOR FRACTURE MAPPING

Each spectral band of ERTS imagery was evaluated for use in fracture mapping. Bands 5 and 7 were of greatest value. Band 6 was largely redundant of band 7 (Table 1). Bands 6 and 7 also proved extremely useful for delineating strip mine land, evaluating the amount and kind of reclamation, and mapping the size and shape of water bodies.

TABLE 1. ERTS Imagery Evaluation

ERTS MSS spectral band	4	5	6	7	Color Composite
Fracture detection		XX	X	X	X
Mined land delineation			X	XX	X
Reclamation (vegetal cover)		X	X	XX	XX
Water bodies (size and shape)			X	XX	X
Water discoloration and turbidity	XX				XX
Physiographic features		X	X	X	XX

X = fair to good   XX = good to excellent

Independent analysis of imagery from repeated overpasses indicated that there is considerable seasonal effect on fracture information and that only with such in-depth analysis was it possible to extract full fracture (lineament) information. Prevailing atmospheric conditions (especially haze) at the time of overpass had a marked effect on information content and analysis capabilities.

Indiana is located in a temperate climatic zone that receives substantial rainfall and is exposed to a wide range of temperatures which cause the vegetative cover to undergo drastic seasonal changes. This is especially crucial in fracture detection in the Illinois Basin where many streams reflect structural control.

Although cloud cover and haze prevent a precise comparison of the time-lapse imagery, it is evident from consecutive ERTS band 5 imagery that tree-lined drainage systems which are relatively obscure in August, are most highly contrasted in October and diminish in contrast in November (Wier, et al., 1973). This is the result of a relatively uniform vegetal cover over the entire area consisting of cultivated crops in the flat uplands and natural vegetation along the stream courses. The die-back of the cultivated species occurs earlier than the natural growth along the streams; consequently, as the remaining green vegetation becomes dormant, the stream courses again become subdued. Imagery through 13 September is uniformly white indicating a high degree of infrared reflectance throughout the scene. By 1 October the farmlands appear darker, but the vegetation along the streams is still highly reflective. The situation becomes reversed by 6 November when tree-lined streams are darker in tone than the farmlands (Figure 2).

Table 2 summarizes the seasonal dependency of the various fracture manifestations observed in the investigation:

TABLE 2 Seasonal effects on lineament detection and mapping

Kind of lineament manifestation	Optimum season for detecting
Expressed by topography	Winter, when lowest sun angle has greatest shadowing effect.
Controlled by small streams and expressed by vegetational differences.	Fall and early spring, when a differential between natural and cultivated plant growth is at a maximum.
Expressed as linear changes in soil tones	Spring, after most fields are bare from plowing and before cultivated crops effectively cover the soil

TABLE 3. Suitability of ERTS data.

Characteristic	Fracture Mapping	Mapping Subsidence
Scale	Excellent	Fair
Resolution	Very Satisfactory	Unsatisfactory
Frequency	Good	-------
Timeliness	Good	Good
Optimum Bands	5 and 7	5 and 7
Optimum season	Fall	Fall

In summary, (Table 3) ERTS imagery is suitable for lineament studies in the Midwest. Scale and resolution are more than adequate and, with the normal amount of cloud cover, good imagery is available at least once each season of the year. In general, the imagery also is more than adequate for mapping surface subsidence except for resolution constraints. Most sinkholes or individual subsidence areas are too small to be detected because they cover less than an acre (about 4047 square meters).

RELATIONSHIP OF LINEAMENTS AND FRACTURES

It is hypothesized that fracture systems are reflected through the lithological column above coal seams and show up as lineaments on orbital and aerial imagery even in areas where thick unconsolidated overburden conceals the bedrock. Work done by Mollard (1957) and by Wobber (1967) have demonstrated that fractures can exert an influence at the surface and can be mapped as lineaments through as much as 250 feet of unconsolidated drift material. Mollard discussed the causes for fracture trace development in glaciated regions, and suggested that there are two basic mechanisms for fracture development:

1. An oscillatory or rhythmic mechanism caused by short-duration stresses in which the earth's crust behaves like an elastic material with a definite strength limit; and

2. A non-oscillatory deep-seated tectonic mechanism induced by long-duration stresses to which the earth's crust behaves like a plastic material with a yield point.

The first mechanism results mainly from earth tides and is most responsible for maintaining existing fracture traces through thick unconsolidated cover. The second mechanism is related to continental isostatic adjustment and is similar to the stress buildups associated with earthquakes, though of smaller magnitude. Once a break has been established within the glacial cover, the fracture trace is accentuated and deepened by long-continued leaching and settlement of the overburden which eventually causes slight surface depressions. These subtle depressions may in turn be accentuated by surface runoff. Differences in microrelief and soil permeability localize soil moisture and therefore accelerate vegetal growth. Both of these phenomenon may be expressed by variations in image tone.

Thus, the principal two kinds of phenomena to be observed includes (1) fracture lineaments at or near the surface, and (2) fracture traces, i.e., bedrock fracture lineaments identified through an unconsolidated overburden at the surface.

A lineament map was prepared for southwestern Indiana (Figure 3). The lineaments were mapped on both ERTS imagery and color infrared aerial photography (Scale of 1:120,000). In general, orientation of lineaments from the two sources agree but are not identical. The aircraft and ERTS imagery complement each other in that fractures were mapped on each that were not found on the other. The most common set of lineaments trend northeast-southwest and northwest-southeast. Some areas show a paucity of fractures and others show close-spaced and intersecting fractures.

Ground truth, that is, measurement of fracture orientation on the ground, is not easily done. In the coal-bearing rocks bedrock is effectively concealed by glacial drift, loess and wind-blown sand, alluvial deposits, and thick residual soil. However, directional measurements were made in roof rock of coal beds in the highwall of strip mines, roofs of a few underground mines, and road cuts. In general, the directions matched closely with the lineaments mapped on the imagery.

ROOF FALLS AND MINE SUBSIDENCE

A roof fall results when the roof rock in an area of the mine falls into the opening left when the coal is removed. Massive roof falls fill the mine room or entry with a pile of rock rubble and leave a pyramid shaped opening extending upward as much as 30 feet. Anything that contributes to weakening the supporting strength of roof rock will increase the likelihood of roof falls. Some contributors are poor mining practices, swelling due to water, lithologic irregularities, and fractures.

A study by Wier (1970) showed that in the Thunderbird Mine, an underground coal mine in Sullivan County, Indiana, fractures in the roof rock did contribute to roof falls. Unfortunately additional costs of maintaining a safe roof and cleaning up roof falls caused the mine to close before the present study got underway. Thus mapping additional areas was not possible.

Surface evidence is available in some areas to show where roof falls have occurred in mines that have been abandoned and are no longer accessible. These are the sinkholes and subsidence areas. However, not all roof falls cause subsidence at the surface. Subsidence due to underground mining has long been recognized in the Indiana coal field, especially over many of the old, relatively shallow mines. In many areas, mine subsidence has created serious environmental and engineering problems as it has caused road beds to shift, utility lines to break, building foundations to collapse, and farmland to become swamps.

Subsidence in an area east of Sullivan, Sullivan County, Indiana, was noted on the 1:30,000 scale color infrared photography. Extensive underground mining has occurred in the Sullivan area during the first half of this century, but nearly all mining had ceased operation by 1950. Coal was extracted mainly from Coal V, (Figure 4) which in this area is about 200 feet beneath the surface. A lesser amount of mining was done in Coal VI which occurs about 70 feet higher in the stratigraphic section.

The black and white infrared photography (Figure 5) was taken in March 1973, (NASA C-130 underflight) after considerable rainfall and when most surface depressions were filled with water. These depressions, predominantly on the floodplain of Busseron Creek, reflect the room and pillar configuration conventionally used in underground coal mining. The area along Busseron Creek appears to be unusually susceptible to subsidence. It is a broad low-lying valley filled to a substantial depth with unconsolidated sand, silt, and clay which hold moisture longer than the surrounding uplands. In this area, the downward percolation of water through the overlying bedrock, possibly along zones of fracturing has caused the mine supports to weaken and collapse with subsequent subsidence which extends to the surface. That the presence of the floodplain is a significant factor in the occurrence of subsidence is indicated by the minimal subsidence which occurs in the better drained undermined uplands.

FRACTURES IN TEST SITES

A primary objective of this investigation is to relate fractures to roof fall problems in underground mines. Thus four underground sites and one strip mine site (Figure 1) are being used for detailed investigations of the relationship between fracture patterns and mine safety. Fracture analyses have been completed for each mine site. The test mine sites are:

- Kings Station Mine, Gibson County: Until its closure in late 1973 this mine was the largest underground coal mining operation in Indiana. Glacial cover is thin, being generally less than 50 feet thick. Roof falls occurred in scattered areas in the mine.

- Thunderbird Mine, Sullivan County: This mine experienced extensive roof fall problems;many associated with roof rock fractures. As a result, the mine was closed in 1972.

- Mecca Mine, Parke County: This site was selected because of the topographic relief and apparent fracture control on the drainage systems.

- Keensburg Mine, Gibson County, Indiana and Wabash County, Illinois: This mine is being developed with mining to commence at the 800-foot level. Fracture data in this area can be of substantial value to this operation, and possibly serve to reduce roof fall hazards.

- Lynnville Strip Mine, Warrick County: Four large strip mines are operating in this area (Lynnville East, Lynnville Main, Lynnville West, and Log Creek Mines). Fracture analysis in this test site will be applied to blowouts and wall failures associated with strip mining.

Detailed information on the Kings, Thunderbird and Mecca Mines are discussed herein.

Kings Station Mine

A preliminary fracture analysis of the Kings Station Mine was done in late 1972 and refined in early 1973. A serious roof fall in November 1972 claimed the life of a miner and injured three others. The investigators visited the mine in April 1973 and discussed the various types of roof fall problems with the mine operators. Three of the four main areas of concentrated and intersecting fractures were also areas of frequent roof falls. The predominant fracture directions mapped from ERTS and high altitude color infrared photography are N 40° to 60° E and N 20° to 60° W (Figure 6). These correlate well with joints measured in the field which occur in two dominant directions of N 20 to 30° E, N 70 to 80° E, and N 40 to 60° W.

Thunderbird Mine

The Thunderbird Mine was plagued by roof fall problems throughout most of its operating period and the mine closed in September 1972 because of the increased expense associated with the high incidence of roof falls. Wier (1970) gathered considerable data on fractures, roof falls, and clay squeezes before the mine closed.

A summary of the directions of the fractures measured in the Thunderbird Mine are shown in Figure 6. Major fractures associated with clay squeezing in the eastern part of the mine were measured in Coal VI with trends averaging N 40° E. Several smaller fractures were measured with trends in a northwesterly direction. Dominant fracture directions of N 40° to 50° E and N 70° to 80° W later were measured in Coal VI in the western part of the mine.

Surface fracture traces have been compiled from ERTS and aircraft imagery and summarized (Figure 6). A total of 119 fracture traces were mapped and the rose diagrams indicate two predominant directions -- a major set of fractures oriented at N 40° to 50° E and a subordinant set at N 30° to 50° W. This correlates very closely with the underground fracture data.

Mecca Mine

The Mecca Mine lies in an area of relatively rugged terrain in which the fracture-controlled drainage system is deeply incised and is easily recognized on both ERTS imagery and high altitude photography (Figure 7). The test site is actually a series of closely-spaced mine shafts which have been abandoned since the early 1900's; however, large reserves of coal remain in the area, and it is reasonable to assume that additional mining will take place in the future.

Coverage of the Mecca area includes ERTS images enlarged to 1:250,000 scale, and color infrared photography at 1:120,000 and 1:30,000 scale. A detailed fracture analysis of the area was conducted using these various scales of imagery. Ground truth data is unavailable in the Mecca area at this time, however, general agreement exists between the primary fracture directions mapped on the imagery and the available ground data outside the test site. However, analysis of the various scales and types of imagery within the Mecca area produced differing sets of fracture traces. Primary directions for the three types of imagery are:

COLOR IR 1:30,000	COLOR IR 1:120,000	ERTS
N 30-40° E	N 30-40° E	N 20-30° E
N 60-70° W	N 30-40° W	N 70-80° W
N 80-90° E	N 80-90° E	N 60-70° E

The primary directions of fracture traces were consistent for both the 1:30,000 and 1:120,000 scale color infrared photography (Figure 8). However, the fracture directions mapped from the ERTS imagery differ from those mapped on aircraft imagery by ten to twenty degrees. These differences are being investigated.

HAZARDS PREDICTION MAPS

Various criteria were examined and tested for the preparation of a hazards classification map. Many lineaments mapped, particularly on ERTS imagery are believed to be zones of fractures rather than a single joint. Although the fracture represents a zone of bedrock weakness, fracture junctions are particularly significant and these were rated as the highest hazard areas. The zone of influence around a junction is conjectural, and an arbitrary value of 200 foot radius was selected as realistic figure for the scale maps being produced.

Verification of the validity of the hazards maps by underground mine data is limited by the lack of mine records. At the Kings Station Mine there was good correlation with predicted hazards zones and known roof fall areas (Figure 9).

The Thunderbird Mine closed due to excessive roof fall problems just before work was initiated on this experiment. Thus underground data is limited. Mapped fractures (from ERTS and aircraft imagery) show good trend correlation with existing underground mine data, however, predicted hazard zones do not show the same degree of coincidence as that of the Kings Station Mine. This is in part due to the lower quantity of detected fractures. Disturbed surficial material over and near the mine site reduces the ease of fracture identification.

OTHER COAL RESOURCES PROGRAMS

A prototype of a National Mined Land Inventory Map series has been prepared in Indiana and distributed to interested members of Congress and various State offices. A coal refuse bank (gob pile) inventory is being completed to aid the Indiana State Legislature in drafting laws and to establish tax requirements on coal production. This will be completed in January 1974 in time for the Spring legislative session. Some work has been done in utilizing ERTS imagery for evaluating the amount of revegetation in a variety of reclamation practices.

Maintaining high levels of safe underground mine production and protecting the environment following surface mining operations are increasingly important elements with the impact of the energy crisis. The ERTS program has provided opportunities to demonstrate the application of satellite imagery and integrated high altitude aerial platforms to address coal resources problems in Indiana. ERTS can produce equally important benefits to other coal producing states, as well.

CONCLUSIONS

Most lineaments mapped on ERTS imagery and aircraft color infrared photography do represent bedrock fractures. After mapping fractures a conference with mine officials indicated that three areas of dense and intersecting fractures in the Kings Station Mine had roof fall problems while mining. Hazardous areas can be predicted from ERTS and aircraft photography, but further work must be done to evaluate the degree of accuracy.

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Wier, C. E., F. J. Wobber, O. R. Russell and R. V. Amato, Fracture mapping and strip mine inventory in the Midwest by using ERTS-1 imagery, in Symposium of significant results obtained from the Earth Resources Technology Satellite-1, NASA, V. 1, 1973.

Wobber, F. J., Fracture Traces in Illinois. Photogrammetric Engineering V.33, May, 1967, pp. 499-506.

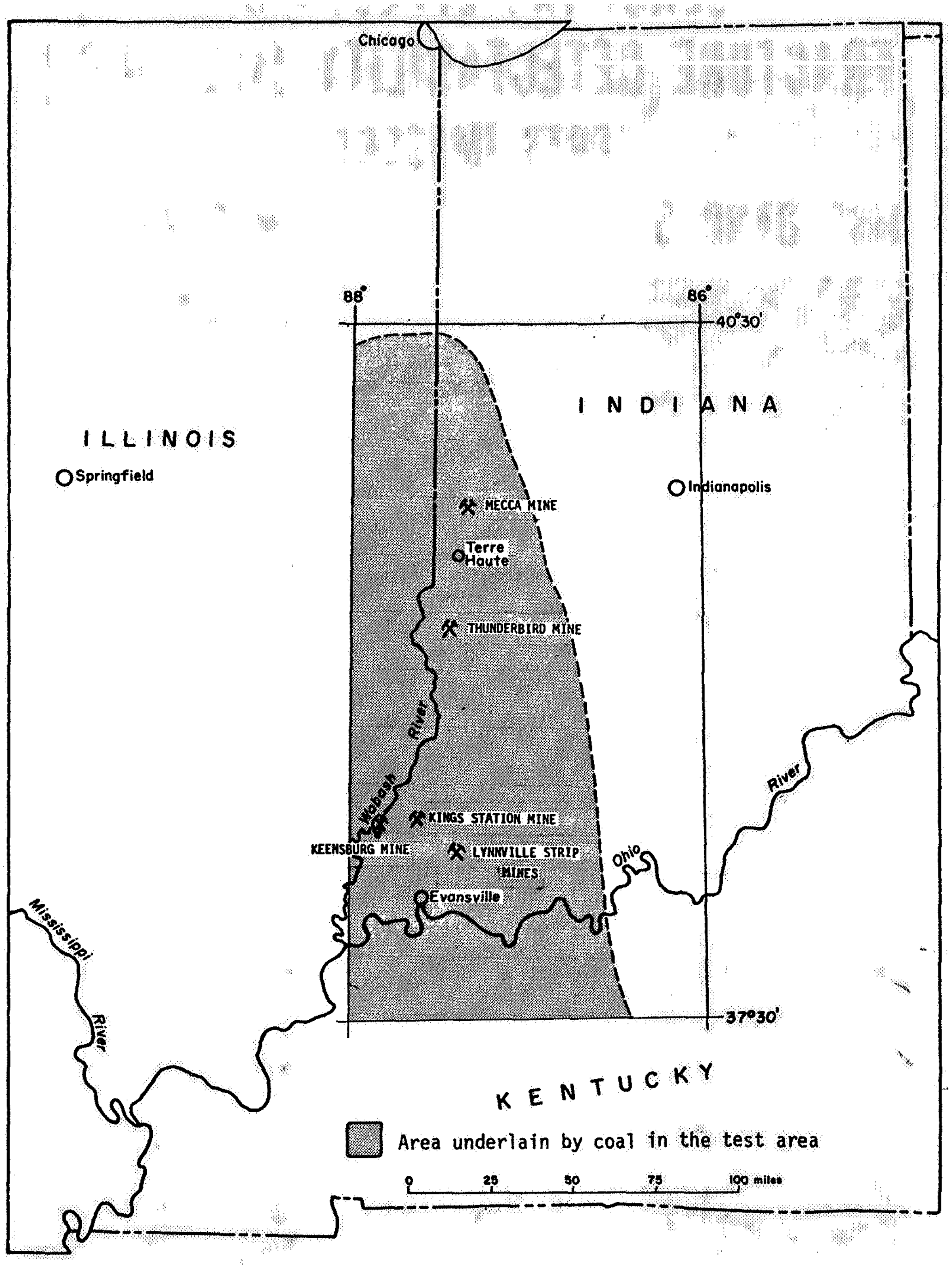


Figure 1. Map of Indiana and parts of Illinois and Kentucky showing the boundaries of the test area and the location of the individual test mine sites.

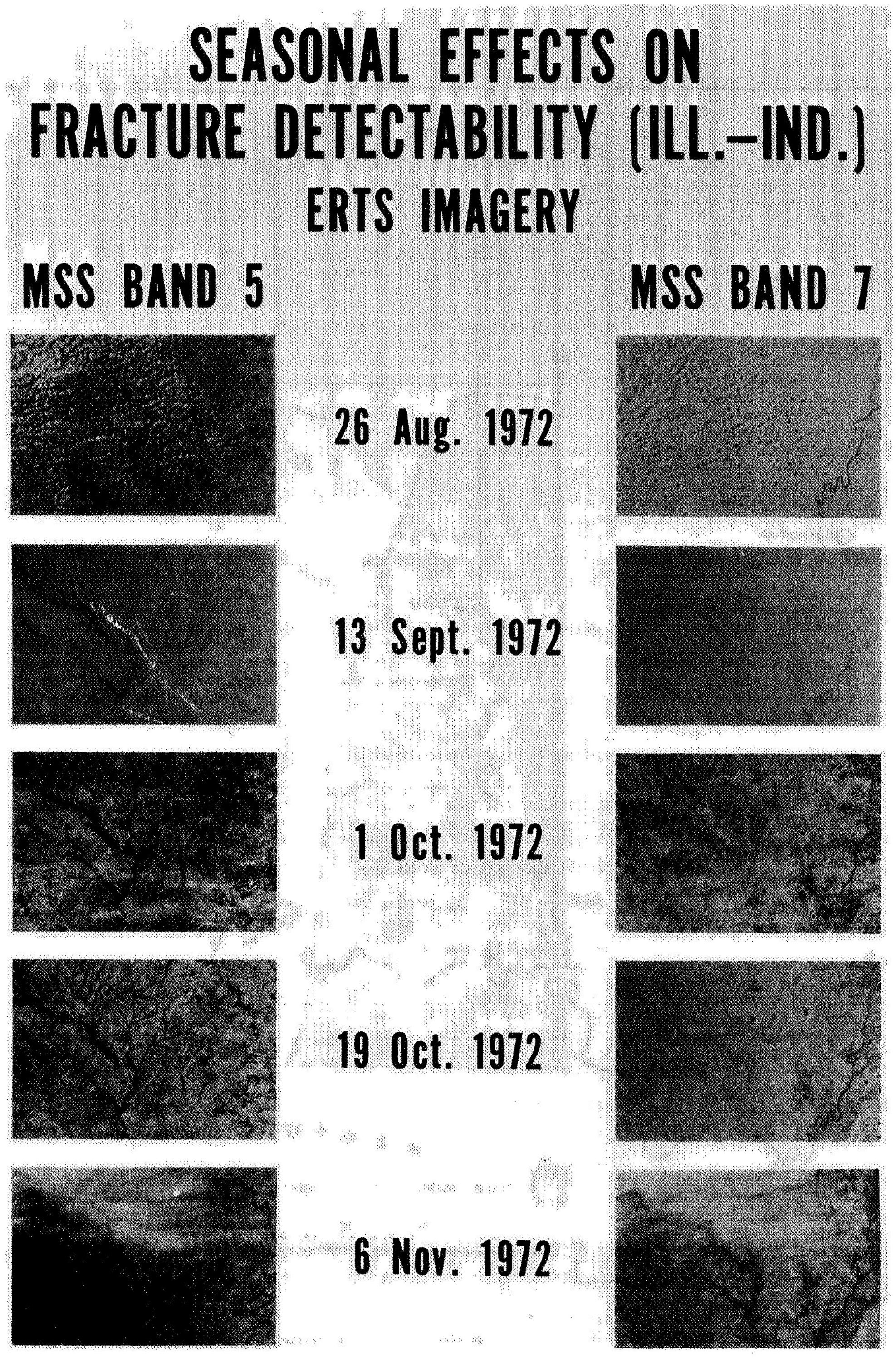


Figure 2. A series of ERTS-1 images of the same area (Illinois-Indiana) demonstrating the seasonal effects on fracture detectability in the temperate climate of the midwest.

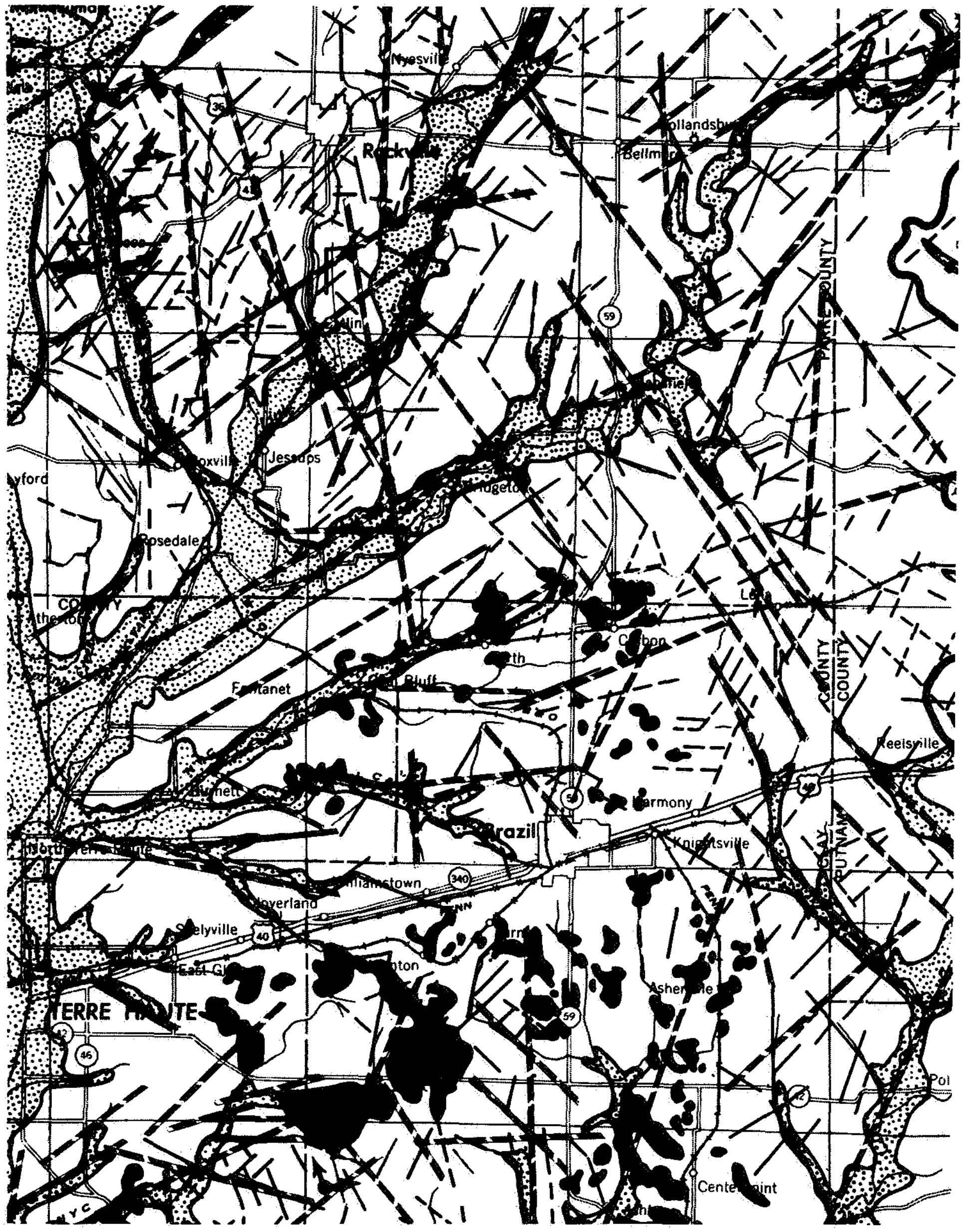
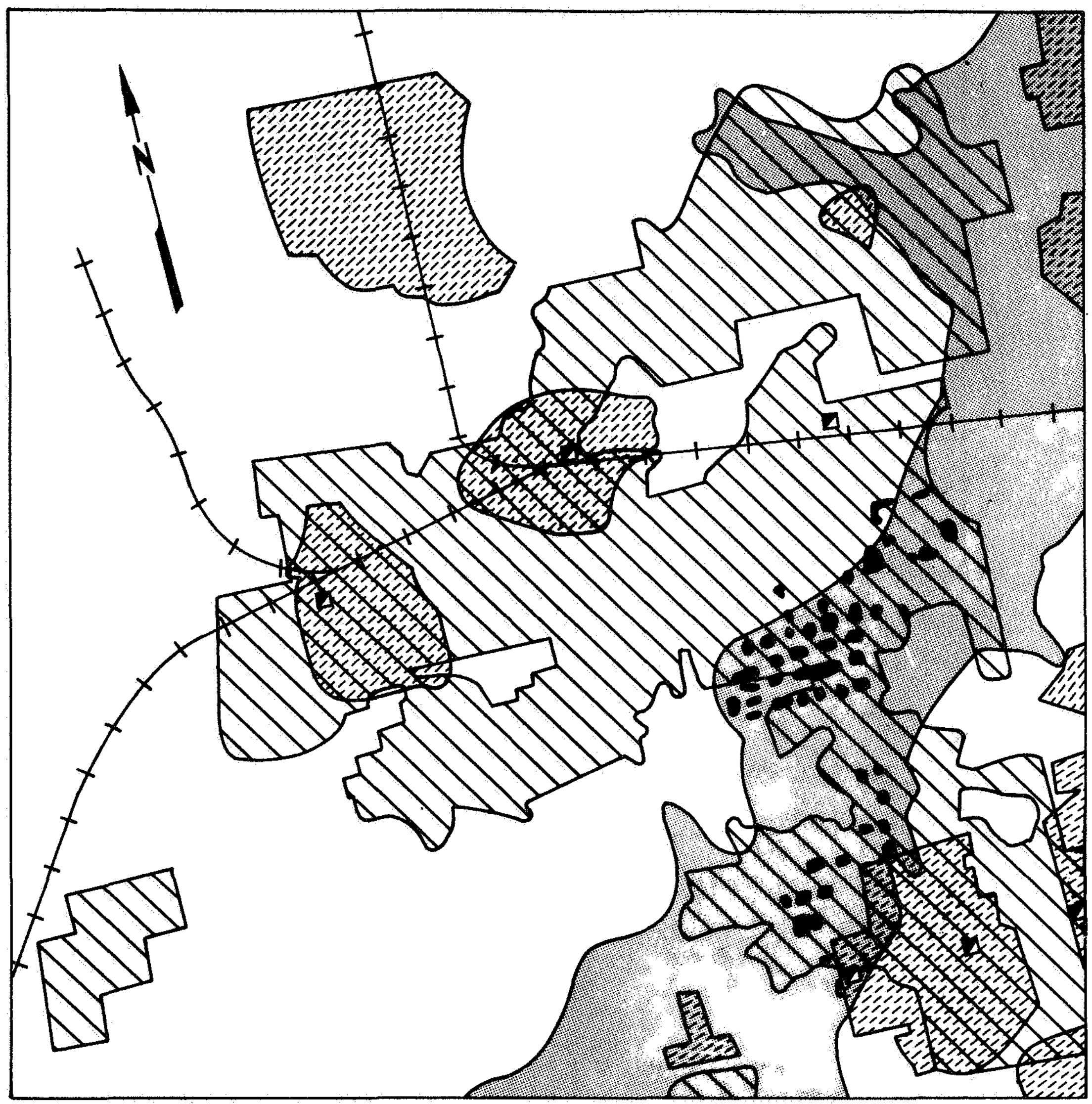


Figure 3. This portion of the Indianapolis 1x2° Quadrangle is representative of the fracture and lineament data derived from ERTS and aircraft imagery. The heavy diagonally dashed lines represent interpreted lineaments from ERTS imagery and the thin lines from small-scale aerial photography. Black areas are coal strip mines. Maps of this type have been prepared for the entire Indiana coal field.



Approximate Scale 1:40,000

FLOODPLAIN OF BUSSERON CREEK

UNDERGROUND MINED AREA OF COAL V APPROXIMATELY 200 FEET DEEP

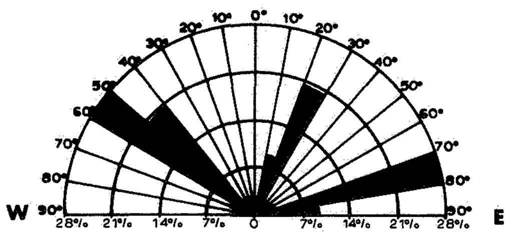
UNDERGROUND MINED AREA OF COAL VI APPROXIMATELY 100 FEET DEEP

AREA OF SUBSIDENCE

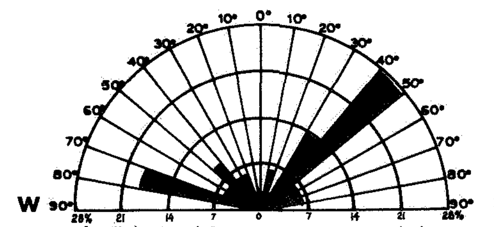
SHAFT MINE

Figure 4. Map of a part of Sullivan County, Indiana, showing area from which coal has been mined by underground methods, and area of subsidence derived from analysis of image in Figure 5.

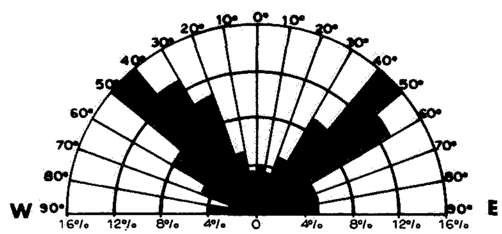
Figure 5. Black and white infrared image of part of Sullivan County, Indiana, showing extensive surface subsidence along Busseron Creek caused by underground coal mining.



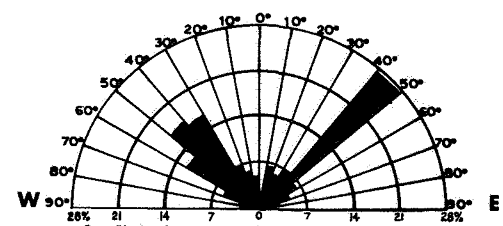
Underground fracture measurements made in the Kings Station Mine.



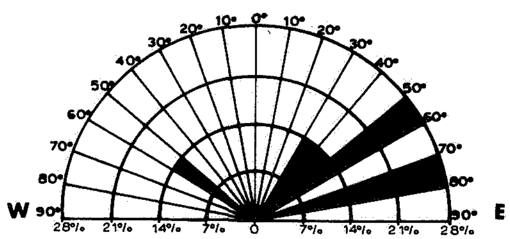
A. Underground fracture measurements made in the Thunderbird Mine in Coal Seam VI



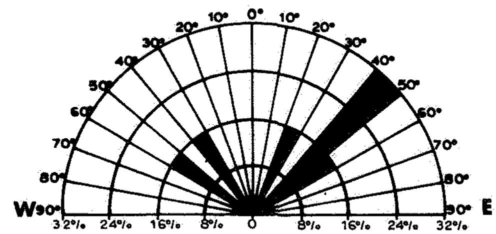
Fracture traces measured from large scale color infrared imagery over the Kings Station Mine.



B. Photo interpreted fracture trace measurements made in the mine area from 1:120,000 color infrared photography.



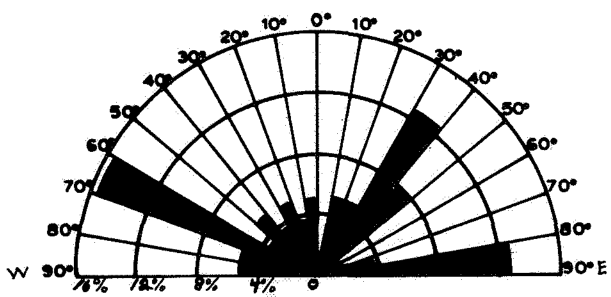
Fracture-lineaments measured from 1:250,000 scale ERTS-1 imagery over the Kings Station Mine.



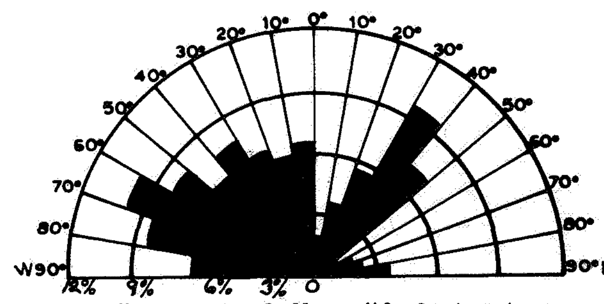
C Fracture-lineaments measured from ERTS-1 imagery over the Thunderbird Mine.

FIGURE 6. ROSE DIAGRAMS OF FRACTURE MEASUREMENTS FROM THE KINGS STATION MINE AREA, GIBSON COUNTY (LEFT COLUMN) AND THE THUNDERBIRD MINE AREA, SULLIVAN COUNTY, INDIANA (RIGHT COLUMN).

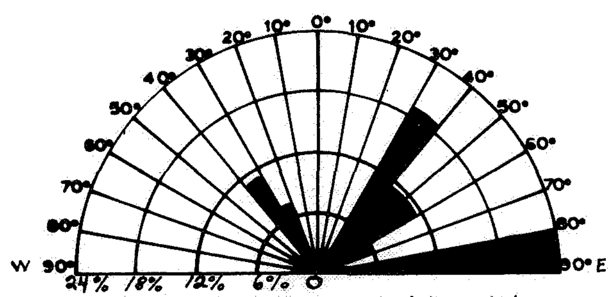
Figure 7. Black and white rendition of a color infrared image of the Mecca Mine area, Parke County, Indiana, showing area of underground mining and fractures mapped.



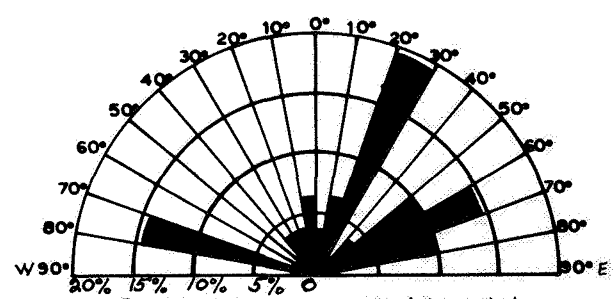
A. Measurements of fracture traces greater than 1,250 feet in length interpreted from 1:30,000 scale color infrared photography



B. Measurements of all possible fracture traces that could be interpreted from 1:30,000 scale color infrared photography



C. Fracture trace measurements interpreted from 1:120,000 scale color infrared photography



D. Fracture trace measurements interpreted from a 1:250,000 scale enlargement of ERTS-1 image 1177-15593-7

Figure 8. Rose diagrams of fracture measurements in the Mecca Mine area, Parke County, Indiana.

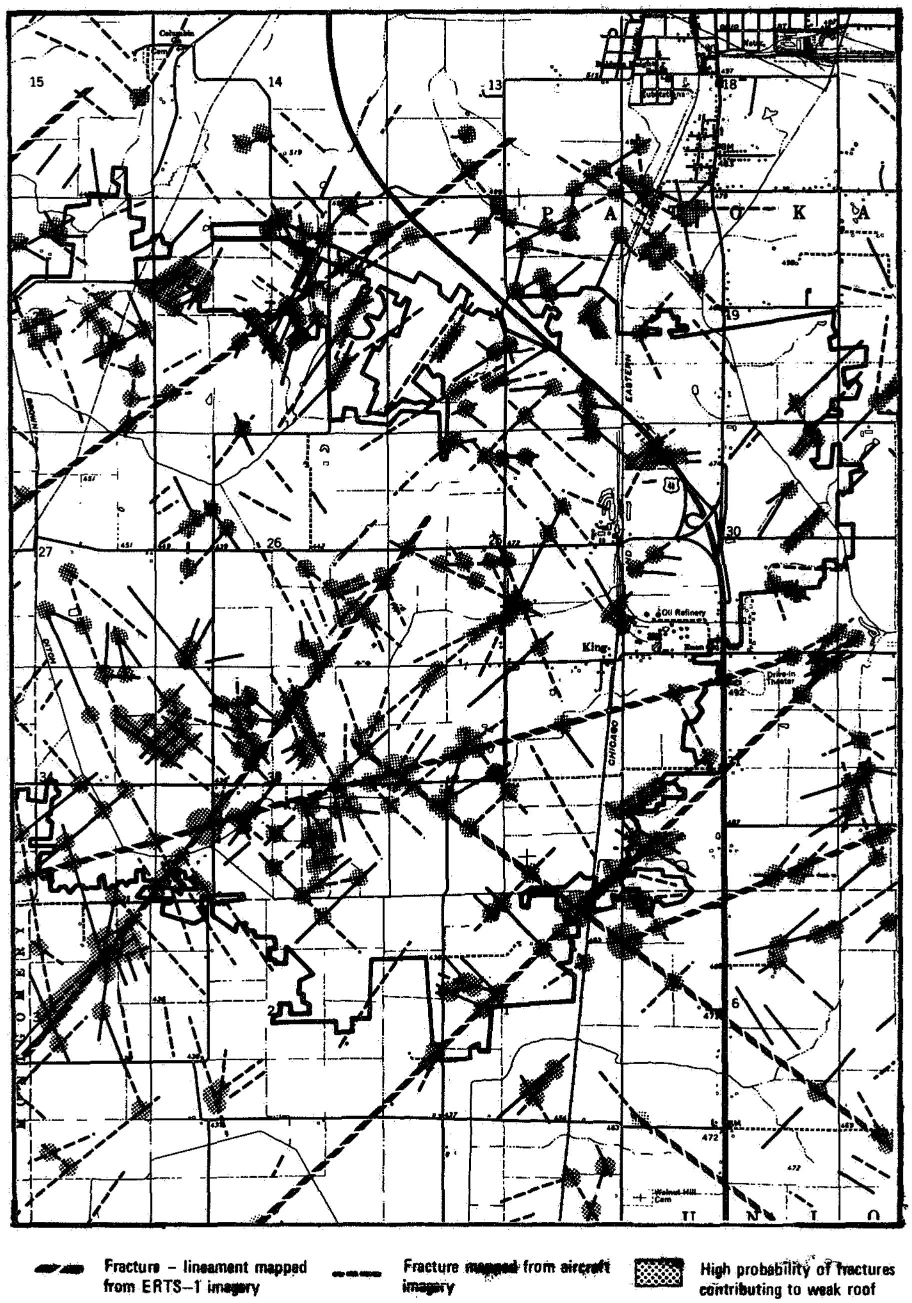


Figure 9. A portion of the King Station Mine Hazards Prediction map showing the distribution and concentration of fractures and lineaments mapped from ERTS and aircraft imagery. Stippled areas represent predicted zones of high probability of roof fall occurrance.