ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF ENFORCEMENT

EPA-330/3-75-001

An Application Of ERTS Technology To The Evaluation Of Coal Strip Mining And Reclamation In The Northern Great Plains

NATIONAL FIELD INVESTIGATIONS CENTER-DENVER

AND

REGION VIII DENVER, COLORADO

FEBRUARY 1975

ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF ENFORCEMENT

AN APPLICATION OF ERTS TECHNOLOGY TO THE EVALUATION OF COAL STRIP MINING AND RECLAMATION IN THE NORTHERN GREAT PLAINS

National Field Investigations Center - Denver
and
Region VIII
Denver, Colorado

February 1975

CONTENTS

TABLES

FIGURES

CONVERSIONS

multiply	*by*	*to obtain*
Metric Unit		English Unit
hectares*	2.471	acres
kilometers (km)	0.621	miles (mi)
meters (m)	3.280	feet (ft)
metric tons	1.102	tons (short)

* *Multiply pixels by: 0.486 to obtain hectares; or 1.199 to obtain acres.*

ABBREVIATIONS

ERTS - earth resources technology satellite

LARS - Laboratory for the Application of Remote Sensing (Purdue University)

MSS - multispectral scanner

SCS - Soil Conservation Service

USGS - United States Geological Survey

GLOSSARY

borrow pit - an area of special excavation to provide material for an embankment when there is insufficient excavation on or near the job site to form the embankment

embankment - an artificial ridge of earth and broken rocks, or a fill with a top higher than the adjoining surface

high wall - the unexcavated face of exposed overburden and coal in an opencast mine, or the face or bank on the uphill side of a contour strip mine excavation

overburden - the material that overlies a deposit of coal, especially as mined from the surface by open cuts

pixel - the instantaneous field of view within the multispectral scanner

radiometric analysis - an analysis based on the intensity of the light as determined by ERTS multispectral scanner

spectral signatures - a set of four radiant intensities in the ERTS spectral bands defining a class of material

spoil pile - the area where mine waste is disposed of or piled

I. INTRODUCTION

Historically, the production of coal in the Northern Great Plains has been minimal by national production standards, although reserves are very large. The recent energy crisis, however, coupled with the extremely low sulfur content (averaging about 0.6 percent) of the coal have produced increased interest in coal mining in this region. But the potential adverse environmental impacts of surface mining operations, as demonstrated in other parts of the country, have offset this interest.

The Northern Great Plains Resources Program, initiated in 1973 by the Department of the Interior, was to provide tools to quantify the environmental impacts of actual and proposed development of coal resources in Wyoming, Montana, North and South Dakota [Fig. I-1]. As an integral part of the program, the National Field Investigations Center-Denver (NFIC-Denver), Office of Enforcement, EPA, was requested by EPA Region VIII, Denver, Colo., to conduct a study of coal mines in Montana, North Dakota, and Wyoming. The purpose of the study was to document the size, shape and location of the following:

1. The actively mined area within each coal strip mine site
2. The untouched spoils piles within the mine site
3. The reclaimed or recontoured areas within the mine site
4. Newly vegetated recontoured areas within the mine
5. Abandoned spoils piles that have been naturally revegetated with native plants.

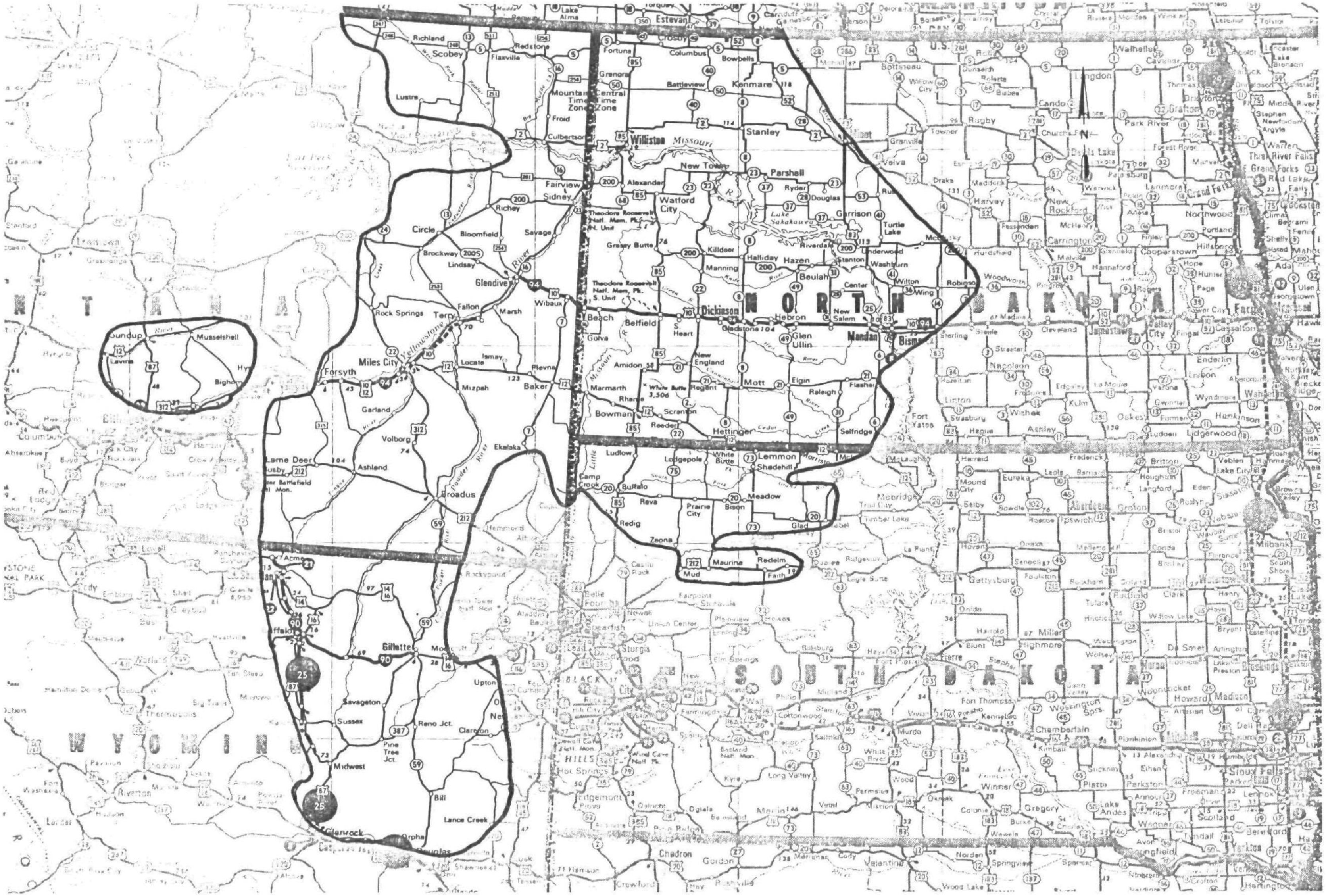


Figure I—1. Northern Great Plains Coal Field

The study was conducted with the use of remote sensing data from the Earth Resources Technology Satellite (ERTS), recorded from late June through late August 1973. To verify mining data, a telephone survey of companies operating active coal mines was conducted in early 1974. Other verification data included USGS and SCS aerial photographs of mining areas, maps provided by mining companies, and aerial photographs taken by NFIC-Denver personnel.

Besides presenting a synoptic inventory of Northern Great Plains coal strip mines, this report demonstrates how computer classification of satellite data can be applied to monitoring land use. Future ERTS imagery of this area, when compared to the baseline information in this report, can be used to detect various changes at the mine sites.

II. SUMMARY AND CONCLUSIONS

Thirty active, inactive and proposed coal mine sites identified by the Northern Great Plains Resources Program in the states of Montana, North Dakota and Wyoming were evaluated in this study. Three underground mines and three proposed mines were not computer classified. Computer classification was not attempted for eight additional mines because they were small, inactive, or lacked ERTS data. Of the remaining sixteen sites, computer classification was successful at fourteen. Attempts to classify the other two mines were unsuccessful because of the small size of one mine and the masking effects of cultivated cropland at the other.

Land use, or classification, at each mine evaluated was defined by computer processing the ERTS data which was in the form of digital magnetic tapes. A multipectral classification algorithm was used after accepted procedures for smoothing, filtering and line drop-out corrections were applied to the digital data.

In most cases, the computer classification techniques were successful in separating mine areas into: active mining areas, graded spoils piles, ungraded spoils piles and revegetated spoils areas. Other topographical and cultural features such as ponds, roads, railroads and cropland in the mine vicinities were defined.

The results of the computer classifications are presented in Table II-1. Disturbed areas of all types for the mines classified totaled 45.2 km^2 (11,159 acres; 17.4 mi^2). In addition to this total, several

TABLE II-1.
Summary of Mine Classifications

Mine[a/] No	Active Mine Hectares	Active Mine Acres	Spoils: Ungraded Hectares	Spoils: Ungraded Acres	Spoils: Graded Hectares	Spoils: Graded Acres	Revegetated Hectares	Revegetated Acres	Miscellaneous Hectares	Miscellaneous Acres	Total Disturbed[b/] Hectares	Total Disturbed[b/] Acres
1	Mine not computer classified										27	66
2	Mine not computer classified										85	210
3	Mine not computer classified										2	4
4	247[c/]	610[c/]					125	305	182	450	554	1365
5	21	53	28	68	44	108					93	229
6			145	356			16	38	20	49	180	444
7	Proposed mine											
8	Mine beginning operation											
9	Proposed mine											
10	Proposed mine											
11	40	100	44	108					56	137	140	347
12	74[c/]	182[c/]									74	182
13	42[c/]	104[c/]			25	61			23	56	90	222
14	61	151	508	1255	304	750			64	158	937	2315
15	18	44	161[d/]	398[d/]							179	442
16	Mine not computer classified											
17	Underground mine											
18	Underground mine											
19	Underground mine											
20	36	90	81	199					6	14	123	304
21	135[c/]	334[c/]	162	401	136	337	138	341			572	1414
22	129	320	536	1324							665	1644
23			362	892	164	405			32	78	557	1375
24	Mine closed											
25	Mine not classifiable											
26	93[c/]	230[c/]							31	75	124	306
27	Mine not computer classified											
28	Mine not computer classified											
29			28	68			69	172	20	50	117	290
30	Mine not computer classified											
TOTALS	896	1988	2055	5069	673	1661	348	856	434	1067	4519	11,159

a/ Mine locations shown on Figures V-1, V-12, V-22 inside back cover.
b/ Area of mines not classified was determined from ERTS transparencies
c/ Includes ungraded spoils
d/ Includes roads and areas in preparation for mining

square kilometers of land have been disturbed at the small mines not classified. Ungraded spoils piles accounted for the largest portion (45 percent) of the mine area. Active mine areas including some ungraded spoils accounted for another 20 percent of the total mine area. Only four mines had significant areas that had been revegetated, accounting for 8 percent of the total area. An additional 15 percent of the area contained in 5 mines had been graded but not vegetated. Some degree of natural revegetation has occurred on both graded and ungraded spoils at several mines.

The application of ERTS technology to land use classification and areal determination was most successful for the large mines containing large areas with the same land use. The minimum size object or land area that can be defined by the ERTS sensors is about 0.5 hectare (1.2 acre), about the size of a football field. This limited spatial resolution means that present ERTS technology can be effectively used only for mines with homogeneous areas at least 200 m (660 ft) on a side and preferably 340 m (1,100 ft) in minimum dimension. ERTS technology to be implemented in the next few years will substantially improve the spatial resolution, allowing classification of small as well as large mines.

The most efficient use of ERTS technology could be achieved by collecting detailed ground truth or field data on one or two mines, calibrating the computer procedures using this data, and then extrapolating to other mines, thus completing the classification without additional data collection. In practice, this did not prove feasible. Significant variations between mines, and even for the same mine, were observed in the ERTS data for the same type of mine area such as ungraded spoils piles. This required that the classification algorithm be calibrated for each mine site. The accuracy of the classification at each mine was thus largely dependent upon the availability of ground truth such as low-level aerial photographs, maps, or field observation.

Two types of problems were encountered in distinguishing areas disturbed by mining activities from adjacent lands not disturbed by mining. Due to the semi-arid climate, native vegetation near mines in Wyoming and most of Montana is relatively sparse. If reclamation or natural revegetation of spoils piles produced significant vegetative cover, it was often difficult to distinguish between such disturbed areas and the surrounding lands because both types of terrain yielded similar ERTS imagery. A similar problem was encountered in distinguishing between nonvegetated mine areas and adjacent lands with eroded or cultivated soil. These problems also occurred for North Dakota mines where adjacent lands often consisted of alternate strips of bare cropland and growing crops.

III. BACKGROUND

The area known as the Northern Great Plains encompasses portions of the states of Montana, North Dakota, South Dakota, Nebraska and Wyoming. At present, active coal mines are located only in Montana, Wyoming and North Dakota. The area is sparsely settled and the principal activity is ranching with a limited amount of farming.

Climatology

The climate of the states included in the study area may be described as a typical mid-latitude continental climate. The Rocky Mountains, located west of the study area, act as a barrier to the moist Pacific air in the prevailing westerly flow. There are no major geographic features to modify air masses originating in the cold polar regions of Canada, or the warm moist regions of the Gulf of Mexico before they overflow the study area.

Weather changes frequently occur over the area with a passage of cold fronts and their associated pressure systems; these generally follow an easterly track. Stagnant air masses which would adversely affect atmospheric dispersion occur rather infrequently. Warm windy periods may occur in Wyoming, Montana and the Black Hills of South Dakota during the winter as a result of warm chinook winds reaching 40 to 80 km/hr (25 to 50 mph). These periods may last several days and tend to aid in the dispersion of any atmospheric pollutants.

Within the study area, average wind speeds range from 13 to 23 km/hr (8 to 14 mph), while the average temperature varies between 6 and 9°C (42 and 49°F) with annual average highs of 10 to 16°C (50 to 60°F) and average lows of 1 to 2°C (30 to 35°F). The mean annual relative humidity is 60 percent but averages 70 percent for the fall and winter quarters. Annual precipitation in the region varies from 25 to 50 cm (10 to 20 in.) per year. Montana and Wyoming are generally more arid than the three eastern states in the region. Usually 50 percent or more of the rainfall occurs in spring while winter is the driest time of the year. The Dakotas receive about 91 cm (36 in.) of snow annually, except for the Black Hills area which receives 152 to 254 cm (60 to 100 in.) per year. Wyoming receives 91 to 152 cm (36 to 60 in.) annually.

Coal Resources

The Northern Great Plains Region contained about 46 percent of the estimated remaining coal resources of the United States as of January 1, 1972. This reserve was contained in an area of 218,000 km^2 (84,000 mi^2), representing only 18 percent of the total area of coal bearing rock in the United States. The presence of 46 percent of the tonnage in 18 percent of the area of coal bearing rock provides convincing evidence of the concentration of coal in the study area, a fact explained primarily by the greater thickness of individual coalbeds in the region as compared to the bed thickness in other parts of the United States.

The coal in the Northern Great Plains Region occurs in a sequence of beds 460 to 910 m (1,500 to 3,000 ft) thick of late Cretaceous to

Eocene Age. This sequence is divided from bottom to top into the Hell Creek, Tullock, Fort Union and Wasatch formations. The coal resources are concentrated in the Fort Union formation of Paleocene Age, and only subordinate amounts are present in the underlying and overlying formations. The rocks associated with the coal consist primarily of poorly consolidated sandstone and siltstone with minor amounts of shale. Many of the coal outcrops have been ignited by spontaneous combustion, forest fires, lightning and acts of man. Areas thus effected are characterized by the red color of the baked rocks over the burnout coal. These baked rocks are locally termed "clinker," but are more properly identified as "baked shale." Some of the burning took place thousands of years ago, and some is recent.

The coal bearing strata of the Northern Great Plains are nearly horizontal. Throughout most of the region, measurable dips are only 1 to 2°. However, these low dips are locally reversed and give rise to three broad regional structural features: 1) the Wiliston Basin, centered in western North Dakota; 2) the Cedar Creek Anticine, near the Montana-North Dakota line; and 3) the Powder River Basin in northeastern Wyoming and southeastern Montana. The steepest dips, commonly 5 to 10° eastward, are along the western edge of the Powder River Basin in north-central Wyoming. Because of the gentle dips and the reversals of dips associated with the three structural features mentioned above, the coal bearing rocks are near the surface in most parts of the region. In the deepest part of the Powder River Basin in Wyoming, the coal bearing rocks are a little more than 610 m (2,000 ft) below the surface, but are nearer the surface over most of the Wyoming Part of the basin. In eastern Montana, most of the coal is less than 460 m (1,500 ft) below the surface. In North Dakota all the coal is less than 370 m (1,200 ft) below the surface, and 98 percent is less than 300 m (1,000 ft) below the surface. In South Dakota, all the coal is less than 300 m (1,000 ft) below the surface, and about 80 percent is less than 150 m (500 ft) below the surface.

The Bull Mountain field, which lies mostly in Musselshell and Yellowstone Counties, Montana is a broad shallow basin with a northwest trending synclinal access. Throughout most of the basin, the coal bearing seams dip 1 to 5° toward the center of the basin, but are nearly flat to the east and south, and are steeper to the north. In the northwest part of the basin, the dip steepens to a maximum of 30°. Most of the past and current mining has been in the broad, central part of the basin where dips are low.

Production

Throughout the years, production of coal in the Northern Great Plains has been minimal by national production standards. In 1965, for example, the region produced about 5 million tons, or 1 percent of the national total of 512 million tons. In 1972, the region produced about 20 million tons, or about 3.3 percent of the national total of 595 million tons. This may be compared to 1972 production of 144 million tons, or 24 percent of total national production, from the Illinois coal basin in Illinois, Indiana and Western Kentucky. The Illinois basin is only half the size of the Northern Great Plains coal bearing region, and it contains only one-fourth as much coal. The recent energy crisis, and the extremely low sulfur content of coal in the Northern Great Plains (averaging about 0.6 percent), however, have significantly increased interest in mining of coal from this region.

IV. STUDY TECHNIQUES

SATELLITE DATA

The source of the remote sensing data for the Northern Great Plains study was the Earth Resources Technology Satellite. ERTS was launched into earth orbit in July 1972. Its orbit around the earth is inclined 9° with respect to the true north and south poles. The altitude of the satellite above the surface of the earth varies from 900 to 950 km (560 to 590 mi) due to the slight flatness (oblateness) of the earth and to the perturbing gravitational forces induced by the sun, moon and earth. ERTS completes an orbit every 103 min, making fourteen complete orbits per day. A typical ground trace for the daylight passes shown in Figure IV-1. A particular target on the earth's surface is covered by the satellite every 18 days with respect to the previous over-pass. Likewise, it views the entire earth every 18 days. For every 18-day period, the satellite ground trace repeats its earth coverage at the same local time. The overlap registration of a current ERTS frame (rectangular format for the recorded data) is within 37 km (23 mi) of the frame recorded 18 days earlier.

ERTS is commonly referred to as an observatory containing various sensors and communications systems [Fig. IV-2]. The sensor data used for this study was obtained from the multispectral scanner (MSS). The MSS is a line scanning device which uses an oscillating mirror to continuously scan perpendicular to the spacecraft path of travel

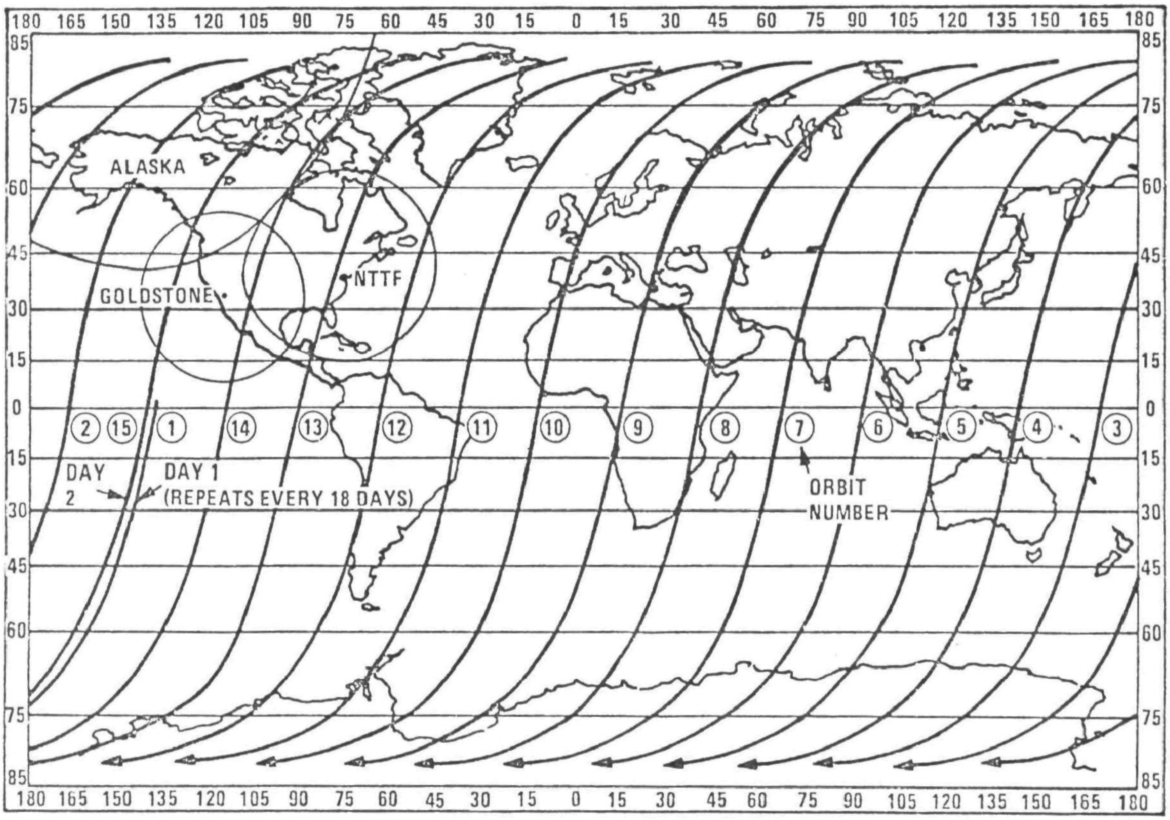


Figure IV—1. Typical ERTS Daily Ground Trace

(Daylight Passes Only)

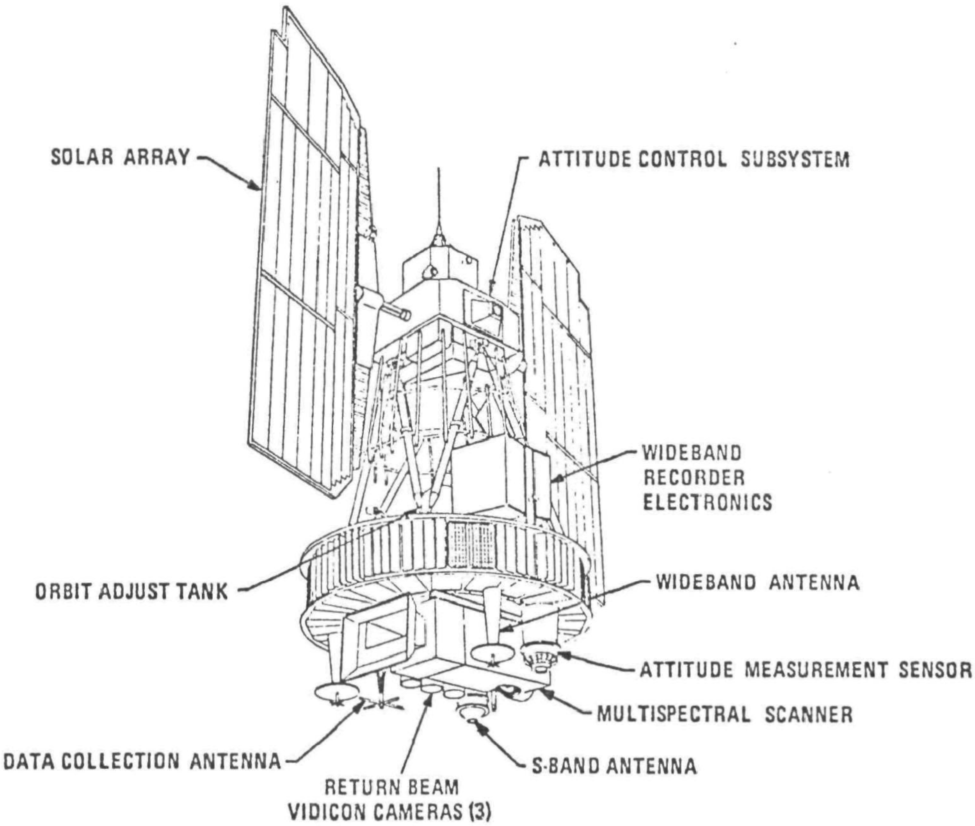


Figure IV—2. Observatory Configuration

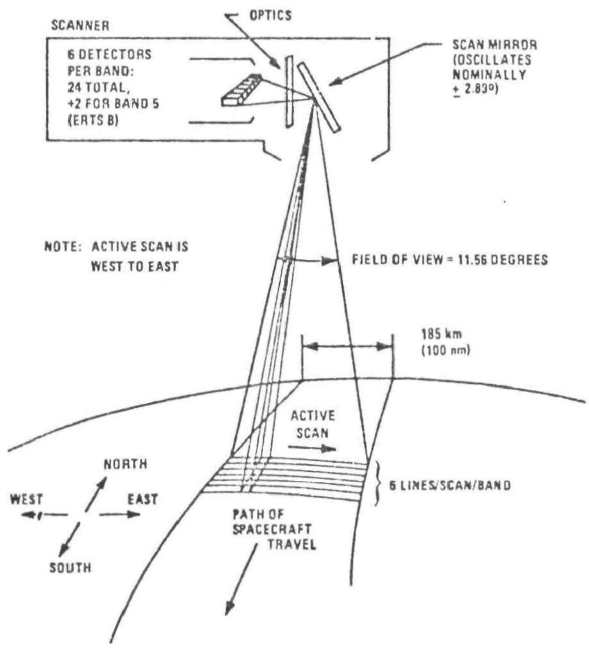


Figure IV—3. MSS Scanning Arrangement

[Fig. IV-3]. Six lines, with the same bandpass, are scanned simultaneously in each of four spectral bands for each mirror sweep. Spacecraft motion provides the along-track progression of the six scanning lines. Optical energy reflected from the earth's surface is sensed simultaneously by an array of detectors in the four spectral bands with the bandwidths shown below:

Table IV-1
Spectral Bandwidths

Channel Number	Color Designation	Bandwidth (microns)
1	Green	0.5 to 0.6
2	Red	0.6 to 0.7
3	Infrared I	0.7 to 0.8
4	Infrared II	0.8 to 1.1

At the ground station, the continuous strip of imagery from ERTS is transformed to framed images with a 10 percent overlap of consecutive frames measuring 185 x 185 km (100 x 100 nautical mi).

The complete orbital coverage of ERTS for the Continental United States is shown in Figure IV-4. In this ground trace pattern, every location within this country is imaged every 18 days at the same respective local time. With a particular target in mind, one can check the date of satellite coverage [Fig. IV-4] for orbit number and geographical coordinates. With this information, a search of the NASA data base is instituted to find the exact satellite frame(s) (imagery) desired. The imagery can be obtained in three forms:

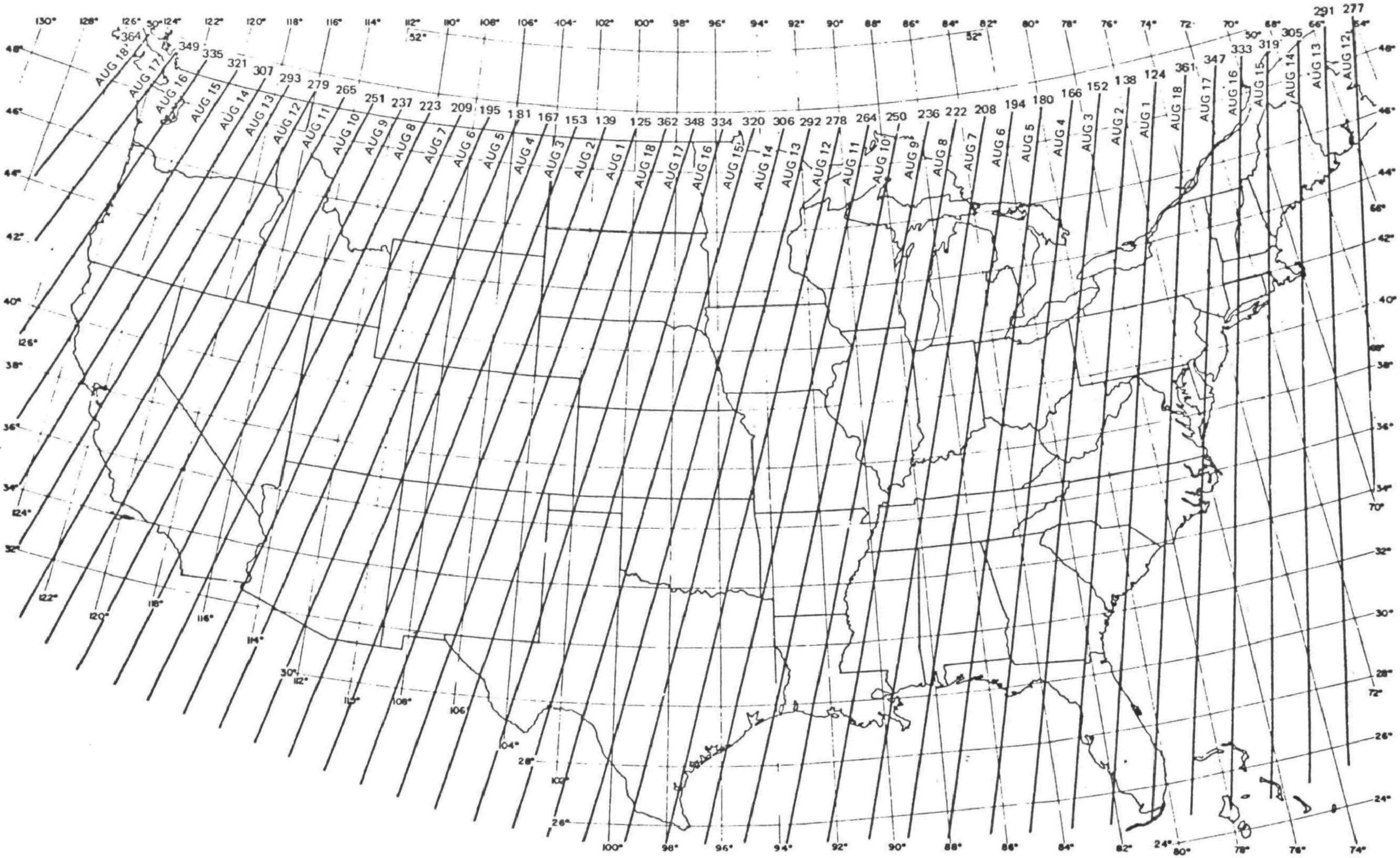


Figure IV—4. ERTS Coverage of Continental United States

1. Digital computer compatible tapes
2. 22.9 x 22.9 cm (9 x 9 in.) optical transparencies, scale 1:1,000,000
3. 22.9 x 22.9 cm (9 x 9 in.) black and white prints, scale 1:1,000,000.

GROUND TRUTH

The ground truth for this study consisted of the following items:

1. Large scale low-level aerial photographs of various mines recorded by Soil Conservation Service and U. S. Geological Survey from 1969 to summer 1973
2. Large scale detail maps of certain mines defining active, recontoured and revegetated areas
3. Aerial photography of certain mines recorded by NFIC-Denver personnel during the summer of 1974.

The information contained in these types of ground truth data was used during the computer analysis of the ERTS data.

DATA INTERPRETATION AND ANALYSIS

Data Source

The ERTS data was obtained from the NASA data base for the thirty areas reported to be sites of coal strip mines. The data consisted of nine sets of 22.9 x 22.9 cm (9 x 9 in.) transparencies and the respective sets of digital computer compatible tapes. Nine ERTS frames were required to completely cover the Northern Great Plains area. The selectivity of the data was based upon the time interval of late summer 1973, near-zero cloud cover over the respective mine locations, and freedom from telemetry degradations and errors.

The transparencies were used to visually locate the general area of each mine. The precise geographical location of each mine was used in cueing the computer for selection of the area(s) within the computer tape to be radiometrically analyzed. The detailed analytical work was subsequently performed using a general purpose digital computer (IBM 360-44) and the digital computer compatible tapes which provided an accurate radiometric analysis.

The four separate spectral bands of the ERTS imagery afford a multispectral identification and classification of a particular target in question within the limits of the spatial resolution of the satellite scanner. Its resolution capability is 4,860 m^2 (1.2 acres) which by definition is 1 pixel, the instantaneous field of view within the multi-spectral scanner. A sample ERTS image constructed from the computer compatible tapes is shown in Figure IV-5, a red band image of the Dave Johnston Mine (Mine 4). The tick marks on the perimeter of the image are guides to a coordinate system used in selecting training sights as discussed below.

A multispectral statistical computer classification technique was used to analyze the area in and around each coal mine. This program was an adaptation of one developed at the Laboratory for the Application of Remote Sensing (LARS), Purdue University, for the classification of agricultural (farm) land from digital aircraft and satellite data. The LARS program operates by reading the optical intensity (in this case ground reflectance of sunlight) of each pixel in the four ERTS spectral bands (tape) and then determines the statistical classification of that element in relation to all other pixels in the target area or scene.

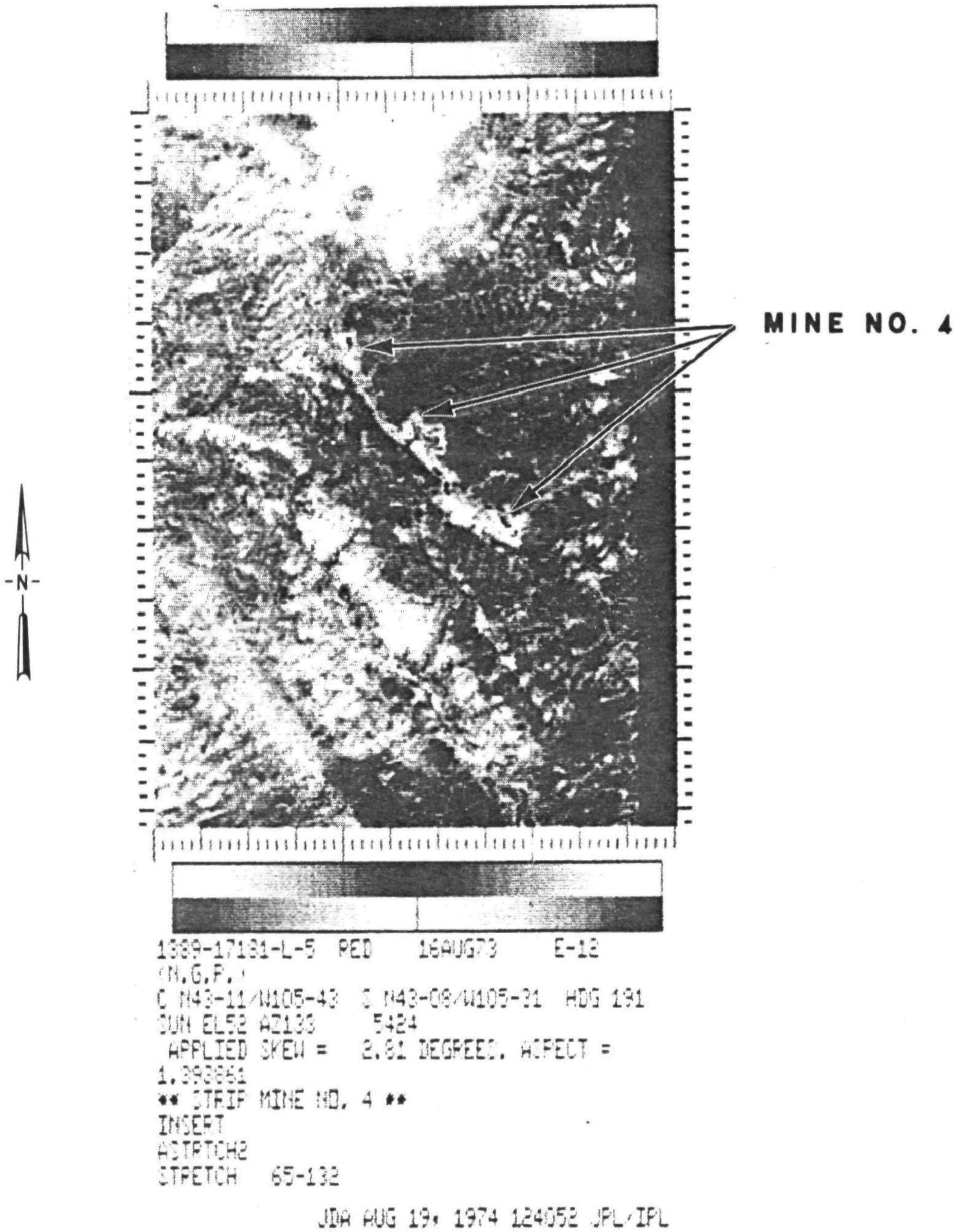


Figure IV-5. Red Band Image of Mine No. 4

Data Categories

The satellite data for each coal mine were classified into the following categories:

1. The actively mined area within each strip coal mine site
2. The untouched spoils piles within the area of the mine site
3. The reclaimed or recontoured areas within the area of the mine site
4. Newly vegetated recontoured areas within the mine
5. Abandoned spoils piles that have been naturally revegetated with native plants.

Training Areas

During the computer analysis of satellite data, training areas (areas of known target character such as active mine locations derived from ground truth) were used to define the spectral characteristics of the target classes into which the total scene is to be classified. The LARS program classifies each pixel of the target area into one of the previously defined training classes and then computes a number representing the statistical confidence with which the pixel falls into that respective class. By examining the confidence numbers, the program analyst can determine the effectiveness of the classification routine.

Data Forms

The output of data from the computer is presented in several forms. A symbolic display map of the pixel intensities in each of the four spectral bands is used initially to identify and select training areas.

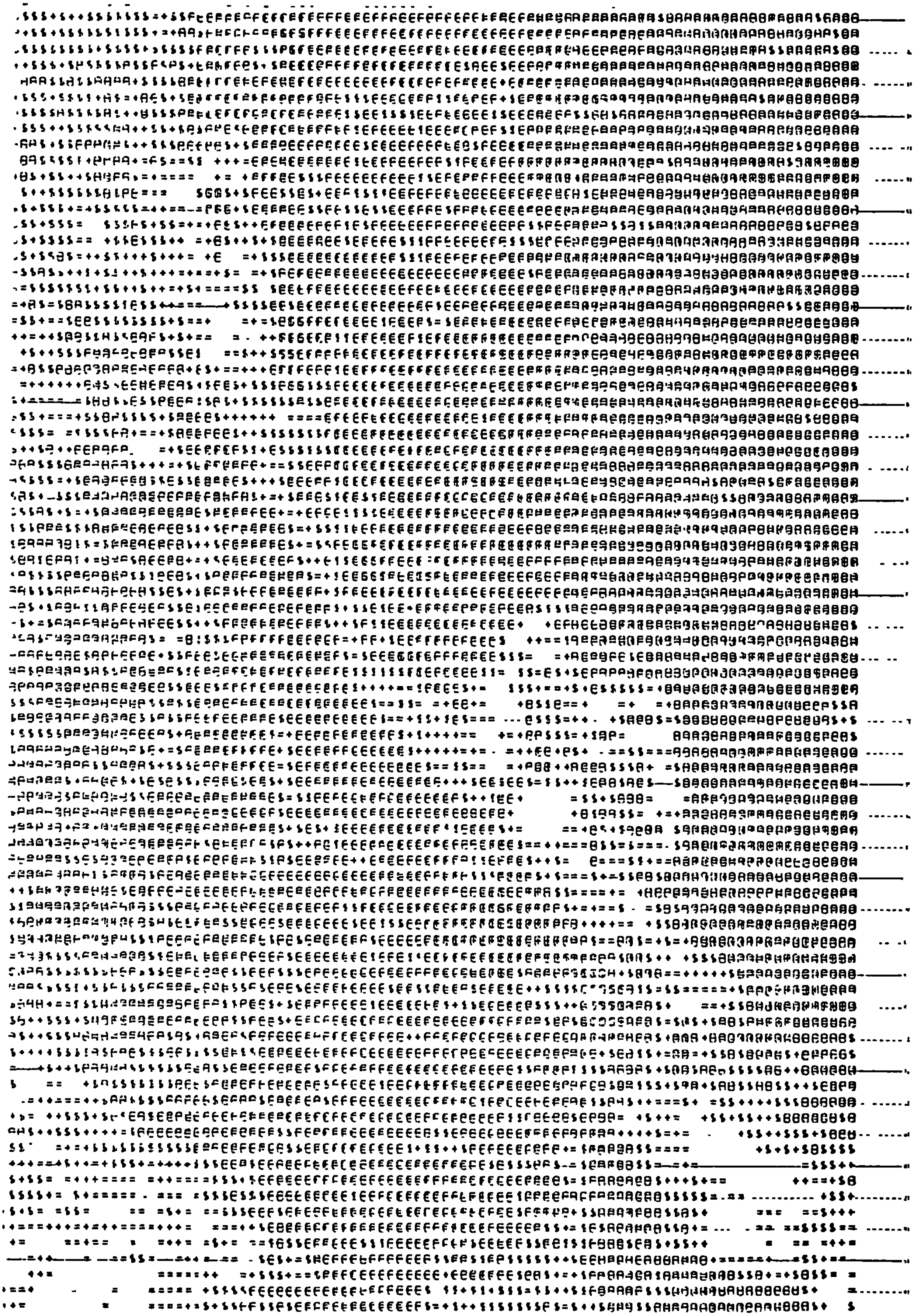


Figure IV—6. Sample Symbolic Map - Mine 4

A symbolic map for Mine 4 is shown in Figure IV-6. Using maps or aerial photographs as a reference, training sites are established on the symbolic display and the coordinates are entered into the computer. The statistics for the four bands are computed and displayed in the form of histograms for the training areas that have been selected. After the selection of the respective training areas has been finalized, a classification of the image is made and a computer map is printed out in which the number of the particular class is printed in place of each pixel [Fig. IV-7].

By inspection of the histogram for confidence levels assigned to all the pixels or elements within the target area, a lower limit of confidence may be selected which permits a second classification map to be printed, on which confidence levels lower than the selected limit are replaced by blank spaces. By observing this map, the analyst can tell at a glance in which regions of the image his choice of classification categories is deficient. He can then combine similar classes, determine new classes or alter the boundaries of training sites if necessary. Then the process described above is repeated until an acceptable confidence level is reached for the particular classification scheme being employed. An interpretive overlay* [Fig. IV-8] is drawn to illustrate the results of the final classification and annotated to identify significant features.

ERTS Measurement Limitations

Limitations can be placed on the accuracy or uncertainty of the

* Some scale distortion is inherent in producing an overlay map (on the computer line printer) which can be avoided only by additional processing. In scaling the overlay map to a USGS topographic map, the longitudinal axis of the former must be reduced to 80% of its nominal value.

```
 1 2316611626111133111111333333111111113331111111111
 2 2261256661111133111213333113113331113311111331---
 3 671112211122333311226333311113133341111111116111
 4 1111122121133333333111333311111111113331116111 1
 5 6212221122633333333333113311111111111311221111 1
 6 66112211211133333331133311331111111111111111111
 7 1611122162611111231333311111111111111111111111
 8 111116616211111221333111111111111111111111666 -
 9 61111221126625622513111331111111111111111111111
10 211112522645542666333111121111111111166111111
11 211211255545333661111111221112121111111111111
12 6211125264554331261111111111121261111111111111
13 54222112126624331273313111111111111111111111111
14 546221121665563144622111111111111111111111111111—
15 6267222226655434440666111111111111111161111111111
16 661122222662644445641113113311111111111111111131
17 222222622522655542656113131111111111111111111111
18 1222211666555556111333133331111113111111111111
19 112111116665555566666633333331111111111666111131
20 11161111626625555556633333112111111111111113333—
21 111111111121655526666333313111131331111333333333
22 111111111112116522666333111111133333333331111111
23 1122111111126111666666133221113332331111111111 1
24 61111161111115116666663312111333331111131111111
25 211111112111112666666524443331332333333111113
26 1211124661111111626666211113311323333113311111—
27 1111155526111133121266672226333133333311111133
28 11111166642113333112556111113333133331111111133
29 1111111112211111122266111111333113311111133333 3      10     15     20     25     30     35     40
30 1111113111111113111125211111433241131333311111 3
31 6111111313111233333111252111343111333333331111133111111311111131333311133111133113
32 611111111111262131111116561224331233333311113111111111111111111111111331331111333111
33 656111111111221111111112512333333333331134311333313311111111111111111133113111111111331
34 261111111111652211113111262116333333113333323331111111111111111111113311311111113331
35 11111161111266111111111112222133332311333311111111111111111131111111111111111113333331
36 111111116112613111111311112611333333333313311111111111111111111133111111111111133311131
37 131111111111112111131111311316121113333333311331111112111111113331133311311111111331
38 111111111122642113111111111122612433311331133111654211111133311133311111111111111
39 131111114561112111313311111111266144111333113112554441111113311131131133311311111
40 111111112221112111113333111122111333311113111222444421131111113111111111132311111 1
41 1122111111122111113313333311131222226331111112244464322711111111111111131111111111
42 111113111111111113333131331111116262544133126444124454661121165511111333331111111
43 31111311111113311133333333333311722225444312444432114425556655421111113323333111
44 111131111111113311331111111311133116257124232276444312144454413333263111111131111111
45 11111111124111331333222111111311111222722 6755444433211444334445541111111121431111
46 111111112411331333331211111111111111162222 4266444443321164445265251111111333333111 1
47 11111112661211111331722111331111111311225 22444444333221111211655111111333111111111
48 11111211111111113311322611131311111111116 6 2461323344330611111116551111133333311111
49 1111121111111133133166621111133333333111 1 612231106440666122133655556333331113311111
50 1111111111111111331131161131131133131111131 1111314444444432111164456311111333311111
                                                1111122554444441622333351111113331113111
                                                1111331666222744322624444611333333333111
                                                1111133166664443442626541333233323311111
                                                3111113316664444444461113313333113113311
                                                1111331133112644446642111133313311111111
                                                3333333333311644441442111133333333333131
                                                3333333333311246444566113332113233331111
                                                3333333333331114433662262133333333313311
                                                3333333333331113343326256122133133331113
                                                3333331133333333344333552626223133133313
                                                1111133124442333333334462222552113333333
                                                6213113331214433333331244452562213331133
                                                1113311131111133333333143366111111333111 1
                                                1121111331113333333111123412113333331111
                                                1113111331311131431112643352411111112611
                                                1131131127333121121111662433111112621112211
                                                3311111311133311331311111116336611111166666 61
                                                1411113411111111111112226243256116 6666 11
                                                1111111111111111111155666224461671222611 11
                                                11113111331111133166772622765454566666622
```

Figure IV—7. Sample Classification Map - Mine 4

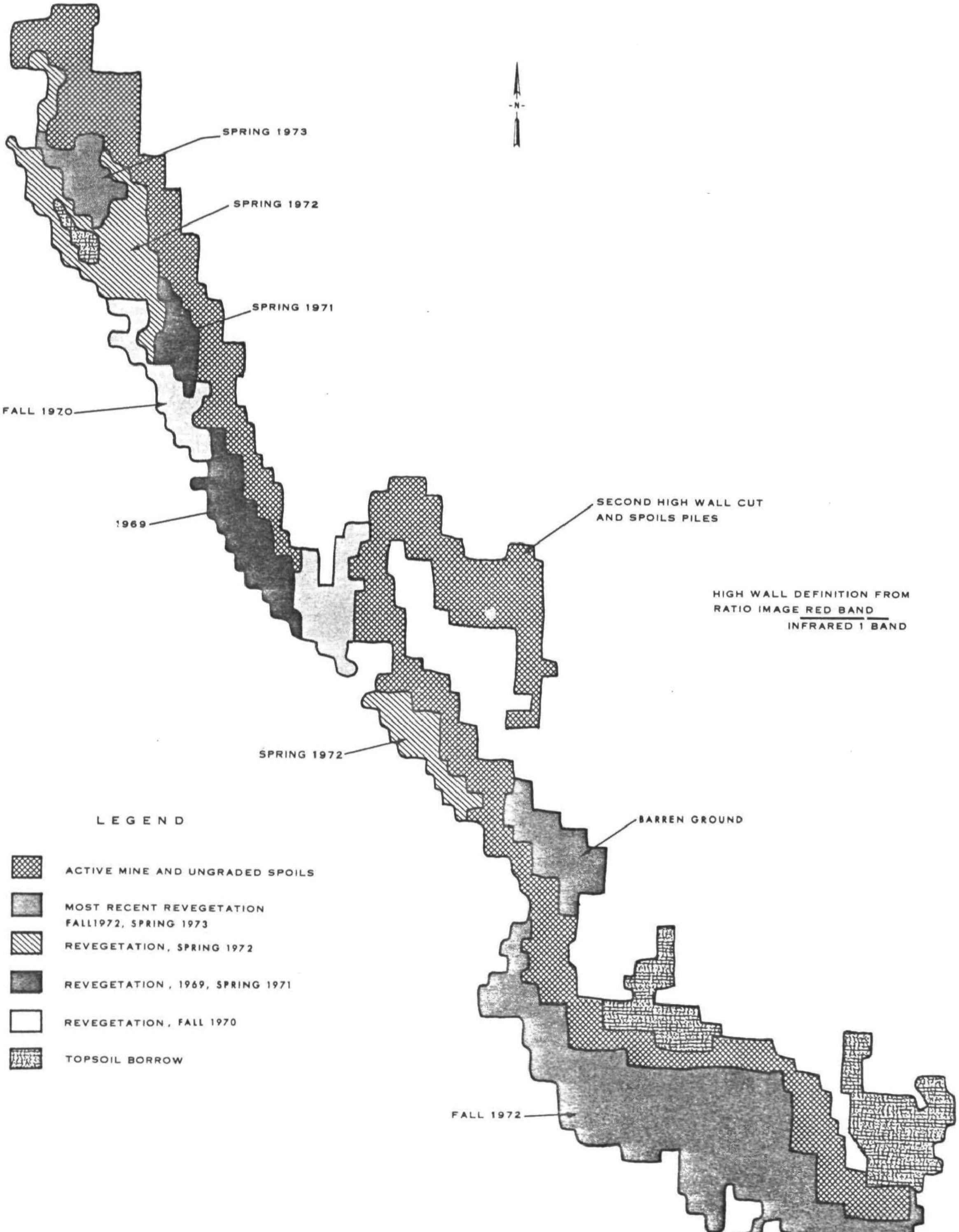


Figure IV—8. Sample Interpretive Overlay of a Classification Map - Mine 4

physical measurements carried out on the ERTS (frame) transparencies and the computer compatible tapes. Any measurements for linear distance and surface area in the transparencies were made with scaling instruments and light table microscopes.

The uncertainty for linear distance (ΔLD) is

$$\Delta DL = \pm\ 5 \times 10^{-4} \times \text{image scale (m)}.$$

The image scale of the transparencies is 1:1,000,000. The value for ΔLD is

$$\Delta LD = \pm\ 5 \times 10^{-4} \times 10^{6}\ m = \pm\ 500\ m\ (1,640\ ft)$$

A distance X, measured physically on the ERTS transparency is accurate to within ±500 m (1,640 ft).

The uncertainty for the surface area (ΔSA) is (rectangular)

$$\Delta SA = \Delta LD\ (\pm X \pm Y)\ m^2.$$

For the ERTS imagery

$$\Delta SA = 500\ (\pm X \pm Y)\ m^2.$$

For example, a rectangular area with dimensions of X ±500 m and Y ±500 m would have the value

$$\text{Area} = [XY + 500\ (\pm X \pm Y)]\ m^2.$$

The uncertainty in the computer analysis of the computer compatible tape data is limited to one pixel which measures approximately 4,860 m^2 (1.2 acres). Due to the digital character of the recorded data the computer can resolve two targets only if they are separated by a distance of at least 80 m (260 ft). In calculating the surface area of a target, the computer counts the number of pixels present in the image which is significantly more precise than through visual measurements. The integrity of the satellite data is greatly enhanced by fourteen distinct geometric corrections [Fig. IV-9] carried out immediately on the telemetered data received at the various ground stations. The data is further improved through precise geometric and contrast corrections before being analyzed.

A full technical description of the accuracy achieved in the analysis would require a mathematical treatment of the problems of separating overlapping Gaussian distributions in a multidimensional spectral space. Some of the practical problems affecting accuracy will be discussed.

A problem exists in obtaining registration between the satellite image and the aerial photograph or map used as ground truth. Some features such as the location of a pond or high wall in the infrared bands are quite distinct, but others, such as the exact boundary of a revegetated area, are not. The latter can result in the inclusion of an erroneous area in a training site or in extending a training site to a large enough size to avoid an area that is questionable.

Lack of adequate spatial resolution is the most significant problem in using ERTS imagery. The individual picture elements are approximately the size of a football field. For a large mine this is not significant but for smaller mines, the size of the picture elements severely limits the amount of detail that can be seen. This results in the blending of

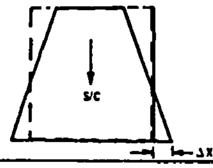
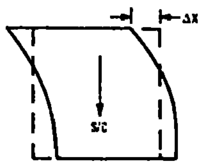
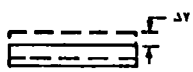
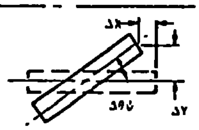
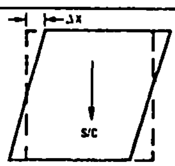
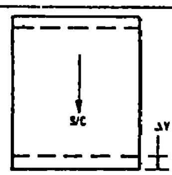
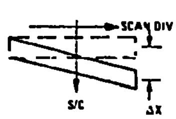
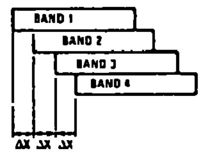
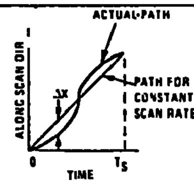
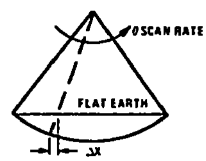
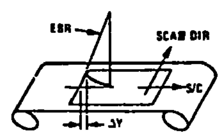
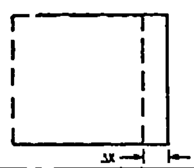
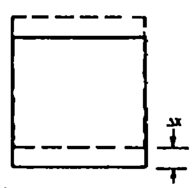
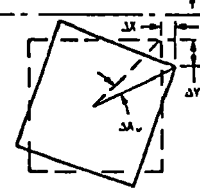
PARAMETER	GEOMETRIC FOOTPRINT	MAGNITUDE OF CORRECTION – METERS ON THE GROUND
SCALE ADJUSTMENT – ALTITUDE VARIATIONS WITHIN A FRAME 9 CORRECTIONS WITHIN THE FRAME		$\Delta X = 9.26 \times 10^4 \frac{\Delta h}{h_n}$ (AT EDGE OF FRAME)
ATTITUDE VARIATIONS WITHIN A FRAME ROLL 9 CORRECTIONS WITHIN A FRAME		$\Delta X \approx h \Delta\theta_R$
PITCH 9 CORRECTIONS WITHIN A FRAME		$\Delta Y \approx h \Delta\theta_P$
YAW 9 CORRECTIONS WITHIN A FRAME		$\Delta X \approx 4.63 \times 10^4 (\Delta\theta_\psi)^2$ $\Delta Y \approx 9.26 \times 10^4 \Delta\theta_\psi$
IMAGE SKEW CAUSED BY EARTH ROTATION (FUNCTION OF LATITUDE)		$\Delta X \approx 8.88 \times 10^4 \, \sigma_{ER}$
AVERAGE VELOCITY CHANGE FROM NOMINAL		$\Delta Y \approx 8.88 \times 10^4 \frac{\Delta V}{V_n}$ (AT TOP AND BOTTOM OF FRAME)
IMAGE SKEW CAUSED BY FINITE SCAN TIME		ΔX ≈ 213 METERS
SPECTRAL-BAND OFFSETS		ΔX = 112 METERS
SCAN MIRROR VELOCITY CORRECTION		ΔX_{MAX} = 395 METERS
PERSPECTIVE CORRECTIONS SWEEP TO FRAME IN DIRECTION OF SCAN		ΔX_{MAX} = 115 METERS
FRAME CORRECTION IN DIRECTION OF SPACECRAFT TRAVEL – (EBR CORRECTION)		ΔY_{MAX} = 64 METERS
ALIGNMENT CORRECTIONS – RELATIVE ALIGNMENT OF MSS TO AMS ROLL		$\Delta X = h \Delta A_R$
PITCH		$\Delta Y = h \Delta A_p$
YAW		$\Delta X \approx 8.88 \times 10^4 \Delta A_\psi$ $\Delta Y \approx 9.26 \times 10^4 \Delta A_\psi$

Figure IV—9. MSS Geometric Corrections

picture elements that straddle the border between two different classes of terrain. The resulting spectral signature is a blend of the two types of material viewed. These effects are noticeable at the border between two distinctly different classes of material where one or two pixels on the border will drop into some intermediate spectral class. For smaller mines, these can represent a significant portion of the area.

The low ERTS spatial resolution also causes a statistical problem in selecting a training site commonly composed of only 16 to 25 picture elements. A much larger number of representative samples of a class is desirable to adequately define the mean and standard deviation of that class relative to other classes against which the classification algorithm is trying to discriminate for the size mines that are being used in this analysis.

Since the multispectral scanner detects only the optical properties of the surface observed, there are circumstances where uncertainty can arise. One of the most common is the extensive areas around a mine from which the vegetation has been stripped by trucks and other equipment. These are particularly noticeable in the area about to be mined in front of the high wall. The exposed soil is difficult to separate from spoils where the earth has been disturbed. Although graded and ungraded spoils can be separated, in general, exposed dirt has about the same spectral signature regardless of its form or physical state. Other sources of misclassification arise when spoils piles have naturally overgrown with vegetation, in which case they resemble the spectral characteristics of the natural landscape. In areas that are being revegetated the spectral difference between grass planted at different times seems to be due to the ratio of exposed soil to vegetation.

The accuracy and extent to which a mine can be classified also depends upon the level of detail supplied in the ground truth available. Three computer runs usually suffice to overcome the mathematical data analysis problems involved in multispectral classification. The resulting accuracy is then determined by the detail provided in the ground truth and the ability to secure registration of the satellite image to the ground truth.

As an example of the changes in the classification map that result from small changes in definition of the training sites, Figure IV-10 displays two overlays of the northwest corner of the Dave Johnston Mine that resulted from the second and third attempts at classification. While small deviations in the revegetated areas defined as Classes 5 and 6 are noticed, the general features remain consistent. Class 6 has two arms extending northward that enclose the Class 5 area on the east and west. Two sections of revegetated area extend northward with the Class 6 area to the west of Class 5. A small finger of Class 6 extends southward on the east side of yet another class of reclaimed spoils.

The differences in the classification maps were caused by expanding the size of the training areas by one additional column to include additional representative samples of the different classes. To illustrate how small the differences between the classes are in the second and third classification runs, the numerical values for the intensities can be examined. The light intensities in each spectral band are expressed on an arbitrary scale from 0 to 256. The intensities of the plus and minus one standard deviation points about the mean value are given below.

Table IV-2
Standard Deviation Point Intensities

Class	Run	Green Band	Red Band	Infrared Band 1	Infrared Band 2
5	2nd	102 - 114	114 - 126	118 - 128	116 - 124
	3rd	104 - 112	118 - 130	122 - 132	120 - 126
6	2nd	90 - 98	96 - 106	106 - 116	106 - 114
	3rd	88 - 98	94 - 106	108 - 116	106 - 114

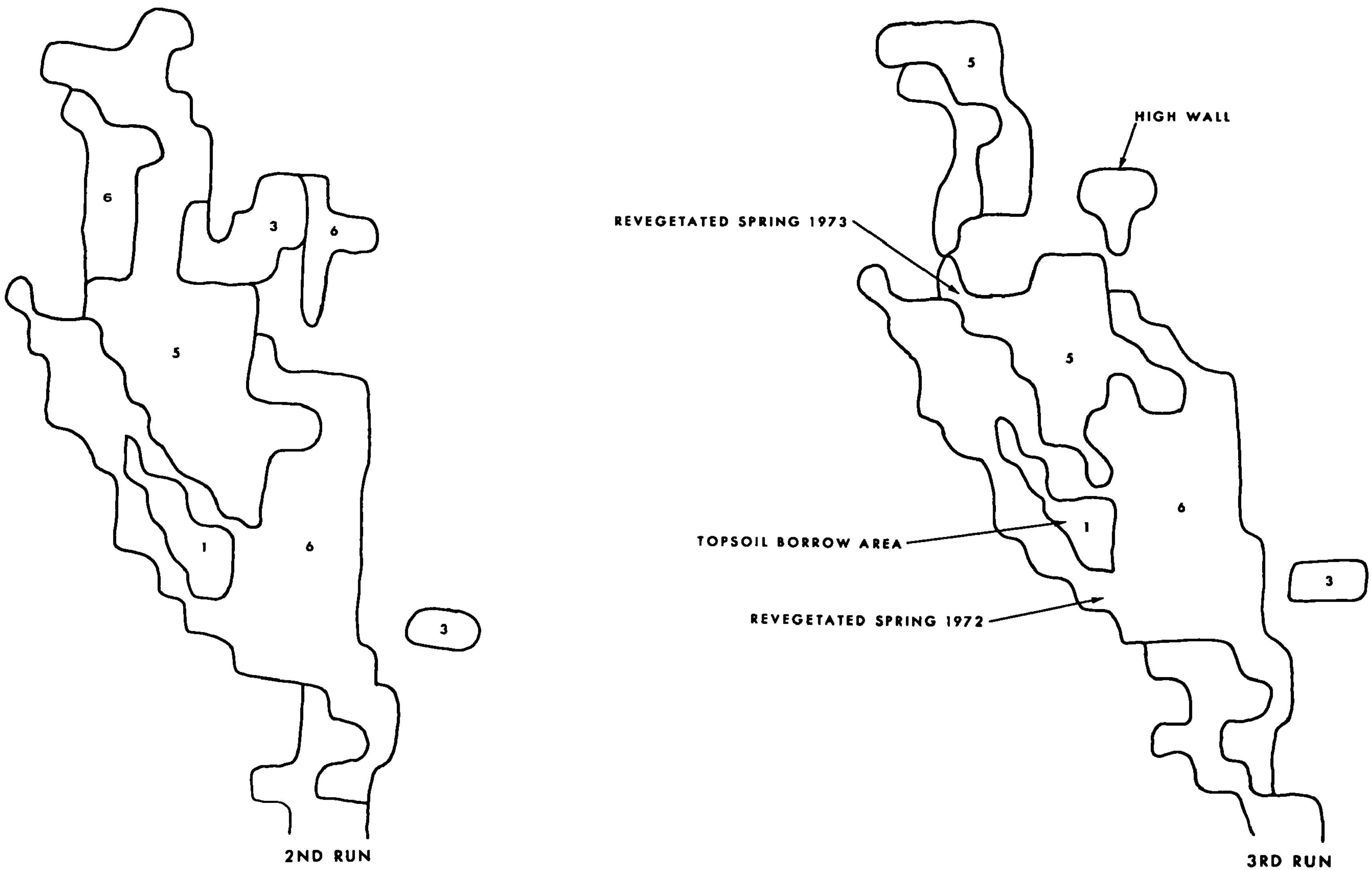


Figure IV—10. Comparison of Successive Classifications

To determine the accuracy of the computer classification, an overlay drawing was prepared from a 1974 aerial photograph outlining the features of the mine at the same scale as the computer line printer overlay. An exact comparison could not be made because the horizontal and vertical dimensions of the line printer output differ 20 percent in scale. The two maps of Mine 4 were brought into optimum registration and overprinted in Figure IV-11.

Comparison of the two maps shows that in the northwest section of the mine roads were included as a part of the revegetated areas in the computer classification. A small strip of land between the mine haulage road and the automobile road to the west was included as part of the mine. The northwesternmost tip of the mine seems to have been revegetated recently where the computer classified a high wall area. In the center of the mine a revegetated area just east of the road leading to the second cut but unmarked on the company supplied map is discerned. A road and some unreclaimed spoils cutting across the mine to the high wall was classified as background. Revegetated areas planted in the spring and fall of 1972 were classified as background; examination of photographs showed that the revegetation that had grown in these areas was more dense than in other revegetated plantings and more closely resembled the natural vegetative cover of the background classification. The 1974 high wall extends further to the northeast than the positions determined by the computer analysis in 1973; this is the area currently being mined.

A numerical comparison of the areas allotted to high wall and spoils shows that the computer recorded 86.3 percent of the acreage shown in the aerial photo one year later. The computer counted 105.7 percent of the acreage devoted to revegetated land and topsoil borrow. The overall area of the mine as determined by the computer was 96.9 percent of the area recorded in the aerial photo one year later.

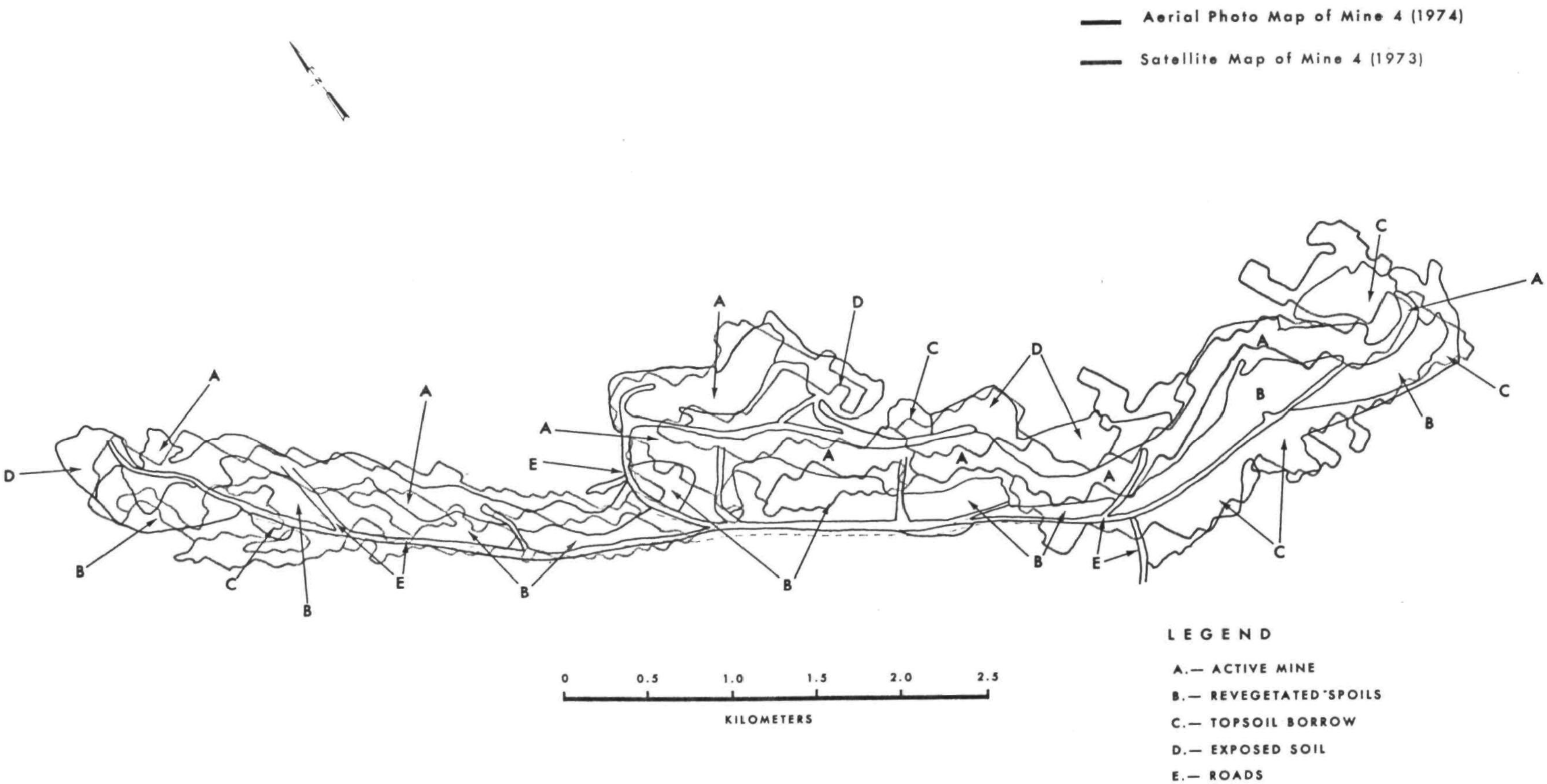


Figure IV—11. A Comparison of Mine 4 Classification Maps

V. RESULTS AND EVALUATION OF THE DATA ANALYSIS

This section presents the results of the computer analysis of the ERTS satellite data for coal strip mines in the Northern Great Plains. Of the thirty mines identified via satellite, fourteen were successfully classified using the techniques described in Section IV. Eight mines were not classified because of their small size or lack of ERTS data. Two of the mines were not classified because the necessary computer compatible tape was not received from the NASA data base; classification results will be reported when available. Three mines were not yet in operation and three underground mines were not classified.

Satellite images are presented for each mine classified. A classification map is also presented showing the shape, location and relative size of the active mine areas, graded and ungraded spoils piles, and areas in various stages of revegetation. Where appropriate, adjacent topographical and cultural features such as stream beds, cropland, roads and railroads are shown. The area of each type of land use is tabulated.

The problems encountered in applying ERTS technology to the classification of strip mines are also discussed. Such problems include masking of disturbed areas by revegetation and similarities between cropland and mine areas.

Coal production figures given for the mines for 1972, 1975 and 1980 were obtained from the mining companies for the Northern Great Plains Research Committee.

WYOMING MINES

MINE 1 - WYODAK RESOURCES DEVELOPMENT CO., WYODAK MINE

The Wyodak mine, about 10 km (6 mi) east of Gillette [Fig. V-1, inside back cover], produced 0.56 million metric tons (0.62 million tons) of coal in 1972. Coal production for 1975 and 1980 is projected to be 0.9 and 1.4 million metric tons (1.0 and 1.5 million tons), respectively. The thickness of the coal deposit averages about 27 m (90 ft) within the mine.

Based on a satellite image of this area, the surface area of the mine was about 27 hectares (66 acres) in 1973. The computer tape for this mine was not received from the NASA data base; however, when available, a classification map will be addended to this report.

MINE 2 - AMAX COAL CO., BELLE AYR MINE

About 22 km (14 mi) south of Gillette [Fig. V-1], this mine yielded only 0.027 million metric tons (0.03 million tons) of coal in 1972. A major increase in production is expected in the future with projected levels of 1.6 and 8.6 million metric tons (1.75 and 9.5 million tons) for 1975 and 1980, respectively. The coal deposit averages 21 m (70 ft) thick.

The surface area of this mine, as determined from a satellite transparency recorded in July 1973, was about 85 hectares (210 acres). The computer tape for this mine was not received from the NASA data base; however, when available, a classification map will be addended to this report.

MINE 3 - BEST COAL CO., EAST ANTELOPE MINE

This mine is about 80 km (50 mi) north of Douglas in the Thunder Basin National Grassland [Fig. V-1]. The mine is small with a 1972 production of only 910 metric tons (1,000 tons). No increase in production is expected through 1980. The average thickness of the coal deposit is about 12 m (40 ft).

The surface area of the mine, measured from a USGS aerial photograph was about 1.5 hectares (3.7 acres) in 1969. The land surrounding the mine is characterized by essentially bare soil with little vegetation. The optical characteristics (spectral signature) of this land as recorded in the ERTS data were nearly identical to those of the mine area precluding any meaningful computer classification of land use within the mine.

MINE 4 - PACIFIC POWER AND LIGHT CO., DAVE JOHNSTON MINE

Background

Situated about 48 km (30 mi) northeast of Casper and 26 km (16 mi) north of Glenrock [Fig. V-1], the Dave Johnston Mine produced 2.4 million metric tons (2.6 million tons) of coal in 1972. Production is expected to increase only slightly as reflected by projections of 2.4 and 2.5 million metric tons (2.7 and 2.8 million tons) for 1975 and 1980, respectively.

As shown in the satellite image [Fig. V-2], the mine has a long, narrow configuration. The 8 km (5 mi) long high wall lies in a southeast direction. Excavation is advancing to the northeast into an arid landscape thinly covered by sagebrush and prairie grass. Spoils piles and revegetated areas lie to the southwest of the high wall. Revegetation was begun in 1969 and closely follows the excavation activities. The area of unreclaimed spoils piles is thus relatively small. The status of reclamation as of Spring 1973 is shown in Figure V-3 provided by the mining company.

For verification, aerial photographs of various areas of the mine were taken by NFIC-D personnel, four of which are shown in Figures V-4 through V-7.

Classification of Mine Areas

As shown in Figure V-3, about 55 percent of the disturbed area of the mine has been revegetated. The computer classification defined the disturbed areas but difficulty was encountered in separating older

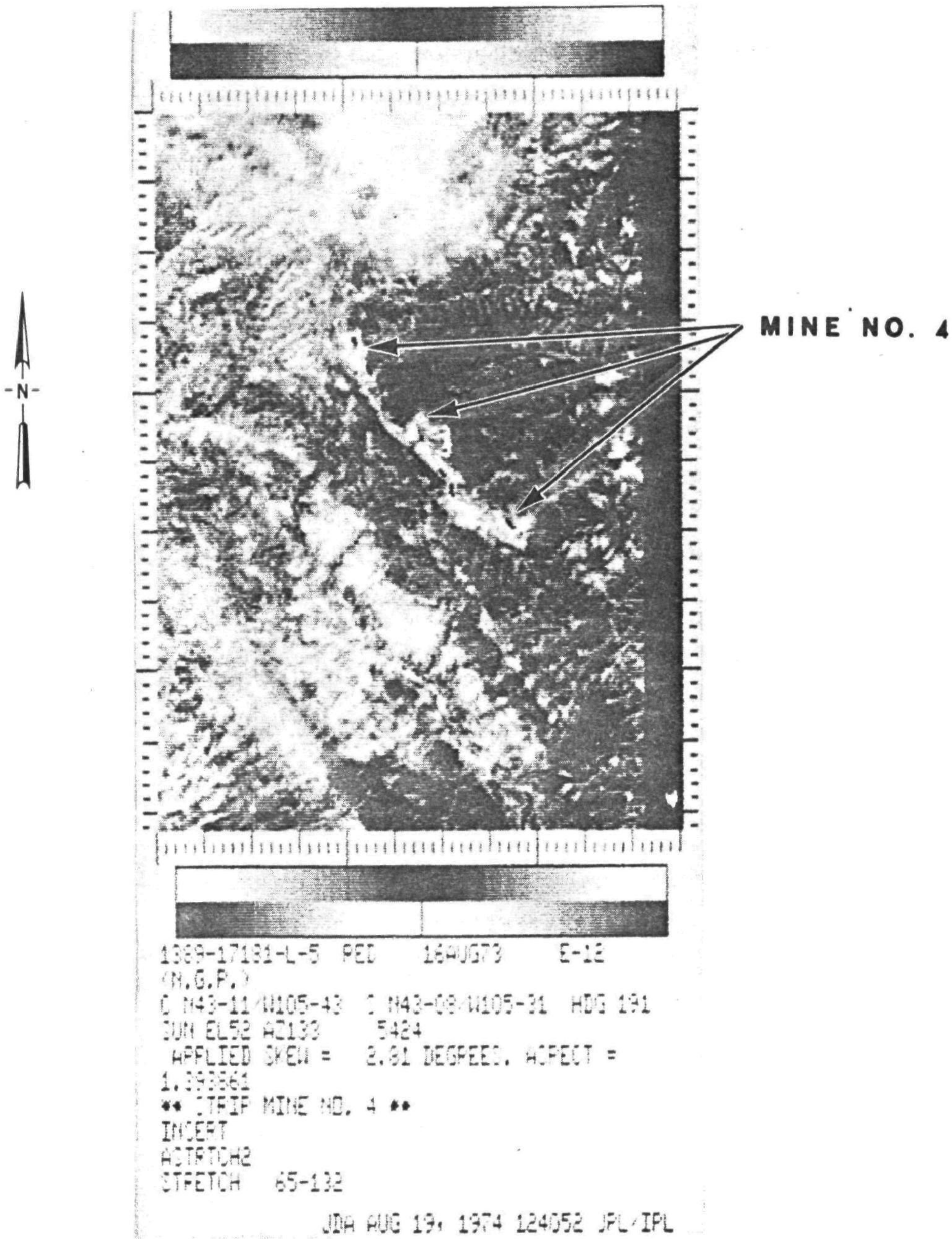


Figure V-2. Satellite Image of Mine No. 4

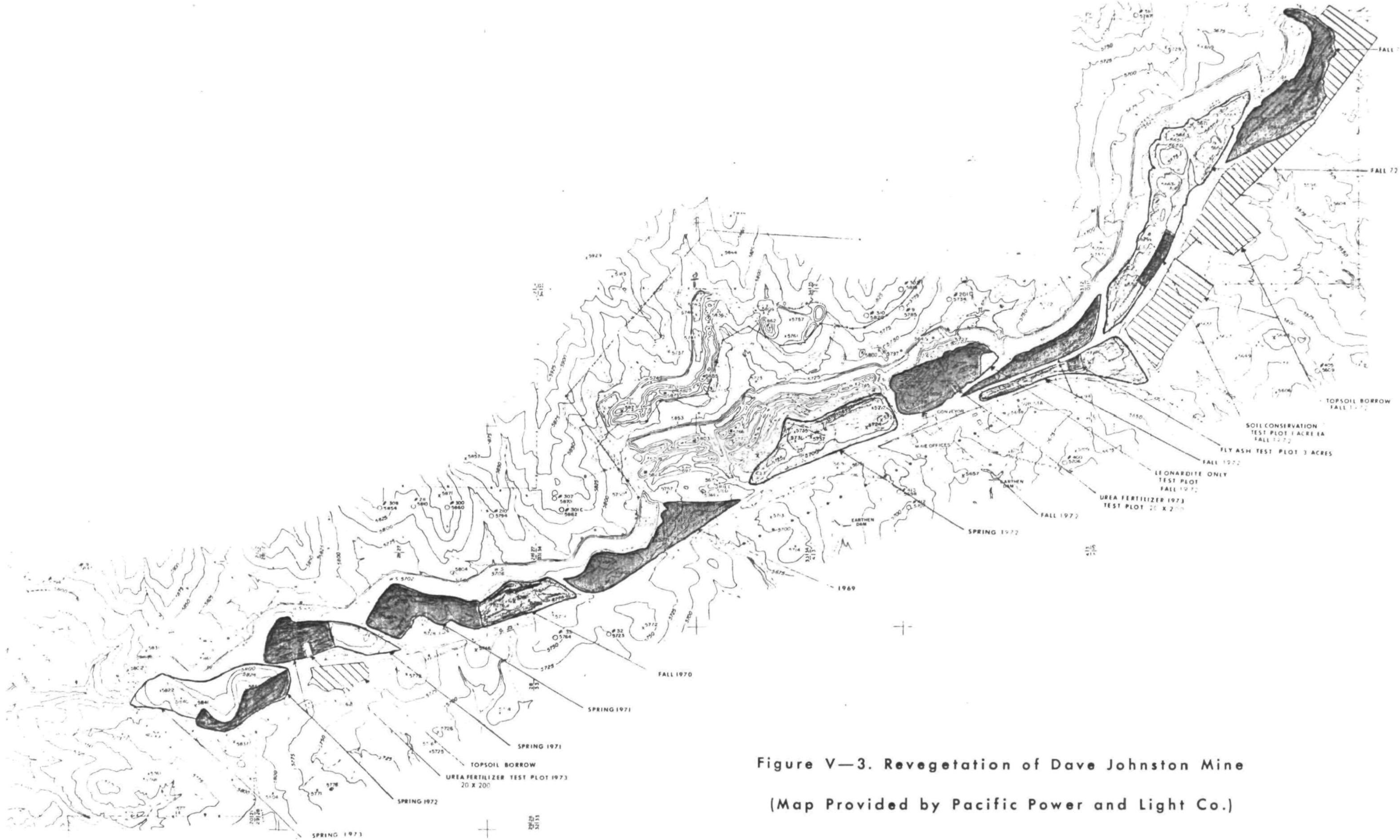


Figure V—3. Revegetation of Dave Johnston Mine

(Map Provided by Pacific Power and Light Co.)

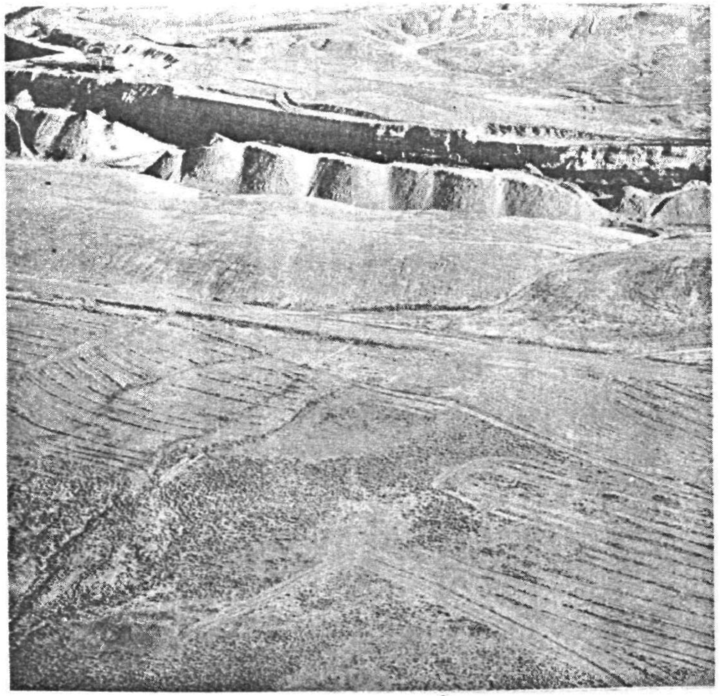


Figure V-4.

Topsoil Borrow Area in Foreground.

Revegetated Area Between Road and Spoils Pile.

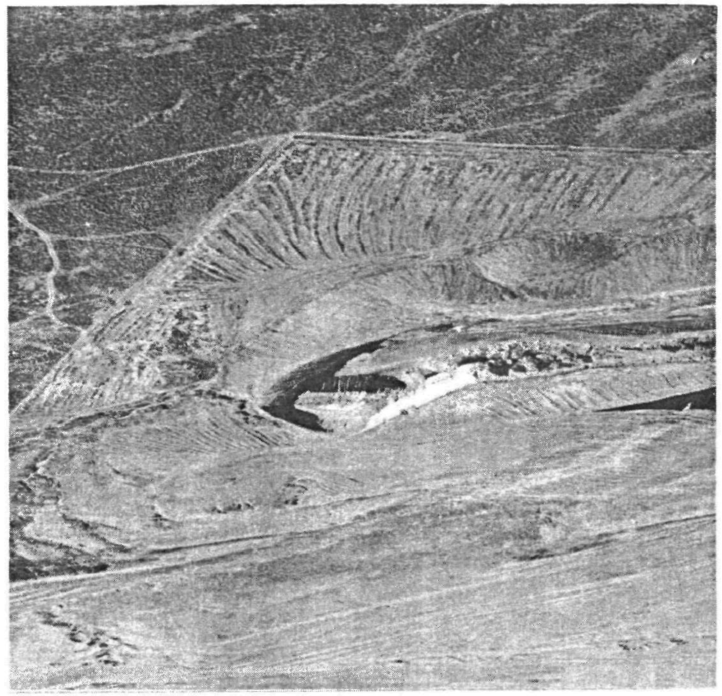


Figure V-5.

View of Southeast End of Mine Looking North.

Note Topsoil Borrow Area North of Mine.

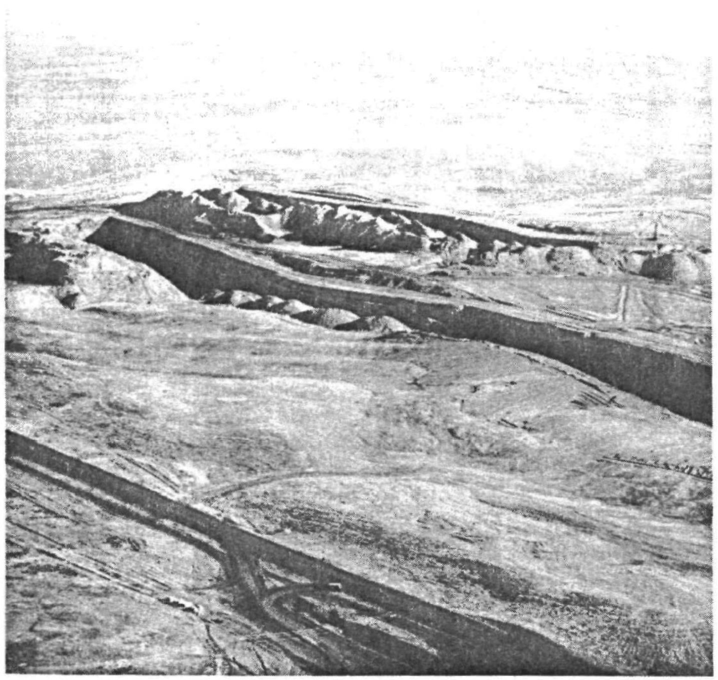


Figure V-6.

Middle Area of Mine Showing Second Cut.

Figure V-7.

Middle Area of Mine Showing Discontinuity in High Wall.

revegetated areas from undisturbed native vegetation. This separation was achieved using Figure V-3. Difficulty was also encountered in defining the high wall location in the northwestern area of the mine during the initial classification. The high wall was then defined by preparing a ratio image of the green band to the infrared 1 band. A composite map [Fig. V-8]* of the classifications of various mine areas was prepared using both the ratio image and the multispectral classification.

In the northwestern corner of the mine, land revegetated in Spring 1973 was discernible from grass in an adjacent area planted one year earlier. A topsoil borrow area on the west side was also identified. Proceeding to the southeast, revegetated areas planted in 1969, 1970 and 1971 as designated on the map produced spectral signatures the same as undisturbed native vegetation thus indicating a comparable density of vegetation had been achieved.

The southeastern portion of the mine contains much revegetated land and many topsoil borrow areas. In the borrow areas, a scraper has removed strips of topsoil leaving native vegetation in alternating strips as shown in Figure V-4. Some natural revegetation has taken place in the disturbed strips. The revegetated land and the borrow areas were spectrally indistinguishable from one another as both consist of areas of vegetation mingled with bare soil.

---

* Some scale distortion is inherent in producing an overlay map (on the computer line printer) which can be avoided only by additional processing. In scaling overlay maps to USGS topographic maps, the longitidinal axis of the former must be reduced to 80% of its nominal value.

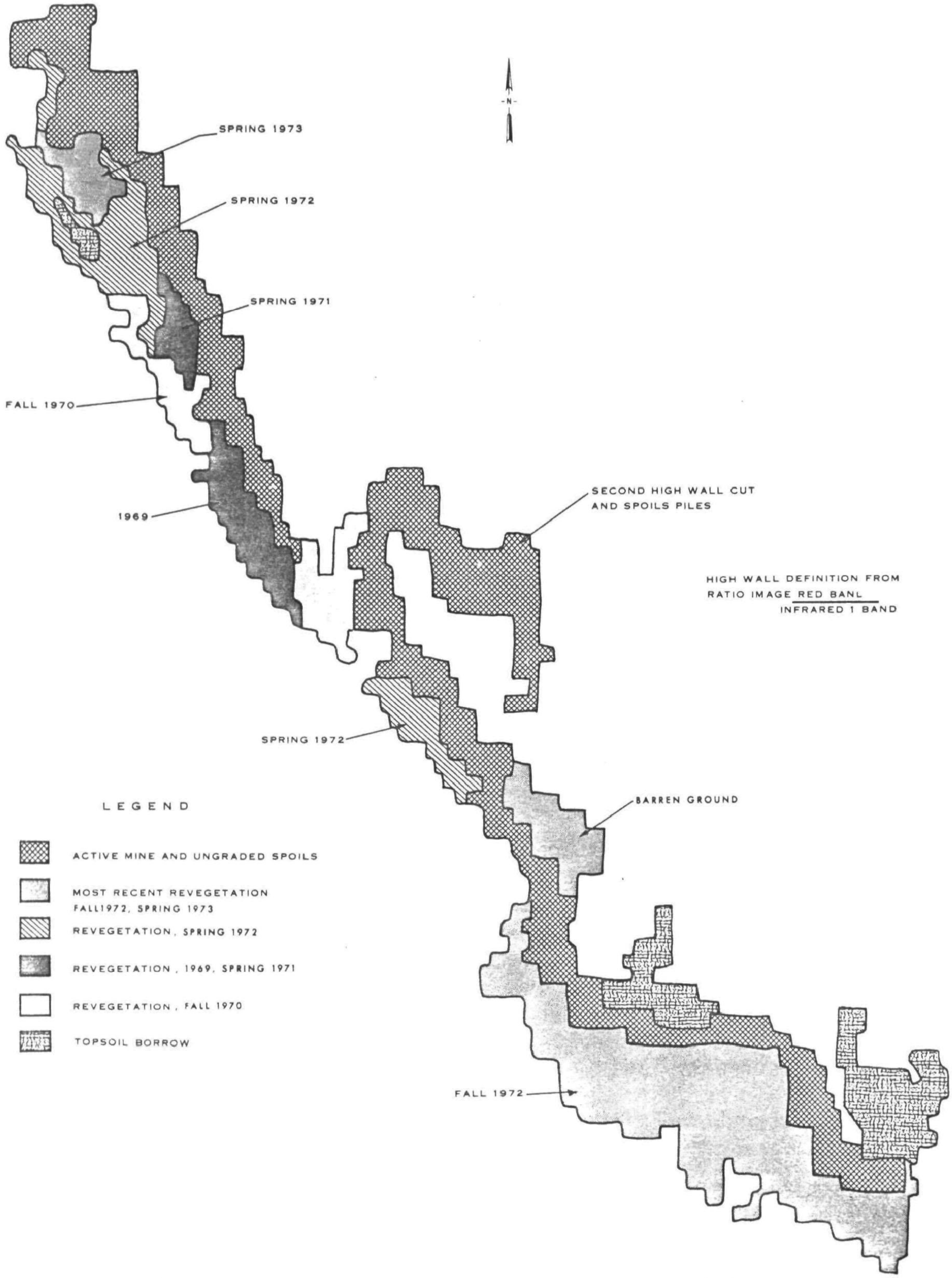


Figure V—8. Classification Map of Mine 4 — Pacific Power and Light Company, Dave Johnson Mine, Glenrock, Wyoming

The land north of the high wall in the southeastern part of the mine had a signature characteristic of revegetation or topsoil borrow. No activity in this area was indicated on the company map [Fig. V-3]. An NFIC-D aerial photograph [Fig. V-5] verified, however, that this was a topsoil borrow area.

Characteristics of the most extensive spoils piles near the second cut in the center of the mine are shown in Figures V-6 and V-7.

By counting pixels, the computer keeps track of the area in each classification. The area of each classification for the Dave Johnston Mine is presented in Table V-1. Of the 554 hectares (1,365 acres) of disturbed area, about 55 percent has been revegetated.

Table V-1

Areal Distribution of Land Use
Mine 4

Land Use	Area		
	Pixels	Hectares	Acres
High wall and spoils	508	247	610
Northwest Portion of Mine			
Spring 1973 Revegetation	26	13	31
Topsoil Borrow	7	3	8
Spring 1972 Planting	67	33	80
Spring 1971 Planting	17	8	20
Fall 1970 Planting	33	16	40
Fall 1969 Planting	46	22	55
	196	95	234
Southeast Portion of Mine			
Spring 1972 Planting	30	15	36
Fall 1972 Planting	36	18	43
Fall 1972 Planting and Topsoil Borrow in Southwesternmost Corner	368	179	442
	434	212	521
Total Mine Area	1,138	554	1,365

MINE 5 - BIG HORN COAL CO., BIG HORN MINE

Background

This mine, at Acme about 11 km (7 mi) north of Sheridan, produced nearly 0.9 million metric tons (1.0 million tons) of coal in 1972 [Fig. V-1]. Production is expected to remain the same through 1980. The mine lies in a valley at the confluence of Goose Creek and the Tongue River. Mine 6, which is discussed in the next section, is a few kilometers to the west.

Classification of Mine Areas

The satellite imagery [Fig. V-9] revealed a complex setting for this mine. The mine is bound on the north by the Tongue River and on the west by a small reservoir on Goose Creek. Graded spoils lie between the reservoir and the active area of the mine [Fig. V-10]. On the east is a bluff with a surface of eroded soil and brush that gives the same spectral signature as the graded spoils. The mine is being extended eastward into the bluff.

To the west of the mine, a gravel pit and a coal loading area are distinguishable. Across the Tongue River Valley to the north of the mine, an area of abandoned spoils piles and a pond from previous mining activity were defined. The area disturbed by mining activities in this vicinity is shown in Table V-2.

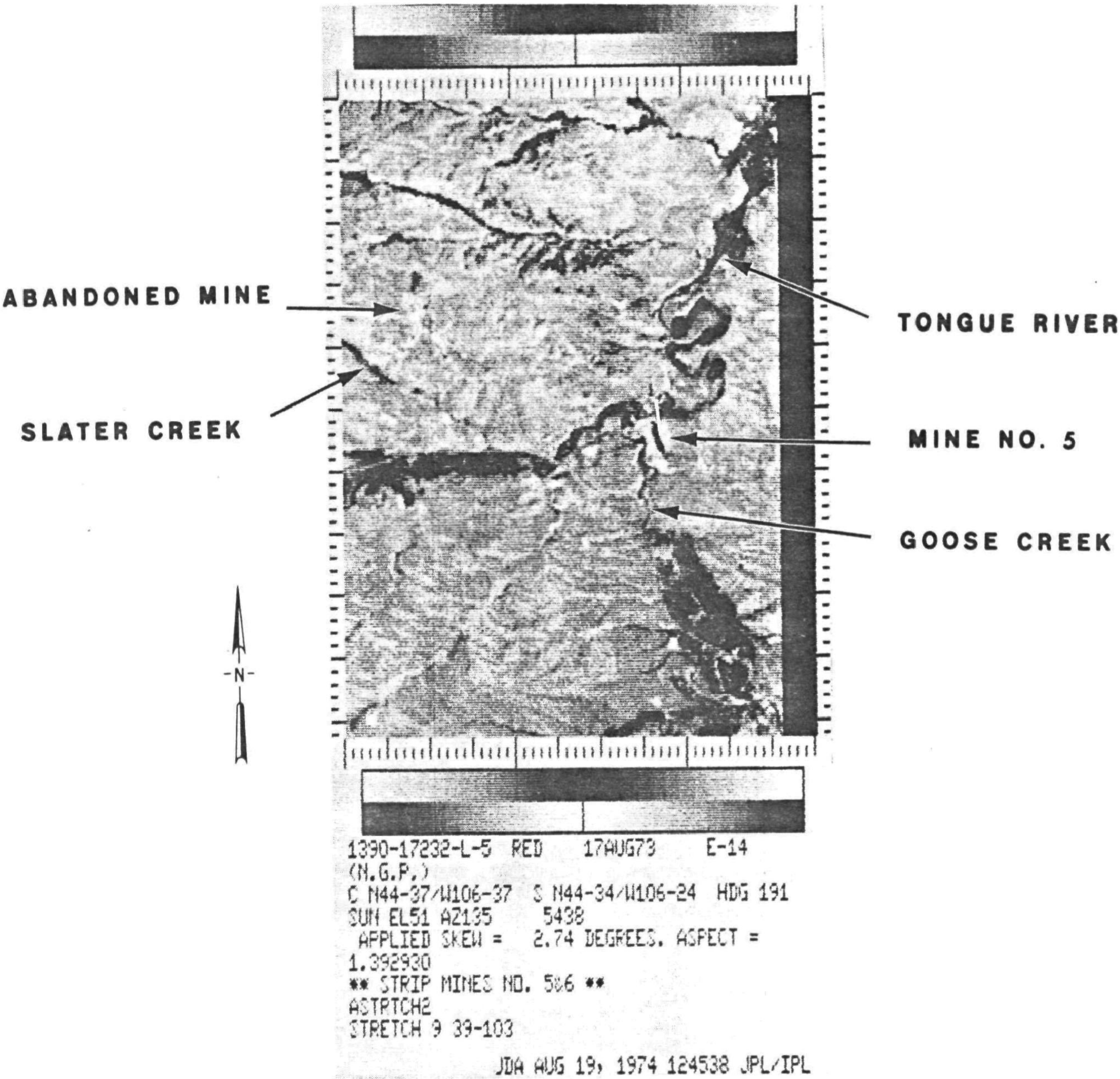


Figure V-9. Satellite Image of Mines No. 5 and 6

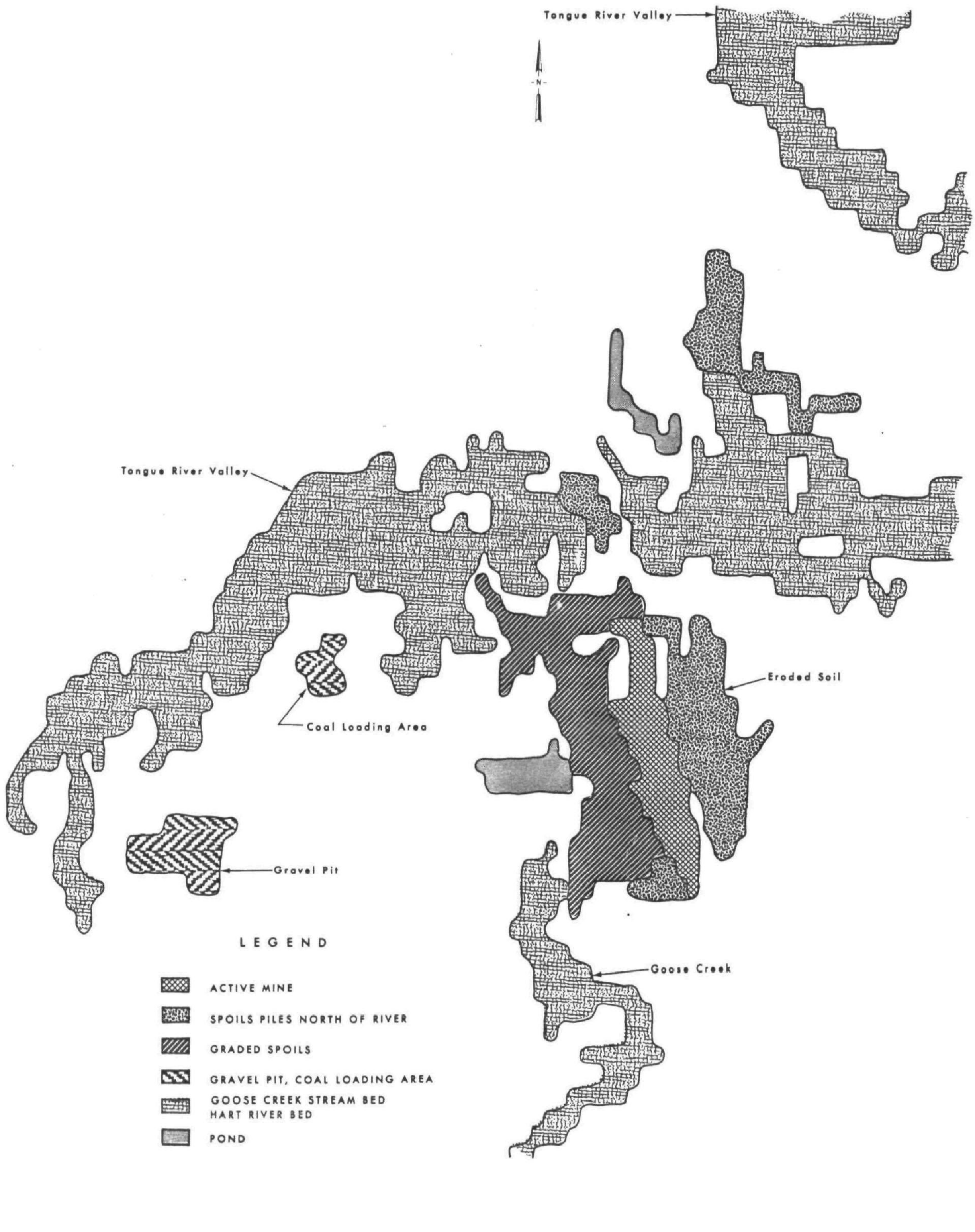


Figure V—10. Classification Map of Mine 5— Big Horn Coal Company, Big Horn Mine, Acme, Wyoming

Table V-2

Areal Distribution of Land Use
Mine 5

Land Use	Area		
	Pixels	Hectares	Acres
Active mine	44	21	53
Graded spoils	90	44	108
Total, Big Horn Mine	134	65	161
Abandoned spoils north of Tongue River	57	28	68
Total, Acme, Wyoming	191	93	229

MINE 6 - WELCH COAL CO.

Background Information

Welch Coal Company operates a small strip mine about 16 km (10 mi) northwest of Sheridan and a few kilometers west of the Big Horn Mine [Fig. V-1]. Production in 1972 was only 18,100 metric tons (20,000 tons) with no projected production through 1980.

The active mine is very small. Computer classification was thus difficult and of little value. However, extensive spoil piles of an abandoned mine in the area north of the Tongue River and the town of Kleenburn [Fig. V-9] were classified and are discussed below.

Classification of Abandoned Mine Areas

Four areas of spoils piles with varying degrees of re-vegetation are apparent [Fig. V-11]. Several small ponds were defined in the three major spoils areas. Exposed spoils in the three areas yielded differing spectral signatures.

Spoils in the northwestern area were overgrown with vegetation. In the northeastern area, the spoils were uniformly graded and gave the highest intensity signature because they were oriented in an optimum direction (east-west) for reflecting sunlight.

Several ponds and areas of vegetation break up the structure of the middle spoils pile. By carefully locating the training areas, the spectral signature of the spoils alone was determined.

Much of the southeastern area is covered by ungraded spoils. Some of the spoils are partially overgrown with vegetation.

To the west of the middle spoils is an area where much light-colored soil is eroded and exposed. Such an area is frequently classified into the same categories as the spoils piles because of similar spectral signatures.

The areal distribution of each classification of the abandoned spoils piles is summarized in Table V-3.

Table V-3
Areal Distribution of Land Use
Abandoned Spoils Near Mine 6

Land Use	Area		
	Pixels	Hectares	Acres
Overgrown spoils	32	16	38
Lakes (total)	41	20	49
Northern section spoils	67	33	80
Middle section spoils	113	55	136
Southern section spoils	117	57	140
Total Area	370	180	444

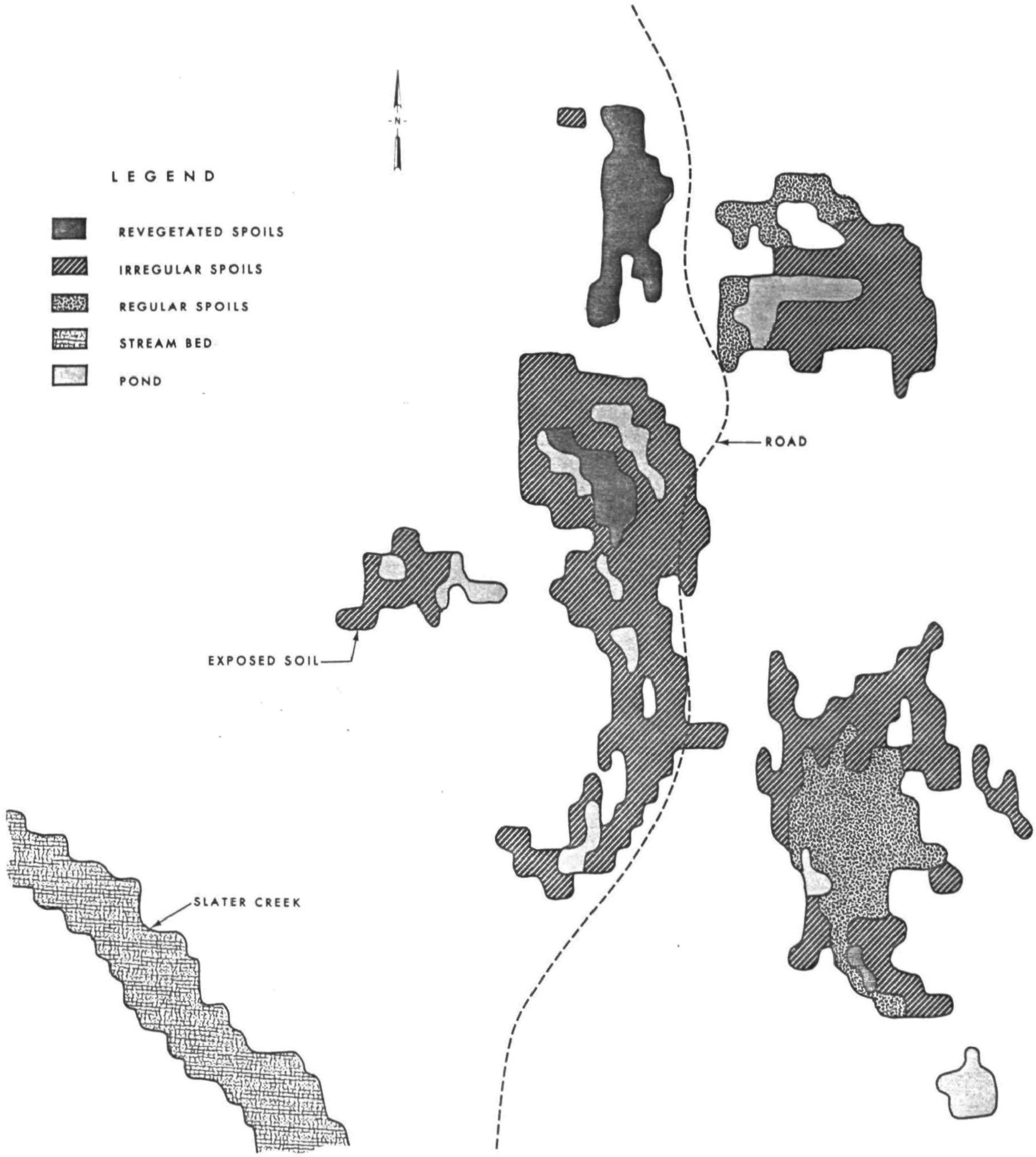


Figure V—11. Classification Map of Abandoned Spoils Piles North of Mine 6—
Welch Coal Company, Kleenburn, Wyoming

MINE 7 - CARTER OIL CO.

Carter Oil Company has proposed a mine about 12 km (7 mi) north of Gillette [Fig. V-1]. It is doubtful that mining will begin before 1985.

MINE 8 - ATLANTIC RICHFIELD

Situated 68 km (42 mi) south of Gillette, this mine is just beginning operations with 1975 production estimated to be 0.18 million metric tons (0.2 million tons) [Fig. V-1]. Production is expected to increase sharply, reaching 6.4 million metric tons (7.0 million tons) annually by 1980. No indication of the mine was visible on the ERTS imagery.

MINE 9 - REYNOLDS METALS, INC.

A mine has been proposed 32 km (20 mi) south of Sheridan [Fig. V-1]. Production plans are uncertain.

MINE 10 - KERR-McGEE

No 1975 production is planned at this proposed mine 63 km (39 mi) south of Gillette and a few kilometers north of Mine 8 [Fig. V-1]. Coal production of 6.4 million metric tons (7.0 million tons) is planned for 1980.

MONTANA MINES

MINE 11 - DECKER COAL CO., DECKER MINE

Background

West of the Tongue River Irrigation Reservoir 30 km (19 mi) north of Sheridan, Wyoming, this mine is about 24 km (15 mi) northeast of Mines 5 and 6 [Fig. V-12, inside back cover]. Coal production was only 0.7 million metric tons (0.8 million tons) in 1972; however, a major increase in production to 5.4 and 11.8 million metric tons (6 and 13 million tons) is expected for 1975 and 1980, respectively, making this the second largest mine in the Northern Great Plains.

The satellite imagery [Fig. V-13] shows that the disturbed area of the mine is characterized by a circular pattern. The loading area is in the center with radial roads extending to the active mine area. The mine is advancing along a circular arc into the hillside to the west and south.

Classification of Mine Areas

In addition to the high wall, two types of disturbed areas were present in the mine area. The area to the west and south of the high wall was being prepared for mining and the vegetation had been removed [Fig. V-14]. However, the surface had not been disturbed to any great extent. The land to the east and north of the high wall contained spoils piles. Both types of disturbed areas displayed the same spectral signature precluding separation by computer analysis.

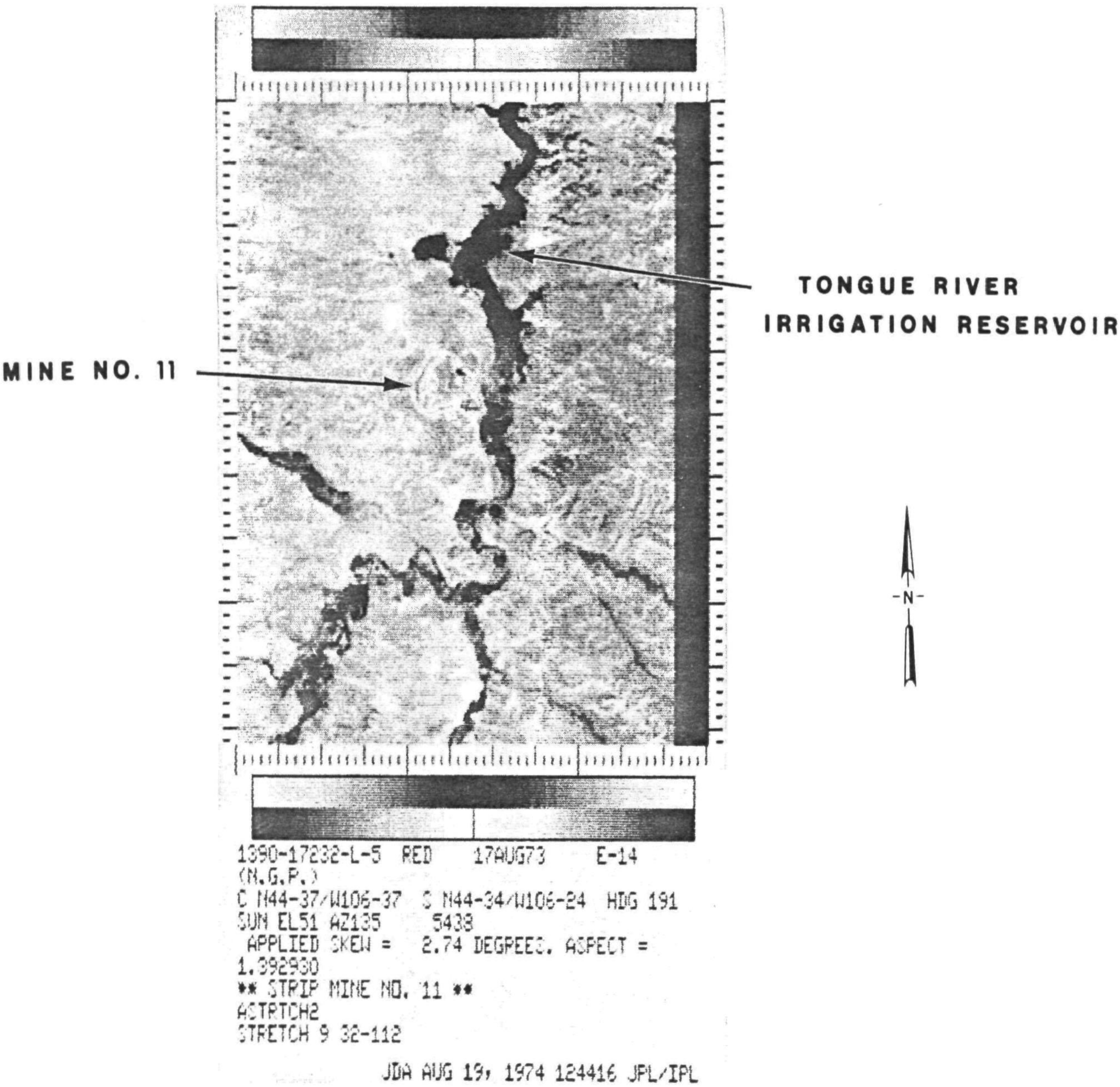


Figure V-13. Satellite Image of Mine No. 11

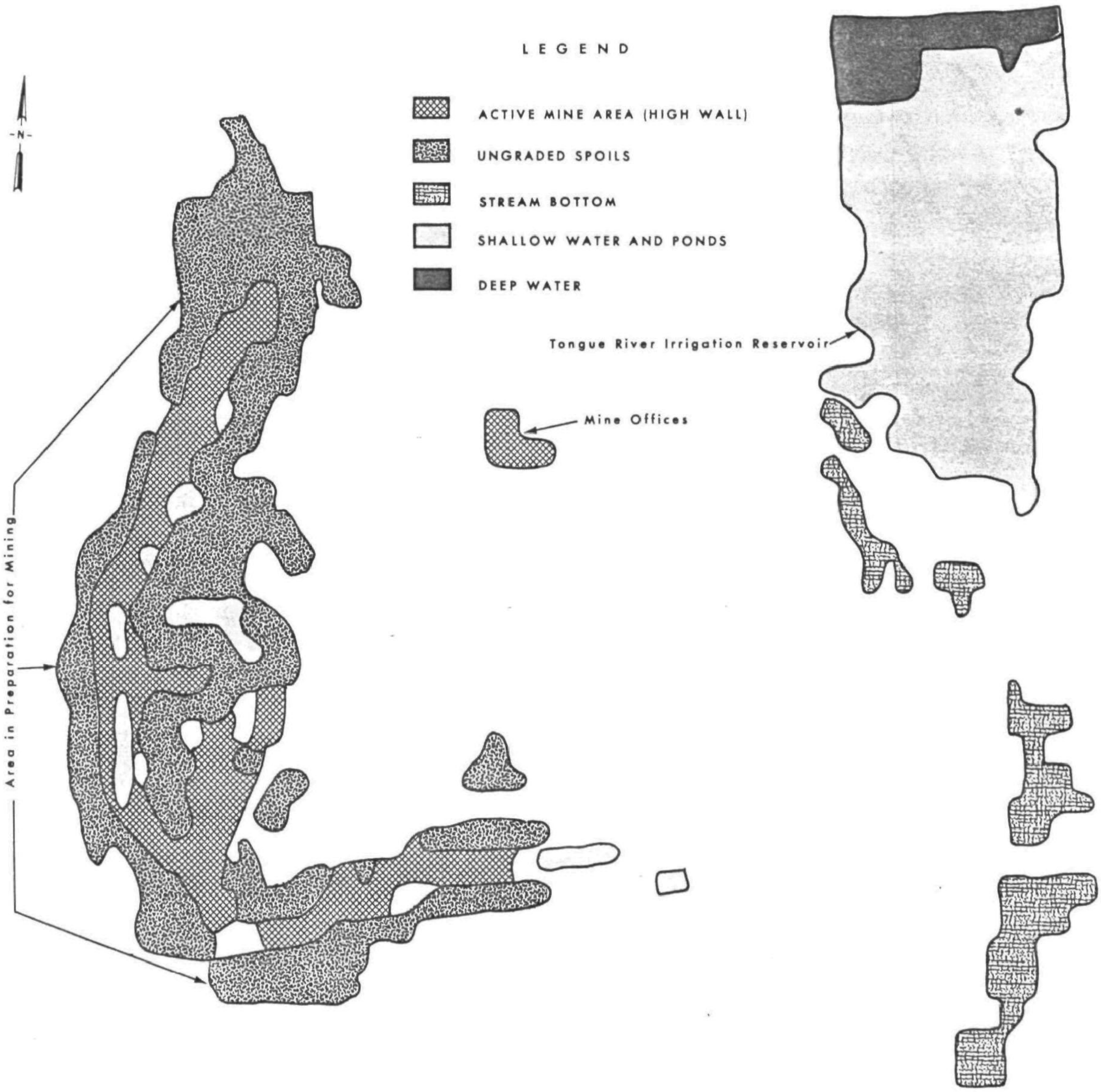


Figure V—14. Classification Map of Mine 11— Decker Coal Company, Decker, Montana

Because the active area is a narrow cut, the picture elements blend the active area with the disturbed areas on both sides. The pure spectral signature of the active area was present for the north-south cut, but the majority of the picture elements covering the active area fell into a different class because of the blending. This effect was particularly noticeable in the southern portion of the mine. Small ponds of water were defined in the active area.

The upstream end of the Tongue River Irrigation Reservoir is east of the mine [Fig. V-13]. Two distinctly different spectral signatures were observed in this portion of the reservoir. Either the end of the reservoir has been shoaled by silt deposition giving the light image area, or more probably, turbid river inflow had discolored the southern end of the reservoir. The valley of the Tongue River south of the reservoir was clearly distinguishable.

The areal distribution of land use at this mine is summarized in Table V-4.

Table V-4
Areal Distribution of Land Use
Mine 11

Land Use	Area		
	Pixels	Hectares	Acres
Active mine	83	40	100
Ponds in mine	9	4	11
Spoils	90	44	108
Area in preparation for mining	107	52	128
Total Area	289	140	347

MINE 12 - WESTMORELAND RESOURCES, SARPY CREEK MINE

Background

Westmoreland Resources operates this strip mine about 40 km (25 mi) northeast of Hardin in the upper Sarpy Creek drainage area [Fig. V-12]. The mine began operation in 1973. Projected annual production for 1975 and 1980 is 3.6 million metric tons (4 million tons).

A small tributary of Sarpy Creek bisects the mine site. A substantial area of cropland (light-colored areas) is present in the vicinity of the mine as shown in the satellite image [Fig. V-15].

Classification of Mine Areas

This mine had just begun operation when the ERTS image was taken during the summer of 1973. A large area in the vicinity of the mine was distinguishable as disturbed area, different from the native rangeland [Fig. V-16]. Separation of this area into mined areas and cropland was difficult.

Those areas classified as mined areas exhibited spectral signatures similar to the high wall and spoils areas of Mine 14 about 32 km (20 mi) to the east on the same ERTS frame. Close examination of a 1971 USGS aerial photograph of the mine vicinity revealed that part of the area south of the tributary stream, which showed the same spectral signature in 1973 as the mined area, was actually cropland in 1971. The area to the north of the stream classified as mined area does not appear to be cropland in the 1971 aerial photograph. Whether this area is being mined or has been placed in cultivation since 1971 is unknown.

A summary of the land classification is shown in Table V-5.

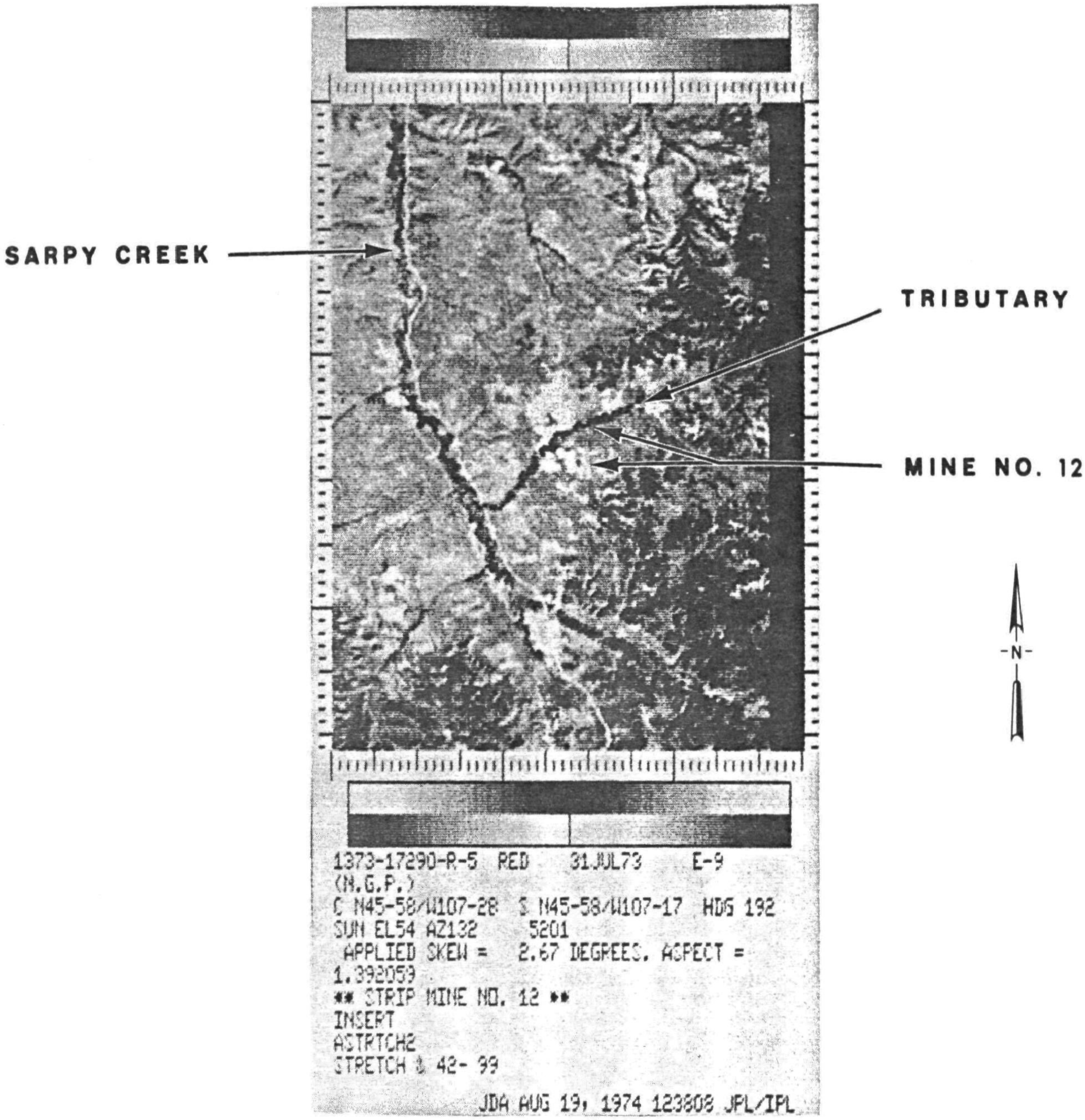


Figure V-15. Satellite Image of Mine No. 12

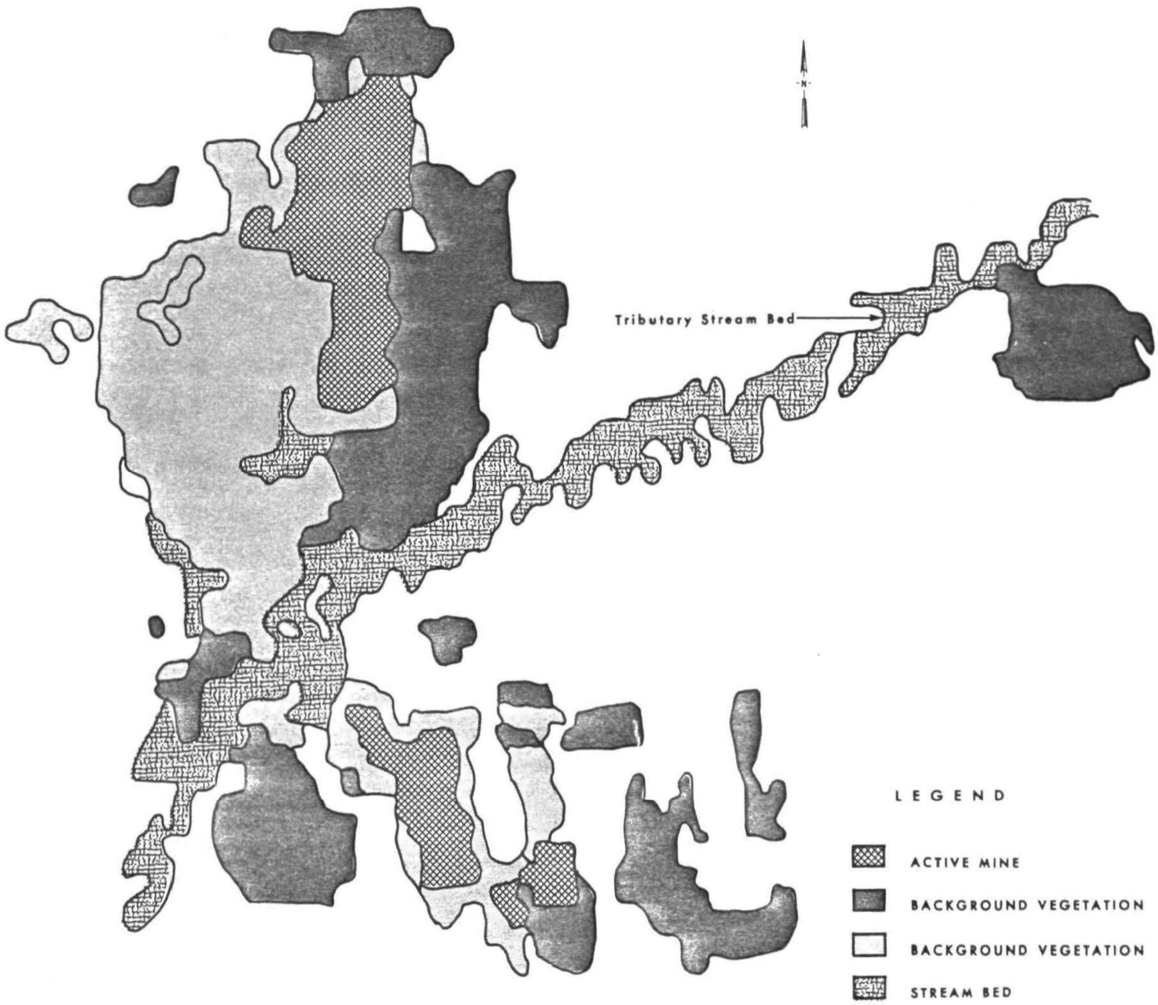


Figure V—16. Classification Map of Mine 12— Westmore Land Resources, Sarpy Creek Mine, Hardin, Wyoming

Table V-5

Areal Distribution of Land Use
Mine 12

Land Use	Area		
	Pixels	Hectares	Acres
Mined area north of tributary	99	48	119
Mined area south of tributary	53	26	64
Total area	152	74	182

MINE 13 - PEABODY COAL CO., BIG SKY MINE

Background

Peabody Coal Co. operates the Big Sky Mine about 8 km (5 mi) southwest of Colstrip [Fig. V-12]. Annual coal production is estimated to be 3.6 million metric tons (4 million tons) during the 1975 to 1980 time period, a significant increase over 1972 production of 1.4 million metric tons (1.6 million tons).

The Big Sky Mine and the large Rosebud Mine at Colstrip are visible in the satellite image [Fig. V-17]. Colstrip is in the headwaters of Armells Creek, a small tributary of the Yellowstone River.

Classification of Mine Areas

Comparison of the classified image with a USGS aerial photograph indicated that excellent discrimination was achieved between graded and ungraded spoils [Fig. V-18]. Disturbed ground in the railroad car loading area and an area where turning trucks had eroded the grass from the soil yielded the same spectral signatures as the spoils.

Two classes were identified for surrounding undisturbed areas. One was grass covered, the other grassy areas interspersed with patches of

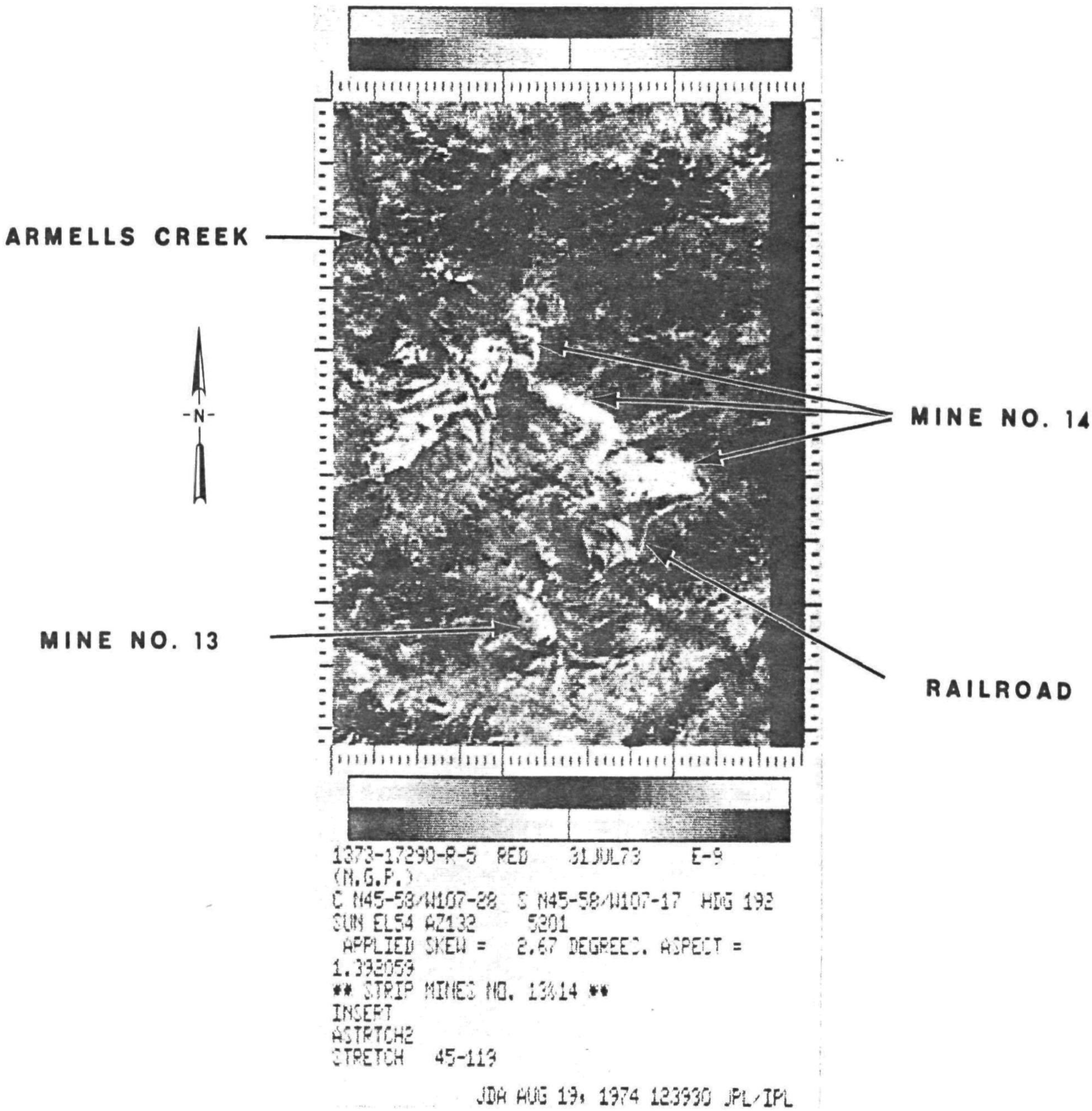


Figure V-17. Satellite Image of Mines No. 13 and 14

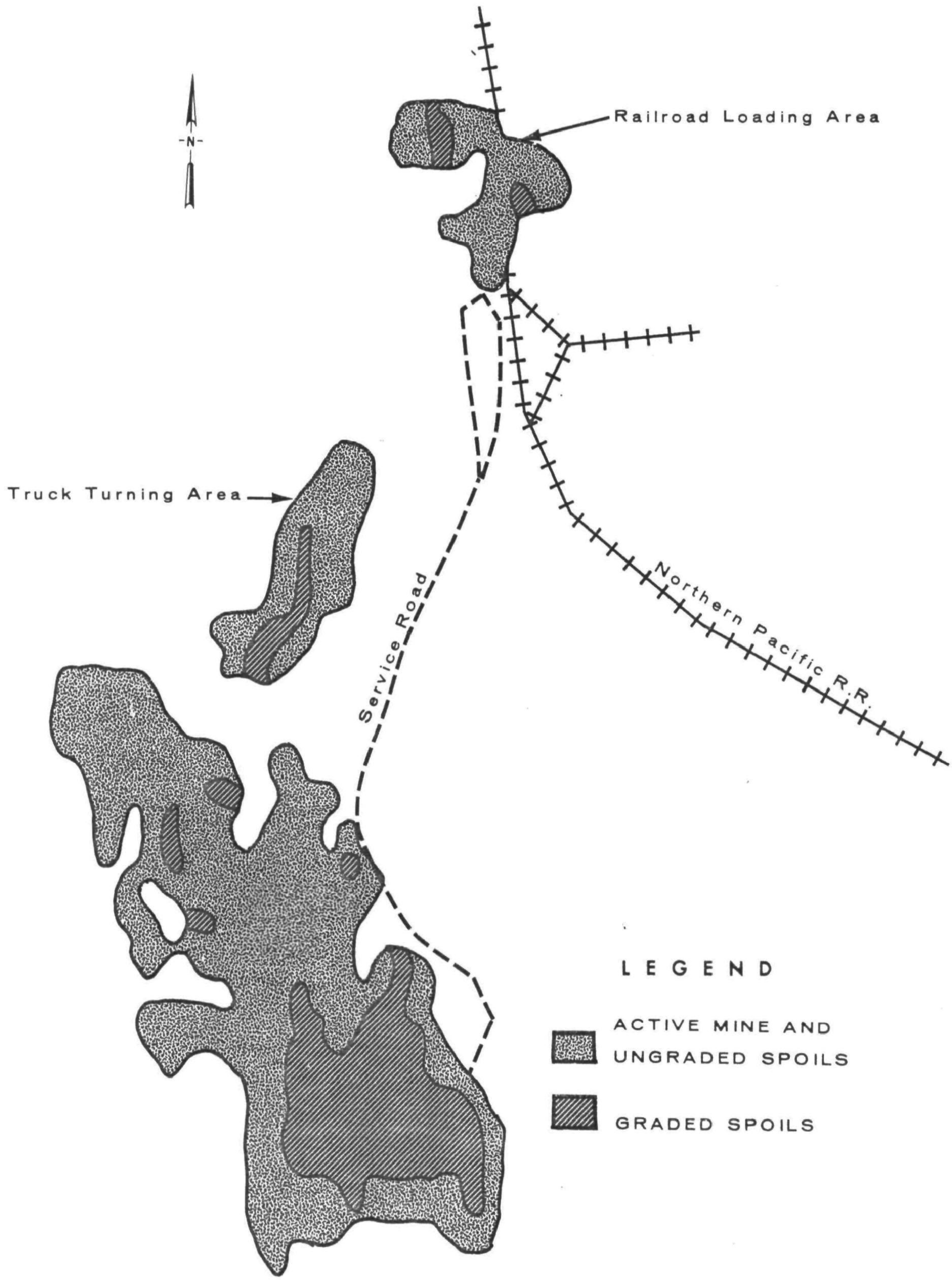


Figure V—18. Classification Map of Mine 13— Peabody Coal Company, Big Sky Mine, Colstrip, Montana evergreens. Comparison with the aerial photograph indicated that these types of vegetative cover were successfully separated.

The area of disturbed land is summarized in Table V-6.

Table V-6
Areal Distribution of Land Use
Mine 13

Land Use	Area		
	Pixels	Hectares	Acres
Railroad loading and turnaround	47	23	56
Graded spoils	51	25	61
Active mine and ungraded spoils	87	42	104
Total area	185	90	222

MINE 14 - WESTERN ENERGY CO., ROSEBUD MINE

Background

The Rosebud Mine at Colstrip is the largest coal strip mine in the Northern Great Plains [Fig. V-12]. It produced 5 million metric tons (5.5 million tons) of coal in 1972 with the same value projected for 1975. By 1980 the yield of the mine is projected to increase nearly four-fold to 17.5 million metric tons (19.3 million tons) per year.

Because of its size, the mine is an excellent target for satellite imagery and does not pose the problems of small size training areas and blending of spectral signatures that are associated with smaller mines. The mine is clearly visible in the satellite image [Fig. V-17]. Geometrically the mine is complicated, consisting of three arms of spoils piles in the northern section, a northwest-southeast central arm, a goose neck and the southern active mining area.

Classification of Mine Areas

The mine was classified in two steps since the initial aerial photograph obtained from the Company covered only the southern section. Classification of the southern section defined the high wall, the spoils piles, an older revegetated area, and a more recent attempt at revegetation [Fig. V-19]. Also identified were the areas in preparation for mining south of the high wall and a railroad and highway corridor skirting the east side of the mine. Distinguishing the mined area from eroded soil west of the southern section and the goose neck proved difficult.

Figure V—19. Classification Map of the Southern Section of Mine 14 — Western Energy Company, Rosebud Mine, Colstrip, Montana

When the spectral signatures derived from training sites in the southern part of the mine were applied to the northern part, the results were poor due to the changing character of the spoils. New training sites were thus established in the northern part of the mine. Examination of aerial photographs covering the northern section shows that the spoils piles occur in well-ordered rows that are oriented along the direction of the arms of the mine. The orientation of the spoils piles to the incident solar radiation thus changes with location, also changing the spectral signature.

Figure V-20 illustrates the classification derived from training sites on spoils piles in the northern section of the mine, plus a few of the original training sites from the southern section of the mine. Some overlapping occurred since several different classes of spoils piles were used that closely resemble each other spectrally. It was possible, however, to distinguish between graded, irregular ungraded, regular (uniform) graded and partially overgrown spoils.

The high wall areas in the northern section of the mine did not classify separately because they were too narrow. In the one successful attempt at classifying the northern section highwall, only a few pixels one column wide were detected. Due to natural revegetation, the western part of the spoils (shown by the dashed line) near the landing strip on the southwestern arm classified as background. The area northeast of the drainage ditch has naturally revegetated. The full extent of the area mined was thus not classified as disturbed area.

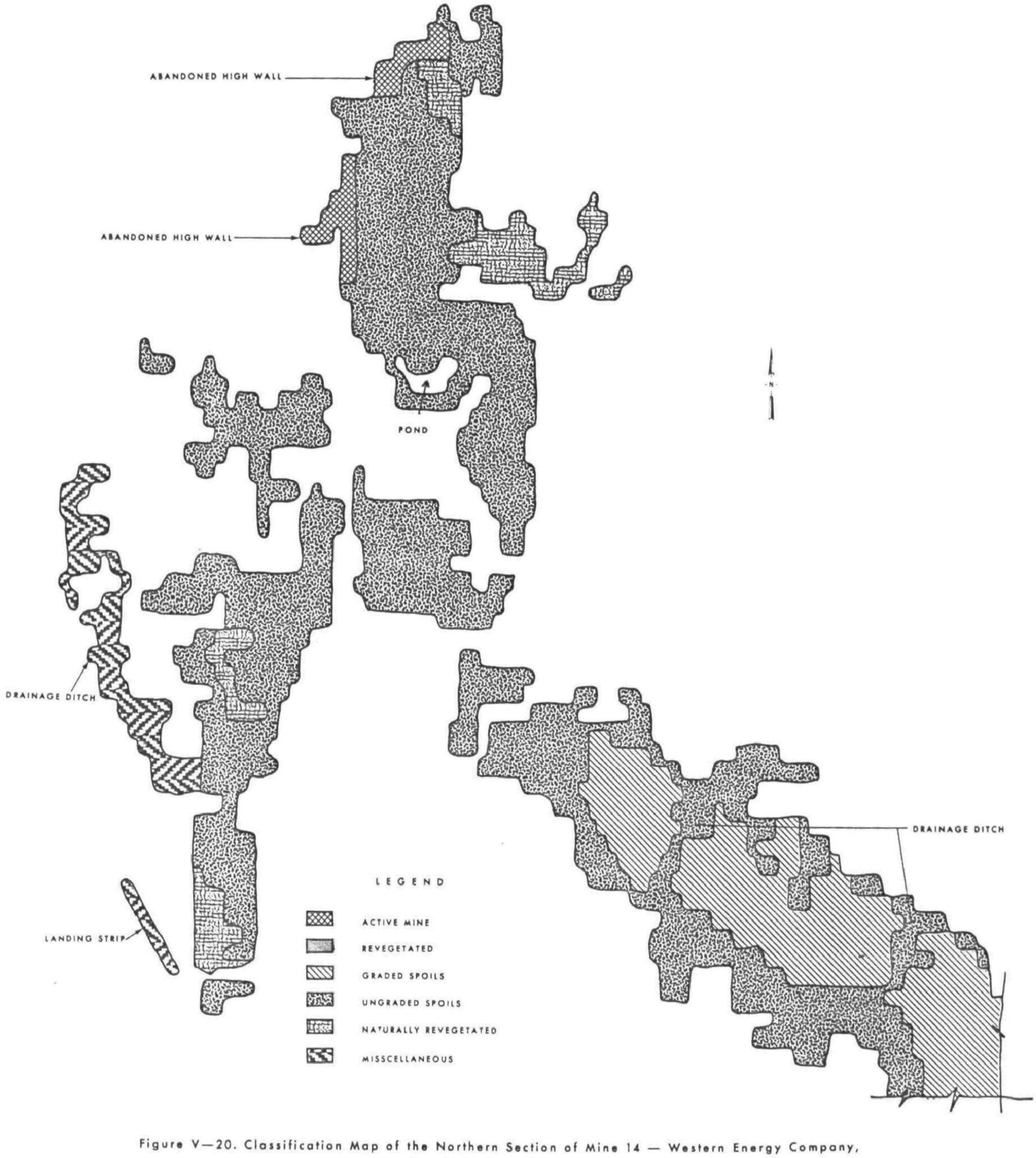


Figure V—20. Classification Map of the Northern Section of Mine 14 — Western Energy Company, Rosebud Mine, Colstrip, Montana

In the diagonal middle part of the mine, the drainage ditches and roads that cut across the graded spoils [Fig. V-20] were identifiable.

Table V-7 summarizes the classification of mine areas.

Table V-7

Areal Distribution of Land Use
Mine 14

Land Use	Area		
	Pixels	Hectares	Acres
Northern section			
High wall			
Ungraded spoils	26	13	31
Partially overgrown spoils	479	233	575
Subtotal	530	257	636
Middle section			
Graded spoils	299	145	359
Ungraded spoils	335	163	402
Roads and drainage ditches	132	64	158
Subtotal	766	372	919
Southern section			
High wall	100	49	120
Graded and seeded	85	41	102
Ungraded	207	101	248
Graded for special studies	241	117	289
Subtotal	633	308	759
Total high wall	126	61	151
Total graded	625	304	750
Total ungraded	1046	508	1255
Road and ditches	132	64	158
TOTAL AREA	1,929	937	2,315

MINE 15 - KNIFE RIVER COAL CO., SAVAGE MINE

Background

The small Savage Mine is about 13 km (8 mi) northwest of Savage near the North Dakota border [Fig. V-12]. Annual coal production from 1972 to 1980 is expected to average 0.29 million metric tons (0.32 million tons).

Classification of Mine Areas

Four east-west cuts and a smaller cut to the south comprise the mine [Fig. V-21]. In the north area, the two cuts have advanced toward each other, meeting in the high wall area shown. A similar mining pattern was present in the middle section. The small southern cut and its highwall were separately discernible. Much of the disturbed area may not have been excavated, but may represent roads and areas stripped of vegetation in preparation for mining. The classification of mine areas is summarized in Table V-8.

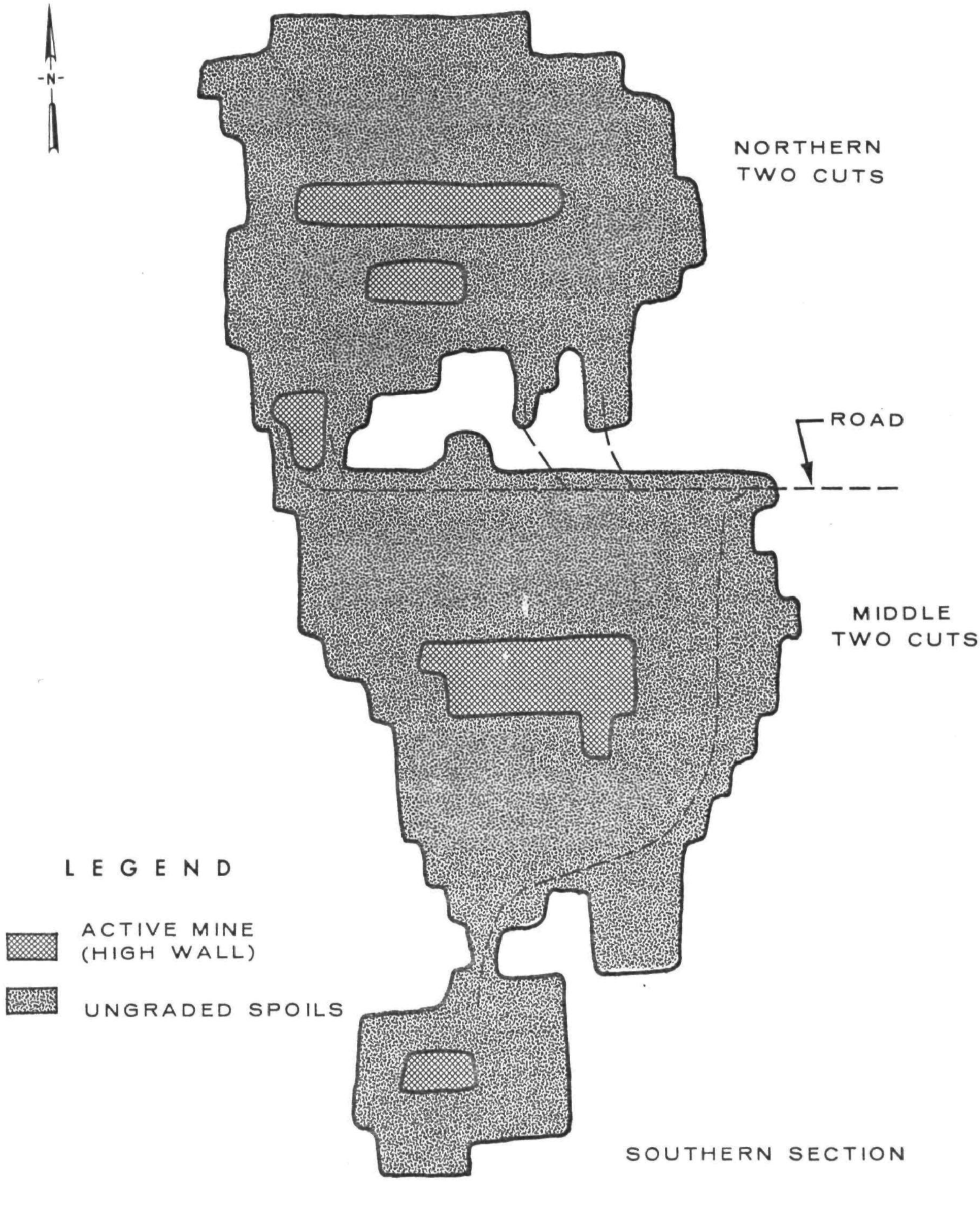


Figure V—21. Classification Map of Mine 15—
Knife River Coal Company, Savage, Montana

Table V-8

Areal Distribution of Land Use
Mine 15

Land Use	Area		
	Pixels	Hectares	Acres
Northern two cuts			
Spoils, roads and areas in preparation for mining	145	70	174
High wall	15	7	18
Subtotal	160	78	192
Middle two cuts			
Spoils, roads and areas in preparation for mining	154	75	185
High wall	18	9	22
Subtotal	172	84	206
Southern section			
Spoils, roads and areas in preparation for mining	33	16	40
High wall	3	2	4
Subtotal	36	18	43
TOTAL AREA	368	179	442

MINE 16 - RELIABLE COAL CO., RELIABLE MINE

Located 87 km (54 mi) northeast of Billings [Fig. V-12], this mine produced less than 910 metric tons (1,000 tons) of coal in 1972; 1975 and 1980 projections were not available. Because of its small size this mine was not classified.

MINE 17 - DIVIDE COAL CO., STORM KING MINE

This small mine is 48 km (30 mi) north of Billings. Previously an underground mine, surface operations were begun in late 1972, producing less than 0.11 million metric tons (0.12 million tons) of coal. No estimates of future production were available. Because of its small size this mine was not classified.

MINE 18 - WESTERN COAL CO., WESTERN MINE

This small underground mine, 64 km (40 mi) north of Billings, produced less than 910 metric tons (1,000 tons) of coal in 1972; projections for 1975 and 1980 were not available. Since this is an underground mine, ERTS technology does not apply and the mine was not classified.

MINE 19 - NIES COAL CO., NIES COAL MINE

Also an underground operation, this small mine 74 km (46 mi) north of Billings produced less than 0.11 million metric tons (0.12 million tons) of coal in 1972; projections were not available. The mine was not classified.

NORTH DAKOTA MINES

MINE 20 - BAUKOL NOONAN INC., CENTER MINE

Background

This mine is about 5 km (3 mi) east of Center [Fig. V-22, inside back cover] and 2 km west of an impoundment on Square Butte Creek. Coal production in 1972 was 1.3 million metric tons (1.4 million tons) and will be similar (1.4 million metric tons) in 1975. By 1980 production is expected to increase to 4.1 million metric tons (4.5 million tons).

The mine is in two sections with only the north one active. These areas are clearly visible in the satellite image [Fig. V-23].

Classification of Mine Areas

A thermal electric generating plant adjacent to the impoundment [Fig. V-24] was defined. An adjacent coal pile was also defined and had the same spectral signature as dark areas of the mine. The east end of the road connecting the plant and mine was identified. A parking area surrounding a large building is alongside this road.

The northern section of the mine is the smaller but is rapidly expanding. Mining is proceeding to the north and west. The southern mine section is in the shape of a long arc curving to the southwest. Some revegetation may have occurred to the east of the high wall and spoils piles in the southern section. Without ground observations, it was impossible to distinguish this revegetated land from the surrounding cropland.

The areal distribution of land use is summarized in Table V-9.

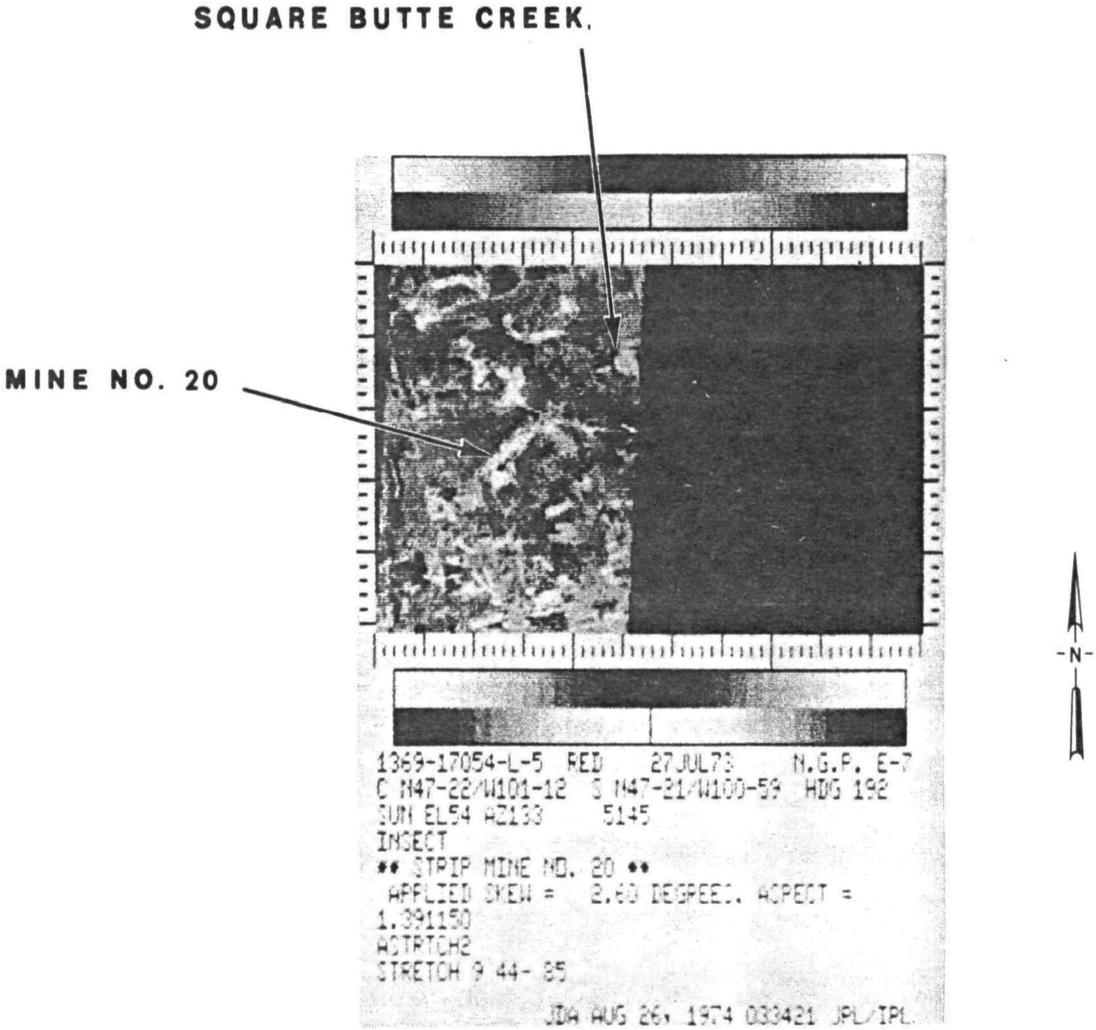


Figure V-23. Satellite Image of Mine No. 20

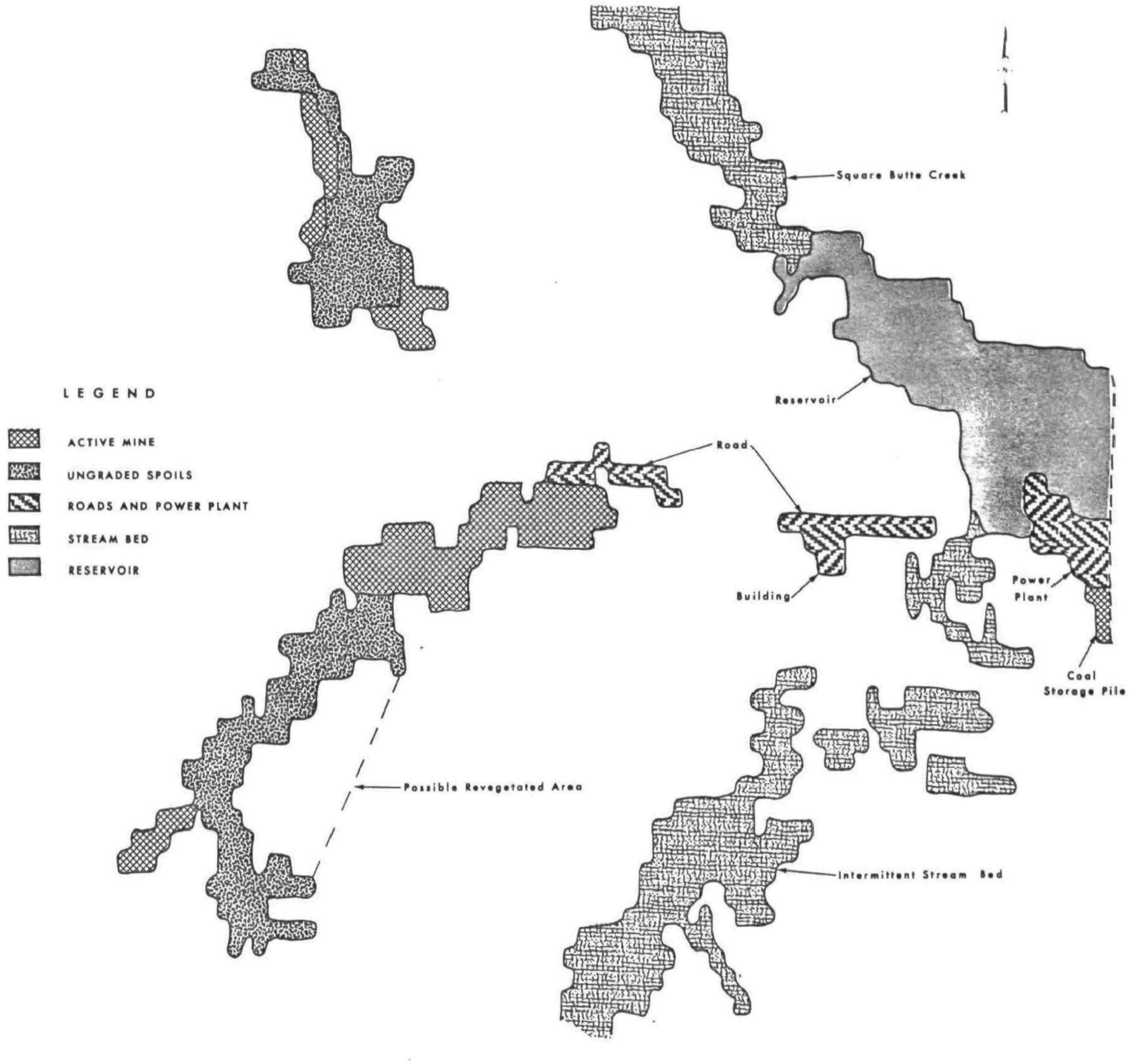


Figure V—24. Classification Map of Mine 24— Baukol Noonan Inc., Center Mine, Center, North Dakota

Table V-9

Areal Distribution of Land Use
Mine 20

Land Use	Area		
	Pixels	Hectares	Acres
Northern section			
High wall	19	9	23
Spoils	66	32	79
Subtotal	85	41	102
Southern section			
High wall	56	27	67
Spoils	100	49	120
Road	12	6	14
Subtotal	168	82	202
TOTAL AREA	253	123	304

MINE 21 - NORTH AMERICAN COAL, INDIANHEAD MINE

Background

Coal production from this mine at Beulah [Fig. V-22] was 0.9 million metric tons (1.0 million tons) in 1972. Expected production for 1975 will be similar (1.1 million metric tons) but may increase to 4.1 million metric tons (4.5 million tons) by 1980.

The Knife River a few kilometers to the southeast is between the Indianhead Mine and the Knife River Coal Mining Co. operation (Mine 22) [Fig. V-25]. A substantial area in the vicinity of these mines is cropland.

Classification of Mine Areas

Several examples of the problems involved in the classification of strip mines using satellite multispectral data were encountered at this site. In the easternmost toe of the mine [Fig. V-26], the spectral classification of the graded and seeded area changed in the northern part due to a dark discoloration of the soil. In the middle of the mine, an old spoils pile that was overgrown with vegetation had a spectral signature indistinguishable from vegetation outside the mine. It was difficult to obtain a representative spoils pile signature anywhere in the eastern portion of the mine. Close examination of Soil Conservation Service aerial photographs indicated that there was little consistency in the size and angular orientation of the spoils piles. Consequently, the spectral signature varied with location in the mine. The effect became more noticeable at the northern end of the mine at the site of current activity. There the spoils were piled up in unusually high and

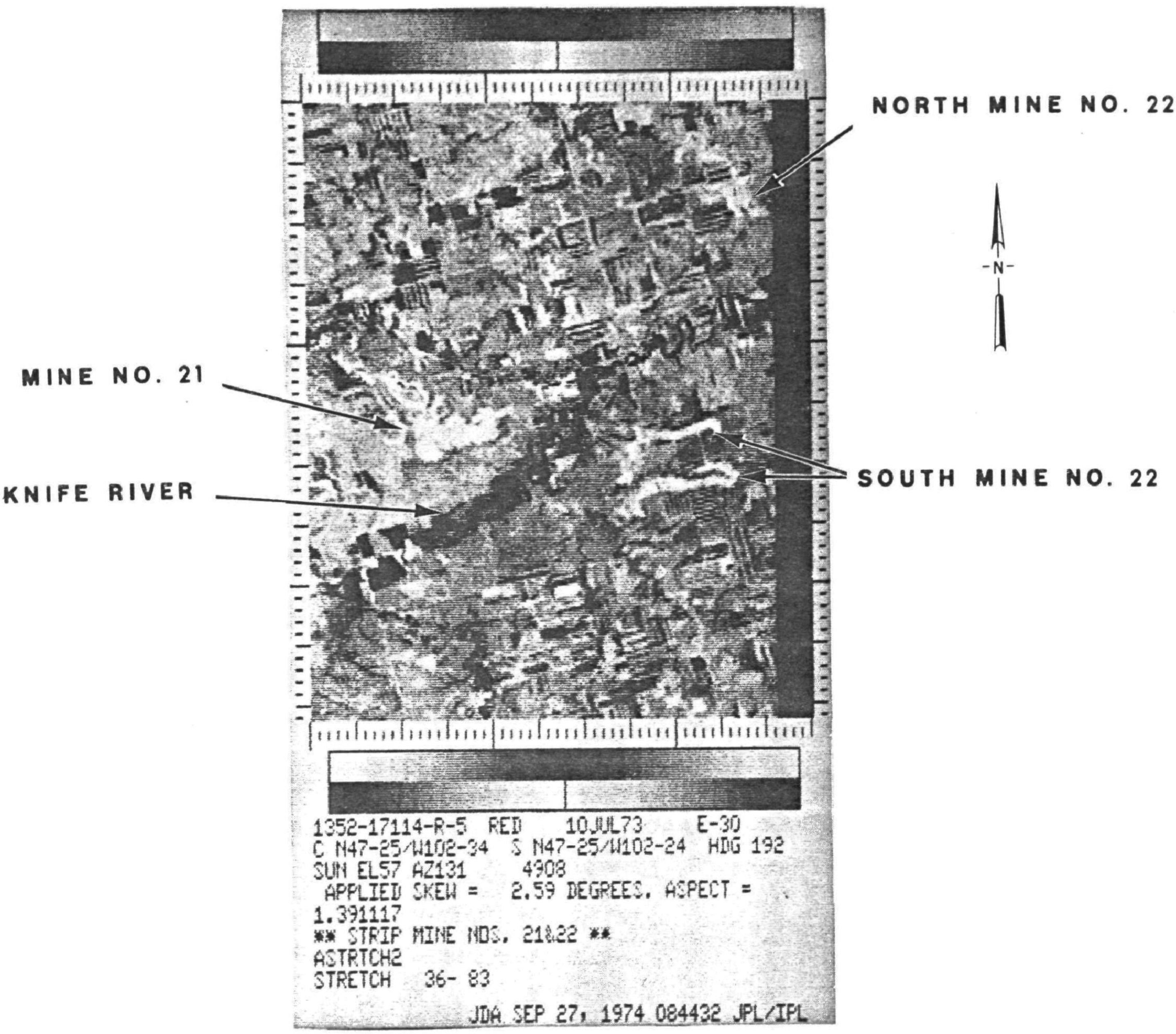


Figure V-25. Satellite Image of Mines No. 21 and 22

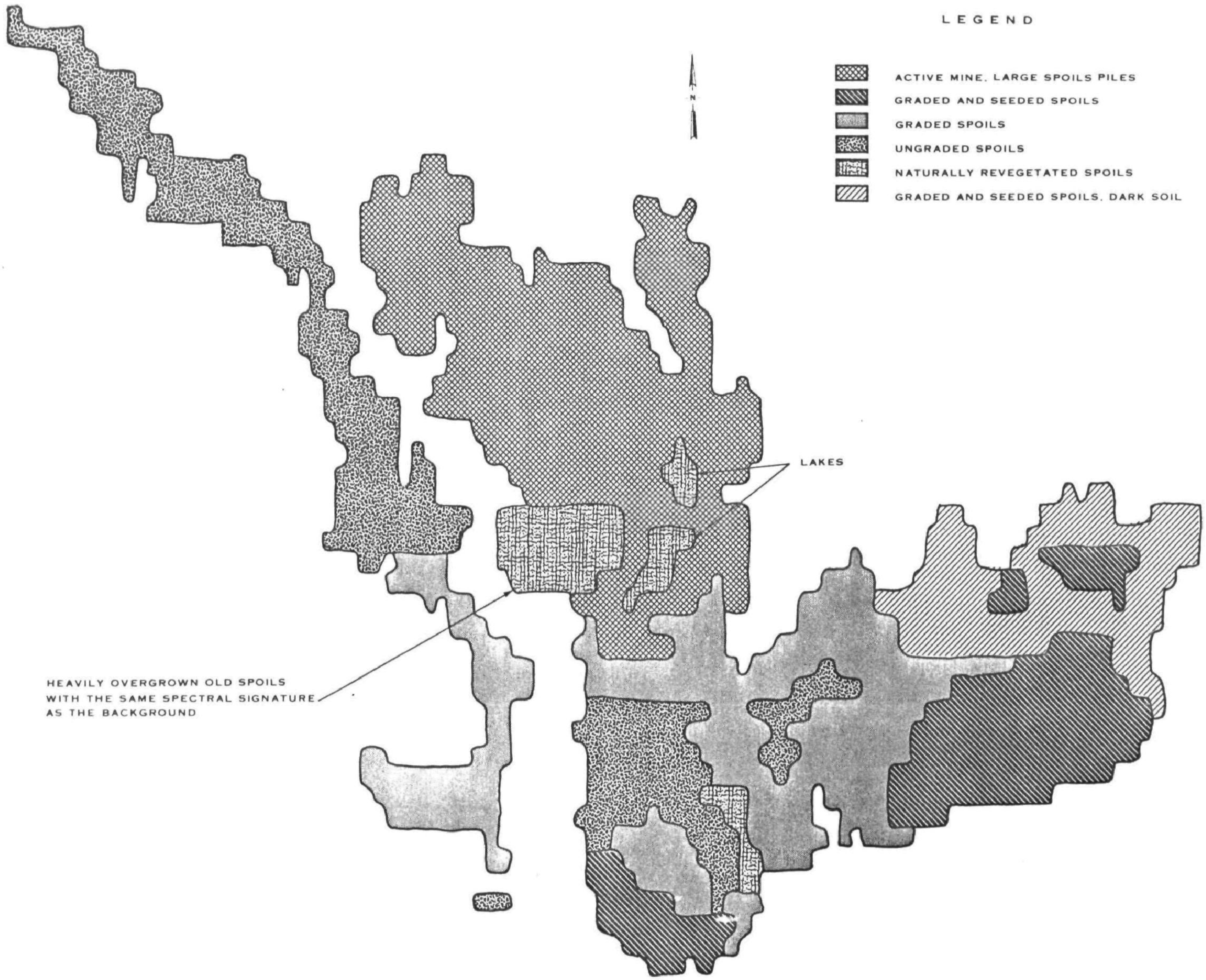


Figure V—26. Classification Map of Mine 21 — North American Coal Company,

Indian Head, North Dakota

large mounds at varying orientations to the sun, producing an extremely large statistical variation in the spectral signature. The area was very difficult to classify and was outlined from pixels that did not fall into any of the other classifications.

The orientation of the spoils in the western cut of the mine was relatively uniform and produced a consistent terrain that classified easily into graded and ungraded spoils.

The classification of mine areas is summarized in Table V-10.

Table V-10
Areal Distribution of Land Use
Mine 21

Land Use	Area		
	Pixels	Hectares	Acres
Western arm			
Ungraded spoils	155	75	186
Graded spoils	62	30	74
Subtotal	217	105	260
Eastern section			
Graded and seeded	170	83	204
Graded and seeded (dark soil)	114	55	137
Graded only	219	106	263
Ungraded spoils	180	87	215
Active mine and large spoils piles (Northern part)	278	135	334
Subtotal	961	447	1153
TOTAL AREA	1,178	572	1,414

MINE 22 - KNIFE RIVER COAL MINING CO., BEULAH MINE

Background

This Company operates two mines near Beulah on the Knife River east of Mine 21 [Fig. V-22]. One mine consists of two long and narrow cuts about 8 km (5 mi) south of Beulah clearly visible in the satellite image [Fig. V-25]. The second mine is a similar distance northeast of Beulah and north of the Knife River. Coal production through 1980 is expected to remain at the 1972 level of 1.4 million metric tons (1.5 million tons).

Classification of Mine Areas

The south mine consists of two long, parallel east-west cuts with small north-south cuts on the western edge. The spoils have not been revegetated or graded. The mine was classified into high wall (dark material) and ungraded spoils (light material) [Fig. V-27].

At the time of the initial computer analysis, the existence of the north mine was unknown. Therefore, no training sites were selected from the north mine. Upon realizing that the north mine existed, a computer classification was performed using the statistics from the training sites in the south mine. Comparison of the resulting classification map with a 1971 aerial photograph showed that the areas on the northern and eastern portions of the mine were fairly well defined but the spoils piles on the southwestern corner were largely missed. The explanation for this is not known, but experience with Mine 21 suggests that if the spoils piles were overgrown with vegetation, they would give the same classification as the surrounding agricultural land. Questions

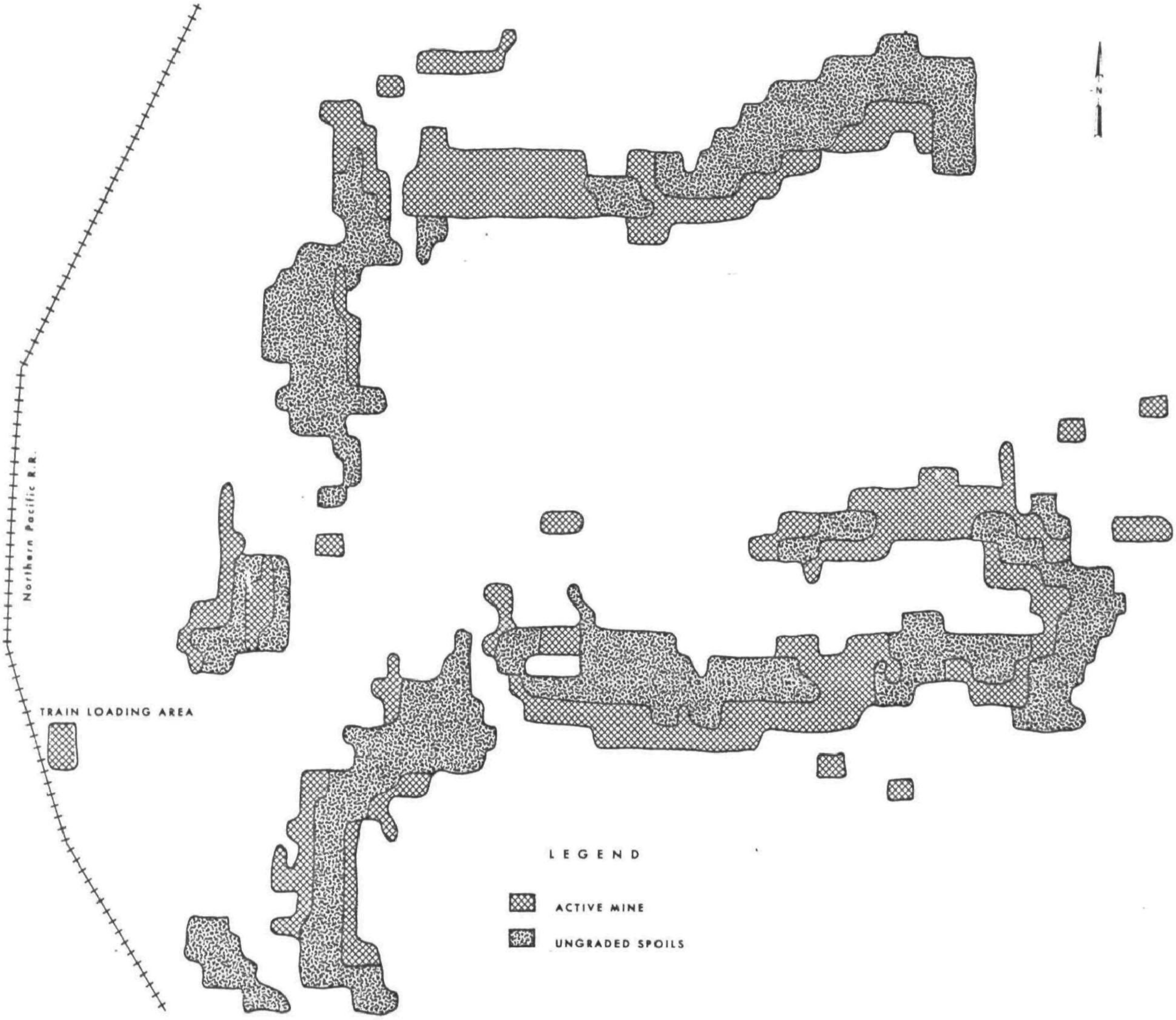


Figure V—27. Classification Map of Mine 22—
South Mine of Knife River Coal Company, Beulah, North Dakota

such as this can only be resolved by more extensive ground observations.

Mine 21 is on the same small element of the image extracted from the Earth Resources Technology Satellite frame and would be expected to have spectral characteristics similar to the north mine. The north mine was classified using the statistics from training sites at Mine 21. Comparison of the resulting classification map [Fig. V-28] with the similar map derived using training sites from the south mine showed that the use of statistics from Mine 21 resulted in systematically larger areas classified as part of the mine. However, the southwest corner of the mine was still largely classified as agricultural land. The classification of the north mine based on Mine 21 training sites was selected as the most representative. Because of the difficulty in extrapolating classifications from mine to mine, no further sub-classification of the disturbed areas of the north mine was attempted. Table V-11 summarizes the classification of disturbed areas for both mines.

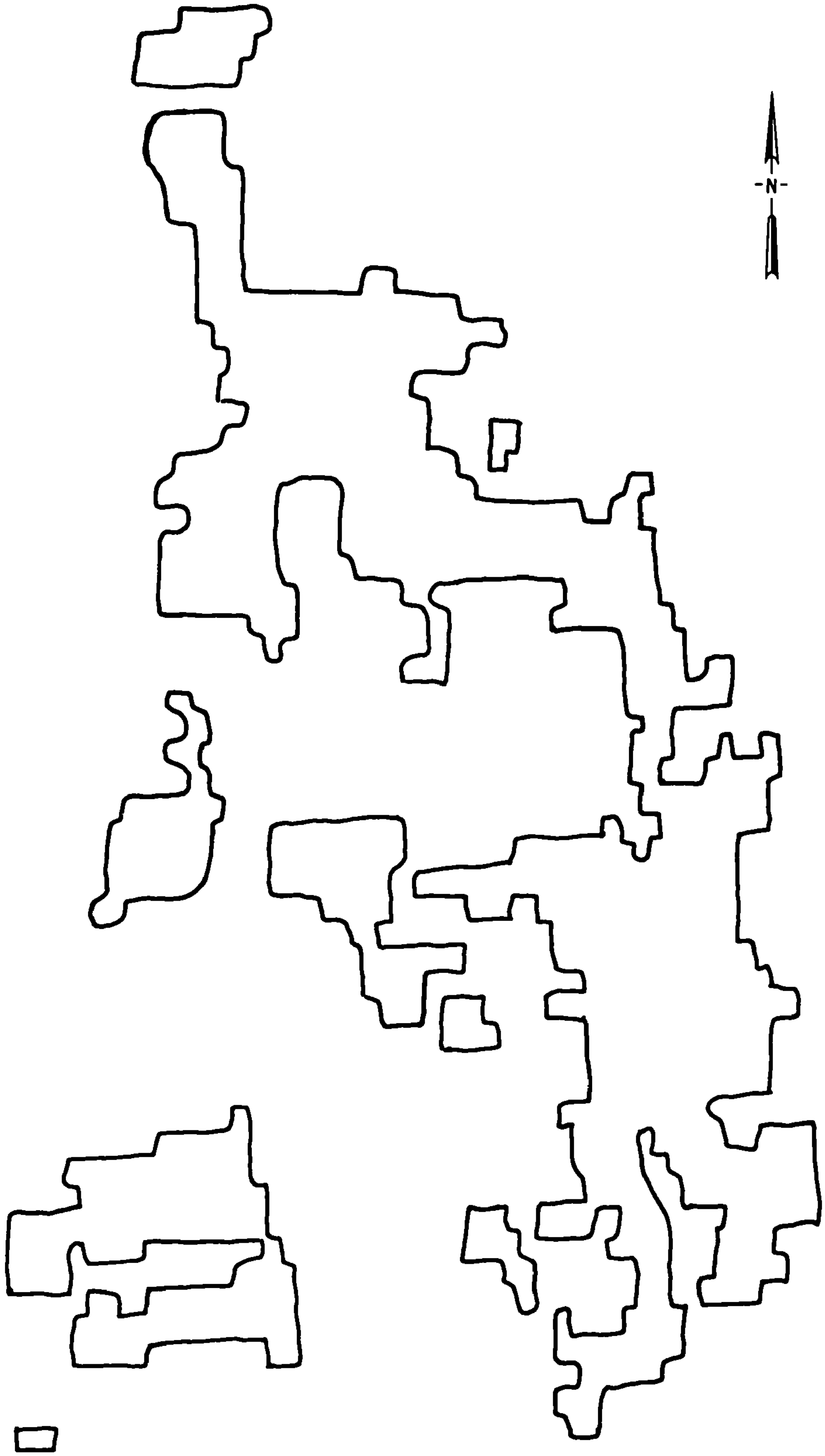


Figure V—28. Classification Map of North Mine of Knife River Coal Mining Co. Beulah, North Dakota

Table V-11

Areal Distribution of Land Use
Mine 22

Land Use	Area		
	Pixels	Hectares	Acres
South Mine			
North arm			
High wall	116	56	139
Spoils	138	67	166
	254	123	305
South arm			
High wall	151	73	181
Spoils	202	98	242
	353	171	424
Subtotal south mine	607	295	728
North mine			
Using training sites from Mine 21	763	371	916
Using training sites from southern part of Mine 22	488	237	586
TOTAL AREA	1,370	665	1,644

MINE 23 - CONSOLIDATION COAL CO., GLEN HAROLD MINE

Background

This mine 8 km (5 mi) southeast of Stanton and 64 km (40 mi) northwest of Bismark [Fig. V-22] produced 1.3 million metric tons (1.4 million tons) of coal in 1972. An annual yield of 3.6 million metric tons (4 million tons) is forecast for the 1975 to 1980 period.

The mine is in very hilly terrain in the bluffs south of the Missouri River. The disturbed area is large, as shown in the satellite image [Fig. V-29]. The physical configuration is heavily influenced by the terrain that has divided the mine into a north section and two south sections separated by a northeast-southwest ridge.

Classification of Mine Areas

At the time of data collection, reclamation had progressed to the point where most of the mine area could be separated into graded or ungraded spoils. About half of the west section had been graded with the rest of the irregular or ungraded spoils [Fig. V-30]. Most of the east section is ungraded with small irregular sections. The highwall is the south edge of these two sections but was not detected in the classification. Separation of spoils types was not clear in the north area. Table V-12 summarizes land use in the mine.

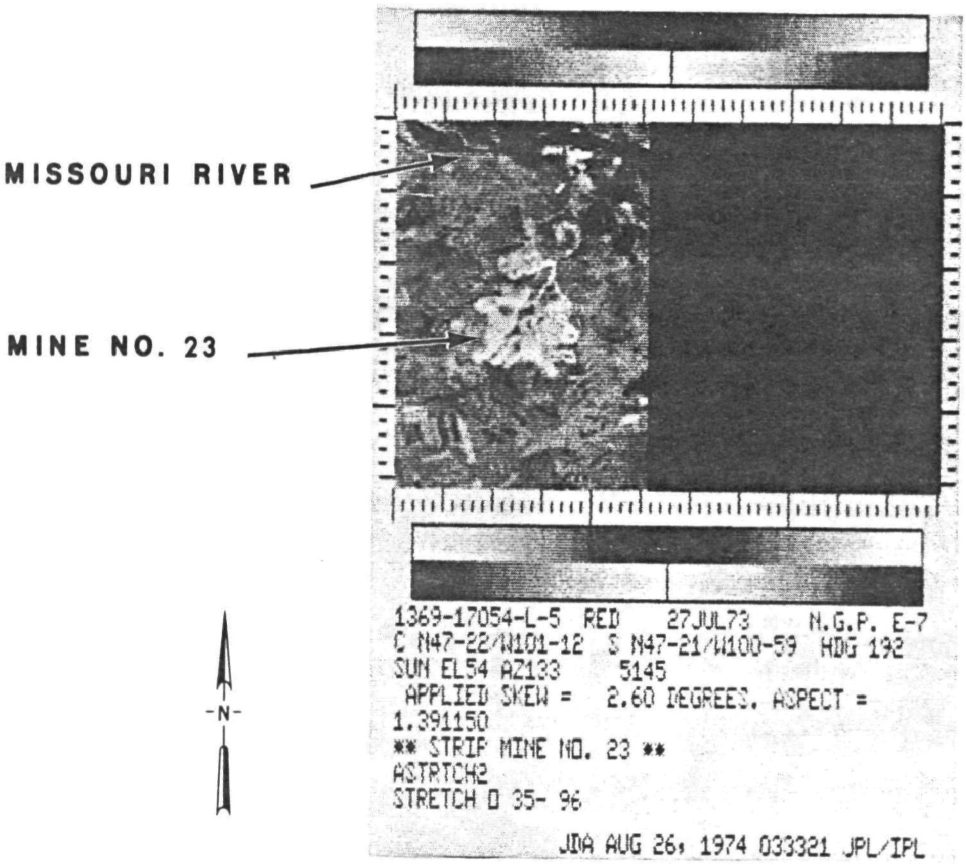


Figure V-29. Satellite Image of Mine No. 23[1]

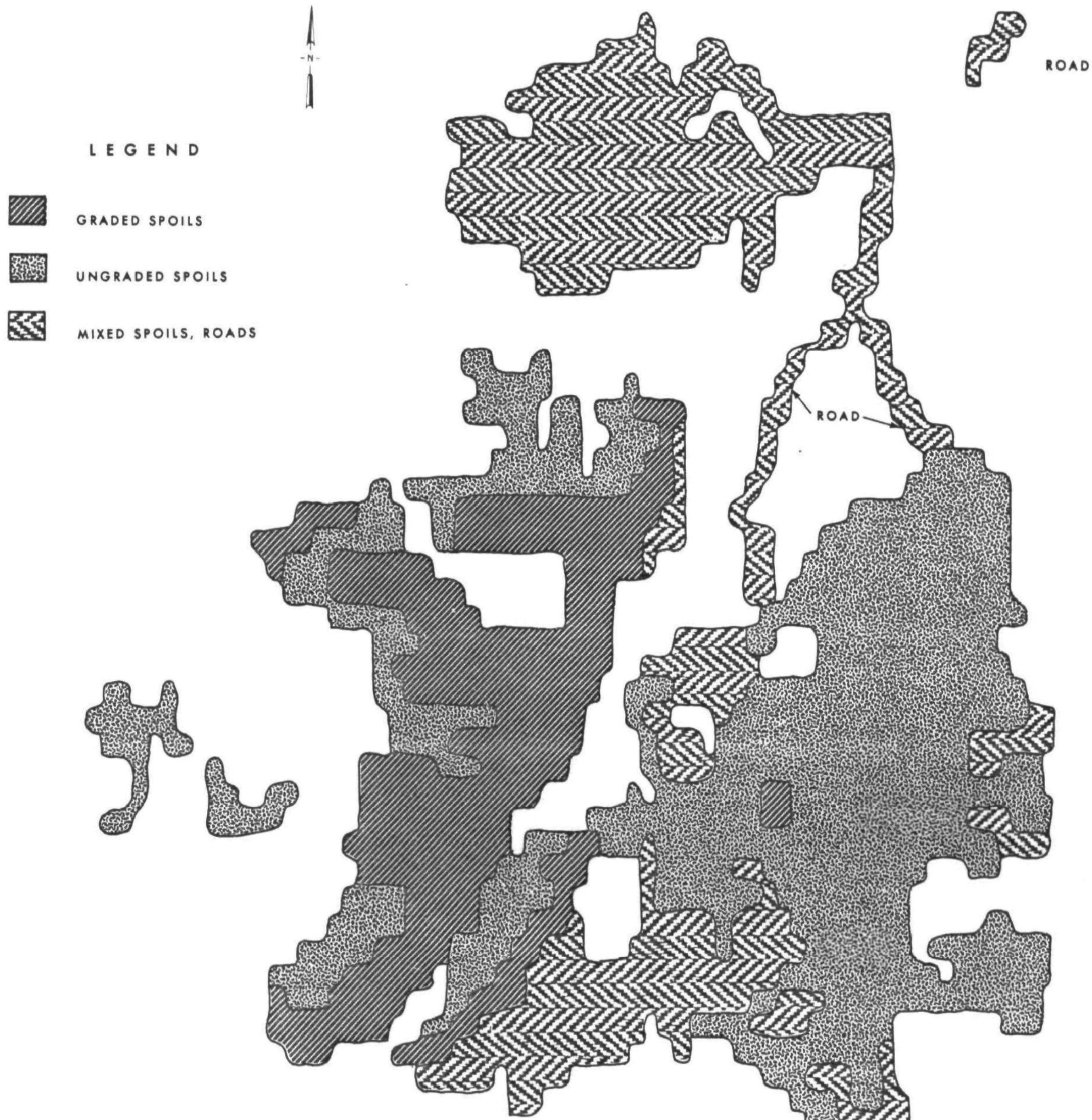


Figure V—30. Classification Map of Mine 23— Consolidation Coal Company, Glen/Harold Mine, Stanton, North Dakota

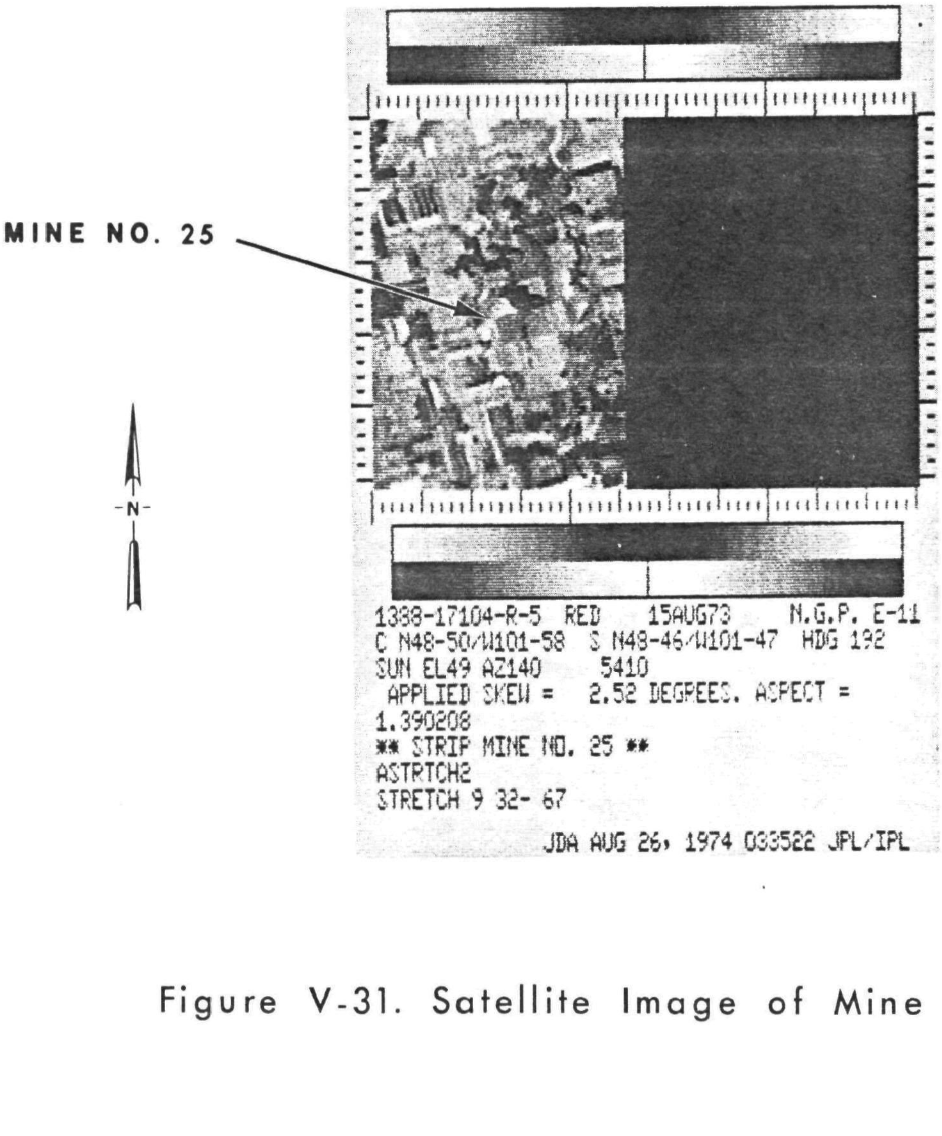


Figure V-31. Satellite Image of Mine No. 25

Table V-12

Areal Distribution of Land Use
Mine 23

Land Use	Area		
	Pixels	Hectares	Acres
North Section			
Assorted spoils	170	83	204
West Section			
Graded spoils	209	102	251
Ungraded spoils	167	81	200
East section			
Graded spoils	128	62	154
Ungraded spoils	407	198	488
Roads	65	32	76
TOTAL AREA	1,146	557	1,375

MINE 24 - BAUKOL NOONAN, INC., NOONAN STRIP MINE

This mine 5 km (3 mi) east of Columbus [Fig. V-22] produced 0.4 million metric tons (0.5 million tons) in 1972. An aerial photograph of the mine indicated that its two large areas of spoils piles measure 5 km (3 mi) by 1.3 km (0.8 mi) and 2.4 km (1.5 mi) by 2.1 km (1.3 mi). As the mine is closed with no future production expected, no classification was performed.

MINE 25 - CONSOLIDATION COAL CO., VELNA MINE

Background

Located 40 km (24 mi) southeast of Minot [Fig. V-22], this mine produced 0.43 million metric tons (0.47 million tons) of coal in 1972. Production for 1975 and 1980 is estimated to remain at this level.

Classification of Mine Areas

The satellite image of this mine [Fig. V-31] was very difficult to interpret visually. But two sources assured that the mine is located within this particular part of the ERTS frame: one was an accurate examination of the ERTS frame at the known geographical coordinates of the mine; another was the location of the mine at the northern edge of an easily identifiable strip of land that represents the terminal moraine of the continental ice sheet during the Glacial Age. A careful comparison of the satellite image with aerial photographs showed two bright areas at the ends of the mines that can be identified, and dark vegetation is growing in stream bottoms immediately southwest of the mine.

All attempts at multispectral classification failed to separate the middle area of the mine lying between the two bright areas at the ends from the surrounding cropland. In classifying other mines it was observed that when the land surrounding the mines was planted in the rectangular pattern common in midwestern agricultural practice, an effective camouflage pattern was formed. That factor made the mine very difficult to distinguish with the multispectral recognition algorithms currently used.

MINE 26 - KNIFE RIVER COAL CO., GASCOYNE MINE

Background

Located 8 km (5 mi) northeast of Gascoyne [Fig. V-22], this mine produced only 0.15 million metric tons (0.16 million tons) of coal in 1972. A major expansion of mining activity is planned, however, with annual production for the 1975 to 1980 period forecast at 2.7 million metric tons (3 million tons).

Classification of Mine Areas

A majority of the land in the vicinity of the mine is cultivated farmland as shown in the satellite image [Fig. V-32]. Discrimination between mine areas and the adjacent striped cropland proved to be difficult. Only two classes of spoils (light and dark) could be separated [Fig. V-33]. The mid-section of the mine was very irregular and contained several small ponds. The computer classification map of this area was also irregular and difficult to interpret. Several small remotely located pits to the east and south of the mine were picked up in the computerized classification. The coal loading area to the south of the mine was distinct. Extensive enlargement of the mine had occurred compared to a 1957 aerial photograph. The areal distribution of land use is summarized in Table V-13.

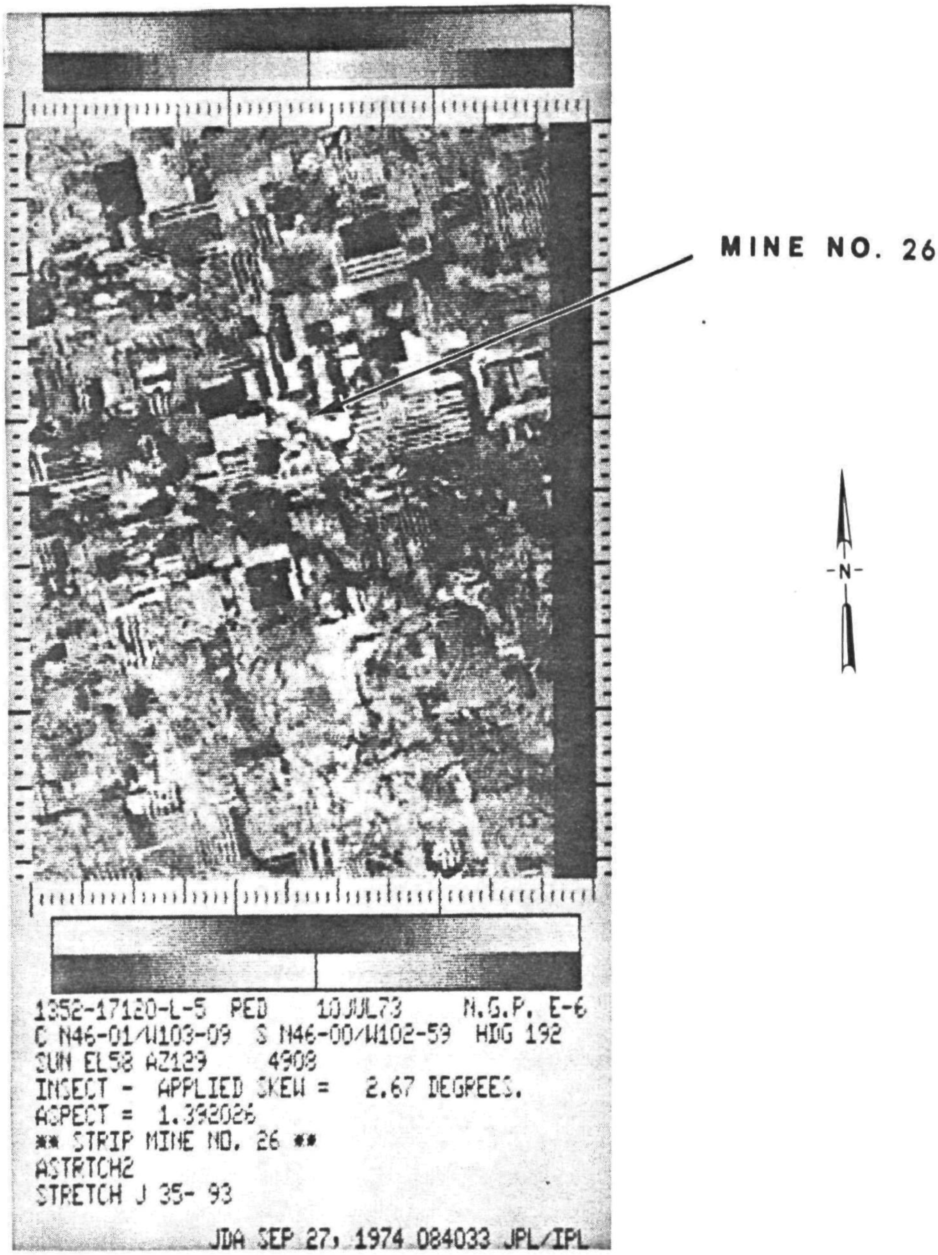


Figure V-32. Satellite Image of Mine No. 26

Figure V—33. Classification Map of Mine 26—Knife River Coal Mining Company, Gascoyne, North Dakota

Table V-13
Areal Distribution of Land Use
Mine 26

Land Use	Area		
	Pixels	Hectares	Acres
Active mine and spoils	192	93	230
Small ponds	37	18	44
Railroad loading area	26	13	31
TOTAL AREA	255	124	306

MINE 27 - BONSNESS COAL MINE

Production in 1972 from this mine 5 km (3 mi) south of Columbus [Fig. V-22] was less than 0.11 million metric tons (0.12 million tons). The mine was closed by 1973 and it was therefore not classified. An aerial photograph shows that spoils piles cover an area of about 5.8 km^2 (2.3 mi^2) in a strip 7.2 km (4.5 mi) by 0.8 km (0.5 mi).

MINE 28 - UNDERWOOD COAL CO., INC., UNDERWOOD MINE

This company operates a mine 3 km (2 mi) southeast of Underwood [Fig. V-22]. Production in 1972 was less than 0.11 million metric tons (0.12 million tons). Projections for 1975 and 1980 were not available.

This mine was not located on the ERTS imagery and, therefore, was not classified. On a Soil Conservation Service aerial photograph, the mine dimensions were roughly 400 m (1300 ft) by 270 m (900 ft).

MINE 29 - HUSKY BRIQUETTING INC., LEHIGH STRIP MINE

Background

This small mine 5 km (3 mi) east of Dickinson [Fig. V-22] produced less than 0.11 million metric tons (0.12 million tons) in 1972. Production estimates for 1975 and 1980 were not available.

Classification of Mine Areas

The small size of this mine compared to the spatial resolution of the ERTS imagery [Fig. V-34] and the presence of cropland in the vicinity limited the accuracy of the classification. The mine is divided into three sections by the Heart River and the Northern Pacific Railroad [Fig. V-35].

Inspection of an aerial photograph indicated that spoils in the north area are overgrown with vegetation. Two of three ponds were identified in the classification map.

In the west section, the bright spectral signature of the spoils was indicative of recent mining activity. Two of three ponds in this area were also identified. A 17 hectare (7 acre) area that has been revegetated was not identified in the computer classification map due to its small size.

In the southern part of the mine, the large pond and mine buildings were dominant. The spoils piles in the northern part of the southern segment were overgrown with vegetation and did not classify uniquely.

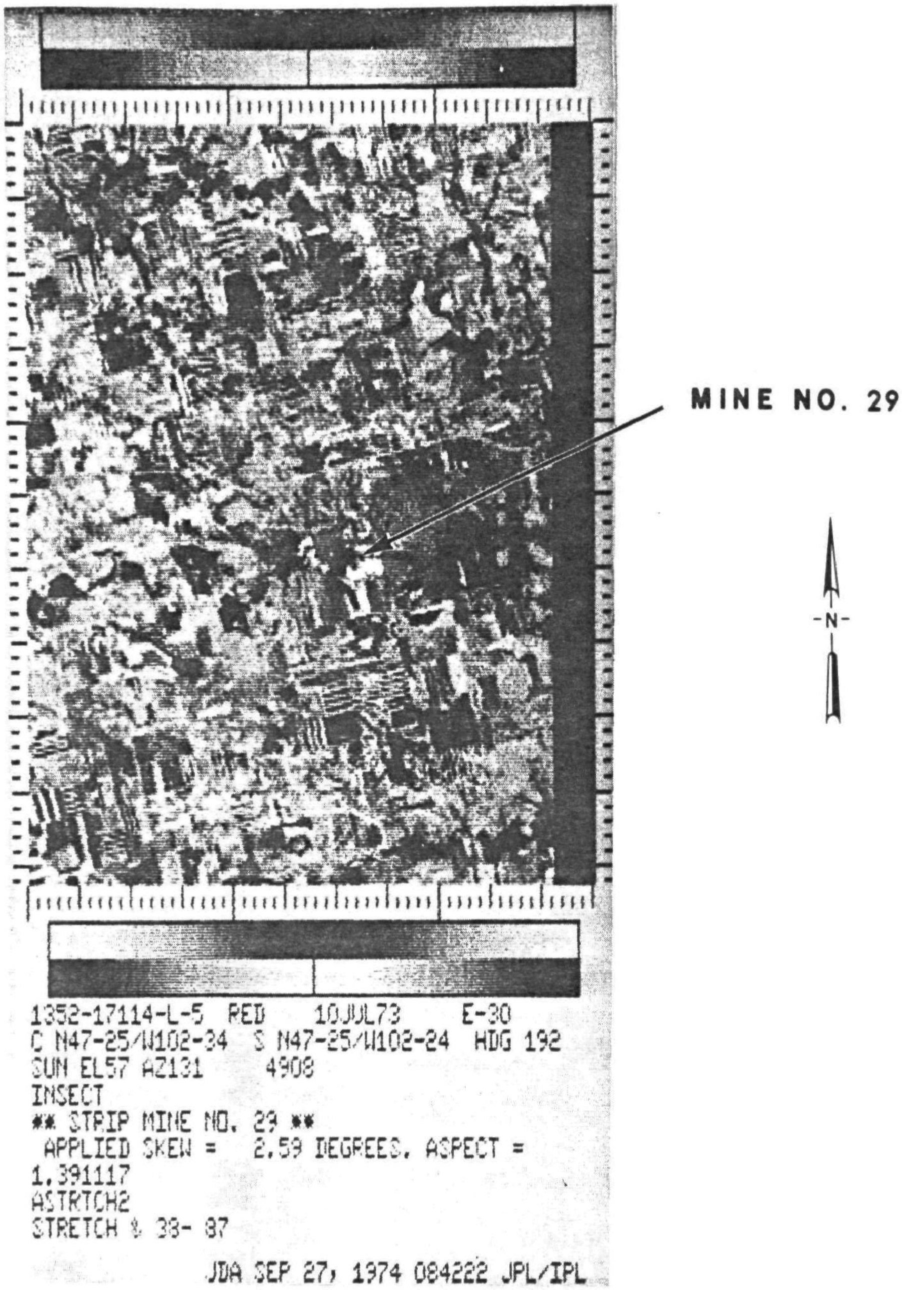


Figure V-34. Satellite Image of Mine No. 29

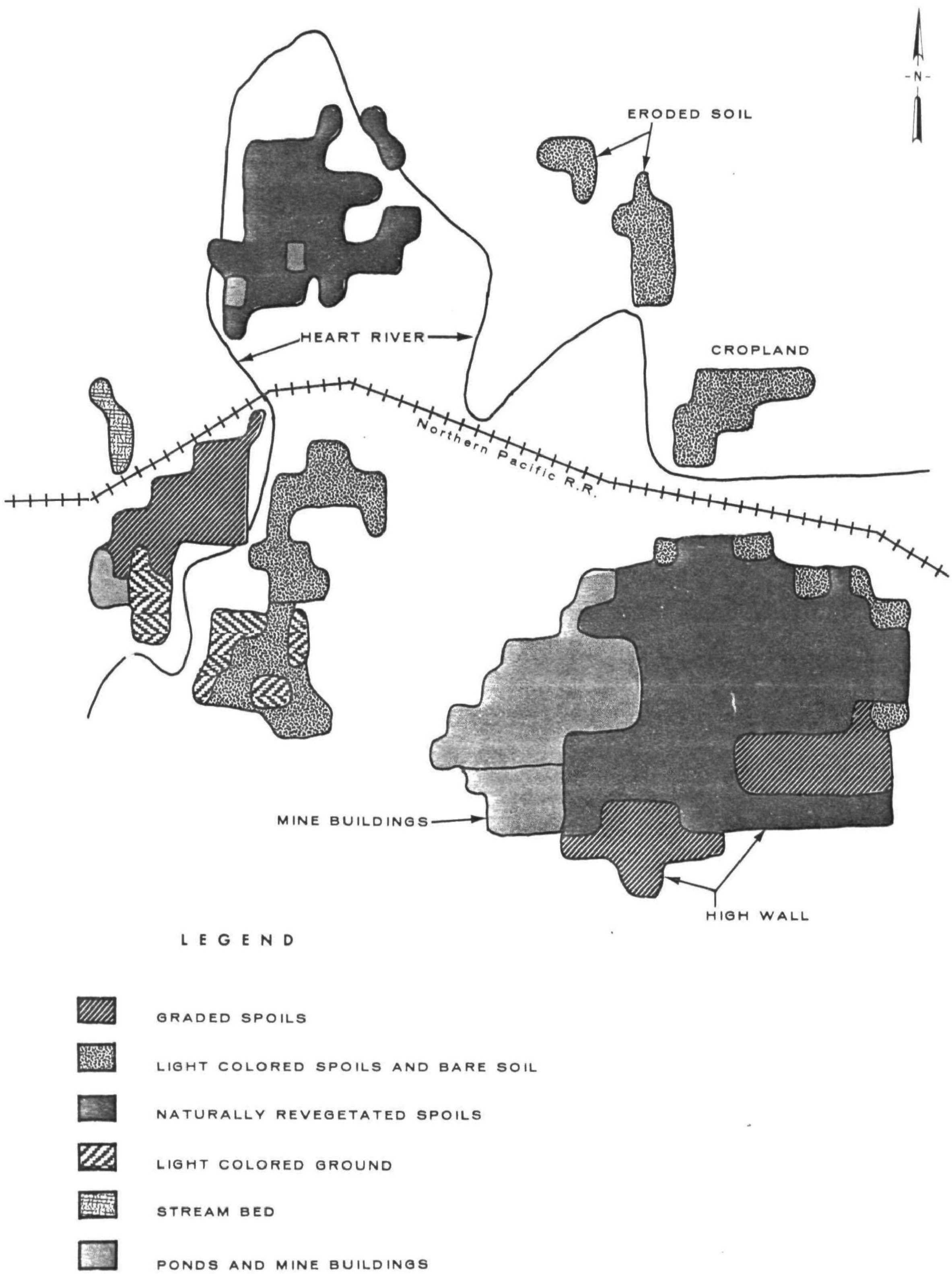


Figure V—35. Classification Map of Mine 29— Husky Briquetting Inc., Lehigh Strip Mine, Dickinson, North Dakota

The two revegetated areas in this section are too small to identify; however, the bright spoils behind the high wall showed up distinctly. Spoils were being graded so close to the high wall that the spatial resolution of the image was inadequate to define the high wall. Table V-14 summarizes the classification of land areas.

Table V-14
Areal Distribution of Land Use
Mine 29

Land Use	Area		
	Pixels	Hectares	Acres
Northern section			
Ponds	2	1	2
Overgrown spoils	33	16	40
Subtotal	35	17	42
Western section			
Ponds	5	2	6
Bright spoils	26	13	31
Subtotal	31	15	37
Southeastern section			
Pond and overgrown spoils	35	17	42
Overgrown spoils and revegetated spoils	110	53	132
Bright spoils	31	15	37
Subtotal	176	85	211
TOTAL AREA	242	118	290

MINE 30 - ARROWHEAD COAL CO., ADAMS MINE

Production in 1972 from this small mine was less than 0.11 million metric tons (0.12 million tons). Production estimates for 1975 and 1980 were not available.

Overall mine dimensions on an aerial photograph were 4.6 km (2.8 mi) by 340 m (1,100 ft). The mine was too small to locate on the ERTS image and therefore was not classified.

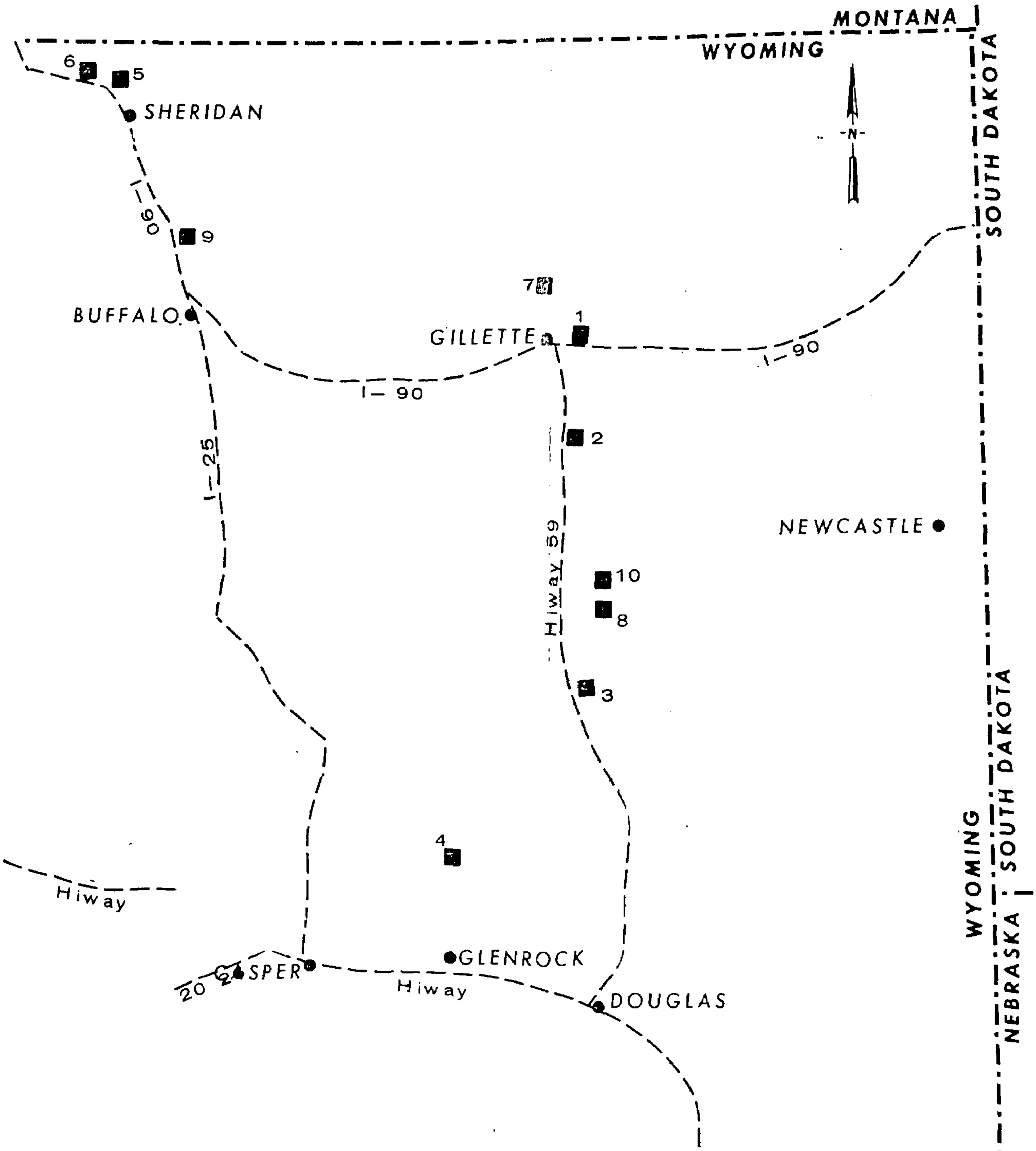


Figure V—1. Locations of Wyoming Coal Mines

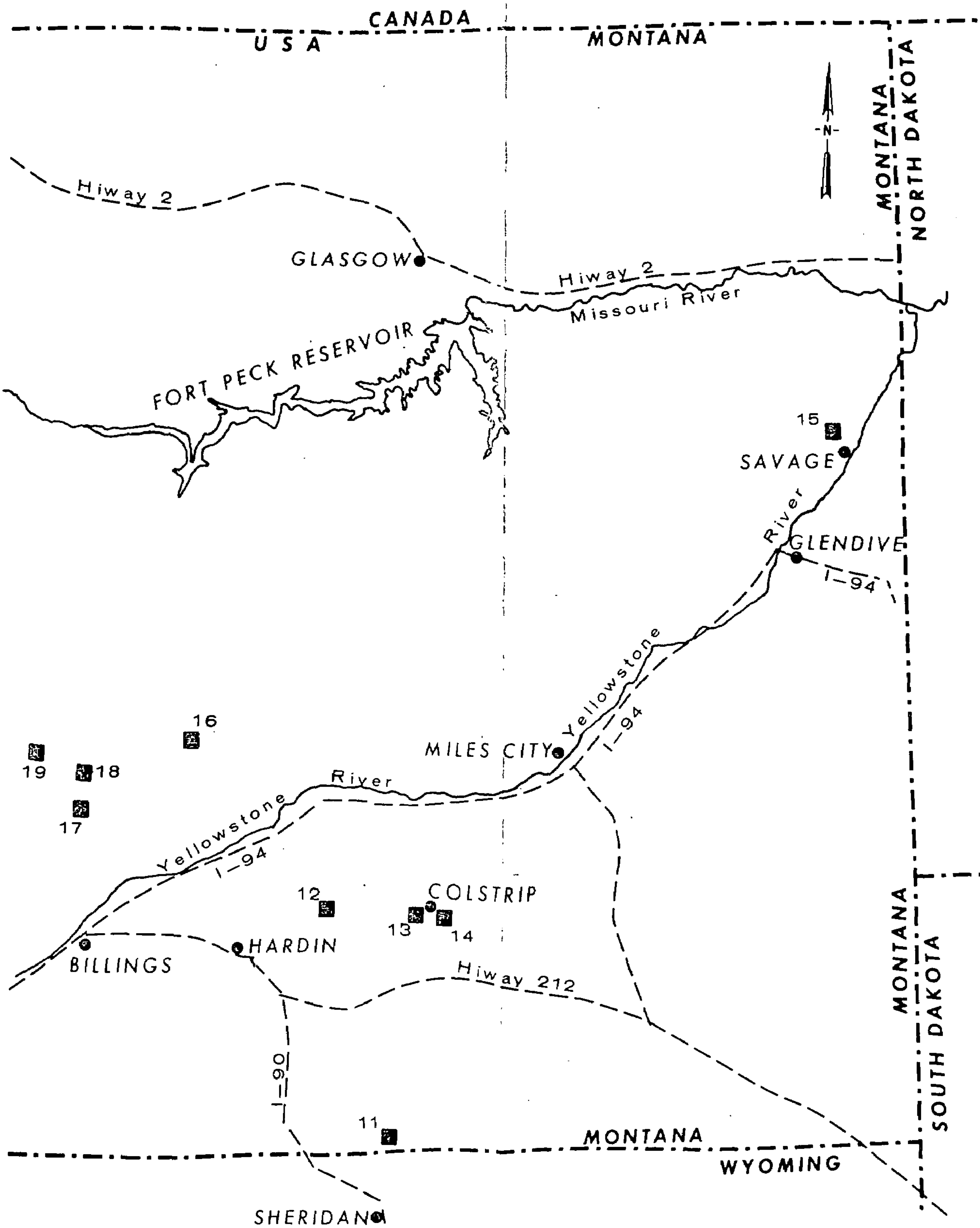
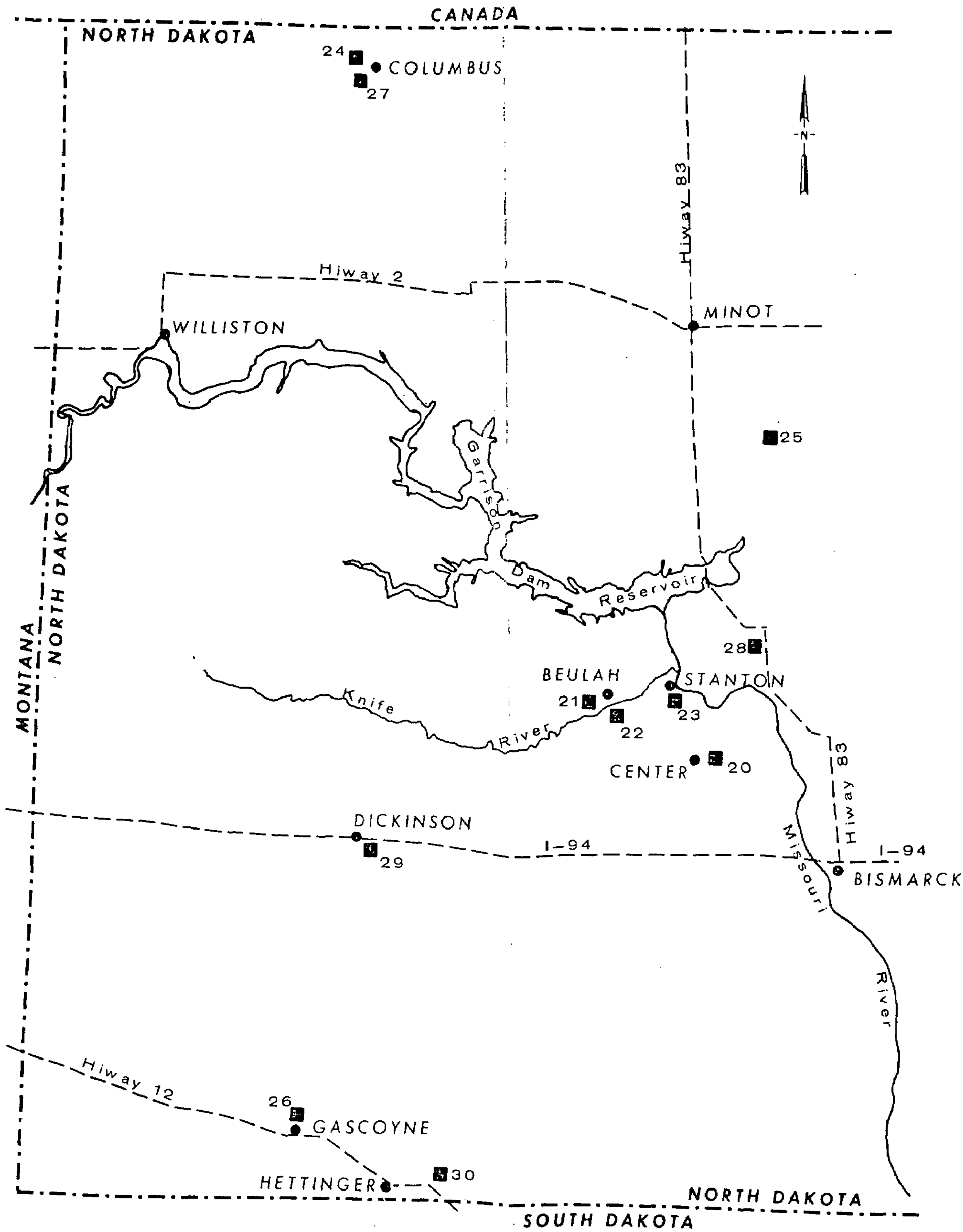


Figure V—12. Locations of Montana Coal Mines



GPO 857-646

Figure V—22. Locations of North Dakota Coal Mines