APPLICATION OF EREP, LANDSAT AND AIRCRAFT IMAGE DATA TO ENVIRONMENTAL PROBLEMS RELATED TO COAL MINING

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ABSTRACT

The synoptic and repetitive views of aerial remote sensing records offer valuable environmental and dynamic change data in areas of both surface and underground coal mining. Depending upon the accuracy of requirements, these data are available through both low and high level aircraft surveys as well as LANDSAT and EREP (SKYLAB) imagery. Remote sensors can provide timely and accurate information on surface mining status and reclamation progress, coal mine refuse piles and slurry ponds, acid water and siltation problems, and various aspects of environmental impact. With two concurrently-orbiting earth resources satellites (LANDSAT 1 and 2) providing repetitive coverage every nine days, mining-environmental data can be supplied to state and federal agencies in a timely manner. This is particularly important because of the accelerated development of coal resources to meet unprecedented energy demands.

Remote sensing techniques were used to study coal mining sites within the Eastern Interior Coal Basin (Indiana, Illinois, and western Kentucky), the Appalachian Coal Basin (Ohio, West Virginia, and Pennsylvania) and the anthracite coal basins of northeastern Pennsylvania. Remote sensor data evaluated during these studies were acquired by LANDSAT, SKYLAB and both high and low altitude aircraft. Airborne sensors included multispectral scanners, multiband cameras and standard mapping cameras loaded with panchromatic, color and color infrared films.

The research that has been conducted in these areas is a useful prerequisite to the development of an operational monitoring system that can be periodically employed to supply state and federal regulatory agencies with supportive data. Further research, however, must be undertaken to systematically examine those mining processes and features that can be monitored cost effectively using remote sensors and for determining what combination of sensors and ground sampling processes provide the optimum combination for an operational system. The preliminary studies described in this paper supply information useful for directing the scope of this necessary follow-on research.

INTRODUCTION

Surface mining for coal is expanding rapidly to meet increasing energy needs and at the same time both the public and government are placing increasing emphasis on ensuring that coal and other minerals can be extracted from the earth with a minimum of environmental damage. This increasing concern over the adverse environmental effects of surface mining is resulting in the need for the acquisition of a large quantity of new data related to mining and mined land reclamation and for a rapid and cost effective means of such data acquisition.

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Remote sensors can provide timely and accurate information on surface mining status and reclamation progress, coal mine refuse piles and slurry ponds, acid water and siltation problems, and various aspects of environmental impact. Depending upon the accuracy of requirements of various user agencies, these data are available through both low and high level aircraft surveys as well as LANDSAT and EREP (SKYLAB) imagery. With two concurrently-orbiting earth resources satellites (LANDSAT 1 and 2) providing repetitive coverage every nine days, the potential exists for providing mining-environmental data to state and federal agencies in a timely manner.

This paper summarizes the results of several investigations in which remote sensing records were used to supply data on various environmental problems related to both surface and underground coal mining. These investigations were made on coal mining sites in the Eastern Interior Coal Basin (Indiana, Illinois, and western Kentucky), the Appalachian Coal Basin (Ohio, West Virginia and Pennsylvania) and the anthracite coal basins of northeastern Pennsylvania. Remote sensor data evaluated during these studies were acquired by LANDSAT, SKYLAB and both high and low altitude aircraft. Airborne sensors included multispectral scanners, multiband cameras and standard mapping cameras loaded with panchromatic, color and color infrared films.

LANDSAT IMAGERY

LANDSAT imagery has proven useful for detecting changes resulting from active mining and from land reclamation developments. The spatial resolution of the system is, however, a significant problem, particularly for small areas of only a few hectares. Since one pixel element is almost 0.5 hectare in size, the averaging of energy in a pixel that extends across a boundary of mined and non-mined land can produce erroneous area measurements of substantial dimensions. The larger the mined area, the smaller the percentage of error that will be encountered.

Based on this fact, the potential for the application of LANDSAT imagery to mined land monitoring are greater for states with area1/ mining than for states with contour mining.

The discrimination of mined land features is somewhat limited on LANDSAT imagery. For instance, it is difficult to identify land disturbed by actual mining and that disturbed by other associated activities, particularly the systematic removal of vegetation in advance of actual stripping operations. Also, as mined land is revegetated, it blends into the non-disturbed land and is difficult to identify.2/ This is illustrated in Figure 1. The reflective properties of freshly mined spoil (A) is similar to the exposed strata (B) where the soil cover has been removed. Partially revegetated

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1/ The term "area" mining" is normally used for surface mining in low relief terrain where the overburden can be totally removed and all the coal extracted, thus large areas are uniformly disturbed. "Contour mining is restricted to areas of high relief and the coal bed is uncovered in a narrow band around the mountain. As many of the coal beds where this technique is used lies nearly horizontal, the stripping essentially follows the contour of the mountain, thus the name.

2/ This, of course, is one of the objectives of mined land reclamation and the difficulty mentioned extends to analysis of aerial photography and even to ground observations if the land is well reclaimed.

mine spoil (C) will have a reflective character intermediate between bare rock and undisturbed land (D). Reclaimed land which has been reseeded to grasses (E) has reflective properties much like the natural terrain (D).

LANDSAT imagery can be employed for delineation of freshly stripped non-mined land, and for making one or two intermediate classifications of stages of revegetation.

SKYLAB (EREP) IMAGERY

The larger scale of SKYLAB photography in comparison to LANDSAT imagery offers a greater potential for acquiring surface mined land information usable by state and federal agencies.

To determine the degree of utility of SKYLAB imagery and to make comparisons between SKYLAB, LANDSAT and aircraft imagery for such studies, two test sites in the Eastern Interior Coal Basin were selected. These sites were the Sullivan area south of Terre Haute in western Indiana and the Millport area in Muhlenburg and Hopkins counties of northwestern Kentucky.

Sullivan, Indiana Test Site

The area between Sullivan and Terre Haute, Indiana was selected as a test site for surface mining because of the presence of (a) several large active surface mines, (b) large areas of older reclaimed and unreclaimed mined land and (c) two large underground coal mines. Black and white enlargements of the S-190B color and color infrared imagery were made to determine the maximum scale to which the imagery could be enlarged without excessive image deterioration and to determine the optimum scale(s) for visual analysis. To test analysis quality at different scales, photographic enlargements were made to 1:500,000, 1:250,000, 1:100,000, 1:50,000 and to 1:24,000, the latter a 40X enlargement. The 1:250,000 and 1:100,000 scale enlargements proved most useful for this investigation.

The 1:250,000 scale enlargement was compared with a recently published (June, 1972) strip mine area map of Indiana. This analysis revealed significant advances of strip mining in the Dugger, Jasonville and Sullivan areas, and the opening of a new mine near Hymera. Land which has been strip mined and reclaimed recently (within the past 5 years) was evident; however, on the SO-242 film, older mined lands overgrown with trees were difficult to differentiate from the nearby unmined farm and forest lands. However, in areas of medium to high contrast, changes in mined areas as small as 1 hectare could be identified visually on the imagery.

Analysis of the 1:100,000 scale, black and white S-190B enlargements indicated that nearly all past and current, if less than 75% vegetal covered, could be accurately delineated and that one or two classes of reclamation assessment could be detected. Cultural detail at this scale was adequate for positioning the mine delineations accurately on existing base maps.

A 1:24,000 black and white enlargement was made of the large, active Minnehaha Mine to determine if S-190B data was suitable for updating existing large scale mined land maps or for use as 7-1/2' quadrangle-sized, photobase, mined-land maps. This enlargement illustrated in Figure 2 is about the maximum enlargement permissible for SKYLAB S-190B imagery without excessive image deterioration. Although the mined areas could be readily delineated (especially where high contrast exists between the freshly mined soil and rocks and the much darker surrounding vegetation), the resolution of the enlargement at this scale was not adequate to produce the detail and accuracy deemed necessary for some state and federal agency needs. At this scale, high contrast mined areas could be delineated with a tolerance of $\pm$ 1mm ($\pm$ 17 meters), whereas some of the lower contrast, previously reclaimed areas could only be delineated with a line accuracy of $\pm$ 2.5mm or about 60 meters.

Millport, Kentucky Test Site

The Millport test site was selected because of previous investigations in the areas and the availability of considerable ground truth data. This site, with its thin soil cover and bedrock exposures also contrasts with the Sullivan test site which is overlain with a varied thickness glacial drift cover up to several meters thick. A mined land inventory map was prepared at 1:24,000 scale using quadrangle centered 1:80,000 scale panchromatic photography. LANDSAT and SKYLAB imagery were evaluated for possible use in updating this map. A 1:24,000 scale enlargement was made from S-190B color infrared imagery of this 7-1/2' quadrangle area, and enlargements to 1:80,000 scale were made of both SKYLAB (Figure 3) and LANDSAT (Figure 4) imagery to compare directly with the high altitude aerial photographs. The SKYLAB imagery was acquired on September 15, 1973, whereas the highest quality LANDSAT frame for this same area, and the one used in this study, was acquired on September 30, 1972. Mined land maps prepared from the aircraft, SKYLAB and LANDSAT images formed the basis for determining the detail of delineation possible with each type of imagery.

The enlarged SKYLAB imagery allowed discrimination of eight categories of mining activity and reclamation (Figure 5). These include areas which have been mined but are essentially bare soil and rock, areas mined with 50 to 100% revegetation, unmined areas, refuse areas and slurry ponds, water bodies, highwalls, haulage roads and other types of activity associated with the mining of the coal. The investigators could not differentiate contour mining from area mining in this site on SKYLAB imagery although some contour mining could be delineated with stereo viewing of the high altitude aircraft photography. The SKYLAB color infrared imagery proved moderately good for identification of areas which had been revegetated although distinguishing between different degrees of vegetal cover was difficult. This imagery clearly differentiates water bodies from coal mine refuse and slurry ponds. Highwalls were also identified where high contrast existed between the mined area and the surrounding vegetation. Consecutive S-190B image frames were studied stereoscopically, but the relatively low relief in the area minimized the advantage of the third dimension. It did provide binocular image reinforcement and an apparent improvement in image quality.

The six categories of mined land reclamation and features identified on the LANDSAT Band 7 enlargement of the same area (Figure 6) included some highwalls, mined lands with 50% or more vegetal cover, mined lands with less than 50% vegetal cover, mined lands with essentially bare soil or rock, unmined lands, and water bodies or coal mine refuse areas. The quality of the LANDSAT imagery severely deteriorated at the 1:80,000 scale enlargement, but it still showed high contrast between the mined and unmined areas and proved superior to the SKYLAB imagery for rapidly mapping lands disturbed by surface mining.

Disadvantages of LANDSAT compared to SKYLAB include the lack of resolution of distinguishing cultural features to aid in transferring the data accurately to geographic base maps, the inability to distinguish between mine refuse areas, i.e. refuse piles and slurry ponds and naturally occurring or other mining - related water impoundments. Other features associated with surface mining such as haulage roads, railroads, mine preparation plants and areas being cleared or readied for surface mining were also difficult or impossible to identify.

It appears from this comparison that once an accurate data base has been established from aerial photography, high quality LANDSAT imagery[3/] enlarged to scales as much as 1:100,000, could be used on a regional basis if accuracy requirements are not stringent. Repetitive imagery with resolution approximating the S-190B camera would provide significantly superior data for monitoring mining and reclamation activities.

A portion of the SKYLAB S-190B color infrared imagery was also enlarged to a scale of 1:24,000. The greater clarity and contrast of vegetational boundaries on the color infrared imagery (EK 3443) rendered an enlargement considerably superior for analysis to the S-190B color film (SO-242) enlargement of the Sullivan test site. However, the resolution and contrast of these enlargements were not adequate to provide the accuracy of mined land delineations deemed necessary for most state requirements. It did, however, within the accuracies possible, provide substantial data for updating the existing 1:24,000 scale mined lands map produced from the high altitude aerial photography acquired 2-1/2 years before.

AERIAL PHOTOGRAPHY

Aerial photography of various scales and film types have been used to investigate a wide range of environmental problems produced by surface and underground mining.

Small scale (1:120,000) color infrared photography acquired by NASA provided an excellent media for evaluating a variety of mined land problems to an accuracy that will satisfy most potential users. Resolution of this film and scale are such that detection of moderate contrast targets is possible if the size exceeds about 5-10 meters. Target sizes for identification and mapping, however, are more of the order of 10-15 meters. Such imagery is adequate for mapping both mining and reclamation progress, and presenting the data on 1:24,000 scale base maps. The degree of regrading and replanting is easily discernable and accurate assessments of vegetal ground cover rapidly made. Mapping units of two hectares or more are practical although units of a fraction of a hectare are possible. Such imagery does lack the resolution for resolving individual tree sets used in reclamation or for accurately mapping the detail of acid mine drainage.

The color rendition of the 1:120,000 scale color infrared photography provides an added dimension for interpretation, and the subjective judgment of the analysts are that, with this film and image scale, interpretations are more readily made and are as accurate as that attained on 1:80,000 panchromatic photography.

A practical application of 1:120,000 color infrared photography for mined land studies was made recently in Indiana as part of a LANDSAT-1 experiment. The photography was used to map the refuse piles and slurry ponds for the entire coal field area of Indiana. Information developed was provided to the Indiana State Legislature to assist them in designing legislation for the reclamation of such features. The disposal sites of the coal waste from preparation plants were identified, located by township, range and quarter section and plotted on 1:250,000 scale base maps.

The image of each coal refuse site was optically enlarged and classified. However, area measurements on sites less than .8 hectare (2 acres) was not attempted. Sites

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3/ Experience in the midwest area of the United States indicates that atmospheric vapor or haze seriously degrades much of the LANDSAT imagery and that an image of superior clarity may be acquired only once or twice a year.

were segregated into three primary height classes based on stereoscopic examination and acreage values were computed with a polar planimeter. Quality control of data obtained from the small scale color infrared aerial photography included spot checking with 1:20,000 scale color and color infrared aerial photography, where available, ground and light aircraft observations. Reclamation costs for each site were estimated by integrating data derived by remote sensing with statistics acquired from industry and government sources.

Efforts were made to identify those areas where acid drainage, vegetation damage, or stream sedimentation were present. The proximity of refuse areas to drainage systems was also noted.

Small scale (1:80,000) panchromatic photography of western Kentucky was used to test the utility of such imagery for surface mined-land classification. This photography permitted mapping of twenty-two separate categories of mined land disturbances, reclamation and mining features. These categories included areas of active strip mining, three categories of vegetal cover where no reclamation grading had occurred, three classes of vegetal cover where only partial grading had occurred, three vegetal cover classes where complete reclamation grading had occurred, three vegetal cover classes for graded and ungraded contour mining, plus the identification of water bodies, coal preparation areas, coal refuse areas, delineation of high walls, and the identification of areas disturbed by mining activities although not actually mined. Figure 7 is a portion of the photobase map prepared at a scale of 1:24,000.

Large-scale imagery is useful for detailed reclamation assesssment, including monitoring of slope angle, spoil type classification and seedling and grass growth and survival; other environmentally degrading factors which can be monitored are the identification and location of acid spoil and acid mine drainage sources, siltation sources and deposition sites, classification of materials in mine refuse dumps, and burning refuse piles.

A further demonstration of the use of remote sensor data for identifying the environmental effects of mining was recently completed. With aircraft support of NASA-Lewis Research Center, a mine subsidence mapping program was conducted for the Pennsylvania Department of Environmental Resources and the Appalachian Regional Commission. In this study, the utility of various types of large-scale aircraft imagery were evaluated for the detection of surface subsidence features. The remote sensing data used for the investigation included LANDSAT-1 imagery, side looking airborne radar (SLAR) imagery, multispectral scanner imagery for 11 spectral bands (including thermal infrared), color, color infrared and panchromatic aerial photography. LANDSAT imagery of all seasons was available whereas most of the other remote sensor data was acquired in winter or spring. NASA-Lewis Research Center acquired the SLAR, MSS imagery and the color, color infrared and panchromatic photography in the spring of 1974 specifically for this investigation. Additional aerial photography was obtained from NASA, U.S. Geological Survey, and the Pennsylvania Department of Environmental Resources. Complete photographic coverage of the Northern Anthracite Field was obtained for the years 1974, 1973, and 1969, and selected areas were studied using photographic coverage from as far back as 1949.

Significant results of the investigation include the verification of aerial remote sensing as an accurate method of mapping surface subsidence features in the anthracite coal fields of Pennsylvania. More than 1,000 such features were identified in the Northern Anthracite Coal Field which were previously unrecorded and unknown. The subsidence features were classified as pothole (Figure 8), regional, or linear based on interpretation keys and developed in the study on field verification. Early spring or late winter proved to be the optimum times for acquiring aerial photography for subsidence detection in the northeastern United States. Large-scale (between 1:10,000 and

1:20,000) color, color infrared and panchromatic photography were most useful for subsidence analysis. Table 1 summarizes the results of the subsidence investigations.

CONCLUSIONS

We believe this research is a useful prerequisite for developing an operational monitoring system for state and federal regulatory agencies. The synoptic and repetitive views of satellite and aerial remote sensing imaging systems offer the potential of deriving valuable enviornmental and dynamic change data in areas of both surface and underground coal mining. Dependin upon the accuracy requirements, these data are available through both satellite and low and high level aircraft surveys.

Integration of remote sensing monitoring systems into the state mined land regulatory programs depends upon many factors that differ substantially from place to place due to state requirements and the environment.

At present, it appears that for most state requirements for around-the-year, surface mined land monitoring, LANDSAT, or imagery of comparable resolutions, is of limited value. Not only are most of the necessary judgments of mined land status difficult or impossible to make on the best quality of such imagery, but, in many parts of the United States, the acquisition of cloud free imagery is uncertain. However, for periodic, e.g., yearly updating of regional surface mine maps, LANDSAT may provide sufficient accuracies for some users. With appropriate baseline data, LANDSAT can provide information rapidly and economically for updating progress of new mining and reclamation of mined land.

Satellite imagery of S-190A and S-190B quality offers greater potential for use in routine monitoring programs, and if available on a continued basis, undoubtedly would find application by state agencies concerned with mined land reclamation. A real question still exists, however, as to what extent analysis of satellite imagery would replace or supplement current monitoring procedures and what the real cost savings would be.

These questions are largely academic unless the data are put in the user's hands in a timely manner. For example, the assessment of reclamation quality for release of bond monies requires timely information. The identification and apprehension of mining companies conducting illegal mining requires the acquisition and prompt analysis of the imagery to be an effective surveillance method.

Aerial photography, particularly color and color infrared types, can provide data for the evaluation of virtually all surface mining activities ranging from pre-planning of mining activities, through actual mining and reclamation to an acceptable state. The scale of photography and film type used depends upon the specific requirements of the investigation. 1:120,000 scale imagery is sufficient for reliable regional assessment of mining activities, whereas, large scale photography better provides engineering data and detail of acid mine problems. Table 2 is a summary assessment of the utility of the various remote sensor data for mined land investigations.

No one has made a systematic evaluation of aerial photography for mined land studies, either from a technical or economic point of view. However, the U.S. Bureau of Mines has just initiated a project to do this. The results of this study and of current LANDSAT studies may provide the impetus needed to encourage state regulatory agencies concerned with mining to incorporate remote sensing data into their programs.

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TABLE 1. UTILITY (AS TO SCALE) OF REMOTE SENSORS USED FOR ANALYSIS OF MINE SUBSIDENCE

SENSOR DATA USED	USABLE SCALES	UTILITY	OPTIMUM SEASON
LANDSAT-1 Imagery	1:1,000,000-1:250,000	Detection of regional Lineament and Fault patterns	Various; Band 5, 7 Spring, Autumn
SLAR IMAGERY	1:500,000-1:100,000	Fracture detection	Various; Spring, Winter, Autumn
Small Scale Photography	1:130,000-1:90,000	Detection of Fracture traces and regional subsidence	Early Spring
Color infrared (IR) photography	1:30,000-1:130,000	Detection of regional subsidence, fracture traces and pothole subsidence	Spring
Color Photography	1:30,000-1:130,000	Detection of regional subsidence and fracture traces	Spring
Panchromatic, color IR, color aerial photography	1:16,000-1:30,000	Detection of regional subsidence, fracture traces, and linear subsidence (extension)	Late Winter, Spring
Panchromatic, color, color IR aerial photography	1:10,000-1:16,000	Detection of pothole subsidence, linear subsidence, fracture traces, regional subsidence, environmental impact analysis	Late Winter; Early Spring
Thermal imagery	1:20,000-1:10,000	Regional subsidence detection	Spring

TABLE 2. UTILITY OF DIFFERENT SCALES OF IMAGERY FOR EFFECTIVE IDENTIFICATION OF SELECTED MINED-LAND FEATURES

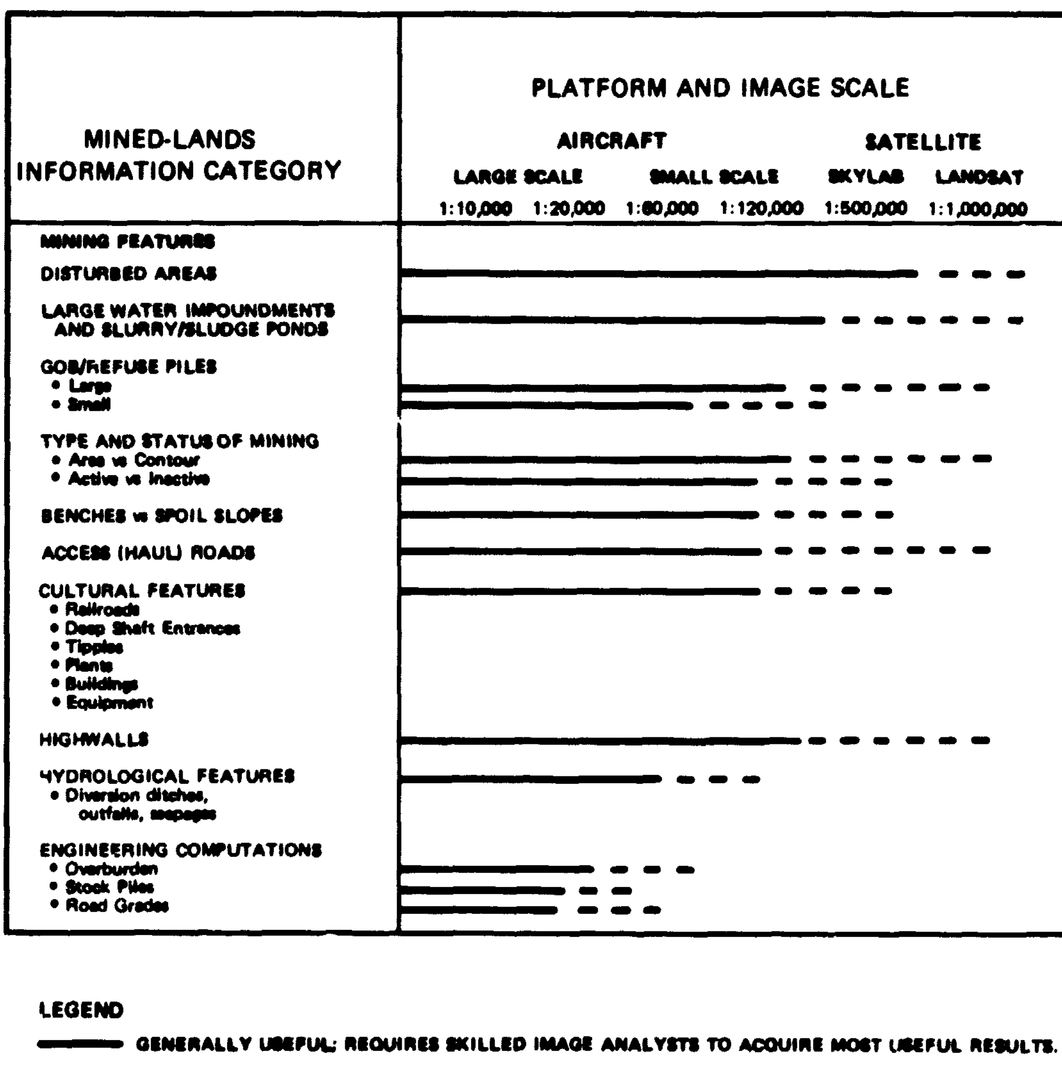

TABLE 2 (Cont'd - 2). UTILITY OF DIFFERENT SCALES OF IMAGERY FOR EFFECTIVE IDENTIFICATION OF SELECTED MINED-LAND FEATURES

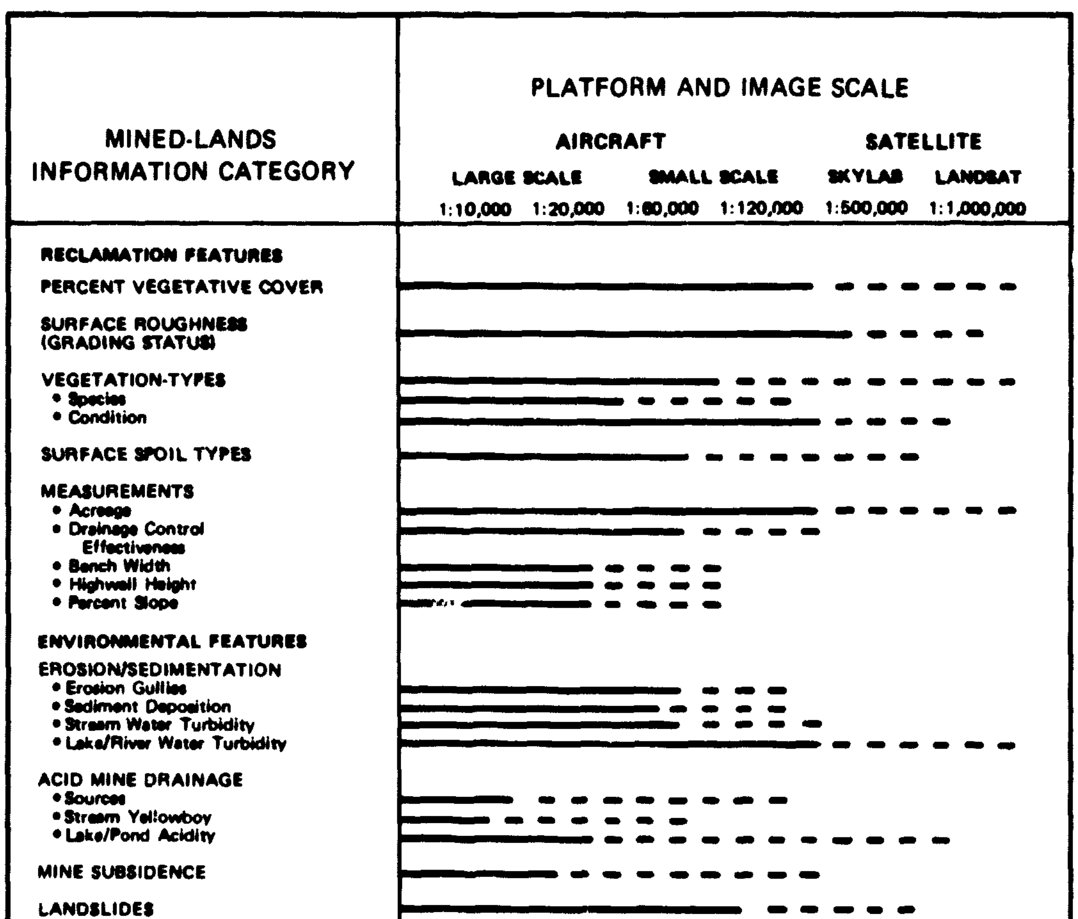

FIGURE 1. This aerial oblique view of surface coal mining activity illustrates a wide variety of land disturbances associated with this industry. Area (A) is freshly disturbed overburden material. Area (B) has had the soil layer removed in preparation of mining. Area (C) is older, ungraded spoil piles which were seeded to grasses and trees with partial reclamation success. Area (E) has been graded to a rounded topography and seeded to grasses. Such lands blend well with the natural terrain (D) and are difficult to differentiate on satellite imagery.

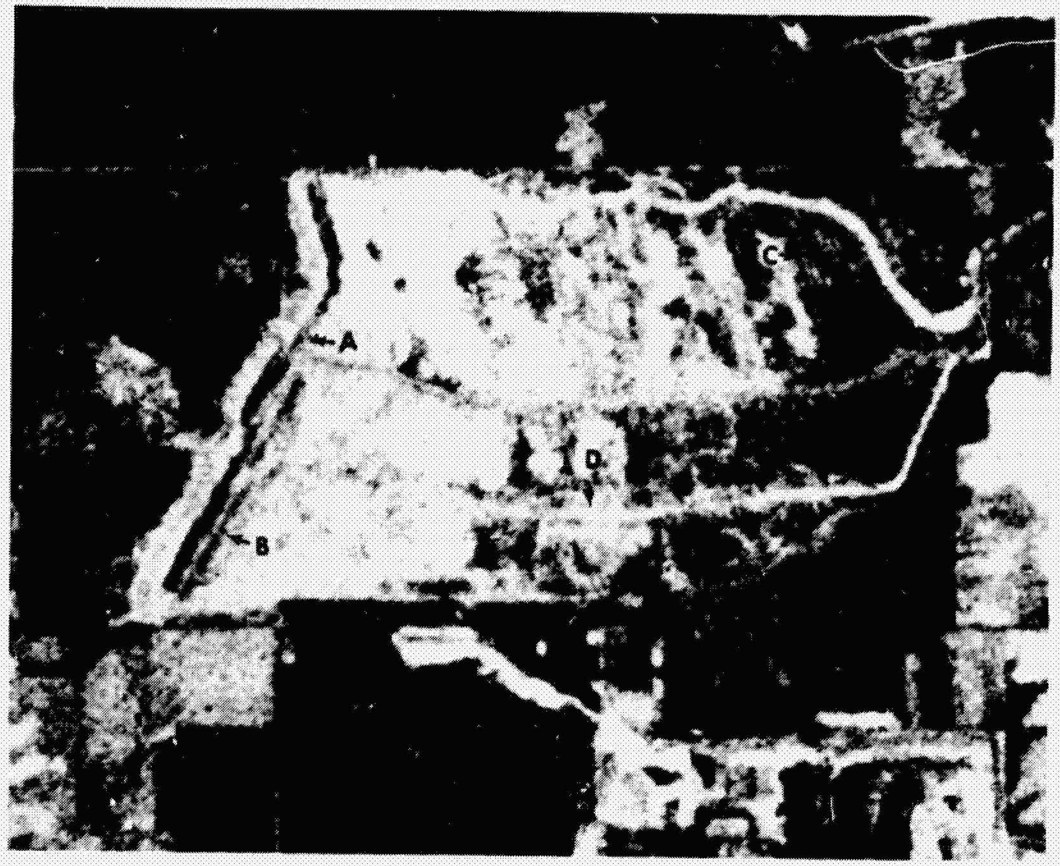

FIGURE 2. Black and white enlargement to 1:24,000 scale of SKYLAB S-190B color image of the large Minnehaha surface mine in the Sullivan, Indiana test site. A large dragline used for removing the overburden can be distinguished on the original image at (A) as can be the highwall and the current mining furrow. Two ridges of ungraded mine spoil are evident at (B). Land reclaimed under old mining laws which did not require the ridges to be leveled is identifiable at (C). The old and current haul roads are obvious at (D). The older, now unused, road is imaged with less contrast.

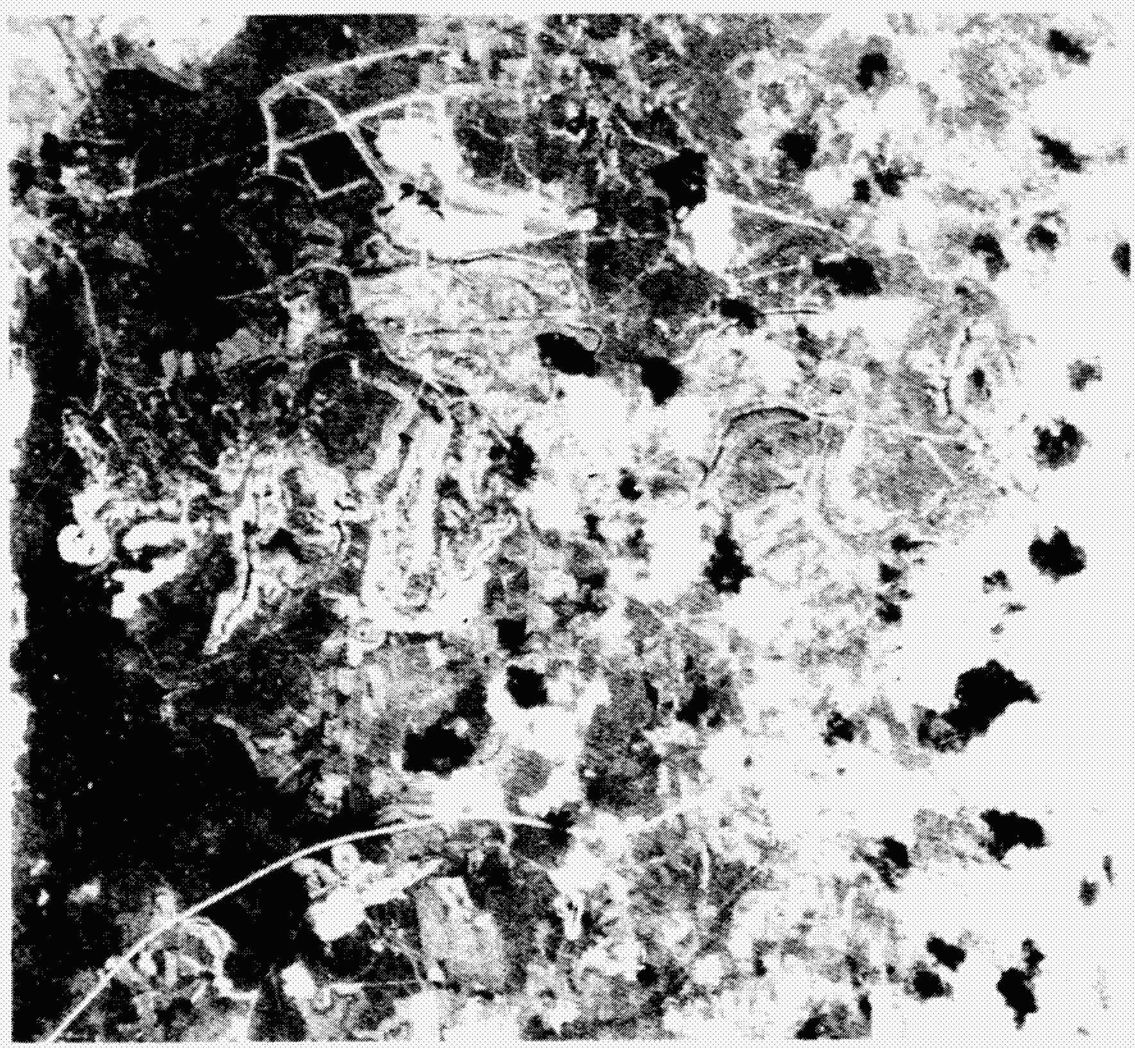

FIGURE 3. This 1:80,000 scale image is a black and white rendition of a SKYLAB S-190B color infrared photograph acquired in September, 1973 over the Millport, Kentucky test site. Although a few scattered clouds appear on the imagery, the quality and resolution were sufficient to permit mapping of eight categories of mined land disturbance.

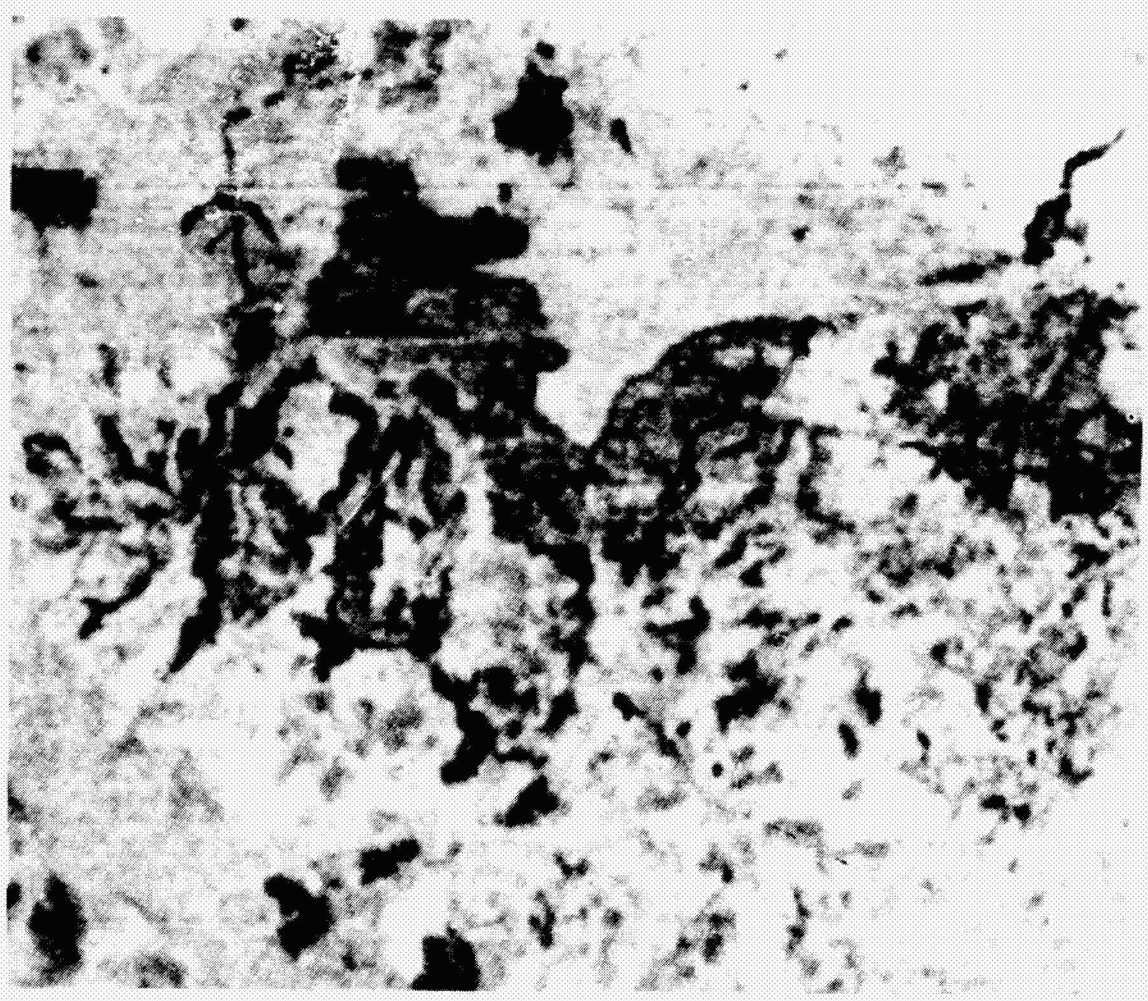

FIGURE 4. LANDSAT-1 image of the Millport, Kentucky area enlarged to approximately 1:80,000 scale. This Band 7 image (No. 1069-15594) was acquired on September 30, 1972 and provides some of the highest contrasts between mined and unmined lands seen on LANDSAT imagery of this test site.

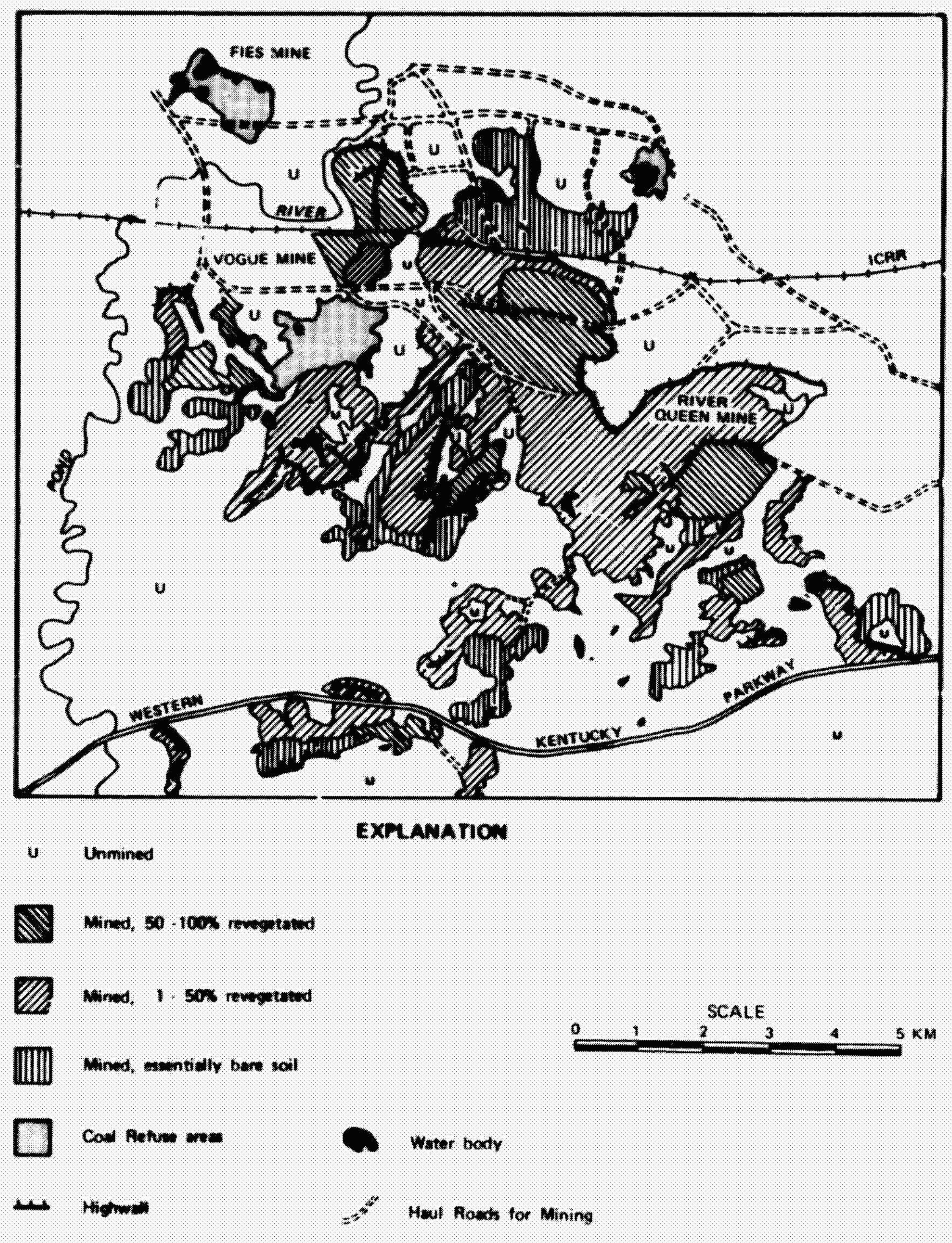

FIGURE 5. Map of surface mining disturbance features delineated from SKYLAB S-190B (September 15, 1973) imagery of the Millport, Kentucky area shown in Figure 3.

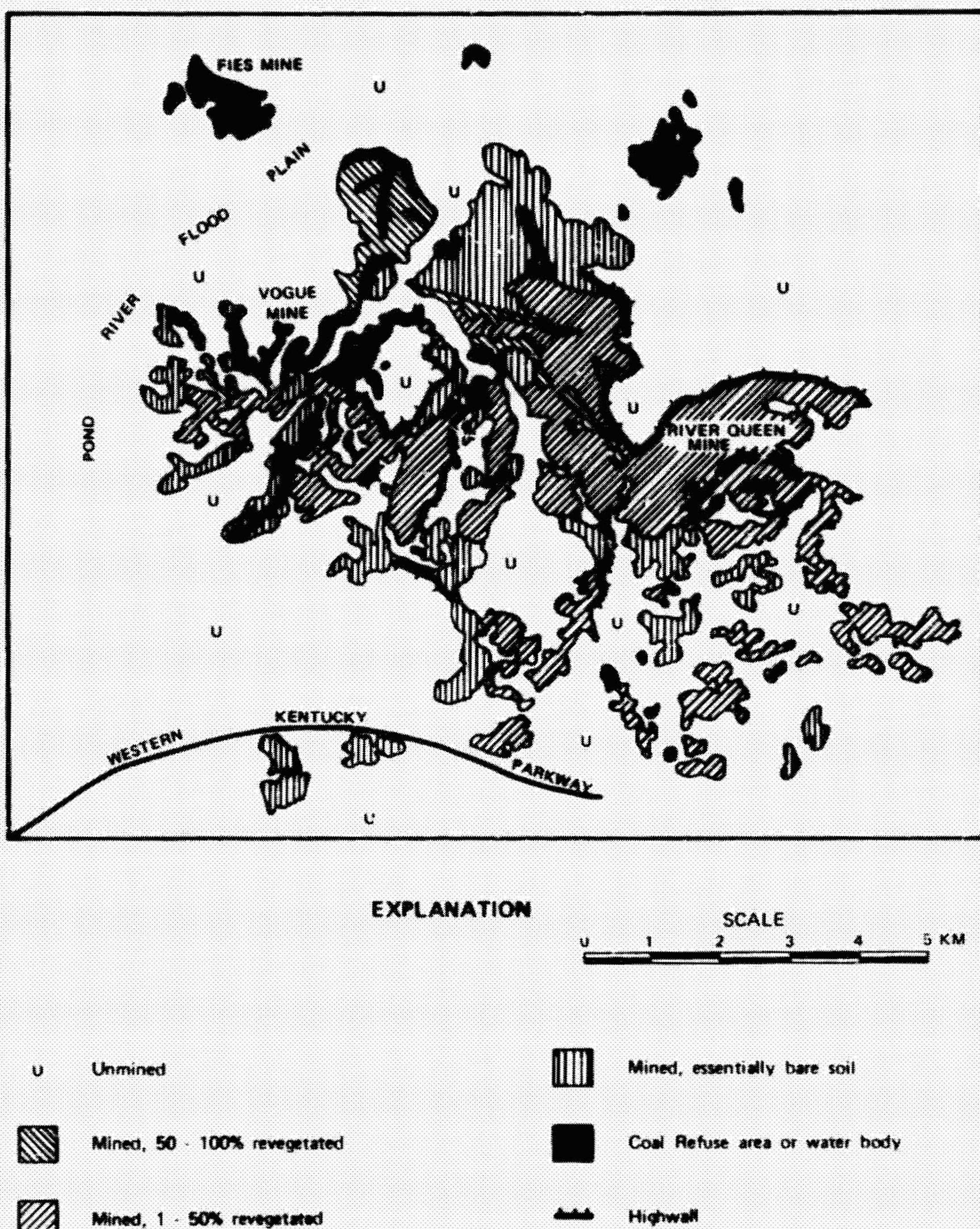

FIGURE 6. Map of surface mining disturbance features delineated from LANDSAT-1, Band 7 imagery shown in Figure 4. Differences between this map and that made from the SKYLAB imagery shown in Figure 3 are mainly attributed to the problem on LANDSAT imagery of accurately distinguishing between reclaimed land and vegetated non-mined land.

LEGEND

110	STRIP MINING,	ACTIVE		
111	STRIP MINED,	NO GRADING	0-25%	VEGETAL COVER
112	STRIP MINED,	NO GRADING	25-50%	VEGETAL COVER
113	STRIP MINED,	NO GRADING	50-75%	VEGETAL COVER
121	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	0-25%	VEGETAL COVER
122	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	25-50%	VEGETAL COVER
123	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	50-75%	VEGETAL COVER
131	STRIP MINED,	GRADED, ROLLING TERRAIN	0-25%	VEGETAL COVER
132	STRIP MINED,	GRADED, ROLLING TERRAIN	25-50%	VEGETAL COVER
133	STRIP MINED,	GRADED, ROLLING TERRAIN	50-75%	VEGETAL COVER
210	CONTOUR MINING,	ACTIVE		
211	CONTOUR MINED,	NO GRADING	0-25%	VEGETAL COVER
212	CONTOUR MINED,	NO GRADING	25-50%	VEGETAL COVER
213	CONTOUR MINED,	NO GRADING	50-75%	VEGETAL COVER
231	CONTOUR MINED,	GRADED, ROLLING TERRAIN	0-25%	VEGETAL COVER
232	CONTOUR MINED,	GRADED, ROLLING TERRAIN	25-50%	VEGETAL COVER

L – LAKE OR POND
P – COAL PREPARATION PLANT
S – SLURRY REFUSE AREA
——— HIGH WALL
G – GOB REFUSE AREA
D – DISTURBED AREA ASSOCIATED WITH PREPARATION PLANT

FIGURE 7. This image is a portion of an annotated photobase map prepared from 1:80,000 scale panchromatic photography. The map was prepared at a scale of 1:24,000 and is presented here at a scale of about 1:50,000. Although good results were obtained with this type and scale of imagery, 1:120,000 scale color infrared photography permits better discrimination of reclamation status.

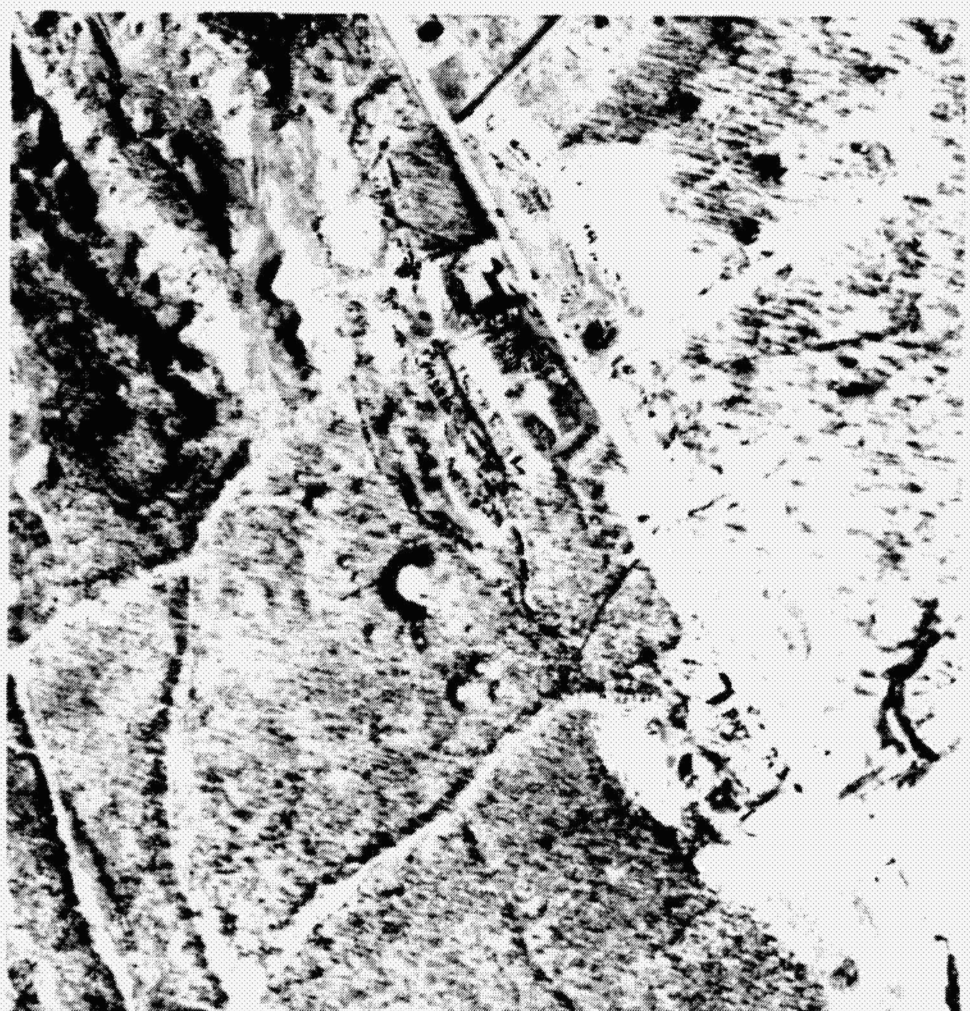

FIGURE 8. This 1:6,250 scale enlargement of a 1:16,000 scale panchromatic aerial photograph is an excellent illustration of pothole subsidence features as they occur in the anthracite coal fields of eastern Pennsylvania. Such subsidence features are usually the result of mining the coal seam too close to the surface or to the base of unconsolidated valley fill.