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DETERMINE UTILITY OF ERTS-1 TO DETECT AND MONITOR AREA STRIP MINING AND RECLAMATION

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16. Abstract

The report summarizes the technical activity over the reporting period. Data and imagery from ERTS-1 was received during the reporting period and several significant products obtained. Imagery and alphanumeric printouts has been produced from the CCT for the test site (five counties in Southeastern Ohio). Decision imagery (autographic theme extraction) have been obtained by processing the CCT data for the test site. The categories are stripped earth, water, partially reclaimed earth (less than 50%), and vegetation (including 100% reclaimed strip mine areas). The remaining unclassified areas are noted as all other. A color composite combining these categories is included. It has been shown that, once trained in one area of a single tape, the computer can perform unsupervised classification of the remaining portion of that tape, of the other tapes in the same scene, of other tapes in another scene on the same orbit. ERTS-1 can and is being used to map disruption caused by coal strip mining in the Ohio.

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Preface

(a) Objective of the Program

1. To map the acreage stripped or otherwise disturbed by coal mining operations in southern and eastern Ohio.

2. To detect, identify, and map the secondary effects of coal mining operation (strip) on the environment. These include erosion, vegetative stress, and sedimentation in rivers and lakes. The effects of water drainage and mine acid seepage are also of interest.

3. To study the after-effects of mining operations and compare recovery time and effectiveness with which mined areas are restored to usefulness.

4. To investigate the feasibility of transfer of knowledge gained by this study of Ohio to other strip mining regions of the U.S.

(b) Scope of Work. The scope is to compare the ERTS-1 imagery to ground truth and to aircraft imagery. The ERTS-1 imagery will be that as received from NASA and that as produced by the Bendix data processing facility from the computer compatible tapes. Comparison of the mapping and monitoring capability for several seasons will also be made.

(c) Conclusions

The most significant conclusion is that the disruption caused by strip-mining can be automatically mapped by processing the ERTS-1 Computer Compatible Tapes (CCT). This map includes the after effects resulting from no or unsuccessful reclamation.

It is anticipated that types of reclamation used (if in sizeable acreage) and the types of water remaining in the mined areas will be mapped.

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DETERMINE UTILITY OF ERTS-1 TO DETECT AND MONITOR AREA STRIP MINING AND RECLAMATION

1. INTRODUCTION

During recent years the expansion of industry in the United States has created an increasing demand for fuel. Newspapers almost daily record grim near and long-term shortages of oil reserves and limitations in distribution and storage. Coal is a major fuel source in both Appalachia and Ohio, and the new demand for it will increase the already extensive area of underground and strip mining in the region.

Strip mining is on the increase in Appalachia. From 1940 to 1963 strip mining has increased from 9 to 34% of the Appalachia coal production (US bureau of Mines, 1963). For five states - Kentucky, Maryland, Ohio, Pennsylvania, Tennessee - strip mine production accounted for over one-third of the production, and for two - Ohio and Maryland - over 60%. The increase in stripped acreage in five counties in Ohio, as shown in Table 1, is typical. The area encompassing stripping (as well as continuing underground mining) is shown in Figure 1 (Breseckei and George, 1966). The deposit area is approximately 50, 000 square miles.

1.1 TEST AREA IN OHIO

The area encompassed by this investigation includes five counties in the coal mining region of the dissected Allegheny Plateau in east-central Ohio. The counties, which comprise nearly 3, 000 square miles, include, from west to east, Muskingum, Coshocton, Guernsey, Tuscarawas, and Belmont. They lie in a hilly region along the western flank of Appalachia and are bounded on the east by the Ohio River. Their location within Appalachia is shown in Figure 1. The test site is in part shown in Figure 6, which is an enlargement of 70 mm strip imagery of Band 7 produced from the Computer Compatible Tapes at Bendix (scene 1084-15415). For ease of location the test site (5 counties) is outlined on a special hydrology map of Ohio in Figure 2.

In recent years (1966 to 1970) the reclamation has not kept up with the stripping as seen in Figure 3. The stripped areas in Figure bears silent witness to this lag in reclamation. Since 1970 reclamation has increased as shown later in the report.

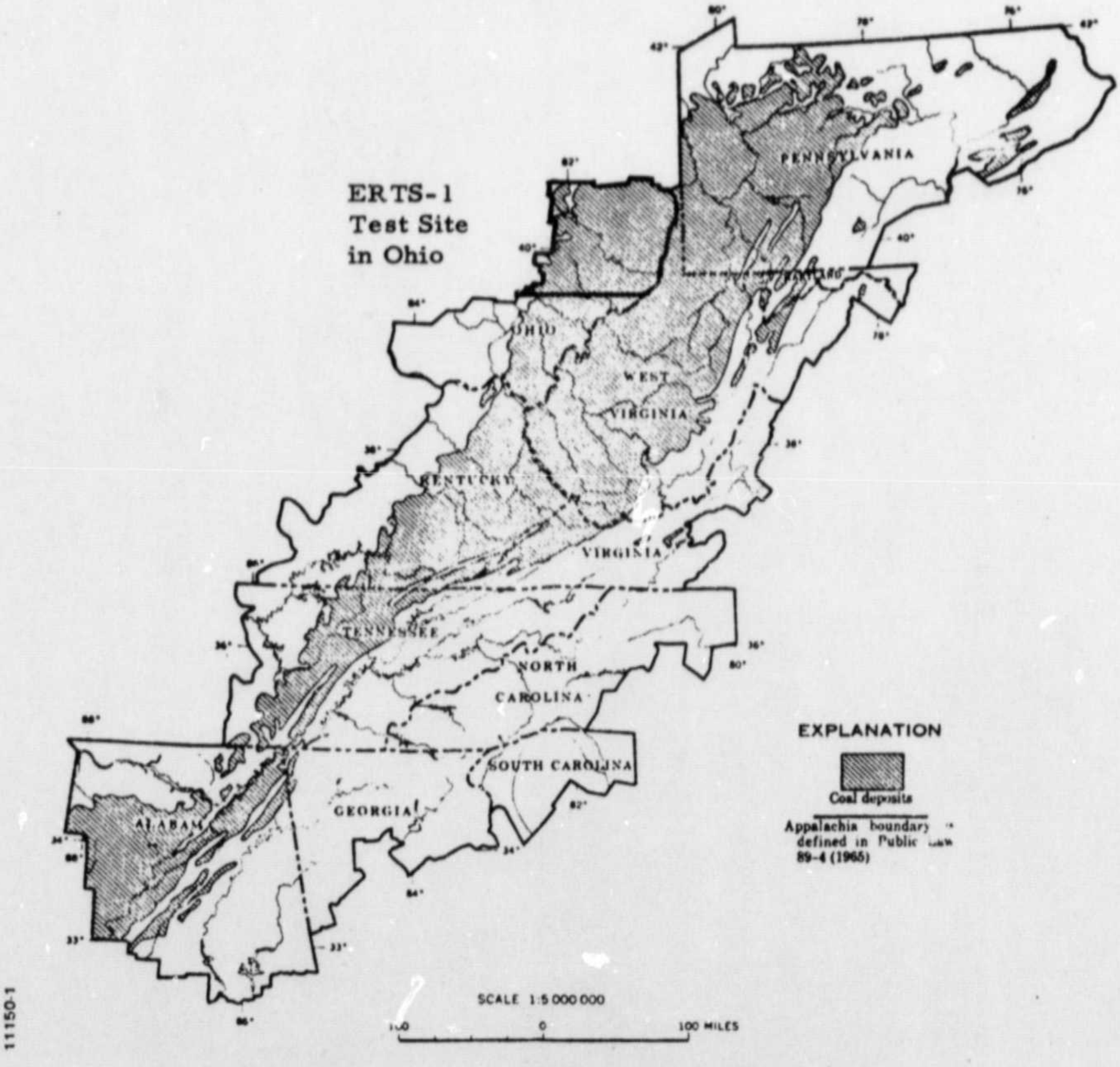

Figure 1 Location of Coal Deposits

Figure 2 Ohio Hydrology Map

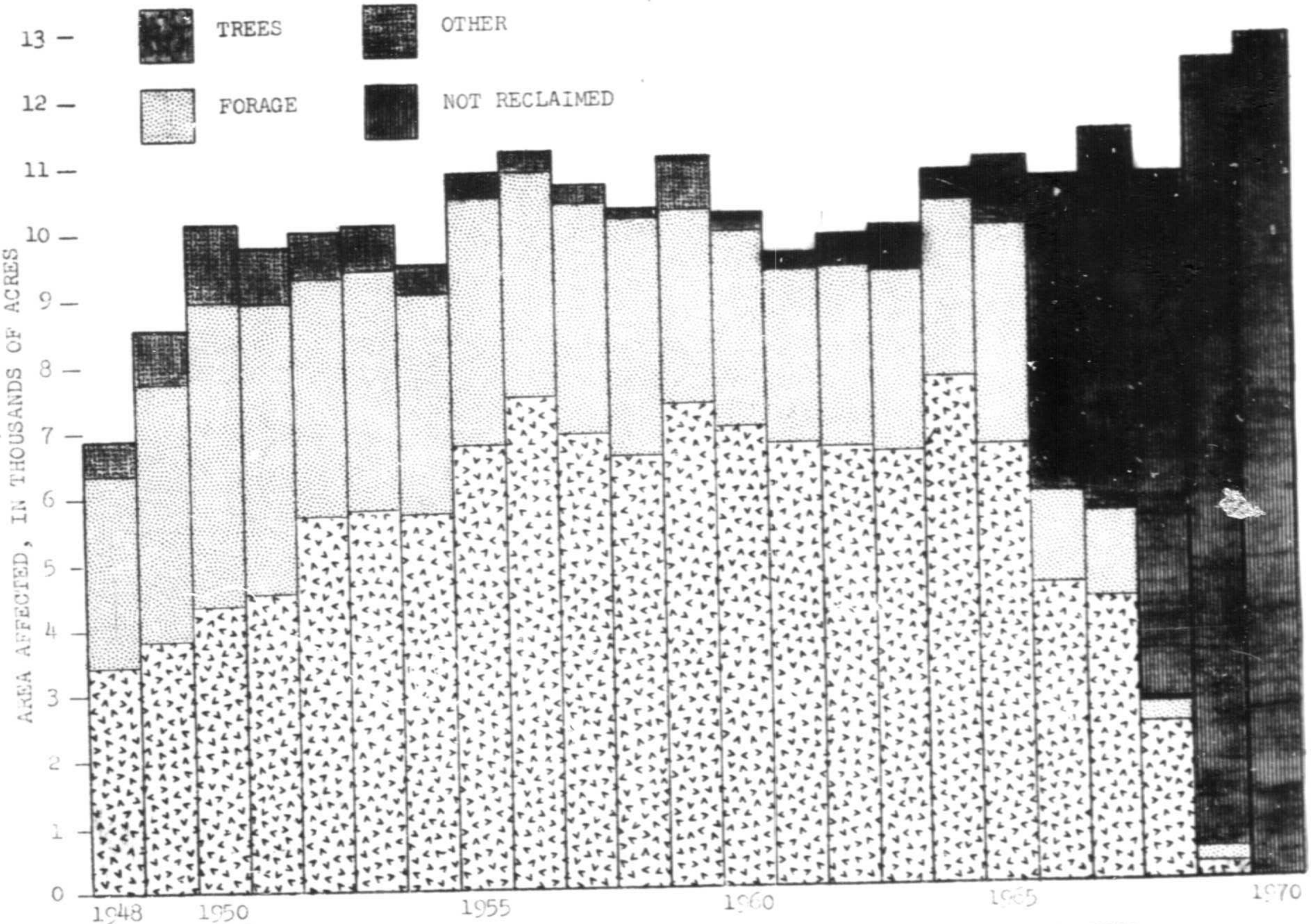

Figure 3 Areas Affected by Strip Mining and Reclaimed During the Period 1948 - 1970

TABLE 1
COUNTY DATA OF STRIP MINING, IN ACRES*

	Coshocton	Belmont	Guernsey	Tuscarawas	Muskingum
County Total	349,000	343,000	332,000	353,000	424,000
1914-1947	622	2,254	355	4,956	1,604
1948-1971	16,818	21,042	4,014	18,039	12,280
Total Area Affected	17,440	23,296	4,369	22,995	13,884
Percentage Total Area Affected	5.00	6.79	1.31	6.51	3.27
Total Reclaimed	13,390	11,443	3,705	14,885	7,699

*Data taken from Division of Forestry and Reclamation, Ohio Department of Natural Resources (March 1, 1972).

1.2 GEOLOGY OF THE AREA

Although only a very small part of the area was glaciated, extensive deposits of outwash fill the valleys of the major rivers and a few of their tributaries. Elsewhere bedrock crops out, striking in a northeast-southwest direction and dipping about 25 ft/mile to the southeast.

The oldest rocks crop out in the western part of Muskingum and Coshocton Counties; eastward the rocks become progressively younger. All of the exposed bedrock represent Paleozoic strata that range in age from Mississippian to Permian. They include the shale, sandstone and limestone of the Logan and Maxville units of Mississippian age; the Pottsville, Allegheny, Conemaugh and Monogahela Formations of Pennsylvania age, consisting of shale, sandstone and coal forming the Dunkard Group of Permian age, which covers much of Belmont County. These exposed strata range in thickness from about 610 feet in Coshocton County to about 1100 feet in Belmont County.

A detailed discussion of the geology of Ohio and the geologic features observable in ERTS-1 imagery is included in the Special Paper (Preliminary Evaluation of the October 15, 1972 ERTS-1 Imagery of East-Central Ohio (scene 1084-15415) by Wayne Pettyjohn) presented in total in the appendix.

1.3 THE STUDY PURPOSE AND MAJOR ACCOMPLISHMENT

The primary purpose of the study is to prepare an autographic theme extraction map that depicts strip mine disruption and degree of reclamation. A disruption map identifies the stripped areas and the impounded water between the spoils bank and the high wall. Impounded water also results from haulway roads connecting high walls. A reclamation map shows the degree to which the spoils bank has been leveled and the water removed, and to which vegetation has returned to the stripped area. Vegetation results from either natural recovery or restocking by man. This paper presents the results and discusses a major accomplishment: the development of the automated disruption and reclamation map. It also addresses briefly the problem of extending the automated map development to other stripped areas.

2. DISRUPTION AND RECLAMATION MAPPING WITH ERTS-1 DATA

There are two types of ERTS-1 data products obtainable for preparation of a disruption and reclamation map. The first type of product is various forms of imagery, such as bulk processed 70 mm negatives in each band, B&W positives and positive transparencies in each band, color composite positives and positive transparencies, and precision processed imagery of some of the above bulk imagery. The second data products are Computer Compatible Tapes. This ERTS-1 feasibility demonstration uses the 70 mm negatives to determine whether to order color composites and CCT's. If they are ordered, then the color composites are used in conjunction with aerial photos and maps to orient the investigator when he is viewing the color display of the data in the CCT. To date the precision processed imagery has not been ordered. The primary interest of this study to date is extracting information from the complete data available on the Computer Compatible Tapes.

2.1 ERTS-1 IMAGERY AND DISRUPTION MAPPING

One significant result is the relative ease with which ERTS-1 will monitor new and unreclaimed stripping activities in Southeastern Ohio and in all of Appalachia. The widths of the contour strips of new or unreclaimed stripped areas are listed in Table 2 by ERTS-1 band numbers. This measurement is obtained from comparison of the ERTS-1 scene to aerial photos (Figure 4).

TABLE 2
MINIMUM DIMENSION OF STRIP MINES BY BAND
(WIDTH OF A STRIPPED CONTOUR IN FEET)

Band 4	Band 5	Band 6	Band 7
400	200	250	250

The strip mines stand out well enough to be easily identified without other graphic aids (photos or maps). Since the shape is quite distinctive, detection of other areas in Appalachia without other graphic aids appears possible for a trained photo interpreter. The portion of the ERTS-1 scene (1084-15361 of 21 Aug 1972) shown in Figure 5 is Band 5 and in Figure 6 is Band 7. These are produced at Bendix from the CCT. The area enlarged represents approximately one-fourth of an ERTS scene or 2400 sq. miles. Since ERTS CCTs are received in four parts per scene the images represent approximately one-half of two CCTs. These were picked because they represent the optimum, one-scene coverage of the test site to date.

It should be noted that positive enlargements from CCTs are likely to be of better quality than positive enlargements from NDPF* because of the film generation differences. Information contained in the images is fairly equal with the edge going to the second generation CCT positive images. For example, standing water appears in the image of Band 7 (Figure 6) in the sawtooth shaped strip mine along the upper left edge. The water body is approximately 6 acres in size and visible in both NDPF film products and Bendix CCT imagery. A low flying airplane observed the same water body on the mine as well as several others of smaller size not visible in NDPF film products or straight CCT imagery. This is one reason for turning to the CCTs and digital printouts.

*NASA Data Processing Facility

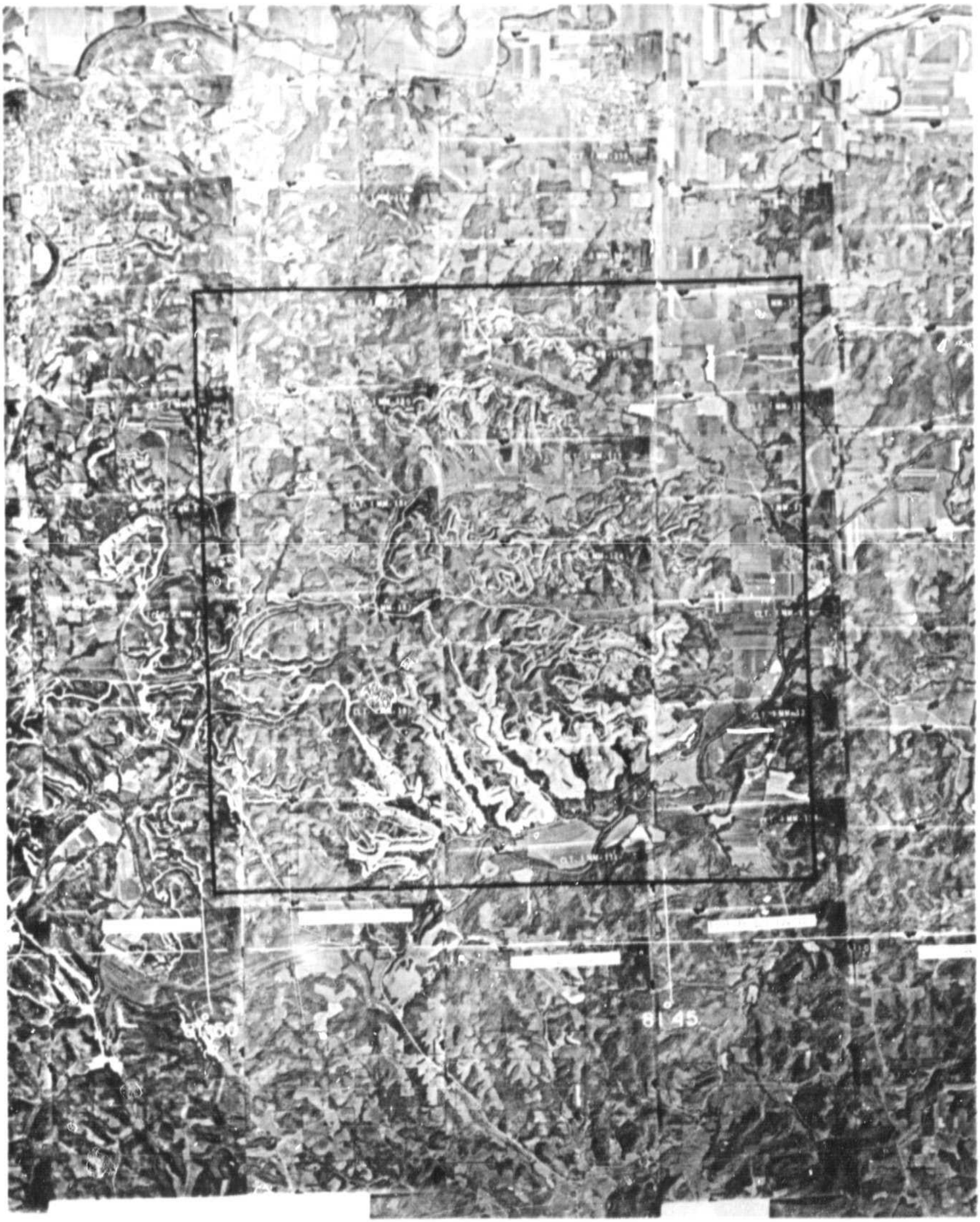

Figure 4 Aerial Photo Mosiac Coshocton Mine East

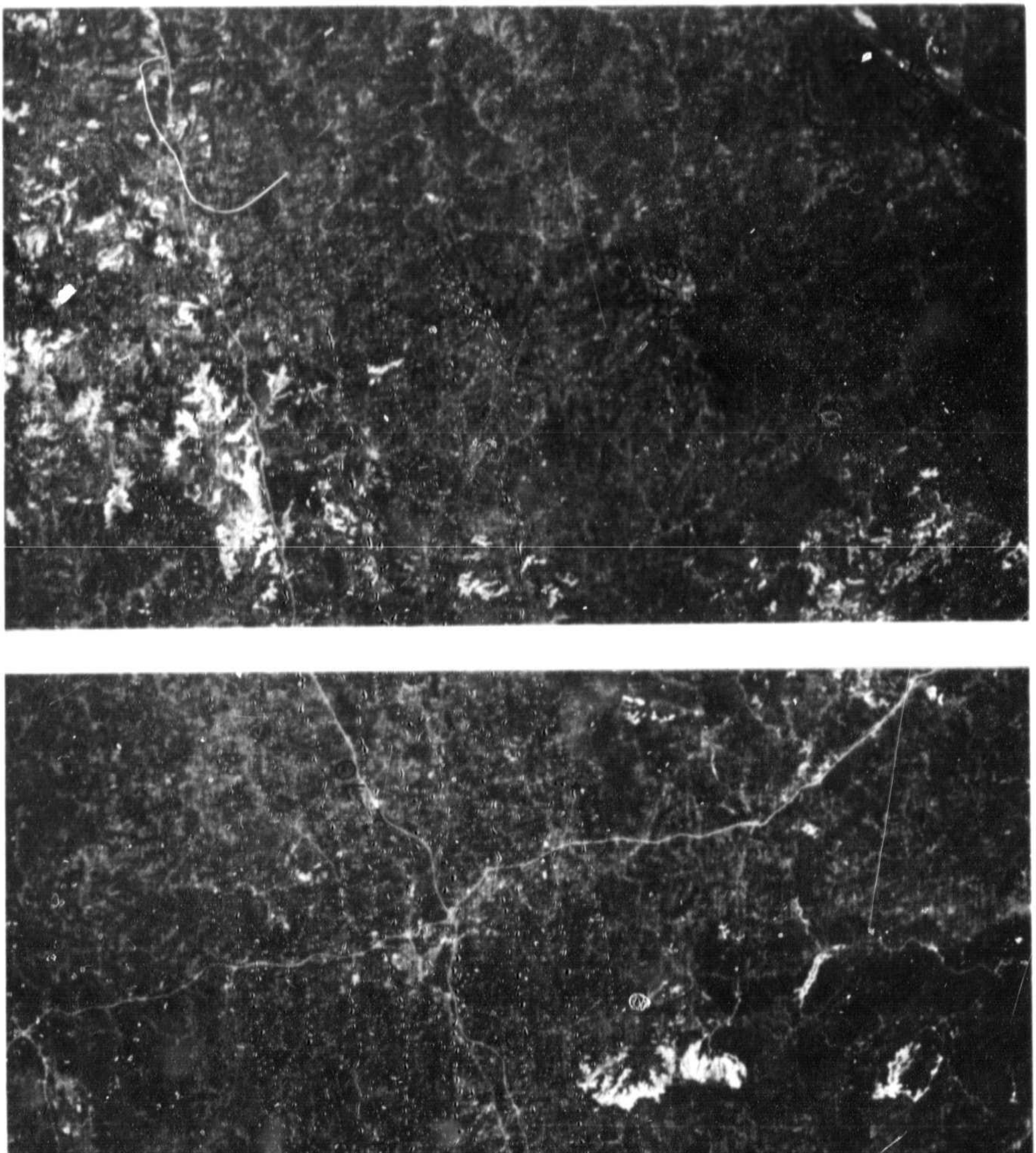

Figure 5 Band 5 ERTS-1 Scene 1029-15361

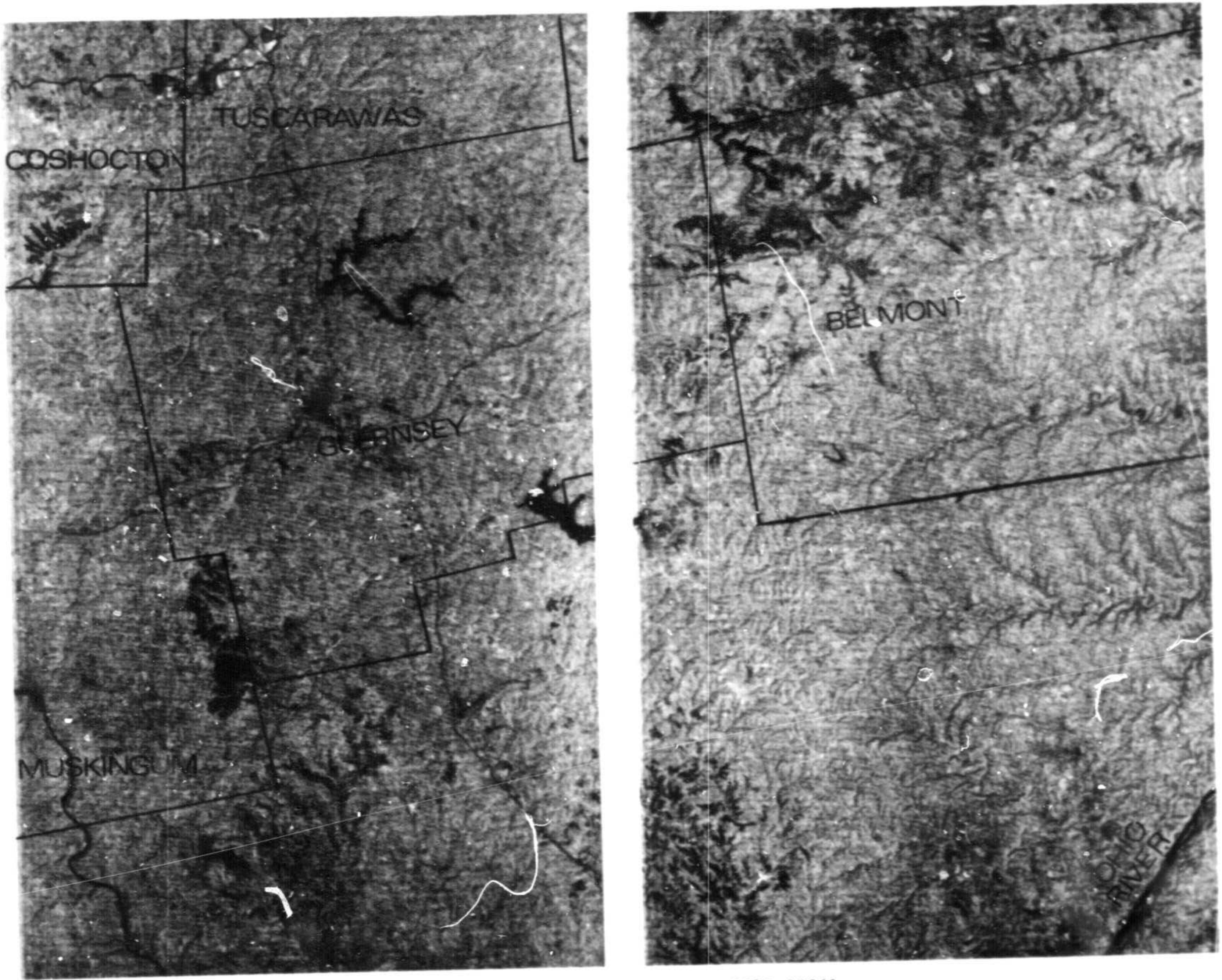

Figure 6 Band 7 ERTS-1 Scene 1029-15361

Figure 7 and Figure 8 are digital printouts (in the "negative" state) of a strip mine east of the Coshocton as shown in Figures 4, 5 and 6. Figure 7 is Band 7 and Figure 8 is Band 5. As stated before the printouts are in the "negative" state, therefore, light areas on the image are shown as dark symbols and dark areas on the imagery are shown as lighter symbols or as no symbol. By studying the digital printout one can readily see that standing water is visible in the printout but not visible in the imagery. (Comparison with the aerial photomosaic is performed with care since the photomosaic was produced one year earlier. Water is shown in the third spike from the left in the Band 7 printout and a dam has been constructed but not filled with water at the same point in the photomosaic). The Band 5 printout can be used for contrast with specific areas of Band 7. Aerial photomosaics presented more information than either the Bendix or NASA/GSFC imagery. Since the Digital printouts also presented more than the generated imagery, the CCT information was statistically processed for target classification.

The digital printouts reflect an advantage in processing the CCT. The printouts shown in this report were set for only one grey level for water. This is determined by the selection of 16 levels of the color display described later. However, another ERTS-1 study* has obtained 3 or 4 levels for water masses of small inland lakes. Imagery received from NASA/GSFC is limited to 14-16 grey levels ranging from high reflecting clouds to low reflecting water. The Bendix imagery for this report is obtained with a uniform spread of grey levels across the dynamic range. Again the lack of capability of the eye film system to clearly demark greater than 16 grey levels is evident. The advantage of setting grey levels for particular ranges in each band is apparent when noting that four might be bunched for water, another 3 bunched for wetlands, 4 bunched for stripmine vegetation and 4 bunched for bare earth. This would yield unusual appearing imagery with some confusing targets removed. However, there is more efficient method of separating and classifying targets. This is the use of both data level selection and multivariate statistical classification.

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*Chase, P.E., Smith, V.E., and Reed, L., "Utilization of ERTS-1 Data to Monitor and Classify Eutrophication of Inland Lakes." Bendix Corporation, BSR 4010, Ann Arbor, Michigan, February 1973.

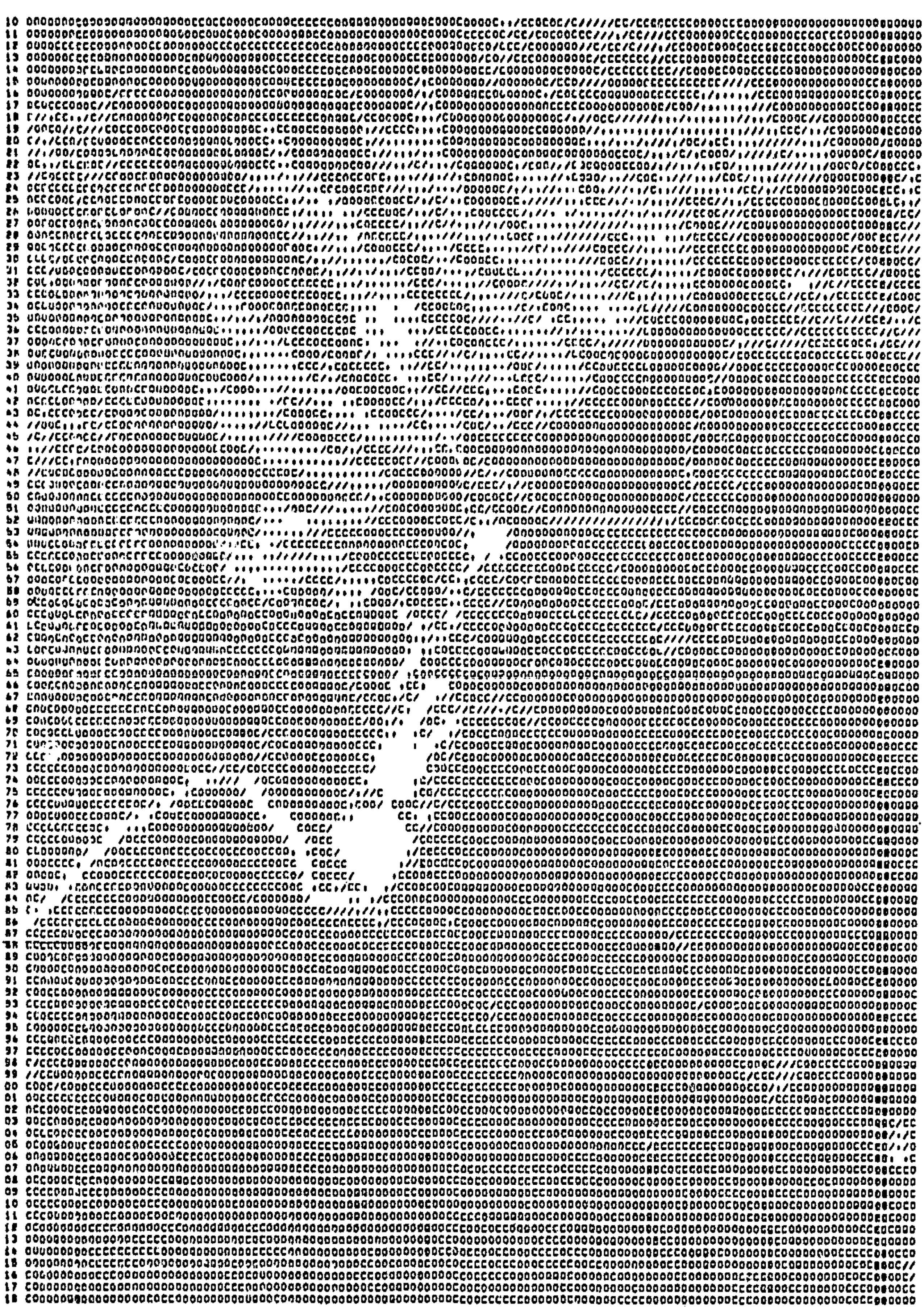

Figure 7 Digital Printout Band 7

Figure 8 Digital Printout Band 5

2.2 AUTOGRAPHIC THEME EXTRACTION (DECISION IMAGERY)

The first step in the development of decision imagery is the location of areas in the region of interest that typify targets of interest. Available ground truth in map form, aerial photomosaics, and the ERTS-1 imagery (either in the form of individual bands or color composite) are examined to select the general location within the scene, i.e., which of the four computer compatible tapes are to be used. The tape information is then displayed on a color display and appropriate locations identified. These areas are then recorded on grey scale computer printout for each band used, as shown previously in Figures 7 and 8. The training sets are located by recording the four corners of each area through the number indicators running vertically and horizontally as shown in Figure 9. An additional and important step is employed when the targets or themes are bunched more closely in grey level. For example, the water masses might be of three or four different types. A data processing routine would be used (called Data Select) that would realign grey levels so that the structure within the water bodies would then be selected again.*

Before applying the selected training sets to the CCT and producing decision imagery, two steps are accomplished to help the interpreter decide whether the training sets are truly representative of the category and whether there is confusion with other target categories. Figure 10 is a representation of a scatter diagram used in this analysis. They demonstrate graphically that target Category B (stripped Earth) will separate easily from Categories A (water) and C (vegetation). Should this analysis not be successful then further training set selection is accomplished. If successful, the interpreter, as a further check of success, assigns each target category a color and applies his training sets to the CCT. The computer rejects all information except the target categories and displays them on the color display. By sampling the particular CCT on the color display the interpreter can determine exactly the success of his training sets.

If the investigator is satisfied, he can now apply his training sets to the entire CCT or any portion that he desires and produce 70 mm strips of

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*It is anticipated that finer structure grey level selection such as this will be used when investigating degree of reclamation and water quality.

Figure 9 Digital Printout with Training Sets Annotated

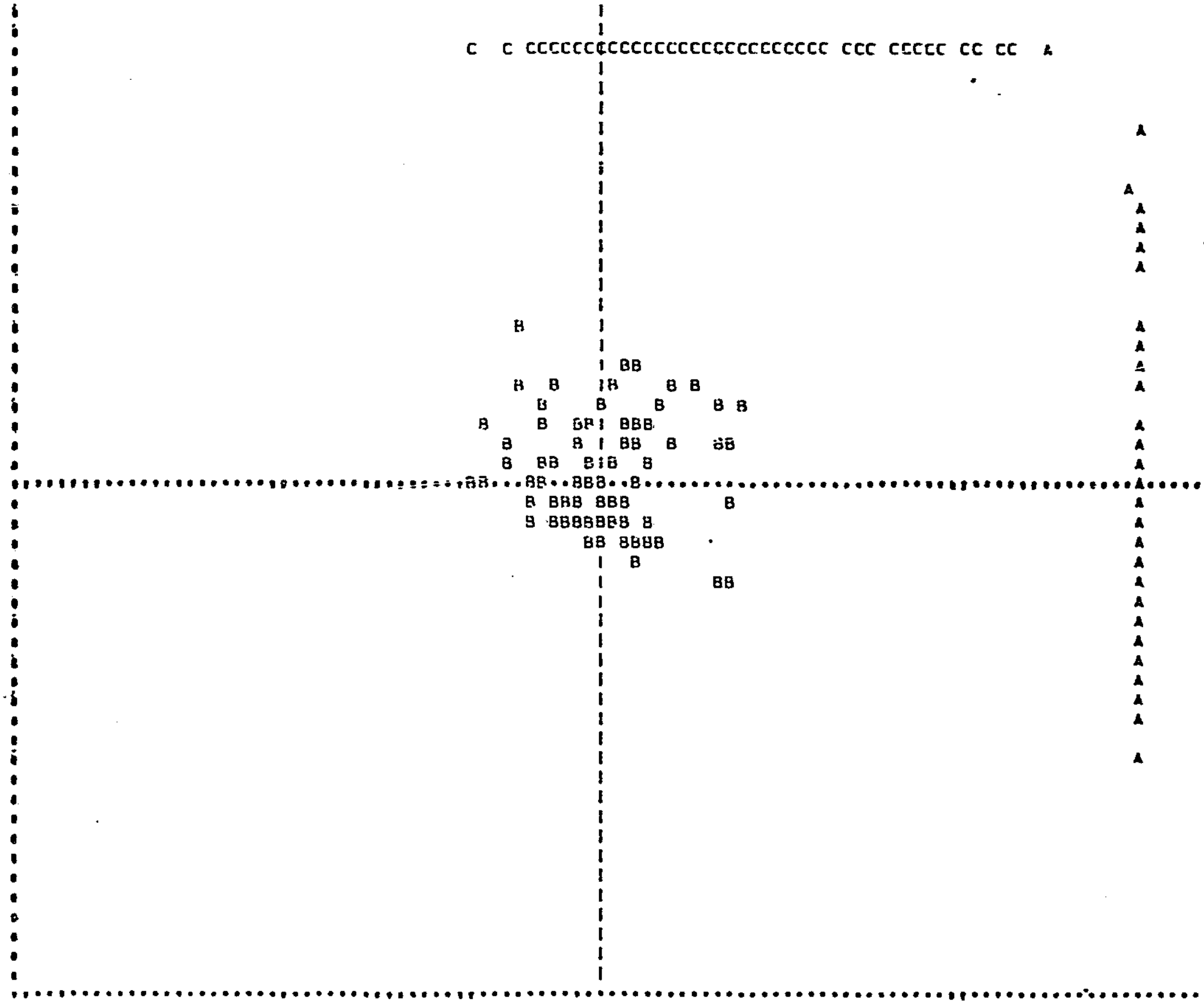


Figure 10 Scatter Diagram

decision imagery. Figure 11 shows Decision Imagery of CCT number one of scene 1029-15361 of 21 August 1972 from which training sets were picked. (It should be stated at this point that all four bands were statistically combined to produce this imagery and each band contributed to each category.) The now familiar scallop-shaped mine east of Coshocton is useful for orientation. Super-highways also also aid location.

The training sets were then applied to tape two of the same scene and Figure 12 was produced automatically and without human intervention. This provided all the coverage of the project test site on this scene.

The same training sets were also successfully applied (contextual agreement) to the adjacent scene 1029-15354 but imagery was not produced. These results lead to the following conclusions:

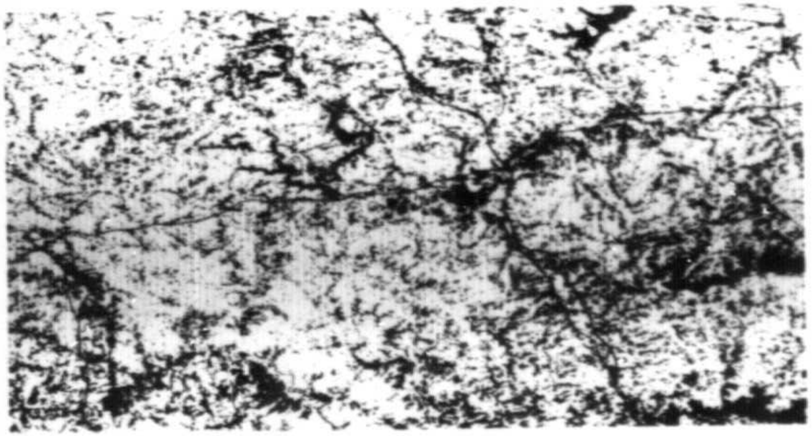
(1) Training sets can be applied to different CCTs of the same scene.

(2) Training sets can be applied to CCTs of different scenes in the same general area and the same orbit. As soon as possible tests will be made to determine if training sets can be successfully applied to scenes of the same area on different orbits (cycles) during the same season and finally to scenes in similar geographical areas (Pennsylvania, West Virginia, etc) at the same time of year.

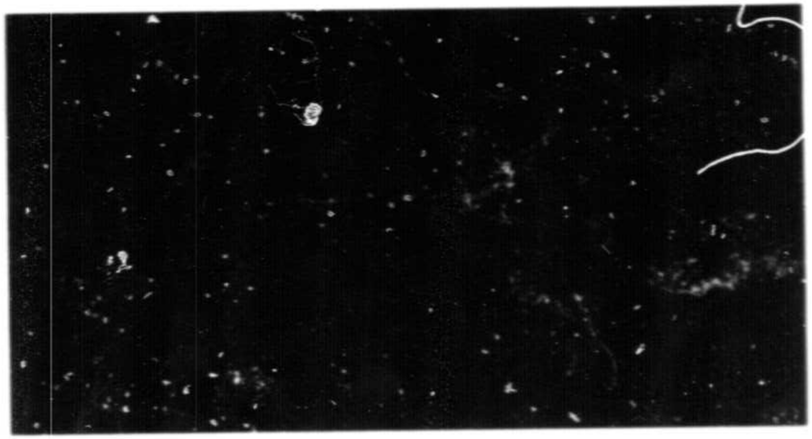
Figure 13 is a Color Enhancement of the decision imagery in Figures 11 and 12. This was produced by simply exposing the decision imagery through colored filters onto one piece of color paper. The water category appears incomplete because only strip mine associated water (highly sedimented or shallow) was processed. The color composite to the left in Figure 13 is tape one and contains the area from which training sets were derived. The color composite to the right is automatically produced.

The definition of success is limited to comparisons of the decision imagery to aerial photomosaics and enlargements of ERTS-1 imagery. The comparison is made in context and not through a detailed comparison of correctness of the decision for each "piece" of digital data. It is difficult to make this latter type of comparison because the aerial photomosaics are at least one year older than the ERTS-1 data. There will be a thorough comparison of the decision imagery with recent low-level aircraft data

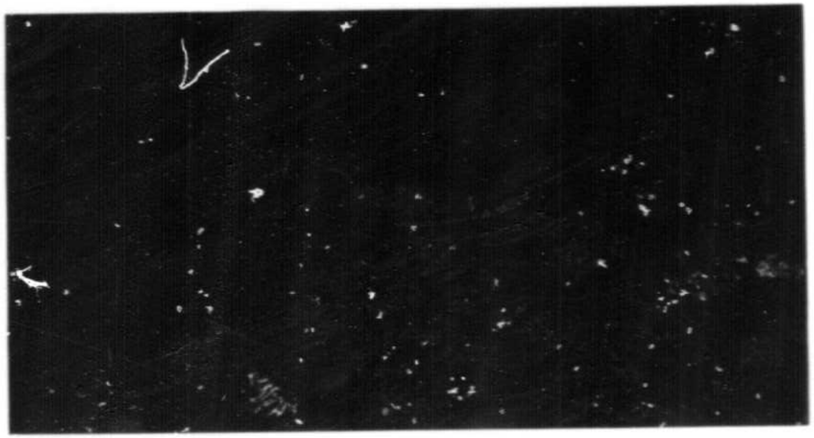
DECISION IMAGERY — COSHOCTON COUNTY



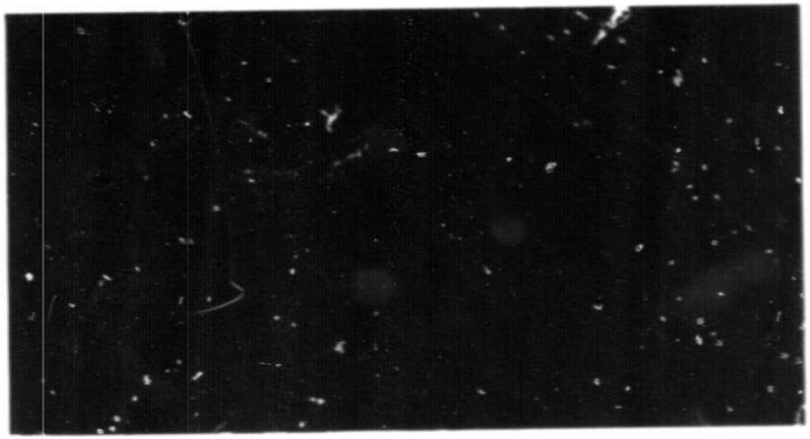
COVERED EARTH



PARTIALLY RECLAIMED EARTH



STRIPPED EARTH



WATER

Figure 11

DECISION IMAGERY — BELMONT COUNTY

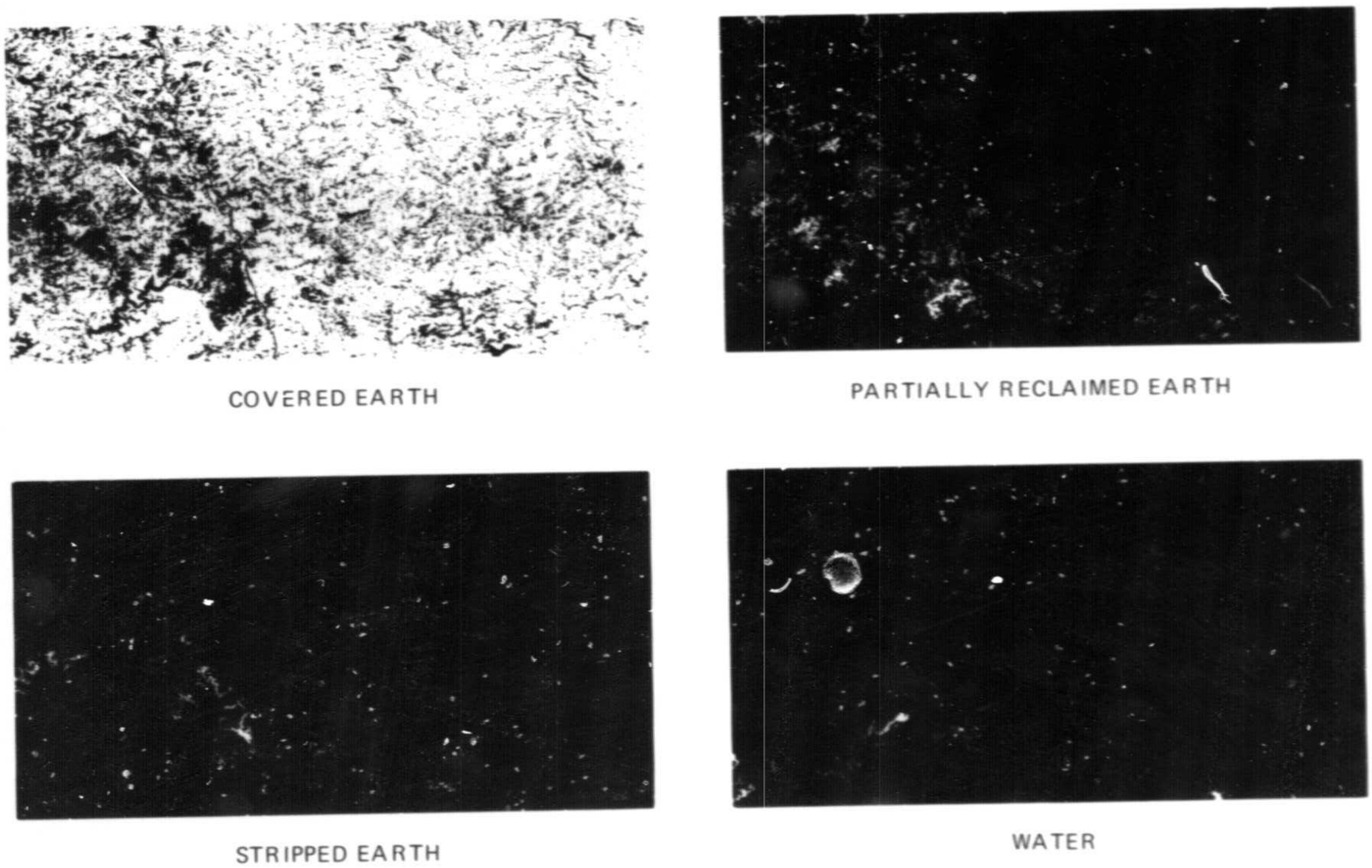
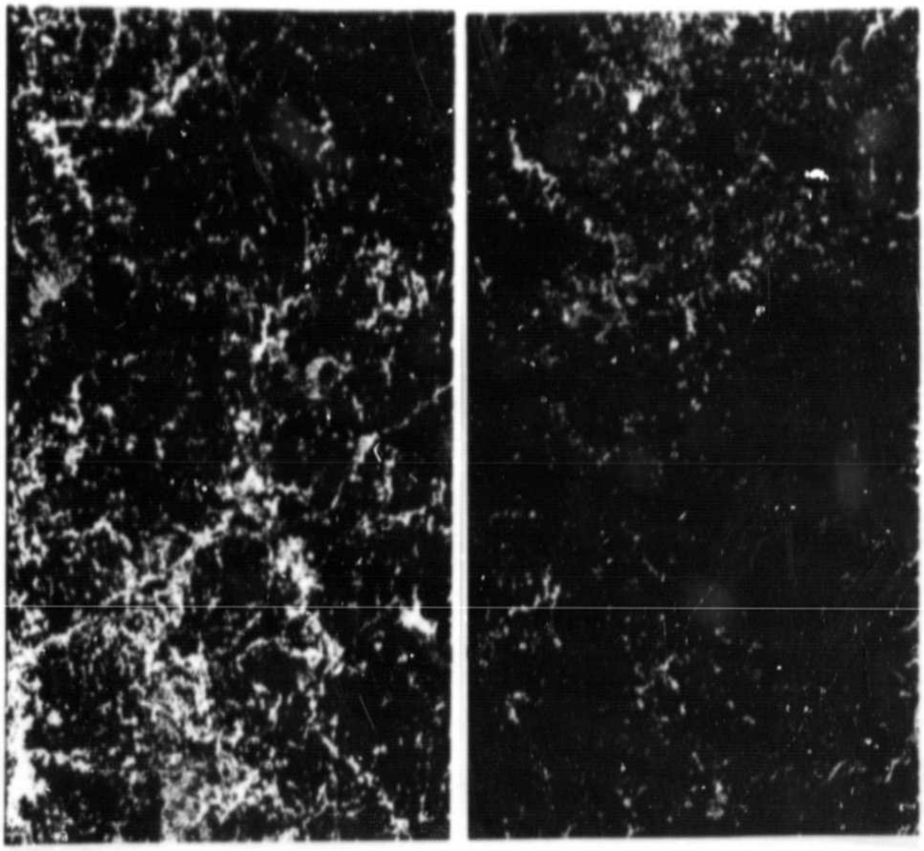


Figure 12

COLOR ENHANCEMENT OF DECISION IMAGERY
SOUTHEASTERN OHIO



BLUE - WATER
MAGENTA - PARTIAL RECLAMATION
YELLOW - STRIPPED EARTH
GREEN - VEGETATION
WHITE - OTHER

ERTS-1 Scene 1029-15361 of 21 August 1972 was processed for the above listed categories. The area imaged is located in Coshocton and Belmont Counties in Ohio, with the center point lying approximately sixty miles Southwest of Pittsburgh, Pennsylvania. Training Sets were picked from the left image and applied to the right. Only strip mine associated water categories were processed.

Figure 13

(framing camera imagery and multispectral scanner data) as well as ground observation and (it is hoped) inspection of maps prepared by the mining companies for the State of Ohio. However, the decision imagery is believed to be at worst mostly correct and at best rarely wrong in identifying either unreclaimed or partially reclaimed (less than 50%) areas.

3. NEW TECHNOLOGY

There has been no new technology developed to date.

4. PROGRAM FOR NEXT REPORTING INTERVAL

Activities over the next reporting will be directed towards; (1) thoroughly verifying the accuracy of the autographic theme extraction imagery prepared to date; (2) developing special decision imagery of types of reclamation (black locust, crown vetch) and natural recovery vegetation, and special decision imagery of categories of water within stripped areas; (3) determining the extent to which training sets derived within one tape in one scene of one cycle for one season of the year can be applied both to scenes of other seasons of the year for the test and other areas and to a scene of another cycle in the same season for the test and other areas.

These activities will require continued statistical processing of ERTS-1 imagery and possibly new processing of aircraft multispectral data. Additional ground truth will be required in verifying types of vegetation for key mines in the test area and in water quality data.

5. CONCLUSIONS

The initial goal of the study has been reached. Acreage stripped or otherwise disturbed by coal mining operations in southern and eastern Ohio has been mapped by means of autographic theme extraction (decision imagery) of ERTS-1 data. This is the disruption map of turned earth, water and poor natural recovery or poor reclamation.

It has been demonstrated that the training sets developed in one area of Ohio are applicable to other areas. Unsupervised computer decision imagery is presented in Figure 13 (right hand decision imagery) of this report.

It is anticipated that reclamation maps will be prepared in the near future because of the quality of the ERTS-1 digital data and the power of the statistical processing techniques. Confidence in the data quality and processing techniques is such that we can state that secondary effects should be detected and classified where their extent is great enough to be resolved.

6. RECOMMENDATIONS

It is recommended that ERTS-1 data be obtained outside of the test area to determine the extent to which developed training sets can be used in other stripped areas. (Objective 4 of the study).

APPENDIX

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PRELIMINARY EVALUATION OF THE OCTOBER 15, 1972 ERTS-1 IMAGERY OF EAST-CENTRAL OHIO (SCENE 1084-15415)

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Prepared in cooperation with Larry Reed and Phil Chase (PI)
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16. Abstract

This special report presents a general, physical interpretation of ERTS-1 imagery of East-Central Ohio. Special emphasis is placed upon geologic features, such as linear features and hydrologic features. Man-made features are included as a matter of interest and image location. The interpretation is compared to available maps of the area and from this an assessment that ERTS-1 is potentially useful for updating and producing geological maps.

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INTRODUCTION

The successful launch of the first Earth Resources Technology Satellite and subsequent receipt of multispectral scanner data provided investigators with an exceedingly large quantity of high resolution information that far surpassed pre-launch expectations. The ERTS imagery provides a synoptic view of a large area that, with continuous reception, will provide data on a wide range of physical, chemical, and biological conditions. Interpretation of this imagery will allow more thorough understanding and better management of our environment.

Geologic and hydrologic information obtained from a study of a single set of ERTS multispectral data (bands 4, 5, 6, and 7) allows a more realistic approach to the evaluation of and potential solutions to existing problems, such as the monitoring of strip mining. These data also permit one to examine lateral changes that occur in geologic units throughout wide areas, which might lead to the discovery of additional mineral resources, a better understanding of geologic processes, or provide clues that in selecting future highway rights-of-way will minimize slumping and maintenance costs. Data on erosion, deposition and pollution loading in streams and reservoirs are also provided. Various linear features may indicate the pattern of fractures in rocks that control the subsurface movement of fluids such as oils or water. Many other bits of information can be gleaned from a direct examination of ERTS imagery, particularly seasonal data, but sophisticated analyses of computer compatible tapes will swing wide the door to an abundance of other possibilities that will permit us to more readily understand, monitor and regulate our environment.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this report is to describe several man-made, geologic, and hydrologic features revealed on the October 15, 1972, ERTS-1 imagery (Scene 1084-15415) which covers much of east-central Ohio. The 70-millimeter negatives, representing bands 4, 5, 6, and 7, were enlarged so that each of the final prints was about 15 inches square, representing a scale of approximately 1:500, 000. For inclusion into this report, all interpreted information was transferred to Bands 5 and 7 and reduced. (Figures 1 and 2). The enlargements were made by standard photographic techniques with

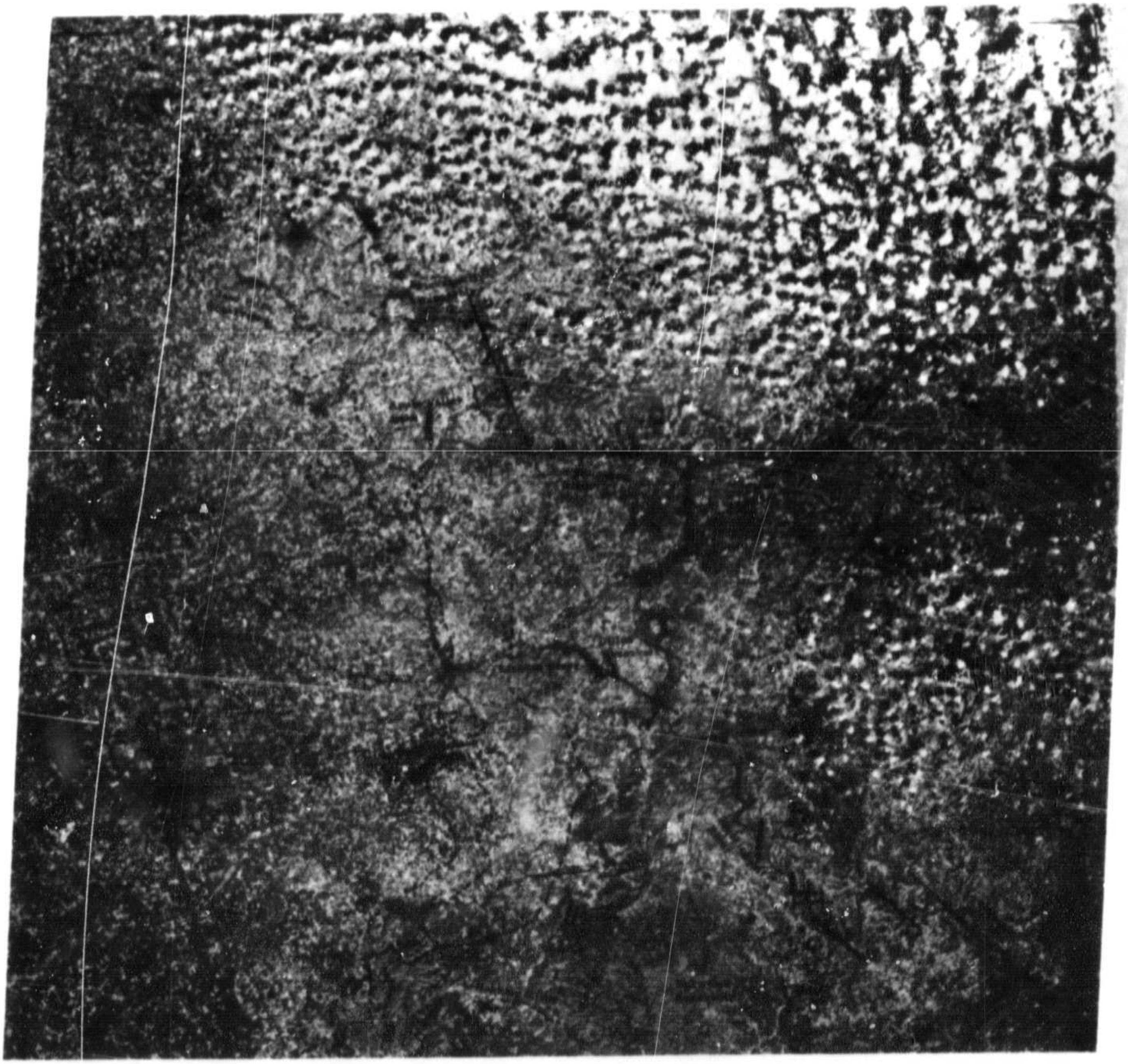


Figure 1 ERTS -1 Band 7
Scene 1084-15415

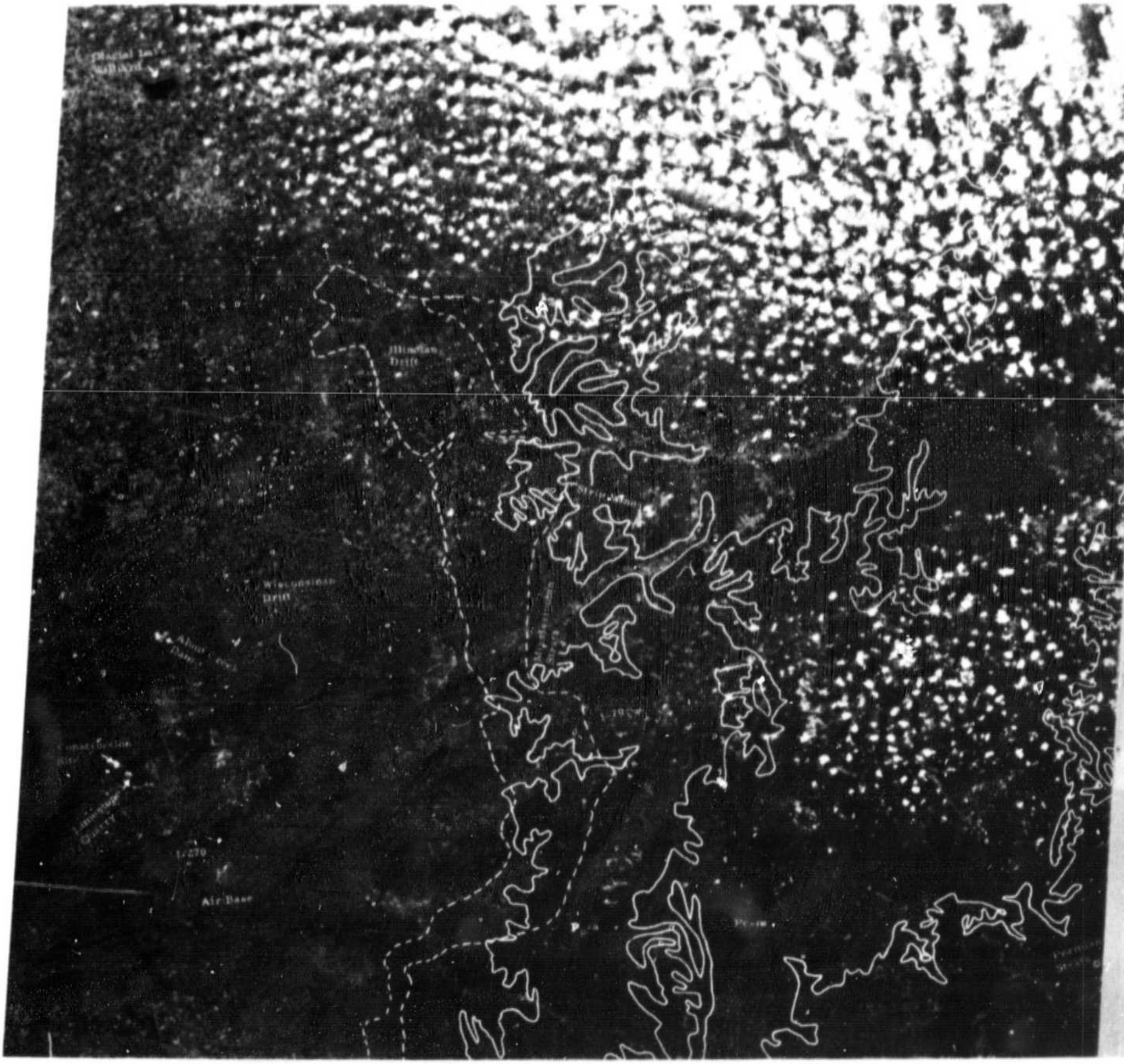


Figure 2 ERTS-1 Band 5
Scene 1084-15415

minimal quality control. Nonetheless, the final product permitted a recognition of a wide variety of features.

The imagery has about 30 percent cloud cover, much of it in the northern one-third of the area. A few scattered clouds obscure the terrain in the east-central part but elsewhere the sky was largely clear.

MAN-MADE FEATURES

Population Centers

An abundance of man-made features are readily visible on all four bands of the imagery (Figures 1 and 2). These include cities and metropolitan areas, roads, dams and reservoirs, airports, excavations, and evidence of farming practices among others. Although several cities, towns, and villages are within the area covered by the imagery, only the City of Columbus is obvious. The greater Columbus area occupies nearly all of Franklin County, which is approximately 25 miles square. The city, many times larger than any other populated area shown on the imagery, is characterized by a distinct spectral response within the area enclosed by I-270 Outerbelt, a four- to eight-lane highway that completely surrounds the city.

Bisecting the city in a generally north-south direction is I-71, while I-70 crosses the southern part in an east-west direction. These major highways consist of concrete and their spectral response contrasts with that of Route 23, (High Street) which parallels I-71. Much of Route 23 has been covered with asphalt, which very likely is the major cause of the contrast between it and most of the other streets and roads in the Columbus area.

Several obvious features enclosed by I-270 include developed and undeveloped areas, parks, golf courses, quarries, and construction sites, as well as such familiar features as airports, dams and reservoirs. A very large area presently being developed into a huge apartment complex lies in the west-central part of Columbus near I-270. Throughout this area the topsoil has been stripped, much of the underlying glacial till has been removed, and limestone is exposed in the central part of the excavation. The construction area, which appears as a very light spot on bands 4, 5, & 6, contrasts but slightly with a similar region about a mile to the southeast. The second area, which also appears as a light tone, represents a very large limestone quarry into part of which has been dumped a large quantity of lime sludge from the local water treatment plant for the past several years.

Nearly all patterns relating to land-use in Columbus are best identified by using bands 4 and 5. Bands 6 and 7 provide the greatest amount of information concerning surface water reservoirs and flooded excavations such as limestone quarries, gravel pits, and borrow pits.

Roads and Highways

Roads and highways are most evident on bands 4 and 5. The most obvious of these include the Interstate highways such as I-270, I-70, I-71, and I-77, although state routes that are at least four lanes wide are also evident. Narrower roads can be seen on the imagery in the more hilly areas in the eastern part where they cut through the unglaciated timber-covered bedrock hills.

Dam Construction

Dams and reservoirs are, of course, most obvious on the infrared bands (6 and 7) when the impoundment contains water. Location of reservoirs under construction, even though they contain no water, can be determined on the ERTS imagery. Of particular interest is the light-colored rectangular area (bands 4 and 5) located a few miles north of Columbus and just to the west of I-71. This represents the area where the Alum Creek Dam is now being constructed. All of the vegetation and soil have been removed from the site, making it a major source of sediment that washes into Alum Creek. The spillway has not been completed and water will not be impounded for several months, or possibly a few years.

Although the Alum Creek dam site has a distinctive signature due to lack of vegetation, it contrasts significantly with Apple Valley Lake, a few miles east of Mt. Vernon. This lake, which began filling in 1970, does not appear to exhibit any type of scar where the soil and subsoil was removed. Either the excavation site at Apple Valley Lake recovered rapidly or a relatively small area was affected.

Airports

Airports are most easily delineated on bands 4 and 5. Particularly obvious is Lockbourne Air Force Base south of Columbus, which appears to have three major parallel runways (northeast-southwest) intersected by north-south east-west runways. The Lockbourne area differs considerably in spectral response from either Port Columbus at the east-central edge of Columbus or Don Scott Airport in the northwest corner of the city. The runway at Lockbourne is over 12,000 feet long; at Port Columbus it is 10,700 feet long, and at Don Scott it is 4,400 feet long. Even less evident is the east-west runway south of Delaware (25 miles north of Don Scott field), which is 4,100 feet long.

Excavations

Several types of excavations can be identified by their shape, size, and location. Small rectangular areas that range from a few hundred feet to about a half mile in length, lie along I-71 north of Columbus. These areas represent flooded borrow pits that were excavated for road fill during highway construction. The fact that they are flooded, as indicated by bands 6 and 7, shows that the water table is near land surface. Other major excavations include sand and gravel pits and limestone quarries, which are especially abundant in the vicinity of Columbus. Huge flooded rectangular to pieshaped sand and gravel pits, many of which are more than a mile long, occur at the southern edge of Columbus along the Scioto River. Northward along the river, are abandoned and operating limestone quarries. Abandoned quarries are almost invariably flooded and generally are much smaller than the sand and gravel pits. They occur only where the glacial drift that covers the limestone is thin. Limestone quarries being operated are generally most vivid on bands 4 and 5 because the floors of the pits are either above the water table or are kept dry by pumps that lower the water table below the working surface. These light-colored areas (bands 4 and 5) are more irregular in shape than sand and gravel pits or the coal mines found much further to the east.

Abundant coal strip mines are revealed by the imagery in the eastern half of the area. These mines are characterized by disrupted soil and bedrock and can be accurately delineated on bands 4 and 5. Most stripped areas tend to have a dendritic pattern. Differences in strip mine tones from place to place reveal various reclamation schemes. Generally, the lightest pattern indicates the most recent stripping. In those areas that have been rather extensively reclaimed, as for example those in the southeastern part of the area, much of the lighter tone and pattern characteristics are missing.

In contrast to other disrupted areas, many of the strip mines can best be studied and delineated on bands 6 and 7. Of these, band 7 is by far the most usable. Not only is it possible to delineate areas that have been stripped, but lakes, which commonly form between the stripped area and the highwall representing unstripped material are also evident. Unquestionably, it will be possible to not only map the areal extent of strip mining, but also to evaluate the effects of reclamation.

GEOLOGIC FEATURES

Several types of geologic features (Figures 1 and 2) are evident on the imagery and it is strongly suspected that a careful evaluation of the data will provide insight into the geologic history as well as the mineral and water resources of Ohio. The imagery can be used to determine various types of linear features, such as faults and joints, aid in the mapping of various geologic formations and glacial deposits, and relate rock type or form to man's activities.

Linear Features

Although numerous linear features are evident on the ERTS imagery, their significance is not revealed by existing geologic literature dealing with Ohio. Careful study of the various patterns might lead to additional tectonic studies or a reevaluation of the potential availability of economic mineral deposits including high-yield areas of wellwater supplies.

Basically, there are two major types of linear features evident in the eastern half of the imagery of Ohio. Along a north-south strip beginning at the western edge of the imagery and extending eastward to the east margin of Columbus, are a number of lineations that trend north-south. They are exemplified by the water courses, such as the Olentangy and Scioto Rivers. Reservoirs are also aligned in the same general direction. These lineaments are probably controlled by the strike of the bedrock units. In this region, for example, the bedrock strikes in a more or less north-south direction and dips to the southeast.

In addition to the linear features related to streams flowing along the strike of bedrock deposits, are those characteristic of the unglaciated terrain in the eastern part of the State. They can be mapped by using two different techniques:

1. Linear features characterized by straight, wide, valleys. These are most readily examined on bands 4 and 5.

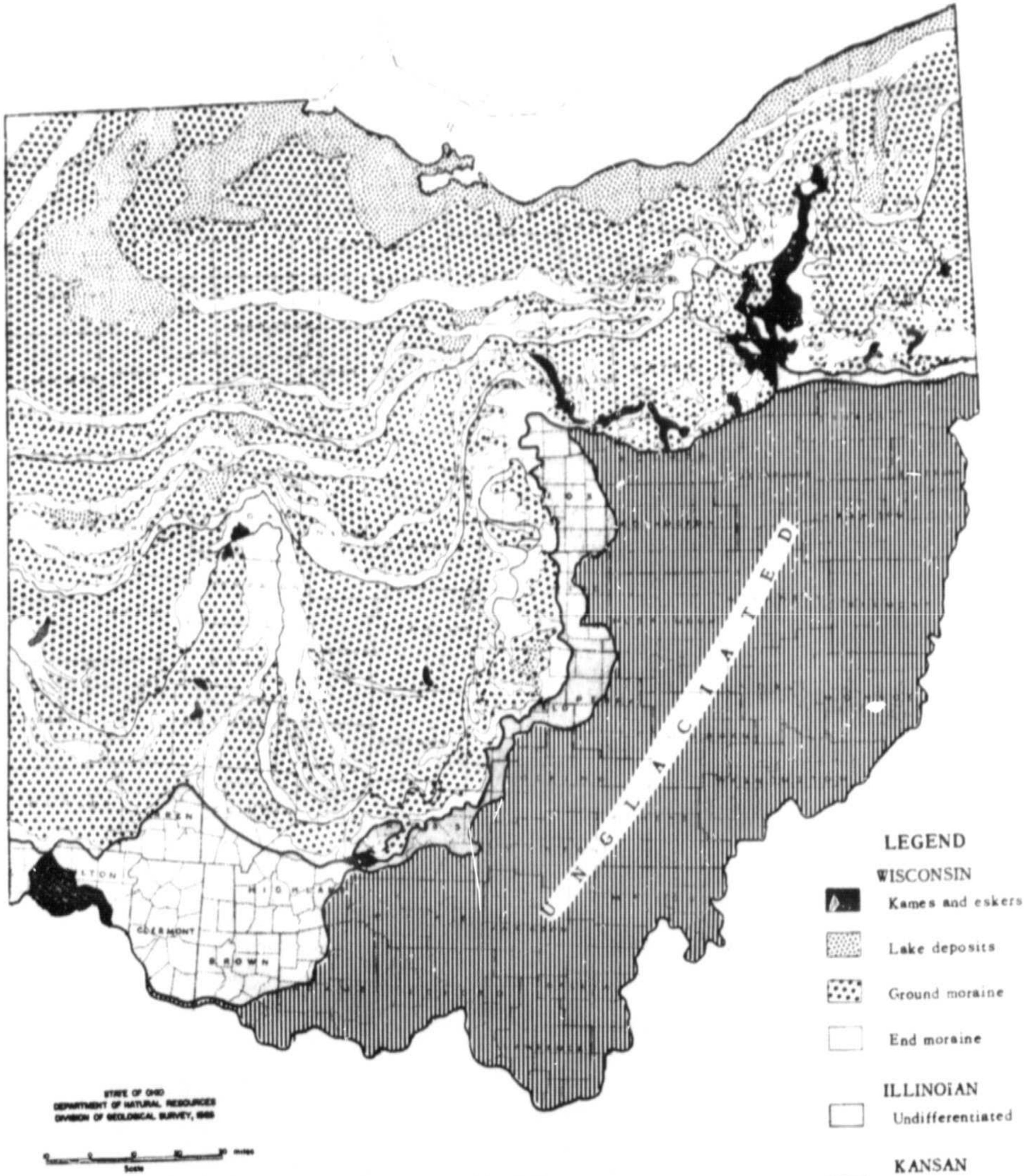
2. Straight reaches of streams and rivers in which the channels are wide enough to be delineated on bands 6 and 7.

Perhaps the best example of the first type is found in the central part of the imagery. Starting just east of Apple Valley Lake is the eastward trending valley of the Kokosing River that flows into the Walhonding. The east-west trend continues into the Tuscarawas River Valley and thence turns northeastward. This linear feature, which is nearly 50 miles long, may be structurally controlled. Similar though shorter east-west trends can be seen, among many others, in valleys south of Dillon Reservoir and along the Mohican River where it flows into Pleasant Hill Reservoir.

The second type of lineation is best studied by examining the trend of the Muskingum River. At the confluence of the Walhonding-Tuscarawas-Muskingum Rivers, the major channel extends southward. A similar parallel trend is noticed throughout many relatively short segments of the river all the way to its confluence with the Ohio River. In addition to the north-south trend, a second pattern, exemplified not only by the Muskingum and Ohio Rivers, but also by the trend of reservoirs such as Dillon, Glendening, Piedmont and Salt Fork among others, trends northwest-southeast, a third pattern trends northeast-southwest, while a fourth set extends in a general east-west direction. Interestingly enough, these trends are very similar to the joint patterns that exist, on a much smaller scale, in limestone quarries in the Columbus area.

Glaciated Areas

The western half of the area has been glaciated. (Figure 3 and broken lines on Figures 1 and 2). Glacial deposits of Illinoian age extend eastward, beyond the limits of younger deposits, to a north-south trending belt ranging from one mile to about 13 miles wide. To the west and north of this belt Illinoian deposits are covered by Wisconsinian age till and related rock types (Figures 1, 2, and 3).



GLACIAL DEPOSITS

OF

OHIO

Figure 3

The boundaries separating Illinoian till from bedrock strata and the contact between the Illinoian and Wisconsinian deposits were transposed from the Glacial Map of Ohio (Goldthwait et al, 1964) to the enlarged imagery. In many areas there appears to be good agreement between the mapped contacts and the gross spectral response of the imagery. Elsewhere the boundaries are difficult to locate. The younger drift is characterized by a rectangular or patchwork agricultural pattern showing a considerable range in tone. Although the older drift also reflects farming practices, field size, crop type, and tonal contrast are considerably reduced compared with conditions in younger drift areas.

In most areas that include the drift-bedrock border, changes in relief between the two regions are quite distinct, with bedrock areas showing considerable difference in topography as exemplified by road patterns, stream valleys, and relatively steep slopes. It should be borne in mind, however, that the easternmost part of the Illinoian drift was mapped in the field on the basis of soil characteristics, boulders and thin patchy deposits of till. The boundary is difficult to locate in the field because most of the land forms are more typical of bedrock than of glacial deposits. In view of this problem it is little wonder that it is difficult to accurately locate this particular boundary on the imagery.

Several Wisconsinian end moraines, which arc to the south and west in the western part of the area, can be fairly accurately mapped on ERTS imagery. The moraines generally appear as narrow (1 to 3 miles) bands that are lighter than the surrounding terrain. This is due, in part, to the greater depth to the water table in the topographically higher belts compared with that in the lower-lying ground moraine. Many of the agricultural fields, both on end moraines and ground moraines, are drained by field tile systems.

Glacial lake deposits form generally wet areas that have a high organic content, and appear on the imagery as dark or black areas, especially on bands 5, 6, and 7. By far the most obvious of these deposits on the imagery is glacial Lake Willard (northwest corner), which is bounded by two end moraines. These lake deposits, which consist of a very rich black and wet organic soil, are heavily farmed and are the basis for a major celery growing region. Individual rectangular fields are readily visible on all channels, but particularly on bands 6 and 7.

Partially filling the valleys of parts of the Tuscarawas, Muskingum, and Scioto Rivers, are extensive deposits of outwash. These water-saturated sand and gravel deposits tend to have fairly distinct patterns and tones. The patterns reflect the topographic expression of the deposits while the differing tones seem to indicate changes in both lithology and moisture content. These features are best depicted on bands 5, 6, and 7. Similar signatures typify alluvial deposits along Alum Creek and the Walhonding, Tuscarawas and Muskingum Rivers.

Unglaciated Areas

Bedrock formation boundaries were transferred from the Geologic Map of Ohio (Bownocker, 1920) to the imagery. The geologic map is greatly in need of revision and, because of this, many contacts are subject to change. Bedrock deposits east of the Illinoian drift border consist of southeastward dipping Mississippian-age shale, sandstone, and limestone (Figure 4 and broken lines in Figure 2). Further east these strata are covered by the Pottsville and Allegheny Formations of Pennsylvanian age, consisting of coal, sandstone, shale and limestone. The Pottsville and Allegheny Formations, in turn, are concealed still farther to the east by interbedded layers of shale, sandstone, coal, and limestone of the Conemaugh and Monongahela Formations. The youngest bedrock unit is the Dunkard Group of Permian age that consists of shale, sandstone, and coal. Thirty-eight coal seams in the Pennsylvanian and Permian rocks have been named, and there are several other thinner units. Some of these coal beds have been mined since 1804.

The bedrock formations are similar in lithology and it is surprising to find that it is possible to delineate several of these on the ERTS imagery.

Mississippian strata appear to have a subdued relief and may appear darker than adjacent deposits. Pottsville and Allegheny strata contain an abundance of strip mines, are commonly lighter, and show a different relief pattern and tone than either the Mississippian rocks or the Conemaugh and Monongahela formations to the east. The latter two units also support many strip mines but their most distinctive characteristics are their more rugged terrain and herringbone-like pattern along the major drainage ways. Although at first glance, the spectral response of all the formations seems subtle, a careful examination shows the features to be quite distinct. The Dunkard strata, which are exposed along the Ohio River in the southeast part of the area covered by the imagery generally tend not to show abrupt changes in relief and appear flatter with a much lighter tone. On band 5 the tones are lighter than for any other bedrock type.

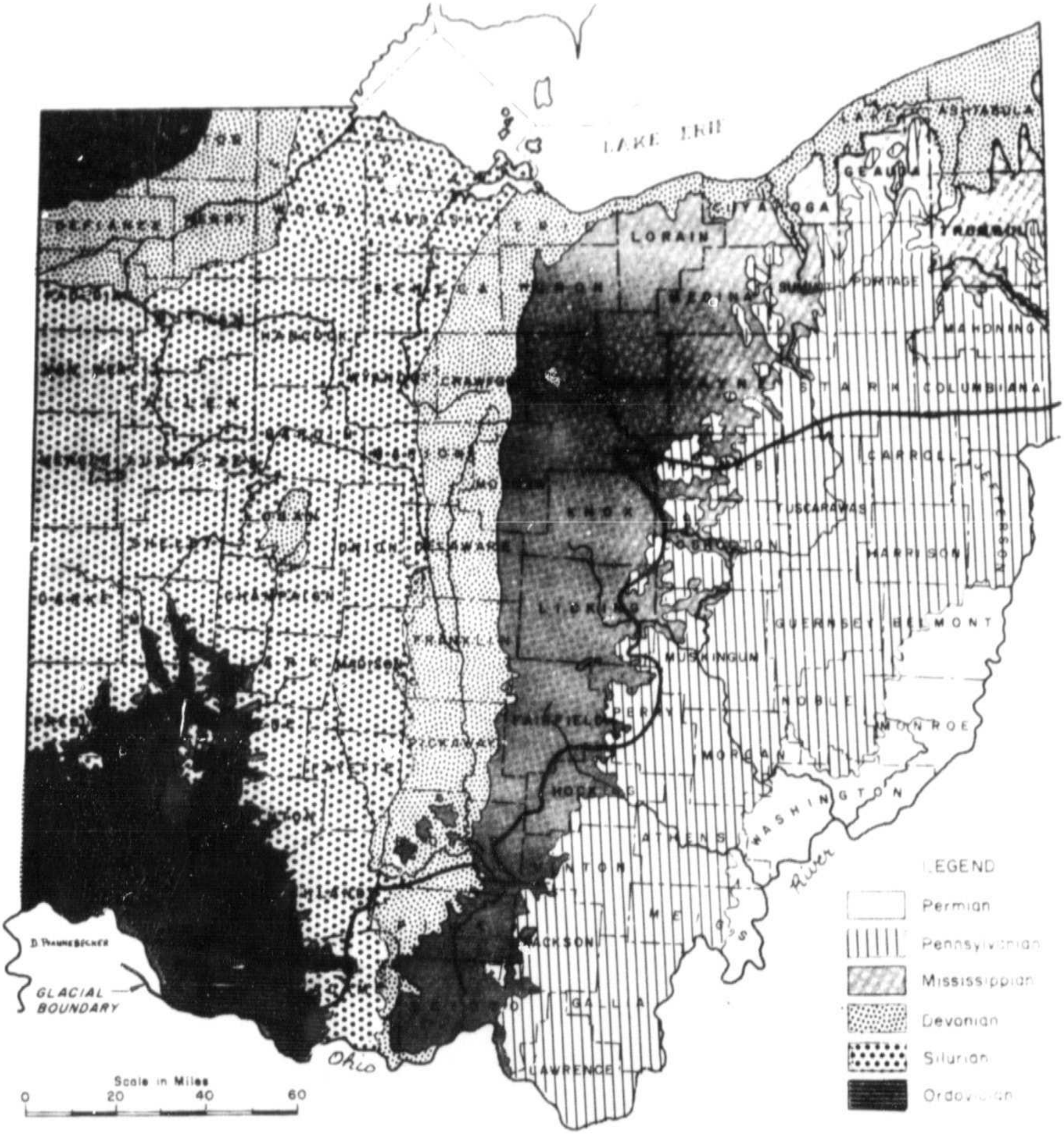


Figure 4 Geological Map of Ohio

The features that help in distinguishing between these major rock units depend in large part on the percentage and thickness of individual layers, which account for changes in relief, moisture content, slope and vegetation.

HYDROLOGIC FEATURES

Ancient Drainage Patterns

The major drainage pattern in Ohio was considerably different in past geologic ages than it is at present. Before the Ice Age, major tributaries flowed into the Teays River system of which the master stream flowed northwestward from the vicinity of Portsmouth into Indiana south of Ft. Wayne. Several large streams of this system drained much of what is now east-central Ohio (Figure 5). East of the glacial drift borders, the channels of a few of these rivers are still evident, in the form of wide, flat-bottomed valleys, containing underfit streams. Elsewhere the valleys have been filled with glacial materials and can only be located by test drilling.

Where there is some topographic expression, the ancient valleys can be easily mapped on ERTS imagery. An excellent example is the valley of the former Cambridge River that had its headwaters in Tuscarawas County (Figure 5). The drainage was blocked during the Ice Age and the modern Tuscarawas River flows through much of the ancient channel. The upper part of the Muskingum River also occupies a short reach south of Coshocton. The former river turned southwestward a few miles south of Coshocton and continued to Newark, where it was joined by the ancient Groveport River. From Newark the Cambridge River flowed south toward the west end of what is now Buckeye Lake, but its exact course is hidden by glacial till. The upper reaches of these ancient river systems can easily be delineated on the imagery using, in order of decreasing effectiveness, bands 5, 4, 7, and 6.

Where the valleys have been hidden by an infilling of glacial till, their trend is largely obscured. Some subtle tonal differences on all four bands, however, may be used to locate them. Additional work along these lines is urgently needed as these valleys commonly contain extensive deposits of saturated sand and gravel that offer a large potential for water-supply development. Presently, the search for them is based entirely on test drilling, which is extremely expensive and time-consuming.

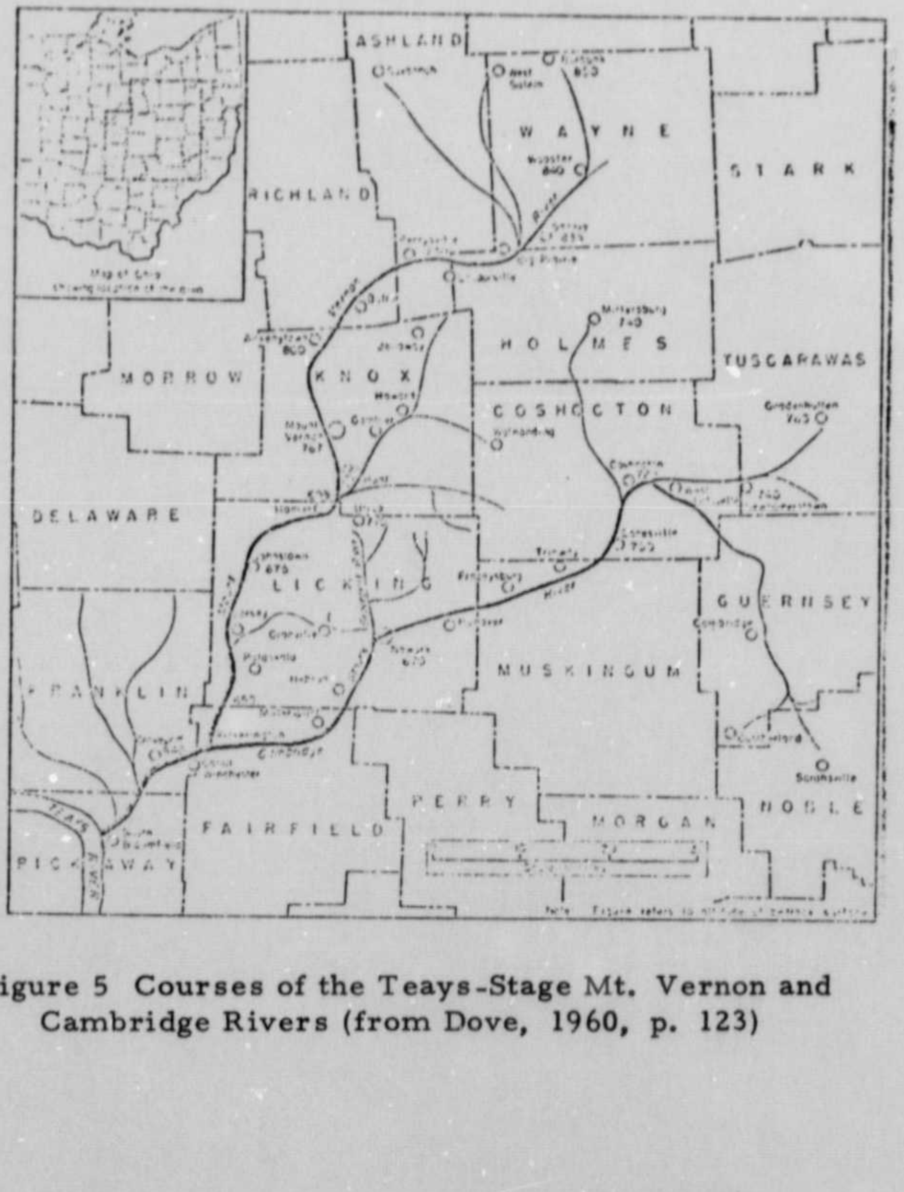


Figure 5 Courses of the Teays-Stage Mt. Vernon and Cambridge Rivers (from Dove, 1960, p. 123)

Reservoirs

Although reservoirs can be clearly distinguished on bands 6 and 7, there are obvious to subtle differences between them on bands 4 and 5. Data concerning the reservoirs are shown in Table 1.

Perhaps one of the most interesting water bodies is Buckeye Lake, which is clearly discernible on all four bands. Buckeye Lake is very old and represents the remains of an old canal. In fact, a careful examination of band 6 or 7 permits one to trace the former tow path along the canal. Water has been impounded at the site since 1832.

Owing to its age and the abundance of homes along the shore, probably all of which use septic tanks or cesspools that ultimately drain into the lake, Buckeye Lake is characterized by an abundance of algae. Thick deposits of rich organic mud cover much of the bottom. Moreover, peat deposits that underlie the lake, commonly break free and float to the surface during the summer, affording a hazard to boaters and water skiers. Additionally, the water is highly turbid due to the abundance of suspended mud and algae. These conditions account for the unusual signature of Buckeye Lake.

In contrast to Buckeye Lake is the recently developed Apple Valley Lake near Mt. Vernon. This small reservoir shows up on all four bands, although the impoundment is only two years old. Perhaps the signature of Apple Valley reflects an abundance of sediment and organic matter due, not to aging, but to the inwash of material as the surface area of the lake continues to grow.

Reservoirs that lie on agricultural areas of low relief, typical of till plains, are difficult to identify on bands 4 and 5 in contrast to those in hilly eastern regions. Very possibly the tonal differences are related to sediment content and turbidity of the reservoirs and the streams that feed them. The streams in the glaciated areas appear to carry a greater, though finer, sediment load than those in bedrock regions. One would also suspect a greater nutrient concentration due to fertilizers and sewage in the eastern agricultural areas.

Recent convective storms or frontal precipitation may account for some of the differences in reservoir spectral response. For example, Senecaville Reservoir, although clearly discernible on bands 6 and 7, is nearly invisible on band 5. This contrasts with such reservoirs as Salt

Reservoir	Date	Bedrock				Glacial		Evident in Bands			
		Dev.	Miss.	Pp-a	Pc-m	Wisc.	Ill.	4	5	6	7
Apple Valley	1970		X[3]				X		X	X	X
Buckeye[5]	1832		X[3]			X		X	X	X	X
Burr Oak	1952			X						X	X
Charles Mill	1936		X[3]			X				X	X
Clear Fork	1953		X[3]			X				X	X
Clendening	1937				X				X[1]	X	X
Deer Creek	1968	X[3]				X				X	X
Delaware	1947	X[3]				X				X	X
Dillon	1959			X						X	X
Griggs	1908	X[3]				X			X[2]	X	X
Hoover	1955	X[3]				X		X	X[2]	X	X
Knox[4]	1954		X[3]			X			X	X	X
Lake Logan	1955		X							X	X
O'Shaughnessy	1925	X[3]				X			X[2]	X	X
Piedmont	1937				X			X	X[1]	X	X
Pleasant Hill	1938		X[3]			X			X[2]	X	X
Salt Fork	1967			X					X[1]	X	X
Senecaville	1937				X			X	X[2]	X	X

1. Shallow part of reservoir not evident in this band.
2. Evident but very difficult to delineate on this band.
3. Age of bedrock underlying glacial deposits; may crop out in or along reservoir.
4. Filled in 1949, drained, 1950, refilled, 1954.
5. Former canal.

Dev. - Devonian
Miss. - Mississippian
Pp-a - Pennsylvanian; Pottsville, and Allegheny
Pc-m - Pennsylvanian; Conemaugh, and Monongahela

Table 1. Reservoir Data

Fork, Piedmont and Clendening, which lie a few miles to the north and can be easily delineated on band 5. These four water bodies occur in very similar geologic and topographic terrain. In spite of a few obvious difficulties, a great deal of information concerning reservoirs could be retrieved from further study of ERTS imagery.

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