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Paper E 1

FRACTURE MAPPING AND STRIP MINE INVENTORY IN THE MIDWEST BY USING ERTS-1 IMAGERY

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ABSTRACT

Analysis of the ERTS-1 imagery and high-altitude infrared photography indicates that useful fracture data can be obtained in Indiana and Illinois despite a glacial till cover. ERTS MSS bands 5 and 7 have proven most useful for fracture mapping in coal-bearing rocks in this region. Preliminary results suggest a reasonable correlation between image-detected fractures and mine roof-fall accidents. Information related to surface mined land, such as disturbed area, water bodies, and kind of reclamation, has been derived from the analysis of ERTS imagery.

1. INTRODUCTION

Mine safety in underground coal mining has received considerable public attention because roof falls in underground mines often result in loss of life. Roof falls and rock bursts may account for only one or two fatalities in any underground mine over a period of several years, but the occurrence rate is much higher than accidents resulting from other causes. Ground truth studies in the Thunderbird Mine, Sullivan County, Indiana, showed that roof failure in the Coal VI underground workings was closely associated with zones of weakness produced by the combination of mining activity and the natural fractures in the roof rock above the coal being mined. In most cases, the mine operator cannot predict the presence and magnitude of the fractures in advance, and it is only when mining excavates such an area and roof-fall problems are caused that these fractures can be mapped. Meanwhile it is extremely hazardous to the miner and becomes expensive to the operator who must increase the required roof support and, perhaps, adjust direction of the mining entries or make other major modifications to the standard mining plan. Although the coal companies commonly do extensive core drilling before putting in a large underground mine, this drilling program does not normally record the presence of fractures because the fracture zone is usually a few inches or less in thickness. Even if the core intersects a fracture zone one could not determine the orientation of the fracture unless the

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10th and Dakota Avenue
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drilling method included acquiring expensive oriented cores. The authors maintain in this experiment that useful fracture data can be acquired from aircraft and ERTS-1 remote sensing records. Such imagery has not been routinely used by the mining industry for fracture mapping in coal-producing areas. Equally significant, the discrimination of fractures in areas with thick overburden has not been widely investigated. The opportunities provided by repetitive aerial and/or orbital coverage to detect subtle lineaments that are indicative of deeply buried bedrock fractures is just now being explored.

2. FRACTURE PATTERNS FROM ERTS IMAGERY

NASA's ERTS-1 program provided an opportunity to utilize repetitive synoptic coverage to develop fracture mapping techniques in areas where bedrock is obscured by thick overburden of unconsolidated deposits and to rapidly acquire such data in an area of active surface and underground coal mining. An ERTS-1 image (1070-16050-5) flown October 1, 1972, and located near the center of the Eastern Interior Coal Region (Mattoon, Illinois, to Vincennes, Indiana) shows sharply pronounced fracture trends. A predominant trend of about N 30° E is most obvious near the center of the picture (Figure 1). Fracture sets extending N 60° W also are obvious. This image on MSS band 5 (red) was acquired at the critical time interval when farmland vegetation was largely dead or plowed under and the natural vegetation along the drainage systems was still vigorous. Dead agricultural vegetation images lighter in tone than the green (dark toned) vegetation along the natural drainage systems. The contrast between the two environments reveals the structure control exerted upon the drainage systems by fractures in the underlying bedrock even though in places it is buried by more than 100 feet of glacial drift. The image immediately to the north of this area (1088-16050-5, 19 October 1972) in the vicinity of Terre Haute, Indiana, and Danville, Illinois, also shows striking fracture trends developed on the drainage pattern. Here the predominant direction of the fractures is N 10°-15° W with a secondary trend of N 70°-80° E.

The value of the repetitive coverage of ERTS imagery is obvious when one compares the imagery of the same area flown on other dates. The fracture patterns so well developed on Figure 1 are difficult to identify and trace on images of the same area acquired on 16 August (1034-16050-5), 13 September (1052-16050-5), and 6 November, 1972 (1106-16054-5).

Thus, this ERTS-1 imagery in band 5 shows a flat glacial drift-covered area which is densely cultivated except for areas that are dissected by incise drainage systems. Two major vegetal categories occur in the area: 1) short-lived cultivated crops and 2) indigenous tree and bush cover along the stream. The cultivated crops mature and die or become dormant early in the fall, whereas the other vegetation remains green and vigorous for a somewhat longer period. Reflective differences between the deadand live vegetation is pronounced at this time period. ERTS images acquired during the short duration transitional period emphasize drainage patterns which in many places are structurally controlled as evidenced by pronounced linearity or in echelon patterns.

Another aspect of seasonal influences on fracture detection is illustrated in imagery acquired on 5 November 1972 in southwestern Indiana (1105-15595-7). Indiana lies in a temperate climatic zone that receives substantial rainfall and is vegetation-covered most of the year. Band 7 (near infrared) imagery acquired during the growing season displays relatively uniform vegetative tones, and shows few surface details except for water courses and water bodies. When the vegetation has died back in early winter, band 7 provides greater detail and more nearly resembles band 5 imagery. Figure 2 reveals a lack of highly reflective vegetation which, when combined with the low sun angle of winter, emphasizes the intricate fracture pattern in limestone upland areas. The lineaments shown on this imagery reflect both straight sections of upland stream patterns and long narrow ridges. Most of the lineaments shown are in upland areas and the bedrock is not covered by glacial drift but from one to 30 feet of residual limestone soil. The preferred orientation direction of N 40°-50° E and N 60° W are also demonstrated in ground truth measurements of limestone jointing in road cuts and quarries.

Many caves have been mapped in the limestone area to the southwest of Bloomington and extending southward into Kentucky. Some of these cave maps show an elongated development along fractures that closely parallel the direction and the position of lineaments noted on Figure 2. Perhaps the best known of these caves is Wyandotte Cave that is just north of the Ohio River in Crawford County and extends for nearly two miles in a N 40° E direction. Blue Springs Cave, in southern Lawrence County, extends about two miles in a N 55° W direction.

A trace of the Mt. Carmel Fault also is shown where it cuts through the Borden siltstones to the east of Bloomington. Although the position of the Mt. Carmel Fault as shown on the imagery already had been mapped in the field, the imagery shows some indication of additional fault fractures. These are being checked in the field to ascertain whether they are related to the Mt. Carmel Fault or to the regional fracture system.

3. PHYSIOGRAPHIC UNITS FROM ERTS IMAGERY

The physiographic provinces of southwestern Indiana are readily identifiable on Figure 2. The Norman Upland, extending southward between Columbus and Bloomington, is a highly dissected and largely uncultivated area developed on the Borden siltstone. The lighter textured area extending southerly through Bloomington is predominantly pasture land and cultivated fields of the Mitchell Plain that is developed on Middle Mississippian limestones. The darker toned area to the southwest of Bloomington and extending in a southerly direction is the dissected and largely uncultivated Crawford Upland that is developed on Upper Mississippian beds of alternating shale, sandstone, and limestone. To the west the broad area occupying about the western half of the imagery is the Wabash Lowland and is developed on Pennsylvanian rocks. Except for the extreme southeastern part, the Wabash Lowland is covered with a thick mantle of unconsolidated material. More than 100 feet of glacial outwash sands and gravels covered by Recent alluvium occupy the major valleys. Flat lowland areas are covered with lacustrine deposits. The upland areas are covered by several tens of feet of glacial till, overlain by a thin veneer of loess. It is in the area of the Wabash Lowland where the majority of the strip mining and underground mining of coal has occurred.

4. FRACTURE PATTERNS FROM AIRCRAFT PHOTOGRAPHY

Fracture information also is being acquired from color infrared photography at the scale of 1:120,000. This small-scale photography was flown in May, June, and August, 1971, to study the corn blight. The May flight proved of greatest utility because vegetative cover is limited and subtle soil variations indicative of buried bedrock fractures can be seen. Vegetative growth present at the time of June andAugust photographies seriously handicapped fracture analysis. This high altitude color infrared photography provides an area overview at a scale intermediate between ERTS imagery and the low altitude aircraft photography (1:20,000) that is generally available in the state. Many more sets of fractures can be delineated on this small-scale photography than has been shown on available ERTS imagery. Although fracture patterns in the exact same position on each set of imagery are not always noted, it appears that additional ERTS imagery is received and interpreted there will be a good general correlation in direction and density. Where lineaments were indicated on the high altitude color infrared photography which intercepts bedrock exposures in active and abandoned strip mines, the measured direction of fractures in the mines shows a close correspondence to the direction indicated on the photography (Figure 3B).

Studies of the relative abundance of mapped fractures in various parts of southwestern Indiana show that there are considerably more fractures that can be detected in the glaciated area than in the nonglaciated area of the coal fields. Furthermore, the area covered by the younger Wisconsinan drift to the north exhibits a greater number of fracture traces than does the area to the south which is covered only by the older Illinoian drift. This relationship has also been noted on the black and white aerial photography at the scale of 1:20,000.

Some color infrared photography at 1:20,000 scale was available. It was studied to detect short (probably secondary) fracture systems. Fracture analysis using this photography emphasized the utility of an integrated multilevel multiband approach to fracture detection, that is, lineaments identifiable using 1:20,000 scale photography are not always detectable on the 1:120,000 scale photography. Conversely, lineaments found on the small-scale photography often have a too subtle signature to be detected using large-scale photography. In general, orientation of the lineaments and relative densities are similar at the two scales.

While this study was underway one coal miner was killed and three were injured in a roof fall at the King Station Mine south of Princeton, Indiana (Nov. 8, 1972). This mine which uses the conventional room and pillar system of underground mining has been in operation for nearly 50 years. Roof-fall problems and some subsidence at the surface have occurred intermittently in the northwestern part of the mine during the past 10 years of operation. The 1:120,000 color infrared photography of this area shows several prominent linear patterns expressed as soil (tonal) anomalies or straight stream segments. Intersecting fracture systems in the vicinity of the accident site are of particular interest as they represent probable zones of structural weakness. A preliminary analysis of the fracture data at the King Station Mine shows the major fracture trends as N 7° W and N 50° E (Figure 3A). The greatest fracture density as shown on the photography is approximately in the area of the greatest concentration of roof falls. Additional ground truth information must be obtained underground in the mine in order to better confirm these findings.

5. MINED LAND INVENTORY FROM ERTS IMAGERY

Although the main purpose of this experiment is to relate lineaments on the imagery to fractures in the roof rock over coal beds, it was obvious that one could do a creditable job in plotting the area of surface mining (strip mining) of coal (Figure 4). Seasonal conditions influence the amount of information which can be obtained; for instance, band 7 acquired during the growing season in Indiana sharply contrasts the nearly bare disturbed mine lands from the nearby undisturbed and vegetated terrane. Older strip mine areas that were ungraded and planted in trees are, in general, easy to identify but areas that have been leveled and converted to pasture land and row crops are more difficult to outline. After an inventory of a mining area has been made, the new surface mining area can readily be recognized and outlined. The repetitive ERTS coverage would provide an excellent monitoring system to map the new strip mining area on a three-months or a year basis. Isolated strip mine areas containing more than ten acres can be easily identified and mapped, but even with high contrast conditions probably isolated areas of less than five acres cannot be identified and mapped. The mined land inventory map prepared (Figure 4) was carefully checked with the strip mine maps obtained from the individual coal companies. The mapped area from ERTS imagery (1033-15591-7 and 1033-15594-7) matched closely with the ground truth mapping.

6. CONCLUSIONS

The authors conclude that repetitive ERTS-1 imagery is a useful tool for mapping regional fractures in the areas covered by thick glacial drift and for monitoring recent mined lands in coal producing areas. Seasonally dependent MSS bands 5 and 7 imagery is most useful for fracture detection. There appears to be good correlation between fractures mapped on high altitude color infrared photographs and fractures measured in the field. The likelihood of applying ERTS-derived fracture data to improve coal mine safety in the entire Eastern Interior Coal Region appears practical from the current studies being conducted in Indiana. Band 7 appears to be best for regional mined land inventories. Mapping changes of only a few acres in the configuration of large surface mined lands appear realistic with comparative analysis of time-lapse imagery.

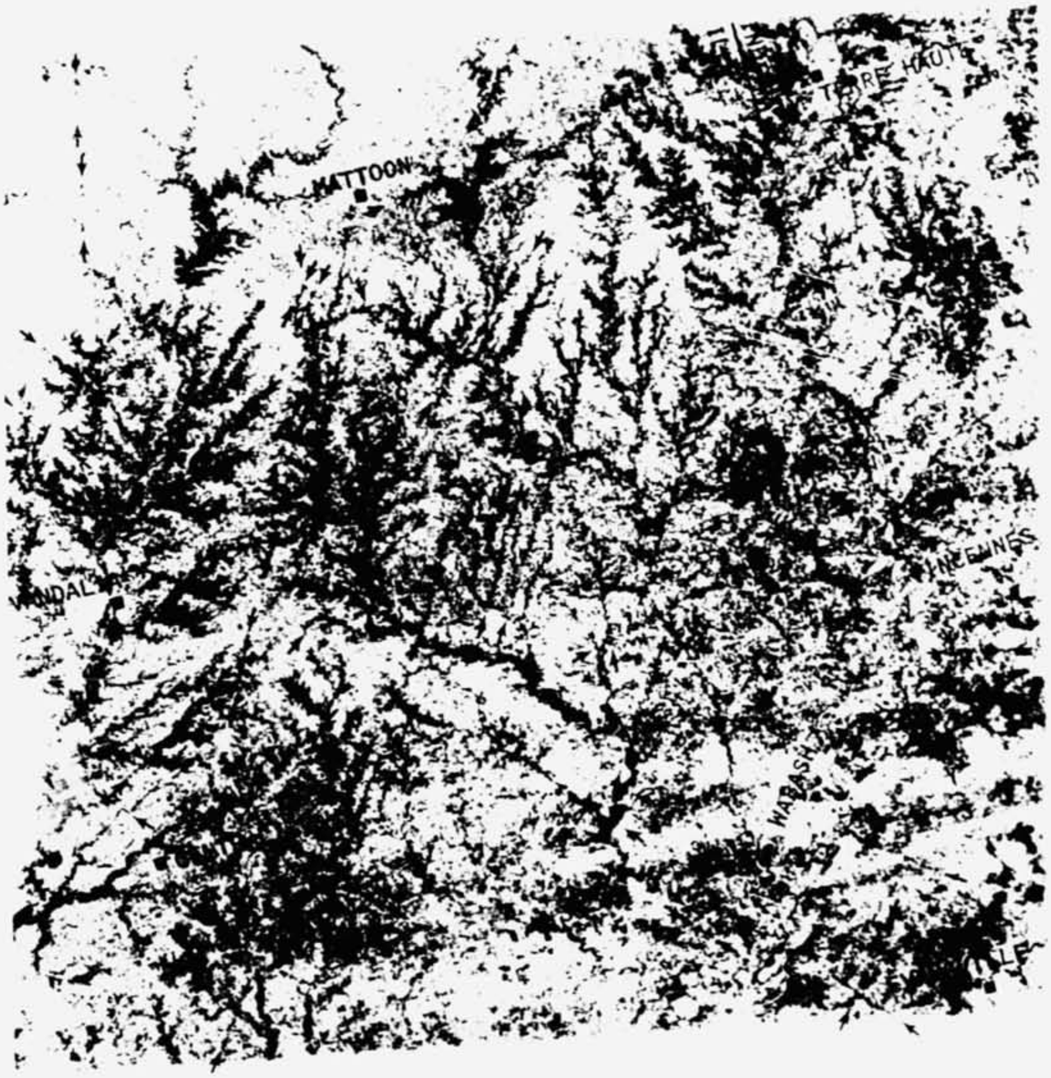

Figure 1. ERTS-1 image (1070-16050-5, 1 October 72) of parts of Indiana and Illinois, showing fracture trends along drainage patterns.

Figure 2. ERTS-1 image (1105-15595-7, 5 November 72) of southwestern Indiana, showing fracture patterns along drainageways and ridges in upland areas underlain by Mississippian limestone and siltstone.

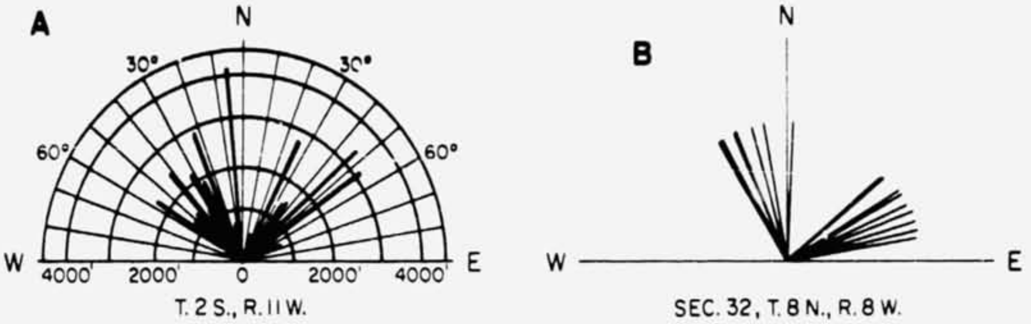

Figure 3. Rose diagrams showing orientation of fractures. A. Direction and length of fractures mapped on aerial photographs. B. Direction of fractures mapped along a strip mine highwall.

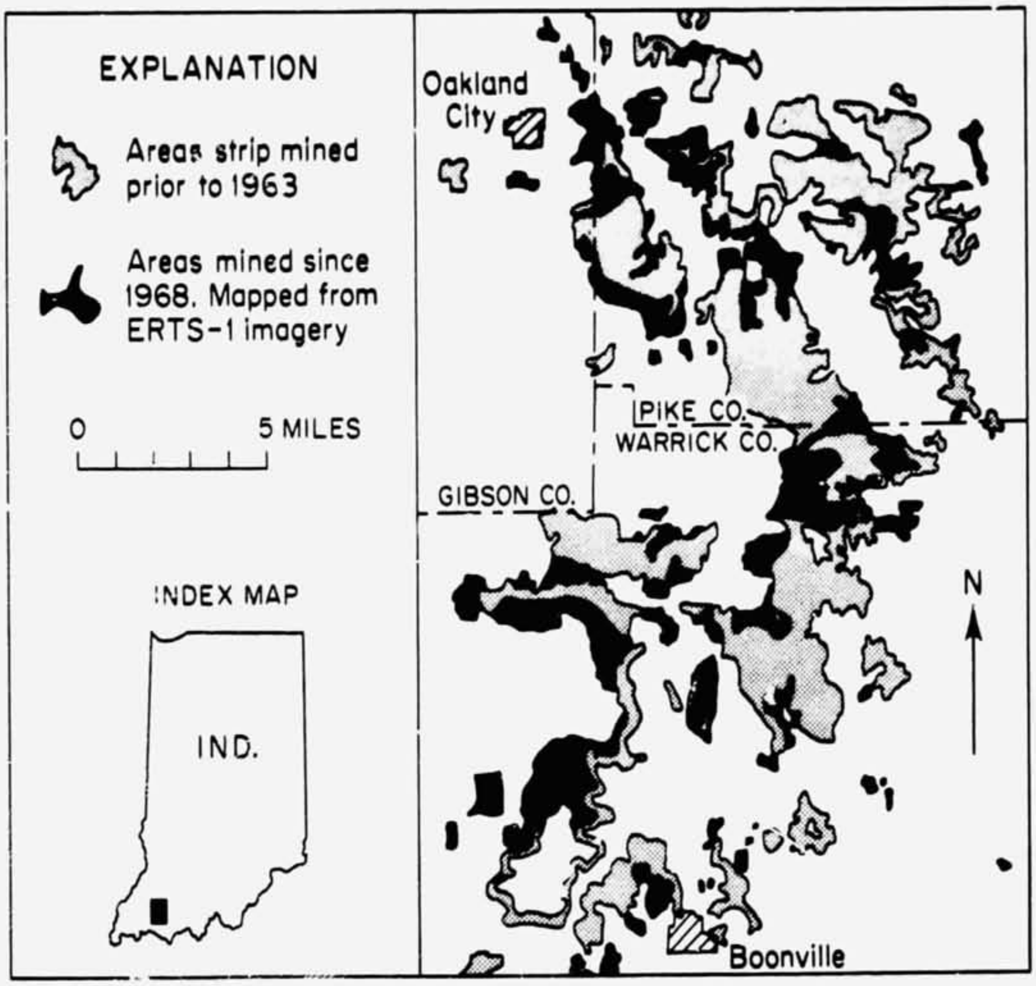

Figure 4. Map of parts of Pike and Gibson Counties in southwestern Indiana, showing strip mine areas previously mapped and that area mapped from ERTS-1 imagery.