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MAPPING OF ANTHRACITE REFUSE

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INTERDISCIPLINARY APPLICATION AND INTERPRETATION OF ERTS DATA WITHIN THE SUSQUEHANNA RIVER BASIN

Resource Inventory, Land Use, and Pollution

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MAPPING OF ANTHRACITE REFUSE

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One of the most serious land reclamation problems facing Pennsylvania and other coal-producing areas is the accumulation of wastes from coal mining and processing. After separation of the marketable coal from the slate, shale, and low-grade coal, these coarse-textured wastes have most often been simply piled in the nearest accessible place, creating virtual mountains of barren black refuse. Finer-textured material is transported in hydraulic suspension and accumulated in large settling basins. Conspicuous in both size and ugliness, such refuse piles contribute both silt and acid pollution to streams. Some have caught fire, producing sulfur dioxide air pollution; blowing silt from settling basins is also a locally severe problem. These difficulties are compounded by the fact that most of the waste accumulations are either within or very close to towns or cities.

Although the coal waste is a potentially valuable resource and much of it may eventually be used, the problems it creates demand more immediate solution. Effective reclamation programs are likely to involve reshaping of the piles, treatment to ameliorate adverse chemical and physical conditions, and establishment of vegetative cover. Planning and implementation of such programs will require the development and periodic updating of inventories of the number, extent, and location of areas in need of reclamation. Because such inventories would be needed on a regional scale and because of the need for periodic updating, it was felt that ERTS-1 multispectral scanner (MSS) data would be an ideal source of the needed information. A study of the feasibility of such an applied use of ERTS-1 data is now in progress.

Site Selection

An area including the southern and middle fields of the Anthracite Coal Region of eastern Pennsylvania (Figure 1) was chosen as representative of those areas most seriously affected by mining. The anthracite

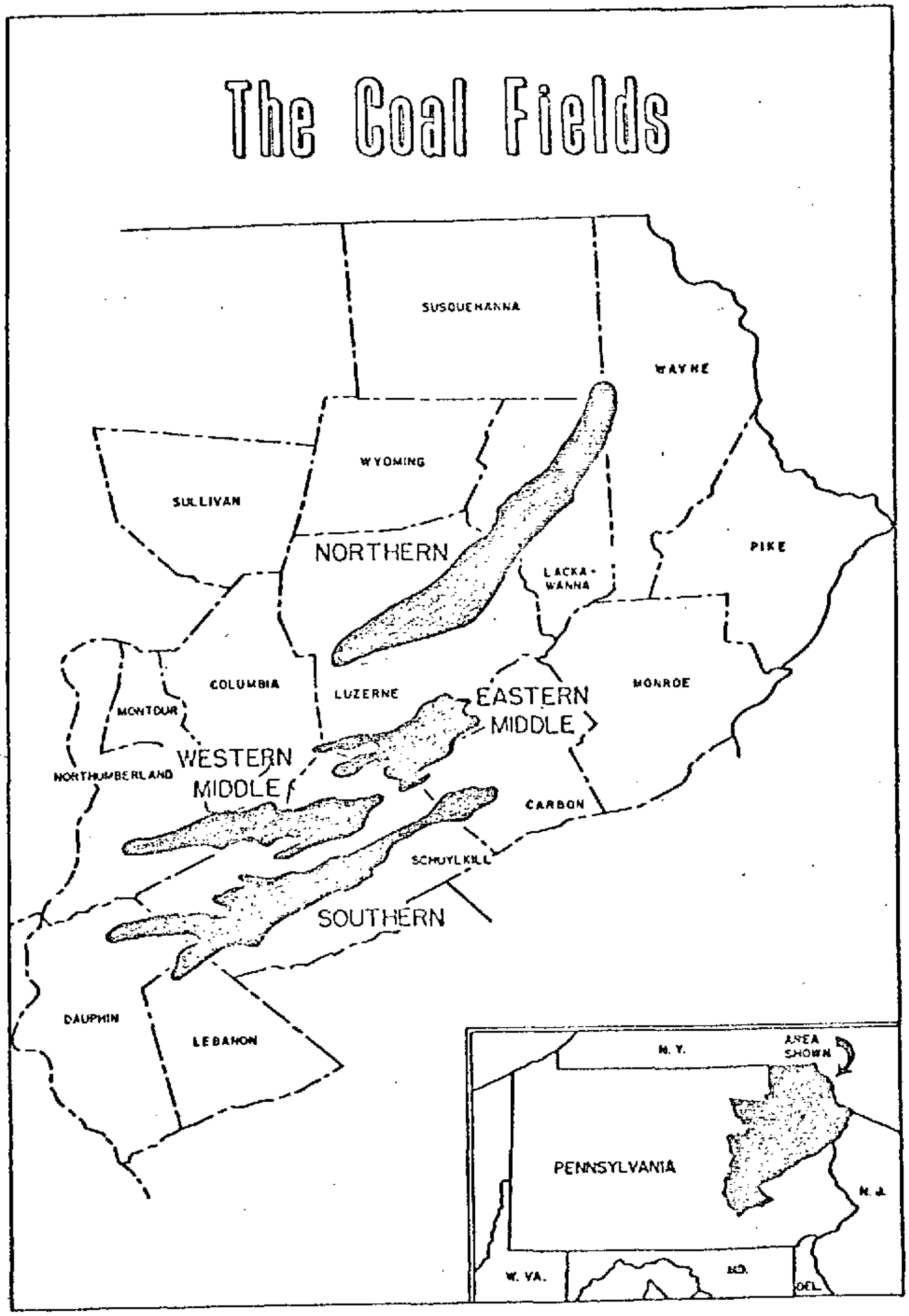

Figure 1: The four major coal fields in the Anthracite Coal Region of Pennsylvania. (Figure 4, p. 6, of Frank, 1964.)

coal fields are relatively compact areas with well-defined boundaries; they have been the subject of several studies that were expected to be helpful in the verification of our results. All data analysis has been by computer processing of digital MSS data using the active program package developed by ORSER. Thus far, data from only a single scene have been utilized, that of October 11, 1972 (scene number 1080-15185).

Preliminary Investigation

For the initial phase of the investigation, the eastern tip of the Southern Anthracite Field was selected for intensive study. This relatively small area, shown as Area 1 in Figure 2, is bounded by mountain ridges and includes the coal-mining towns of Nesquehoning, Summit Hill, Lansford, Coaldale, and Tamaqua. All of these towns have locally extensive refuse accumulations and substantial segments of the surrounding land have been strip-mined.

Procedure

The first step in analysis was production of an intensity map using the NMAP program[1], which maps the total reflectance recorded in the four channels on the data tape. After adjustment of the program parameters, this map clearly delineated the mountain ridges and the Lehigh River valley, permitting accurate orientation with respect to features seen on the USGS 7 1/2 minute topographic maps. Additional digital maps were then produced using the UMAP program, which identifies areas of comparative local uniformity of spectral response. By inspection of these uniformity maps in conjunction with both the intensity maps and the topographic maps, initial training areas for determination of spectral signatures were selected. These areas were thought to represent reservoirs, coal refuse accumulations, silt basins, towns, strip-mines, and several vegetation types. Since no underflight data were available, few targets could be identified unequivocally and some guesswork was involved.

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[1] Program descriptions may be found in ORSER-SSEL Technical Report 10-73.

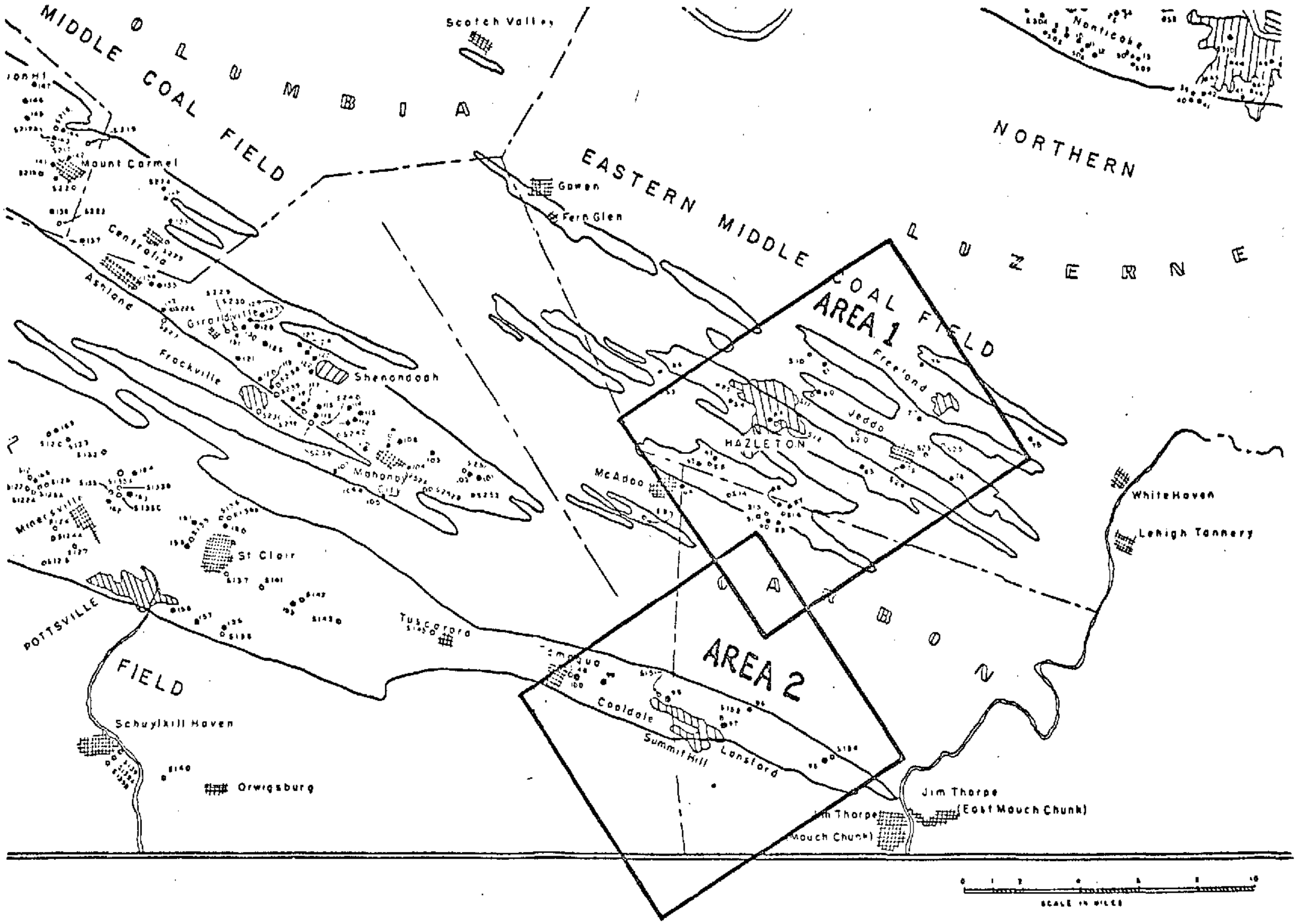

Figure 2: The two areas of preliminary investigation. (Shown on a base map from Peters, Spicer, and Lovell, 1968, p. 38.)

Using these signatures, the first trial classification maps were produced. The euclidean distance classifier called DCLASS treats each data point or category-defining spectral signature as a point in four-dimensional space. Each data point is assigned to that category for which the euclidean distance between the points is minimum, providing the distance is less than some specified critical value. A different critical value was specified for each category based on its minimum distance from any other category with a different mapping symbol. Without underflight coverage, known target areas could not be defined by photointerpretation. Most additional category-defining signatures were therefore developed using a cluster analysis algorithm (the DCLUS program) for small areas of interest. The categories thus defined were identified by inference from the pattern of their spectral response and by reference to the topographic maps. A profusion of signatures was developed in this manner and then reduced to manageable proportions by grouping those with very small calculated distances of separation. Signatures so determined were added to the original classification categories and additional digital maps were produced. The foregoing procedure was reiterated several times until a reasonably satisfactory map of the area was obtained. Particular importance was placed on the correct mapping of the coal refuse and silt.

The study was then extended to the second area shown in Figure 2, which includes the communities of Hazleton, McAdoo, and Freeland, as well as vast deposits of coal refuse. Using the same set of categories, with signatures based on targets in Area 1, digital maps of Area 2 were obtained.

Results

The classification map of Area 1 is shown in Figure 3. (It should be noted that although the working map was in digital form, the map displayed in this figure, and those following, has been plotted from the digital map using the LMAP program. This program corrects for the line and element distortion inherent in the digital output.) All known coal refuse piles and silt basins, as determined from topographic maps and from previous studies (Peters, Spicer, and Lovell, 1968; Frank, 1964),

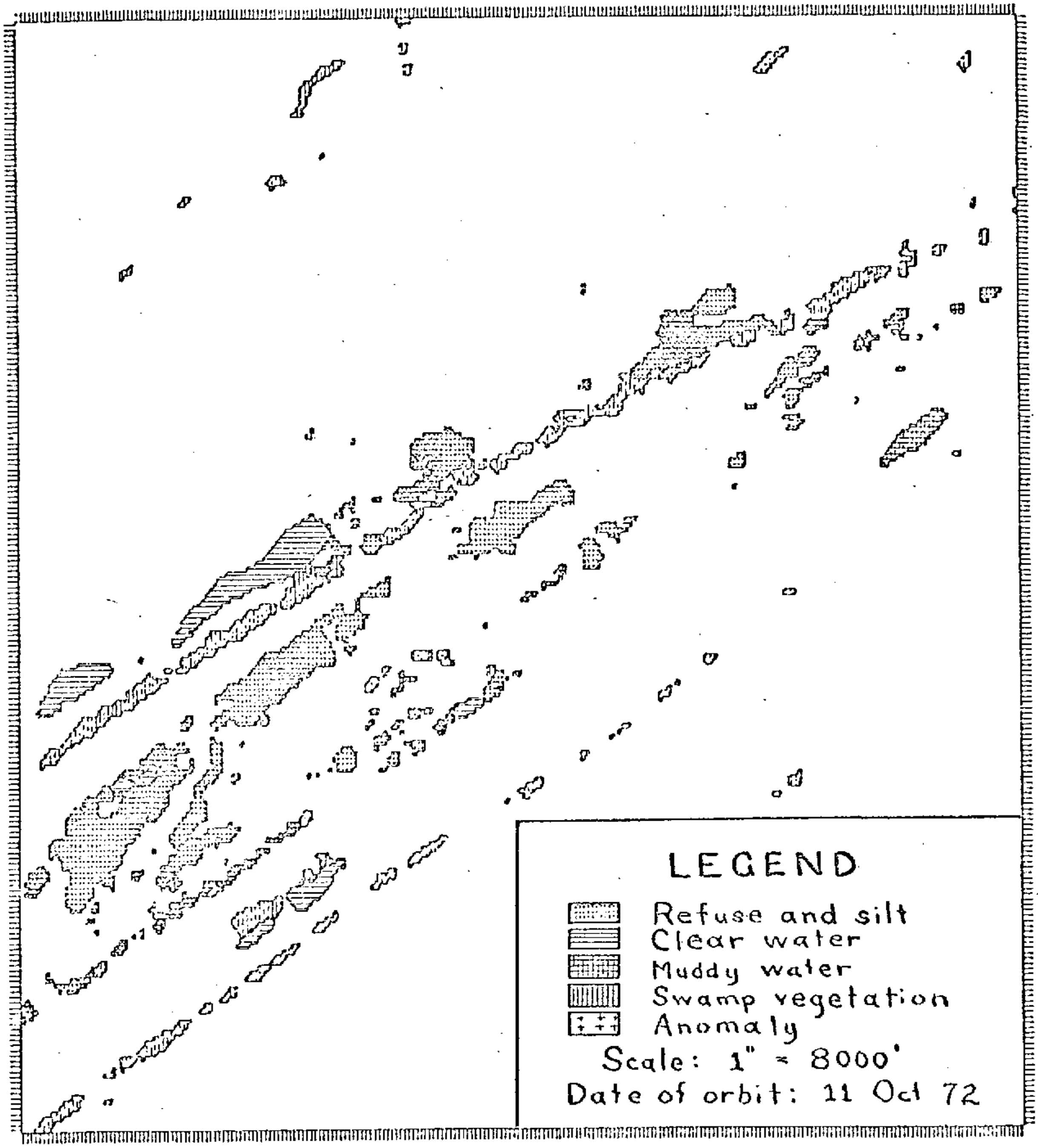

Figure 3 : Computer map generated from ERTS-1 data, showing coal refuse accumulations in the east end of the Southern Anthracite Field.

were mapped as either refuse or silt. There was some confusion between these two materials since they are similar in composition and color, differing primarily in texture. Confusion also occurred where the nearly black carboniferous rocks associated with the coal measures have been exposed by strip-mining. Such strip-mine spoil, being the same geologic material as most of the coal refuse, has roughly the same pattern of reflectance. Consequently, some areas of unreclaimed black strip-mine spoil were mapped incorrectly as coal refuse. Although unfortunate, this consequence may not be serious, since the same kinds of environmental and reclamation problems are involved in either case. One lake, near the east-central edge of Figure 3, was first identified as coal refuse, but seemed anomalous because of its location on the opposite side of a ridge from any other evidence of mining. Because its spectral signature, as determined by cluster analysis, was intermediate between those of coal refuse and water, it was tentatively called muddy water. Although no impoundment showed on the topographic map, subsequent on-the-ground inspection confirmed the existence of a newly constructed dam and lake. Other small water bodies that showed on the digital maps, but not on the topographic maps, were determined to be water-filled abandoned strip-mine pits.

A computer-generated map of Area 2 is shown in Figure 4. The results were similar to those from Area 1, with all known refuse piles and silt basins again mapped successfully. Water bodies were easily identified, including several more not shown on the topographic maps. All towns and cities in both areas were also mapped correctly and four-land highways could be discerned where they traverse forested areas. The problem of some strip-mine spoils being mapped as coal refuse persisted, although its true severity cannot be evaluated until underflight photographic coverage of the area is available. The only other major shortcoming in this phase of the analysis was a three-way confusion among some strip-mines, towns, and agricultural areas. As previously stated, the towns themselves were mapped almost entirely correctly. However, some strip-mines and much farmland were also mapped as towns. The inverse of this incorrect classification is not a problem, as strip-mine and vegetation symbols rarely occurred in anomalous places.

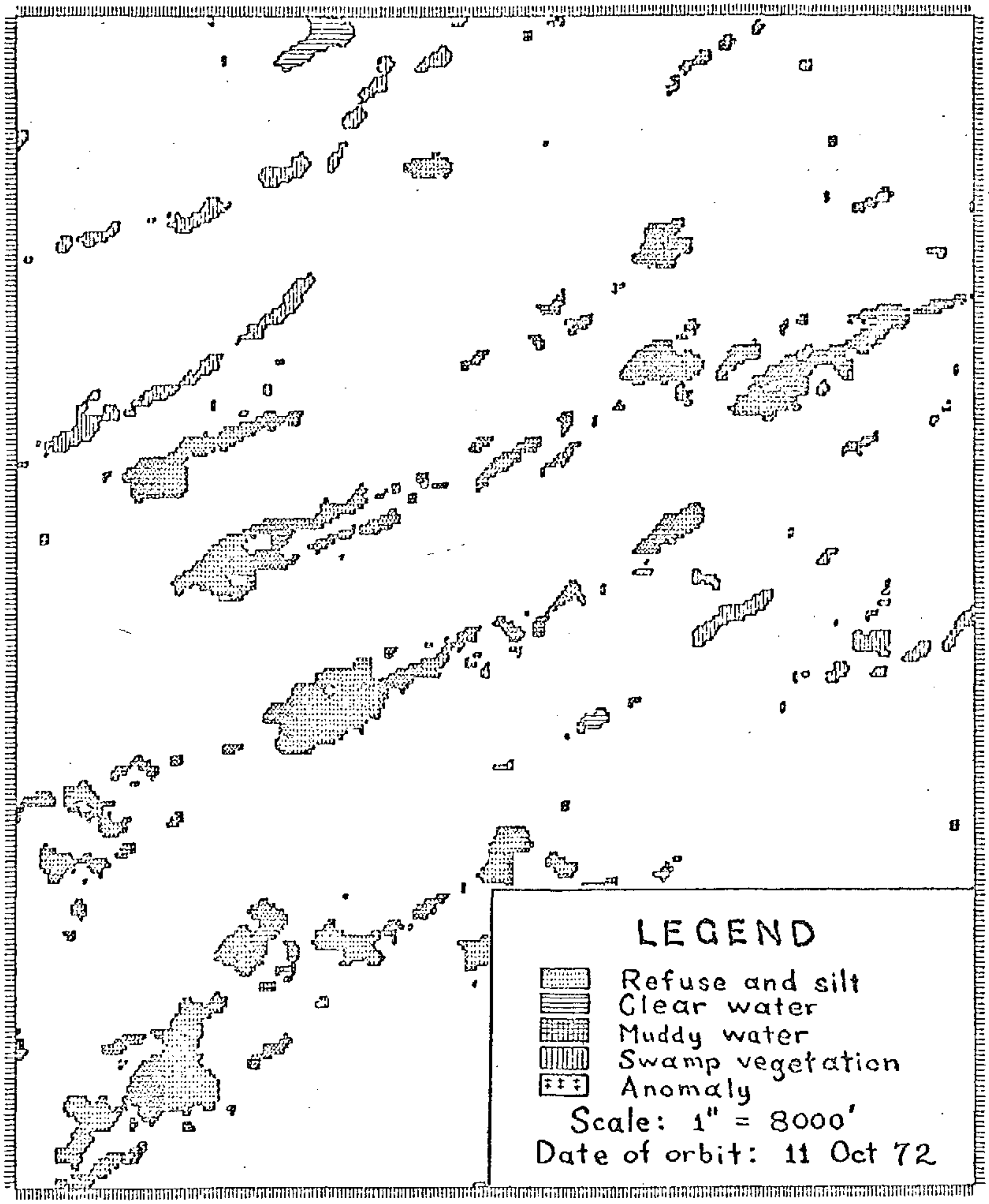

Figure 4 : Computer map generated from ERTS-1 data, showing coal refuse accumulations in the eastern end of the Eastern Middle Anthracite Field.

Application

The basic intent of the application phase of this study was to produce working maps of the location and extent of coal refuse and silt accumulations in the Middle and Southern Anthracite Fields. Such maps should be useful to mine inspectors, land reclamation and water pollution control personnel, and the mining industry.

Procedure

The study area, as shown on the map of the Anthracite Region in Figure 5, was subdivided into 27 mapping blocks; each approximately 7 by 8.5 miles. The size was chosen for convenience: it kept the computer printout for each block small enough to handle easily and to reduce to a convenient scale for publication. Digital maps of each block were produced using the same classifier and, at first, the same set of categories as in the preliminary investigation. Because of the large area involved, substantial portions could not be classified and there were many seemingly anomalous classifications. The cluster analysis procedure was employed in these cases to identify additional categories, which were then used in subsequent mapping. In addition, several signatures obtained in a study of the Harrisburg area (see "Land Use Mapping" by Borden, et al., in the chapter on tasks) were added to the list of categories. This area overlaps the southwestern tip of the coal region study area. The current list of categories, presented in Table 1, includes 59 distinct spectral signatures representing 13 different mapping categories. Representative spectral patterns for several categories are plotted in Figure 6. As the set of signatures was expanded and refined, additional maps were produced and features such as towns, lakes and reservoirs, mountain ridges, and coal refuse accumulations were identified by correlation with the topographic maps.

Results

The principal result, to date, of the application phase of this study was a set of 27 character maps, one for each of the 27 mapping blocks shown in Figure 5. A line map (generated from the digital map

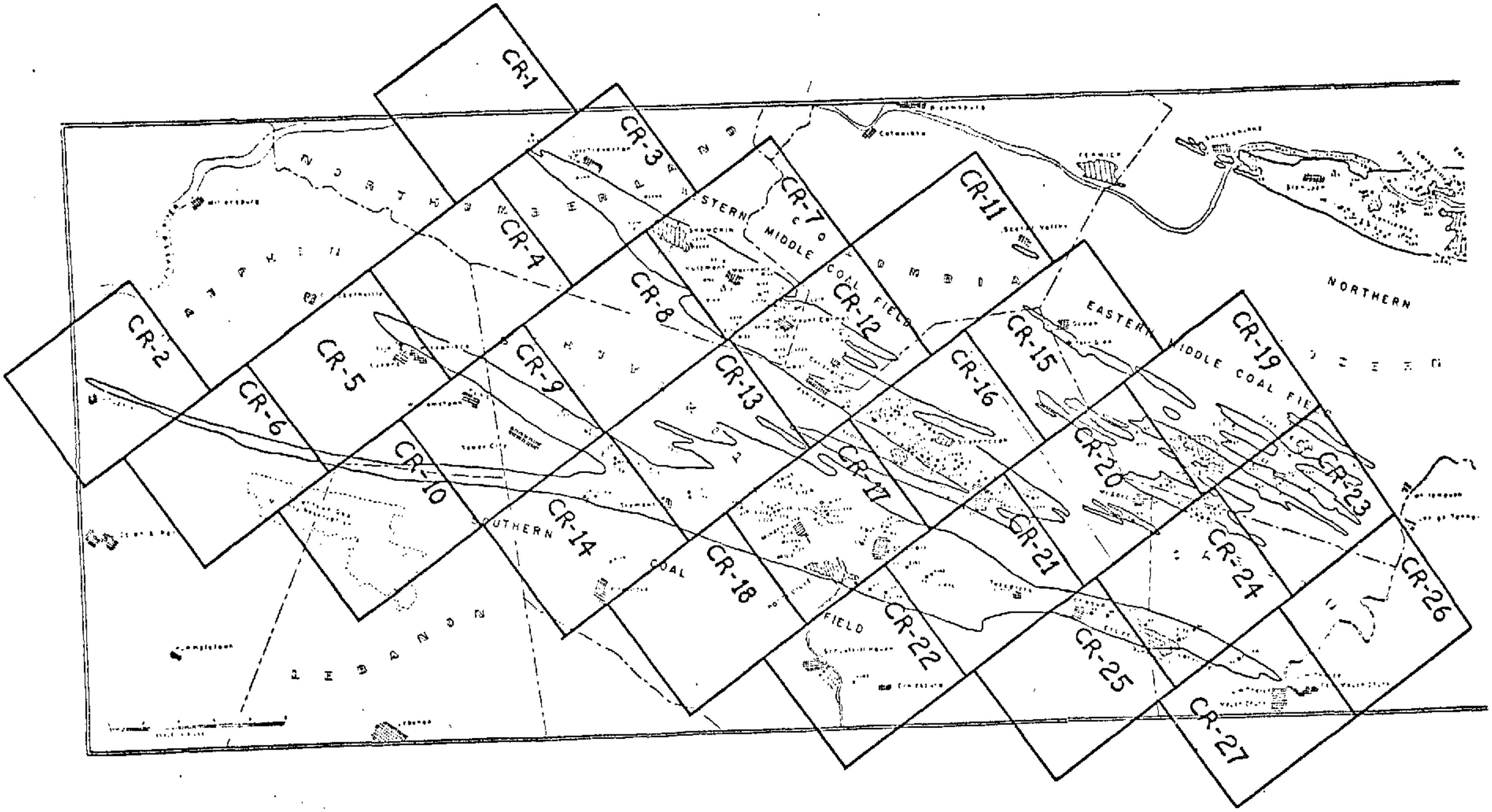

Figure 5 : Mapping blocks used in the application phase of the study. (Shown on a base map from Peters, Spicer, and Lovell, 1968, p. 38.)

Table 1: List of Categories and Spectral Signatures

Category Number	Category Name	Classifying Limit	SPECTRAL SIGNATURE Channels 1	2	3	4
1	CLEAR WATER	6.7	16.79	7.57	4.79	0.69
2	TURBID WATER	5.5	16.40	8.16	5.87	1.42
3	RIVER WATER 1	2.8	16.36	8.63	8.96	3.43
4	MUDDY WATER 1	3.3	20.12	15.67	10.10	1.98
5	RIVER WATER	4.5	18.31	9.90	6.03	0.89
6	MUDDY WATER 2	1.6	18.76	10.38	8.33	2.86
7	MUDDY WATER 3	1.3	19.08	11.92	11.08	3.92
8	MUDDY WATER 4	5.7	23.85	14.23	7.88	1.54
9	REFUSE 1	3.4	20.88	14.43	12.34	4.42
10	REFUSE 2	3.2	20.23	13.39	13.32	5.26
11	REFUSE 3	4.7	21.77	15.59	14.73	5.84
12	REFUSE 4	1.3	19.73	12.99	11.04	3.66
13	REFUSE 5	2.1	24.37	19.50	17.11	6.49
14	SILT 1	1.6	18.49	10.79	9.79	3.26
15	SILT 2	2.8	16.50	9.58	11.33	4.58
16	STRIPMINE 1	2.1	24.44	19.50	18.80	7.69
17	STRIPMINE 2	3.1	29.20	26.66	24.92	9.92
18	STRIPMINE 3	3.2	26.10	22.82	24.55	10.79
19	STRIPMINE 4	3.6	32.62	31.46	31.70	14.77
20	STRIPMINE 5	3.7	30.58	29.42	28.33	11.65
21	STRIPMINE 6	3.5	21.02	15.47	18.47	8.54
22	INDUSTRY 1	3.1	28.75	24.50	22.92	9.00
23	INDUSTRY 2	3.2	26.97	21.87	20.70	8.74
24	INDUSTRY 3	12.0	42.00	38.00	30.33	11.33
25	BARE SOIL	15.2	36.00	41.33	42.50	17.00
26	TOWN 1	3.6	33.21	28.67	30.12	13.32
27	TOWN 2	3.2	25.23	19.48	21.46	9.70
28	TOWN 3	3.2	27.57	22.38	26.62	12.69
29	TOWN 4	3.7	24.56	20.51	27.33	14.08
30	TOWN 5	4.0	24.50	19.26	23.74	11.42
31	TOWN 6	3.9	24.05	18.97	26.45	13.61
32	TOWN 7	1.8	21.26	13.78	26.08	14.70
33	TOWN 8	3.3	24.81	18.08	27.73	15.00
34	TOWN 9	3.2	30.14	27.14	37.14	19.00
35	TOWN 10	3.5	26.40	21.80	28.20	13.90
36	ROAD 1	5.3	28.82	25.45	30.73	15.32
37	ROAD 2	3.5	26.50	23.18	30.64	16.02
38	ROAD 3	4.7	27.42	23.47	31.68	16.84
39	BRUSH 1	3.3	25.08	19.77	30.19	16.27
40	BRUSH 2	5.0	24.41	19.62	32.64	18.50

(Continued)

Table 1 (Continued)

Category Number	Category Name	Classifying Limit	SPECTRAL SIGNATURE Channels 1	2	3	4
41	BRUSH 3	4.8	22.44	20.11	30.56	17.33
42	BRUSH 4	3.6	23.14	18.97	30.06	16.97
43	VEGETATION 1	2.5	20.42	15.12	31.80	18.99
44	VEGETATION 2	4.8	19.61	15.12	29.62	17.86
45	VEGETATION 3	1.8	19.65	14.01	25.43	14.25
46	VEGETATION 4	3.5	21.46	16.85	27.62	15.31
47	VEGETATION 5	3.8	18.14	12.81	23.86	13.81
48	VEGETATION 6	2.4	19.34	12.46	26.48	15.33
49	VEGETATION 7	2.2	20.52	12.96	27.31	16.11
50	VEGETATION 8	3.9	19.18	17.00	25.27	14.27
51	VEGETATION 9	2.5	20.96	16.48	33.41	20.20
52	VEGETATION 10	5.7	20.93	15.99	36.47	22.17
53	VEGETATION 11	9.5	22.12	17.97	39.72	24.19
54	VEGETATION 12	9.0	19.92	13.44	38.87	24.29
55	VEGETATION 13	3.2	27.81	25.14	36.09	19.12
56	VEGETATION 14	3.5	20.15	14.43	20.83	10.69
57	VEGETATION 15	4.5	18.27	12.05	18.64	9.52
58	SWAMP 1	3.8	18.39	12.72	20.56	11.94
59	SWAMP 2	3.6	18.44	10.50	13.59	6.53

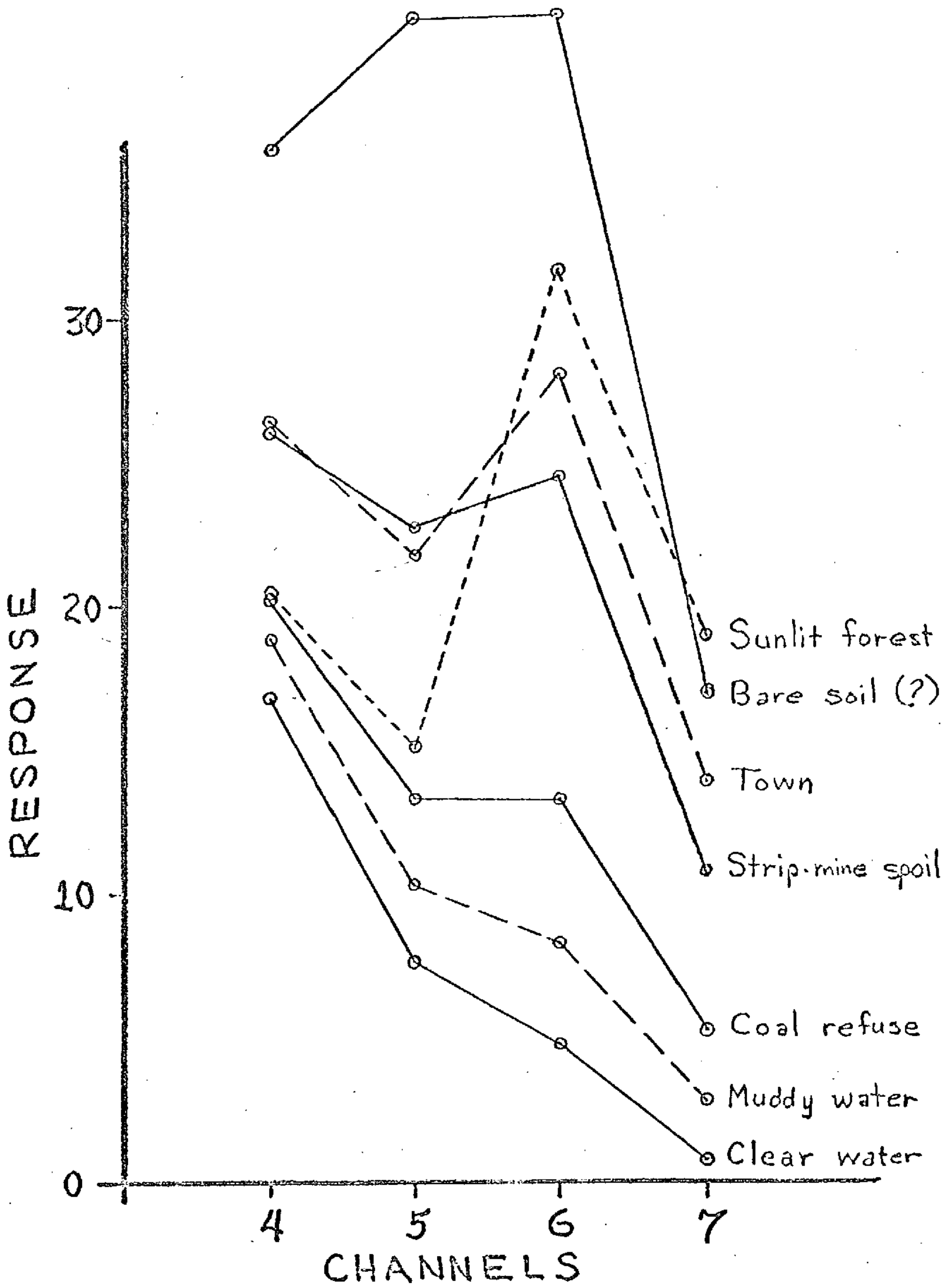

Figure 6 : Representative spectral patterns for several major categories.

by the LMAP program) of block 16 is shown in Figure 7. For the sake of clarity, only the targets of major interest are shown, with vegetation included to outline the mountain ridges, for orientation. All other categories, although included in the classification, were left blank. It was found necessary to determine signatures for all targets of significant areal extent, even those of no great intrinsic importance; otherwise such targets might be incorrectly classified into one of the categories of particular interest.

Results throughout the 27 blocks are similar to those in the preliminary phase, although the additional signatures identified have produced significant improvements. All major towns and cities and major mountain ridges have been identified throughout the area, by comparison with 7 1/2-minute topographic maps. These have been noted on working copies of the digital maps, for orientation purposes, along with named lakes and reservoirs, and major four-lane highways. Together, these features make it possible to establish the location, with respect to known geographic points, of almost any area of interest on the digital maps. The study by Peters, Spicer, and Lovell (1968) includes a numbered listing of many of the refuse banks and silt basins in the Anthracite Region, but with apparent emphasis on those large enough to have potential commercial value. Point locations for these deposits are shown by number on the map on which Figure 5 is based. Many of these deposits do not show on the topographic maps, but all can be located on the digital maps we have produced. Additional deposits, not on the Peters, Spicer, and Lovell map, are shown on the digital maps. Some can be verified by reference to the topographic maps or to the study by Frank (1964); others cannot, and verification will depend on either on-site inspection or underflight photography. Difficulties have been encountered in attempts at on-site inspection due to lack of usable access roads and the problems of on-the-ground orientation in country so thoroughly devastated by mining activity. Although the locations of the coal refuse banks and silt basins are accurately established by the digital maps, it appears that in some instances their extent is exaggerated. This is probably the result of the previously discussed misclassification of some strip-mine spoils as refuse.

Figure 7: Line map of block 16, showing targets of major interest. (Scale: 1 inch = 6000 ft)

With the widened area under investigation, it was found necessary to add additional signatures representing coal refuse and water in order to correct some misclassifications. The resultant greater range of spectral patterns in each of these categories, however, seems to have created a new problem. Many refuse and silt deposits now map partly as water, as is evident in Figure 7. In some cases, the presence of water in these locations can be verified from the topographic maps. Other instances, however, seem highly unlikely and it is probable that some refuse is being misclassified as water. It is felt that this problem can be resolved by further refinement of the set of characteristic signatures being used.

The three-way confusion among some strip-mines, towns, and agricultural areas encountered in the preliminary phase of this study, apparently has carried over into this second phase of the investigation. The problem has, however, been made less serious by selective elimination of those signatures that caused most confusion. Additional signatures representing urban and industrial areas were added and virtually all towns and cities now map solidly. A glance at the northwest portion of Figure 7, however, shows that the problem of some farmland mapping as towns persists, as does the mapping of some strip-mined land as towns. We feel that this primarily occurs on partially reforested strip-mines. The overall problem seems to be a consequence of the fact that all three categories are mosaics of vegetation and some dissimilar material: roofs and pavement in the case of towns, bare soil on farmland, and bare spoil on the strip-mines. It can be seen from the patterns shown in Figure 6 that taking the mean of the signatures for strip-mine spoil and sunlit forest would give a pattern very close to the town signature shown. This makes it unlikely that the problem can be completely resolved merely by further juggling of the characteristic signatures, although some improvement should be possible. It is likely that more refined techniques, such as merging data from several scenes of the same area, thereby making use of the temporal dimension, will lead to the solution of this problem.

Plans for Further Study

The most important effort in the continuation of this investigation will be verification of the results by comparison with underflight photography. Such data are not yet in hand, but flights have been requested. Further refinement of characteristic signatures is also planned. Major emphasis will be placed on exploitation of temporal changes, by merging data from several passes, in order to clarify the areas of confusion which have persisted through the study. Extension of this investigation to the Northern Anthracite Field, which includes the major cities of Scranton and Wilkes Barre, is also contemplated.

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