NASA CONTRACTOR
REPORT

NASA CR-150781

REMOTE SENSING OF STRIPPABLE COAL RESERVES AND MINE INVENTORY IN PART OF THE WARRIOR COAL FIELD IN ALABAMA

Prepared by

Thomas J. Joiner
State Geologist
Geological Survey of Alabama
University, Alabama

Final Report, Contract NAS8-31573

(NASA-CR-150781) REMOTE SENSING OF STRIPPABLE COAL RESERVES AND MINE INVENTORY IN PART OF THE WARRIOR COAL FIELD IN ALABAMA Final Report (Geological Survey, University, Ala.) 128 p HC A07/MF A01 CSCL 08G G3/43

N78-32520

Unclas
30319

July 1978

Prepared for

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA CR-150781	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Remote Sensing of Strippable Coal Reserves and Mine Inventory in Part of the Warrior Coal Field in Alabama		5. REPORT DATE July 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Charles W. Copeland, Jr., Donald D. Russell, Francis E. Evans, Jr., C. Daniel Sapp, and Peter A. Boone		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS Geological Survey of Alabama University, Alabama		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. NAS8-31573
		13. TYPE OF REPORT & PERIOD COVERED Contractor Report Final
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This work was done under the technical supervision of Mr. John Bensko, Data Systems Laboratory, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

Estimates of remaining strippable coal in Alabama vary greatly. The diversity of these estimates makes it all but impossible to develop the policy and regulatory guidelines needed to develop these resources in the most expeditious and environmentally compatible manner.

This study, consisting of two parts, was designed to develop and analyze two different methods by which estimates of the remaining reserves of strippable coal in Alabama could be made. The first part coordinated the acquisition and use of NASA's Earth Resources Office information to analyze and map existing surface mines in a four-quadrangle area in west-central Alabama. Using this information and traditional methods for mapping coal reserves, an estimate of remaining strippable reserves has been derived. The second part of this project was designed to develop techniques for the computer analysis of remotely sensed data and other types of available coal data to produce an estimate of strippable coal reserves for a second four-quadrangle area. Both areas lie in the Warrior coal field, the most prolific and active of Alabama's coal fields. They were chosen because of the amount and type of coal mining in the area, their location relative to urban areas, and the amount and availability of base data necessary for this type of study. The four-quadrangle area chosen for the first part of the study was the Jasper, Cordova, Parrish and Goodsprings quadrangles, and for the second part, the Adamsville, Brookside, Sylvan Springs, and Dora quadrangles.

17. KEY WORDS	18. DISTRIBUTION STATEMENT Unclassified-Unlimited J. T. POWELL Director, Data Systems Laboratory

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	95	NTIS

MSFC - Form 3292 (Rev. December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151.

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INTRODUCTION AND PURPOSE

Coal constitutes the single largest reserve of fossil fuels in the United States; an estimated 90 percent of the total proven domestic fossil fuel reserves. Because coal is the nation's largest source of fossil fuel energy, its importance as a major energy source is increasing. The President has called for a doubling of coal production by 1985 in order to meet the country's future energy needs. In order to meet this goal, the surface mining of coal will have to increase.

Estimates of remaining strippable coal in Alabama vary greatly. The diversity of these estimates makes it all but impossible to develop the policy and regulatory guidelines needed to develop these resources in the most expeditious and environmentally compatible manner.

This study, consisting of two parts, was designed to develop and analyze two different methods by which estimates of the remaining reserves of strippable coal in Alabama could be made. The first part coordinated the acquisition and use of NASA's Earth Resources Office information to analyze and map existing surface mines in a four-quadrangle area in west-central Alabama (fig. 1). Using this information and traditional methods for mapping coal reserves, an estimate of remaining strippable reserves has been derived. The second part of this project was designed to develop techniques for the computer analysis of remotely sensed data and other types of available coal data to produce an estimate of strippable coal reserves for a second four-quadrangle area.

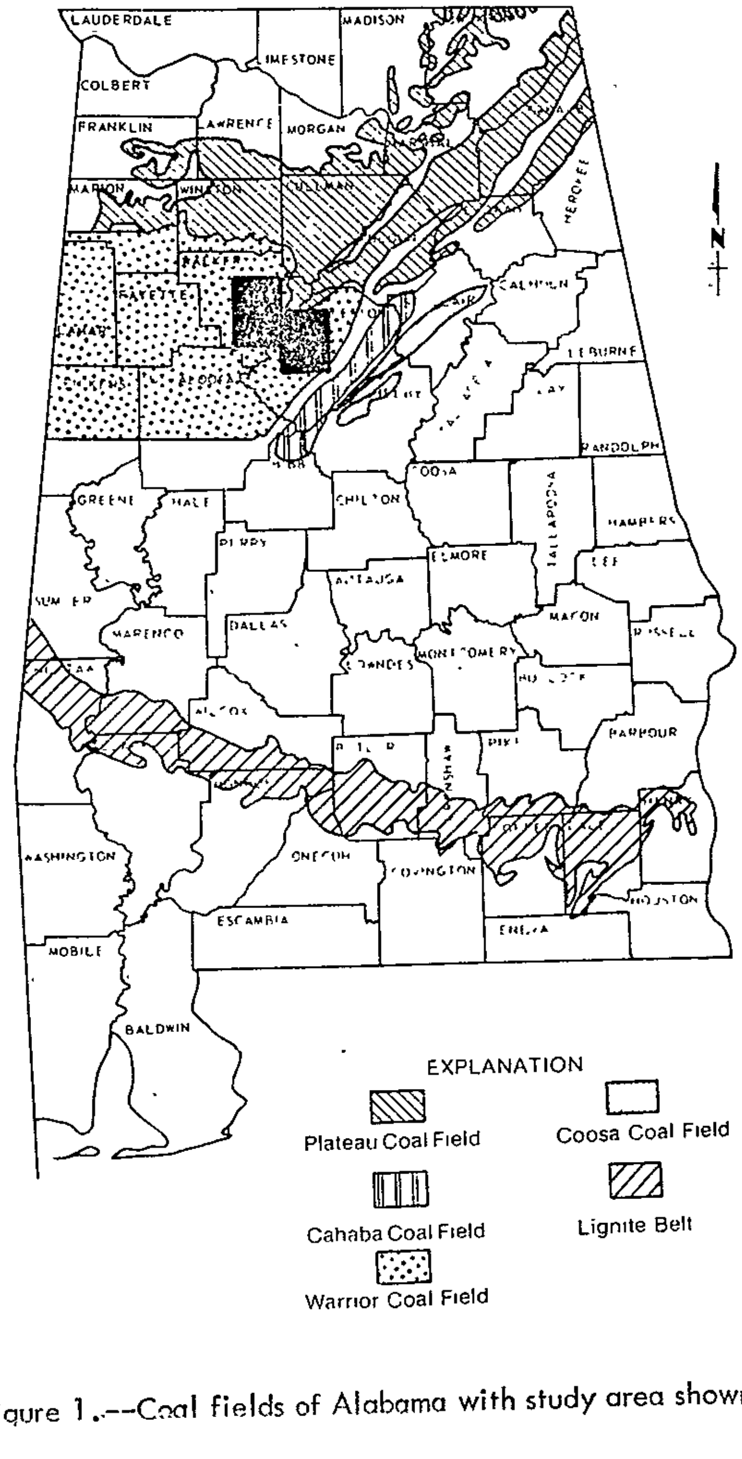


Figure 1.--Coal fields of Alabama with study area shown in black.

Both four-quadrangle areas lie in the Warrior coal field, the most prolific and active of Alabama's coal fields. They were chosen because of the amount and type of coal mining in the area, their location relative to urban areas, and the amount and availability of base data necessary for this type of study. The four-quadrangle area chosen for the first part of the study was the Jasper, Cordova, Parrish and Goodsprings quadrangles, and for the second part, the Adamsville, Brookside, Sylvan Springs, and Dora quadrangles (fig. 2).

Units of the English system of weights and measures are used in the report rather than those of the International Metric System because the English system is more widely used and clearly understood by the American coal industry.

Acknowledgments

Special appreciation is expressed to Mr. John Bensko, Earth Resources Office, National Aeronautics and Space Administration, for his helpful advice and comments in achieving and presenting the results of this study. The authors also gratefully acknowledge information contributed by numerous Alabama coal companies. Thanks are also expressed to Robert L. Barnett and Bruce M. Veek for assistance in preparing the inventory of surface and underground mines and the calculations of strippable coal reserves.

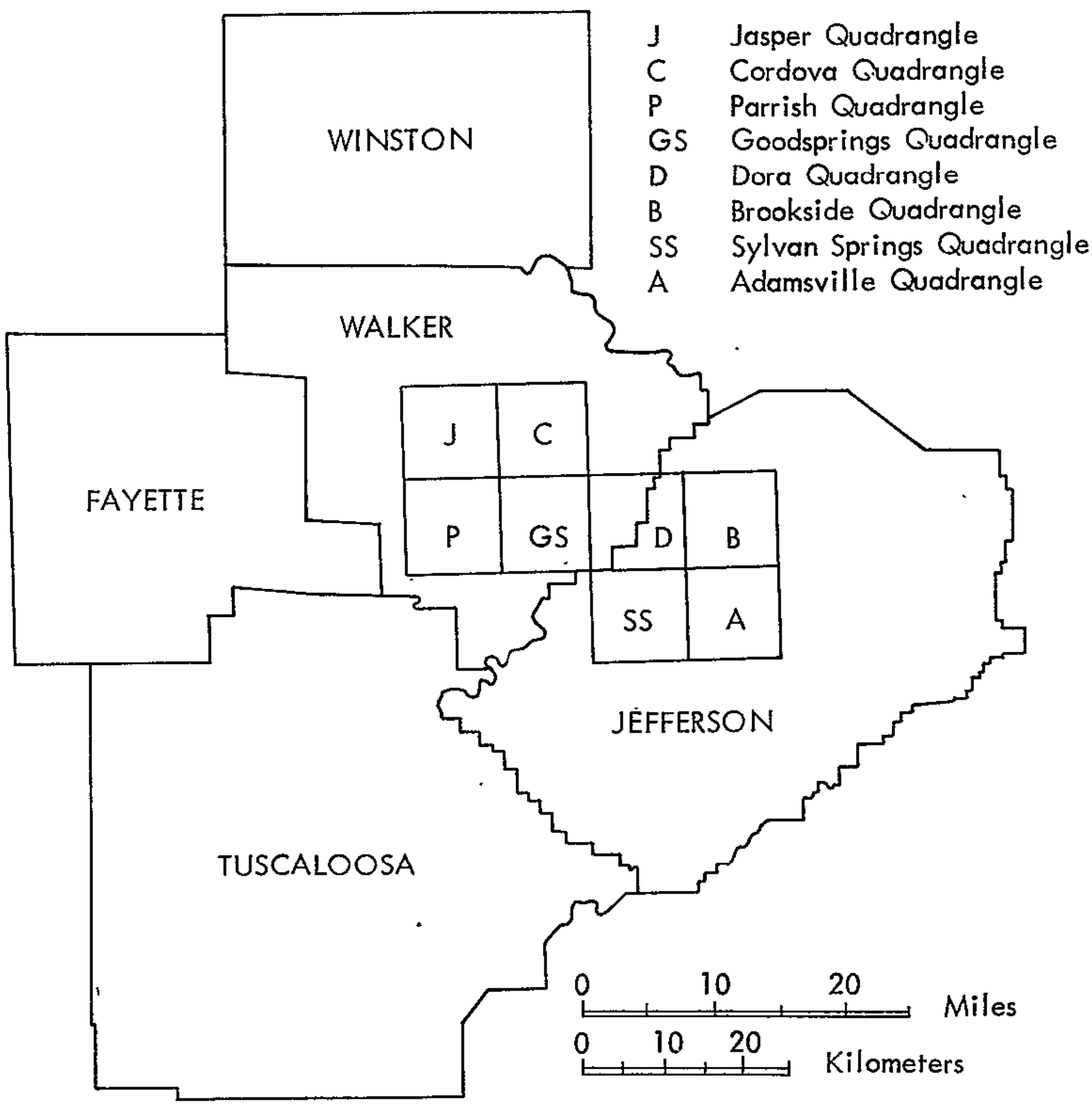


Figure 2.--Index map showing study area.

GEOLOGY

Coal underlies more than 8,600 square miles of north Alabama in four fields: the Warrior, Cahaba, Coosa, and Plateau (fig. 1). These fields comprise the southernmost part of the Appalachian coal region of the United States. The major coal-bearing unit in Alabama is the Pottsville Formation of Pennsylvanian age. The Pottsville consists of approximately 7,700 feet of medium- to dark-gray shale, siltstone, sandstone, conglomeratic sandstone, and coal beds with associated underclays. Some 60 coal beds of varying thickness occur in this sequence.

Warrior Coal Field

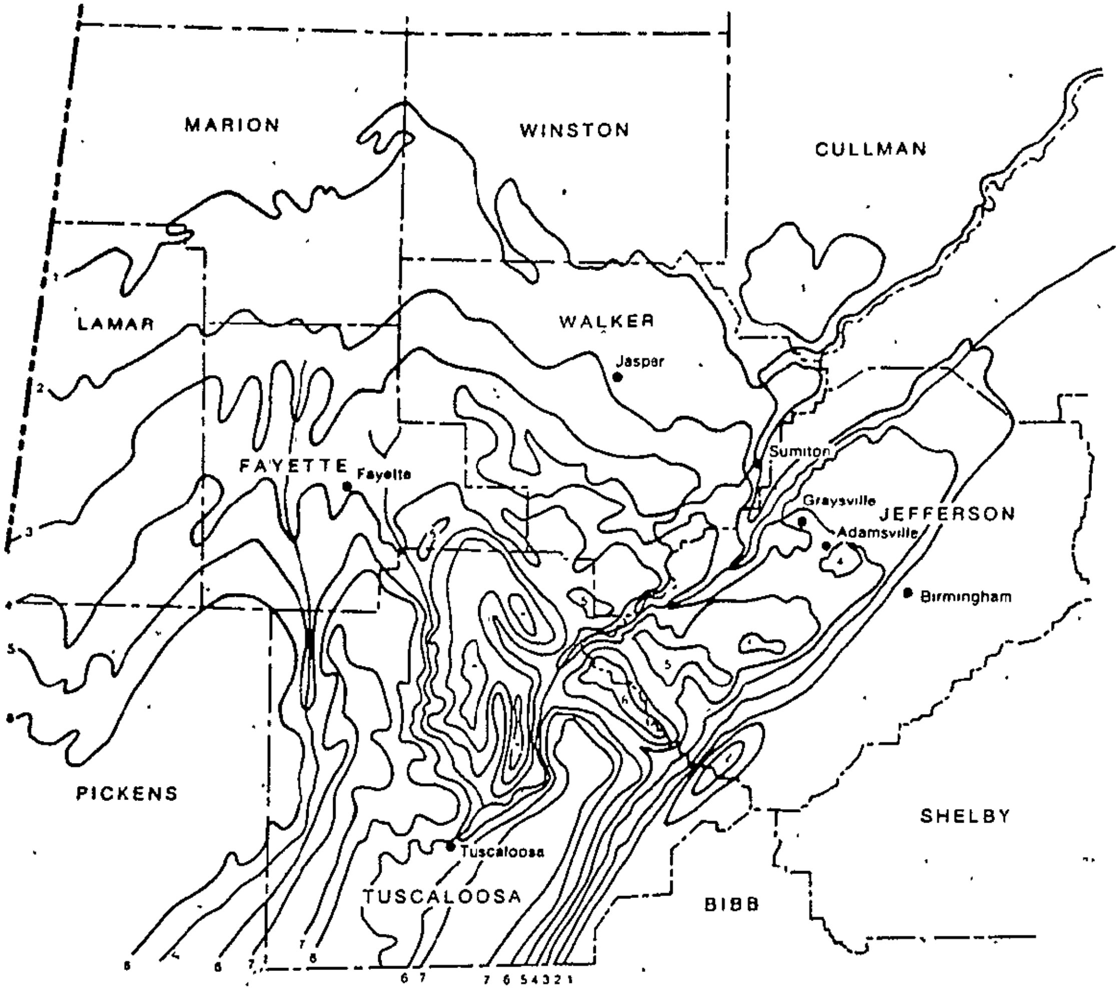
The Pottsville Formation in the Warrior field can generally be divided into lower and upper parts. The lower part of the Pottsville consists predominantly of quartzose sandstone with a few interbeds of coal. The upper part of the Pottsville is the major coal-bearing segment and consists of interbedded shale, sandstone, underclay, coal, and thin calcareous zones containing marine and brackish water invertebrate megafossils.

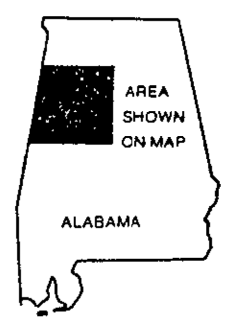
The Warrior coal field is the most productive of Alabama's coal fields. It covers approximately 3,500 square miles in central and west-central Alabama and includes all or part of Tuscaloosa, Jefferson, Lamar, Marion, Winston, Fayette, Cullman, Blount, and Walker Counties.

The Warrior coal field is a part of a broad basinal structure, irregularly triangular in shape. It is bounded on the southeast by the faulted and steeply dipping structures of the folded and thrust-faulted Appalachians; the northern boundary is placed at the outcrop of the Black Creek coal bed, which separates the lower and upper parts of the Pottsville. The southern and western boundaries are presently defined by the contact of the Pottsville with the sediments of the overlying Tuscaloosa Group of Cretaceous age; however, coal occurs at minable depths in some of the area overlain by the Cretaceous material. Therefore, the western boundary may be extended to the Alabama-Mississippi State line while the southern boundary may be extended into Greene, Sumter, and Hale Counties.

The coal-bearing rocks in the Warrior coal field dip regionally to the southwest at approximately 30-100 feet per mile. The dip increases sharply near the southeastern boundary of the field and may be locally disrupted elsewhere. Numerous high-angle faults, trending northwest-southeast, occur throughout the field. These faults affect dip and continuity of beds locally and are a major problem in the development of coal mines, especially the underground type.

The Warrior coal field contains 7 coal groups with a total of more than 20 beds (fig. 3). Most of these beds are commercially minable in some part of the field. Of the more than 20 coal beds occurring in the field, 9 beds in 4 groups are considered to be major coal beds. These are, in descending order, the Brookwood, Milldale, and Carter beds of the Brookwood group; the Pratt and American beds of the Pratt group: the Mary Lee and Blue Creek beds in the Mary Lee group; and the Jefferson and Black Creek beds in the Black Creek group.





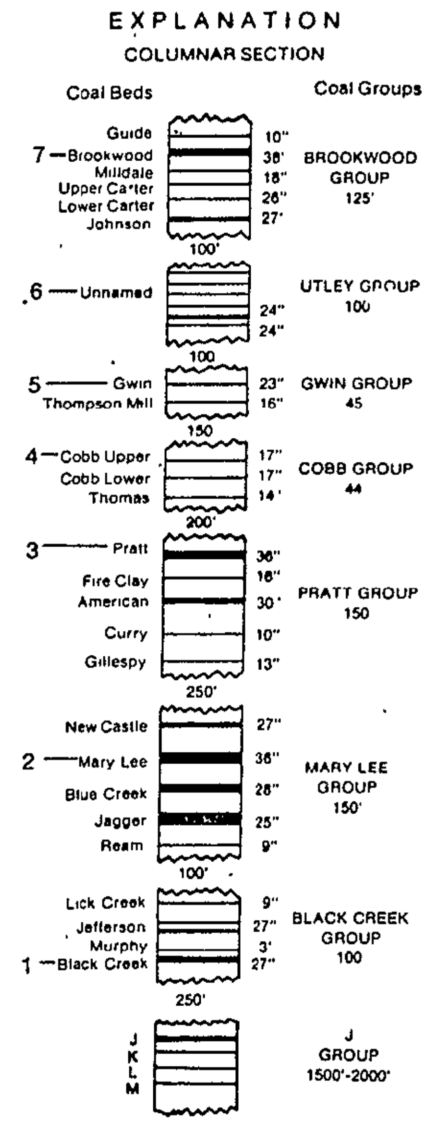


Figure 3.—Major coal beds in the Warrior coal field of Alabama

MANUAL RESERVE CALCULATIONS

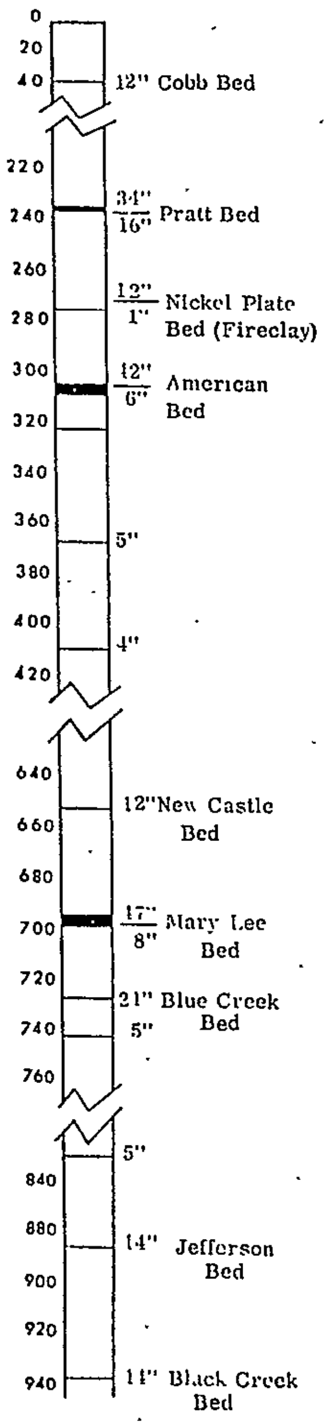
Area of Study

The area chosen to demonstrate the manual method of determination of strippable coal reserves includes the Jasper, Cordova, Goodsprings, and Parrish quadrangles (fig. 2). These lie in the central part of the Warrior coal field and contain six major and numerous minor coal beds. The major coal beds contain about 170 inches of coal in less than 1,000 feet of section (fig. 4).

Except for the metropolitan areas of Jasper, Parrish, and Cordova, the area is sparsely populated. Most of the coal mined in this area is used elsewhere and transportation is provided by an adequate network of highways, railroads, and waterways.

Methodology

The methodology used to determine remaining strippable coal reserves in this part of the project was predominantly manual. The primary data sources were from remotely sensed imagery and photographs, core holes, outcrops, and underground mines. The information obtained was used to compile maps and overlays showing coal thickness, overburden thickness, and an inventory of surface and underground mines. Using these data, estimates were calculated for the original and remaining strippable reserves. Remaining strippable reserves for each of the major coal beds are shown in plates 1-6.



COBB BED - 200' above PRATT; average thickness 12"

PRATT BED - average thickness 38" with sandstone roof.

Average Analysis

VM	FC	Ash	Sulphur	Spc. Gr.	Btu's
35.00	56.00	9.00	1.50	1.33	13,700

NICKEL PLATE BED (Fireclay) - approx. midway between PRATT and AMERICAN; average thickness 12"

AMERICAN BED - average thickness 38"

Average Analysis

VM	FC	Ash	Sulphur	Spc. Gr.	Btu's
31.50	56.50	12.00	1.80	1.38	13,000

NEW CASTLE BED - 50' above MARY LEE average thickness 12"

MARY LEE BED - average thickness 47"

Average Analysis

VM	FC	Ash	Sulphur	Spc. Gr.	Btu's
31.30	53.62	15.05	0.80	1.38	12,600

BLUE CREEK - 30' below MARY LEE Intermittent and combines with MARY LEE; average thickness where seen 21"

JEFFERSON BED - 200' below MARY LEE average thickness 14"

BLACK CREEK BED - 250' below MARY LEE average thickness 14"

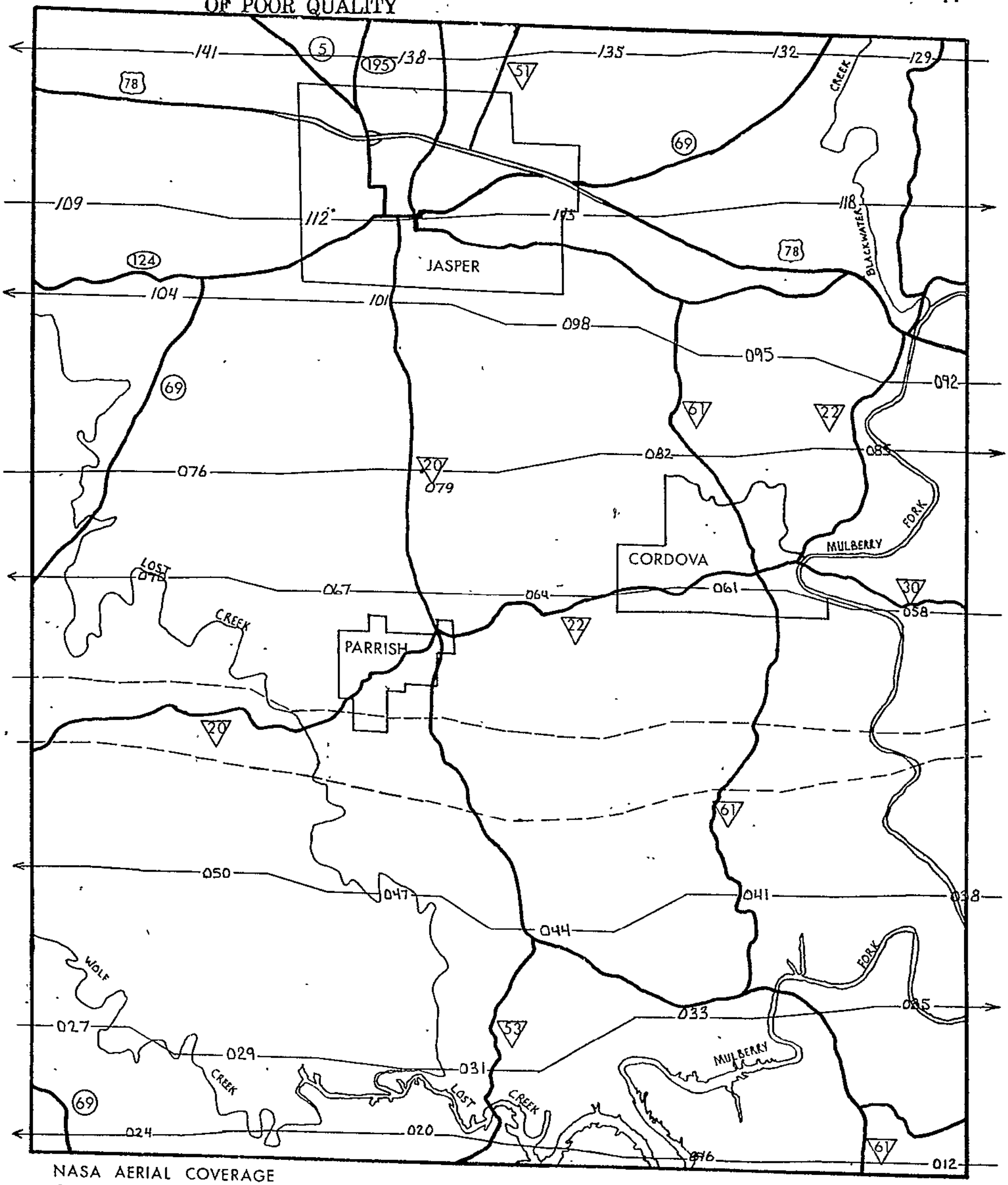
Figure 4.--Representative section and information on the thicker coal beds in the study area.

Remote Sensing

The section of the project devoted to remote sensing had two objectives: first, to map and measure surface mines in the study area as of January 30, 1976; second, to evaluate several different types of remotely sensed data as to their effectiveness in monitoring surface mine dynamics in Alabama. Black-and-white, color infrared, and multispectral photography was acquired from low- and high-altitude aircraft and from Skylab Four. Landsat multispectral scanner imagery in the form of color composites and 70 mm transparencies was also used.

Surface mine inventory.-- The surface mine inventory was conducted using conventional 9-inch format black-and-white and color infrared aerial photography. The photography was provided by NASA's Earth Resources Office under MSFC Mission No. 34 at a nominal scale of 1:24,000 and was flown on January 30, 1976 (fig. 5). Supplementary black-and-white photography was borrowed from the Alabama Department of Revenue to provide coverage of a small area not included in the NASA photography. These photographs are at a scale of approximately 1:20,000 and were flown in March 1974.

Outlines of surface mines were traced on mylar overlays of the photographs and compiled on 7.5-minute topographic quadrangle sheets (pl. 7). Using a dot grid, all surface mines were then measured and percentages were computed for surface mined areas within each quadrangle (table 1). As will be explained in a later section of this report, calculated volumes of coal removed from these surface mined areas were subtracted from the total strippable reserve estimates to produce an estimate of the remaining strippable coal reserves.



NASA AERIAL COVERAGE
COLOR INFRARED PHOTOGRAPHY (RC-10)
JANUARY 30, 1976
SCALE 1:24,000

0 1 2 3 4 MILES

Figure 5.--Index to NASA color infrared photography.

Table 1.--Surface mined land in project area

Quadrangle	Area mined in acres	Percentage of area mined
Goodsprings	5551.0	14.0
Cordova	2314.5	5.8
Jasper	2807.8	7.1
Parrish	2290.1	5.8

Evaluation of other types of remotely sensed data.-- In addition to the surface mine inventory, an effort was made to evaluate the usefulness of various types of remotely sensed data to monitor surface mine dynamics. Other than the above mentioned 9-inch format photography, Skylab multispectral photography, Landsat multispectral scanner imagery, high-altitude aircraft photography, and International Imaging Systems (I^2S) multispectral photography were analyzed. The low-altitude color infrared photography proved to be the most useful for mapping surface mines because of its excellent resolution and spectral characteristics. Even older, heavily vegetated mines, which were difficult to detect on conventional black and white photography, proved easy to map because of the characteristic spectral signatures produced by plants growing on the spoil piles.

High-altitude color infrared photography taken in February 1973 from one of NASA's U-2 research aircraft was also judged to be excellent for mapping surface mines. In addition to the excellent resolution provided by the photography, the scale (1:130,000) allows much larger areas to be covered than is possible with the low-altitude photography. The major drawback of this type of photography is that it is very expensive and cannot be routinely acquired.

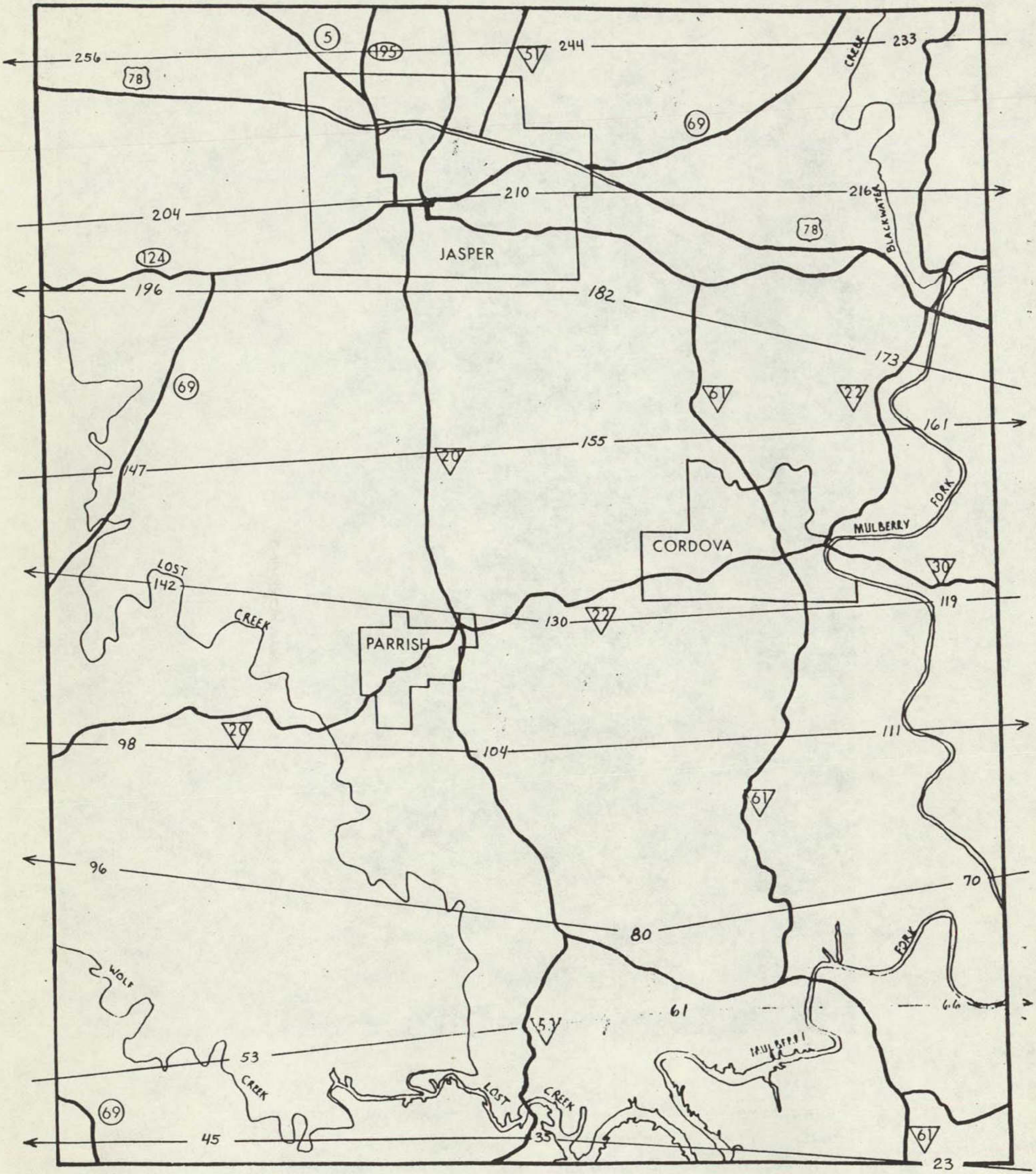
Two different examples of Landsat multispectral scanner imagery were examined and found to be unacceptable for surface mine analysis when manual interpretation was attempted. The first type of imagery analyzed was a color composite of bands 4, 5 and 7 reproduced at a scale of 1:250,000. Although the larger mines are clearly visible, the edges are indistinct, and small, older mines cannot be seen. The second type of Landsat imagery evaluated was 70 mm positive transparencies composited from all four spectral bands that were registered and mounted on clear acetate for use with the I^2S color additive viewer. Unsatisfactory identification of the mined areas resulted because the ground glass rear projector display further decreases the quality of the already low-resolution Landsat imagery. Digital processing of Landsat computer compatible tapes will be discussed in another part of this report.

In addition to Landsat imagery, orbital photography taken from Skylab 4 was evaluated. The red band (0.6-0.7 μm) photograph taken with the S190 multispectral camera in early February 1974 was used (fig. 6). Because of its resolution of approximately 91 feet and its large area coverage, this photograph is adequate for a regional inventory of surface mines and repetitive coverage of this type would be valuable for monitoring surface mine dynamics.

Low-altitude multispectral photography compatible for use with the I^2S color additive viewer (fig. 7) was acquired at the same time as the above mentioned low-altitude color infrared photography. Overall, the I^2S viewer did not prove to be as valuable a tool for surface mine interpretation as the 9-inch color infrared transparencies used with a stereoscope and light table. It was helpful in the interpretation of specific areas surrounding particularly active surface mines. For example, new active silt fans in the Warrior River south of the Gorgas Steam Plant were more readily noticeable on the I^2S photography than on the color infrared photography.

Because it was felt that vegetation could possibly obscure some of the older surface mines, conventional black-and-white photography dated August 1938 and December 1958 was used to inventory mines existing prior to those dates. It was found that the interpretation of these photographs did not alter the interpretation

Figure 6.--NASA Skylab 4 image of four-quadrangle project area. Red spectral band. City of Jasper is at top center and Gorgas steam plant is at lower right, on Mulberry Fork. Large surface mines are easily discerned on this image.



NASA AERIAL COVERAGE
MULTISPECTRAL PHOTOGRAPHY (I^2S)
JANUARY 30, 1976
SCALE 1:24,000

0 1 2 3 4 MILES

Figure 7.--Index to NASA multispectral photography.

of the low-altitude color infrared photography. However, since vegetative indicators of the older surface mines are not as apparent on black-and-white photography, the older photographs were useful in the interpretation of the 1974 photography.

During the course of this study, it became apparent that surface mine interpretation is based primarily on pattern recognition and secondly on spectral reflectance. The low-altitude color infrared photography provided the best combination of these factors and was considered to be superior to other types of photography and imagery evaluated in this report.

Drill Hole and Outcrop Data

Drill hole and outcrop data pertaining to the study area were collected from as many sources as possible. Information was obtained from private companies operating in the area, field work, and file data from the Office of Coal Information, Geological Survey of Alabama. These data were compiled on the appropriate quadrangle maps so that approximate coal and overburden isopachs could be constructed. Because the data are incomplete or absent in places, the strippable reserve figures computed from these data are approximate. In the absence of necessary data, certain assumptions were made about coal thicknesses which will be explained where necessary.

Reserve Calculations

Original, in-ground strippable reserve estimates were calculated by analyzing coal thickness versus the thickness of overburden using the ratio given in table 2. Using a 7-inch contour interval, coal isopachs were constructed for the Pratt, Nickel Plate (Fire Clay), Mary Lee, Blue Creek, and American coal beds (plates 8-12). Because of an insufficient amount of core hole information, the Black Creek, Jefferson, and Cobb coal beds were each assumed to have a thickness of 14 inches.

Table 2.— Coal thickness overburden limits for surface mined coal beds

Coal thickness (inches)	Overburden (feet)
7	21
14	42
21	63
28	84
35	105
42	126
49	147
56	168
63	189
70	210
77	231
84	252
91	273
98	294
105	315

Overburden isopachs with a contour interval of 50 feet were derived primarily from core hole and topographic information (plates 13-15). By using a 50-foot contour interval, it was found that all coal beds, except the Black Creek and Jefferson, occur within 50 feet of either the Pratt, American, or Mary Lee coal beds so that these were the only overburden isopachs that were required. Because of the lack of drill hole data for the Black Creek and Jefferson, overburden limits were estimated by using outcrop elevations and topography. Original strippable reserve figures within quadrangles are summarized by townships and ranges in tables 3 - 6 and were calculated using a standard 1,800 tons per acre-foot.

Remaining strippable coal reserves were calculated by subtracting the amount of coal already mined from the original reserve figures. Areas from which coal had been removed by surface mining were determined by analyzing aerial photography and other remotely sensed data with the assumption that all strippable reserves had been removed by surface mining prior to 1976. Information on underground mines which would affect strippable reserves was obtained from the Alabama Department of Industrial Relations, Division of Safety and Inspection, from coal companies operating in the area, and from the Office of Coal Information of the Geological Survey of Alabama. It was estimated that 40 percent of the original strippable reserves remain in underground mines in the form of pillars and walls.

Estimates of original and remaining strippable reserves are given in table 7 and are considered to be conservative. The primary reason for this conservatism is that coal isopachs were constructed based on the smallest value within a given contour interval. For example, coal thickness values of 7 inches through 13 inches

Table 3.— Strippable coal reserves of the Cobb, Pratt, American and Mary Lee seams in the Parrish quadrangle
(Summarized by townships and ranges)

Seam	Location	Original strippable reserves (tons)	Remaining strippable reserves (tons)	Coal produced by surface mining to 1976 (tons)
Cobb	T 16 S, R 7 W	1,854,579	1,854,579	-
	T 15 S, R 8 W	106,192	106,192	-
	T 16 S, R 8 W	4,315,967	3,889,306	426,661
Pratt	T 15 S, R 7 W	5,395,648	4,489,489	761,092
	T 16 S, R 7 W	8,649,964	7,021,993	1,627,970
	T 15 S, R 8 W	3,161,130	1,667,718	304,356
	T 16 S, R 8 W	2,906,075	2,787,176	-
American	T 15 S, R 7 W	10,210,540	8,081,242	1,851,680
	T 15 S, R 8 W	4,945,546	4,449,285	465,541
	T 16 S, R 7 W	22,164,898	13,312,413	4,354,809
	T 16 S, R 8 W	8,155,026	8,102,877	52,149
Mary Lee	T 15 S, R 7 W	7,585	7,585	-
	T 15 S, R 8 W	1,379,566	1,379,566	-

Table 4.— Strippable coal reserves of the Mary Lee, Jefferson and Black Creek seams in the Cordova quadrangle
(Summarized by townships and ranges)

Seam	Location	Original strippable reserves (tons)	Remaining strippable reserves (tons)	Coal produced by surface mining to 1976 (tons)
Mary Lee	T 14 S, R 6 W	7,259,035	3,001,274	3,967,060
	T 15 S, R 6 W	14,124,586	8,411,400	1,824,248
	T 14 S, R 7 W	1,950,345	1,073,306	877,039
	T 15 S, R 7 W	2,751,530	1,864,821	868,505
Jefferson	T 13 S, R 6 W	1,530,313	1,530,313	-
	T 14 S, R 6 W	3,821,040	3,821,040	-
Black Creek	T 13 S,R 6 W	379,259	379,259	-
	T 14 S, R 6 W	549,925	549,925	-

Table 5.— Strippable coal reserves of the Pratt, American and Mary Lee seams in the Goodsprings quadrangle (Summarized by townships and ranges)

Seam	Location	Original strippable reserves (tons)	Remaining strippable reserves (tons)	Coal produced by surface mining to 1976 (tons)
Pratt	T 15 S, R 6 W	4,029,640	2,578,206	1,404,212
	T 16 S, R 6 W	11,718,186	7,797,965	2,851,085
	T 15 S, R 7 W	7,789,989	5,431,195	1,836,551
	T 16 S, R 7 W	16,429,271	6,762,582	4,593,562
American	T 15 S, R 6 W	6,546,967	3,300,502	3,246,465
	T 15 S, R 7 W	12,855,961	6,323,772	3,964,220
	T 16 S, R 6 W	17,046,134	10,478,751	5,939,034
	T 16 S, R 7 W	21,724,931	9,677,768	5,405,108
Mary Lee	T 15 S, R 6 W	23,460,549	16,356,481	955,900
	T 16 S, R 6 W	10,884,754	10,884,754	-

Table 6.— Strippable coal reserves of the Mary Lee seam in the Jasper quadrangle
(Summarized by townships and ranges)

Seam	Location	Original strippable reserves (tons)	Remaining strippable reserves (tons)	Coal produced by surface mining to 1976 (tons)
Mary Lee	T 14 S, R 7 W	20,645,359	13,973,870	4,715,495
	T 15 S, R 7 W	1,795,796	1,080,891	669,393
	T 13 S, R 8 W	2,216,675	1,138,347	418,986
	T 14 S, R 8 W	33,105,440	21,573,627	10,444,194
	T 15 S, R 8 W	4,529,989	4,529,989	-

Table 7.— Reserve estimates of strippable coal in study area by coal bed

Seam		Original strippable reserves (tons)	Remaining strippable reserves (tons)	Coal produced by surface mining to 1976 (tons)
Cobb		6,276,738	5,850,077	426,661
Pratt		60,079,903	38,536,324	13,378,828
Nickel Plate		10,080,000	10,080,000	?
American		103,650,003	63,726,610	24,922,664
New Castle		7,402,500	7,402,500	?
Mary Lee		124,111,209	85,275,911	24,141,910
Blue Creek		4,977,000	4,977,000	-
Jefferson		5,251,353	5,251,353	-
Black Creek		929,184	929,184	-
	Total	322,757,890	221,998,959	62,940,063

were all assigned to the 7-inch interval. Secondarily, it was assumed that all coal that can presently be stripped economically was recovered from surface mines operated prior to 1976. It was felt that this conservative bias was necessary because of areal inconsistencies in coal thicknesses that may not have been reflected in the core hole data and because of the possible presence of older underground mined areas that have not been adequately recorded.

Findings

Total remaining strippable coal reserves in the four quadrangle area (table 8) are estimated to be 221,998,959 tons with an overburden of less than 300 feet. Strippable reserves are as follows: 929,184 tons for the Black Creek coal bed; 5,251,353 tons for the Jefferson coal bed; 85,275,911 tons for the Mary Lee coal bed; 4,977,000 tons for the Blue Creek coal bed; 7,402,500 tons for the New Castle coal bed; 63,726,610 tons for the American coal bed; 10,080,000 tons for the Nickel Plate coal bed; 38,536,324 tons for the Pratt coal bed, and 5,850,077 tons for the Cobb coal bed. Maps showing remaining strippable coal reserves in this four quadrangle area are given in plates 1-6.

Table 8.— Reserve estimates of strippable coal in study area by quadrangles

Quadrangle	Original strippable reserves (tons)	Remaining strippable reserves (tons)	Coal produced by surface mining to 1976 (tons)
Jasper	65,264,759	45,268,224	15,649,158
Cordova	33,158,533	21,423,838	7,536,852
Parrish	77,452,716	61,319,421	9,557,916
Goodsprings	146,881,882	93,987,476	30,196,137
Total	322,757,890	221,998,959	62,940,063

COMPUTER DERIVED RESERVE CALCULATIONS

The second part of this project is designed to demonstrate the application of computer modeling techniques to determine strippable coal reserves. A second four quadrangle area adjacent to the first study area and composed of the Sylvan Springs, Dora, Brookside, and Adamsville (USGS) 7.5-minute topographic quadrangles (fig. 2) was chosen so that general comparisons of the two techniques presented in this project for determining strippable coal reserves could be made. This area was chosen for the same reasons as the first four quadrangle area except that it was felt that the computer techniques could handle problems relating to urban areas better than manual methods.

It has been shown (Durfee and others, 1977) that computer analysis of several different types of digital data can be useful in assessing the effects of surface mining in a given area. This type of analysis has the potential for providing fast accurate results which can easily be updated. In this project, information derived from remotely sensed data, core holes, underground mines, data on structural geology, and the outlines of inhabited areas as shown on maps was analyzed to provide an estimate of remaining strippable coal reserves. Mr. Nickolas L. Faust of the Engineering Experiment Station at the Georgia Institute of Technology was contracted to provide the computer analyses of digital data gathered by the Geological Survey of Alabama. The software developed under this contract is compatible with computer facilities available to the Geological Survey of Alabama and will be transferred here in the near future for testing and future implementation.

Methodology

In preparing an estimate of remaining strippable coal reserves, the accumulated data on coal seam thicknesses, overburden thicknesses, locations of the seam outcrops, outlines of existing surface and underground mines, locations of urban areas, and structural geology were digitized to match the computer compatible tapes of Landsat data provided by the EROS Data Center.

Throughout this part of the project, location information was based on the Universal Transverse Mercator (UTM) 1-kilometer grid system. This system allows for a much more accurate geographic location of data than the township and range system.

Two different computer techniques were developed and tested, based on the available data, and are described in the following section of this report.

Core Hole Data

Core hole data in the project area was secured from the files of the Geological Survey of Alabama and from the mining companies operating in the area. Desired data included seam thickness, number of seams, surface elevation, seam elevation, and thickness of partings. The location of each core hole was plotted on the 7.5-minute quadrangle maps so that proper UTM coordinates could be derived. Digital topographic data provided by the Army Map Service were used to supplement core hole data on seam elevation so that more refined overburden estimates could be produced. These data were then entered on a coal data form (fig. 8) and keypunched for computer analysis.

COAL DATA FORM

Reference No.	Coal Field
County	Quadrangle
Sec., T., R.	UTM
Bed Name	Rank
Form.	Age
Data Source	
Type of Data	
Bed Thickness - C P	T
Elev. Coal Depth	Elev. Surface
Overlying Unit	Thickness
Underlying Unit	Thickness
Type of Sample	Type of Analysis
Moisture	Forms of S O
Vol. Matter	P
Fixed Carbon	S
Ash	Trace Element
C	BTU
H	FSI
O	Fusibility of Ash -- I.D.T.
N	S. T.
S	F. T.
	Grindability Index

Figure 8.--Coal data form.

Landsat Satellite Data

The National Aeronautics and Space Administration (NASA) has launched two Landsat satellites, the first in July 1972 and the second in January 1975. These satellites have been used in a number of earth resources applications, including several studies demonstrating their effectiveness in monitoring surface mine dynamics. One of the more recent of these (Anderson and others, 1977) has shown that it is possible to achieve accuracies of 97 percent when locating mines greater than 100 acres in size and an average of greater than 92 percent for all surface mines when Landsat imagery is processed by computer.

Because one of the most important variables in determining strippable reserves is the volume of coal which has already been removed by stripping, computer processed Landsat imagery was used in the Least Squares Fitting Technique to inventory existing surface mines. The volumes of coal removed were calculated and were then subtracted from the total reserve figures as part of the process for determining remaining strippable reserves.

Urban Area Data

According to the Alabama Surface Mine Reclamation Act of 1975, surface mining cannot be conducted within 300 feet of an occupied dwelling, public building, school or church. For the purpose of this study, these areas were removed from the reserve calculations except where it was indicated to us by mining companies that it was economically feasible for them to remove the structure rather than to mine around it.

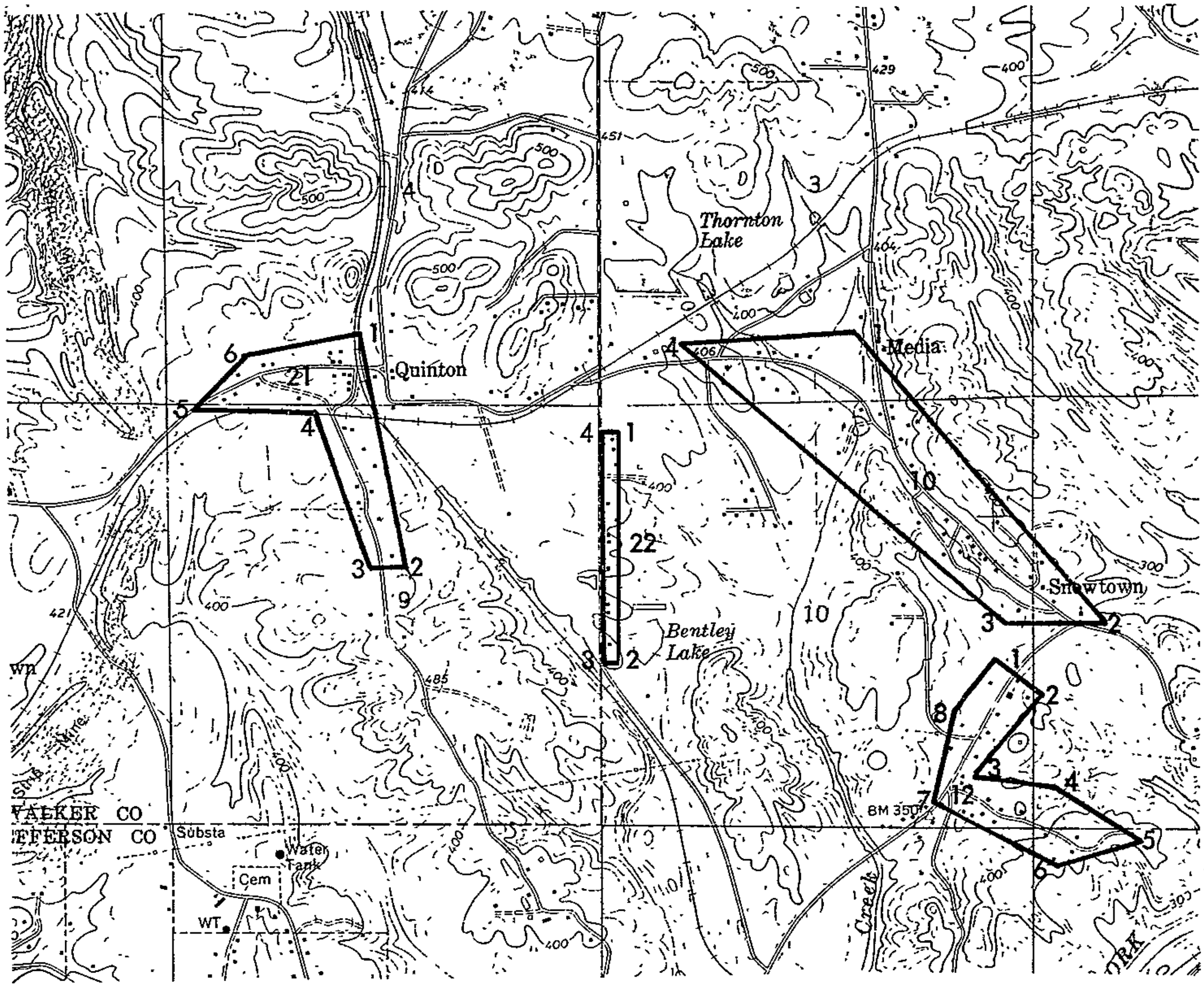
Since the quadrangle maps used in this study have been photo revised fairly recently, the cultural information presented on them was used without modification.

The method used for deleting the areas from reserve calculations was to enclose each area in a polygon (fig. 9) and assign UTM coordinates where an angle occurred. During the calculation process, these areas were automatically removed from consideration.

Underground Mine Data

Underground mining at a depth of less than 300 feet affects the reserve calculations, and therefore it was necessary to identify and account for these mines. Data for these were secured from the Alabama Department of Industrial Relations, Division of Safety and Inspection, from the files of the Geological Survey of Alabama, and from mining companies operating in the area. These mines were plotted on USGS 7.5-minute quadrangles and UTM coordinates were assigned (fig. 10). Because support pillars and walls were left in place inside these mines, approximately 40 percent of the strippable coal reserves are still in place. In areas of underground mining, this figure (40 percent) was used to calculate remaining strippable reserves.

Because accurate records were not kept for early mining in this area, many small "truck" mines could not be located or measured. For this reason, these small mines were not considered in the reserve calculations.



Area 10

	Meters North	Meters East
1.	3725680	495000
2.	3725680	495650
3.	3724600	496550
4.	3724600	496200

Area 12

	Meters North	Meters East
1.	3724450	496150
2.	3724300	496300
3.	3724000	496040
4.	3723980	496350
5.	3723780	496700
6.	3723680	496350
7.	3723900	495900
8.	3724250	496000

Area 21

	Meters North	Meters East
1.	3725740	493780
2.	3724850	493920
3.	3724850	493800
4.	3725450	493600
5.	3725450	493150
6.	3725650	493320

Area 22

	Meters North	Meters East
1.	3726350	494750
2.	3724450	494750
3.	3724450	494650
4.	3725350	494650

Figure 9.--Urban area outline.

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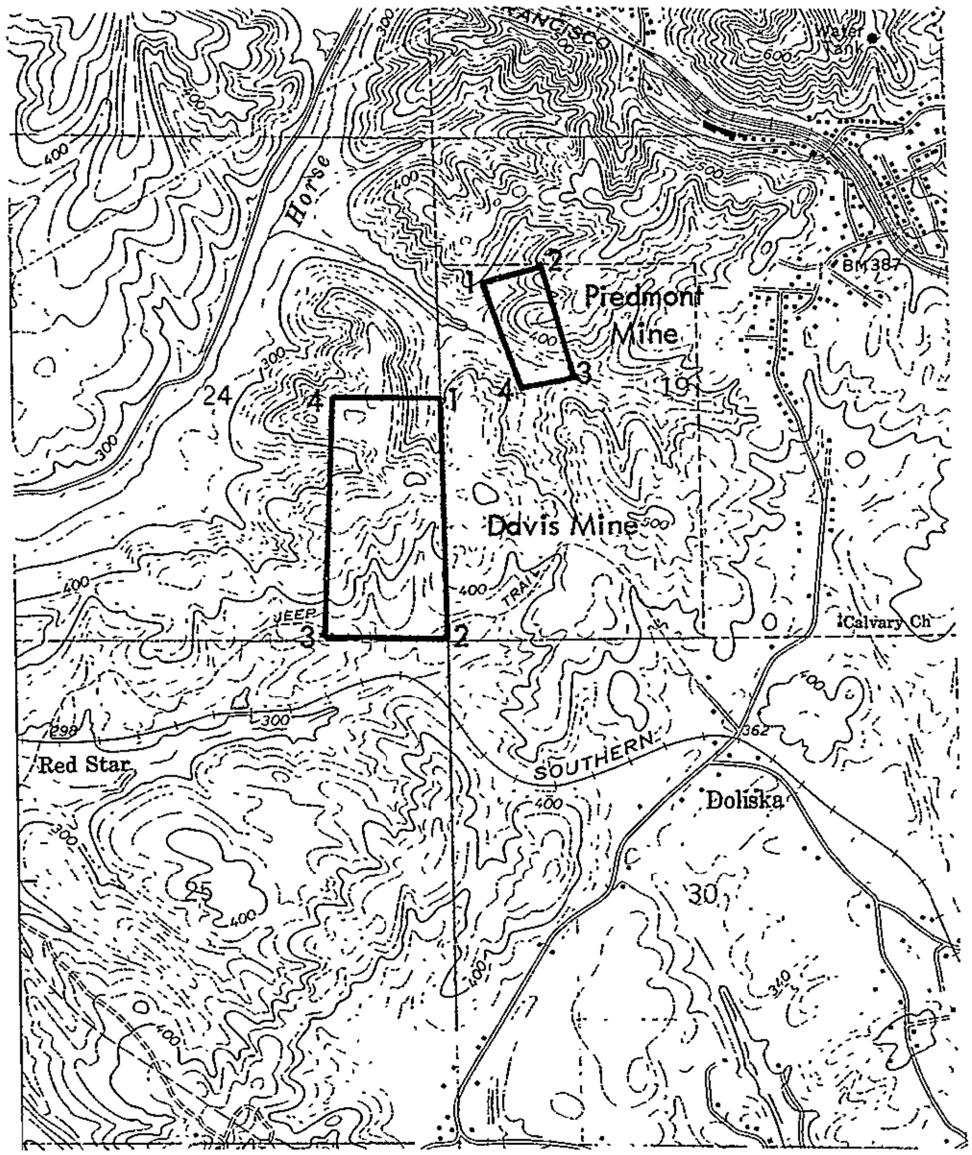

Davis Mine

	Meters North	East
1.	3731140	489800
2.	3730360	489800
3.	3730360	489500
4.	3731140	489500

Piedmont Mine

	Meters North	East
1.	3731500	489920
2.	3731560	490100
3.	3731200	490200
4.	3731180	490040

Figure 10.--Underground mine outline.

REFERENCES

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Durfee, R. C., Edwards, R. G., Ketelle, M. J., and Honea, R. B., 1977, Assignments of ERTS topographical data to geodetic grids for environmental analysis of contour strip mining: Oak Ridge National Laboratory, open-file report, 40 p.

National Aeronautics and Space Administration, 1976; Landsat Data Users Handbook, Goddard Space Center, Greenbelt, Maryland, National Aeronautics and Space Adm., 157 p.

DEVELOPMENT OF INFORMATION RETRIEVAL AND MODELING COMPUTER TECHNIQUES FOR COAL DATA IN THE WARRIOR BASIN

By Nickolas L. Faust
G. David Gentry
and Michael D. Furman

LEAST SQUARES FITTING TECHNIQUE

Coal drill holes and surface mine data were accumulated for four quadrangles in the Warrior basin. The variables required for this analysis included:

X location (UTM coordinates in meters),
Y location (UTM coordinates in meters),
Surface elevation in feet,
Number major seams in core, and
A variable for each seam:
- Elevation of top of seam
- Total thickness of coal (inches)
- Total thickness of partings in seams.

These data were subsequently keypunched for entry into the data base system. By knowing the geographic positioning of each data variable, it is possible to produce maps for each data variable by using a least squares technique for defining a surface which corresponds to each variable. A least squares technique gives the surface which most closely approximates the given data over the specific area. An estimate of how well the surface fits the data is also given as well as an equation that defines the surface. At present the analysis system can only calculate surfaces up to the seventh order, but this may be modified in the future.

After the surface fit of each variable has been completed, a new data set is calculated by evaluating the surface equation at various points along a geographic grid system. These data will finally be inserted into a geographic data base management system. The system currently in use for this project is the IMGRID system developed at the Harvard School of Landscape Architecture. IMGRID accepts data in a gridded format and allows the interaction of many data variables and incorporation of mathematical models for analysis.

One obvious drawback to such a system as this evolves if the basic assumptions of the system are violated. For example, it was assumed that the coal beds would be gently varying continuous surfaces. In fact, for this area there are many faults which have vertically displaced coal beds relative to the general trend of the basin. For this situation it was decided that each faulted block would be treated independently to minimize errors in our surface fitting. The known fault traces in the area were digitized and were used to identify faulted blocks.

The area that was covered by the available data was divided into three parts according to abrupt changes in geologic structure. The UTM coordinates for the divisions (Areas A, B, and C) are shown in figure 11. These data were then subdivided again by coal beds.

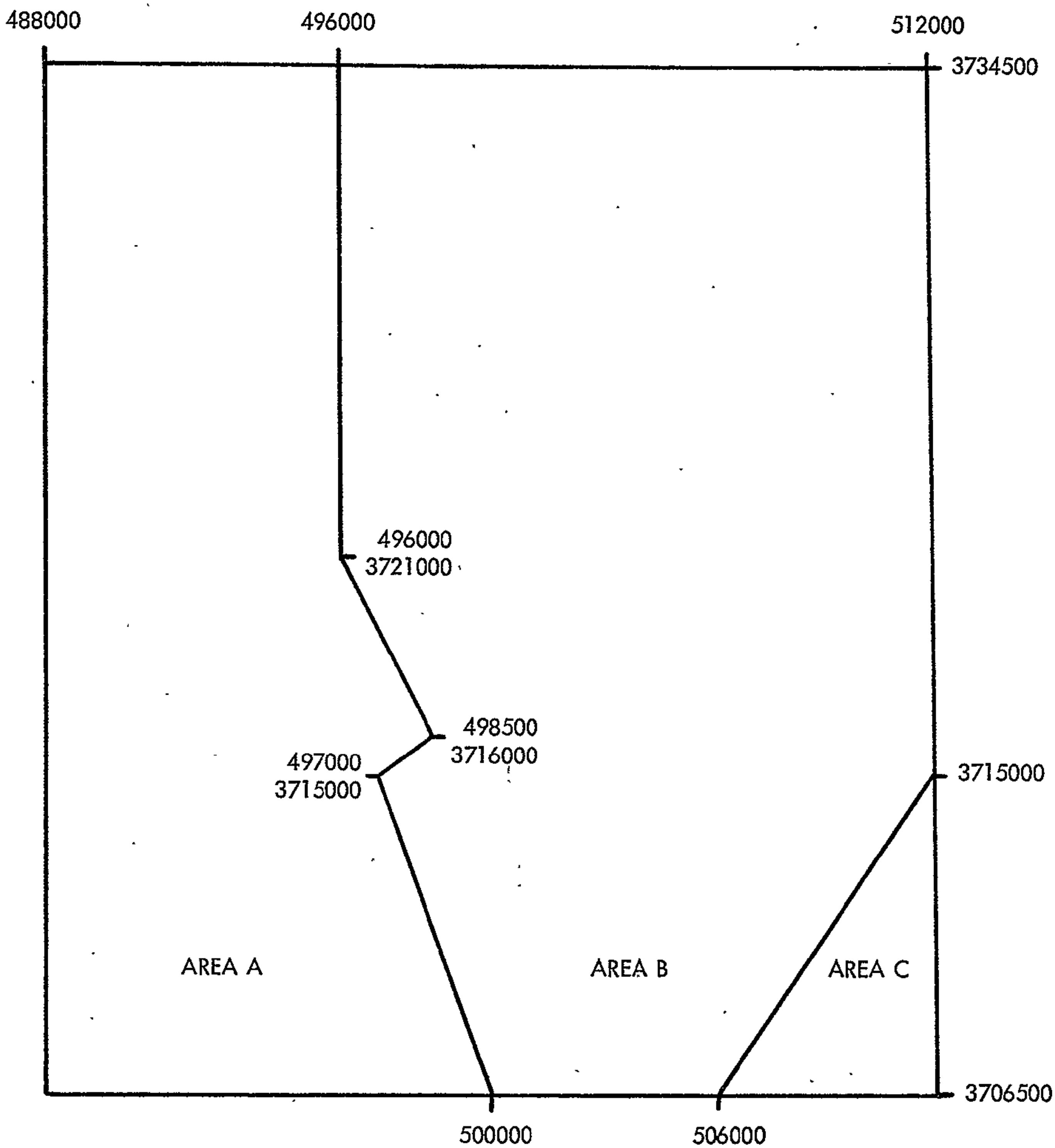

Figure 11.--Subareas defined by structural features.

The analysis of the data for each coal bed in each area was obtained by fitting a seventh order equation to the data. This equation is:

$$Z = C(1) + C(2)X + C(3)Y + C(4)X^2 + C(5)XY + C(6)Y^2 + C(7)X^3 + C(8)X^2Y$$
$$+ C(9)XY^2 + C(10)Y^3 + C(11)X^4 + C(12)X^3Y + C(13)X^2Y^2 + C(14)XY^3$$
$$+ C(15)Y^4 + C(16)X^5 + C(17)X^4Y + C(18)X^3Y^2 + C(19)X^2Y^3 + C(20)XY^4$$
$$+ C(21)Y^5 + C(22)X^6 + C(23)X^5Y + C(24)X^4Y^2 + C(25)X^3Y^3 + C(26)X^2Y^4$$
$$+ C(27)XY^5 + C(28)Y^6 + C(29)X^7 + C(30)X^6Y + C(31)X^5Y^2 + C(32)X^4Y^3$$
$$+ C(33)X^3Y^4 + C(34)X^2Y^5 + C(35)XY^6 + C(36)Y^7$$

where X and Y are the UTM coordinates in meters and Z is the dependent variable. The equation contains 36 parameters to be estimated, which requires a minimum of 37 data points. The goodness of fit of the predictions for this equation to the data is reflected in the coefficient of determination (square of the correlated coefficient), which is the percentage of variance in the data accounted for by the predicted surface. If the data were random, the coefficient of determination would be 0.0; if the surface matched exactly, the coefficient of determination would be 1.0. The coefficient for the equation and the coefficient of determination for each analysis are given in table 9 (included at the end of the report).

During the course of the project, it became obvious that existing core hole information was adequate for only the Pratt and Mary Lee coal beds. Estimates of strippable coal reserves could not be made for other coal beds in the study area because there was either an insufficient quantity of data or the data that existed occurred in non random clusters. The number of usable data points for each coal bed for all three areas is shown in table 10. Coal beds with insufficient data to allow an analysis are indicated by an asterisk.

Table 10.— Data points used, by coal seam

Coal bed name	Five digit code	Number of seam thickness data points	Number of elevation data points
Gwin	20700	0*	0*
Thompson Mill	20800	0*	0*
Upper Cobb	21700	0*	2*
Cobb	21801	0*	5*
Pratt	22702	53*	398
Nickel Plate	22803	9*	36*
American	22900	21*	45
Curry	23000	1*	1*
Gillespy	23100	1*	1*
New Castle	27800	15*	14*
Mary Lee	27903	156	220
Blue Creek	28000	6*	5*
Jagger	28100	9*	8*
Ream	28300	8*	7*
Lick Creek	29700	15*	13*
Jefferson	29800	13*	12*
Black Creek	29900	36*	24*

*Indicates insufficient data to fit seventh order equation.

Results

The computer modeling technique presented in this part of the study produced total strippable reserve estimates of 1,089,195,765 tons for the Pratt coal bed and 531,685,640 tons for the Mary Lee coal bed. Remaining strippable reserves were estimated to be 961,314,820 tons for the Pratt coal bed and 531,685,640 tons for the Mary Lee coal bed. Approximately 9 percent of the total strippable reserves lie under populated areas and were removed from consideration. Existing surface mines mapped by Landsat accounted for approximately 2 percent of the total strippable reserves and were subtracted from the reserves figures. Although these estimates are extremely high, it is felt that with further refinement and additional core hole data, this technique can be used to produce accurate estimates.

GENERAL PURPOSE CONTOURING PROGRAM

Utilization of coal drill hole data for the purpose of accumulating the amount of coal reserves in the Warrior basin is facilitated by the use of Georgia Tech's Cyber 74 and Calcomp's General Purpose Contouring Program (GPCP).

Basically, GPCP accepts two types of data spacing: 1) regularly spaced (gridded) or 2) irregularly spaced. For this application, irregularly spaced data, such as drill hole data, must contain at least three parameters:

(1) the UTM X-coordinates,

(2) the UTM Y-coordinates, and

(3) the "Z" value to be coordinated.

GPCP then uses the data to produce a contour surface approximation by the five closest data points to the specific grid position. In addition, GPCP produced a regularly spaced data grid as specified by the operator and limited only to the memory capacity of the computer. This grid provides the vehicle by which overlays of various data types (overburden and thickness) may be computed on a one-to-one basis.

The Pratt seam in the Adamsville quadrangle and the Mary Lee seam in the Sylvan Springs quadrangle were selected for presentation as examples of the application of the GCPC technique. The Mary Lee seam in the Sylvan Springs quadrangle has been mined by underground methods to some extent and the Pratt seam in the Adamsville quadrangle has been mined extensively by underground methods. The results of the GCPC analyses are shown on plates 16-23.

Within the Sylvan Springs quadrangle the distribution of points for thickness overburden and elevation data for the Mary Lee seam is fairly good. Within the

Adamsville quadrangle the distribution of points of overburden and elevation data is excellent, but the data for the Pratt coal seam thickness is localized. However, by including data from neighboring quadrangles for Pratt thickness in the GPCP analysis and assuming continuity for the Pratt thickness contour, the representation of the thickness contour is optimized.

GPCP produced, in addition to a surface contour, a grid of data approximating the surface interval of 200 meters in both X and Y directions. These grids are then overlaid in a one-to-one fashion to compare the relationship between thickness and overburden. The equation:

$$TH = (OVB/3.0)^{*}$$

where "TH" is the thickness (in inches) and "OVB" is overburden (in feet) is used to facilitate the relationship between coal reserves and coal resources. However, the drill hole overburden data is a poor approximation for the actual overburden. It represents the distance from the surface down to the coal seam only at the specified point but it is an inadequate approximation of the topographic relief. Therefore, high density TOPOCON** data are employed to represent an accurate expression of the topography. The coal surface elevation is then subtracted to represent the overburden, which allows estimation of coal reserves when overlaid with the thickness data.

* Deduced from table 2.

** TOPOCON terrain data is obtained from the National Cartographic Information Center which utilizes the Defense Mapping Agency Topographic Center's library of digital terrain tapes.

Results

Analysis of the data generated by the seventh order fit and the GPCP techniques indicated that GPCP was a more acceptable technique for surface modeling in the study area.

Due to numerous faults, the coal elevation surface exhibited discontinuities at several places within the area. The seventh order technique tends to smooth out these discontinuities and thus give an oversimplified surface expression of the coal beds. The seventh order technique also tended to smooth high frequency topographic data, and as a result, the coal reserve calculations using these data were overly optimistic.

However, the GPCP technique allowed the representation of high frequency spatial data by localized surface fitting. Topography, elevation, thickness, and overburden contours were generated using this technique.

Areas of extensive suburban development along U.S. Highway 78 in the Adamsville quadrangle and that part of Birmingham located southeast of the boundary of the Warrior coal field in the southeastern part of the quadrangle (pl. 20) were digitized and removed from consideration. The areas of the underground mines were subtracted from the computer derived estimates of reserves; however, due to incomplete underground mine data, the reserve figures presented are for demonstration purposes only. Cumulative coal reserves and resources for the Mary Lee seam in the Sylvan Springs quadrangle and the Pratt seam in the Adamsville quadrangle are shown in table 11.

Table 11.— Coal reserves,[1/] coal resources [2/] and volume of overburden for the Mary Lee seam in the Sylvan Springs quadrangle and the Pratt seam in the Adamsville quadrangle (Coal reserves and resources are expressed in tons and the volume of overburden is expressed in cubic yards.)

Mary Lee coal seam for Sylvan Springs quadrangle		Pratt coal seam for Adamsville quadrangle	
Reserves:		Reserves:	
Coal	62,007,944	Coal	64,038,192
Overburden	733,639,698	Overburden	709,866,784
Resources:		Resources:	
Coal	278,883,003	Coal	299,727,949
Overburden:	42,609,693,350	Overburden	19,636,720,950
Total:		Total:	
Coal	340,890,947	Coal	363,766,141
Overburden:	43,383,333,048	Overburden	20,346,587,734

1/ Reserve - That portion of the identified resource from which a usable mineral or energy commodity can be economically and legally extracted at the time of determination (U.S. Bureau of Mines and U.S. Geological Survey).

2/ Resource - A concentration of naturally occurring solid, liquid, or gaseous materials in or on the earth's crust in such a form that economic extraction of a commodity is currently or potentially feasible (U.S. Bureau of Mines and U.S. Geological Survey).

Conclusions

In summary, GPCP is more adapted to the evaluation of high frequency data than is the least squares fitting technique; hence, it was chosen to represent the coal surfaces.

Due to relative lack of data in the area of thickness, the estimations of coal reserves are inexact, but demonstrate the overwhelming potential for the technique for use in areas where coal reserve estimates are needed.

Plate Descriptions

Plate 16. Conventional structural contour map showing the configuration of the top of the Mary Lee coal seam in part of the Sylvan Springs quadrangle. Map provided by John Bensko NASA/MSFC for qualitative comparison to the computer generated data. Contour interval: 20 feet.

Plate 17. General Purpose Contouring Program (GPCP) contour map showing the configuration of the top of the Mary Lee coal seam in part of the Sylvan Springs quadrangle. Prepared from coal drill hole data.

Plate 18. GPCP isopach map of the Mary Lee coal seam in the Sylvan Springs quadrangle. Contour interval: 5 inches.

Plate 19. GPCP isopach map of the overburden overlying the Mary Lee coal seam in the Sylvan Springs quadrangle. Vertical control is from TOPOCON digital terrain tapes obtained from the National Cartographic Information Center. Contour interval: 50 feet.

Plate 20. Conventional structural contour map showing the configuration of the top of the Pratt coal seam in the Adamsville quadrangle. Map provided by John Bensko NASA/MSFC for qualitative comparison to the computer generated data. Fault displacements were interpreted from the contours and subsequently entered as control data for the GPCP program. The area of Birmingham southeast of the Warrior coal basin was not included in the calculations of coal reserves. Contour interval: 20 feet.

Plate 21. GPCP contour map showing the configuration of the top of the Pratt coal seam in the Adamsville quadrangle. Prepared from coal drill hole data. The computer derived contours generally follow the trends shown in plate 20 and indicate that with adequate drill hole data an automatic method may be used to approximate coal elevation contours in highly faulted areas. Contour interval: 25 feet.

Plate 22. GPCP isopach map of the Pratt coal seam in the Adamsville quadrangle. Thickness data were compiled in part from adjoining quadrangles. Contour interval: 2.5 inches.

Plate 23. GPCP isopach map of the overburden overlying the Pratt coal seam in the Adamsville quadrangle. Vertical control is from TOPOCON digital terrain tapes obtained from the National Cartographic Information Center. Contour interval: 50 feet.

TABLE 9 – STATISTICS AND COEFFICIENTS FOR EACH ANALYSIS

OVERBURDEN MARY LEE AREA A

TOTAL VARIATION	5171304.965516	
MEAN	189.517241	
VARIATION NOT EXPLAINED BY SURFACE	1642776.352844	
VARIATION EXPLAINED BY SURFACE	3528528.612673	
COEFFICIENT OF DETERMINATION	.682328	
COEFFICIENT OF CORRELATION	.826032	
STANDARD DEVIATION	119.003635	
F – RATIO	4.713460	WITH 36 AND 79 DEGREES

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COEFFICIENTS

C(1) = .345000743E+07	C(2) = .104905115E+02	C(3) = -.405298395E+01
C(4) = -.270339889E-04	C(5) = -.218718298E-04	C(6) = .935856412E-06
C(7) = -.163267009E-08	C(8) = -.634403772E-11	C(9) = .630219043E-12
C(10) = -.988857992E-12	C(11) = .859040681E-15	C(12) = -.579543480E-16
C(13) = -.825165806E-18	C(14) = -.772228120E-18	C(15) = -.112235161E-16
C(16) = .199832340E-21	C(17) = -.304807785E-21	C(18) = .402191804E-22
C(19) = -.427479638E-23	C(20) = .106616734E-23	C(21) = .795419863E-25
C(22) = .468612953E-26	C(23) = -.265706544E-27	C(24) = -.131568755E-27
C(25) = -.970121914E-29	C(26) = -.198720364E-29	C(27) = .168139137E-30
C(28) = .205299273E-31	C(29) = -.115905104E-31	C(30) = -.143988846E-32
C(31) = -.166069892E-33	C(32) = -.267327242E-35	C(33) = .595737182E-36
C(34) = .340776039E-36	C(35) = .363231417E-37	C(36) = -.266164837E-38

TABLE 9 - Continued OVERBURDEN MARYLEE AREA B

TOTAL VARIATION	3162189.037037
MEAN	311.407407
VARIATION NOT EXPLAINED BY SURFACE	392483.640215
VARIATION EXPLAINED BY SURFACE	2769705.396822
COEFFICIENT OF DETERMINATION	.875882
COEFFICIENT OF CORRELATION	.935886
STANDARD DEVIATION	85.253830
F - RATIO	3.332410 WITH 34 AND 17 DEGREES

COEFFICIENTS

C(1) = .340659000E+08	C(2) = -.373339692E+03	C(3) = .189618271E+02
C(4) = -.171793147E-02	C(5) = -.201434769E-03	C(6) = .432082686E-04
C(7) = .483446023E-09	C(8) = -.121061760E-08	C(9) = -.152610399E-09
C(10) = .160349578E-10	C(11) = -.914103493E-14	C(12) = .289059584E-15
C(13) = -.145129850E-16	C(14) = -.283981938E-17	C(15) = .278866749E-15
C(16) = .102209469E-20	C(17) = .145000756E-20	C(18) = .137003384E-21
C(19) = .789803282E-22	C(20) = .353068182E-23	C(21) = -.407986876E-24
C(22) = .322542525E-25	C(23) = -.113208396E-26	C(24) = .174740673E-28
C(25) = .839241788E-28	C(26) = -.271746698E-28	C(27) = -.216838125E-29
C(28) = .191262323E-30	C(29) = -.175695608E-31	C(30) = .724427749E-32
C(31) = .138393741E-32	C(32) = .152023351E-33	C(33) = .143914061E-34
C(34) = .968094124E-36	C(35) = .617793986E-37	C(36) = .378057593E-37

OVERBURDEN MARYLEE AREA C

TABLE 9 - Continued

TOTAL VARIATION	4984211.744681
MEAN	576.489362
VARIATION NOT EXPLAINED BY SURFACE	77873.526007
VARIATION EXPLAINED BY SURFACE	420548.218674
COEFFICIENT OF DETERMINATION	.843760
COEFFICIENT OF CORRELATION	.918564
STANDARD DEVIATION	40.704834
F - RATIO	1.500111 WITH 36 AND 10 DEGREES

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COEFFICIENTS

C(1) = -.131670140E+08	C(2) = -.170580573E+01	C(3) = .104421585E+02
C(4) = .212505933E-04	C(5) = -.115550610E-04	C(6) = .790522825E-06
C(7) = .102699791E-08	C(8) = .549872360E-10	C(9) = .334085186E-11
C(10) = .190042851E-13	C(11) = -.902538811E-15	C(12) = -.196615996E-15
C(13) = -.642242674E-18	C(14) = .979243950E-19	C(15) = -.123522083E-16
C(16) = -.239304404E-20	C(17) = .262176884E-21	C(18) = -.216964749E-22
C(19) = -.127236345E-23	C(20) = .431706122E-24	C(21) = .330196451E-25
C(22) = .774011897E-27	C(23) = -.330445040E-27	C(24) = -.897396640E-28
C(25) = -.141465247E-29	C(26) = -.459744383E-30	C(27) = -.173726608E-30
C(28) = -.310883744E-31	C(29) = .456602510E-32	C(30) = -.402102547E-34
C(31) = -.116362824E-34	C(32) = -.346117332E-35	C(33) = .100833785E-35
C(34) = .228205600E-36	C(35) = .502614330E-37	C(36) = .652300433E-39

COAL ELEVATION MARY LEE AREA A

TABLE 9 - Continued

TOTAL VARIATION	3826321.887930
MEAN	160.836207
VARIATION NOT EXPLAINED BY SURFACE	1001439.344382
VARIATION EXPLAINED BY SURFACE	2824882.543548
COEFFICIENT OF DETERMINATION	.738276
COEFFICIENT OF CORRELATION	.859230
STANDARD DEVIATION	92.914465
F - RATIO	6.190138 WITH 36 AND 79 DEGREES

COEFFICIENTS

C(1) = -.403474719E+07	C(2) = -.954064313E+01	C(3) = .321717096E+01
C(4) = .121163355E-04	C(5) = .153658231E-04	C(6) = -.711441956E-06
C(7) = .122346266E-08	C(8) = .467560619E-11	C(9) = .235498237E-12
C(10) = .746149909E-12	C(11) = -.569622182E-15	C(12) = .377081848E-16
C(13) = .466587430E-18	C(14) = .580911784E-18	C(15) = .955568065E-17
C(16) = -.267182971E-21	C(17) = .259219386E-21	C(18) = -.334022570E-22
C(19) = .317217208E-23	C(20) = -.808814645E-24	C(21) = -.538419202E-25
C(22) = -.345231299E-26	C(23) = .218473545E-27	C(24) = .102646005E-27
C(25) = .697591229E-29	C(26) = .144562903E-29	C(27) = -.125853186E-30
C(28) = -.170823594E-31	C(29) = .953662316E-32	C(30) = .114876031E-32
C(31) = .116731765E-33	C(32) = .274964048E-35	C(33) = -.260544684E-36
C(34) = -.258898021E-36	C(35) = -.245447119E-37	C(36) = .187118953E-38

TABLE 9 – Continued : COAL ELEVATION MARYLEE AREA B

TOTAL VARIATION	2882244.759259
MEAN	111.796296
VARIATION NOT EXPLAINED BY SURFACE	651932.407481
VARIATION EXPLAINED BY SURFACE	2230312.351778
COEFFICIENT OF DETERMINATION	.773811
COEFFICIENT OF CORRELATION	.879665
STANDARD DEVIATION	109.876396
F – RATIO	1.615510 WITH 36 AND 17 DEGREES

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COEFFICIENTS

C(1) = -.650382851E+08	C(2) = .649200094E+03	C(3) = .299369131E+02
C(4) = .317396233E-02	C(5) = .365027821E-03	C(6) = -.797256007E-04
C(7) = -.906842030E-09	C(8) = .220520146E-08	C(9) = .277835397E-09
C(10) = -.293303221E-10	C(11) = .168056377E-13	C(12) = -.512132217E-15
C(13) = .259891839E-16	C(14) = .521177515E-17	C(15) = -.513425373E-15
C(16) = -.127054045E-20	C(17) = -.260514950E-20	C(18) = -.241285479E-21
C(19) = -.144291641E-21	C(20) = -.652879724E-23	C(21) = .749152248E-24
C(22) = -.596554626E-25	C(23) = .220510385E-26	C(24) = -.312927075E-28
C(25) = .152643634E-27	C(26) = .493126860E-28	C(27) = .396088944E-29
C(28) = -.348285615E-30	C(29) = .337274274E-31	C(30) = -.130133276E-31
C(31) = -.252412583E-32	C(32) = -.279679613E-33	C(33) = -.260660276E-34
C(34) = -.177061227E-35	C(35) = -.100700151E-36	C(36) = -.678498783E-37

COAL ELEVATION MARYLEE AREA C

TABLE 9 - Continued

TOTAL VARIATION	510136.638298
MEAN	11.170213
VARIATION NOT EXPLAINED BY SURFACE	17937.475331
VARIATION EXPLAINED BY SURFACE	492199.162967
COEFFICIENT OF DETERMINATION	.964838
COEFFICIENT OF CORRELATION	.982262
STANDARD DEVIATION	19.535824
F - RATIO	7.622142 WITH 36 AND 10 DEGREES

COEFFICIENTS

C(1) = .142717697E+07	C(2) = -.419285734E+00	C(3) = -.339400446E+01
C(4) = -.376626124E-05	C(5) = .466551129E-05	C(6) = -.209034080E-06
C(7) = -.274210101E-09	C(8) = -.190805132E-10	C(9) = -.714993170E-12
C(10) = -.435423941E-13	C(11) = .220848045E-15	C(12) = .695519625E-16
C(13) = -.119572023E-20	C(14) = -.255762290E-19	C(15) = .286724706E-17
C(16) = .725886258E-21	C(17) = -.832705676E-22	C(18) = .691100397E-24
C(19) = .330468577E-24	C(20) = -.191773429E-24	C(21) = -.148149137E-25
C(22) = .147822210E-27	C(23) = .541318093E-28	C(24) = .319018690E-28
C(25) = .278670395E-30	C(26) = -.150405141E-31	C(27) = .515117163E-31
C(28) = .968839097E-32	C(29) = -.137172272E-32	C(30) = .126775107E-36
C(31) = -.824871872E-35	C(32) = .161382100E-35	C(33) = -.175275172E-36
C(34) = -.859521237E-37	C(35) = -.175137193E-37	C(36) = -.451733753E-39

TABLE 9 - Continued

TOTAL VARIATION	22320.168675
MEAN	55.265060
VARIATION NOT EXPLAINED BY SURFACE	19655.177190
VARIATION EXPLAINED BY SURFACE	2664.991485
COEFFICIENT OF DETERMINATION	.119398
COEFFICIENT OF CORRELATION	.345541
STANDARD DEVIATION	15.388611
F - RATIO	.173250 WITH 36 AND 46 DEGREES

COEFFICIENTS

C(1) = -.669315485E+08	C(2) = -.157438013E+03	C(3) = -.260649950E+02
C(4) = .402483176E-03	C(5) = .299070501E-04	C(6) = .350567064E-05
C(7) = -.131789994E-08	C(8) = .824034065E-10	C(9) = -.234924783E-11
C(10) = -.126070740E-11	C(11) = .189576600E-14	C(12) = -.535887204E-15
C(13) = -.544983804E-17	C(14) = -.691583121E-19	C(15) = .675811077E-16
C(16) = -.469645688E-20	C(17) = -.611411147E-21	C(18) = -.242409730E-21
C(19) = .309227240E-22	C(20) = .477643808E-24	C(21) = .903649609E-25
C(22) = -.682519279E-26	C(23) = -.102146264E-26	C(24) = .269675640E-27
C(25) = -.201003458E-28	C(26) = .158033786E-29	C(27) = .452259569E-30
C(28) = -.495061780E-31	C(29) = .176524852E-31	C(30) = .182971439E-32
C(31) = -.510328164E-33	C(32) = .877251834E-35	C(33) = .101678877E-34
C(34) = .332157383E-36	C(35) = -.355266216E-37	C(36) = -.184690816E-37

SEAM THICKNESS W/O PARTINGS · MARY LEE AREA B

TABLE 9 – Continued

TOTAL VARIATION	22700.652778
MEAN	46.069444
VARIATION NOT EXPLAINED BY SURFACE	11131.508791
VARIATION EXPLAINED BY SURFACE	11569.143987
COEFFICIENT OF DETERMINATION	.509639
COEFFICIENT OF CORRELATION	.713890
STANDARD DEVIATION	12.433997
F - RATIO	1.010445 WITH 36 AND 35 DEGREES

COEFFICIENTS

C(1) = -.246074997E+07	C(2) = -.289491966E+02	C(3) = .509269555E+00
C(4) = -.109130521E-04	C(5) = .340757427E-06	C(6) = -.667722162E-06
C(7) = -.180069522E-09	C(8) = .106278789E-10	C(9) = .840031605E-11
C(10) = .315488882E-12	C(11) = .663736015E-15	C(12) = -.290659150E-16
C(13) = -.102388723E-17	C(14) = .110986568E-18	C(15) = .611640530E-19
C(16) = -.581923731E-21	C(17) = .100827217E-21	C(18) = -.250876783E-22
C(19) = .118184246E-23	C(20) = .174134448E-24	C(21) = .128537773E-24
C(22) = .432207251E-27	C(23) = -.174440517E-27	C(24) = .904238481E-29
C(25) = .600170791E-29	C(26) = -.721347232E-30	C(27) = .686012282E-31
C(28) = .506265584E-32	C(29) = .142669245E-32	C(30) = .934208246E-33
C(31) = .943180203E-34	C(32) = -.481462087E-35	C(33) = .246409297E-35
C(34) = .222645383E-36	C(35) = -.880460002E-38	C(36) = -.462353426E-38

TABLE 9 - Continued OVERBURDEN AMERICA AREA A

TOTAL VARIATION	373710.975000
MEAN	69.775000
VARIATION NOT EXPLAINED BY SURFACE	140732.835167
VARIATION EXPLAINED BY SURFACE	232978.139833
COEFFICIENT OF DETERMINATION	.623418
COEFFICIENT OF CORRELATION	.789568
STANDARD DEVIATION	59.315435
F - RATIO	.137955 WITH 36 AND 3 DEGREES

COEFFICIENTS

C(1) = .326271288E+07	C(2) = -.626548972E+02	C(3) = -.156615618E+02
C(4) = .173259706E-03	C(5) = .172886220E-04	C(6) = .207447887E-05
C(7) = -.115879553E-09	C(8) = .863805253E-10	C(9) = -.723013461E-11
C(10) = .671964529E-12	C(11) = .852407164E-16	C(12) = -.628474354E-16
C(13) = -.470283206E-18	C(14) = -.637815372E-20	C(15) = .255976651E-17
C(16) = -.680141649E-21	C(17) = -.221519891E-21	C(18) = .858749033E-23
C(19) = -.277813885E-23	C(20) = -.238408135E-25	C(21) = .250699416E-25
C(22) = .231390546E-26	C(23) = .399952354E-27	C(24) = .453306863E-28
C(25) = .478715465E-29	C(26) = .698613292E-30	C(27) = -.190267848E-31
C(28) = .443591125E-32	C(29) = .211527420E-32	C(30) = .112137900E-32
C(31) = -.447244696E-34	C(32) = -.240007778E-34	C(33) = -.155983295E-35
C(34) = .699484869E-37	C(35) = -.330162725E-37	C(36) = -.290593819E-38

TABLE 9 - Continued COAL ELEVATION AMERICA AREA A

TOTAL VARIATION	130347.975000
MEAN	321.475000
VARIATION NOT EXPLAINED BY SURFACE	20114.788961
VARIATION EXPLAINED BY SURFACE	110233.186039
COEFFICIENT OF DETERMINATION	.845684
COEFFICIENT OF CORRELATION	.919611
STANDARD DEVIATION	22.424757
F - RATIO	.456684 WITH 36 AND 3 DEGREES

COEFFICIENTS

C(1) =	.475671892E+07	C(2) =	-.687382915E+01	C(3) =	.697132304E+01
C(4) =	-.130802383E-03	C(5) =	-.714842404E-05	C(6) =	-.114262588E-05
C(7) =	.739461109E-10	C(8) =	-.746482905E-10	C(9) =	.431021560E-11
C(10) =	-.198765896E-12	C(11) =	.452031653E-16	C(12) =	.278437751E-16
C(13) =	.497237698E-19	C(14) =	-.694080451E-19	C(15) =	.741809965E-17
C(16) =	.540035509E-21	C(17) =	.270536935E-21	C(18) =	-.321442991E-23
C(19) =	.145755347E-23	C(20) =	.118383745E-24	C(21) =	-.191119493E-25
C(22) =	-.159563487E-26	C(23) =	-.215072733E-27	C(24) =	-.432036767E-28
C(25) =	-.239784721E-29	C(26) =	-.427703361E-30	C(27) =	.44886618[illegible]E-31
C(28) =	-.384620620E-32	C(29) =	-.262246733E-32	C(30) =	-.883051110E-33
C(31) =	.804964835E-34	C(32) =	.124101518E-34	C(33) =	.938857376E-36
C(34) =	.991951781E-37	C(35) =	.146288466E-37	C(36) =	-.398992856E-39

TABLE 9 - Continued

COAL ELEVATION PRATT AREA A

TOTAL VARIATION	1161558.194690
MEAN	258.522124
VARIATION NOT EXPLAINED BY SURFACE	122160.836425
VARIATION EXPLAINED BY SURFACE	1039397.358266
COEFFICIENT OF DETERMINATION	.894830
COEFFICIENT OF CORRELATION	.945955
STANDARD DEVIATION	32.879619
F - RATIO	17.962249 WITH 36 AND 76 DEGREES

COEFFICIENTS

C(1) = -.126420589E+07	C(2) = .194665746E+03	C(3) = .307851974E+02
C(4) = .496215929E-03	C(5) = -.285865284E-05	C(6) = -.415329274E-05
C(7) = -.119943485E-08	C(8) = -.349544914E-10	C(9) = .472471469E-12
C(10) = -.640353478E-12	C(11) = .986189634E-15	C(12) = .195783354E-15
C(13) = .944364528E-18	C(14) = .677554218E-18	C(15) = -.209396803E-16
C(16) = -.196505294E-20	C(17) = -.594233271E-21	C(18) = .449940093E-22
C(19) = -.609904215E-24	C(20) = -.339643495E-24	C(21) = .699424215E-25
C(22) = -.237630929E-26	C(23) = .830665827E-27	C(24) = -.126587149E-27
C(25) = -.260003430E-28	C(26) = .385956709E-30	C(27) = .233871993E-30
C(28) = .176167782E-31	C(29) = .521831768E-32	C(30) = -.164287162E-32
C(31) = -.225239603E-34	C(32) = .536944256E-34	C(33) = .460179435E-35
C(34) = -.478206183E-37	C(35) = -.103412715E-37	C(36) = .209566611E-38

TABLE 9 - Continued

COAL ELEVATION PRATT AREA B

TOTAL VARIATION	1116495.625468
MEAN	317.962547
VARIATION NOT EXPLAINED BY SURFACE	274952.131786
VARIATION EXPLAINED BY SURFACE	841543.493682
COEFFICIENT OF DETERMINATION	.753736
COEFFICIENT OF CORRELATION	.868180
STANDARD DEVIATION	32.090236
F - RATIO	19.554414 WITH 36 AND 230 DEGREES

COEFFICIENTS

C(1) = .130513351E+06	C(2) = -.847186433E+00	C(3) = -.132888920E+01
C(4) = .199697518E-04	C(5) = -.317556075E-05	C(6) = -.806108119E-06
C(7) = -.486157716E-10	C(8) = -.481291378E-11	C(9) = -.609072262E-12
C(10) = .122556935E-12	C(11) = -.109575641E-15	C(12) = .225621006E-16
C(13) = .170063179E-18	C(14) = .425872308E-19	C(15) = .242686900E-17
C(16) = .617912922E-21	C(17) = -.199769753E-22	C(18) = -.271940188E-26
C(19) = .343822557E-24	C(20) = -.643358772E-25	C(21) = -.205231004E-25
C(22) = -.858994688E-27	C(23) = .219558075E-28	C(24) = .126561694E-28
C(25) = .409780273E-30	C(26) = .261321910E-30	C(27) = .618299091E-31
C(28) = -.117436475E-32	C(29) = -.288280543E-34	C(30) = -.197192389E-33
C(31) = -.237806390E-34	C(32) = .168351775E-35	C(33) = -.140038732E-36
C(34) = -.368082305E-37	C(35) = .130450239E-37	C(36) = .114698036E-38

SEAM THICKNESS W/O PARTINGS PRATT ALL AREAS

TABLE 9 - Continued

TOTAL VARIATION	3130.679245
MEAN	31.603774
VARIATION NOT EXPLAINED BY SURFACE	1454.337163
VARIATION EXPLAINED BY SURFACE	1676.342082
COEFFICIENT OF DETERMINATION	.535456
COEFFICIENT OF CORRELATION	.731749
STANDARD DEVIATION	5.238351
F - RATIO	.512289 WITH 36 AND 16 DEGREES

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COEFFICIENTS

C(1) = .986756435E+06	C(2) = .486807110E+01	C(3) = .617322281E+00
C(4) = -.938990021E-05	C(5) = .732190389E-06	C(6) = .317490114E-06
C(7) = -.237024717E-10	C(8) = -.310976806E-11	C(9) = -.260000906E-12
C(10) = .430582820E-14	C(11) = -.374125730E-16	C(12) = -.956054939E-17
C(13) = .862725533E-19	C(14) = -.218606298E-19	C(15) = -.838358689E-18
C(16) = .129815417E-22	C(17) = -.739154666E-23	C(18) = .240058706E-23
C(19) = -.952852068E-25	C(20) = .187713989E-25	C(21) = -.153721649E-26
C(22) = .201441928E-27	C(23) = .459542197E-28	C(24) = .258630341E-29
C(25) = .842275706E-31	C(26) = -.381381018E-31	C(27) = -.200678719E-32
C(28) = -.139545739E-33	C(29) = .122744111E-33	C(30) = .775244832E-34
C(31) = .957126035E-35	C(32) = .771406537E-36	C(33) = -.510238929E-37
C(34) = -.265600654E-37	C(35) = -.441103973E-38	C(36) = -.334125004E-39

TABLE 9 - Continued

OVERBURDEN PRATT AREA 8

TOTAL VARIATION	4817372.411983
MEAN	208.464419
VARIATION NOT EXPLAINED BY SURFACE	1551162.159228
VARIATION EXPLAINED BY SURFACE	3266210.252756
COEFFICIENT OF DETERMINATION	.678007
COEFFICIENT OF CORRELATION	.823412
STANDARD DEVIATION	76.220707
F - RATIO	13.452787 WITH 36 AND 230 DEGREES

COEFFICIENTS

C(1) =	-.575692877E+06	C(2) =	-.125409705E+02	C(3) =	-.223712410E+01
C(4) =	.913418287E-05	C(5) =	-.193244282E-05	C(6) =	.127658264E-06
C(7) =	.231810394E-10	C(8) =	-.347038363E-11	C(9) =	-.141196062E-11
C(10) =	.305528396E-12	C(11) =	-.204373003E-15	C(12) =	.980484429E-17
C(13) =	.896585801E-19	C(14) =	.112154313E-19	C(15) =	.387777147E-17
C(16) =	.358198879E-21	C(17) =	.616059570E-23	C(18) =	-.255005742E-23
C(19) =	-.295228783E-24	C(20) =	.467295954E-26	C(21) =	-.163068865E-25
C(22) =	-.360383433E-28	C(23) =	.670672450E-29	C(24) =	.763375527E-29
C(25) =	.190761424E-29	C(26) =	.338007977E-30	C(27) =	.209379801E-31
C(28) =	.786672747E-33	C(29) =	-.833410487E-33	C(30) =	-.177718278E-33
C(31) =	.190407206E-35	C(32) =	.173689475E-35	C(33) =	-.305665113E-36
C(34) =	.292159202E-37	C(35) =	.134044187E-37	C(36) =	.122971121E-38

COMPARISON OF MANUAL AND COMPUTER METHODS

By Donald D. Russell

Two methods for computing strippable coal reserves have been demonstrated in this project. The first involves manual computation of coal data which have been plotted on a series of maps showing coal thickness, overburden thickness, and surface and underground mining activities. To determine areas which could be economically surface mined, a ratio which compared the overburden isopach to the coal isopach was used. Using remotely sensed data collected from low- and high-altitude aircraft, a surface mine inventory was conducted so that these areas could be excluded from the reserve estimates. Similar data were included for underground mines shallower than 300 feet. Since approximately 40 percent of the coal is left in underground mines in the form of pillars and walls, that figure was used to determine the remaining strippable reserves. All this information was then compiled and estimates of strippable coal reserves were made for an area composed of four 7.5-minute topographic quadrangles.

The second method employed in this study involved the manipulation by computer of a number of variables relating to coal resources. In an effort to produce the most accurate reserve estimates, two separate computer programs were developed and tested. Both techniques used core data consisting of coal and overburden thicknesses, number of seams, and thickness of partings), data on underground mines shallower than 300 feet, and locations of housing or other areas to be excluded.

The Least Squares Fitting Technique was developed based on the assumption that the coal surface under study was a gently varying continuous surface and that adequate, randomly spaced core hole information was available. During the course of the project, both assumptions were violated to the extent that little reliance could be placed on the reserve estimates derived.

To remedy these problems, the General Purpose Contouring Program, developed by Calcomp, was employed. This technique used the available data much more efficiently and produced considerably more accurate strippable reserve estimates than the preceding technique. Of the two programs tested, it is felt that the GPCP demonstrated the greatest potential for future implementation.

Both the manual method and the computer methods used essentially the same basic types of data from similar sources. The primary differences occur in how the data are manipulated to produce the reserve estimates. It was found that fairly accurate generalizations, based on general knowledge of the study area could be applied in the manual method to fill in gaps in the basic data. However, the computer techniques employed require precise point data which could not be generalized. As a result, it will be difficult to use these methods accurately until the required data become available. Conversely, the manual method essentially requires a completely new study each time an update is required. Once either computer technique is established, it would only be necessary to add new data for a complete or partial update.

Because the first study area was sparsely populated, urban areas did not pose a problem in the manual computation of strippable coal reserves. The second study area, however, contained many areas which cannot be legally mined because they are fairly heavily urbanized. It was found that these areas could easily and quickly be removed from consideration by computer processing; using the manual method would have required a great deal more time. Areas of underground mining that required careful and laborious measurements in the manual method were easily accounted for in the computer method. Therefore, in a long term application, the computer method would be more efficient and less costly. In addition to these advantages, it would be a fairly simple process to input additional data into either program to analyze other aspects of surface mining. For example, either program could be modified to include data on the cost of road repair versus the volume of coal mined so that more efficient use of funds for repairs could be made.

In summary, each method has its advantages and disadvantages. Whereas the manual method requires data which can be generalized to a certain extent, the computerized method requires adequate and precise data which may or may not be available. The computerized method can be easily modified to analyze data on coal resources and extraction which would require a separate study using the manual method. Generally, the manual method is less expensive to set up, but the computer method will cost less in long term application. Sparse data on the geological structure in a given area will not noticeably affect the manual computation, but it has a very noticeable effect on computerized results. This problem makes the manual method universally applicable, whereas the computer method would have to be modified on a quadrangle by quadrangle basis to account for regional changes in structure.

Generally, if further development of the computer methods demonstrated in this project shows that accurate results can be obtained from these techniques, these methods would be preferable in a long term application. They would result in savings of both time and manpower and provide a system to which modifications can easily be made for the analysis of additional new types of data.

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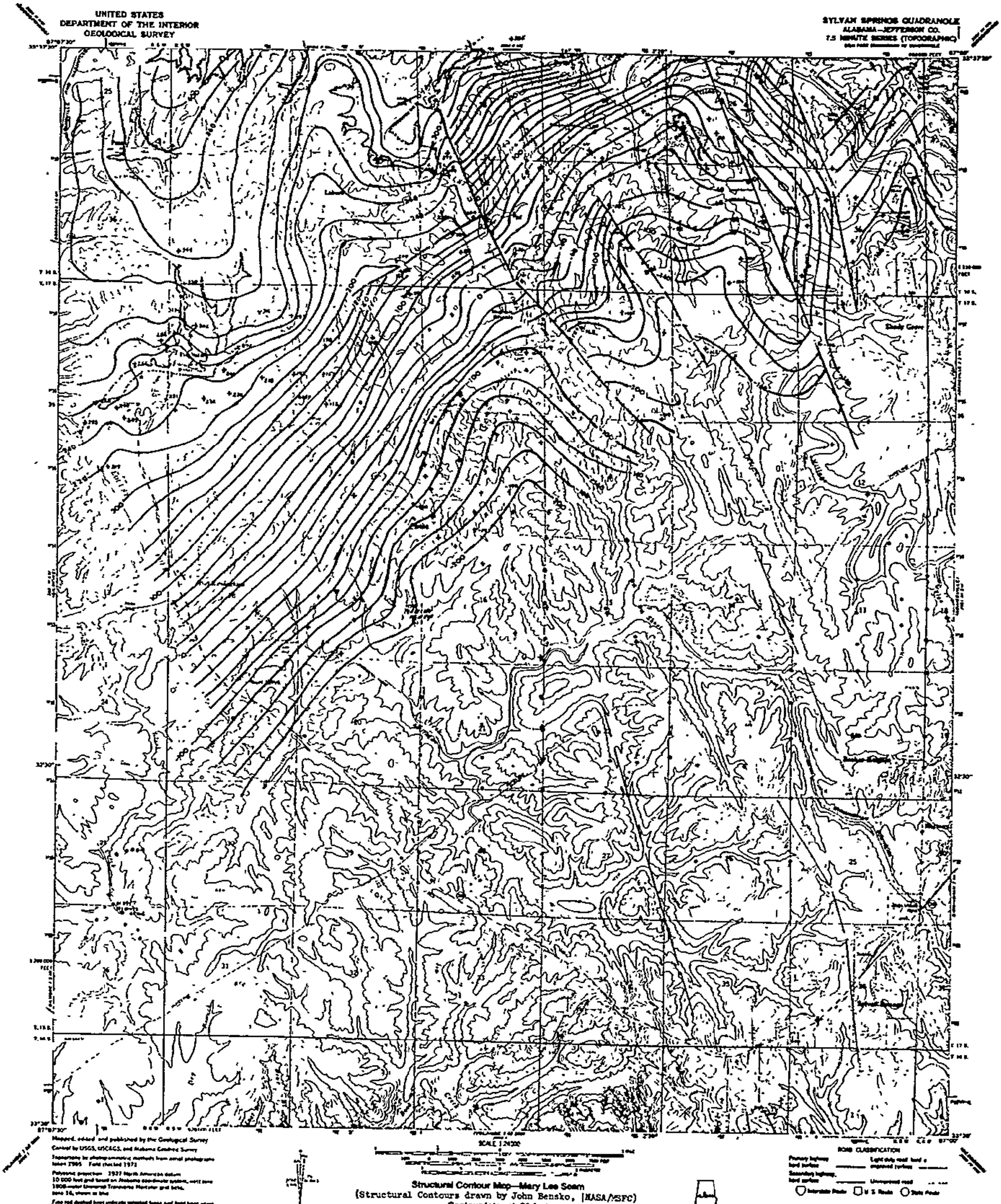

Structural Contour Map—Mary Lee Seam
(Structural Contours drawn by John Bensko, NASA/MSFC)
Contour Interval 20 feet
Datum Mean Sea Level

Prepared by the Engineering Experiment Station, Georgia Institute of Technology for the National Aeronautics and Space Administration, Marshall Space Flight Center

By Nicholas L. Faust, G. David Gentry, Michael D. Furman

Plate 16


489000m
500000m
SYLVAN SPRINGS QUAD
MARYLEE ELEVATION
3720000m
3707000m
489000m
GPCP Contour Map—Mary Lee Seam
Contour Interval 25 feet
Datum Mean Sea Level
Prepared by the Engineering Experiment Station, Georgia Institute of Technology for the National Aeronautics and Space Administration, Marshall Space Flight Center
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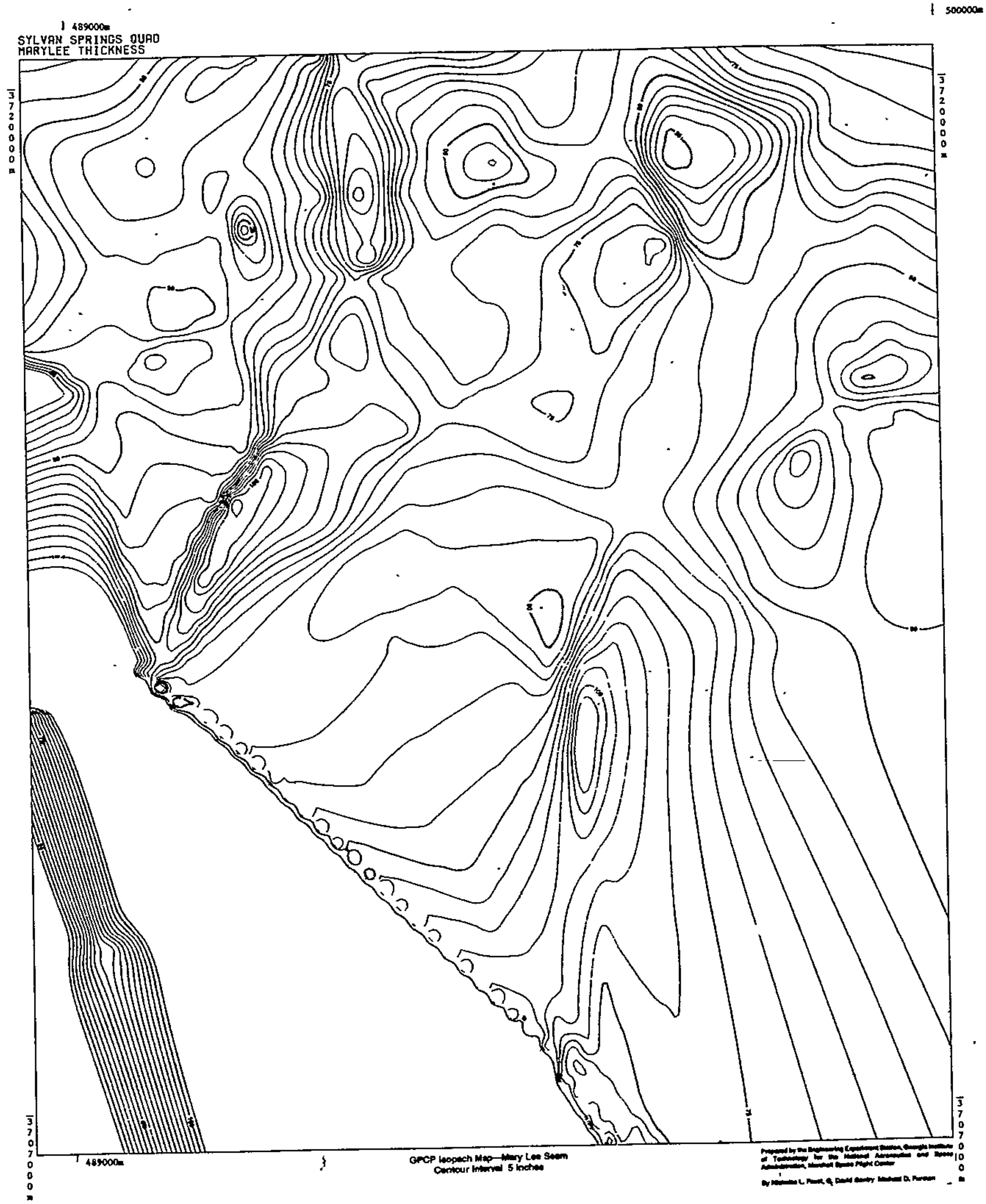
Plate 17



489000m
SYLVAN SPRINGS QUAD
MARYLEE THICKNESS
500000m
3720000m
3707000m
489000m
GPCP Isopach Map—Mary Lee Seam
Contour Interval 5 inches

Plate 18

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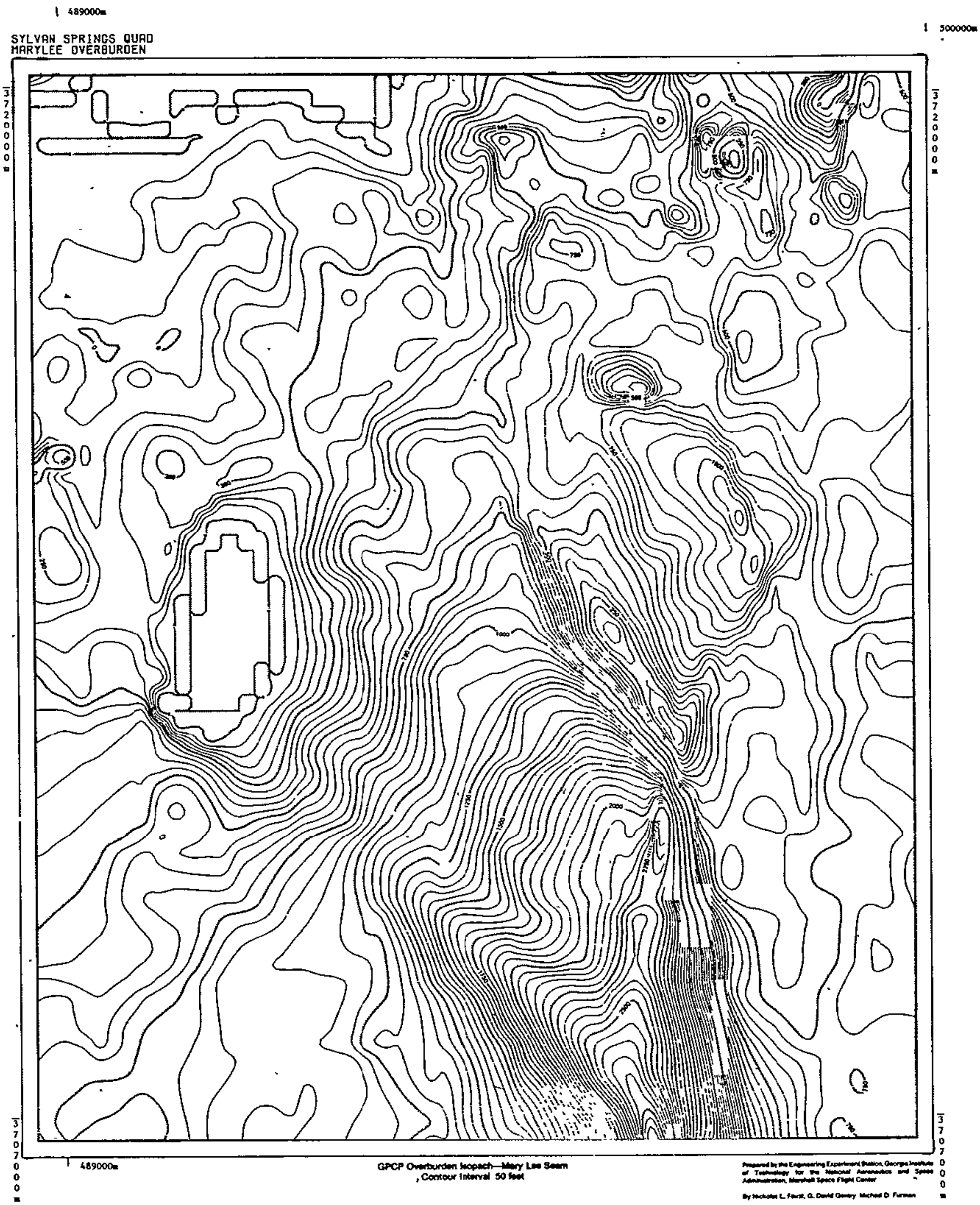
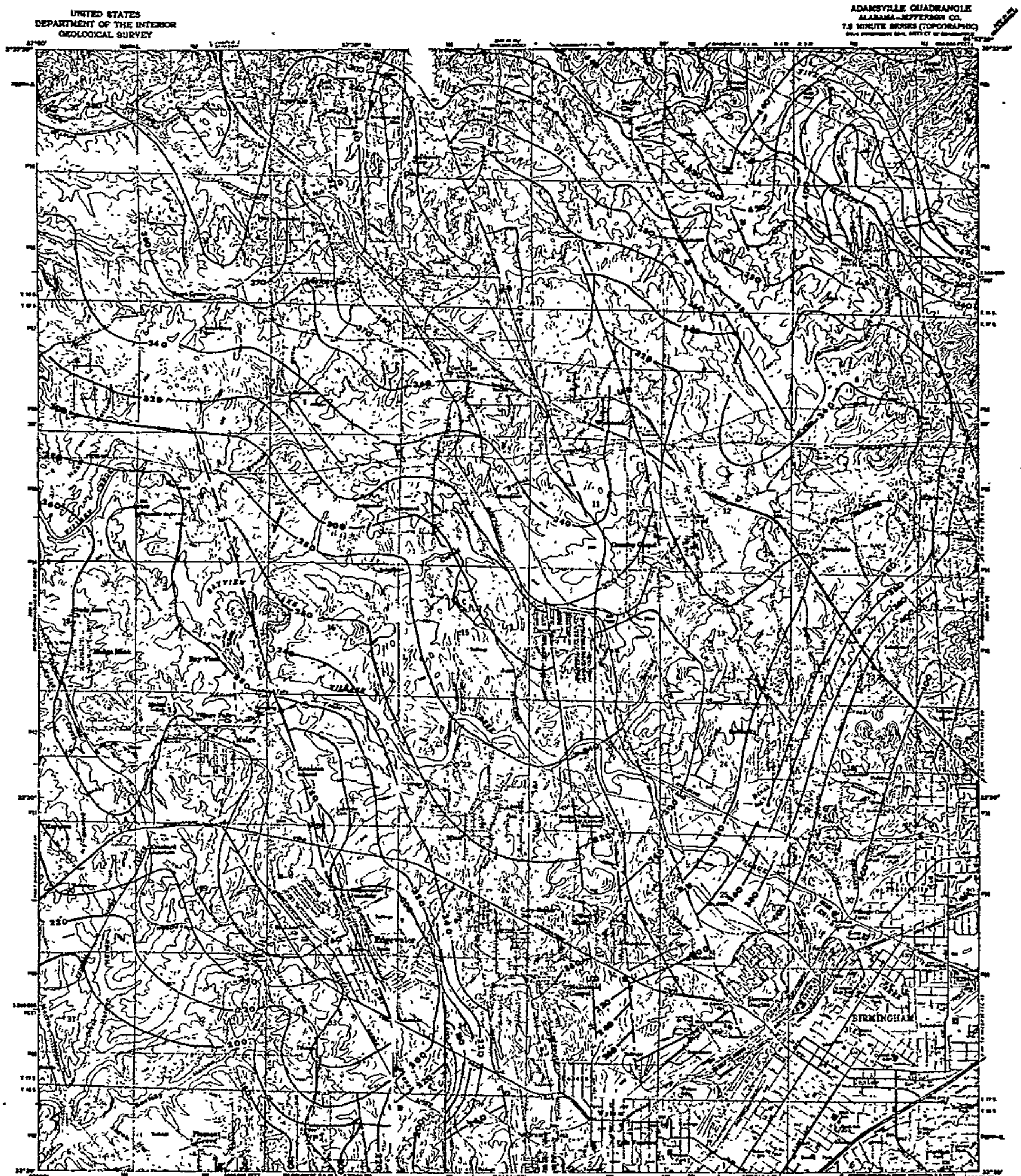


Plate 19



Structural Contour Map—Pratt Seam
(Structural Contours drawn by John Bensko, NASA/MSFC)
Contour Interval: 20 feet
Datum: Mean Sea Level

Plate 20

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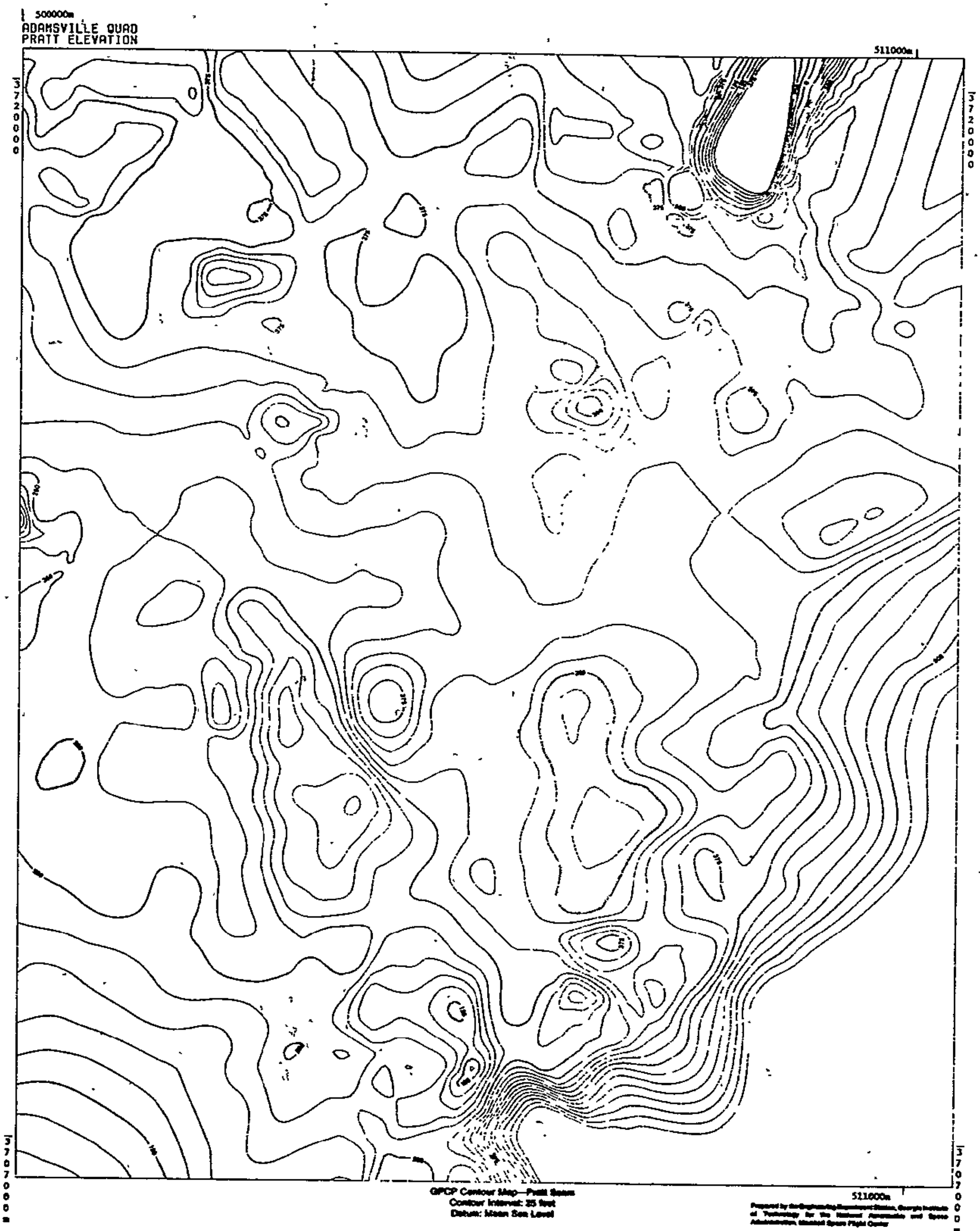
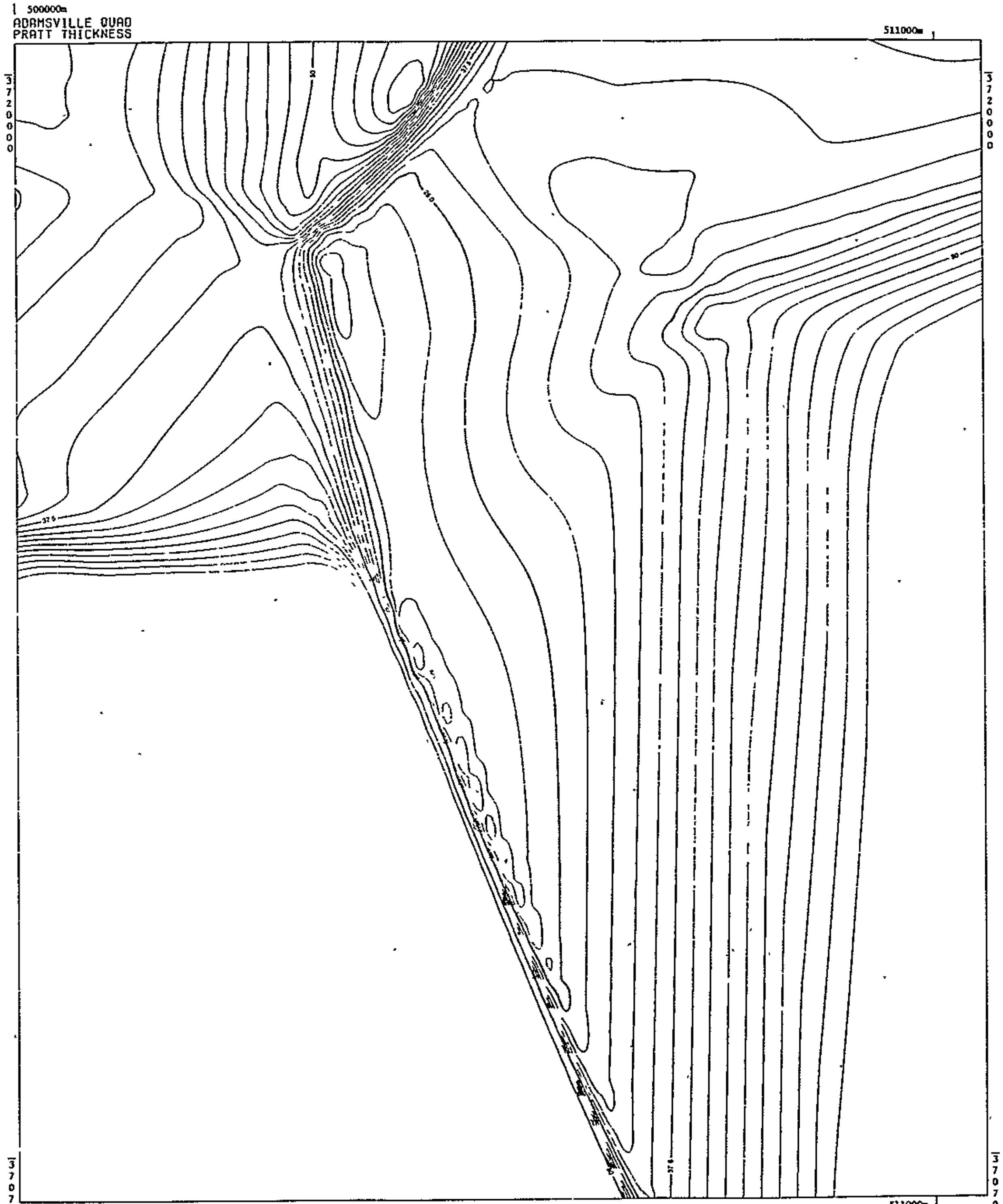


GPCP Contour Map—Pratt Seam
Contour Interval: 25 feet
Datum: Mean Sea Level

Plate 21



GPCP Isopach Map—Pratt Seam
Contour Interval 2.5 inches

Prepared by the Engineering Experiment Station, Georgia Institute of Technology for the National Aeronautics and Space Administration, Marshall Space Flight Center

By Nickolas L. Faust, G. David Gentry, Michael D. Furman

Plate 22

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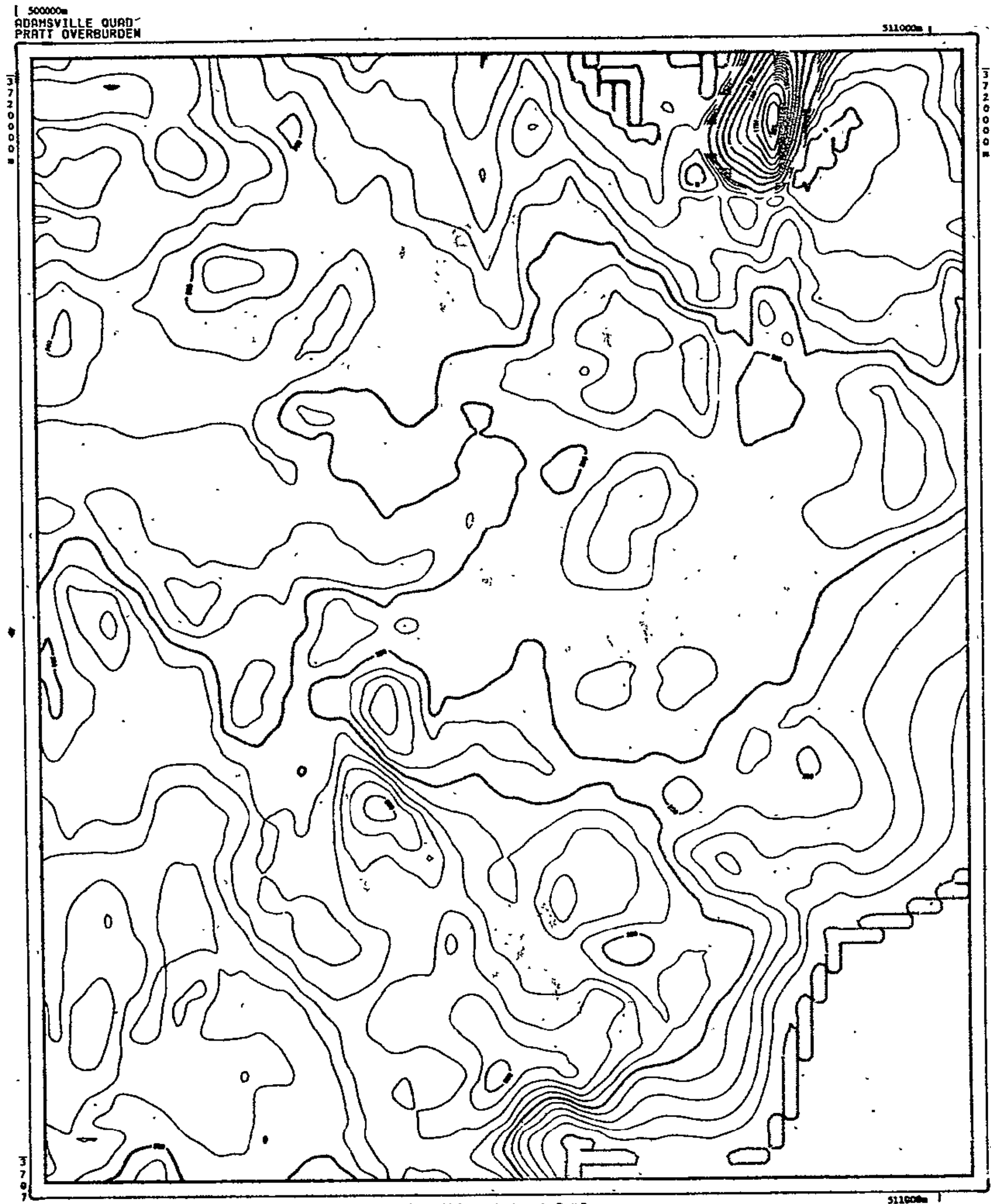

GPCP Overburden Isopach—Pratt Seam
Contour Interval: 50 feet

Plate 23