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FINAL REPORT
Period
1 July, 1973 to 30 June, 1975

ASSESSMENT OF PRACTICALITY OF REMOTE SENSING TECHNIQUES FOR A STUDY OF THE EFFECTS OF STRIP MINING IN ALABAMA

NASA contract NAS8-29936
Project 1-3-80-0084 (1F)

Prepared by
Travis H. Hughes; Andrew C. Dillion, III; James R. White, Jr.; S.E. Drummond, Jr.; and W. Gary Hooks
Department of Geology and Geography

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THE UNIVERSITY OF ALABAMA
P.O. Box 2846
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"Delineation of Geological Problems for use in Urban Planning"

for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration.

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Acknowledgements

Completion of a project involving strip mines is wholly dependent upon gaining access to the lands involved, and having freedom to collect necessary data. At a time when there are public and private outcrys against mining companies and much condemnation of the strip mining process, it requires courage and far sightedness on the part of mining company officials to allow independent researchers the access and freedom to study strip mining.

With these thoughts in mind, the acknowledgements below are not just recognition of aid, but rather, are tributes to the companies and officials involved.

Marigold Mining Company provided mine maps and other data as well as access to lands near Cordova, Alabama.

Drummond Coal Company provided maps and access to the area near Searles, Alabama. In addition, the company and its representatives provided hours of discussion, guided tours of its operations in Walker and Tuscaloosa Counties, flights to photograph the strip mines, aid in identifying the age of spoils, as well as free and unhindered access to any area of mining.

Willard Ward and George Wood of The University of Alabama offered invaluable aid during the course of this study by spending several days in the field with us, and providing maps and discussion.

SUMMARY

Some of the more important aspects of the research project entitled "Assessment of Practicality of Remote Sensing Techniques for a Study of the Effects of Strip Mining in Alabama" are outlined below:

1. The introductory section describes the structural setting and the stratigraphy of the Pottsville Group in the Warrior Coal Basin.

Two areas in the Warrior Coal Basin were selected for study. The Cordova Area is a test site of approximately 23 square kilometers near the town of Cordova, Alabama. Contour stripping has occurred continuously since 1967 and intermittantly prior to that time. Two coal beds in the Mary Lee Group are the principal pay zones. The Searles Area is a study site which covers about 18 square kilometers west of the town of Searles, Tuscaloosa County, Alabama. This area has been mined almost continuously since 1944 by stripping. Coal is produced from four coal beds in the Brookwood Coal Group. During the second year of study, all research was conducted in the Searles Area.

2. AREAL EXTENT OF STRIP MINING

The only photographs provided for this study were taken by NASA-MSFC in December, 1973. Measurements to determine the extent of mining were taken from these photographs.

Cordova Area--This study area covers 3266 hectares, of which 516.76 have been affected by strip mining (15.8% of the total). Sub-areas are identified and categorized by age of mining.

Searles Area--The total area covered by NASA photography is 5036.4 hectares of which 953.03 hectares have been strip mined (18.9% of the total). Sub-areas are identified and categorized by age of mining.

3. RECLAMATION OF STRIP MINED LAND

Reclamation by grading--Vegetation planted under the 1969 Alabama Surface Mining Act is usually not visible on the available photographs, even though it is present. The grading performed under the act is, however, easily distinguishable from ungraded lands.

As of December 1973, 296.22 hectares had been reclaimed by grading in the Cordova Area. This represents 57.3% of all strip mined land in the area.

As of December 1973, a total of 357.50 hectares had been reclaimed by grading in the Searles Area. This represents 37.6% of all strip mined land in the area.

Common species of vegetation are listed for each area.

Natural revegetation--The percent pine cover resulting from natural revegetation was estimated for 58 slopes in the Searles Area. Steep slopes, mined in the interval between 1944 and 1949 had an average of 64% pine cover. Gentle slopes of similar age averaged 70% pine cover. Steep slopes produced in the 1960-1964 interval had an average of 12% pine cover and gentle slopes averaged 29% cover.

EROSION STUDIES--SEARLES AREA

Twenty slopes were selected within the Searles Area for measurement of the amount of material removed by rill and gully erosion. Slopes were chosen to represent areas of maximum erosion. Criteria used for selection of slopes required that the slopes have minimum vegetation cover, maximum slope angle (modal class is 36°), and similar distribution of grain sizes within the spoil materials. In addition the slopes were placed into four different age groups according to the date of mining (1955-1960, 1961-1965, 1966-1970, and 1971-1974). Each slope was mapped; each rill and gulley was measured and

and mapped, and the amount of material removed by rill and gulley erosion was calculated.

Slope Evolution--Linear and Areal Elements

Three stages in the evolution of rill and gully channel profiles has been recognized. Stage 1, the rill stage, is characterized by a straight line channel profile and lasts three to six years after mining. Stage 2, the intermediate stage, charcterized by a channel profile with a series of nick points, lasts six to eight years. Stage 3, the gulley stage begins twelve to fifteen years after mining, is identified by a gentle channel profile that abruptly meets a single steep or vertical headwall.

Disection of the original slopes by rill and gulley erosion allows subdivision of the slope area into imaginary areas of the slope overlying rills and gulleys (gulley area) and the areas of the slope between individual rills and gullys (divide area). Divide areas (A_D, in m^2/hectare of slope area) decrease with time (T, in years before 1974) according to the equation:

$$A_D = 9638\ (0.93^T)$$

Gulley area increases with time as shown by the equation:

$$A_G = 2478\ (1.07^T)$$

The volume of material removed by rill and gully erosion is illustrated by the equation:

$$V\ (m^3/\text{hectare}) = 802\ (1.1^T)$$

Measurements of divide area, gulley area and total slope area taken in the field or from aerial photographs can be used to estimate the volume of material removed by rill and gulley erosion according to the following equations:

$$V\ (m^3/\text{hectare}) = 7079\ (0.79^{A_D})$$

and

$$V = 515\ (1.25^{A_G})$$

SEDIMENTATION IN BLUFF CREEK--SEARLES AREA

The Bluff Creek drainage basin has an area of 21.08 square kilometers, of which 5.63 square kilometers (26.7%) has been strip mined (as of December, 1973).

The volume of sediment in Bluff Creek was obtained by three methods: 1) Direct measurement, in the field, of the width and depth of sediment in the stream valley, construction of cross-sections and projections of average cross-sectional areas through the distance separating adjacent cross-sections; 2) Measurement and projection of the areas contained in the stream terrace deposits; 3) From the measured cross-sections an empirical equation was derived that relates the cross-sectional area to the width of the stream valley. This equation is:

$$\text{Log Cross-sectional area} = 1.5 \text{ Log width} - 0.49$$

This equation was used to estimate cross-sectional areas in locations where direct measurement was difficult or impossible. This or similar equations can be used for volume estimation based on measurements from aerial photographs.

Approximately 411,000 cubic meters of sediment have been deposited in the Bluff Creek Basin as a result of strip mining activity. The sedimentary system in Bluff Creek can be sub-divided into two important depositional zones (the upper sediment wedge and the lower sediment wedge) separated by a short transition zone. The upper sediment wedge contains approximately 171,00 cubic meters of sediment. The lower sediment wedge, including the delta, contains about 231,000 cubic meters of sediment, and the transition contains 8,500 cubic meters of sediment.

By use of data obtained from available aerial photographs the rate of delta growth has been estimated. The total volume of sediment in the delta may be estimated by measuring the distance (D) downstream from an arbitrary reference point to the end of the prodelta and applying the emperical equation:

$$V = 0.037\ (D - 120) + 195.1\ (D - 120) + 200{,}400$$

GEOCHEMISTRY OF BLUFF CREEK

Production of Acid Mine Water

The adopted model for production of acid mine water begins with oxygenated, slightly acidic rain water infiltrating the spoils and reacting with pyrite or marcasite. As long as abundant oxygen is available in the water, sulfur is oxidized to sulfate and iron (manganese as well) is precipitated as a hydroxide. Oxidation of the sulfur continues, after the oxygen supply is depleted, by hydrolysis of water with the production of sulfate and hydrogen ions. Iron remains in solution in the ferrous state. At low oxidation potential hydrolysis may yield native sulfur as well as sulfate, and with continued decrease of pH, hydrogen sulfide may be produced. Ferrous and manganous ions remain in solution and other acid soluble ions are dissolved.

Mine Drainage in Bluff Creek

Sampling sites were located at 22 stations along Bluff Creek and its tributaries. Field and laboratory analyses were used to measure redox potential, pH, total alkalinity, sulfate, iron, manganese, nickel, chromium, zinc, cadmium, cobalt, and copper.

Sandstone beds with a calcium carbonate cement are exposed along Bluff Creek and act as a natural buffer to provide rapid neutralization of the acid mine water which passes over them. The alkalinity is high in the upper reaches of Bluff Creek and decreases to near zero at the mouth.

The pH of Bluff Creek remains around 6.5 throughout most of its length (although the pH of entering tributaries may be as low as 3). The pH of Bluff Creek decreases in the lower one-third of its course. Iron and manganese behave similarly, do not exceed a concentration of 30 ppm, and generally decrease downstream. Ferrous and manganous ions appear to be the dominant dissolved species of these two elements. Oxidation to ferric or manganic ions is quickly followed by hydrolysis and precipitation of the hydroxides, accompanied with the production of hydrogen ions.

Nickel, chromium, zinc, cadmium, cobalt and copper are all present in Bluff Creek at concentrations less than one part per million.

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INTRODUCTION

During the fiscal year 1970-1971 (Annual Statistical Report, Alabama Department of Industrial Relations) the total coal production in Alabama was approximately 18, 708, 376 metric tons (20, 622, 476 short tons). The total production from underground mines was 7, 662, 910 metric tons (8, 453, 735 short tons). Strip mining produced 10, 951, 827 metric tons (12, 072, 323 short tons), and an additional 87, 469 metric tons (96, 418 short tons) were produced by auger mining. Coal was produced in 13 counties and from three different coal basins (Warrior, Cahaba, and Coosa).

Coal mined in the Warrior Coal Basin in 1970-71 represented only 46% of the total state production (8, 532, 072 metric tons), however this includes nearly 75% of all coal produced by strip mining in the state of Alabama (8, 235, 423 metric tons).

Because of the Volume of coal produced by strip mining, the proximity of mining operations to the University campus, and the diversity of mining methods (e. g. contour stripping area stripping, multiple seam stripping, augering, as well as underground mining), the Warrior Coal Basin seems best suited for initial studies on the physical impact of strip mining in Alabama. Two test sites, (Cordova and Searles) representative of the various strip mining techniques and environmental problems, were chosen for intensive studies in correlation of remote sensing with ground truth data.

During the second year of this study, efforts were concentrated in the Searles Area, since it was more accessible and offered a better opportunity for study of erosional and depositional processes than the Cordova Area.

WARRIOR COAL BASIN

Location

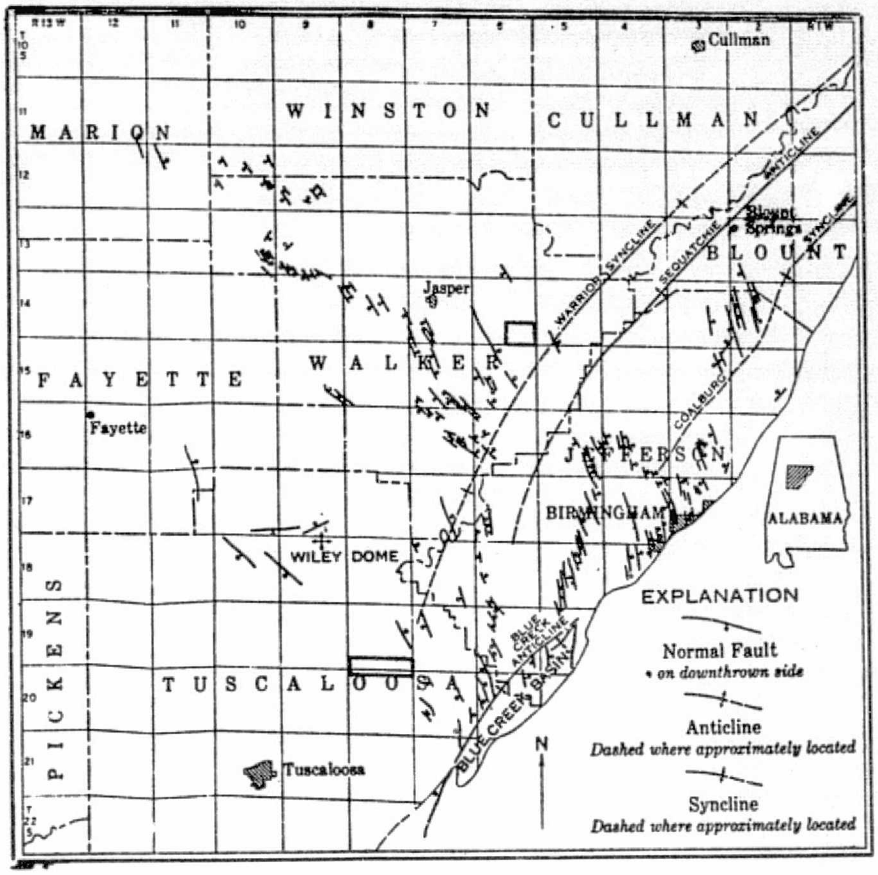
The Black Warrior Coal Basin incorporates approximately 7,770 square kilometers (3,000 square miles) of north-western Alabama, including parts of Jefferson, Tuscaloosa, Marion, Fayette, Winston Counties and all of Walker County (Figure 1). The Black Warrior River and its tributaries drain most at the Warrior Basin, however, however the northern and western parts of the basin are drained by the Tennessee and Tombigbee Rivers respectively. (McCalley, 1900, p.2)

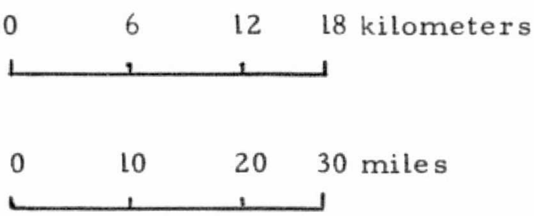
Stratigraphy

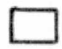
Rocks of the Pennsylvania System dominate the stratigraphy of the Black Warrior Basin and consist of cyclic, lensatic squences

Figure 1

STRUCTURE MAP OF A PART OF THE WARRIOR COAL BASIN, ALABAMA





STUDY AREAS 

of shale, sandstone, conglomerate, under-clay, and bituminous coal (Figure 2). Coal, which constitutes a small percentage of the total rock volume, is contained in numerous individual coal seams with thicknesses which vary from a few centimeters to as much as 4.9 meters (16 feet).

Pennsylvanian System

The Parkwood Formation and the Pottsville Formation constitute the Pennsylvanian System of rocks that are represented in the Warrior Basin.

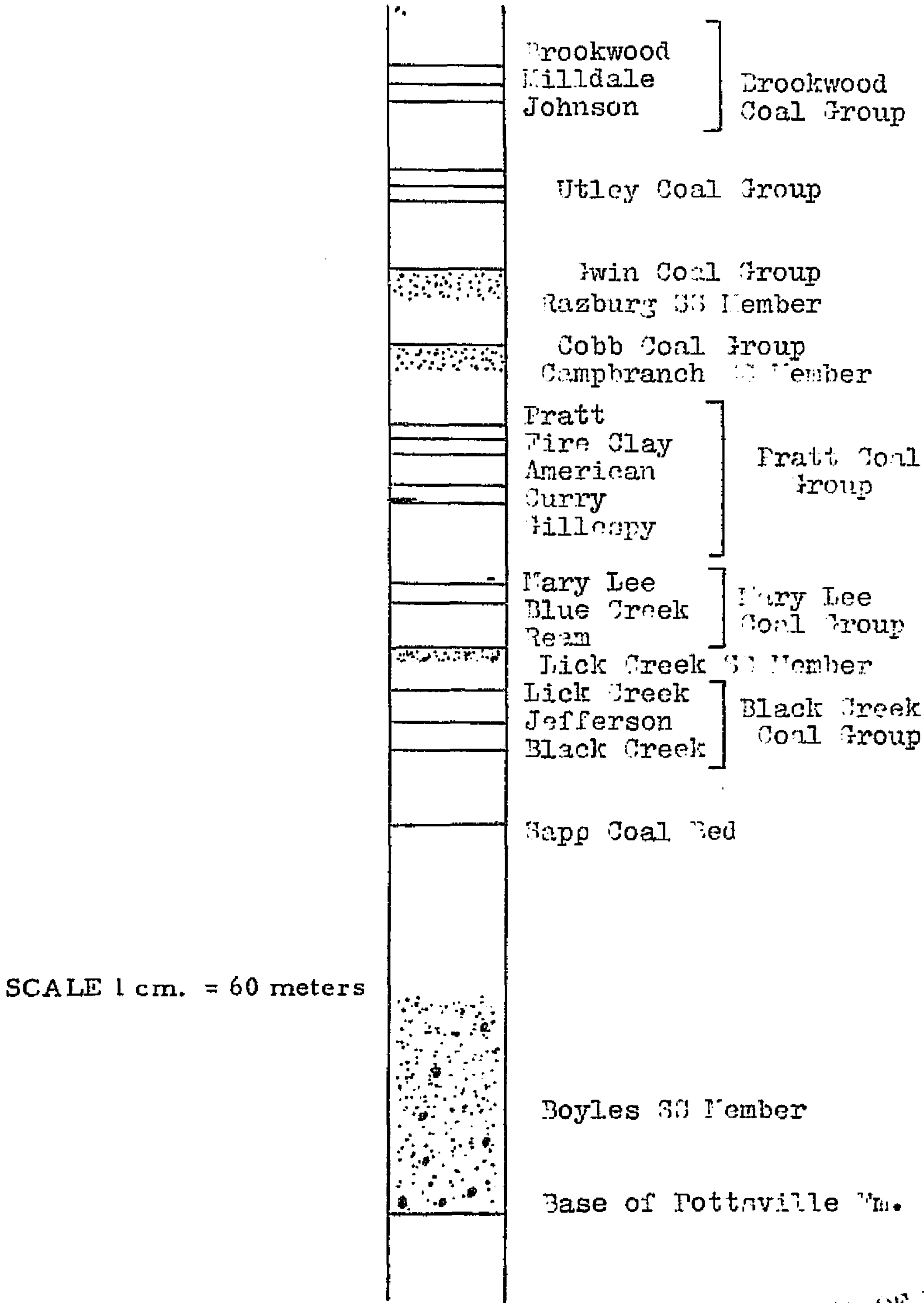
Parkwood Formation

The Parkwood Formation is believed to be of early Pennsylvanian age. It unconformably overlies either the Pennington Formation or the Floyd Shale (of Mississippian age) and is conformably overlain by the Pottsville Formation. In the northwest part of the basin the Parkwood reaches a maximum thickness of approximately 183 meters (600 feet). It progressively thins to the southeast and is locally absent. At such localities the Pottsville may overlie the Floyd Shale (Culbertson, 1964, p. B9).

The Parkwood Formation consists of alternating beds of gray shale, siltstone, sandstone, and a few thin coal beds.

Figure 2

COLUMNAR SECTION OF COAL BEDS AND SANDSTONE MEMBERS OF THE POTTSVILLE FORMATION IN THE WARRIOR COAL FIELD



The coal beds, which lie from 0.3 to 30 meters (1 to 100 feet) below the top of the Parkwood, are not persistant and rarely exceed 45 centimeters (18 inches) in thickness (Culbertson, 1964).

Pottsville Formation

The Pottsville Formation attains a maximum thickness of 1,372 meters (4,500 feet) in the southern part of the Warrior Basin and thin to the north. This formation consists of massive gray shale, gray thin bedded sandstones, massive sandstone beds from 3 to 30 meters thick (10 to 100 feet), conglomerate orthoquartzitic beds as much as 76 meters thick (250 feet), some pebble and cobble conglomerates, and numerous bituminous coal beds with associated underclays.

The lowest, and most unproductive portion of the Pottsville Formation is called the Boyles Sandstone Member and consists of orthoquartzitic sandstones and conglomerates, with a thickness range of 61 to 213 meters(200 to 700 feet). Above the Boyles Sandstone Member are the Lick Creek Sandstone Member, the Campbranch Sandstone Member, the Razburg Sandstone Member, and the Breman Sandstone Member. These units contain the productive coal measures in rhythmical sequences of sandstone, underclays, coal beds, and shale (Culbertson, 1964).

Coal production in the Warrior Coal Basin has come primarily from seven groups of coal, each containing from two to five coal beds. These groups are in ascending order: the Black Creek Group, the Mary Lee Group, the Pratt Group, the Cobb Group, the Gwin Group, the Utley Group, and the Brookwood Group. (Culbertson, 1964 B22).

The Black Creek Coal Group is the basal group of the productive part of the Pottsville Formation and consists of three coal beds--the Black Creek, the Jefferson, and the Lick Creek. Only the Black Creek and the Jefferson are estimated to contain appreciable reserves of coal. These two units consist of high-volatile "A" bituminous coal, having low ash and sulfur content. The Black Creek bed is mined extensively in Walker County, and the Jefferson bed in Walker, Marion, and eastern Winston counties. (Culbertson 1964, p. B22).

The Mary Lee Coal Group is the most wide spread and contains the most coal reserves in the Warrior Coal Basin. This group contains five coal beds: the Ream, the Jagger, the Blue Creek, the Mary Lee (Horse Creek), and the New Castle (McCally, 1900 pg. 5).

The Ream lies from 15 to 61 meters (50 to 200 feet) above the Black Creek Group. Coal in this bed is seldom more than 60 centimeters (two feet) thick. The Jagger and the Blue Creek are in most places only a few meters from each other and can be considered one seam. The Jagger reaches a thickness of 1.2 to 1.5 meters (4 to 5 feet) in the central part of the basin and the Blue Creek attains a thickness of 2.7 meters (9 feet) in the Blue Creek Basin in the southern part of the Warrior Basin. (Culbertson 1964, pg. B29)

The Mary Lee is a dirty or high ash coal with a low sulfur content. The bed varies from a few centimeters thick in the southern part of the basin to 2.7 meters (9 feet) thick in the western portion of Walker County. The New Castle bed is the upper part of the Mary Lee Group, and is often mined as a riderseam with the Mary Lee. (Culbertson, 1964, pg. B31)

The Pratt Coal Group consists of five named coal beds: The Gillespie, the Curry, the American, the Fire Clay and the Pratt. These beds occur within a 30 - 75 meter (100 to 250 feet) stratigraphic interval, which lies from 120 - 200 meter (400 to 650 feet) above the Mary Lee Coal Group. Beds of the Pratt group are mined primarily in Walker and Jefferson Counties. (Culbertson, 1964, pg. B32)

The Cobb Coal Group lies from 64 to 100 meters (210 to 330 feet) above the Pratt group, and consists of an upper and lower coal bed. The thickness of either bed rarely exceeds 60 centimeters (two feet). (Culbertson, 1964, pg. B33)

The Gwin Coal Group lies from 37 to 49 meters (120 to 160 feet) above the Cobb Group and consists of two coal beds: the lower Thomas Mill bed and the upper Gwin bed. The Gwin bed is the only bed of sufficient thickness to be of value and available reserves are found only in southern Jefferson County.

The Utley Group consists of two to six coal beds that are found from 76 to 98 meters (250 to 320 feet) above the Gwin Group, and from 60 to 90 meters (200 to 300 feet) below the Brookwood. The Utley group consists of two to five un-named beds, each of which is less than 25 centimeters (10 inches) thick.

The Brookwood Coal Group is stratigraphically the highest coal group in the Warrior Field, and lies from 60 to 90 meters (200 to 300 feet) above the Utley Group. This group is exposed only in southern Jefferson and Tuscaloosa Counties and consists of five named coal beds.

Structural Setting

The Warrior Coal Field is a structural basin terminated on the southeastern side by the Opossum Valley overthrust and concealed beneath Cretaceous sediments at the southwestern end. (Semmes, 1929) The regional dip is toward the southwest, and is usually less than two degrees. Structural complexities in the basin include the Sequatchie Anticline, the Blue Creek Anticline, the Blue Creek Syncline, the Coalsberg Syncline, the Warrior Syncline, and the Wiley Dome (see Figure 1). Normal, hinge faults are numerous throughout the Warrior Basin. The faults may occur en echelon and locally contain grabens. Reverse faults are rare but may occur on the northwestern limb of minor, overturned anticlines.

The northeast trending Sequatchie Anticline subdivides the Warrior Basin into the Warrior Syncline and the Coalsberg Syncline (Pratt Basin) as shown in Figure 1 . The Sequatchie Anticline has been breached (exposing Cambro-Ordocician rocks along its axis), is overturned to the northwest, and opens as it plunges beneath the Pottsville Formation in southern Jefferson County.

The southwestward plunging, spoon-shaped Coalsburg Syncline lines between the Sequatchie Anticline and the Opossum Valley fault. The strata dip gently to the southwest at a rate of 5 to 10 meters per kilometer (30 to 50 feet per mile), except where they are upturned near the Sequatchie Anticline and the boundry fault. The basin has a marked development of en echelon, hinge faults with maximum displacement of 60 meters (200 feet). Fault displacement seems to vary directly with fault length. Faults with average displacements of 30 meters have average lengths of about 3 kilometers. Grabens occur in isolated areas.

The Warrior Syncline is located northwest of the Sequatchie Anticline. The axis of the syncline is not well defined, but generally parallels the anticline (N3OW). Strata on the eastern limb strike parallel to the syncline axis and dip steeply. Beds on the western limb, however, have an average strike of N6OW and dip more gently. The eastern portion of the syncline contains a belt of en echelon faults.

The Blue Creek Anticline is located near the southwestern margin of the Warrior Coal Field on the western prong of a bifurcated part of the Opossum Valley Fault. The overturned fold is about 40 kilometers (25 miles) long and is accompanied by thrust faulting.

The Blue Creek Basin is separated from the Warrior Field by the Blue Creek Anticline. The northwest flank of the basin dips 30 to 40^{o} and the average dip of the southeast flank is 15^{o}. A small northeast trending anticline is located in the northern part of the basin.

The Wiley Dome has a closure of approximately 60 meters (200 feet) and is a prominant feature in the central part of the Warrior Coal Field. Several faults occur on the flanks of the dome (Figure 1).

STUDY AREAS

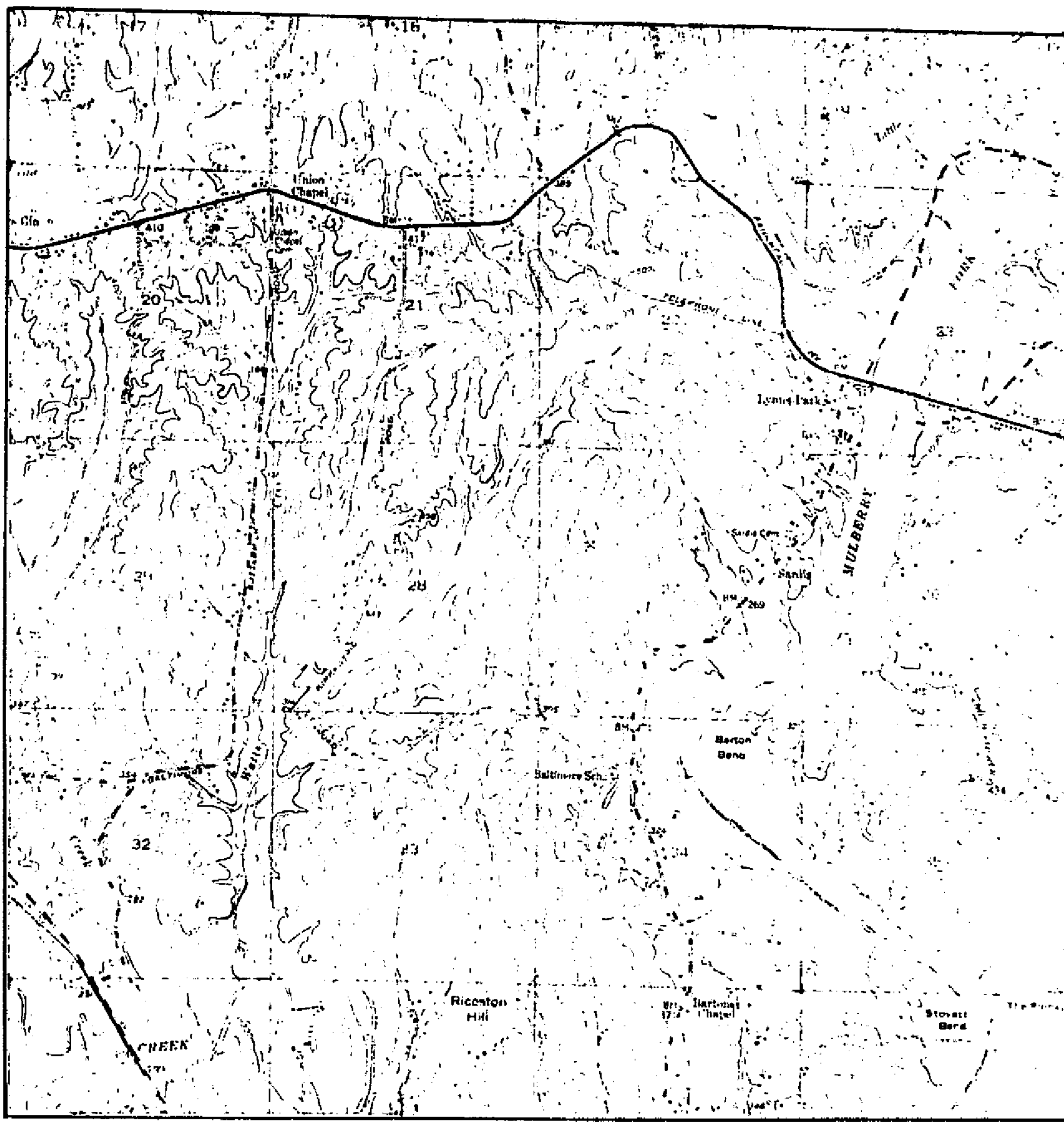
Two areas in the Warrior Syncline have been selected for detailed study under the present NASA contract. One of the areas is located along the axis of the Warrior Syncline near the town of Searles in Tuscaloosa County. (Figure 1 and 3). The other area is north of Cordova, Alabama in Walker County (Figure 1 and 3).

Cordova Area

The Cordova site occupies an area of approximately 23 square kilometers, includes sections 21, 22, 27, 28, 29, 32, 33, 34; T14S, R6W and section 4; T15S, R6W, and lies directly north of the town of Cordova, Alabama (Figure 3). The area is drained by tributaries of Mulberry Fork, which is a major tributary of the Black Warrior River. The Marigold Mining Company of Jasper Alabama has been strip mining this area continuously since 1967 and intermittantly prior to that time. In some areas present strip mining has uncovered older, underground mines, some of which may date back to the turn of the century. Contour stripping is the principal mining method used throughout the central part of the area. The resulting highwalls may exceed 30 meters in relief. Small areas in sections 29 and 32; T14S, R6W have been mined by the area

Figure 3

INDEX MAP CORDOVA AREA



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stripping method. The Marigold Mining Company has provided mine maps, dates of mining, and keys to all locked gates in the area. Numerous hard surface roads and mine roads traverse the entire site, thus allowing ready access to all parts of the area.

Two coal beds of the Mary Lee Group occur in this area (Figure 4). The New Castle occurs at an elevation of 134 meters (440 feet), has an average thickness of 30 centimeters (12 inches) and is mined as a rider seam. The Mary Lee occurs 12 meters (40 feet) below the New Castle and is the major source of coal production in the area. It occurs at an elevation of 122 meters (400 feet) and has an average thickness of 69 centimeters (27 inches). Underclay, beneath the Mary Lee, is also mined in the area and may attain a thickness of 1.5 meters (5 feet).

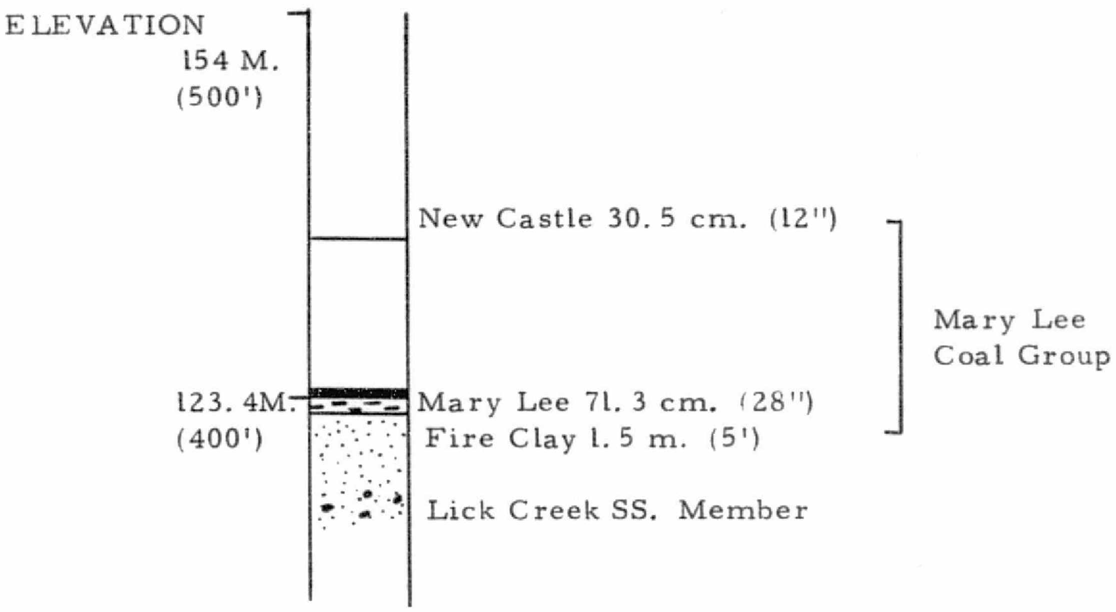
The influence of structural features in this area is negligible. Bedding is essentially horizontal, but may be influenced somewhat by the Warrior Syncline. A few normal faults are found on the perimeter of the study area.

Reclamation in this area is not extensive since much of the mining preceded the Alabama Surface Mining Act of 1969. However, portions of section 21, 28, and 29; T15S, R6W have been reclaimed under that act. A small

Figure 4

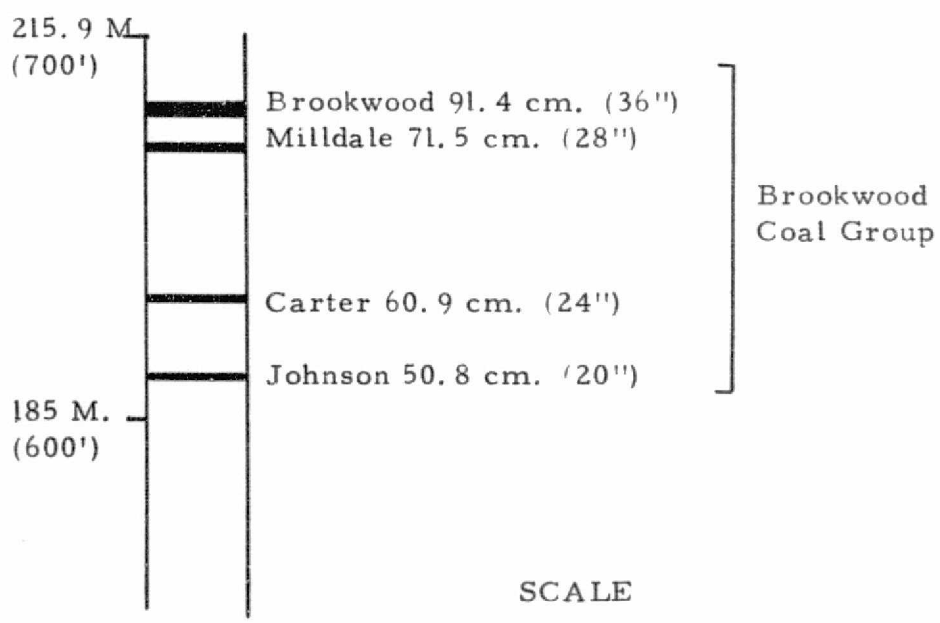
COLUMNAR SECTION - CORDOVA AREA

SW 1/4, SE 1/4, Sec. 28 T14S, R6W



COLUMNAR SECTION - SEARLES AREA

SW 1/4, NE 1/4, Sec. 15, T20S, R8W



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area (16 hectares) of and belonging to the University of Alabama was reclaimed in about 1960 and planted by the University forester (George Wood) in 1962. This area may serve as an index to the rate of pine growth, shale decomposition, and soil formation in the Cordova test site. Spoils from mining contain large angular fragments (up to one meter maximum dimension) of sandstone and shale. Topsoil is seldom preserved in the mining process.

Searles Area

The Searles site is located west of the town of Searles, Tuscaloosa County, Alabama in sections 1 through 18; T20S, R8W (Figure 5). The area drains directly into the Black Warrior River. Permission for use of this area as a test site has been obtained from the Kellerman Mining Company (a division of Drummond Mining Company, Jasper, Alabama). Mine maps have been obtained from the company and access is available through many mine roads.

Four beds of the Brookwood Coal Group are mined in this area (Figure 4). Exposures of the beds vary in elevation from 166 meters (545 feet) to 207 meters (680 feet) due to extensive faulting. The beds, from oldest to youngest, are: the Johnson seam, with an average thickness of 66 centimeters (26 inches); the Carter, 61 centimeters (24 inches); the Milldale, 56 centimeters (22 inches); and the Brookwood, 1.1 meters (44 inches).

The Searles area is influenced by numerous structural features. It lies relatively close to the axis of the Warrior Syncline, and is also probably influenced by the Sequatchie Anticline. Many en echelon, normal faults are found in the area. One such fault in sections 13; 23; and 24 has a displacement of approximately 18 meters (60 feet).

The area has a long (20 to 30 year) history of mining, which includes underground mining, strip mining, and augering. Much of the mining was pre-law and thus, relcamation has not been accomplished. Present technology allows strip mining to greater depths than ever before and as a result, the site will be remined by area stripping methods, and previously un-reclaimed land will be restored to a productive cycle.

Spoils in the Searles area have a smaller average grain size than in the Cordova area and thus are physically more amenable to plant growth, but more subject to erosion. Kellerman Mining Company has reclaimed several large areas by a combination of strike-off, grading, terracing, and has planted trees on the reclaimed areas. Reclamation is in excess of that required by the Alabama Surface Mining Act of 1969 and offers the opportunity for meaningful studies. As a result, research during the second year of this study was concentrated exclusively within the Searles area.

AREAL EXTENT OF STRIP MINING

The areal extent of strip mining as measured for this report represents only those sites which are directly affected by strip mining. It does not include indirectly affected land such as the tops of hills which may be isolated by rim stripping, or stream bottoms covered by sediment from the strip mines.

Cordova Test Site

The Cordova test site is covered by the NASA, 1/25,000 scale, infra-red photograph Frame 0196. This image has been reproduced in black and white and is included as Figure 5 . Twenty-one different subareas have been outlined on Figure 5 , and have been marked as to age of mining. The age of mining of six areas is unknown and these are identified by number.

The area represented by Frame 0196 is 3266 hectares. Of this total area 516.76 hectares have been directly affected by strip mining (15.8% of the total). The earliest mining, identified by age, occurred in 1962. Unless one of the areas of unknown age falls into this category, no mining occurred between 1962 and 1967. Since 1968 mining has been almost continuous.

Table 1 lists by age the total amount of land (in hectares and acres) mined in the Cordova test site. Mining of unknown age represents 14.5% of the total (74.76 hectares). Figure 6 summarizes this data. With the exception of the years 1969 and 1970, there has been a continuous increase

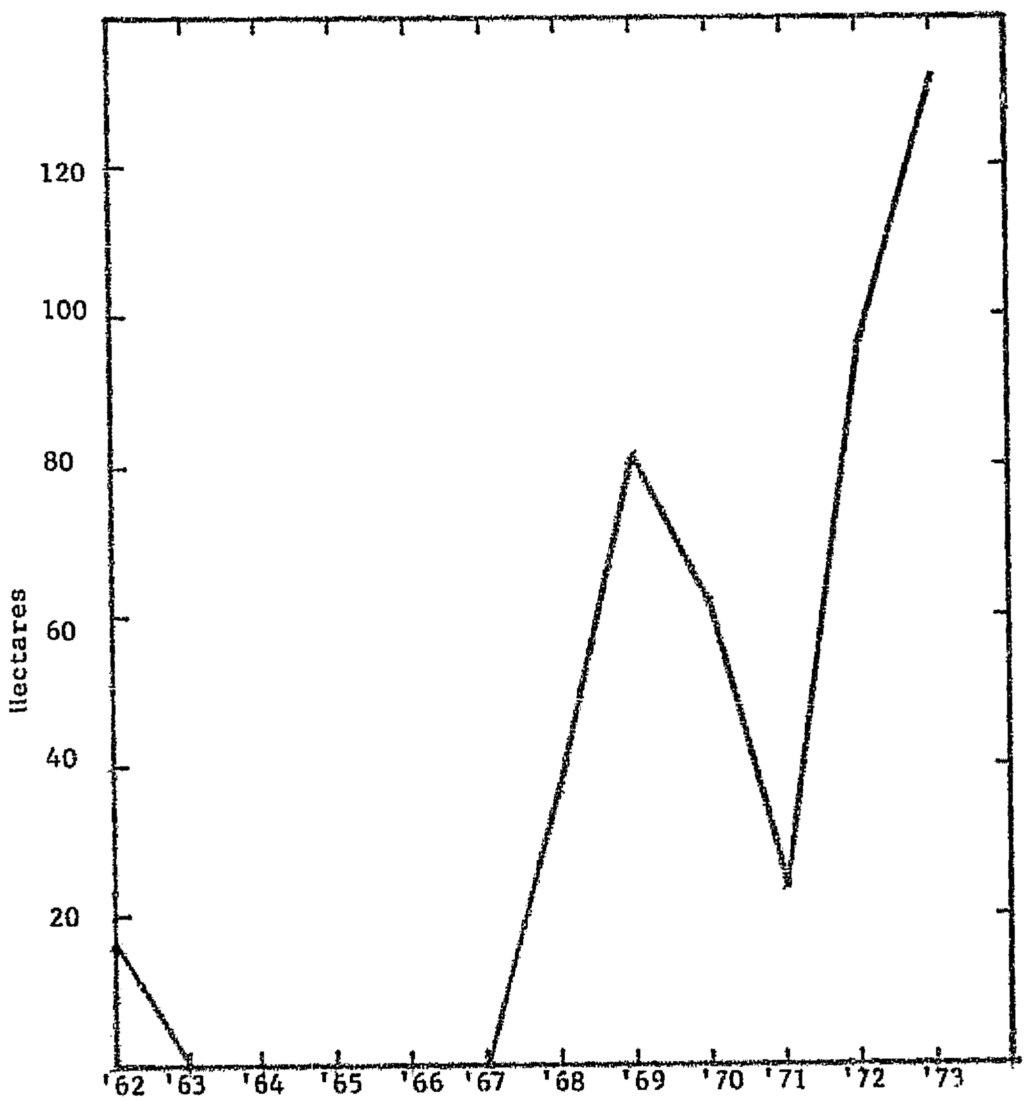
Figure 5 Frame 0196 AREA OF STRIP MINING (See Table 1, Page 21)

Table 1
AREA OF STRIP MINING
CORDOVA TEST SITE FRAME 0196

Age		Area Hectares	Area Acres
1962		16.19	40.00
A 1968		6.54	16.16
B 1968		18.28	45.17
C 1968		12.14	30.00
	Total	36.96	91.32
A 1969		20.60	50.90
B 1969		24.28	60.00
C 1969		12.55	31.01
D 1969		23.73	58.64
	Total	81.16	200.54
A 1970		6.68	16.50
B 1970		8.05	19.89
C 1970		19.51	48.21
D 1970		12.41	30.67
E 1970		15.55	38.42
	Total	62.20	153.69
1971		24.56	60.69
A 1972		34.93	86.31
B 1972		61.80	152.71
	Total	96.73	229.02
A 1973		33.29	82.26
B 1973		47.75	117.99
C 1973		25.38	62.71
D 1973		15.01	37.09
E 1973		10.64	26.29
	Total	132.07	326.34
Unknown Age			
1		9.82	24.26
2		9.41	23.25
3		4.50	11.12
4		18.20	44.97
5		21.50	53.13
6		2.46	6.08
	Total	74.76	162.81
	Total mining	516.76	1274.41
Total area in Frame 0196		3266.00	8070.29

Figure 6

Cordova Test Site
Hectares of Mined Land vs. Age



in the amount of land disturbed by mining each year. The decreases in amount of mined land in the years 1969 and 1970 may not represent a real decrease in the amount of mine output, but rather, may indicate only that mining occurred in another area which is not represented on Frame 0196.

In order to provide access and haul roads for strip mining 18.5 km. of roads have been constructed during strip mining. If the roads average 4m width then an additional 7.4 hectares of land have been affected.

Searles Test Site

The Searles test site is covered by NASA, 1/25,000 scale, infra-red photographs on Frames 0167 and 0170. The sub-areas in the Searles test site are outlined on Figures 7 and 8 . Thirty-three of the sub-areas are marked as to age of mining and twenty-nine sub-areas (34.3% of the total mined area) are of unknown age and identified by number.

The total land area (exclusive of overlap) represented on Frames 0167 and 0170 is 5036.4 hectares (12,444.9). Of this total 953.03 hectares (2354.93 acres), or 18.9% have been directly affected by strip mining. The earliest mining identifiable by age occurred in 1944 and, except for the period 1950-1954, mining has been almost continuous since that time.

Table 2 lists the amount of land mined in Frame 0167. This represents 191.39 hectares or 7% of the total land area in the Frame. Of the mined area 64.49 hectares are of unknown age (33.7% of the total mined area). Table 3 presents similar data for Frame 0170. The mined area in Frame

Figure 7
AREA OF STRIP MINING

Frame 0167 (See Table 2, Page 26)

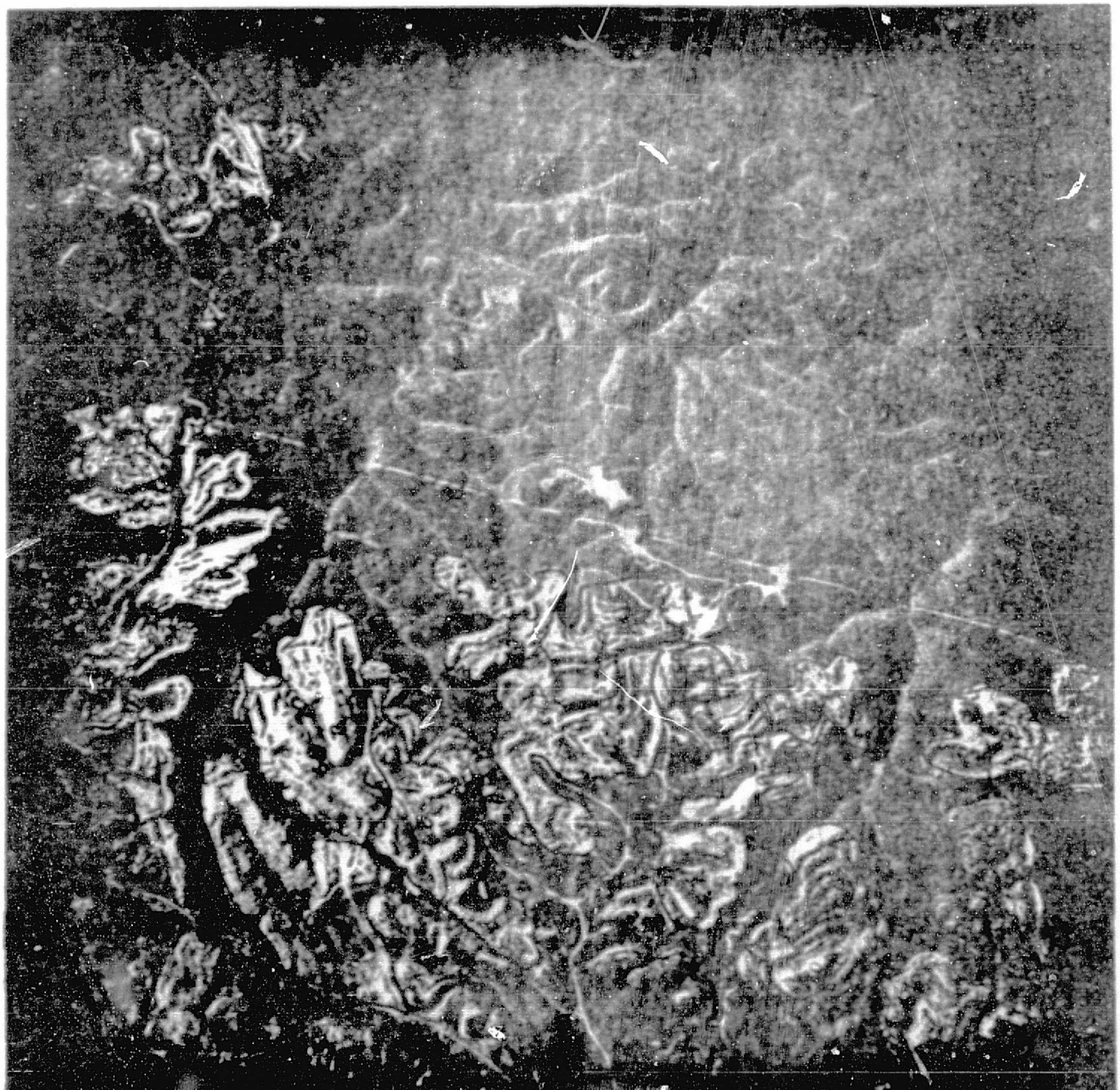


Figure 8

AREA OF STRIP MINING
Frame 0170 (See Table 3, Page 27-28)

Table 2

AREA OF STRIP MINING
SEARLES TEST SITE FRAME 0167

Age		Area Hectares	Area Acres
1944		1.84	4.55
A 1961-62		19.22	47.49
B 1961-62		14.35	35.46
C 1961-62		2.50	6.18
D 1961-62		2.76	6.82
E 1961-62		2.89	7.14
	Sub Total	41.72	103.09
A 1973		37.26	92.06
B 1973		46.08	113.86
	Sub Total	83.34	205.93
Unknown Age			
1		8.29	20.48
2		4.21	10.40
3		5.79	14.31
4		5.26	13.00
5		3.16	7.80
6		17.90	44.23
7		19.88	49.12
	Sub Total	64.49	159.35
	Total	191.39	472.92 (7% of total)
	Net area Frame 0167:		
		2720.77	6723.02

Table 3

AREA OF STRIP MINING
SEARLES TEST SITE FRAME 0170

Age		Area Hectares	Area Acres
1944	Sub Total	2.76	6.82
1949	Sub Total	7.51	18.55
A 1955-60		19.75	48.80
B 1955-60		31.34	77.44
C 1955-60		24.10	59.55
	Sub Total	75.19	185.79
1957	Sub Total	9.55	23.60
A 1958		11.45	28.29
B 1958		3.27	8.08
C 1958		2.63	6.50
D 1958		5.32	13.15
	Sub Total	22.67	56.02
1959	Sub Total	11.66	28.81
1960	Sub Total	24.10	59.55
1962	Sub Total	3.81	9.41
A 1963-64		24.83	61.35
B 1963-64		20.93	51.72
C 1963-64		16.64	41.12
D 1963-64		47.80	118.11
	Sub Total	110.20	272.30
1964	Sub Total	12.63	31.21
A 1968-69		17.32	42.80
B 1968-69		50.36	124.44
	Sub Total	67.68	167.24
A 1969-70		60.17	148.68
B 1969-70		52.53	129.80
	Sub Total	112.70	278.48

Table 3
AREA 0170 CONTINUED

Age		Area Hectares	Area Acres
A 1970		11.19	27.65
B 1970		4.50	11.12
	Sub Total	15.69	38.77
1971-72	Sub Total	23.17	57.25
	Total	499.31	1233.80
Unknown Age			
1		93.60	231.28
2		1.77	4.27
3		11.58	28.61
4		28.70	70.92
5		0.40	0.99
6		3.55	8.77
7		2.23	5.51
8		11.19	27.65
9		4.99	12.33
11		13.96	34.50
16		15.52	38.35
17		19.71	48.70
18		0.78	1.93
19		2.23	5.51
20		4.86	12.01
21		20.93	51.72
22		26.33	65.06
	Sub Total	262.33	648.22
	Total mined	761.64	1882.01
	Net area Frame 0170	2315.63	5721.92

0170 is 761.33 hectares (32.9% of the total land area). Areas of unknown age constitute 34.4% of the mined land (262.33 hectares). Data from the above mentioned tables is summarized in Table 4 and on Figure 9. In each five year interval (except 1950-54) there has been an increase in the amount of land disturbed by mining. The period 1971-73 does not represent a complete five year interval; however, at the present rate of mining activity there is no doubt that at the end of this five year interval significant increases will be present.

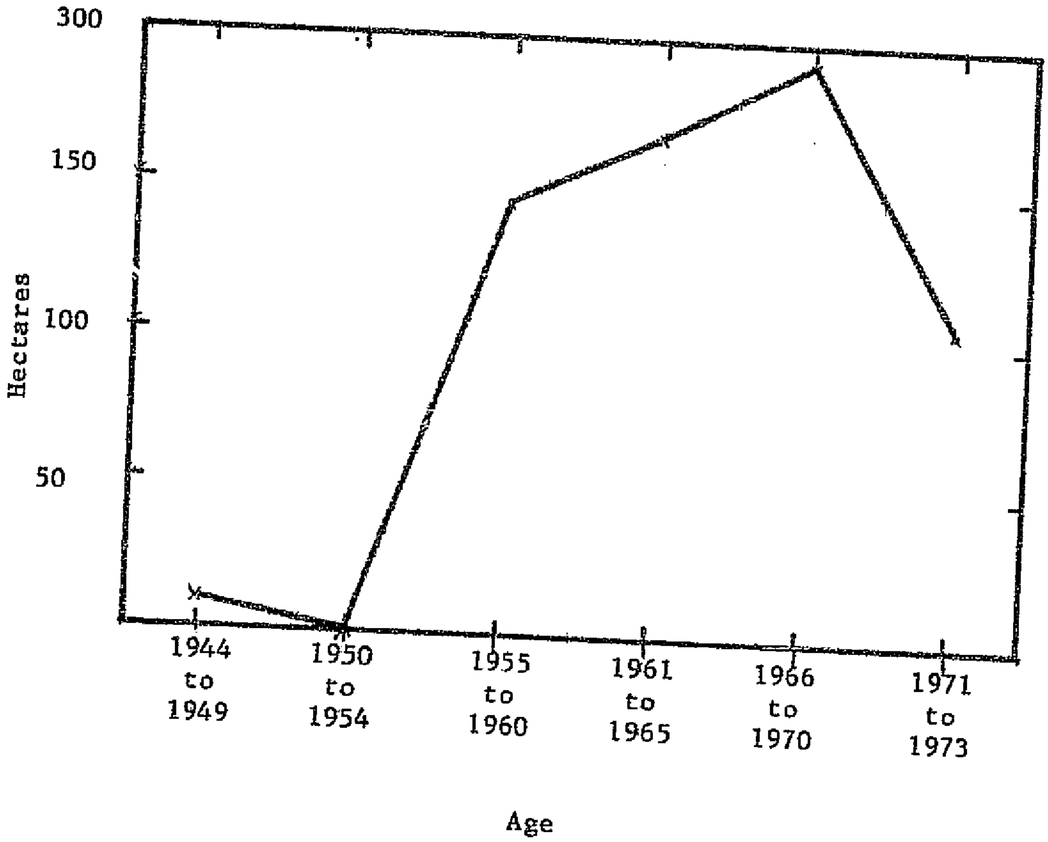
In order to provide access and haul roads for strip mining 33.11 km of new roads have been constructed in the area covered by Frames 0167 and 0170 disturbing 13.2 hectares of land. In addition 1.74 km (0.7 hectares) of roads have been improved and 13.03 hectares of land are used as an airport.

Table 4
SEARLES SITE
AREA OF STRIP MINING
SUMMARY FRAMES 0167 & 0170

Age Area	Area Hectares	Area Acres	Percent of Total*
1944-49	12.11	29.92	1.3%
1950-54	-----	-----	
1955-60	143.17	353.77	15.0%
1961-65	168.36	416.02	17.7%
1966-70	196.07	484.49	20.6%
1971-73	106.51	263.19	11.2%
Unknown Age	327.02	808.07	34.3%
Totals	953.03	2354.93	18.9%
Total Area in Searles Test Site	5036.40	12444.94	

*Summation of percentages may not total 100 due to rounding.

Figure 9.
Searles Test Site
Hectares Mined



RECLAMATION OF STRIP MINED LAND

The Alabama Surface Mining Act of 1969 requires, in essence, grading to a rolling topography, covering toxic material, diversion of water to reduce siltation, erosion, or other damage to streams, and seeding or planting. The Act became effective on October 1, 1970 and allows three years from the expiration date of a permit for completion of reclamation. The Act further allows substitution of earlier mined lands for reclamation rather than those under active mining.

Due to the fact that the Alabama Surface Mining Act is so recent and that the first completed reclamation was in October 1973, there has historically been almost no reclamation of mined land. The earliest recorded reclamation attempts in Alabama were on Marigold Mining Company's land north of Jasper, in 1947. The land was graded and planted in pine seedlings. The timber on this land was cut and sold in 1974. Within the confines of the Cordova test site, 16 hectares of land belonging to The University of Alabama was reclaimed by grading (except for the final cut) and planted in loblolly pine seedlings by the University forester, George Wood, in 1962. This area is present in Frame 0196 and would not be recognized as strip mined land except for the fact that the final cut can be located. The pines in this area average about 15 cm in diameter and offer approximately 90% ground cover.

Table 5 and the summary Table 6 present the areas which have been reclaimed in the Cordova and Searles test sites. Other than the above

Table 5

RECLAMATION - GRADING

CORDOVA AND SEARLES TEST SITES

Ages	Cordova (hectares)	% of Total Mined Land	Searles (hectares)	% of Total Mined Land
1944	----*		0	
1949	----		0	
1955-60	----		0	
1957	----		0	
1958	----		0	
1959	----		0	
1960	----		0	
1962	16.19	3.1		
1963-64	----		0	
1968	0		0	
1969	36.28	7.0	0	
1968-69	----		0	
1969-70	----		112.7	14.8
1970	15.55	3.0	15.69	2.1
1971	24.56	4.8		
1972	96.73	18.7	23.17	3.0
1973	131.47	25.4	83.34	10.9
Unknown age	0		104.79	13.7

*indicates no mining during this period

Table 6

RECLAMATION BY GRADING
CORDOVA AND SEARLES TEST SITE - SUMMARY

Ages	Cordova (hectares)	% of Total Mined Land	Searles (hectares)	% of Total Mined Land
1944-49	----*		0	
1950-54	----		0	
1955-60	----		0	
1961-65	16.19	3.1	0	
1966-70	51.83	10.0	128.39	16.9
1971-73	228.2	44.2	106.51	11.2
Unknown age	0		122.69	12.9
TOTALS	296.22	57.3	357.59	37.6

* ----indicates no mining during this period

mentioned 1962 area, no other evidence of reclamation attempts prior to 1969 are evident on the photographs. In spite of this a surprising 57.3% of the mined land in the Cordova test site has been reclaimed by grading, and 37.6% of the mined land in the Searles test site has been reclaimed by grading. This is due, for the most part, to the fact that in the Cordova region 88% of the mined land of known age has been mined since 1969. In any event, the Alabama Surface Mining Act of 1969 has already had a major effect on the improvement of the state's mined land.

The effects of planting and seeding land reclaimed by grading are not yet visible in the areal photographs. Most of the graded areas either have been planted or seeded, but the seedlings are still less than 50 cm high and are below the limits of resolution on the photographs. Planting in both test sites consists primarily of pine seedlings. Almost no efforts in planting grass have yet been made, in spite of the fact that much evidence indicates that grasses and legumes grow well on spoils and greatly reduce erosion and runoff.

VEGETATION

Harper (1943) described the trees in the Basin Region of Alabama. This region includes both the Cordova and the Searles test areas. Harper published the following list of trees and their habitats.

Larger Trees

Pinus Taeda (short-leaf pine)	throughout
Pinus echinata (short-leaf pine)	Dry uplands
Pinus Virginiana (Cliff pine)	Cliffs and bluffs
Fagus grandifolia (beech)	Ravines and bluffs
Pinus palustris (long-leaf pine)	Poorest soils
Quercus falcata (red oak)	Dry woods
Quercus alba (white oak)	Woods
Liquidambar Styraciflua (sweet gum)	Various habitats
Acer rubrum (red maple)	Branches
Liriodendron Tulipifera (popular)	Ravines
Quercus stellata (post oak)	Dry woods
Quercus Marylandica (black-jack oak)	Driest soils
Quercus montana (chestnut oak)	Rocky slopes
Quercus nigra (water oak)	Along streams
Hicoria alba (hickory)	Dry woods
Quercus velutina (black oak)	Dry woods
Platanus occidentalis (sycamore)	Creeks and rivers
Ulmus alata (elm)	Dry bluffs, etc.
Quercus coccinea (Spanish oak)	Dry woods
Nyssa sylvatica (black gum)	Dry woods

Betula nigra (birch	Creeks and rivers
Magnolia glauca (bay)	Along branches
Hicoria glabra (pig-nut hicory)	Dry woods
Tilia sp. (lin)	Rich woods
Quercus Michauxii (swamp chestnut oak)	Bottoms
Quercus Phellos (willow oak)	Bottoms
Fraxinus Americana (ash)	Rich bottoms
Juniperus Virginiana (cedar)	Dry bluffs
Quercus Muhlenbergii (chinquapin oak)	Dry bluffs
Celtis Mississippiensis (hackberry)	River banks
(Diospyros Virginiana) (persimmon)	Old fields
Ulmus Americana (elm)	Bottoms
Prunus serotina (wild cherry)	Ravines
Magnolia acuminata (cucumber tree)	Ravines
Quercus borealis maxima (red oak)	Ravines
Ulmus serotina (elm)	Rich ravines
Quercus laurifolia (oak)	Sandy river banks

Smaller Trees

Cornus florida (dogwood)	Dry woods
Salix nigra (willow)	Along streams
Ostrya Virginiana	Bluffs, etc.
Carpinus Caroliniana (iron wood)	Along streams
Morus rubra (mulberry)	Bottoms
Acer leucoderme (sugar maple)	Ravines and bluffs
Oxydendrum arboreum (sourwood)	Bluffs, etc.
Magnolia macrophylla (cucumber tree)	Ravines, etc.

Viburnum rufidulum (black haw)	Bluffs, etc.
Ilex opaca (holly)	Ravines and bottoms
Cercis Canadensis (redbud)	Ravines and bluffs
Cladrastis lutea (yellos-wood)	Ravines and bluffs
Crataegus spathulata (red haw)	Dry woods
Fraxinus quadrangulata (ash)	Dry bluffs
Sassafras variifolium (sassafras)	Various habitats
Prunus Americana (wild plum)	Rich woods

Linda Glenboski (Biology Department, University of Alabama) made a preliminary survey of the vegetation present in strip mined areas for both the Cordova and the Searles test areas. The following list, although not complete, indicates the most common plants of the two areas.

Common Trees

Paulownia tomentosa	Side and base of spoils
Pinus taeda	Side and base
Pinus virginiana	Base of spoils
Diospyros virginiana	Base of spoils

Occasional Trees

Platanus occidentalis	Base of spoils
Cornus sp.	Base of spoils
Acer sp.	Base of spoils
Salix nigrum	Side of spoils
Liquidumbar styraciflua	Base of spoils

Common Shrubs

Ambrosia artemisiifolia	Base of spoils
Rhus copallina	Base of spoils
Rhus typhina	Base of spoils
Phytolacca americana	Sides, tops, and base

Herbs and Grasses

Andropogon sp.	Sides of Spoils
Aster Spp.	Sides of Spoils
Solidago Spp.	Sides of Spoils
Chenopodium album	Sides of Spoils

This preliminary survey indicates that the vegetation is quite different from that originally described by Harper, due most probably to the disturbance by the mining activities. By studying the vegetation on various mining sites, successively abandoned over the years, one could probably determine the plant succession on the sites thus far, as well as predict future stages in this process. Perhaps the second year's efforts will allow us to delve deeper into this problem.

Percent Pine Cover in Strip Mined Areas

The percent vegetative cover has been estimated for 58 slopes in the Searles test area, according to the method described in the section on Calculation and Measurement. Visible vegetative cover is predominantly pine trees because the photographs were taken in December, 1973. Thus no attempt has been made to estimate the amount of vegetation that did not have leaf cover in December. Similar attempts to estimate pine cover in the Cordova area have not been made because most mining has been performed since 1967 and these areas were graded during the early 1970's. As a result the vegetation has not attained sufficient size to be recognizable in the 1/25,000 scale photographs.

Table 7 summarizes the data for percent pine cover on strip mine spoils from frames 0167 and 0170 in the Searles area, for the twenty year period from 1944 to 1964. Each sub-area is identified as to age, NASA frame number, facing direction of the slope, and whether the slope is steep (36^{o}), or gentle (top of spoils and slopes less than 36^{o}). We have no evidence to indicate that parts of the Searles area

Table 7

Percent Pine Cover on Strip Mine Spoils
Searles Area Frames 0167 and 0170

Area	Facing Direction	Steep Slopes	Gentle Slopes & Tops	Average Steep	Average Gentle
1944 (0167)	N	95+	95+		
	S	95+	95+		
	E	95+	95+		
	W	95+	95+		
1944 (0170)	N	55	75		
	S	26	55	64	70
1949 (0167)	N	60	22		
	S	18	42		
	SW	36	54		
A 1955-60 (0170)	N	14	50		
	S	2	43		
	SW	22			
	W	64			
	NW	18			
B 1955-60 (0170)	N	58	52		
	E	17	47		
	S	24	26		
	W	16	33		
C 1955-60 (0170)	E	8	30		
	SE	4	18	20	45
	S	24	40		
	SW	16	28		
	W	8	46		
	NW	14	34		
1957 (0170)	SE	--	78		
	SW	5	69		
A 1958 (0170)	N	16	24		
	S	16	80		
D 1958 (0170)	S	--	60		
1959 (0170)	S	--	63		
	NW	27	26		

Table 7

(Continued)

Area	Facing Direction	Steep Slopes	Gentle Slopes & Tops	Average Steep	Average Gentle
1960 0170)	N	9	16		
	S	10	30		
	E	4	20		
	W		24		
C 1961-62 (0167)	SE	12	46		
	S	9	24		
	SW	8	24		
	W	12	30		
	NW	30	--		
A 1961-62 (0167)	N	0	60		
	S	6	56		
	W	13	18		
	NW	27	34	12	29
D 1961-62 (0167)	SE	27	34		
	NW	28	24		
1962 (0170)	N	--	44		
	W	6	37		
1963 (0170)	E	1	--		
	SE	1	6		
	W	1	18		
D 1963-64 (0170)	N	22	32		
	E	--	22		
	SE	6	--		
	S	16	--		

1968 through present

essentially no visible vegetation. Almost all areas have been graded and planted with pine seedlings.

mined prior to 1968 were reclaimed by any method other than natural plant succession. Therefore, percent pine cover may indicate the rate of natural reclamation by pine growth, but the study must be considered preliminary.

There is wide variation among the data; however, it indicates that,as a general rule, natural regrowth of vegetation in strip mined areas tends to cover gentle slopes more quickly and more completely than steep slopes. Further summation of the data (Table 8) by averaging it within specific age periods (1944-49, 1955-60, and 1960-64) indicates that steep slopes facing in a northern direction have a slightly higher percent of pine cover than southern facing slopes. This, however, may not be the case for these strip mines in the 1944-49 age bracket.(The limited number of available data in this age group precludes conclusion.)

The last two columns in Table 8 give the average percent pine cover for all slopes within each age group. This data is shown in graphic form in Figure 15 , and indicates that steepness of slope is an important factor in revegetation of strip mines by pine trees. Figure 10shows that for the first twenty years after mining steep slopes have about 20 percent less pine cover than gentle slopes. Thirty years after mining may be sufficient time for natural establishment of approximately equal pine cover on steep and gentle slopes.

It is obvious that more research pertaining to pine cover, general vegetative cover, rates of growth, plant succession, vegetative stress and lag times is necessary in order to confirm ideas on natural vegetation of strip mined land.

Table 8

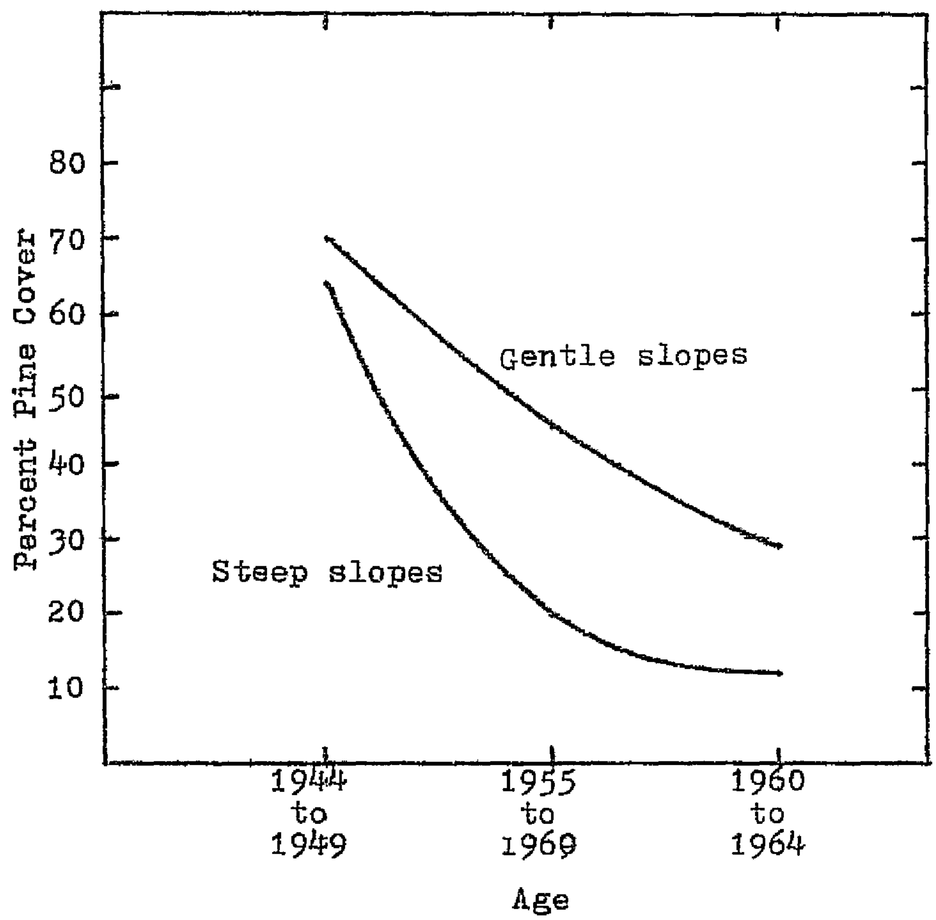
Searles Area (Summary)
Average % Pine Cover and Facing Direction
Frames 0167 and 0170

Areas	Facing	Steep	Gentle and Tops	Average % Cover Steep Slopes	Average % Cover Gentle Slopes
1944-49	N	70(3)*	64(3)		
	S	46(3)	64(3)	64	70
	E	95(1)	95(1)		
	W	95(1)	95(1)		
1955-60	N	29(3)	42(3)		
	E	13(2)	39(2)		
	SE	4(1)	48(2)		
	S	17(4)	52(6)	20	45
	SW	14(3)	49(2)		
	W	29(3)	40(2)		
	NW	20(3)	30(2)		
1960-64	N	10(3)	38(4)		
	E	3(2)	21(2)		
	SE	12(4)	29(3)	12	29
	S	10(4)	37(3)		
	SW	8(1)	24(1)		
	W	8(4)	25(5)		
	NW	28(3)	29(2)		

*( ) number of slopes in average

Figure 10

Percent Pine Cover vs. Age
Searles Test Site



E R O S I O N

INTRODUCTION

Estimation of the effects of time has been a major difficulty in quantitative investigations of the evolution of landforms. As a result, most investigations of the processes of erosion reflect intuitive observations, or utilize labratory scale models. Few studies represent quantitative field measurements or quantative evaluation of slope evolution.

Slope evolution results from mass wasting and erosion. Sheet erosion, resulting from overland flow of water, is the dominant process initiating slope erosion and, according to Emitt (1963), represents from 66 to 100 percent of the sediment yield in the southeastern United States. Any phenomena which tends to channelize overland flow can initiate rill erosion. Rilled surfaces present a striated appearance in plane and a finely serrated appearance in cross-section. Rill systems can terminate in the formation of gullies, which involves the process of deepening and widening of rill channels by headward erosion, micropiracy, and continual destruction of divides between rill channels (Horton, 1945).

This study, as a contribution to quantitative investigations of the processes of erosion, will concentrate specifically on rill and gully erosion of spoil banks from surface mining of coal. Spoil banks, resulting from strip mining, have steep slopes, are composed of unconsolidated material, and due to sparse vegetation, have accelerated erosion rates. The erosional processes acting on spoil banks are accelerated and slopes evolve in a much shorter length of time than do natural slopes, therefore strip mined lands are suitable localities to make detailed studies of the processes of erosion and to evaluate slope evolution.

Location And Description Of Study Area

Due to lack of vegetation, the erosional and sedimentation processes of strip mined lands in the study area simulate the arid cycle of erosion. Several geomorphological features (similar to bolsons, playa lakes, alluvial fans, and pediments) commonly associated with arid climates are found within the strip mined areas. Similiar occurrences have been reported elsewhere including; the badlands at Perth Amboy, New York, (Schumm, 1956); the Ducktown Copper Basin of Tennessee, (Hursh, 1948); and strip mined areas of the Beaver Creek Basin in Kentucky (Musser, 1970).

The specific purpose of this investigation is (1) to study the evolution of slopes relative to time, and (2) to establish techniques by which the volume of rill and gully erosion on slopes can be determined. In order to approach these objectives, slopes of different ages were chosen and the characteristics of each slope determined. Then the volume of material removed by rill and gully erosion was determined by direct measurement and related to other variables (area of divides, and area of rills and gullies). The data was then refined to arrive at a technique which was ameable to rapid volume determination rather than direct measurement.

METHODS OF INVESTIGATION

Field work was undertaken from May through August of 1974 and consisted of essentially three phases of investigation. These were: (1) an initial field reconnaissance and selection of slopes for study, (2) mapping and measurements of rills and gullies, and (3) sampling and grain size analysis of material in spoil banks.

Selection And Description of Slopes

Within the 953 hectares of land affected by surface mining in the Searles area, twenty slopes were selected for study. Several factors were considered in the selection of specific spoil banks for study. These factors are: (1) age of spoils, (2) slope angle and extent of reclamation, and (3) the amount of vegetal cover on spoil banks.

Age of Spoils

One of the major factors involved in slope selection was the age of spoil banks. Time since mining is of major importance to establish trends of slope evolution and to relate the volume of material removed from spoil banks to time. An initial field reconnaissance was undertaken with the aid of Mr. Cecil Armor to determine specific dates of mining of localities in the study area.

Slopes selected for study are of various ages from 1955 to 1974 and are placed into one of four age groups: (1) 1955 to 1960, (2) 1961 to 1965, (3) 1966 to 1970, (4) 1971 to 1974. The 1944 to 1949 group was deleted because these spoils attained sufficient vegetal cover to inhibit rill and gully erosion as will be discussed below. No mining was undertaken from 1950 to 1954.

Slope Angle

Prior to 1966, essentially no reclamation was undertaken in the Searles area. Spoil banks chosen for study in areas mined after this time are the outslopes of reclamed sites. Therefore, slopes selected for study are ungraded and unreclamed and are at an angle corresponding to the angle of repose of spoil materials.

The works of Renner (1939) and Horton (1945) indicate that slope angle is an important variable related to erosion. Horton's Slope Function (see figure 11) illustrates that erosion increases with slope angle and reaches a maximum on 40 degree slopes and thereafter, decreases to zero as the slope angle approaches 90 degrees. Actual measurements of sheetwash as related to slope angle (Dillon, Massingill, and White, 1973 indicate that maximum erosion occurs on slopes of 35 to 50 degrees (see figure 12). A histogram of the twenty slopes selected for study shows that slope angle varies from 31 to 38 degrees and that the modal class is 36 degrees (see figure 13). Therefore, slopes selected for study are at such an angle to enhance maximum erosion.

Vegetation of Spoil Banks

Slopes selected for study have little or no vegetal cover of any type (trees, shrubs, or grasses). Vegetation impedes the erosional processes; therefore, slopes with significant vegetal cover were not selected for study.

Figure 10 relates the extent of pine tree growth to age of spoil banks for steep (36 degrees) and gentle (approximately 15 degree) slopes and is an indication of the extent of vegetation on spoil banks. The graph indicates that no significant pine tree growth (less than 10 percent coverage) occurs on steep or gentle slopes in areas mined from 1960. Figure 10 also shows that steep slopes attain only 20 percent coverage in areas mined after 1955. Therefore, steep slopes in areas mined after 1955, in general are sparsely vegetated.

Figure 10 shows that steep and gentle slopes in areas mined from 1944 to 1949 attain vegetative coverage of 60 to 70 percent, which retards development of rills and gullies. Therefore, those areas

FIGURE 11

HORTON SLOPE FUNCTION FOR SURFACE EROSION

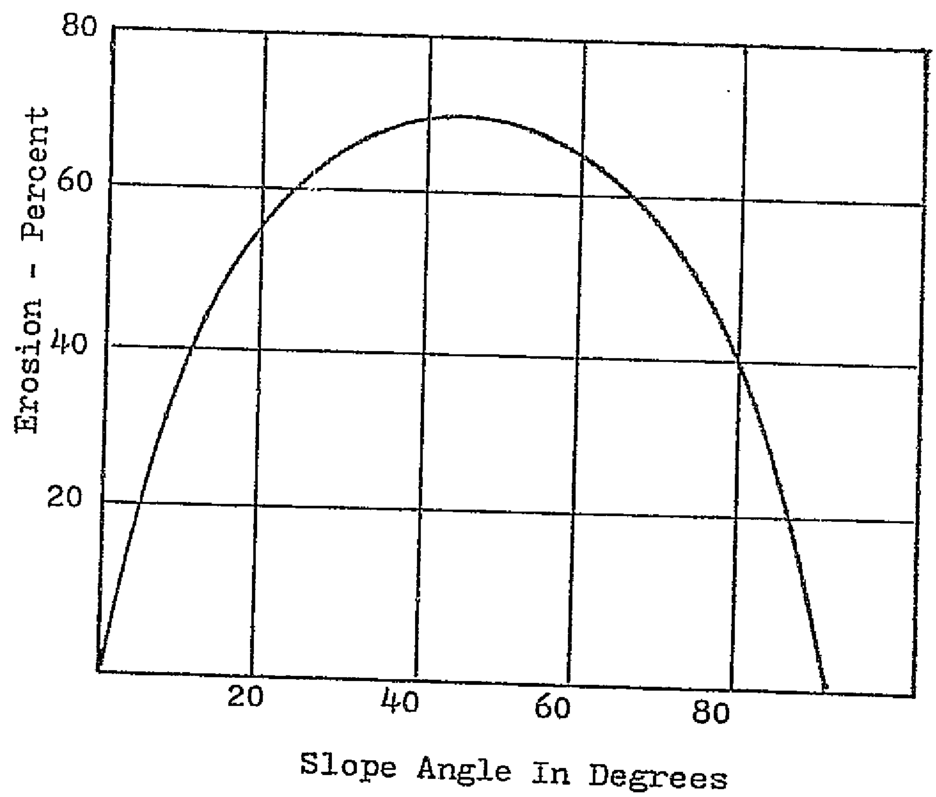


FIGURE 12

EROSION VS. SLOPE ANGLE

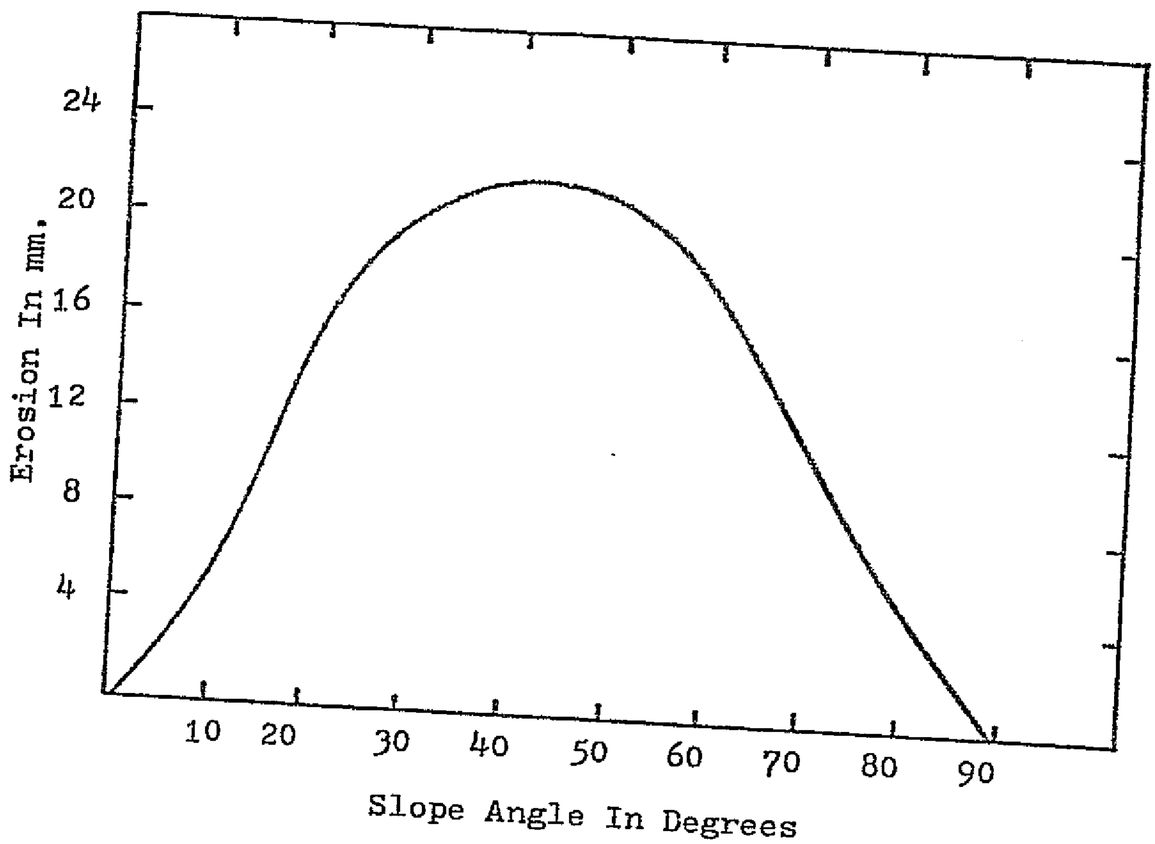
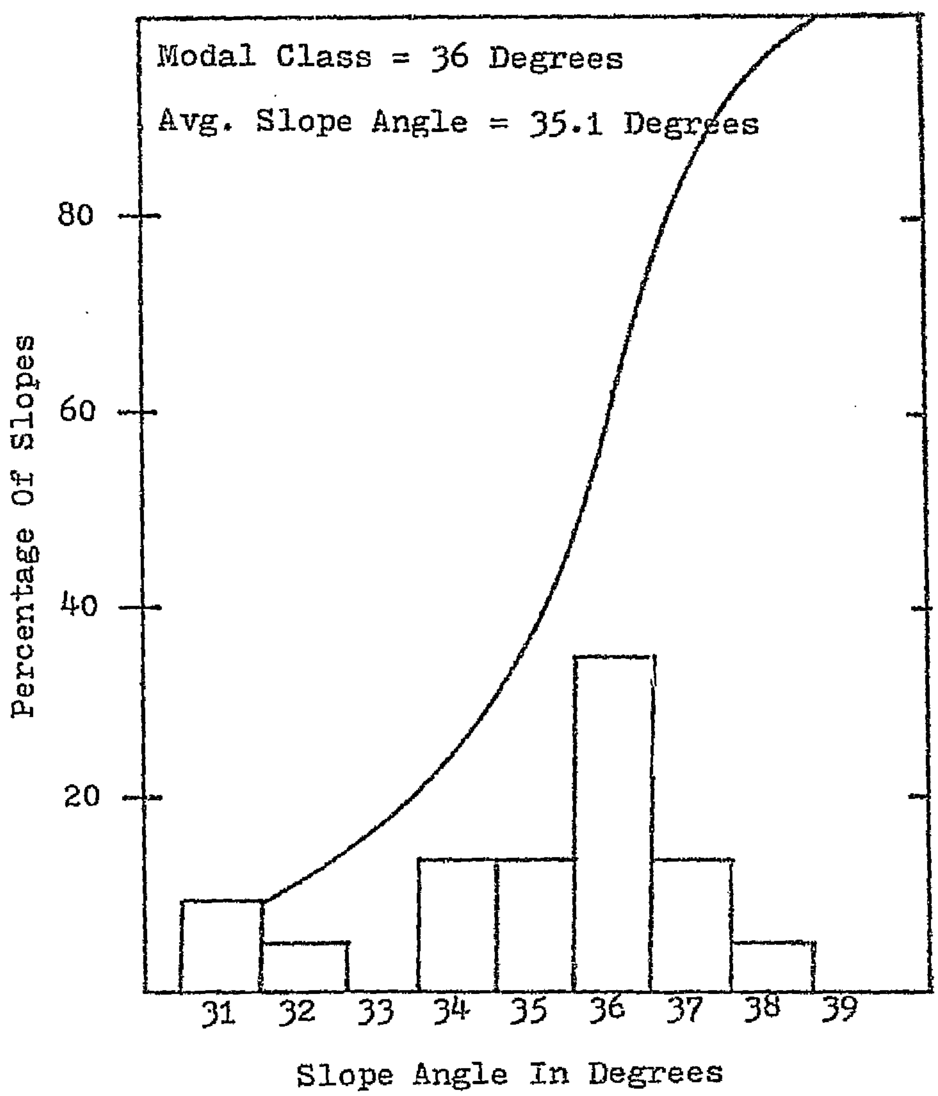


FIGURE 13

HISTOGRAM OF SLOPE ANGLES



mined after 1955 are deleted from study.

Mapping And Measurements Of Rills And Gullies

Field measurements involved the mapping and measurement of rills and gullies on spoil banks and were undertaken utilizing slope maps. Slope maps are generally used to depict steepness of slope over an entire ground surface (Strahler, 1956, p. 573). Spoil banks have a straight line profile and a constant slope angle corresponding to the angle of repose of spoil materials. Therefore, in this study, slope maps represent the slope surface of individual spoil banks.

Individual slopes were mapped in the field and slope maps made for each of the twenty spoil banks selected for study. The mapping proce . .e involved the placement of a series of stakes on each slope at points of equal elevation (see figure 14 .) Stake implacement was accomplished by means of plane table and self-leveling alidade. Lines, marked in one foot incriments, were then stretched between stakes of equal elevation, thus establishing a grid system by which rills and gullies could be accurately located, mapped, and measured. Figure 14 is a schematic drawing illustrating the use of the slope map to map and measure rills and gullies.

The volume of individual rills and gullies can be easily calculated since rills and gullies have a valley profile that is "V" shaped. The cross-sectional area of a rill at any point along the rill is equal to one-half the rill width multiplied by the rill depth (rill width being measured from the line distance and the depth perpendicular to the slope). The volume of a rill can be determined by multipling the average cross-sectional area of the rill by the length of the rill. In figure 14 the area of a rill at point P = 1/2 width x depth. The same is true for the area of the rill at points P' and P".

The rill volume is determined by averaging the cross-sectional area of the rill at 3 points and multiplying by the distance between the 3 points. In reference to figure 14, the total rill volume is:

$$\text{Rill Volume} = \frac{(A_R P + A_R P')}{2} L_1 \qquad \frac{(A_R P' + A_R P'')}{2} L_2$$

where, A_R = Rill cross-sectional area at a point along the rill.

L = Length of rill between points.

and, P,P'P" = Specific points along the rill.

The total volume of material removed from an individual slope is determined by totaling the volume of individual rills and gullies on that slope.

Data obtained from slope maps was used for calculations of true slope area, map area, divide area, gully area, and gully surface area; all are useful parameters to establish trends in slope evolution and are defined as follows:

True Slope Area - The actual planar area of a slope (see figure 14).

Map Area - The area of a slope as visualized from aerial photographs or topographic maps (Map Area = cos θ x True Slope Area; see figure 14).

Gully Area - The imaginary surface area overlying rills and gullies (see figure 14).

Divide Area - That portion of the slope between individual rills and gullies (see figure 14).

Gully Surface Area - The surface area exposed in the sides and bottoms of rills and gullies (see figure 14).

Table 9 is a summation of the data obtained from slope maps of each of the 20 slopes selected for study.

In this study, calculations of volumetric and areal measurements

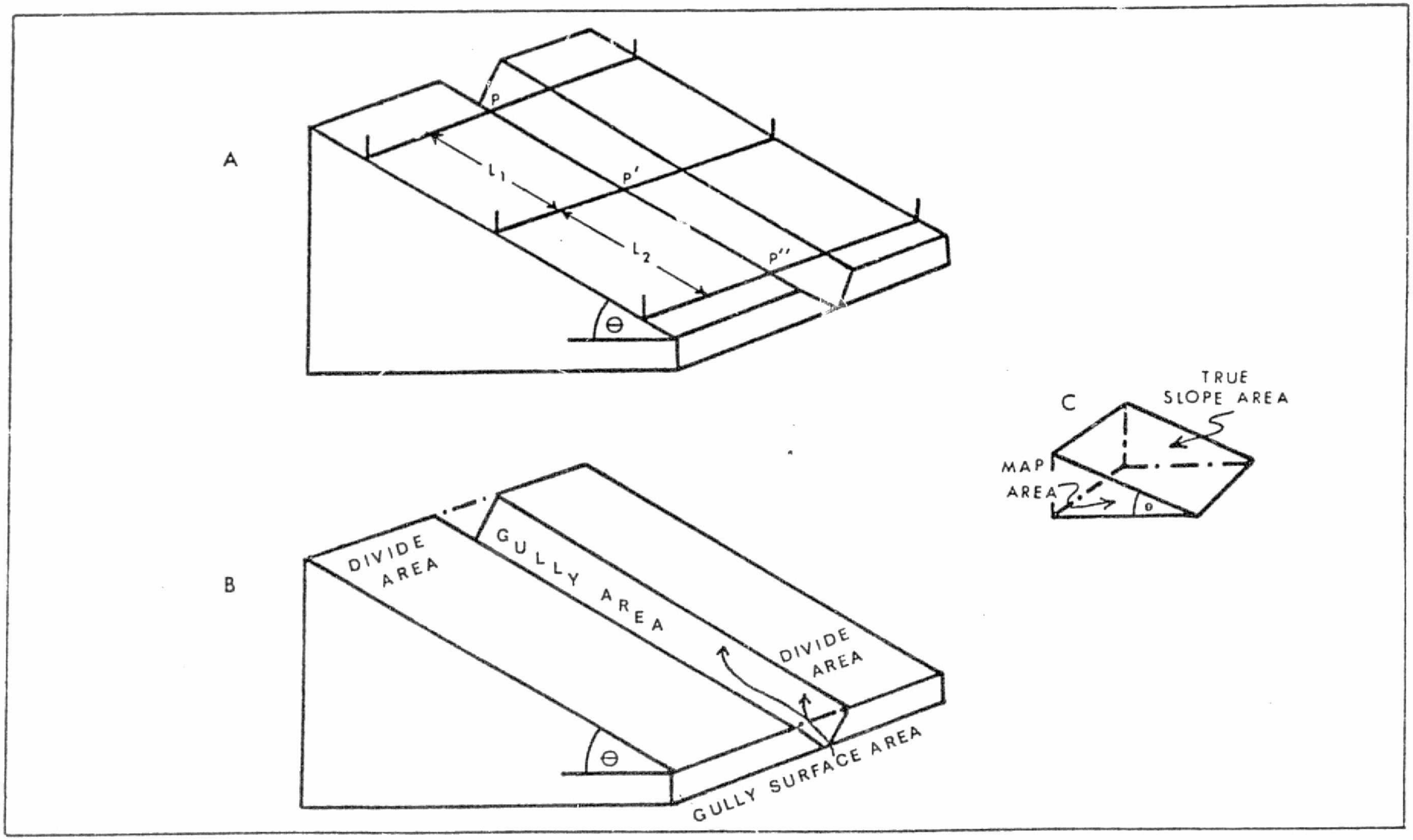


Figure 14 Schematic drawing illustrating (A) use of slope map, (B) divide area, gully area, and gully surface area, and (C) true slope area and map area.

TABLE 9
SUMMARY OF DATA OBTAINED FROM SLOPE MAPS

Slope No.	Date of Mining	V m^3/hec.	A_D m^2/hec.	A_G m^2/hec.	A_{GS} m^2/hec.	AD/AS %	AG/AS %	Facing Direction
1	1973	666	8001	4354	4836	64	36	N
2	1972	1313	9933	2402	7500	80	20	N
3	1973	1108	9309	3075	7996	75	25	W
4	1972-73	1595	8761	3885	5216	69	31	NW
5	1971-72	551	8478	4169	6105	67	33	W
6	1973	1190	6897	5078	6544	56	44	S
7	1970	581	8278	4022	5760	66	33	SW
8	1968-69	2226	4804	7526	10284	39	61	W
9	1968-69	1555	8173	4811	11175	60	39	SW
10	1962	1033	6445	5765	6830	52	48	SW
11	1962	2407	4366	7992	12454	36	65	NE
12	1961-62	2658	7571	10968	14646	12	88	S
13	1963	3614	4794	7380	8921	39	61	SW
14	1961-62	1666	2417	9932	11672	19	81	N
15	1962	2110	6344	5958	9388	51	49	S
16	1961	2920	3115	9430	12492	25	75	SE
17	1957	4261	3361	8982	10496	27	73	NW
18	1957	3061	5033	7332	9515	40	60	SE
19	1956	7302	2888	9472	14430	23	77	W
20	1955	10881	3735	8584	11674	30	70	SE

V = Volume of material removed by rill and gully erosion
A_D = Area of divide
A_G = Gully area
A_{GS} = Gully surface area
AS = True slope area

are expressed in cubic meters or square meters per hectare. Because of the possible confliction of terms, the reader should be aware of the application of true slope area and map area in this study. Divide area, gully area, gully surface area, and volume of material removed are indicative of true slope area per hectare. The hectare, indicates map area (true slope area x cos. θ).

Grain Size Analysis of Spoil Materials

All slopes selected for study were sampled and sieve analysis conducted of samples to determine the grain size of materials in spoil banks. The sampling procedure, as discussed below, is sufficient to adequately describe the average size of spoil materials; however, a detailed statistical analysis of spoil materials would require a much more complex sampling procedure and entail collecting a greater number of samples than was considered necessary by the author for this study.

The sampling procedure involved collecting 10 samples (approximately 1000 grams each) from each slope. Five sampling sites were randomly selected for each slope. At each site, two samples were collected (one at the surface and one at a depth of approximately 15cm) to determine variations in size of spoil materials with depth. All the surface samples for each slope were mixed, as were those collected at a depth of approximately 15 cm, and standard sieve analysis techniques as outlined in Folk (1974) were followed.

Cumulative curves are plotted for the data obtained from sieve analysis of each sample. The modal class, median size, and the weight percent gravel, sand, and silt and clay were determined for each sample and are listed in Table 10. From the cumulative curves it is evident that the surface samples as well as those taken at depth have a high percentage of gravel by weight and the modal class for most samples is

TABLE 10

	Aug % Gravel	Aug % Sand	Aug % Silt & Clay
Surface Samples	74.54	21.08	4.38
Depth Samples	62.5	33.71	3.79

Average percent by weight of gravel, sand, and silt and clay of spoil materials.

-3 phi (8 to 12 mm. in diameter). Grain size analysis indicates that the surface samples have a higher percent gravel than those samples taken at depth as expected. As an average, the surface samples are 75 percent gravel and 21 percent sand by weight, and those samples taken at depth are 63 percent gravel and 34 percent sand by weight. There is little variation in the amount of silt and clay in the samples.

SLOPE EVOLUTION

Slopes erode and change with time. Spoil banks are subjected to accelerated erosion rates, and the trends of slope evolution are therefore much more obvious than on natural slopes. Slopes are comprised of rill and gully channels which are separated by flat planar surfaces termed divide areas. Rills and gullies change and evolve with time and, in essence, control the evolution of slopes.

The distinctions between the terms "rill" and "gully" are poorly defined in the literature, and most authors simply consider that gullies are much larger than rills. Rills are often referred to as "shoe string gullies" (Horton, 1945, p. 289); "micro-channels" (Young, 1973, p. 105); or "small trickling streams of water" <u>AGI Dictionary of Geologic Terms</u>. Gullies, on the other hand, are often defined as "small ravines" <u>AGI Dictionary of Geologic Terms</u>, or "erosional channels so deep that they cannot be crossed by wheeled vehicles or eliminated by plowing" (Cook and Doornkamp, 1974, p. 79). A good description of a gully is proposed by Brice (1966, p. 279) as "a recently extended drainage channel that transmitts ephemeral flow, has steep sides, a steep sloping or vertical headwall, with a width greater than .3 meter and a depth greater than .6 meter." The author agrees with Brice's definition except for the limits of width and depth placed upon gully size. The author feels that size limitations of gullies may well vary with soil properties such as grain size and cohesion.

Investigations by the author of rills and gullies indicate that distinctions between these two erosional channels can be based upon characteristics of the channel profiles. In this study, the term "rill" shall define an erosional channel which has a straight line bottom, and that approximately parallels the slope profile. The term "gully" implies a channel in which the profile has a gentle downslope section that abruptly meets a steeper headwall.

The following discussion of slope evolution includes two geometric slope elements: (1) linear elements of slopes, and (2) areal elements of slopes. Linear elements of slopes include slope profiles and channel profiles of rills and gullies. Areal elements of slopes are: divide area, gully area, and gully surface area. Each of these geometric elements of slope evolution is discussed individually below.

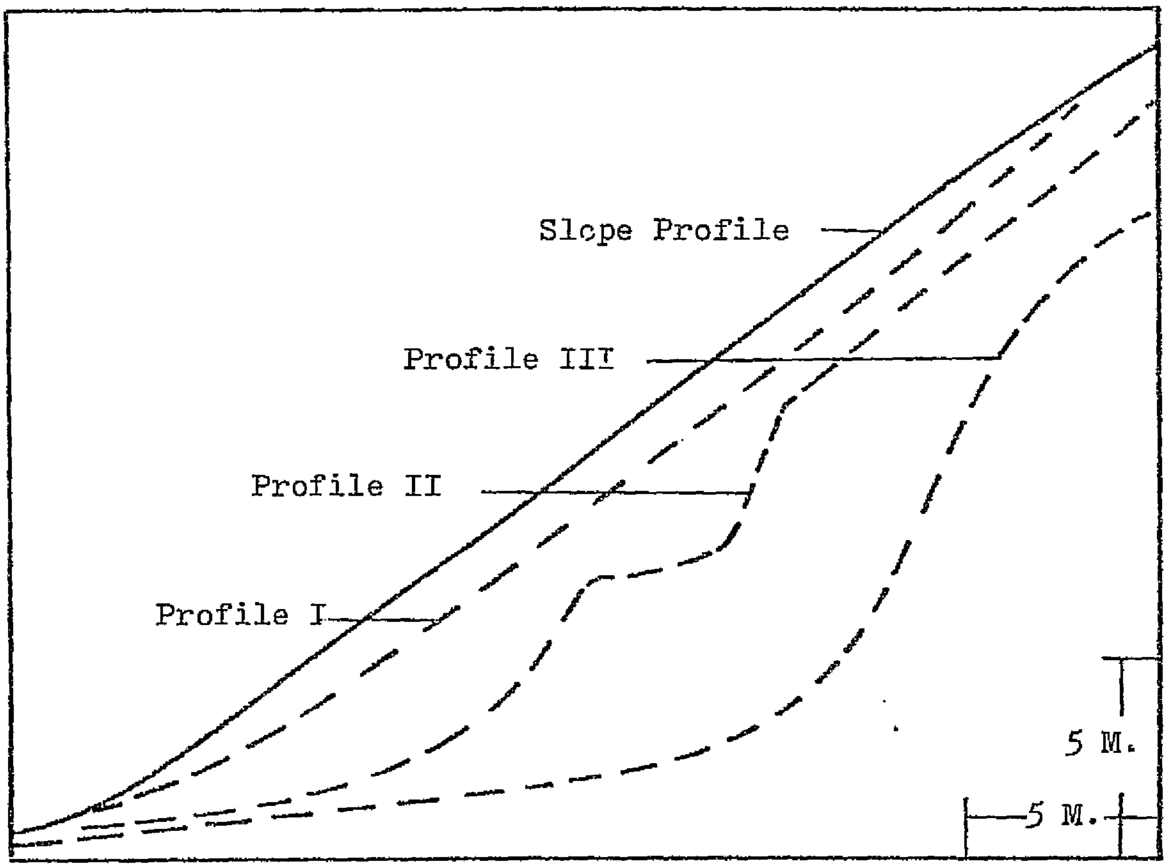
Linear Elements Of Slope Evolution

The author observed three separate stages that are inherent in the evolution of rills and gullies. Indivdual stages can be defined by channel profile characteristics and somewhat delineated by time. These stages shall be referred to as (1) an initial rill stage, (2) an intermediate stage, and (3) a final gully stage. Rill and gully channel profiles can illustratively be divided into three distinct stages; however, the processes of erosion are continuous and there is overlap between the stages. Figure 15 is a schematic drawing illustrating rill and gully profile migration. The profiles drawn are listed by age and are representative of rill and gully channels of each stage of profile migration.

The initial rill stage, stage (1), is characterized by a channel profile that is straight and indicates that rills have a nearly straight

FIGURE 15

RILL AND GULLY PROFILE MIGRATION



Profile I - 1973 - 666 m^3/hec.
Profile II - 1962 - 2407 m^3/hec.
Profile III - 1955 - 7382 m^3/hec.
Slope Profile - 36 Degrees

line bottom (profile I, figure 15). Rill depth increases only slightly downslope and thus, the rill profile approximately parrallels the slope profile (see figure 15). This initial stage exists for three to six years until nickpoints begin to develop in the rill channel and stage (2), or the intermediate stage, begins.

Stage (2) has a channel which is characterized by a series of nickpoints that are caused by boulders of sandstone and shale in the channel which impede verticle downcutting (see figure 15). The channel profile of the intermediate stage assumes a stair step appearance (profile II, figure 15). Stage two lasts for approximately six to eight years and is generally found on spoil banks that date from 1968 to 1960.

Continued erosion eliminates most nickpoints in 12 to 15 years and stage (3) predominates. The channel profile of the gully stage has a gentle or horizontal downslope section which abruptly meets a steep or vertical headwall (profile III, figure 15). The steep portion of the profile results from migration of individual nickpoints by headward erosion to form one conspicious steep headwall.

The slope profile remains constant throughout this process; it is straight and at an angle of approximately 36 degrees from the horizontal as illustrated in figure 15. An undulate slope profile may result in the formation of rill and gully channels differing from those described above; or may, in fact, accelerate the evolutionary process of rill and gully profile migration.

Areal Elements In Slope Evolution

Slopes may be considered as planar surfaces for a short period of time after mining (approximately one year). Essentially, all erosion during this time is accompolished by sheetwash.

In the initial stages of channel erosion, slopes are characterized by numerous small rills which develop into second and third order rill systems by the processes of micropiracy and cross-grading (Horton, 1945, p. 322). Sheetwash continues to operate on divide areas which occupy a large percentage of the slope area (see figure 14). As rills transgress into the intermediate stages by vertical downcutting, divide areas begin to diminish. In the final stages of slope evolution, slopes are characterized by conspicuous gullies that occupy large portions of the slope area originally serrated by rill systems. Divide areas have now decreased to a minimum after approximately 15 to 19 years due to mass wasting on gully walls and convergence of gully channels. The entire slope profile remains linear throughout this process. Divides are eventually eliminated because of continued erosion on gully walls by sheetwash, rill erosion, and mass wasting. The slope profile migrates from one that is linear to a profile which has a convex upslope and concave downslope. Therefore, slope evolution can be relative to divide area, and gully area.

Divide Area

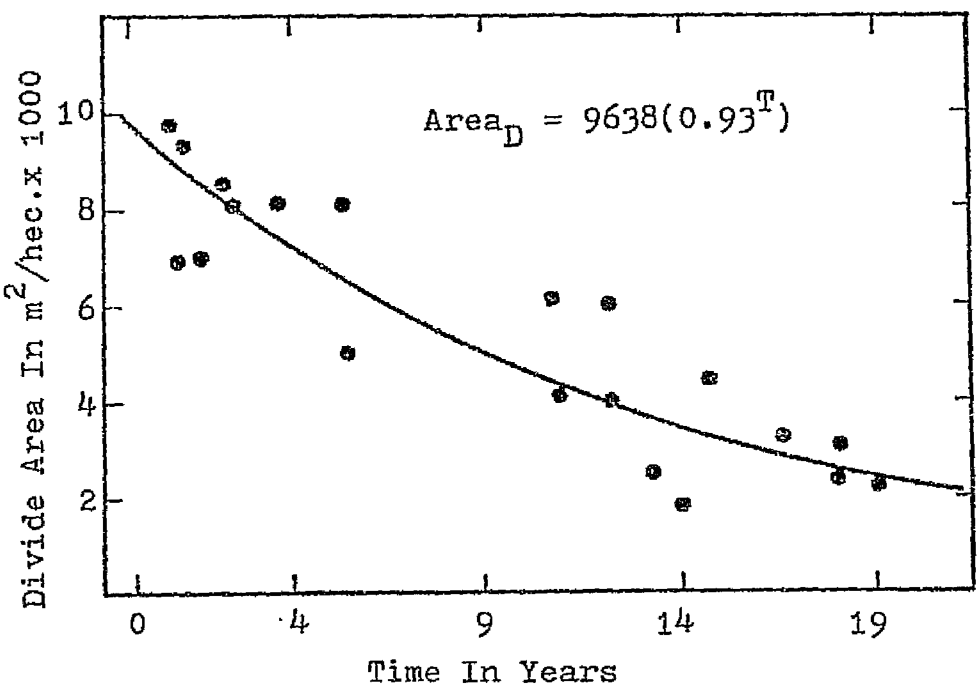
As pointed out above, divide area comprises a large portion of new slope surfaces and with continued erosion, divides are reduced to a minimum. An analysis of the data obtained from twenty slopes in the study area indicates that divide area decreases with time (see Figure 16). A regression line fitted to the points of the scatter diagram in Figure 16 by the method of least squares has the following equation:

$$A_D = 9638\ (0.93^T)$$

where, A_D = Divide area in m^2/hectare.

and T = Time in years.

FIGURE 16
DIVIDE AREA VS. TIME



The standard estimate of error ($s_{y.x}$) is 1.5 and the coefficient of correlation (r) is .80.

Since divide areas occupy large portions of new slope surfaces, measurements of divide area from aerial photographs may be best utilized to indicate the erosional development of younger slopes.

Gully Area

An analysis of the data obtained from twenty slopes indicates that gully area increases exponentially with time as illustrated by figure 17 . The regression line fitted to the data on figure has the equation:

$$A_G = 2478\ (1.07^T)$$

where, A_G = Gully area in m^2/hectare.

and T = Time in years.

($s_{y.x}$ = 1.4; r = .62)

Older spoils are characterized by large gullies that occupy large portions on the slope area originally serrated by rill systems. Therefore, measurements of gully area may be best suited for calculations of the volume of material removed from older spoils where measurements are taken from aerial photographs.

VOLUME OF MATERIAL REMOVED BY RILL AND GULLY EROSION

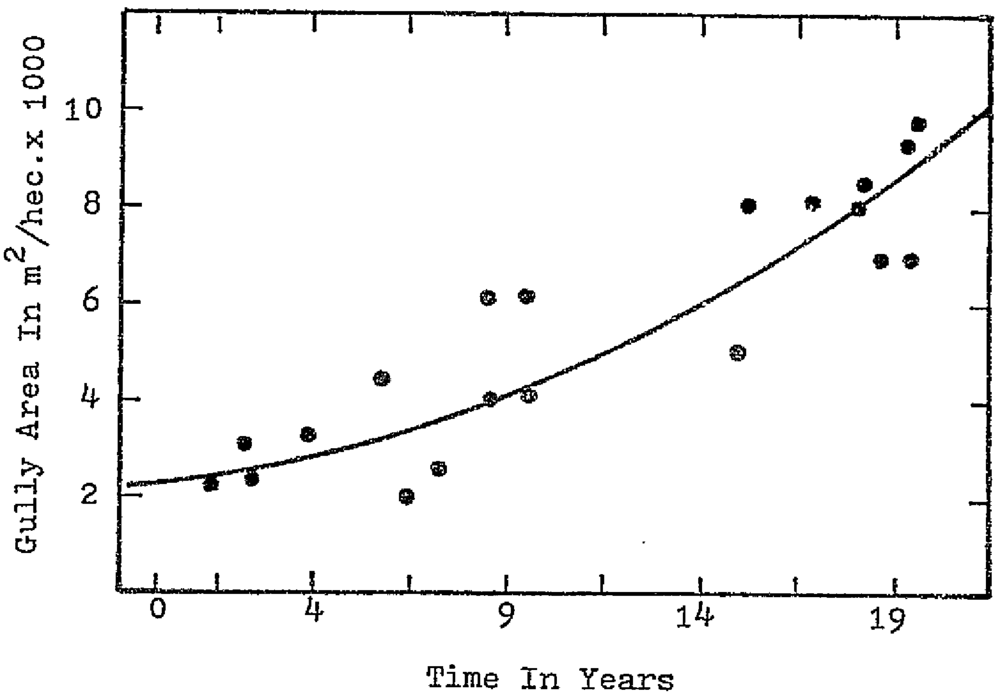
The volume of material removed by rill and gully erosion is discussed relative to time and the areal elements of slopes (divide area and gully area). A technique is devised by which rapid volume determination can be made from measurements of divide area or gully area made in the field or from aerial photographs.

Volume Of Material Removed Vs. Time

Analysis of the data obtained from twenty slopes indicates that the

FIGURE 17

GULLY AREA VS. TIME



volume of material removed by rill and gully erosion increases exponentially with time as illustrated by Figure 18 . From a least squares analysis, the line that best fits the data has the following equation:

$$V = 802\ (1.1^{T})$$

where; V = Volume of material removed in m^3/hectare.

and, T = Time in years.

($s_{y.x}$ = 1.7; r = .70

Figure 18 indicates that, during the first year, there is a high rate of erosion and the volume of material is approximately 880 m^3/hectare, as calculated from the above equation. After the first year, the volume of material removed increases at a rate of 10 percent per year, as illustrated by the regression line in Figure 18 , and the cumulative volume of material removed is 110 percent per year. Therefore, the cumulative volume of material removed increases exponentially with time.

Another interpretation of the data of volume vs. time may be considered. Assuming that the processes of rill and gully erosion occur at different rates, the same data (volume vs. time) may be used to interpret different erosion rates for alternate stages of erosion corresponding to the three stages of slope evolution. The erosion rate would then not be constant as illustrated in Figure 18 ; but would change with time and be dependent on the dominant erosional process.

Figure 19 graphically illustrates these three stages of erosion and the erosion rate change with each stage.

First, there is an initial stage, Stage 1, during the first year, in which the erosion rate is high. During this time, sheetwash removes uncompacted fines from the slope surface.

A second stage of erosion exists when fines have been winnowed and

FIGURE 18
VOLUME OF MATERIAL REMOVED VS. TIME

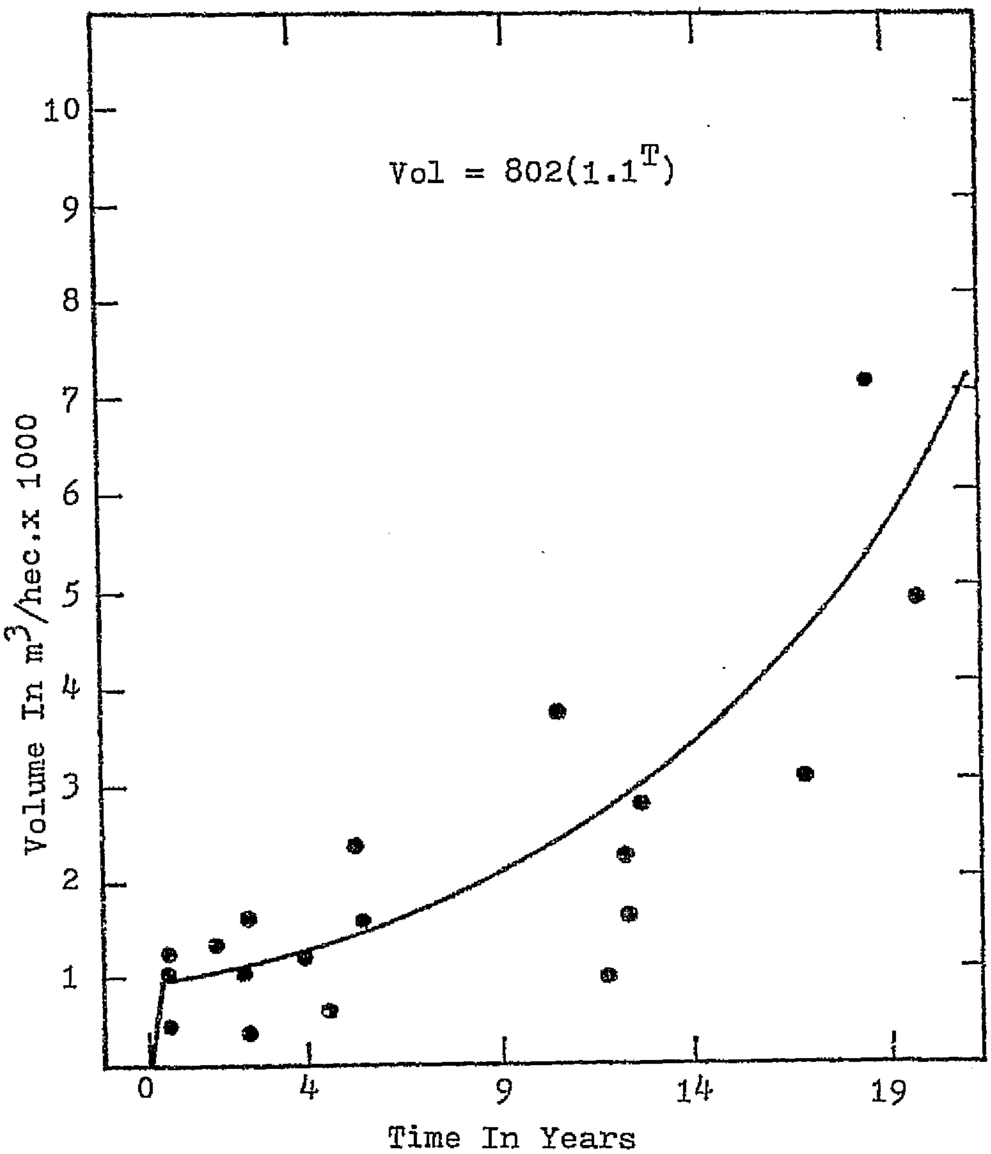
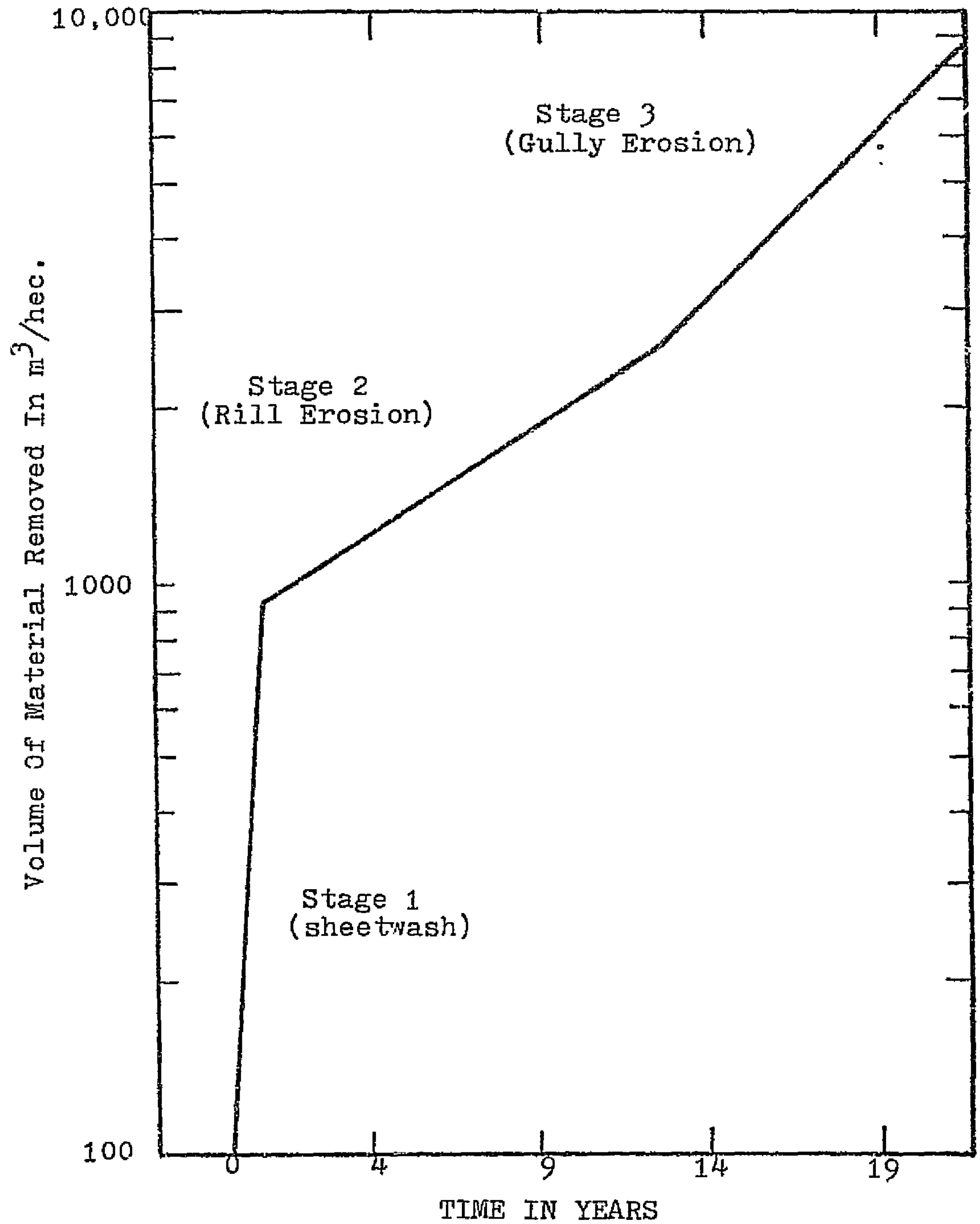


FIGURE 19
EROSION VS. TIME



a case hardened crust of soil, similiar to the duricrust formed in more arid climates, covers the slope surface. The erosion rate decreases due to the resistance of the duricrust. The slope is characterized by rill systems and large divide areas that dominate the slope surface.

After approximately 12 to 15 years, slopes are highly disec[illegible]d by large gullies and divide areas approach a minimum. The erosion rate increases as fresh material is rapidly removed by downward and headward erosion.

Divide Area Vs. Volume of Material Removed

The volume of material removed from slopes increases exponentially with decreasing divide area as illustrated by figure 20 . A regression line fitted to the data by least squares method has the following equation:

$$V = 7079 \quad (0.79^{A_D})$$

where, V = Volume of material removed in m^3/hectare.

and, A_D = Divide area in m^2/hectare.

($s_{y.x}$ = 2.1; r = .51)

Gully Area Vs. Volume of Material Removed

An analysis of the data obtained from twenty slopes in the study area indicates that the volume of material removed increases expoentially with gully area (see figure 21). A regression line fitted to the data by the method of least squares has the following equation:

$$V = 515 \ (1.25^{A_G})$$

where, V = Volume of material removed in m^3/hectare.

and, A_G = Gully area in m^2/hectare.

($s_{y.x}$ = 1.77; r = .66)

FIGURE 20
VOLUME OF MATERIAL REMOVED VS. DIVIDE AREA

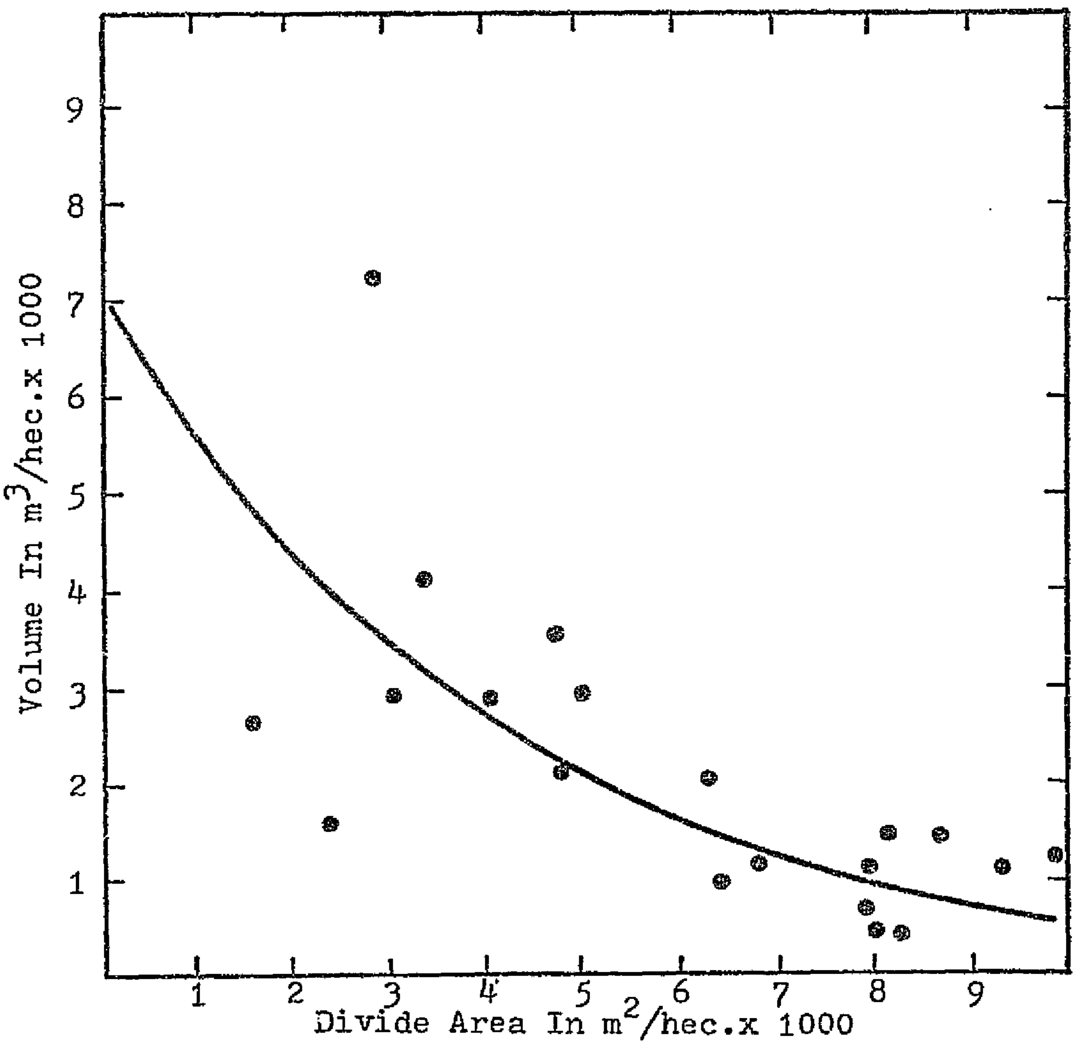
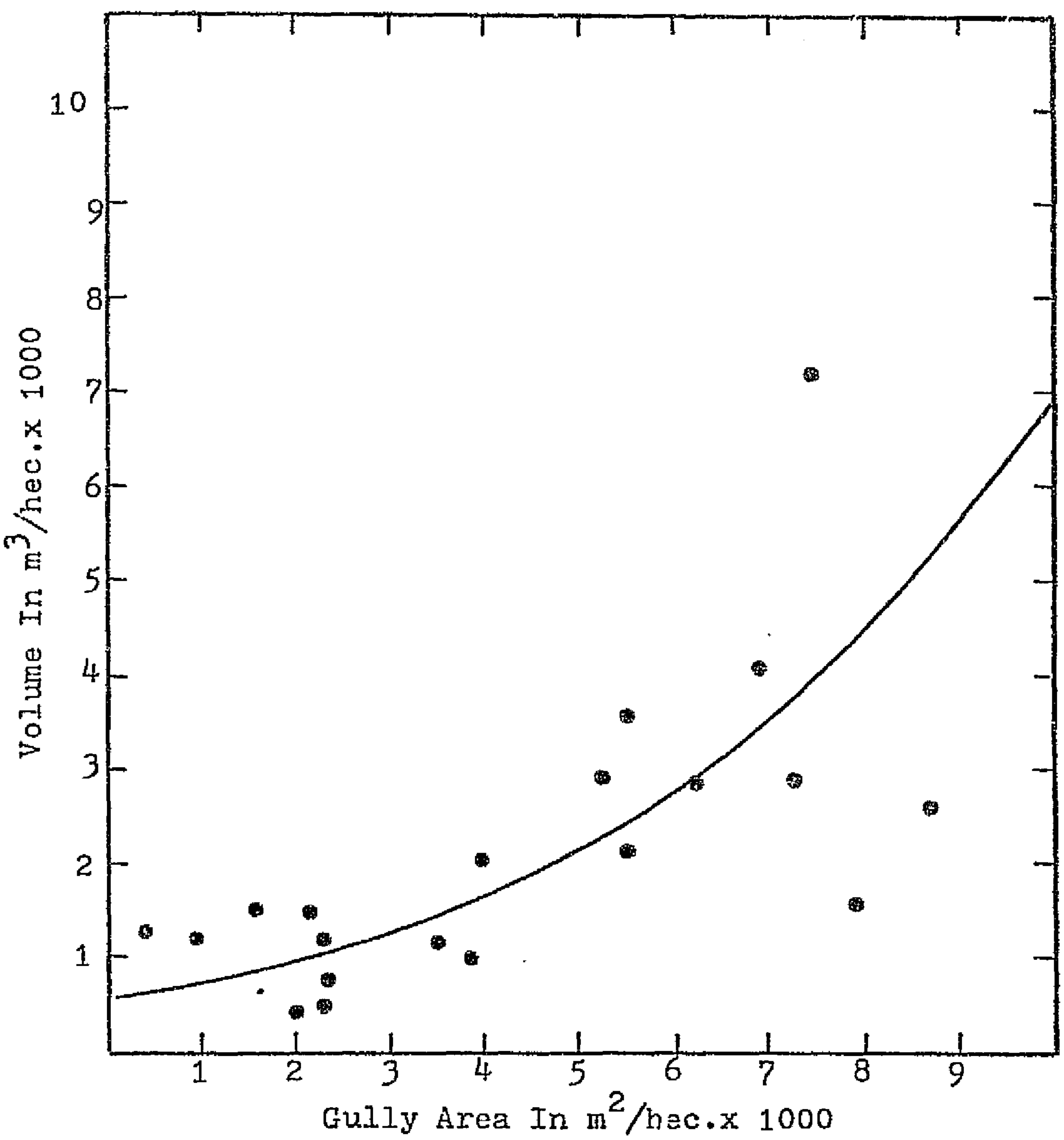


FIGURE 21
VOLUME OF MATERIAL REMOVED VS. GULLY AREA



Techniques For Rapid Determination Of The Volume Of Material Removed
(Monitoring Techniques)

Measurements of divide area and gully area, obtained in the field or from aerial photographs may be used to make reasonable estimates of the volume of material removed from slopes by rill and gully erosion. The system may be further adapted to compensate for variance in slope angle.

For convenience, divide area and gully area are expressed as a ratio of the slope area. These relationships (divide area/slope area, gully area/slope area) compensate for differences in slope area in various localities and allow that calculations of the volume of material removed be easily made from aerial photographs.

The volume of material removed increases exponentially as the ratio of divide area to slope area decreases as illustrated by figure 22 . The regression line that best fits the data has the following equation:

$$V = 7568\ (0.05^{A_D/A_S})$$

where, V = Volume of material removed in m^3/hectare.

and, A_D/A_S = The ratio of divide area to slope area

$(s_{y.x} = 1.7,\ r = .66)$

Since divide areas occupy large portions of new slope surfaces, measurements of divide area may be best utilized to determine the volume of material removed from younger slopes.

The volume of material removed by rill and gully erosion increases exponentially with the ratio of gully area to slope area. The regression line fitted to the data has the following equation:

$$V = 378\ (20^{A_G/A_S})$$

where, V = Volume of material removed in m^3/hectare.

and, A_G/A_S = The ratio of gully area to slope area.

$(S_{y.x} = 1.7;\ r = .52)$

FIGURE 22

RATIO: DIVIDE AREA/SLOPE AREA VS. VOLUME OF MATERIAL REMOVED

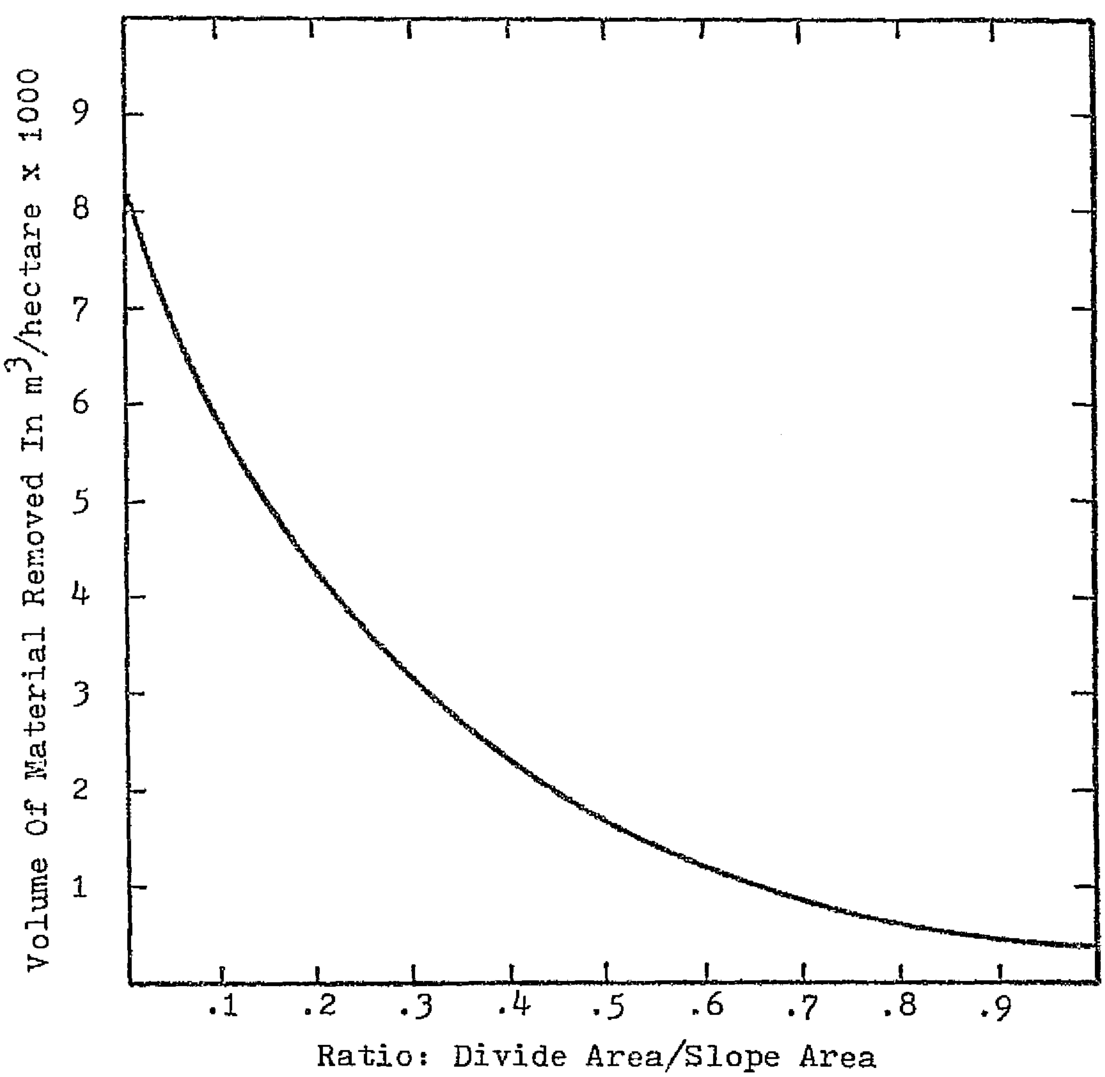
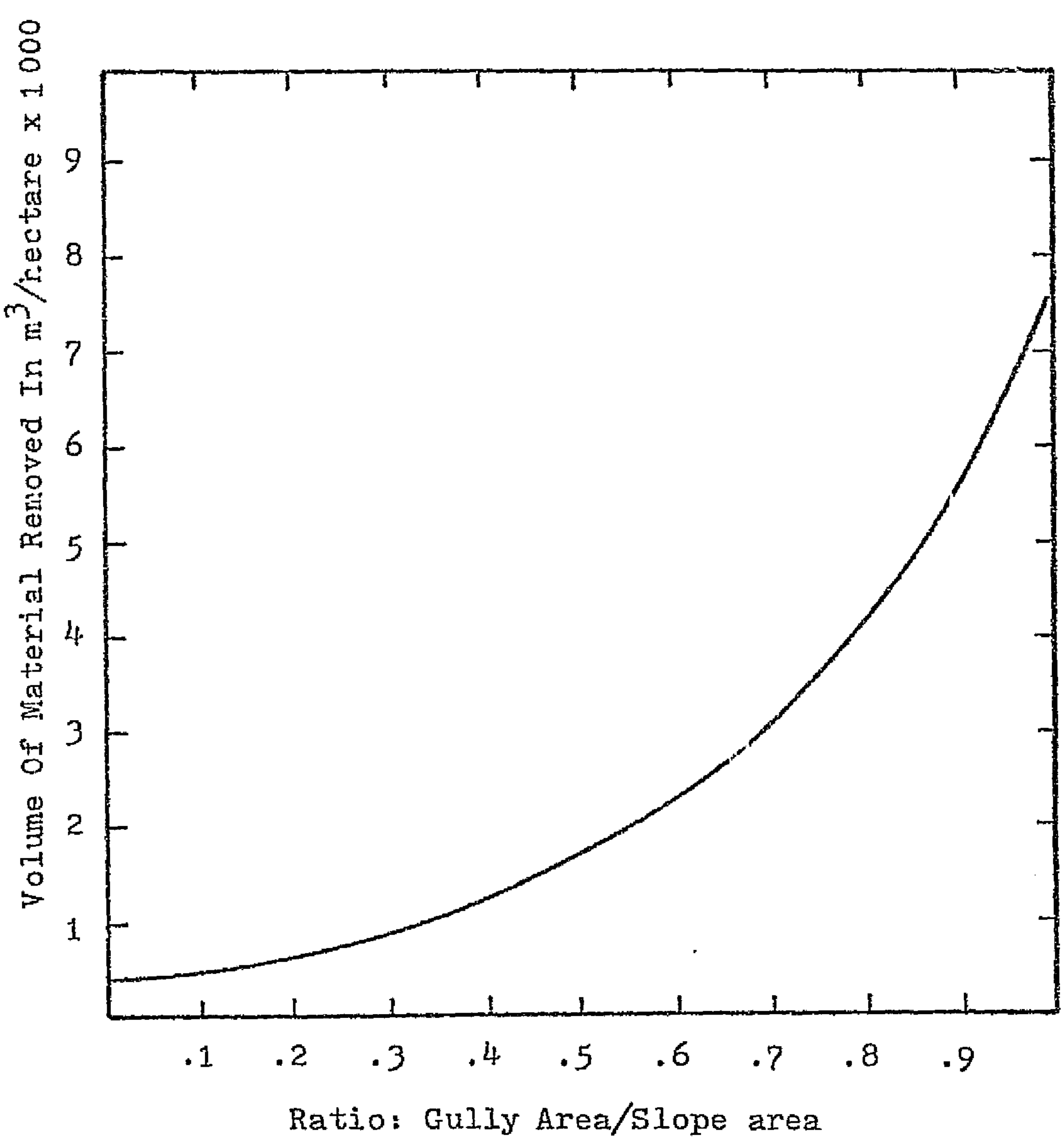


FIGURE 23
RATIO: GULLY AREA/SLOPE AREA VS. VOLUME OF MATERIAL REMOVED



Older spoils are characterized by large gullies that occupy large portions of the slope area originally serrated by rill systems. Therefore, measurements of gully area may be best suited for calculations of the volume of material from older spoils.

All calculations thus far discussed, are based upon measurements from steep slopes (36 degrees). Using Horton's Slope Function, the volume of material removed from gentle slopes can be calculated.

In the Searles Area, as an average, steep slopes occupy 30 percent of the total land area and gentle slopes (15 degrees average) 41 percent of the total land area. The remaining 29 percent of the total land area includes flat areas of valley bottoms and hill tops. Horton's Slope Function indicates that erosion from gentle slopes is 36 percent of the erosion of steep slopes.

An estimate of the rill and gully erosion of any specific area can be made by equating total land area and the volume of material removed from steep slopes to constant of .446 (Total estimated rill and gully erosion = .446. hectares mined x m^3/hectare for steep slopes). The constant .446 represents a summation of the average percent of steep and gentle slopes in the Searles area, and the reduced erosion on gentle slopes as compared to steep slopes. The constant (.446) is an approximate figure and can only be used to estimate erosion in the study area. Table 11 is a summation of the total rill and gully erosion for strip mined areas of each age group.

SUMMARY AND CONCLUSIONS

Approximately 18 percent (953 hectares) of the total land area in the Searles Area has been disturbed by strip mining. The study area has a history of surface mining that dates back to 1944; mining has been

TABLE 11 Volume of Rill and Gully Erosion

Age Group	Avg. Erosion Steep Slopes M^3/Hec.	Area Mined Hec.	Total Erosion Steep Slopes M^3	Total Erosion M^3
1955-60	4200	143.2	601,440	269,204.45
1961-65	2600	168.4	437,840	195,977.18
1966-70	1600	196.1	313,760	140,438.97
1971-73	1100	106.5	117,150	52,436.34
Unknown		327		
		953.0	1,470,189	658,056.94

Erosion 15 deg. slope = 36% Erosion 36 deg. slope

Average
steep slopes = 30%
gentle slopes = 41%

Total Erosion = 0.4476 (hec. mined x M^3/hec. steep) For each age group.

continuous since that time except for a five year period from 1950 to 1954. The Searles area is in a humid climate; however, due to a lack of vegetal cover, strip mined lands simulate the arid cycle of erosion.

The twenty slopes selected for study represent those areas of strip mining that have maximum erosion. Slopes are ungraded, unvegetated, and at steep angles (36 degrees), comparable to the angle of repose of spoil materials.

The distinction between "rills" and "gullies" can be based upon channel profile characteristics. Rill channel profiles are linear and indicate that rills have a straight line bottom. Gullies have channel profiles that are characterized by a gentle or horizontal downslope section that abruptly meets a steep or vertical headwall. An intermediate stage exists that is characterized by a channel profile which has a stair step appearance.

Divide areas decrease exponentially with time and gully areas increase exponentially with time. Slopes, therefore, evolve from those slopes with small rills and broad flat divides to slopes which are highly disected by large gullies and have little divide area.

The volume of material removed from steep slopes of spoil banks increases exponentially with time ($V = 802\ [1.1^T]$). The relationship between volume of material removed and time is that, after the first year, the rate of erosion is constant (10 percent per year), and the cumulative volume of material removed increases exponentially with time (110 percent per year).

From the volume vs. time relationship, three separate stages of erosion can be derived; (1) an initial stage during the first year which has a high rate of erosion, (2) a second stage which lasts for nine to eleven years in which the rate of erosion decreases, and (3) a third stage which exists after approximately twelve to fifteen years of time in which there is a high rate of erosion and extensive gully development.

By relating divide area and gully area to the volume of material removed, a monitoring system can be established. Rapid volume determination can be made from measurements of divide area or gully area taken from aerial photographs or in the field. The system can be further adapted to compensate for variance in slope angle.

TABLE 12

AVAILABLE REMOTE SENSING IMAGERY IN THE SEARLES

(X indicates sufficient resolution for measurements involving the specified aspect of strip mining)

DISTINGUISHING FEATURES	ERTS	U-2	SKY LAB	NASA 1/25,000	SCS 1/20,000
Areal Extent of Mining	X	X	X	X	X
Age of Spoils		X	X	X	X
% Vegetal Cover on Spoils		X		X	X
Slope Angle of Spoils		X		X	X
Erosion (Rill and Gully)				X	X
Sedimentation (Bluff Creek)		X	X	X	X
Reclamination Practices		X		X	X

NASA-Infra-red Aerial Photo-Scale, 1/25,000

U-2 Color Infra-red-Scale, 1/130,000

Sky Lab-Black and White Multi-bank-Scale, 1/500,000

SEDIMENTATION IN BLUFF CREEK

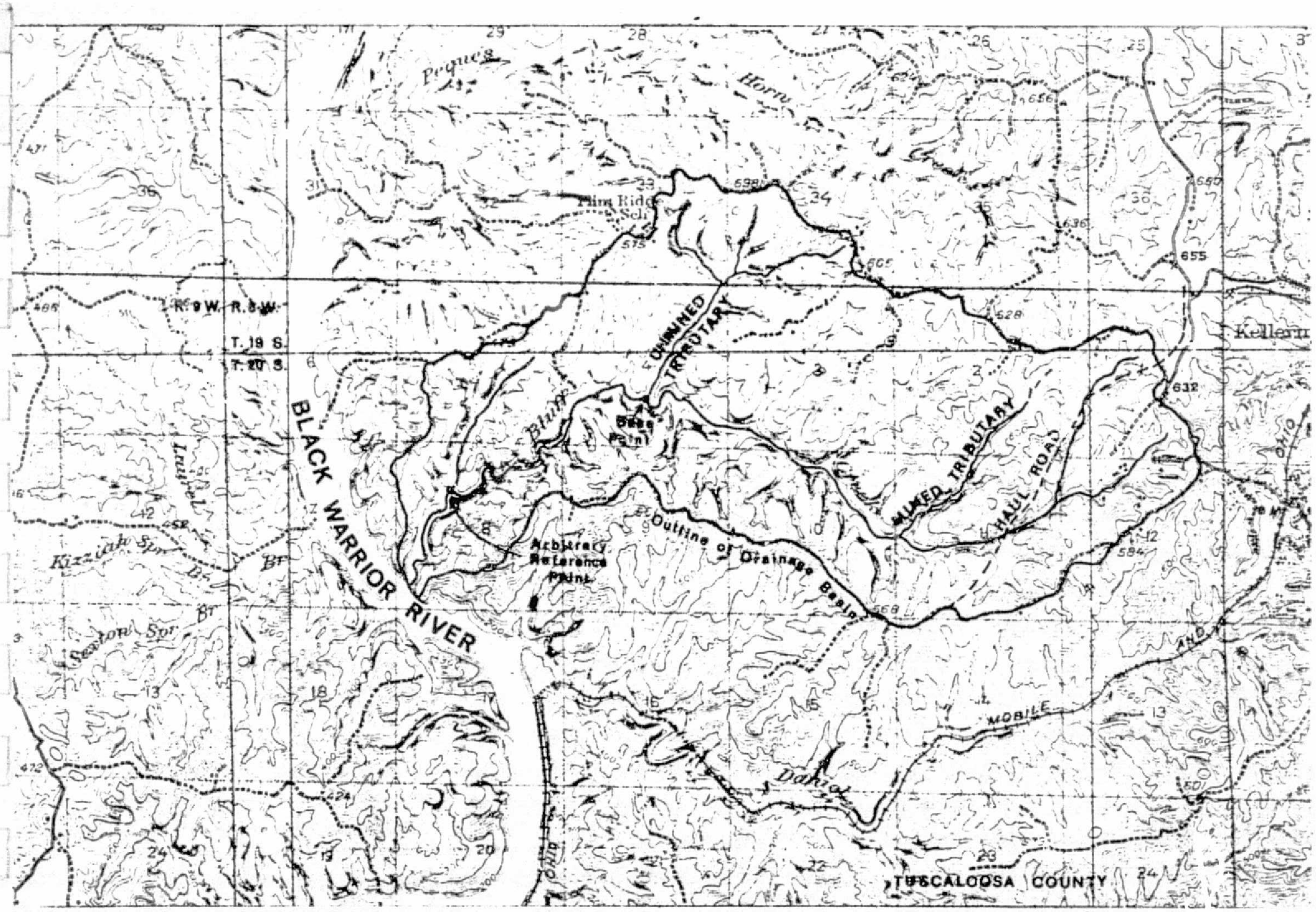
Bluff Creek has experienced an unusual amount of sediment input in recent years due to strip mining along its upper reaches. The purpose of this study is to establish the amount of sediment within the drainage basin and to determine the feasibility of monitoring sedimentation rates of streams associated with strip mined areas by the use of low-altitude aerial photographs. The Bluff Creek drainage basin contains 21.0780 square kilometers, at least 5.6327 square kilometers or 26.72% of which has been strip mined (1973.) The basin is outlined in Figure .

Field measurements along Bluff Creek were made to establish ground control for the study of aerial photographs and to establish the volume of sediment in the stream channel. To determine the volume of sediment in the stream system, the following procedure was used. A base point was established at the intersection of Bluff Creek and the largest unmined tributary that enters Bluff Creek from the north. (See Figure 24.) From this point, measuring stations were located both upstream and downstream. The more varied and irregular the channel, the lower the separating distance between consecutive measuring stations. In areas where the channel was consistent, the segment lengths were chosen at longer spacings because the sediment distribution was more uniform and could be predicted over greater distances. The spacing varied from 30.5 to 152.4 meters.

A cross-section was constructed across the valley floor for each station. Sediment depth was determined at several stations along the cross-section by use of a special probe designed for this purpose. The probe consisted of a 0.9525 centimeter diameter aluminum rod, graduated in meters, with a bullet-shaped "nose" on one end and a removable handle on the other. Extensions which screwed into place between the "nose" end of the

FIGURE 24

BASE MAP OF STUDY AREA



probe and the handle gave the probe a maximum working length of 6.7 meters. In use, the probe was pushed by hand into the stream sediment until a solid mass was encountered at which time its depth was recorded, as shown by the graduations marked on the probe. It was assumed the solid mass encountered was bedrock. With practice, the difference between bedrock and a large boulder in the sediment matrix could be determined.

Terraces were present along the creek throughout most of its length. They were virtually impossible to probe because the vegetation covered sediment created a matrix of dead twigs and vines that could not be penetrated by the probe. When the probe did penetrate the vegetation, the boundary between the stream alluvium and the soil zone it covered could not be determined. This tended to give exaggerated thicknesses. The estimate of terrace volume was based on the terrace width and approximate height above the creek. In cross-section, the terraces were assumed to be wedge-shaped. Graphically reconstructing the terraces allowed calculation of the cross-sectional area.

In the upper reaches of the creek, the nature of the sediment itself disallowed the use of the probe. These areas, especially where mining spoils were close to the creek, contained large clasts of sandstone and shale, often over a cubic meter in size. In these areas valley widths were measured and cross-sectional areas were calculated in the following manner. A formula to calculate width versus cross-sectional area relationships was derived for Bluff Creek by plotting logs of width and area for all the measured data along the creek. The formula for a least square curve to fit this data was calculated from the data plotted. The emperical formula for the least square line is:

$$\log \text{area} = 1.5 \log \text{width} - 0.49.$$

The measured data fit this line with a coefficient of determination of 0.81 and, hence, a correlation coefficient of 0.90. The result provides a means of calculating area, with a standard error of estimate of 0.26 for the cross-sectional area (Y) of a segment of stream of given width (X). Cross-sectional areas of stations 22-32 were calculated in this manner.

With known volume for certain segments of the stream system, cross-sectional areas and distances between cross-sections known, the total volume of sediment contained within the stream system was calculated. In the regions where corss-sections and distances between them were measured, the volume was calculated by assuming the area of the cross-sections measured extended one-half the distance to the adjacent stations. For example, station 10 was located 30.5 meters upstream from station 9 and 91.4 meters downstream from station 11 and contained 5.732 square meters of sediment in cross-section. Therefore, the volume of sediment for station 10 was calculated in the following manner:

$$5.732 \text{ sq. m.} \times \left(\frac{91.4}{2} + \frac{30.5}{2}\right) = 349.365 \text{ cu. m.}$$

The volume of sediment in the Bluff Creek basin east of where the haul road (Figure 24) passes through the basin was not established. The haul road acts as a dam and has created a trapment basin for all sediment that enters the system east of the road. This sediment cannot, at present, enter the lower reaches of Bluff Creek, thus, it was not considered in this report. If, however, in the future, it is allowed to enter the system, it will prove an abundant source of sediment for the creek.

Based on the calculations and measurements made on the data obtained on the Bluff Creek basin, there are presently about 411,000 cubic meters of sediment within Bluff Creek.

The sediment within the creek is generally distributed throughout the creek but is predominantly concentrated in two sediment wedges. One sediment wedge, including the delta, is located at the mouth of the creek, where it intersects the Black Warrior River. This delta is predominantly composed of fine sand and silt, with some gravel and clay. The sediment composing the delta is easily recognized on aerial photographs since it forms a broad barren plain through which Bluff Creek meanders. This wedge extends at least 1676 meters upstream, and possibly further in the form of terraces. Transitional upstream limits of the wedge preclude determination of its ending point.

The present average stream gradient along this lower wedge is approximately 4.5×10^{-3} m/m as determined from a 1975 USGS preliminary 7 1/2' topographic map of the Searles area. The gradient along the same segment, as taken from a 1934 USGS Searles, Alabama 15' topographic map, was 1.07×10^{-2} m/m. Flattening of gradient is the result of two factors. One is the rise in the elevation of the Black Warrior River due to a lock constructed downstream from the Bluff Creek Area and the other factor is the building of the delta.

The other sediment wedge encompasses the entire upper reaches of Bluff Creek and the major tributaries along which mining has occurred. The areal extent of the upper wedge is from the creek's contact with the strip mine spoil piles downstream to within about 366 meters of the point where the largest unmined tributary (control stream) enters Bluff Creek from the north. Again, as in the limits of the lower wedge, the exact extent of the wedge is impossible to determine.

The material composing this upper sediment wedge is generally coarser in nature than the lower wedge. Where gravel-sized and larger particles are rare in the lower wedge, they seem to be a major constituent of the upper wedge. The sediment in the upper wedge is graded along its length, decreasing in size downstream. Boulder-sized sandstone and shale clasts are abundant at the base of the spoils. Sand and pebbles are more common at the lower reaches of the upper sediment wedge. Armoured mudballs are also common on the upper wedge, apparently the result of blocks of underclay from the spoils, entering the stream and armouring themselves with pebbles as they tumble downstream.

The gradient along the upper wedge has been modified by the unusual influx of sediment. The extensively-mined northern tributary to Bluff Creek is a good example. Along part of the tributary, the gradient has been steepened from about 1.[illegible]34 x 10^{-2} m/m (1934) to 3.3153 x 10^{-2} m/m (1975). This steepening of gradient is due to the partial damming of the stream by mass-wasting of the spoils piles in contact with the creek. This damming has caused accretion of sediment in the channel upstream and resulted in a slightly lower gradient; 3.101 x 10^{-2} m/m (1934) as opposed to 2.307 x 10^{-2} m/m (1975) in this area.

In the area between the two sediment wedges, the gradient was only slightly affected, as one would expect. It did change however, with the present stream gradient not as steep as it was over 40 year ago, 8.6389 x 10^{-3} m/m (1934) as compared to 7.7196 x 10^{-3} m/m (1975). This portion of Bluff Creek is characterized by narrow stream widths (generally less than 9.1 meters) and no terraces. Rapids in the stream are common as are channel bars composed of sand and gravel. However, the deposits are not continuous masses of sediment, in that bedrock is exposed intermittently along the bed of the stream. The sediment typically only accumulates in the low-energy portions of the stream between the rapids or as channel or point bars within the stream channel itself. Table 13 summarizes the sediment volume in each segment of Bluff Creek.

A history of mining activity within the Bluff Creek drainage basin is shown in Table 14 . A study of this table is important in understanding the migration of sediment within the drainage system. The migration and

TABLE 13

VOLUME OF SEDIMENT IN BLUFF CREEK (m^3)

Upper Sediment Wedge		
North Tributary		19,000
South Tributary		4,300
Junction of North and South Tributaries 360 m below control stream		148,000
	Subtotal	171,300
Area Between Upper And Lower Wedges		8,500
Lower Sediment Wedge		
Bluff Creek and Delta		215,500
Prodelta		15,500
	Subtotal	231,000
	TOTAL	410,800

TABLE 14

MINING ACTIVITY IN BLUFF CREEK DRAINAGE BASIN

	Age of Mining Activity	Hectares Mined	% of Total Mined Area As Of 12-18-73	% of Basin Mined	Cumulative % of Basin Mined
	55-60	100.27	17.787	4.753	4.753
	60	37.04	6.570	1.755	6.508
	69-70	195.63	34.702	9.273	15.781
	70	7.09	1.258	0.336	16.117
	71-72	223.70	39.681	10.603	26.720
Total		563.73	99.99	26.720	

distribution of sediment within the basin is best studied by the use of aerial photographs taken of the area during the time interval in question. A description of photographs made available for this purpose is presented in Appendix .

Measurements were obtained from the photographs by use of a wild binocular microscope. Data obtained from the aerial photographs was used to study the addition of sediment at the lower sediment wedge. The downstream migration of the delta plain and prodelta, and the upstream migration of sediment in the lower sediment wedge is summarized in Table 15 . A graphical representation of migration distances is shown on Figure 25 .

The lower sediment wedge is building both upstream and downstream at a fairly rapid rate. Figure 25 indicates that in the 12 month period between February 1973 and February 1974, the wedge migrated upstream at an average rate of 2.7 meters per month. Downstream migration of the delta plain occurred at an average rate of 2.5 meters per month. The prodelta migrated downstream at an average rate of 4.5 meters per month. At the present rate of movement the prodelta will reach the Warrior River in 201 years.

Calculations, using measurements from aerial photographs, can be used to estimate future volume additions to the delta plain and prodelta sediment wedge. The method is based on the knowledge and assumptions described below.

1. Station 031 is located 120 m downstream from the "arbitrary reference point" (Figure 24).
2. The width of the delta at station 031 represents the average width of the delta in Bluff Creek.
3. The cross-sectional area of sediment at station 031 is 195.1 m^2.
4. As of May 1975, the delta plain and prodelta extend 152.4 m below station 031 and contain 30,592 m^3 of sediment.

TABLE 15

MOVEMENT OF THE LOWER SEDIMENT
WEDGE, WITH RESPECT TO THE ARBITRARY REFERENCE POINT

(MEASURED FROM AERIAL PHOTOGRAPHS)
(DISTANCES IN METERS)

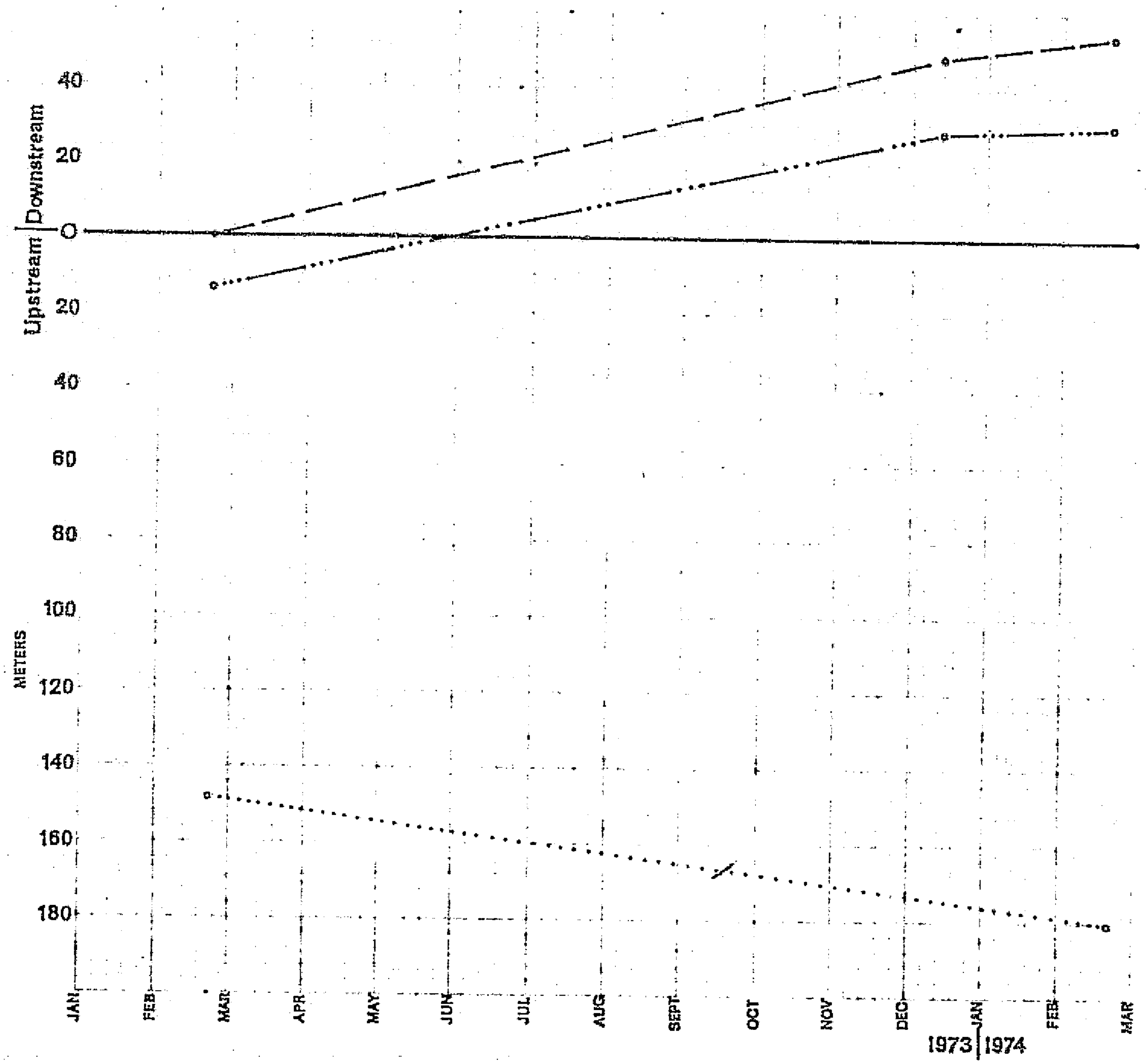
DATE OF PHOTOGRAPHY	DELTAPLAIN	PRODELTA	UPPER VISIBLE LIMIT
2-22-73	13.92 us.*	0	149.35 us.
12-18-73	28.80 ds.**	48.31 ds.	Obscured
2-20-74	30.66 ds.	53.89 ds.	181.17 us.

* us. = upstream

** ds. = downstream

FIGURE 25

MOVEMENT OF LOWER SEDIMENT WEDGE
FROM 2-22-73 TO 2-20-74



ARBITRARY REFERENCE POINT

PRODELTA

DELTAPLAIN

UPPER VISIBLE LIMIT

5. The original (pre-delta) gradient of Bluff Creek was 0.0065 m/m and the average gradient on the surface of the delta (delta plain and prodelta) is 0.0045 m/m.

6. Using a microscope, measurements of distance may be obtained from 1/25,000 photographs with ± 0.025 mm accuracy. This corresponds to an error of 7.6 m on the ground.

The total volume (in m^3) of sediment downstream from station 031 is:

$$V = 0.037\ (D-120)^2 + 195.1\ (D-120)$$

where D is the distance in meters from the terminus of the prodelta to the arbitrary reference point

The volume of sediment added after May, 1975, is then:

$$V = 0.037\ (D-120)^2 + 195.1\ (D-120) - 30{,}592$$

Neglecting upstream additions to the lower sediment wedge, the total volume (in m^3) of sediment in the lower sediment wedge can be estimated by:

$$V = 0.037\ (D-120)^2 + 195.1\ (D-120) + 200{,}400$$

Erosion and Sedimentation - a Comparison

By use of the equations presented in the section on erosion and the data from Table 14, the volume of erosion from spoils in the Bluff Creek drainage basin can be estimated from the equation:

$$V\ (m^3) = 357.69\ A_M\ (1.1)^T$$

where

V = volume in cubic meters

A_M = area of mined land in each age group (in hectares)

The data summarized in Table 16 indicates a total of about 479,500 cubic meters of material have been eroded from rills and gulleys in spoils of the basin. The estimated total volume of sediment in Bluff Creek is 411,000 cubic meters. The reader should be reminded that erosion estimates do not include sheet wash from the divide areas, which are probably quite significant in the first few years after mining. The volume of sediment in Bluff Creek does not include the sediment in the smaller tributaries. Therefore, the numbers presented here are minimum estimates.

The difference in the amount of erosion and sedimentation (68,500 cubic meters) represents a minimum amount of material that has been deposited within the spoils, in the smaller tributaries to Bluff Creek, in the fore-set beds of the delta, or has been transported into the Warrior River.

TABLE 16

ESTIMATED RILL & GULLY EROSION
FROM SPOILS IN THE BLUFF CREEK DRAINAGE BASIN

Date of Mining	Av. Age	Hectares Mined	Calculated Cumulative Erosion (Rills & Gullies)
1955-60	17.5	100.27	190,131
1960	15.0	37.04	55,343
1969-70	5 1/2	195.63	118,196
1970	5	7.09	4,084
1971-72	3 1/2	223.70	111,698
		TOTAL	479,452

GEOCHEMISTRY

Introduction

The conceptual model by which rain water infiltrates spoils, reacts with pyrite and/or marcasite to become acidic and dissolve soluble ions is well accepted, and well documented in the literature. However, because many of the reactions involved in the process are sluggish and controlled by rate inhibiting steps; because many ionic species produced can exist metastably in disequilibrium with their environment; and because of bacterial catalysis enhancing reactions involving iron and sulfur, analysis of mine water often may not yield information comparable with that derived by thermodynamic or stoichiometric calculations. Models, based on such calculations, can be used to predict the limits and validity of inferred chemical reactions, and further, data from the calculations can be used to construct stability fields for the various aqueous species found in mine drainage. Incomplete knowledge as to the ionic strength of the mine drainage, the activities of the various species present, and the total number and kinds of ionic species present, places distinct limits on the ability to calculate the degree to which equilibrium is attained. None the less, the reasonably close agreement between analyses and theoretical calculations is sufficient to justify the use of thermodynamics in attempts to explain the chemistry of mine drainage.

Production of Acid Mine Water

The water of mine drainage is in a continual state of chemical change as it attempts to equilibrate with its surroundings. Conceptually, the system begins as oxygenated rain water, at or near equilibrium with the atmosphere, strikes and infiltrates the spoils from strip mining. Within the spoils, under reducing conditions, the water becomes acidic and dissolves soluble elements contained within the spoils. After emerging from the spoils, the water attempts to equilibrate with the atmosphere and the rocks over which it flows under oxidizing conditions.

We shall briefly summarize the chemistry of acid mine water production using accepted and well publicized equations from the literature. Where ever possible we have calculated the equilibrium constants for the equations (from thermodynamic data in Latimer, 1952, Garrels and Christ, 1965, and Krauskopf, 1967) and have given the limits of the reactions based on the concentrations of iron and sulfur species found in analyses of Bluff Creek and its tributaries. Following this we shall discuss the chemical changes that occur in the water as it drains from the spoils and through the Bluff Creek drainage system.

Rainwater, upon entry into the spoils, should be at or near equilibrium with the atmosphere. The water should be slightly acidic (pH ca. 5.7) due to dissolved carbon dioxide, and should contain dissolved oxygen. Reaction with pyrite and/or marcasite in the spoils will probably occur by way of the often quoted reaction (e.g. Singer and Stumm, 1968) shown by equation (1).

$$(1) \quad FeS_2 + 7/2O_2 + H_2O = Fe^{+2} + 2\ SO_4^{-2} + 2H^+$$

The equilibrium constant, calculated from free energy data, is;

$$K = \frac{[Fe^{+2}]\ [SO_4]^2\ [H^+]^2}{[PO_2]\ 7/2} = 10^{205.6} \text{ at } 25°\ C$$

Substitution of the maximum iron, sulfate, and hydrogen ion values found in Bluff Creek into the equation and solving for the partial pressure of oxygen, indicates that the reaction should continue until the partial pressure of oxygen reaches 10^{-63} atmospheres. (Iron = 10^{-4} m/l, Sulfate = 10^{-2} m/l, and pH = 3) The calculation indicates that equation (1) should be an important reaction even under the strongly reducing conditions that must persist after the water has lost most of its original oxygen supply. This conclusion is supported by data from Krauskopf (1967) and shown in Figure 26 . However, the oxidation rate decreases rapidly as the oxygen supply in the water is depleted and the pH decreases (Smith, Svanks, and Shumate, 1968). The important aspects of the equation are; it can occur under strongly reducing conditions; ferrous ions are produced; sulfide is oxidized to sulfate, and that two moles of hydrogen ions are produced for each mole of oxidized pyrite.

Conditions become continually more reducing as water percolates deeper into the spoils. Near the surface of the spoils, however, conditions may be sufficiently oxidizing that ferrous ions may be oxidized to ferric ions.

$$(2) \quad Fe^{+2} + 1/4\ O_2 + H^{+} = Fe^{+3} + 1/2\ H_2O$$

$$K = \frac{[Fe^{+3}]}{[Fe^{+2}]\ [P_{O_2}]\ 1/4\ [H+]} = 10^{8.8}$$

Equation (2) tends to cause pH to rise by consumption of hydrogen ions, but as long as the pH is above about 3, ferric ions are quite insoluble and precipitate as ferric hydroxide.

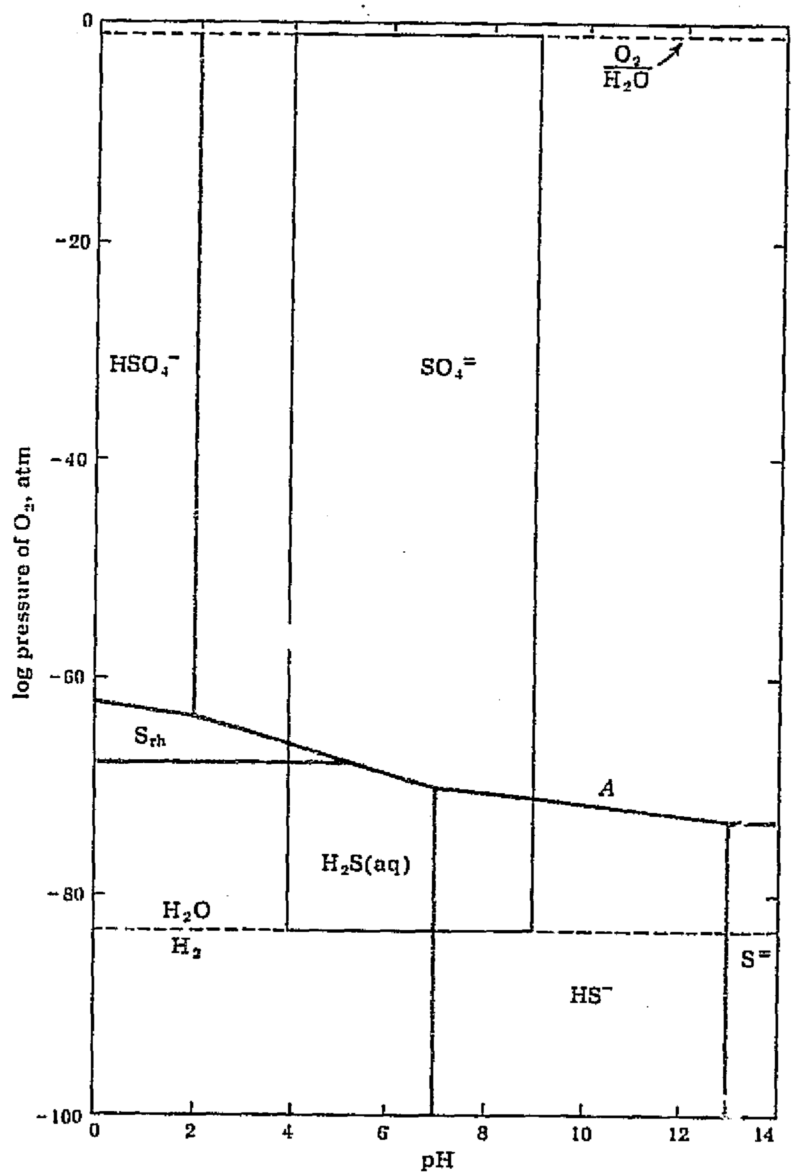
$$(3) \quad Fe^{+3} + 3H_2O = Fe(OH)_3 + 3H^{+}$$

$$K = \frac{[H^{+}]^{3}}{[Fe^{+3}]} = 10^{-11.4}$$

The hydrolysis reaction by which ferric hydroxide is precipitated produces three moles of hydrogen ions per mole of ferric ions.

The zone in which abundant ferric ions (and abundant ferric hydroxide) are produced is probably restricted to the very near surface environment in spoils. In the presence of oxygen, iron-oxidizing bacteria may catalize

FIGURE 26



Stable sulfur species as a function of pH and P_{O_2} at 25°C and 1 atm total pressure. Total concentration of dissolved sulfur species = 0.001M.

from Krauskopf (1967, p. 272)

oxidation of ferrous ions (Lundgren, and Schnaitman, 1965, and Shearer and Everson, 1965) so that a continuing supply of ferric ions and hydrogen ions are supplied to the oxygen difficient portions of the spoils. As the water penetrates deeper into the spoils and the dissolved oxygen is depleted, the Eh of the solution is lowered to the point where equation (2) goes to the left and ferrous ions are the dominant iron species in solution. The ferric ions which are produced by equation (2) with the aid of bacterial catalysis can be used to oxidize pyrite,

(4) $FeS_2 + 14Fe^{+3} + 8H_2O = 15\ Fe^{+2} + 2SO_4^{-2} + 16H^+$

as has been demonstrated by Garrels and Thompson, (1960). The equilibrium constant for the above reaction at 25° C is;

$$K = \frac{[Fe^{+2}]^{15}\ [SO_4{}^{-2}]^2\ [H^+]^{16}}{[Fe^{+3}]^{14}} = 10^{79.8}$$

Using values for total iron (10^{-4} m/l), for sulfate (10^{-2} m/l), and a pH of three, equation (4) should proceed to the right as long as the ferric iron concentration is above 10^{-13} m/l. Equation (2) should continue to produce ferric iron in concentrations above 10^{-13} m/l, as long as the partial pressure of oxygen is above 10^{-63} atmospheres.

In the extremely low oxygen concentrations from the above calculations, sulfate may equilibrate with native sulfur.

(5) $FeS_2 + O_2 + 2H_2O = Fe^{+2} + SO_4^{-2} + S^0 + 4H^+$

$$K = \frac{[Fe^{+2}]\ [SO_4{}^{-2}]\ [H^+]^4}{[P_{O_2}]} = 10^{29.7}$$

Figure 27 (from Garrels and Christ, 1965) illustrates, on an Eh-pH diagram, the stability relations of various sulfur species in aqueous solution at 25° C. It is apparent that in the Eh-pH range of acid mine water native sulfur should frequently be formed. In fact, if either the Eh or the pH is lowered below the native sulfur-sulfate stability boundry, then hydrogen

FIGURE 27

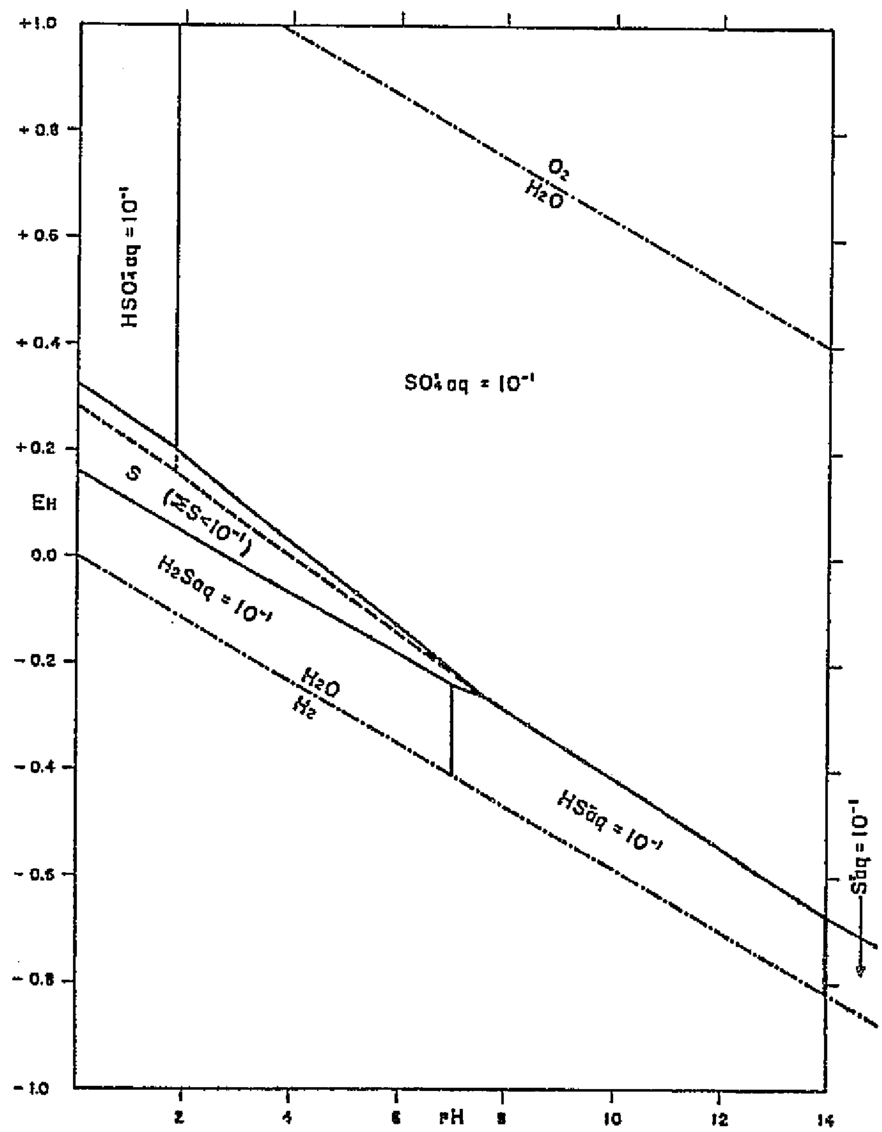


FIG. 7.17. Equilibrium distribution of sulfur species in water at 25 °C and 1 atmosphere total pressure for activity dissolved sulfur = 10^{-1}. Under these conditions, native sulfur is a stable phase. Dashed line indicates equal values of dissolved species within sulfur field.

from Garrels & Christ (1965) p. 217

sulfide could be a stable phase in the water. The presence of native sulfur or hydrogen sulfide does not indicate that elimination of sulfate as the dominant sulfur species present, since sulfate, once formed, is not easily reduced by inorganic means (Barnes, 1965, p. 7.). Thus the sulfate can exist metastably, outside its stability field, for long periods of time unless it is reduced by bacterial action.

Mine Drainage in Bluff Creek

Sampling sites were located at 22 positions along Bluff Creek and its tributaries (Figure 28). Sample stations were chosen on each of the major tributaries, including the eastern most forks, of Bluff Creek as well as on the main stream immediately below the junctions of the tributaries. Station 5 (Figure 28) is a tributary, the drainage basin of which has never undergone surface or sub-surface mining. This tributary is, therefore, used as a control stream.

A combination of field and laboratory analyses were used to measure redox potential, pH, total alkalinity, sulfate, iron, manganese, nickel, chromium, zinc, cadmium, cobalt, and copper. (A complete description of sampling and analytical technique is located in Appendix I) The project was plagued with difficulties involving field analyses, and as a result, the data are fewer in number than originally planned. We believe the results of the analyses represent a significant contribution to the knowledge of mine drainage in this portion of Alabama (Analyses are shown in Tables 17 to 25).

One of the most significant factors exerting control on the chemistry of Bluff Creek is the existence of numerous lenses of calcium carbonate cemented sandstone. These beds act as a natural buffer and provide rapid neutralization of the acid mine water which passes over them. Because of

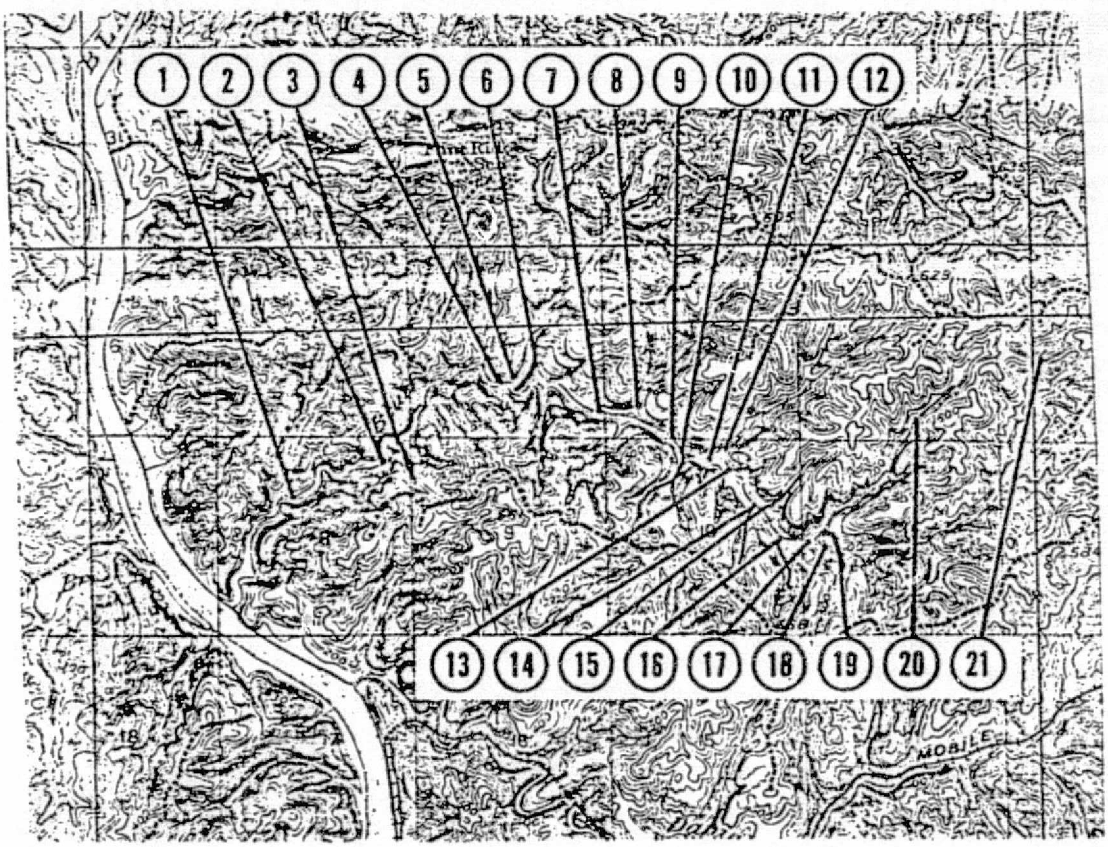


Figure 28

GEOCHEMICAL SAMPLING STATIONS

TABLE 17

GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES October 31, 1974

Sta. No.	mv redox	pH	alk	SO_4	S^{-2}	Fe	Mn	ppm Ni	Cr	Zn	Cd	Co	Cu	cm^3/sec discharge
1	+50	6.75	10	125		.02	14.5	.12	N.D.	.07	.019	.08	.035	
2	+30	7.10	13	30		N.D.	13.6	.114	N.D.	.075	.019	.08	.035	81083
3	SAMPLE NOT TAKEN													
4	+30	7.08	12	125		N.D.	14.0	.09	N.D.	.075	.027	.08	.035	53536
5	+40	7.28	10	3		N.D.	N.D.	.07	N.D.	N.D.	N.D.	N.D.	N.D.	1606
6	+30	7.04	20	210		N.D.	14.0	.095	N.D.	.060	.019	.02	.035	51931
7	+ 8	6.94	20	37		.15	14.0	.115	N.D.	.15	.008	.08	.015	67924
8	+25	4.28	N.D.	160		3.00	11.0	.113	N.D.	.19	.019	.05	.015	
9	+12	6.24	22	60		.15	14.5	.115	N.D.	.07	.008	.08	.035	
10	+46	3.96	N.D.	18		5.20	48.5	.20	N.D.	.48	.008	.60	.035	
11	+17	6.72	40	200		.02	13.4	.148	N.D.	.060	.008	.02	.035	68629
12	+26	4.40	3	15		.04	12.8	.125	N.D.	.12	.008	.05	.035	23614
13	+14	6.74	40	75		.03	13.5	.114	N.D.	.055	.008	.05	.035	45015
14	+44	3.10	N.D.	55		6.30	50.0	.20	N.D.	.61	.008	.98	.050	
15	+26	6.82	25	85		.01	20.3	.115	N.D.	.060	.008	.23	.035	
16	SAMPLE NOT TAKEN													
17	+11	7.25	65	90		.03	10.5	.16	N.D.	.030	.008	.05	N.D.	40624
18	+10	7.20	60	24		.31	13.3	.095	N.D.	.040	.019	.08	N.D.	26973
19	+12	7.25	85	160		N.D.	6.00	.110	N.D.	.035	.008	.05	N.D.	613650
20	SAMPLE NOT TAKEN													

TABLE 18

GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES October 31, 1974

Sta. No.	mv redox	pH	alk	SO_4	S^{-2}	Fe	Mn	ppm Ni	Cr	Zn	Cd	Co	Cu	cm^3/sec discharge
1	+19	5.54	3	89	Less than	1.90	13.0	.15	N.D.	.50	.008	.13	.035	
2	+20	6.77	3	138	.1 ppm	1.90	13.2	.123	N.D.	.20	.008	.15	.035	138897
3	+11	6.80	12	200	"	.07	14.9	.114	N.D.	.17	.008	.08	.035	
4	+8	6.53	8	80	"	1.35	13.7	.115	N.D.	.10	.008	.05	.035	98535
5	+8	7.06	18	13	"	.50	N.D.	.096	N.D.	.015	.019	.02	.015	5162
6	+8	6.53	10	174	"	1.30	13.9	0.95	N.D.	.090	.008	.10	N.D.	93373
7	+7	6.50	11	N.D.	"	1.80	14.2	.115	N.D.	.090	.008	.10	N.D.	97618
8	+26	3.78	N.D.	13	"	.80	11.8	.115	N.D.	.17	.008	.10	.015	
9	+10	6.70	15	82	"	2.00	14.6	.115	N.D.	.075	.008	.05	.015	
10	+33	3.94	N.D.	175	"	22.2	47.5	.162	N.D.	.385	.027	.58	.015	
11	+4	6.54	29	21	"	1.20	13.3	.10	N.D.	.020	.019	.05	.015	74496
12	+20	4.60	3	20	"	.21	13.0	.10	N.D.	.125	N.D.	.02	N.D.	9849
13	+4	7.30	33	90	"	1.20	13.5	.114	N.D.	.050	.008	.02	N.D.	64647
14	+				"			.124	N.D.					
15	+8		19	200	"	2.30	27.8	.124	N.D.	.110	.008	.18	.035	
16	SAMPLE NOT TAKEN				"									
17	Not Measured		52	16	"	.60	11.2	.096	N.D.	.035	.008	.08	.015	
18	Not Measured		48	90	"	1.60	12.5	.113	N.D.	.020	.008	.05	.015	
19	Not Measured		71	34	"	.03	6.3	.096	N.D.	.035	.008	.02	.015	
20	SAMPLE NOT TAKEN				"									

TABLE 19

GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES
(October 31, 1974)

Station Number	Fe DL=.03	Mn DL=.02	Ni DL=.02	ppm Co DL=.05	Zn DL=.005	Cu	Cr	Discharge cm^3/sec
1	0.5	7.6	.13	.08	.07	Not Detected	Not Detected	
2	0.6	6.4	.10	.10	.06	"	"	160265
3	3.4	14.1	.20	.18	.36	"	"	
4	3.6	13.1	.23	.15	.28	"	"	113775
5	0.1	1.1	N.D.	.05	.07	"	"	16567
6	1.6	6.5	.10	.15	.07	"	"	97208
7	3.7	13.1	.13	.12	.12	"	"	97224
8	0.4	4.1	.30	.08	.09	"	"	
9	3.8	14.2	.10	.18	.20	"	"	
10	25.6	30.0	.30	.54	.49	"	"	
11	3.9	14.2	.05	.18	.17	"	"	137242
12	1.1	13.6	.10	.08	.30	"	"	17600
13	3.4	13.4	.07	.13	.10	"	"	119642
14	7.0	11.4	.13	.18	.30	"	"	
15	3.7	10.0	.10	.12	.07	"	"	
16	12.2	29.6	.26	.33	.53	"	"	
17	3.2	10.8	.07	.10	.07	"	"	88310
18	0.5	4.8	N.D.	.10	.03	"	"	70251
19	0.5	6.2	.05	.08	.04	"	"	18059
20	0.2	3.0	.03	.05	.03	"	"	

*DL - Detection Limit

TABLE 20
GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES
April 5, 1975

Sample #	ph	Alk mg/l As $CaCo_3$	SO^4	Fe ppm	Mn ppm	Ni ppm	Zn ppm	Co ppm	Discharge
1	5.5	zero		1.8	5.8	0.15	0.10	0.10	
2	5.6	6		1.4	6.0	0.10	0.12	0.05	627444
3	6.6	8		0.9	3.5	0.05	0.20	0.05	
4		7		1.9	7.0	0.10	0.09	0.05	500199
5		8		0.1	0.1	ND	0.07	ND	
6		5		2.0	7.4	0.10	0.11	0.05	440320
7		5		1.9	7.6	0.15	0.13	0.05	438256
8		2		0.4	4.7	0.10	0.06	0.05	
9		8		1.3	8.0	0.10	0.14	0.05	
10		zero		1.5	3.5	0.15	0.23	0.05	
11		17		0.9	9.2	0.10	0.16	0.05	195121
12		5		1.2	9.2	0.10	0.14	0.05	34265
13		29		0.9	9.0	0.10	0.18	0.05	160855
14		zero		36.4	25.4	0.60	0.59	0.75	
15		75		0.2	24.6	0.25	0.32	0.20	
16		2		4.7	21.2	0.25	0.30	0.30	
17		35		0.4	6.1	0.05	0.15	0.05	150532
18		33		0.5	5.8	0.05	0.13	0.05	125246
19		55		3.4	5.7	0.05	0.16	0.05	30201
20		55		0.1	2.4	L0.05	0.20	ND	

TABLE 21
GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES
(April 19, 1975)

Sample Number	ph	Alk mg/L As $CaCo_3$	SO_4 mg/L	Fe	Mn	Ni	Zn	Co	Discharge
1		10	190	0.2	5.4	0.05	0.12	0.10	
2		4	220	0.5	6.0	0.05	0.14	0.10	421672
3		3	135	0.9	3.7	^{L}0.05	0.15	0.05	
4		10	200	0.3	5.8	0.05	0.09	ND	396157
5		6	9	0.1	^{L}0.1	ND	0.04	0.10	126164
6		12	280	0.3	7.6	0.10	0.11	0.10	269993
7		16	280	0.5	8.2	0.05	0.14	0.10	263717
8		zero	82	0.3	4.4	^{L}0.05	0.07	0.10	
9		20	360	0.3	8.3	0.05	0.16	0.10	
10		375	250	0.1	ND	ND	ND	0.05	
11		23	380	1.3	8.6	0.05	0.15	0.05	202511
12		3	250	1.0	9.3	0.05	0.16	0.05	38002
13		17	390	1.3	8.5	0.05	0.14	0.05	164510
14		zero	800	44.3	25.4	0.60	0.60	0.55	
15		64	825	0.9	22.9	0.20	0.41	0.20	
16		zero	320	5.8	19.8	0.20	0.21	0.20	
17		33	350	0.8	6.1	^{L}0.05	0.16	^{L}0.05	137995
18		31	240	0.8	6.1	^{L}0.05	0.11	^{L}0.05	91899
19		62	550	0.5	5.5	^{L}0.05	0.20	^{L}0.05	46097
20		55	300	0.1	2.0	^{L}0.05	0.23	ND	

TABLE 22
GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES
(May 18, 1975)

Sample Number	pH	Alk	SO_4	Fe	Mn	Ni	Zn	Co	Discharge
1	6.3	zero	170	0.2	5.4	0.05	0.09	0.10	
2	6.5	7.0	165	0.3	5.5	0.05	0.07	0.05	373265
3	6.2	4.2	65	0.4	2.6	0.05	0.14	0.05	
4	6.4	10.0	230	0.5	7.0	0.05	0.08	0.05	302292
5	6.4	2.0	35	0.1	0.1	0.05	0.03	ND	40881
6	6.4	8.0	200	0.5	7.1	0.05	0.13	0.05	262291
7	6.5	10.0	245	0.6	7.5	0.05	0.13	0.05	244413
8	4.8	zero	70	0.2	4.8	0.05	0.09	0.05	
9	6.5	14.0	265	0.6	7.8	0.10	0.12	0.05	
10	6.3	zero	220	8.6	11.6	0.15	0.25	0.05	
11	6.4	17.0	265	0.2	7.6	0.05	0.17	0.05	207198
12	4.9	zero	195	0.2	8.2	0.10	0.12	0.05	15371
13	6.4	18.0	275	0.2	7.5	0.05	0.18	0.05	191827
14	3.7	zero	750	15.7	25.4	0.55	0.83	0.50	
15	6.7	32.0	700	0.3	21.0	0.20	0.29	0.20	
16	4.9	zero	300	3.2	19.3	0.30	0.18	0.20	
17	6.6	44.0	250	0.2	5.8	0.05	0.07	0.05	189254
18	6.5	40.0	500	0.2	5.2	0.05	0.06	0.05	157644
19	6.6	26.0	260	0.2	6.0	0.05	0.07	0.05	31611
20									

TABLE 23

GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES
June 1, 1975

Sample Number	pH	Alk	SO_4	Fe	Mn	Ni	Zn	Co	Discharge
1	6.4	11	350	0.10	9.0	0.20	.12	0.05	
2	6.5	12	350	0.10	9.2	0.15	.12	0.05	142699
3	5.9	4	160	0.10	6.5	0.05	.20	0.05	
4	6.5	13	350	0.50	9.5	0.15	.08	0.05	125345
5	6.5	6	25	0.10	0.10	N.D.	.04	N.D.	25810
6	6.5	14	375	0.60	10.1	0.15	.09		99535
7	6.4	13	400	0.80	10.3	0.15	.12	0.05	96340
8	4.6	zero	120	0.10	7.0	0.15	.04	0.05	
9	6.3	17	450	1.10	10.8	0.10	.18	0.05	
10	6.2	3	260	7.10	8.2	0.2	.20	0.05	
11	6.4	25	500	0.10	11.6	0.10	.15	0.05	98240
12	5.0	zero	300	0.10	9.8	0.10	.10	0.05	10389
13	6.5	28	550	0.10	11.7	0.10	.15	0.05	87851
14	3.6	zero	800	19.2	41.1	0.65	.79	0.75	
15	6.5	33	825	0.30	22.6	0.30	.36	0.20	
16	4.6	zero	300	3.0	20.4	0.35	.30	0.30	
17	6.4	49	465	0.10	9.3	0.05	.15	0.05	55831
18	6.5	54	650	0.10	4.4	0.05	.18	0.05	40410
19	6.4	47	430	0.10	10.5	0.05	.15	0.05	15420
20	6.5	56	280	0.10	1.2	0.05	.12	0.05	

TABLE 24
GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES
June 11, 1975

Sample Number	pH	Alk	SO_4	Fe	Mn	Ni	Zn	Co	Discharge
0	4.8	1	270	0.10	7.9	0.20	.15	0.10	
1	4.8	2	300	0.30	7.7	0.20	.11	0.10	
2	5.8	1	270	0.10	7.5	0.15	.17	0.05	276106
3	6.0	1	155	0.80	5.9	0.05	.17	0.05	
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

TABLE 25
GEOCHEMICAL ANALYSES OF SAMPLES FROM BLUFF CREEK AND ITS TRIBUTARIES
June 29, 1975

Sample Number	pH	Alk	SO_4	Fe	Mn	Ni	Zn	Co	Discharge
0	4.8	1	275	0.40	9.1	0.25	.25	0.15	
1	5.9	4	355	0.20	9.5	0.20	.14	0.10	
2	6.2	5	360	0.30	9.7	0.20	.16	0.10	151915
3	5.7	4	150	0.10	5.5	0.05	.18	0.05	
4	6.2	5	320	0.40	10.2	0.15	.10	0.05	128966
5	6.5	8	10	0.10	0.10	N.D.	.08	N.D.	9963
6	6.2	1	350	0.40	10.8	0.20	.11	0.05	119003
7	6.3	7	360	0.80	11.1	0.20	.12	0.10	
8	6.4	zero	125	0.10	7.9	0.10	.10	0.05	
9	6.5	8	400	0.60	11.4	0.15	.14	0.05	
10	4.8	zero	245	8.60	8.7	0.20	.24	0.05	
11	6.3	12	425	4.00	11.6	0.15	.16	0.05	88572
12	4.8	4	230	0.10	9.7	0.10	.22	0.05	26350
13	6.5	14	450	0.20	11.9	0.15	.16	0.05	61042
14	3.8	zero	750	23.8	39.8	0.60	.89	0.70	
15	6.3	14	750	0.80	22.1	0.25	.47	0.20	
16	5.0	zero	420	7.20	23.6	0.30	.56	0.15	
17	6.4	38	450	0.20	8.0	0.05	.18	0.05	60698
18	6.4	45	600	0.10	4.6	0.05	.14	0.05	49079
19	6.5	28	425	5.05	10.7	0.05	.17	0.05	11618

limited financial support and the completion date for this project, we were unable to accurately define the lateral and vertical distribution of the carbonate beds. However, on the north side of Bluff Creek, the beds occur individually and in zones, up to 18 meters thick. The zones contain layers of sandstone that are alternately cemented with silica and calcium carbonate. Individual beds vary in thickness from 15 centimeters to 2.4 meters, are located between stations 10 and 19, and exposed between elevations 91 and 109 meters.

Cores from three drill holes were checked for the presence of carbonate. Carbonate zones were found in each case, but at different elevations. Core C-1 (see figure 28) has a carbonate zone 60 centimeters thick at elevation 166 meters; C-2 has a 75cm thick zone at elevation 113m; C-3 contains three zones 2.4m at elevation 139m, 60cm at elevation 127m, and 90cm at 119m.

Figure 29 demonstrates the effect of the carbonate beds on the chemistry of Bluff Creek. The alkalinity and pH value shown for each station represents the average value of all analyses at that station between October, 1974 and June, 1975. Station 0 is at the mouth of Bluff Creek where it flows into the backwater of the Warrior River. Stations 18, 19, and 20 are on the eastern most forks of Bluff Creek that constitute its headwaters. In its upper reaches, Bluff Creek and one tributary (represented by station 15) flow over carbonate zones. In these reaches the alkalinity is high and the pH remains ca. 6.5. Acidic water forms tributaries 8, 10, 12, 14, 15, and 16, enter Bluff Creek, and the pH of the main stream remains at about 6.5 because of the buffering capacity of the excess alkalinity of the main stream. Between stations 7 and 4, alkalinity and pH remain essentially constant, but both alkalinity and pH decrease from station 4 to the mouth of Bluff Creek (station 0).

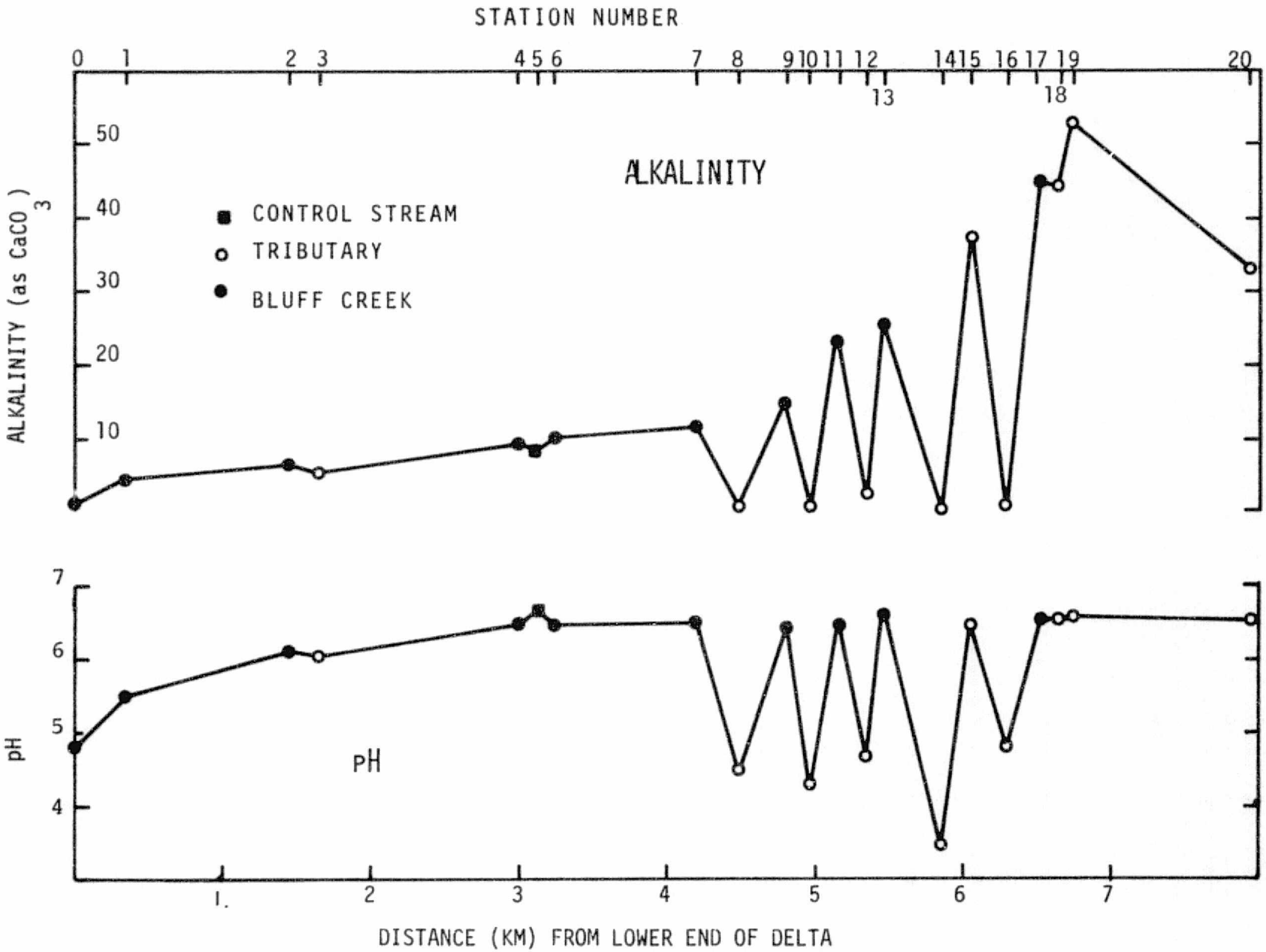


FIGURE 29 AVERAGE ALKALINITY AND pH AT 20 STATIONS ALONG BLUFF CREEK, TUSCALOOSA COUNTY, ALABAMA

There are several factors which may contribute to the decrease in alkalinity and pH below station 4. In this reach Bluff Creek flows over the sediment in and behind the delta and probably reacts with pyrite in the sediment to lower pH. Active oxidation of ferrous ions and the resulting precipitation of ferric hydroxide could also aid in lowering pH. Finally, because the alkalinity of the stream is low below station 4, the stream has very little buffering capacity to retard the pH drop. Therefore, both pH and alkalinity decrease as the stream crosses the delta.

In a general way iron and manganese behave similarly (Figure 30). Concentrations of both elements in the water increase downstream from the headwater areas, behave somewhat erratically in the region where tributaries 8, 10, 12, 14, 15, and 16 join Bluff Creek, decrease downstream to, at least, station 4, and then increase slightly from station 3 to the end of the delta. Manganese concentration is always higher than iron. The Eh of Bluff Creek varies from 8 to 44 mv (Tables 16 , and 17). This indicates that manganous and ferrous ions are the dominant aqueous species present, even though measured Eh values may not accurately represent the true Eh of natural water (Hem and Cropper, 1959). Further support for the opinion that manganous and ferrous ions are the dominant species is provided by the fact that in every sample analyzed iron and manganese concentrations exceeded the solubility of the manganic and ferric ions.

The erratic behavior of iron and manganese between stations 10 and 19, the general decrease in concentration of both ions downstream, and the high pH of Bluff Creek indicate active precipitation of both ions in the Bluff Creek drainage system. Visible deposits of ferric hydroxide ("yellow boy") are almost always present in the tributaries and headwaters

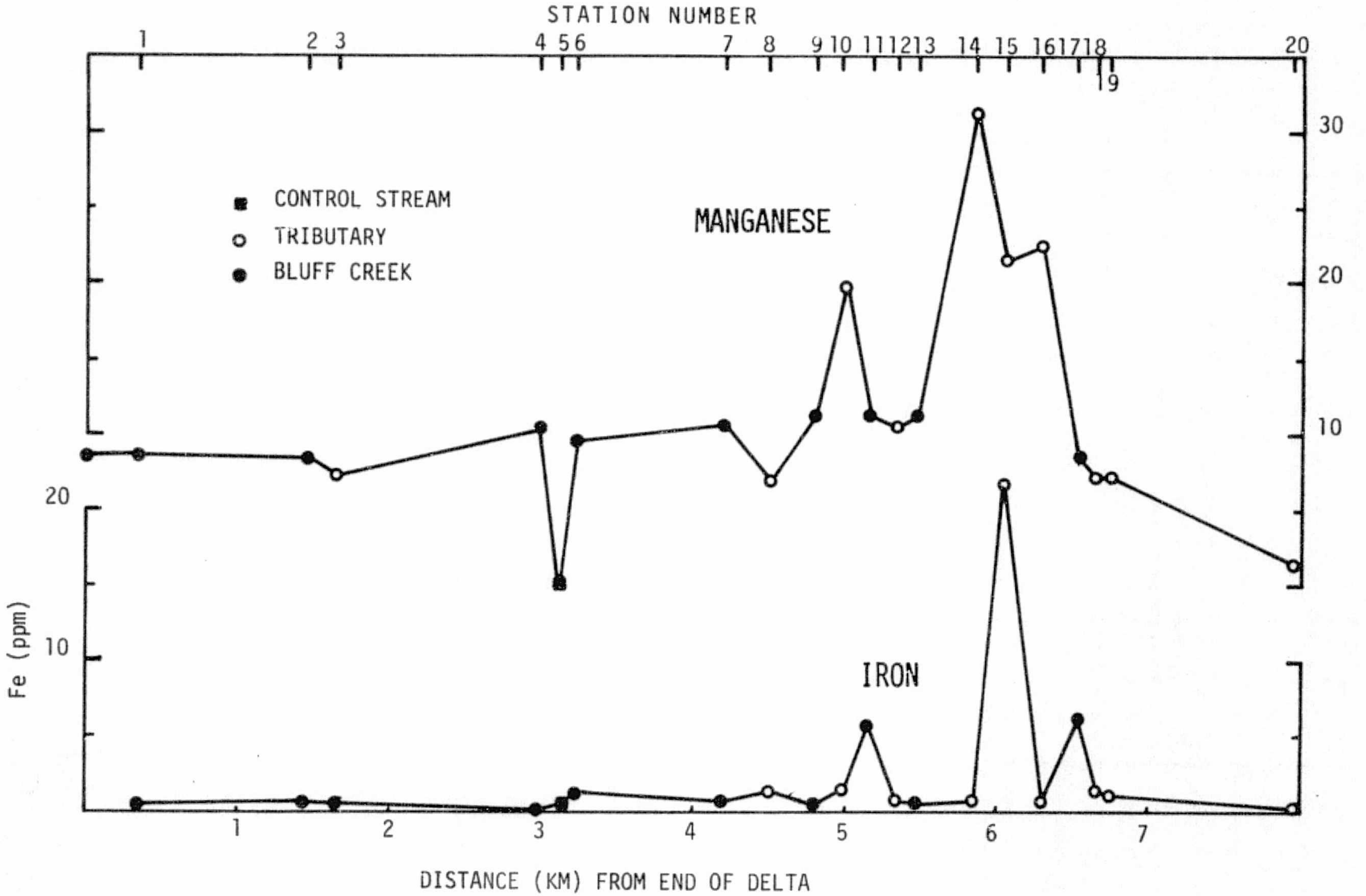


FIGURE 30 AVERAGE MANGANESE AND IRON VALUES FOR 20 STATIONS ALONG BLUFF CREEK TUSCALOOSA COUNTY, ALABAMA

of Bluff Creek; suspended ferric hydroxide is usually present in Bluff Creek itself.

A point of confusion may arise from the realization that the dominant aqueous species present in Bluff Creek are the reduced ions of the elements (Fe^{++} and Mn^{++}) while the precipitates are the oxidized forms (ferric hydroxide and manganic hydroxide). This can be explained by consideration of Figure 31 . This figure shows relationships of iron and manganese phases as a function of concentration and pH. The diagonal line on the left side of each diagram represents equilibrium between trivalent ions in solution (on the left of the line) and trivalent hydroxides as a solid phase (to the right of the line). The diagonal line in the upper right of each diagram represents similar relationships between the divalent phases of iron and manganese. The central part of each diagram represents an area of overlap, where divalent ions of iron and manganese are soluble under reducing conditions or trivalent ions are insoluble under more oxidizing conditions.

Superimposed on the diagrams in Figure 31 are the least squares analyses lines (heavy dashed lines) of concentration vs. pH for iron and manganese analyses of Bluff Creek and its tributaries. The equations for these lines are:

(6) $-\log [Fe] = 0.34 \text{ pH} + 3.04$

and (7) $-\log [Mn] = 0.23 \text{ pH} + 2.49$

The band represented by the lighter dashed lines is the standard error of estimate ($S_{y.x}$) for each equation (for iron $S_{y.x} = \pm$ 0.65, and for manganese $S_{y.x} = \pm$ 0.83).

Assuming that the iron and manganese in our samples were in solution (The samples were filtered through a 0.45 micron filter.) and that the

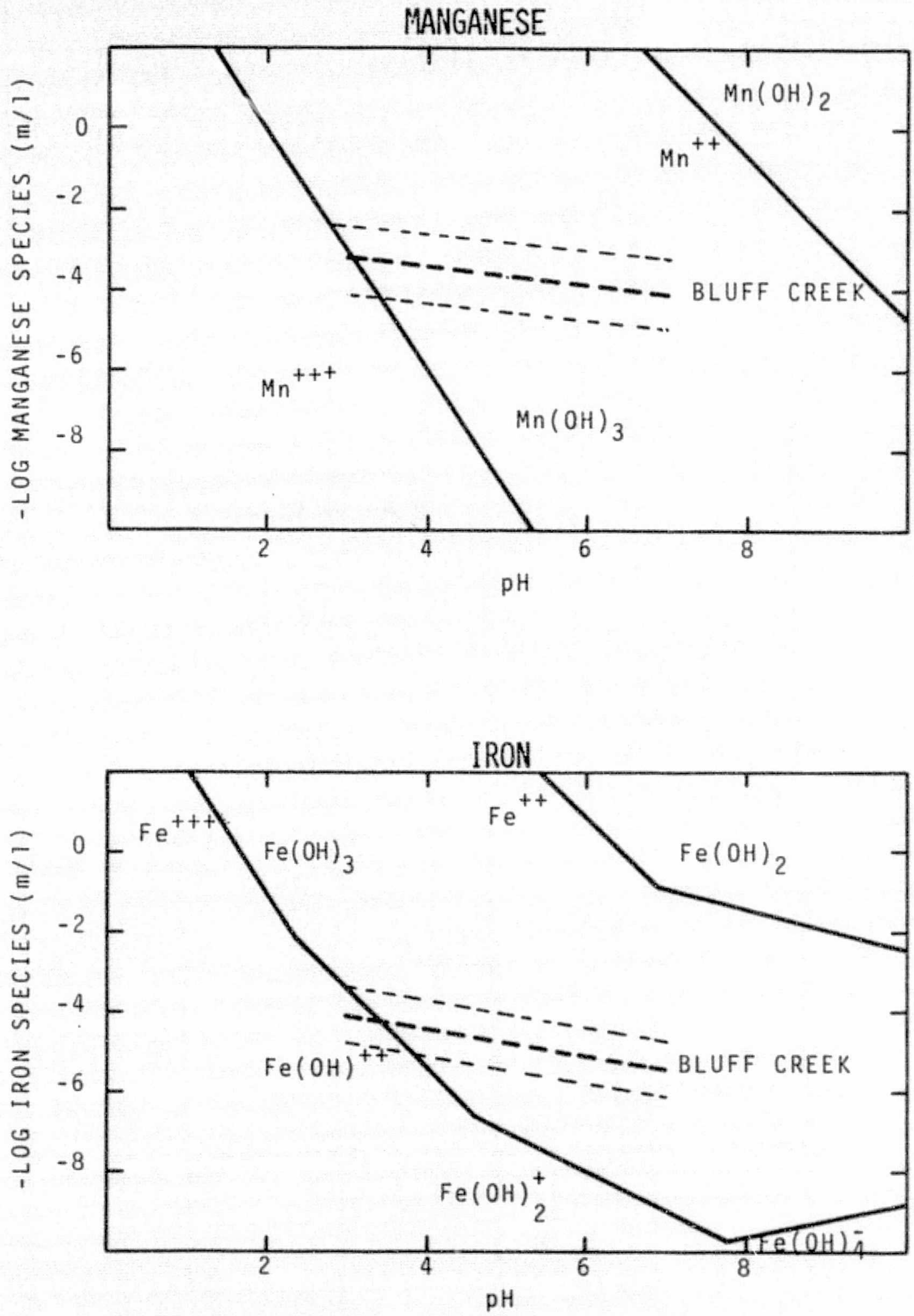


FIGURE 31 CONCENTRATION OF AQUEOUS SPECIES OF MANGANESE AND IRON IN EQUILIBRIUM WITH SOLID HYDROXIDES

Dashed lines represent linear regression lines and standard error of estimate for values in Bluff Creek.

water in Bluff Creek is attempting to equilibrate with the oxygen in the atmosphere, then the rate inhibiting step which slows the precipitation of these elements is oxidation to the trivalent state. Smith, Svanks, and Shumate (1968) have reached similar conclusions and have demonstrated that after oxidation to the ferric state, the half-life for hydrolysis to ferric hydroxide is a matter of a few minutes.

The general behavior of sulfate in the Bluff Creek drainage system is similar to that of iron and manganese. Figure 32 shows that from the headwaters of Bluff Creek, the sulfate rises, behaves differently in the tributaries and main stream in the central reach, and decreases downstream through the delta. It is interesting to note that, except for stations 14 and 15, sulfate is lower in the tributaries than in Bluff Creek. In tributaries 8, 10, 12, and 14 one can frequently smell hydrogen sulfide and find native sulfur floating along the margins of the stream. Thus, the total sulfur content in the tributaries is greater than the sulfate concentration. Neutralization of the tributary water enhances oxidation rates of the sulfur species; therefore, Bluff Creek maintains a higher sulfate concentration than the tributaries.

Station 14 has the lowest average pH of the tributaries and one of the highest sulfate concentrations in the entire drainage system. The strong hydrogen sulfide odor and the abundance of native sulfur indicates that this tributary has a very high total sulfur content as well. Station 15 has the highest average pH of all the tributaries and also has one of the highest sulfate concentrations. The water at station 15 has been almost completely neutralized before reaching Bluff Creek. The high sulfate concentration has probably resulted from almost complete oxidation of other sulfur species since native sulfur or hydrogen sulfide have not been found in this tributary.

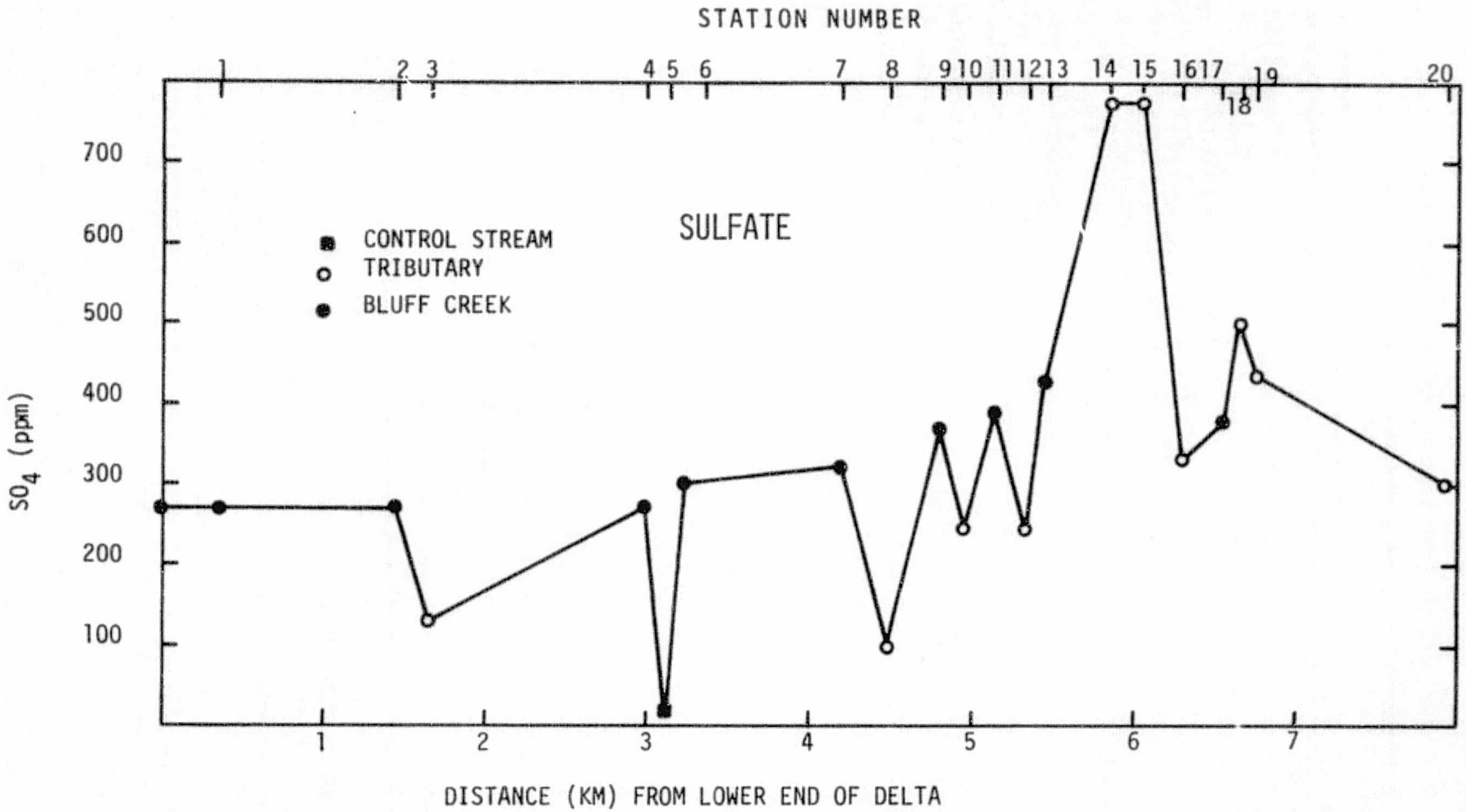


FIGURE 32 AVERAGE SULFATE (ppm) AT 20 STATIONS ALONG BLUFF CREEK, TUSCALOOSA COUNTY, ALABAMA

The sulfate content of Bluff Creek decreases in a downstream direction. This indicates either dilution or sulfate removal from the stream. The increase in discharge downstream may be sufficient to account for the total decrease in sulfate concentration. Another alternative is that sulfate is removed from the stream. Calculations indicate that the calcium concentration in Bluff Creek is too small to allow sulfate removal by precipitation of gypsum or anhydrite. It is possible that sulfate is removed by sorption or complexing with the iron and manganese hydroxide or by sorption on clay minerals.

Figure 33 represent the results of attempts to determine relationships among iron, manganese, and pH. Both iron and manganese correlate with pH, but the corelations are quite poor (e.g. $r^2 = 0.22$ for iron). The relationship between iron and manganese also has a low coefficient of determination ($r^2 = 0.20$).

Assuming the possibility that the iron-pH behavior is different in the tributaries than within Bluff Creek, we grouped the data and calculated separate least squares equations for each group. The results are shown in Figure 34 . Within the tributaries, iron shows a 36 percent dependency on pH. The low correlation is probably a result of the fact that most iron is in the ferrous state and thus soluble in the pH range of the tributaries. The correlation may, however, give an indirect indication of the oxidation rate of iron in the tributaries. Within the main stream there is no correlation between iron and pH. The iron concentration in Bluff Creek is controlled by Eh and the average pH of the stream is above six.

Correlation of iron vs. sulfate is also shown on Figure 34 . The linear regression equation for all data does not represent an average of the equations for the tributaries and Bluff Creek, due to natural grouping of data An inverse relationship exists between iron and sulfate

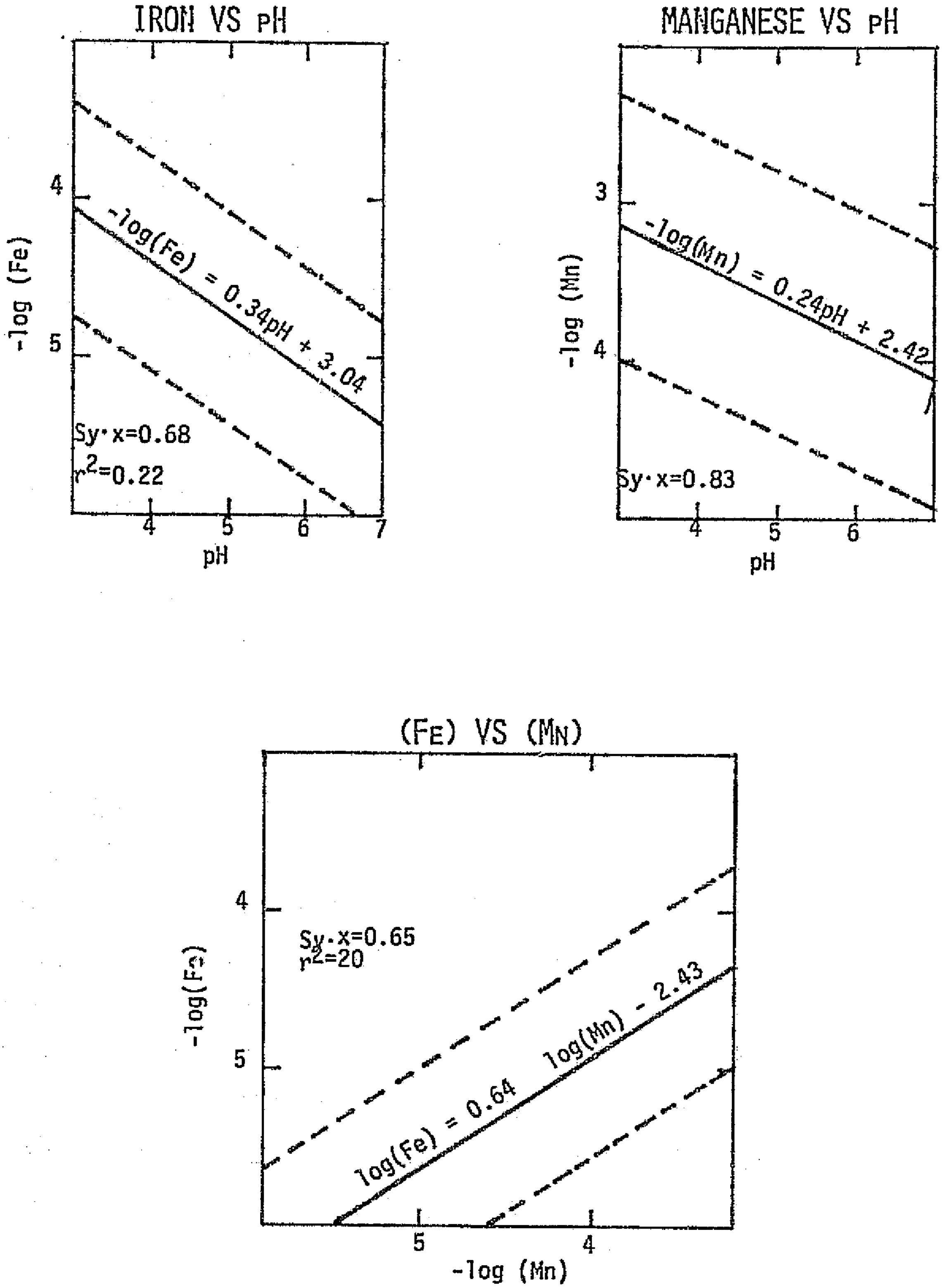
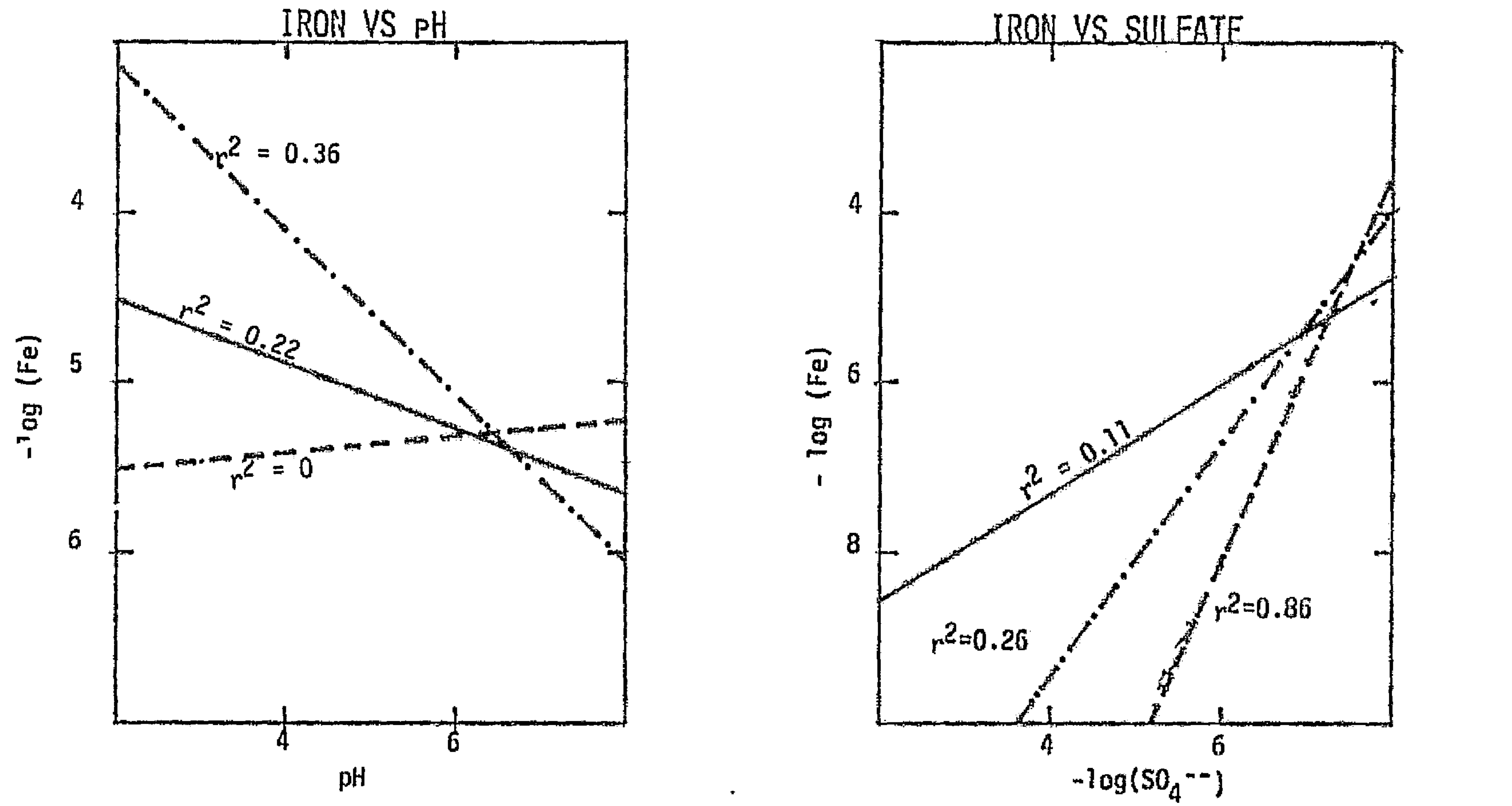


FIGURE 33 LINEAR REGRESSION ANALYSIS OF IRON VS pH, MANGANESE VS pH, AND IRON VS MANGANESE



log (Fe) = 3.02 - 0.35pH	ALL DATA	———	Log (Fe) = 0.62 log (SO_4) - 3.52
log (Fe) = 0.045pH-5.6	BLUFF CREEK	— — —	Log (Fe) = 0.72 + 2.22 log (SO_4)
log (Fe) = 2.14-0.49pH	TRIBUTARIES	—— · ——	Log (Fe) = 1.35 log (SO_4)- 1.3

FIGURE 34 LINEAR REGRESSION ANALYSIS DATA FOR IRON VS pH AND IRON VS SULFATE

concentrations. The low correlation (r^2 = 0.26) within the tributaries is probably due to incomplete oxidation of iron and sulfur species. An excellent, inverse correlation (r^2 = 0.86) exists between iron and sulfate in samples from Bluff Creek. Iron concentrations decrease as sulfate increases. Ferric hydroxide precipitates as iron is oxidized, whereas sulfate, the dominant sulfur species in Bluff Creek, has a much higher solubility than iron.

Other ions present in the Bluff Creek drainage system include nickel, chromium, zinc, cadmium, cobalt, and copper. Of these, chromium, cadmium, and cobalt were present in very low concentrations or not detected in many analyses. Nickel, zinc, and cobalt are present in greater abundance than chromium, cadmium, and copper, but concentrations do not exceed one part per million. The latter three elements are more concentrated in tributaries than in Bluff Creek. (Average values for nickel are 0.10 ppm in Bluff Creek and 0.16 ppm in the tributaries; for zinc 0.116 ppm in Bluff Creek and 0.243 ppm in the tributaries; for cobalt the values are 0.06 ppm and 0.17 ppm.) The lower concentrations in Bluff Creek probably result from dilution or sorption phenomena.

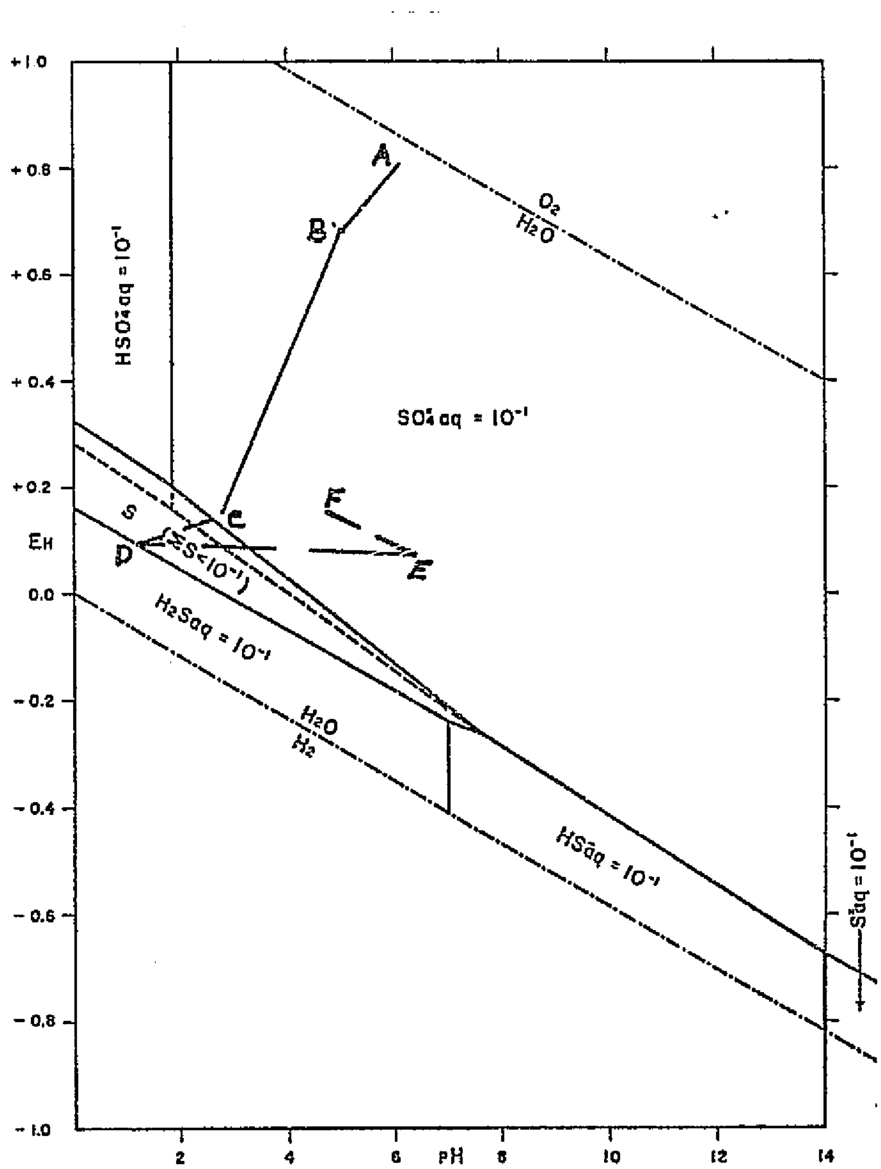
No direct health hazards are expected to occur as a result of the presence of the above six trace elements. Potential, indirect effects could result from use of the water for agricultural purposes since some plants concentrate specific elements which may have accumulative effects if ingested by humans.

Summary of Mine Drainage Chemistry

The chemistry of production of acid mine water and partial re-equilibration of Bluff Creek with the carbonate beds and atmosphere is diagramatically illustrated in Figure 35 by dashed lines superimposed over

FIGURE 35

SCHEMATIC ILLUSTRATION OF MINE WATER EQUILIBRATION PROCESSES SUPERIMPOSED OVER Eh-pH DIAGRAM FROM KRAUSKOPF (1967, p. 217). SEE TEXT FOR EXPLANATION.



the Eh-pH diagram from Krauskopf (1967). The dashed lines are schematic and do not represent actual Eh-pH values.

Rain, in equilibrium with the atmosphere, strikes the spoil piles, oxidizes pyrite to yield ferric ions and sulfate. The ferric ions are rapidly removed from solution as ferric hydroxide. In the process the water is reduced (Eh decreases) and hydrogen ions are produced (pH decreases). This process is indicated by the line A-B in Figure 35 . Under the conditions indicated by point B, the water cannot completely oxidize all ferrous ions from pyrite solution and ferrous ions become the dominant ions in solution. Between B and C (Figure 35) the solution contains ferrous and sulfate ions, but the pH decreases more slowly than between A and B because ferric hydroxide is no longer precipitated in large quantities. As the Eh and pH continue the concentration of other elements, soluble under the new conditions, will increase. Feldspar, clay, and carbonate minerals act as buffers in the system and may greatly retard the rate of acid production.

At point C (Figure 35) pyrite decomposition yields native sulfur in addition to sulfate. Continued solution of pyrite can decrease pH without necessarily decreasing Eh (line C-D) and at point D, hydrogen sulfide becomes a stable phase. The previously formed sulfate is not completely reduced by this process due to the sluggish nature of the reaction.

Rapid neutralization of the water occurs as it flows from the spoils into the tributaries of Bluff Creek because of reaction with carbonate beds in the Pottsville Formation. (line D-E, Figure 35) The rapid rise of pH in an oxidizing environment causes evolution of hydrogen gas and subsequent oxidation to native sulfur and sulfate. Oxidation of ferrous to ferric ions and manganous to manganic ions occurs with precipitation of the respective hydroxides. During this process Eh does not rise appreciably because available oxygen is consumed by chemical reactions. Eh does rise slightly downstream and as the stream crosses the delta, the pH decreases to approximately 5 (line E-F.)

Remote Sensing And Mine Drainage

It is difficult to accurately determine the chemical condition of mine drainage from areal photography or imagery. Low to moderate altitude color photography or multispectral imagery can be used to locate areas of iron hydroxide precipitation, but is not a specific indicator of Eh or pH. The orange-red color of ferric hydroxide is quite visible and indicates an increase in Eh or pH in the stream. It is important to note that iron precipitation occurs as the stream attempts to equilibrate with the atmosphere and/or carbonate beds over which it flows. Thus the presence of ferric hydroxide demonstrates that the stream is recovering from the acid, reducing conditions which obtain within the spoils, but cannot be used to indicate the actual pH or Eh. Tributaries of Bluff Creek may contain ferric hydroxide at any pH between 3 and 6.5. Ferric hydroxide may be present in water but not be visible on the photographs. This is especially true if the water is turbulent or turbid, because turbulent water suspends sediment as well as ferric hydroxide and standing water with high turbidity often contain colloidal sized particles of sediment or ferric hydroxide. In either case, the color of ferric hydroxide is masked and may not be visible.

Standing bodies of water from mine drainage often have a green coloration, falsely interpreted by many workers to indicate low pH. This color is believed to be the result of light diffraction by suspended colloids (dominantly of clay and/or ferric hydroxide) and thus, does not necessarily indicate the pH of the water.

Clear water streams do not necessarily represent pure water systems.

The most unpolluted water in the Bluff Creek drainage basin in found in the control stream (Station 5). It is clear, neutral, and contains low concentrations of dissolved solids. Another tributary that contains clear water, visually as ideal as Station 5, is the tributary represented by Station 14. The water at this station has the lowest pH of all tributaries in the system and contains high concentrations of dissolved solids. The two streams cannot be distinguished by visual means. On the other hand, the tributary at Station 15 has been nearly neutralized (pH about 6.5) by flowing over carbonate beds, is rapidly recovering from the conditions which prevail in the spoils; its bed is blanketed by ferric hydroxide; and the water has a high trubidity. Therefore, it is apparent that in the Bluff Creek drainage system, water that has the lowest aesthetic value may indicate the highest rate of recovery from mine drainage pollution. Future research to determine the use of remote sensing techniques in evaluating natural recovery rates of streams affected by mine drainage is necessary. If recovery results from stream flow over carbonate beds, then remote sensing techniques may indirectly aid in determination of the location and geographic extent of such beds within the Pottsville Formation.

SELECTED REFERENCES

Barnes, I., 1965, Selected Properties of Mine Water and the Chemical Environment Within Some Flooded Anthracite Mines: in Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburg, PA, pp. 1-12.

Bostrom, K., 1967, Some pH-Controlling Redox Reactions in Natural Waters: Chapter 14 in Equilibrium Concepts in Natural Water Systems, R.F. Gould (ed.), American Chemical Series, No. 67, p. 344.

Brice, James C., 1960, "Index for Description of Channel Braiding," Bulletin of the Geological Society of America, Vol. LXXI, p. 1833.

Brice, J.C., 1966, Erosion and Deposition in the Loess-mantled Great Plains, Medicine Creek Drainage Basin, Nebraska, U.S. Geological Survey Prof. Paper 352-H., pp. 255-339.

Brown, Carl, 1950, "Effects of Soil Conservation," in Parker D. Trask (ed.), Applied Sedimentation. New York: Wiley.

Brune, Gunnar M., 1953, "Trap Efficiency of Reservoirs," Transactions, American Geophysical Union, Vol. XXXIV, pp. 407-418.

Brunn, Per, 1968, "Sediment Transport--Fluvial and Marine," in Rhodes W. Fairbridge (ed.), The Encyclopedia of Geomorphology, Encyclopedia of Earth Sciences, Volume III. New York: Reinhold Book Corp.

Campbell, F.B., and Bauder, H.A., 1940, "A Rating-Curve Method for Determining Silt-Discharge of Streams," Transactions, American Geophysical Union, XXI, pp. 603-607.

Carlston, Charles W., 1965. "The Relation of Free Meander Geometry to Stream Discharge and Its Geomorphic Implications," American Journal of Science, Vol. CCLXIII, pp. 864-885.

Cooke, R.U. and Doornkamp, J.C., 1974, Geomorphology in Environmental Management, Oxford: Claredon Press, p. 413.

Culbertson, W.C., 1964, Geology and Coal Resources of the Coal-bearing Rocks of Alabama, U.S. Geological Survey Bulletin, 1183-B, p. 79.

Dillon, A.C., Masingill, J.H., and White, J.R., 1973, Erosion Rates of Selected Createceous and Quaternary Sediments in Tuscaloosa County, Alabama, Academy of Science (abs.), April 1973.

Douglas, Ian, 1967, "Man, Vegetation and the Sediment Yields of Rivers," Nature, Vol. CCXV, pp. 925-928.

Dragoun, Frank J., 1962, "Rainfall Energy as Related to Sediment Yield," Journal of Geophysical Research, Vol. LXVII, pp. 1495-1501.

Drennen, C.W., 1950, Geology of the Piedmont-Coastal Plain in Eastern Alabama and Western Georgia, Alabama University, Unpublished Masters Thesis, p. 84.

Dury, G.H., 1966, "The Concept of Grade" in G.H. Dury (ed.), Essays in Geomorphology, London: Heinemann.

Emmett, W.W., 1968, Gully Erosion, in the Encyclopedia of Geomorphology, New York: Reinholt Book Corp.

Folk, R.L., 1974, Petrology of Sedimentary Rocks, Austin, Texas: Hemphill Publishing Co., p. 182.

Garrels, R.M. and Thompson, M.W., 1960, Oxidation of Pyrite by Iron Sulfate Solutions, American Journal of Science U258-A, p. 57.

Garrels, R.M. and Christ, C.L., 1965, Solutions, Minerals, and Equilibria, New York: Harper & Row Publishers, p. 450.

Gregory, K.J. and Walling, D.E., 1973, Drainage Basin Form and Process. New York: Wiley.

Heidel, S.G., 1956, "The Progressive Lag of Sediment Concentration With Flood Waves," Transactions, American Geophysical Union, Vol. XXXVII, pp. 56-66.

Hem, J.D. and Cropper, W.H., 1959, Survey of Ferrous-Ferric Chemical Equilibria and Redox Potentials, U.S. Geological Survey Water Supply Paper, 1459-A, p. 31.

Horton, R.E., 1945, Erosional Development of Streams and Their Drainage Basins, Geological Society of America Bulletin, Vol. 56, pp. 275-370.

Hughes, T.H., 1975, Erosion Sedimentation and Mine Drainage, in Orientation Session on Surface Mining for the Legislature of Alabama, Mineral Resources Institute, University of Alabama, pp. 31-43.

Hursh, C.R., 1948, Local Climate in the Copper Basin of Tennessee as Modified by the Removal of Vegetation, U.S. Department of Agriculture Cir. No. 774, p. 38.

Krauskopf, K.B., 1967, Introduction to Geochemistry, New York: McGraw-Hill, Inc., p. 721.

Langbein, W.B. and Schumm, S.A., 1958, "Yield of Sediment in Relation to Mean Annual Precipitation," Transactions, American Geophysical Union, Vol. XXXIX, pp. 1076-1084.

Leopold, Luna B. and Wolman, M. Gordon, 1960, "River Meanders," Bulletin of the Geological Society of America, Vol. LXXI, pp. 769-794.

Leopold, Luna B., 1962, "Rivers," American Scientist, Vol. L, pp. 511-537.

Leopold, Luna B. and Skibitzke, Herbert E., 1967, "Observations on Unmeasured Rivers," Geografiska Annaler, Vol. XLIX-A, pp. 247-255.

Long, A.R., 1974, The Climate of Alabama In Climates of the States, Vol. 1--Eastern United States plus Pureto Rico and the Virgin Islands, Port Washington, New York: Water Information Center, pp. 1-15.

Lundgren, D.G. and Schnaitman, C.A., 1965, The Iron Oxidizing Bacteria--Culture and Iron Oxidation, in Symposium on Acid Mine Drainage Research, Pittsburg, PA: Mellon Institute, pp. 14-22.

Maner, Sam B., 1958, "Factors Affecting Sediment Delivery Rates in the Red Hills Physiographic Area," Transactions, American Geophysical Union, Vol. XXXIX, pp. 669-675.

Matthes, Gerald H., 1933, "Diversion of Sediment at Branching Channels," Transacations, American Geophysical Union, Vol. XIV, pp. 506-559.

McCally, Henry, 1900, Report on the Warrior Coal Basin, Alabama Geological Survey Special Report, No. 10, p. 327.

Melton, F.A., 1936, "An Empirical Classification of Flood-Plain Streams," The Geographical Review, Vol. XXVI, pp. 593-609.

Musser, J.J., 1963, Description of Physical Environment and of Strip Mining Operations in Parts of Beaver Creek Basin, Kentucky, U.S. Geological Survey Prof. Paper, No. 427-A, p. 25.

Renner, F.G., 1936, Conditions Influencing Erosion on the Boise River Watershed, U.S. Department of Agriculture Tech. Bullentin, No. 528, Washington, D.C., p. 43.

Schumm, S.A., 1956, The Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey, Geological Society of America Bulletin, No. 67, p. 597-646.

Semmes, D.R., 1929, Oil and Gal In Alabama, Alabama Geological Survey Special Report, No. 15, p. 408.

Shearer, R.E. and Everson, W.A., 1965, Study of Bacteriophages in Controlling Acid Mine Water, Symposium on Acid Mine Drainage Research, Pittsburg, PA: Mellon Institute, pp. 23-34.

Singer, R.E. and Stumm, W., 1968, Kinetics of Oxidation of Ferrous Iron, in Second Symposium on Coal Mine Drainage Research, Pittsbury, PA: Mellon Institute, pp. 12-34.

Smith, E.E., Svanks, K., and Shumate, K., 1968, Sulfide to Sulfate Reaction Studies in Second Symposium on Coal Mine Drainage Research, Pittsburg, PA: Mellon Institute, pp. 1-11.

Smith, Norman D., 1970, "The Braided Stream Depositional Environment: Comparison of the Platte River with Some Silurian Clastic Rocks, North-Central Appalachians," Bulletin of the Geological Society of America, Vol. LXXXI, pp. 2993-3014.

Smith, Norman D., 1974, "Sedimentology and Bar Formation in the Upper Kicking Horse River, A Braided Outwash Stream," Journal of Geology, Vol. LXXXII, pp. 205-223.

Smith, Terence R., 1974, "A Derivation of the Hydraulic Geometry of Steady-State Channels from Conservation Principles and Sediment Transport Laws," Journal of Geology, Vol. LXXXII, pp. 98-104.

Stevens, J.D., 1939, "Silt Problems of the West," Transactions, American Geophysical Union, Vol. XX, pp. 26-32.

Stow, S.H. and Hughes, T.H., in preparation, Geologic Map on the Cottondale Quadrangle, Tuscaloosa County, Alabama, Alabama Geological Survey Atlas Service.

Strahler, A.N., 1956, Quantitative Slope Analysis, Geological Society of America Bulletin, No. 67, pp. 571-596.

Strahler, Arther N., 1958, "Dimensional Analysis Applied to Fluvially Eroded Landforms," Bulletin of the Geological Society of America, Vol. LXIX, pp. 279-300.

Tanner, William F., 1971, "The River Profile," Journal of Geology, Vol. LXXIX, pp. 482-492.

Walker, J.G. and Randles, C.I., 1965, Mechanism of Pyrite Oxidation: in Symposium on Acid Mine Drainage Research, Pittsburg, PA: Mellon Institute, pp. 10-13.

Wolman, M. Gordon, 1967, "A Cycle of Sedimentation and Erosion in Urban River Channels," Geografiska Annaler, Vol. XLIX-A, pp. 385-395.

Young, Anthony, 1969, "Present Rate of Land Erosion," Nature, Vol. CCIV, pp. 851-852.

Young, Anthony, 1973, <u>Slopes, Geomorphology Text 3</u>, Edinburgh, Oliver and Boyd, p. 288.

APPENDIX I
MEASUREMENT AND CALCULATION

Scale Variation

The average scale of photographs provided by NASA is 1/25, 000 (provided by a six inch lens flown at a height of 12, 500 feet above the earth's surface). Because the earth's surface has relief, the camera height cannot remain constant and this produces scale variation in aerial photographs. Scale correction factors have been calculated for both test areas, assuming that camera (lens) height is the distance above median ground elevation, and that the camera lens-axis tilt is negligible.

Ground elevation in the Cordova test site varies from 250-600 feet; the median ground elevation is 435 feet. Thus the scale of the photographs at the highest elevation is 1/24, 650 and at the lowest elevation is 1/25, 350. The maximum scale variation is $\pm$ 1.4 percent. However, since the New Castle coal seam occurs at an elevation of 134 m (440 feet) and the Mary Lee seam at 122 m (400 feet) and the median ground elevation is 130 m (425 feet) the scale variation in strip mined areas is negligible ($\pm$ 0. 16%). Scale correction factors have not been employed in calculations for the Cordova Test Site.

Ground elevation in the Searles Test Site varies from 49 to 213 m (160-700 feet); the median ground elevation is 131 m (430 feet). The scale of the photographs at the highest elevation is 1/24/460 and at the lowest elevation is 1/25, 540. The maximum scale variation is $\pm$ 2. 16 percent. The four principal coal seams in the Searles Site are the Johnson, Carter, Milldale, and Brookwood. All occur between elevations 185 and 216 m (600-700 feet). Virtually all measurements involving the strip mines are subject to scale corrections between -1.36 and -2.16%. The correction factor used in calculations is the average (-1.76%), thus, linear measurements taken from the photographs of strip mined areas have been multiplied by 0.9824, and the maximum error due to variation of scale is 0.4% of the corrected value. Measurements involving areas of different elevations than the coal seams (such as stream valleys) have been subjected to different, but appropriate correction factors.

Photographs with a scale of 1/25,000 at the median elevation present scale variation of $\pm$ 0.000263 meters per meter of elevation different. As a result, correction factors for scale variation (S_v) can be calculated if the median ground elevation, in meters, (E_g) and the average elevation in meters of the area to be measured (E_s) are known. This is shown in equation 1.

$$(1) \qquad S_v = 1 + 0.000263\,(E_g - E_s)$$

In the test areas for this project E_s can easily be determined by reference to topographic maps.

If the units of elevation are feet rather than meters, then equation 1 becomes

$$(1a) \qquad S_v = 1 + 0.00008\,(E_g - E_s)$$

Figure 36
(See text for explanation)

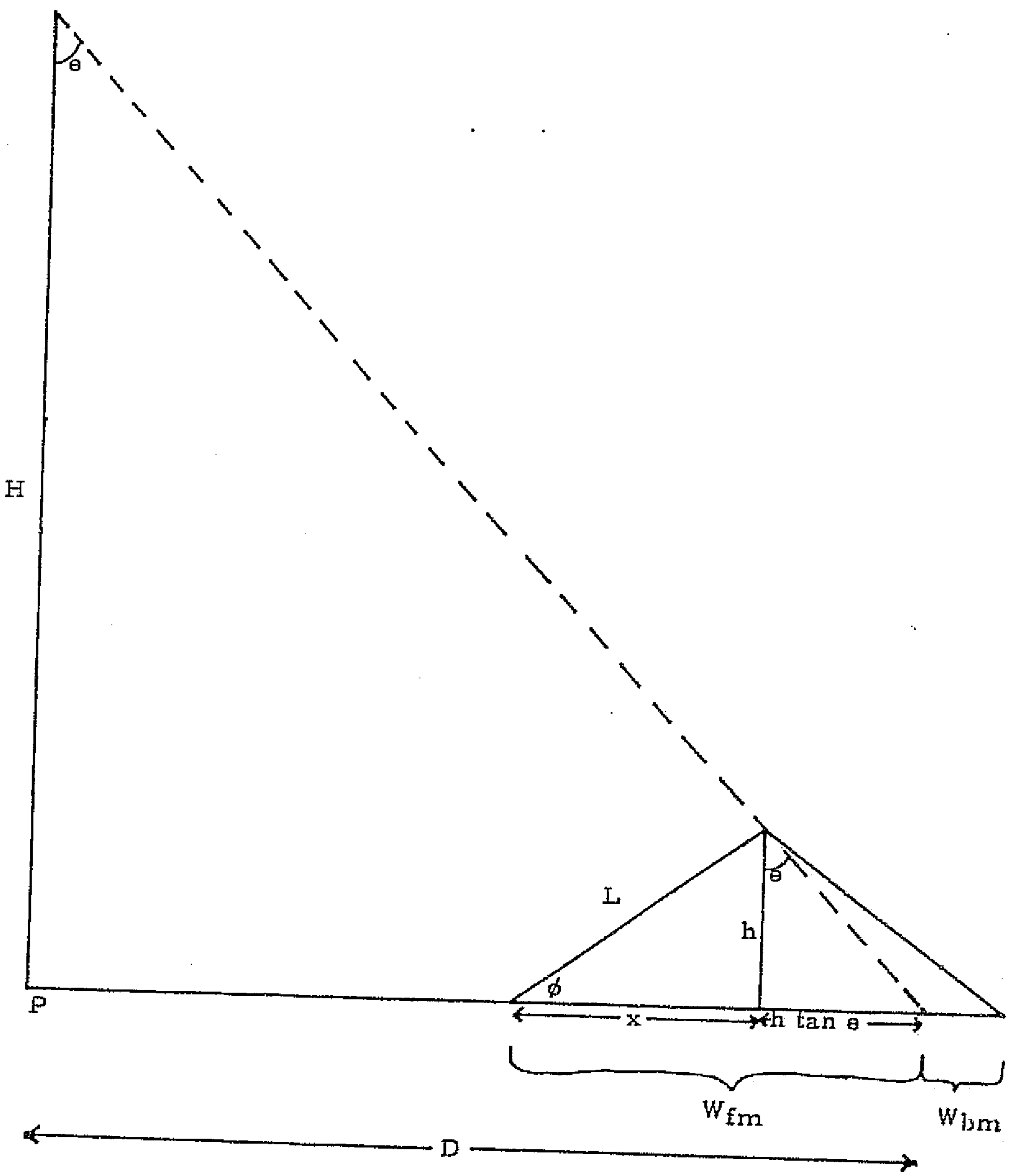
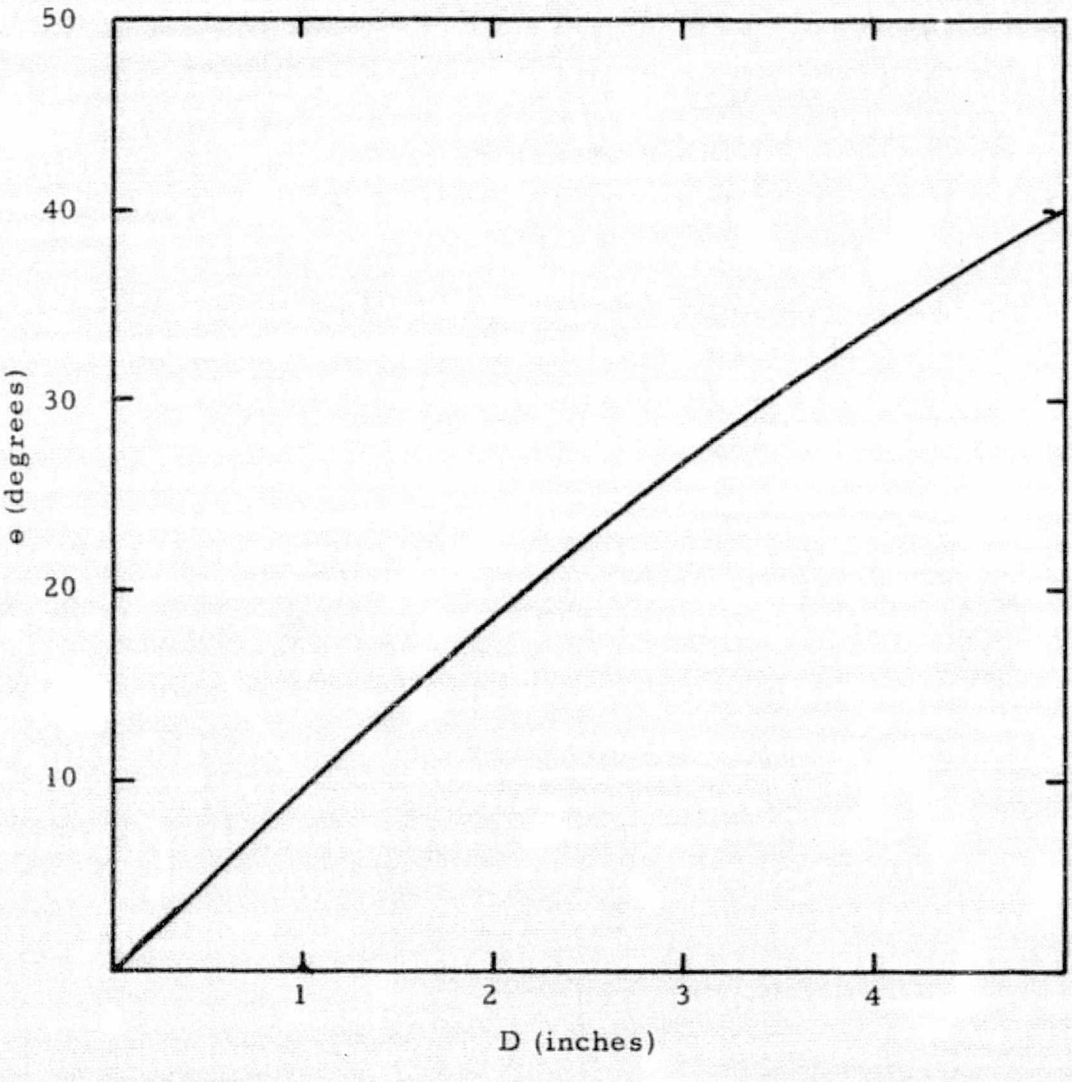


Figure 37
Vertical angle of camera view (θ) vs. distance
From the principal point (D) in inches.
(See text for discussion)



Slope Correction Factors

Slopes whose crest does not lie at the principal point of an aerial photograph appear to be distorted. Slopes which face toward the camera (foreslopes) appear elongated and those facing away from the camera (backslopes) appear shortened. Figure 36 is a schematic drawing representing the special case where the slopes of a symmetrical spoil pile face parallel with a radial line through the principal point (P) of a photograph. H is the camera height; θ is the vertical angle of view from the camera to the top of the spoils; D is the measured distance from the principal point of the photograph to the top of the spoils, corrected for scale variation; W_{fm} is the width of the foreslope as measured on the photograph and corrected for scale variation; W_{bm} is the measured width of the backslope, corrected for scale variation; x is the actual width of the foreslope and backslope; L is the length of the foreslope and backslope; h is the height of the spoils; and ϕ is the angle of repose of the spoils (36^{o} is the average angle of repose of spoils in the test areas).

If D and H are known then theta (θ) can easily be calculated, since:

$$(2) \qquad \theta = \arctan \frac{D}{H}$$

Thus the vertical angle of view from the camera to the top of any spoils is easily determined. A simple graph has been constructed for the 1/25,000 scale photographs provided by NASA and is shown as Figure 37.

The actual dimensions of spoil piles (See Figure 36) can be determined from equation 1 plus measured width of foreslope (W_{fm}) or backslope (W_{bm}), but are subject to the following limits: If the top of the spoils lies at the principal point of the photograph;

$$W_{fm} = W_{bm} = x$$

and if the spoils have a 36^{o} angle of repose (ϕ) and $\theta = 54^{o}$;

$$W_{fm} = 2x$$

and

$$W_{bm} = 0.$$

If θ exceeds 54^{o} then the following calculations do not hold since:

$$W_{fm} \quad 2x$$

and

$$W_{bm} \quad 0$$

Slopes for which θ is between 0^{o} and 54^{o}, and ϕ is 36^{o} are subject to the following equations:

(3) $$W_{fm} = x + h \tan \theta$$

(4) $$W_{bm} = x - h \tan \theta$$

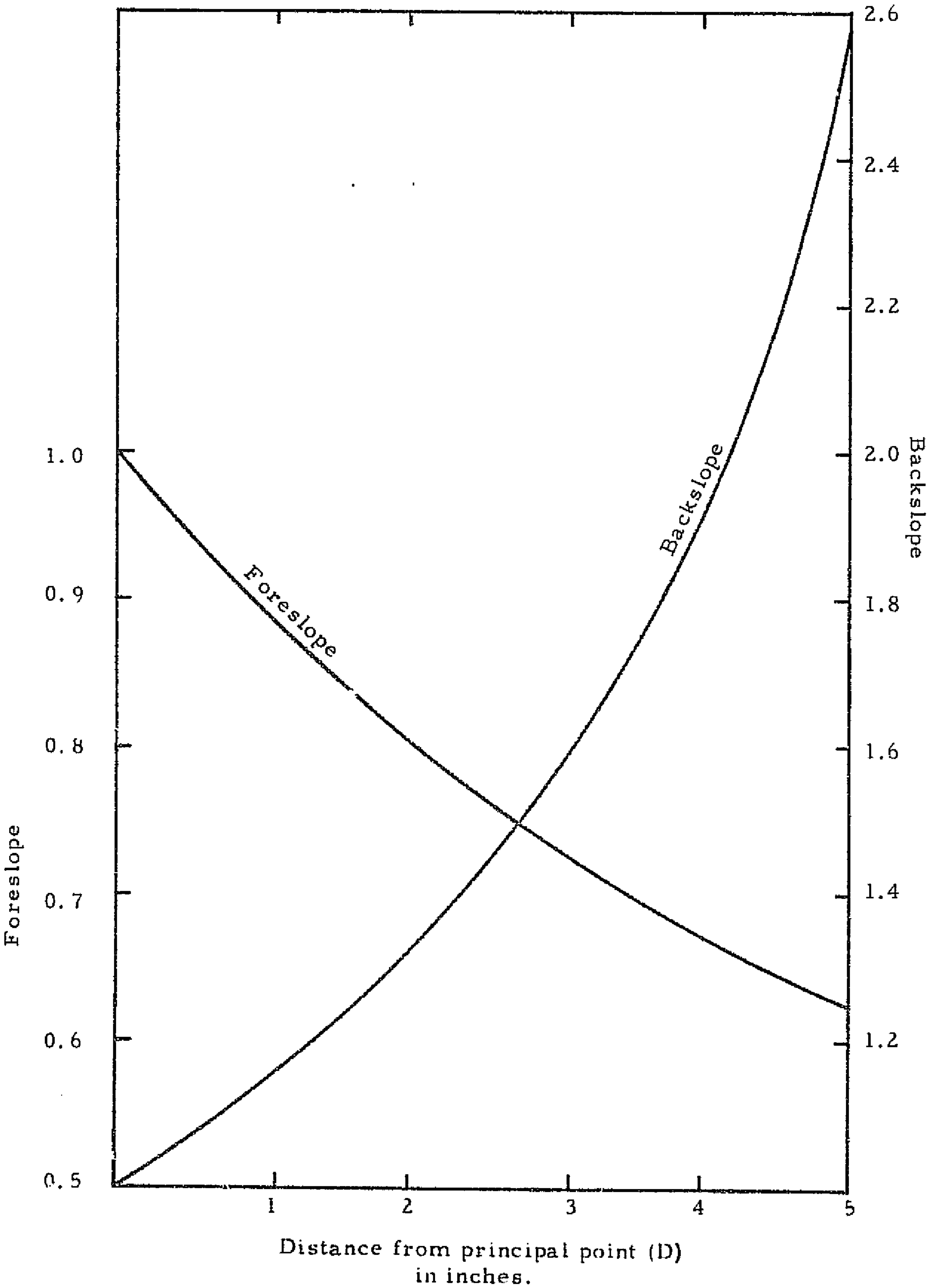
Since, from Figure 36,

$$h = x \tan 36$$

substitution into equation (3) yields

$$W_{fm} = x + x \tan 36 \tan \theta.$$

Figure 38
Slope Correction Factors (S)
for slopes which strike perpendicular
to a radial vector of the photograph



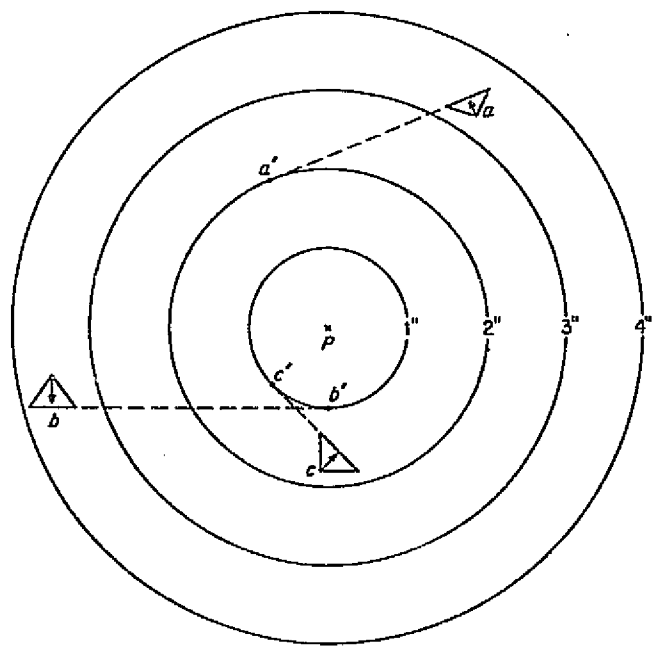


Figure 39
(See text for discussion)
Miller & Miller, 1961

Factoring x and rearranging yields

(5) $x = W_{fm}/ (1 + \tan 36 \tan \theta)$.

Similar reasoning applied to measured widths of the backslope would give equation (6).

(6) $x = W_{bm}/(1 - \tan 36 \tan \theta)$.

In practice x is determined by measuring D (in inches), correcting for scale variation, referring to Figure 38 to determine the proper foreslope or backslope correction factor, and multiplying this factor by W_{fm} or W_{bm}.

Once x is known then:

(7) $L = x/\sin 36^{\circ}$

(8) $h = x \tan 36^{\circ}$

The slope correction factors discussed above assume that the strike of the slope is perpindicular to a radial vector of the photograph. Slopes which are oblique to the radial vector are less distorted than shown in the equations. Such slopes have been corrected by the method described by Miller and Miller (1961, p. 50) and illustrated by Figure 39. Slope "a" lies about 3.4 inches from the principal point of the photograph in Figure 39. The strike of the slope is tangent to a circle two inches from point P. The slope direction for slope "a" is the same as it would be if the slope were at a' (two inches from P).

Thus assuming D = 2 inches, equations 2 through 8 hold.

Linear Measurement

On level ground of known elevation, linear measurements may be scaled directly from the photographs and converted to ground length by:

(9) $L = 25\ L_m\ S_v$

where

L = ground length in meters
L_m = scaled length in millimeters
S_v = correction factor (equation 1)

On sloping ground, measurement must include appropriate slope correction factors (equations 6 and 7).

Many measurements for this project were determined by use of a Wild binocular microscope with a calibrated eyepiece. The constant in equation 9 varies with magnification so that at 6X equation 9 becomes:

(9a) $L = 4.032\ U_m\ S_v$

U_m = units on microscope eyepiece

at 12X magnification:

(9b) $L = 2.016\ U_m\ S_v$

Slope correction must be included when necessary.

Measurement of Area

Measurement of the area of individual strip mines was performed by use of a polar planimeter. One square centimeter on the photograph equals 15.27 units on the polar planimeter (U_p) which is equal to 6.25 hectares, thus area in hectares (A_h) can be calculated as follows:

$$(10) \quad A_h = (6.25/15.27)\ U_p(S_v)^2 = 0.4093\ U_p\ (S_v)^2$$

Because the average elevation of strip mines in the Cordova test area is very near the median ground elevation, S_v is assumed to be unity thus:

$$(10c) \quad A_h = 0.4093\ U_p$$

The average S_v in strip mined portions of the Searles test site is 0.9824, thus $(S_v)^2 = 0.9651$ and

$$(10x) \quad A_h = 0.395\ U_p$$

Estimation of volume

Estimates of the amount of material removed from the slopes of strip mine spoils have been determined by estimating the volume of rills and gulleys from measurements taken from the 1/25,000 scale aerial photographs. The amount of material removed by slope wash has not been estimated from aerial photographs.

Rills seen on the photographs have been classified into first, second, and third order (Strahler, 1950) by assuming that first order rills have no tributaries, second order rills are formed where two first order rills flow together, and third order rills are formed where two second order rills join. We have assumed that on a particular slope, the average dimensions of rills of a given order can be used to represent all the rills of that order, and that the slope of the sides of the rills is 36°. The equations below also assume that the spoils down which the rills flow have a 36° angle of repose. The equations can be modified for different slope angles by substitution of proper values.

If a rill of a given order is assumed to have a triangular cross-section then its volume is

(11) $V_r = 1/2\, W_r\, h_r\, L_r$

where:

V_r = volume of the rill

W_r = average width of the rill

L_r = length of the rill

h_r = average depth of the rill

Since dimensions measured on aerial photographs are subject to correction, as discussed in previous sections, it follows that:

(12) $W_r = W_m S_v$

where:

W_m = measured width of the rill

and that the slope length of a rill can be estimated using a modification of equation 7

(13) $L_r = L_m S_v S \sin 36^\circ$

where: L_m = measured length of a rill

S_v = correction factor due to scale variation

S = slope correction factor (Figures 7 and 8).

If the sides of a rill slope at a 36° angle, the depth of the rill can be expressed in terms of its width.

(14) $h_r = 1/2\ W_m S_v \ / \tan 54^\circ$

Now, substitution of equations 12, 13, and 14 into equation 11 yields:

(15) $$V_r = 1/2\ W_m S_v \cdot \frac{1/2 W_m S_v}{\tan 54} \cdot L_m S S_v \sin 36$$

collecting terms and rearranging yields:

$$V_r = \frac{W_r^2\ L_m S_v^3 S \sin 36}{4 \tan 54}$$

since

$$\frac{\sin 36}{4 \tan 54} = 0.225$$

then the volume of a given rill can be calculated.

(16) $V_r = 0.225\ S_v^3\ S\ W_m^2\ L_m$

If on a particular slope there are N rills of a given order the total volume (V_t) can be calculated by equation 17.

(17) $V_t = 0.225\ S_v^3\ S\ W_m^2\ L_m\ N$

For strip mined areas in the Cordova test site $S_v = 1$, thus

(17c) $V_t = 0.225\ S\ W_m^2\ L_m\ N$

In the Searles area the average $S_v = 0.9824$, thus

(17s) $V_t = 0.213\ S\ W_m^2\ L_m\ N$

Vegetative Cover

The photographs used in this project were flown by NASA in December, 1973. As a result, grasses, shrubs, and trees which have no foliage in December are not included in measurements of the percent vegetative cover. Thus, only evergreens (predominantly pine trees) are easily visible, because of their magenta color in the false color infra-red photographs.

The percent vegetative cover was estimated using a 6X loupe with a superimposed grid divided into squares 0.2 mm on each side (0.04 mm^2 area corresponding to 25 m^2 on the ground). The percent vegetative cover was estimated by placing the loupe over the photograph, counting the number of squares occupied by trees (estimated to the nearest 1/4 filled square), and dividing by the total number of squares counted.

APPENDIX II

DATA FOR EROSION STUDIES

LOCATION: 1972-0170-N

GULLY#	ORDER	A_1	A_2	A_3	A_4	A_5	D_1	AD_1	D_2	AD_2	D_3	AD_3	D_4	AD_4	TOTAL
1.	2	0	8	2	.4	.75	10	4	22	30.8	22	26.4			72.12
2.	2		0	.8	1.2		10		22	8.8	22	11.0			110
3.	2	0	0	1.8	3.0						22	52.8			52.8
4.	1	0	0	2.2	.35				22	24.7	20	28.6			53.3
5.	2	0	4	5.7	2.6		10	20	22	106.7	22	91.3			218.0
6.	2	0	1.5	5.2	3		12	9.0	22	86.6	30	123.75			219.35
7.	3	0	1.5	1.1	4	1.05	12	9		28.2	22	56.1			141.6
8.	2	0	2	1.953			10	10	22	43.45	30	74.25			127.7
9.	2	0	1.8	3	1.7		10	9	22	52.8	30	70.5			132.3
10.	3	0	1.3	1.1	4	2.4	12	7.8	22	26.4	30	96			106.4
11.	3				3	1.65					21	48.8			48.8
12.	3				2.6	22					21	46.2			46.2
13.	3				5.6	.75					21	66.6			66.6
															1395.175 ft.^{3}

AREA = 4000 sq. ft.

VOLUME = 562.7 yd.^{3}/ACRE

= 1062.9 m^3/HECTARE

LOCATION: 1961-62-A-0167-S

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	TOTAL
1.	2		1.8	3.1	16	31.8	39.2
2.	2		1.57	3.8	17	34.6	45.6
3.	2		4.27	3	18	47.2	65.3
4.	2		.8	1.5	18	14.9	21.77
5.	2		5.4	2	21.5	48.1	79.5
							251.37 $ft.^3$

AREA = 262.116 sq. ft.

VOLUME = 1547.15 $yd.^3$/ACRE

= 2922.56 m^3/HECTARE

LOCATION: 1957-58-0170-SE

GULLY #	ORDER	A_1	A_2	D_1	AD_1	TOTAL
1.	2	.9	3.3	22	46.2	46.2
2.	2	2.4	3.3	22	62.7	62.7
3.	2	1.12	3.6	22	51.9	51.9
4.	3	13.2	13.2	22	290.4	290.4
5.	2	2.7	1	22	40.7	40.7
6.	1	0	.5	14	7	7
7.	2	9.8	2.1	22	130.9	130.9
						629.8 $ft.^3$

AREA = 873 sq. ft.

VOLUME = 1163.8 $yd.^3$/ACRE

= 2198.5 m^3/HECTARE

LOCATION: 1949-0170-S

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.	3	14.4	11.1	9.75	12	15.3	16.8	195.5	348.52
2.	3	7.5	16.8	16.1	12	45.8	18.6	309.2	455.0
3.	3	9.75	14.95	16.1	12	148.2	18.8	291.8	440.0
4.	2	0	9.8	14.7	4	19.6	10	122.5	140.1
5.	1	0	2.9	6.24	4	5.95	10	45.7	51.6
									1437.22 ft.^3

AREA = 588 sq. ft.

VOLUME = 3943.3 yd.^3/ACRE

= 7448.9 m^3/HECTARE

LOCATION: 1961-62-A-0167-N

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.	1	.3	1.05	.9	18	20.25	31	30.2	50.475
2.	1	.3	1.75	1.05	36	30.75	31	43.4	74.15
3.	1	1.6	2	.4	36	54		37.4	91.2
4.	1	3.5	2	1.75	36	62.5	31	58.1	140.6
5.	1	2.25	1.2		30	51.75			51.75
6.	1	6.07	1.7		30	116.55			116.55
7.	1	3.5	1.7		30	78			78
8.	2		1.2	4.5	30		31	88.3	88.3
9.	2		3.4	5			31	252	252
10.	2		1.37	.55			31	59.5	59.5
11.	2		2.38	1.75			31	64.015	64.015
									533.27 $ft.^3$

AREA = 946 sq. ft.

VOLUME = 882.38 $yd.^3$/ACRE

= 1666.82 m^3/HECTARE

LOCATION: 1972-0170-N

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.	1	0	2.25	2.25	12.5	14.0	10.5	22.5	35
2.	2	1.1	2.8	2.25	28.5	55.5	31	78.2	106.7
3.	2	0	1.05	2.8	16	8.4	27	51.9	60.3
4.	2	0	.9	1.25	12	5.4	27	27.3	32.7
5.	2	0	1.75	3	12	10.5	27	64.1	74.6
6.	2	0	.7	1.05	12	3	27	23.6	26.6
7.	1	.5	.5		15	7.5			7.5
8.	2	2	.7		20	7			7
9.	2	.3	1.5	1.5	30	2.79	7.5		29.5
10.	1	1.05	1.09		10	10.5			10.5
11.	2	.7	2.8		30	52.5			52.5
12.	3	20	6						120.0
									563.5 $ft.^3$

AREA = 1661 sq. ft.

VOLUME = 547.3 $yd.^3$/ACRE

= 1033.88 m^3/HECTARE

LOCATION: 1973-B-0167-N

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.	2	1.3	3.6	.7	31	75.95	34	73.1	152.6
2.	2	2.4	2.75	2.75	31	79.8	34	93.5	173.3
3.	2	0	3	2	28	42	34	85	128
4.	2	0	1.5	1.8	28	21	34	56 1	77.1
5.	1	0	1.2	1.2	21	12.6	13	15.6	28.2
6.	2	0	3.6	3.05	28	52.4	34	113.05	163.4
7.	1	0	2.25	1.2	22	24.75	34	58.6	83.5
8.	2	0	.5	2	28	7.0	34	42.5	49.5
9.	2	0	.75	2.25	28	10.5	34	51	61.5
10.	1	0	.5	.5	27	6.75	12.5	6.25	13
11.	1	0	1.05		22	11.5			11.5
12.	1	0	1.0		21	10.5			10.5
									951.1 ft^3

AREA = 4349.1 sq. ft.

VOLUME = 352.78 $yd.^3$/ACRE

= 666.4 m^3/HECTARE

LOCATION: 1955-60-A-0170-W

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.	1	0	4.5	2.25	18	40.5	27	91.1	131.62
2.	1	0	2.2	2.2	4	4.4	15	33	37.4
3.	2	8.5	8.7	5.5	20	172	27	191.7	363.7
4.	3	29.9	30.6	20.7	20	816.75	27	692.55	1509.3
5.	2	0	18	25.2	9	81	27	540	621.0
6.	4	90	60.2	40.7	20	1502.0	27	13621	2864.14
7.	2	0	21.6	9.8	15	162	27	4239	585.9
8.	2	0	2.6	6.1	5	6.5	27	117.4	123.9
9.	1	0	1		10	10			10
10.	2	0	1.05	8.6	10	5.5	27	130.2	135.7
11.	2	6.3	15.3	12.8	20	216	27	379.3	595.35
12.	1	0	3		18	27			27
									7005.01 $ft.^3$

AREA = 2891.7 sq. ft.

VOLUME = 3908 $yd.^3$/ACRE

= 7382.4 m^3/HECTARE

LOCATION: 1963-B-0170-SE

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.	1	4.7	14.8		18	176.3			176.3
2.	3	32.6	36.9	40.3	22	849.2	20	725	1574.2
3.	2	22.5			10	225			225.0
4.	3	92.15	52	9	22	1585.6	20	610	2195.65
5.	1	3.2	10.15	10.4	22	146.8	24	244	512.0
6.	3	39.9	95.2		22	148.61			1486.1
7.	3	33	128		22	1771			1771
8.	1	10	17		20	270			270
9. & 10.	3	223.2	230.4		22	4989.6			4989.6
11.	2		0	3.5	30	52.5			52.5
12.	1		0	5.5	30	82.5			82.5
13.	2		179.2	6.6	30	2787			2787
14.	2		95.2	6.6	28	1425.2			1425.2
									17546.95 f

AREA = 4914.1 sq. ft.

VOLUME = 5760.5 $yd.^3$/ACRE

= 10,881.868 m^3/HECTARE

LOCATION: 1970-A-0170-SW

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.a	2	0	.81	1.6	15	6.0	26	31.3	37.33
1.b	1	0	1.2	1.4	15	9.0	26	33.8	42.8
2.	2	.35	35	.6	34	56.95	27.5	49.5	106.45
3.	3	.35	4.25	2.0	34	78.2	27	84.37	157.71
4.	3	.2	5.0	1.2	34	88.4	28	86.8	175.5
5.	3	6.0	4.5	.35	35.5	186.37	28	67.9	253.3
6.	1	3.2	.9	.3/.8	36.0	73.8	28	18.6	92.4
7.	1	1.5	.375/1		35	38.3			38.3
8.	1	1.5	.75		35	15.75			15.7
9.	1		1/.75	2	34	50.3			50.3
10.	2	.65	.6		34	21.25			21.25
11.	2	.6	1.05	1	35	28.8	25	28.7	57.5
12.	2	.2	.6	1	32	12.8	23	18.4	31.2
13.	1	.6			28	16.8			16.8
									1096.14 ft.^3

AREA = 5060.49 sq. ft.

VOLUME = 307.86 yd.^3/ACRE

= 581.5 m^3/HECTARE

LOCATION: 1968-69-0170-W

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.	1	25	61	1.4	10	6.75	8	7.2	14.25
2.	2	2.4	6.0	7.5	17	71.4	10	67.5	138.9
3.	1	0	2.2		11	12.1			12.1
4.	2	0	1.5	2.8	8	6	15	34.4	40.4
5.	2	0	1.65		7.5	6.1			6.1
6.	2	0	1.5		15	11.2			11.2
7.	2	0	4.5	1.65	11	24.75	16	49.2	73.95
8.	2	0	1.8	1.2	11	9.9	17.5	26.25	36.15
9.	2	0	3.37	2.6	11	18.5	17	50.7	69.2
10.	2	0	2.47	2.6	11	13.4	17	43.0	56.095
11.	3	3.5			2	8.75			8.75
12.	3		3.3	4			18		65.7
									696.34 $ft.^3$

AREA = 953.25 sq. ft.

VOLUME = 1178.5 $yd.^3$/ACRE

= 2226.18 m^3/HECTARE

LOCATION: 1963-0170-SW

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	D_2	AD_2	TOTAL
1.	1		0	1.225	12	7.35			7.35
2.	1	0	.68	2.6	9	3.06	33	54.12	59.18
5.	1	0	0		10	6.25			6.25
8.	3	37.8	40.5	5.6	17	665.55	33	760.6	1426.2
9.	3	16	37.5	7.8	17	454.75	33	747.45	1202.2
3.									
4.									
6.	2	1.8	13.1	4.4	17	126.65	33	288.75	415.4
7.	2	0	1.4	1	6	4.2	34	40.8	45
11.	2	0	.6	1	9	2.7	33	26.4	29.1
12.	1		0	.8	10	8			4
13.	1		0	.8	7	2.8			2.8
14.	1		0	2.24	14	15.68			15.68
15.	1		0	1.25	12	7.5			7.5
16.	1		0	1.25	12	7.5			7.5
17.									3226.16 ft

AREA = 2,720.2 sq. ft.

VOLUME = 1913.375 $yd.^3$/ACRE

= 3614.36 m^3 /HECTARE

LOCATION: 1962-0170-NE

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	TOTAL
7.	2	.35	2.25		35	220.5	220.5
9.	2	3.8	7.8		35	204.3	204.3
11.	2	.6	1.815		44.55		44.55
10.	2				38.4		38.4
15.	2	6.9	4.2		33	183.15	183.15
17.	2	0	1.95		33	64.35	64.35
16.	1	0	1.25		18	18.625	18.625
18.	2		1.25	3	18	38.25	38.25
19.	2		1.25	.9	20	21.5	21.5
20.	2		4.37	3.3	17	65.23	65.23
23.	3		78.75	4.95	17.5	111.5	111.56
24.	3		2.25	11.7	17	203.5	203.5
1.	1		0	.5	15	7.5	7.5
2.	1		0	.3	10	3.0	3.0
3.	1	0	4.4		17	37.4	37.4
4.	1	0	2.24		16	17.92	17.92
5.	1	0	.9		7	3.15	3.15
6.	1	0	1.7		5	4.3	4.3
8.	2	.35	2.18		22	23.2	23.2
12.	1	0	2.24		5	5.6	5.6
13.	1	0	1		.10	5.0	5.0
14.	1	0	1		7	3.5	3.5
21.	1	0	3.46		11	12.73	12.73
22.	1	0	1		15	7.5	7.5
							1143.16ft.

AREA = 1447 sq. ft.

VOLUME = 1274.5 yd^3/ACRE
= 2407.5 m^3/HECTARE

LOCATION: 1955-60-A-0170-SE

GULLY #	ORDER	A_1	A_2	A_3	D_1	AD_1	TOTAL
1.	2	1.92	6.65		14/12	51.42	59.98
2.	3	2.0		6.3	12	49.8	58.06
3.	2	1.35	1.5		10	14.25	11.6
4.	2	5.95	3.8		13	63.375	73.8
5.	1	1.2	1.75		14	20.65	24.07
6.	2	6.25	3.0		14	64.75	75.4
7.	1	.9	1.05		10	9.75	11.3
8.	1	.37			6		26
9.	2	6.75	52		14	83.65	97.4
10.	2	1.57	2.85		14	30.9	36.02
11.	1	4.4	4.8		5	23	26.8
12.	2	5.6	9.1		14.5	106.5	124.1
13.	2	1.65	3.2		14.5	13.6	15.3
14.	1	1.1			10	11	12.8
15.	2	.4	1.35		15	13.1	14.8
16.	2	.875			8	7	9.3
17.	2	3	6.5		15	71.25	80.7
18.	1	4.2	6.25		15	78.37	88.79
19.	2	2.85	1.95		15	36.0	40.7
20.	2	6.3	3.2		15	71.2	80.6
21.	1	2.45			8		22.8
22.	1	2.4			8		22.3
							989.74 ft

AREA = 1032.75 sq. ft.

VOLUME = 1546.11 yd^3/ACRE

= 2920.6 m^3/HECTARE

LOCATION: 1955-60-B-0170-SE

GULLY #	ORDER	A_1	A_2	A_3	A_4	D_1	AD_1	D_2	AD_2	D_3	AD_3	TOTAL
1.	1	0	0	2.1		25	26.25					26.25
2.	2	0	1.2	1.2			4.5	8	6			6
3.	3	4.1	13.65			13.5	119.8					119.8
4.	1	1.8	3.6			20	54					54
5.	2	8.75	8.75			12	105.0					105.0
6.	2	7.5	7.5			10	75					75
7.	3	10.8	16.8			13	180.05					180.05
8.	2	0	16.8	5.7		12.5	105	15	169.4			274.42
9.	3	0	21.7	4		13	141.0	25.5	327.6			468.6
10.	2	0	1.5	6.75		13	9.75	25	103.1			112.815
11.	2	0	4.4	3.15		13	15.2	24.5	90.6			105.8
12.	1	0	1.95	1.95		13	12.6	10	19.5			32.1
13.	2	0	2.2	8.4		13	14.13	24	127.2			141.3
14.	2	0	3.4	5.7		13	22.1	22	100.65			122.75
15.	2	0	5.75	4.2		13	74.75	22	109.45			184.2
16.	1	0	1.65			5	4.1					4.1
17.	1	0	.9			14	6.3					6.3
18.	4	16.8	7.5			29.5	358.4					358.4
19.	2	3.6	70.4			11.5	139.4					139.4
												2534.67 f

AREA = 2690.4 sq. ft.

VOLUME = 1519.9 yd^3/ACRE

= 2871.1 m^3/HECTARE

LOCATION: 1973-B-W

GULLY #	ORDER	A_1	A_2	A_3	A_4	D_1	AD_1	D_2	AD_2	D_3	AD_3	TOTAL
1.	1	0	.5	.5		7.5	1.8	20	10			11.8
2.	2	0	2.25	.37		8.0	9	20	26.2			35.2
3.	3	3.8	2.9			8.0	27.1					271
4.	2	6.25	2.9			8	36.6					366
5.	2					6	36					3.6
6.	1	.8	.15			21	9.9					9.97
7.	2	7	9.2	4.8		8	64.8	6.5	45.5			110.3
8.	1	.7				4	2.8					2.8
9.	2	4.75	7.4			8	48.7					48.7
10.	2	4.8	5.6			8	41.6					41.6
11.	1	0	.45			13	2.95					2.95
12.	1	0	.6			15	4.5					4.5
13.	3	.8	1			23.5	21.15					21.15
14.	2	.6	1.5	1.2		9	9.45	11	48.5			24.3
15.	3	1.7	3.9	3.8	.6	10	28	12	46.2	11	24.2	98.4
16.	3	3	3.15	2.6	.6	11	33.8	13	37.3	12	19.2	90.3
17.	3	9.9	1.65			15	86.6					86.6
												655.8 $ft.^3$

AREA = 1803.9 sq. ft.

VOLUME = 586.57 $yd.^3$/ACRE

= 1108.0 m^3/HECTARE

LOCATION: 1962-0170-S

GULLY #	ORDER	A_1	A_2	A_3	A_4	D_1	AD_1	D_2	AD_2	D_3	AD_3	TOTAL
1.	2	0	1.95	6.8		20	19.5	21	92.13			111.6
2.	2	0	5.2	6.8		20	52	21	126			178
3.	2	0	4.37	4	1.2	20	43.7	21	87.15	16	41.3	172.45
4.	2	0	4.75	16.5	2.7	20	47.5	21	215.2	16	149.3	412.3
5.	1	0	2.4	7.25	.9	20	28	21	101.3	16	65.2	194.5
6.	2	0	1.6	4.6		20	16	21	65.1			81.1
7.	2	0	2.5	5.1		20	25	21	79.8			104.8
8.	2	0	1.6	2.2	2.7	20	16	21	39.9	16	39.2	
9.	3			13.65	.4					16	131.12	131.12
10.	3			11.9	2.7					16	116.8	116.8
11.	1			0	1.4	6	4.2					4.2
12.	1			0	.7	12	8.4					8.4
												1515.07 $ft.^3$

AREA = 2188.56 sq. ft.

VOLUME = 1117.12 yd^3/ACRE

= 2110.24 m^3/HECTARE

LOCATION: 1955-60-0167-NW

GULLY #	ORDER	A_1	A_2	A_3	A_4	D_1	AD_1	D_2	AD_2	D_3	AD_3	TOTAL
1.	2	0	13.6	13.2		20	136.0	20	268			404
2.	2	0	5.4	13.2		20	54	20	186			240
3.	3	0	7.25	16.2	20	20	72.5	20	234.5	20	362	668.5
4.	2	0	3	5	15.4	20	30	20	80	20	204	314
5.	3	0	7.5	15.75	25	20	75	20	232.5	20	407.5	715
6.	2	0	7.5	10.8		20	75	20	183			258
7.	2	0	1.5			20	15					15
8.	2	0	1	19.25		20	10	20	202.5			212.5
9.	2	0	9	12.25		20	90	20	212.5			302.5
10.	3		26.25	27.5		20	537.5					537.5
11.	3		22	25.11		20	471					471.0
12.	1			0	4	18	36					36

4174 $ft.^3$

AREA = 2960.95 sq. ft.

VOLUME = 2273.8 yd^3/ACRE
= 4295 m^3/HECTARE

LOCATION: 71-72-0170-NW

GULLY #	ORDER	A_1	A_2	A_3	A_4	D_1	AD_1	D_2	AD_2	D_3	AD_3	TOTAL
1.	2	0	4.25	.825		18	38.25	14	35.5			73.77
2.	2	4.5	3.15	1.8		18	68.85	14	34.65			103.5
3.	1	0	2.1	1.25		16	16.8	14	22.05			38.85
4.	1	0	.25			12	1.5					1.5
5.	2	54.4	16.8			18	640.8					640.8
6.	2	54.4	16.8			18	640.8					640.8
7.	3	16.8	4.9			14						151.9
8.	2	19.9	1.5			16	91.2					91.2
9.	2	9	2.8	.8		18	106.2	14	25.2			131.4
10.	1	0	1	.3		16	8					8
11.	1	0	1.25	.375		18	5	37	30.0			4
12.	2	1	1.05					14	14.35			14.35
13.	1	0	1.3			18	11.7					11.7
14.	1	0	1.8			18						16.2
15.	2	1.8	1.22					14	21.17			21.17
16.	2	5.6	1.65	.9		18	65.29	14	18.13			83.38
17.	1	.4	.6					14	7			7
18.	1	.45	.6					14	7 35			7.35
19.	1	.425	.6					14				8.7
20.	1	.4	.65	1.75				14				7.35
21.	2	4.8	4.8			18	06.4	14	45.8			132.25
22.	2	5.2	7.8	1.6		18	11.7	14	65.8			182.8
23.	1	1.4	.5					14	13.3			13.3
												1749.52 $ft.^3$

AREA = 3341.25 sq. ft.

VOLUME = 844.7 $yd.^3$/ACRE

= 1595.72 m^3/HECTARE

LOCATION: 71-72-0170-W

GULLY #	ORDER	A_1	A_2	A_3	A_4	D_1	AD_1	D_2	AD_2	D_3	AD_3	TOTAL
1.	1	0	1.3	.65		22	13.5					13.5
2.	2	0	.375			30	5.6					5.6
3.	2	0	.8			7.5	3	25	20			27.5
4.	1	0	.45			10	2.2	25	11.25			13.45
5.	3	0	2.25	.7		11	12.3	37.5	59			71.35
6.	2	0	.375	.4		9	1.6	39	15.0			16.6
7.	2-3	0	.6	1.2		8	2.4	37.5	34.11			36.51
8.	2	0	.6			9	2.8					2.8
9.	2	0	.37			9	1.6					1.6
10.	3	.75	.3			37	194	37				19.4
11.	2	0	1.25	.75		11	6.8	37.5	37.5			37.5
12.	1	0	1.5	8.0		8.0	6.0	12	18			24.0
13.	2-3	3.75	.8	.6		9	4.3	35	24.5			28.8
14.	3	1.2	2.1	.25		9	14.85	36	59.8			74.6
15.	1	.9	1			9	8.55	8.5	8.5			17.05
16.	1	.3	.8			9	4.95	8.5	6.8			11.74
17.	3	3.6	.6			28	3					58.8
18.	2	1.6	1.3			34	49.3					49.3
19.	1	.525	1.2	.6		10	8.6	34	30.6			39.2
20.	1	0	1.8	1.75		8	7.2	11	19.5			26.7
21.	1	0	.28	.6		6	.84	34	14.95			15.8
22.	1	0	1.75			9	7.8					7.8
23.	1	0	.4			8	1.6					1.6
												601.19 $Ft.^3$

AREA = 3320.75 sq. ft.

VOLUME = 292.07 $yd.^3$/ACRE

= 551.72 m^3/HECTARE

LOCATION: 68-69-0170-SW

GULLY #	ORDER	A_1	A_2	A_3	A_4	D_1	AD_1	D_2	AD_2	D_3	AD_3	TOTAL
1.	1	.625	1.55	3	1.5	28	32.3	14	32.2	12	27	91.4
2.	1	0	.75	1.375	.625	12	4.5	10	10.6	15	15	37
3.	1	.2	2.55	4.35		28	38.5	10	34.5			73.0
4.	1	1.5	2.1	2.56		28	50.4	10	23.3			41.9
5.	1	0	.2	.45	.225	6	.6	12	3.9	15	5.06	8.96
6.	1	0	.7	1.8	.6	7	2.4	10	12.5	10	19.2	34.5
7.	1	0	.6	1.02		12	3.6	20	16.2			19.8
8.	1	.75	1.8	2.4	1	28	35.7	10	21	17	20.9	60.69
9.	1	0	.8	1		7	2.8	16	14.4			17.2
10.	1	0	1.3	1		7	4.55	13	14.95			19.5
11.	1	0	.075	6		4	.112	28	9.4			9.56
12.	1	2.5	3.25	4	1.4	28	80.5	10	36.25	16	43.2	159.95
13.	1	0	.4	.9		5	1.0	2.8	18.2			19.2
14.	1	0	.5	1.5		20	5	26	26			31
15.	3	2.4	1.2			10	18					18
16.	3	15	3.25			12	109.5					109.5
												751.55 $ft.^3$

AREA = 1472.38 sq. ft.

VOLUME = 823.48 $yd.^3$/ACRE

= 1555.5 m^3/HECTARE

LOCATION: 73-B-0167-S

GULLY #	ORDER	A_1	A_2	A_3	A_4	D_1	AD_1	D_2	AD_2	D_3	AD_3	TOTAL
1.	3		8	3.5	4.9	16.5	94.8	20	84			178.8
2.	2			2.5	3.24			20	57.4			57.4
3.	2		0	1.5	1.6	14	10.5	20	31			41.5
4.	2		0	2.55	1.65	14	17.8	20	42			59.8
5.	2	2	.9	1.5	1.65	23	33.35	17	20.4	20	31.25	8.5
6.	1	0	.8			15	6					6
7.	2	0	.9	1.59	1.2	14	6.3	17	21.2	20	17.9	45.4
8.	2	0	1.125	.7	1.3	14	7.8	17	15.5	20	20.75	44.05
9.	2	0	2.4	1.65	4	14	18	14	16.8	20	40.5	57.3
10.	1			.6	.7					20	13	13
11.	2	0	1.55	3	4.9	4	3.1	17	38.6	20	79.5	121.2
12.	2	0	1.9	1.7		11	10.45	17	30.6	9	15.3	56.35
13.	2	7.5	1.8	2.25		23	106.9	17	34.4	9	20.25	161.55
14.	3	3	3			11	33					33
15.	1			.4	2.4					0	28	28
16.	2	0	1.35	5.3	3.6	10	6.75	17	58.2	20	91	155.9
17.	2	0	1.9	1.7	3	10	9.5	16	28.8	21	49.35	87.65
18.		0	.9			11	49.5					4.95
19.	3	2.8	.6	9.25	6	23	101.2	17	129.6	21	160.1	290.8
20.	3		3.3	8.75	4.8			17	102.4	20	135.5	237.9
21.	1	0	1.35			19	12.8					12.8
22.	1	0	.525			5	1.3	7.5	3.9			5.2
												1783.45 ft.

AREA = 4565.6 sq. ft.

VOLUME = 630.19 yd^3/ACRE

= 1190.4 m^3/HECTARE

APPENDIX II

DESCRIPTION OF PHOTOGRAPHS USED IN SEDIMENTATION STUDIES

DATE: 2/29/56
FRAME: AXO-GR-28
SCALE: 1/20,000
SOURCE: U of A Department of Geology File

Photograph covers lower end of creek and Warrior River. No delta forming, no noticeably unusual sediment deposits. Stream channel is visible throughout its length and continuous, but narrow. The stream appears to average about 6.2 meters in width with the absolute maximum width reaching about 23 meters.

DATE: 3/20/56
FRAME: AXO-7R-86
SCALE: 1/20,000
SOURCE: U of A Department of Geology File

Mined area is visible near upper part of drainage basin. It is limited in area and not closer than 260 meters to Bluff Creek itself.

DATE: 10/28/60
FRAME: AXO-3BB-239
SCALE: 1/23,000
SOURCE: Geological Survey of Alabama, Remote Sensing Division

A delta is beginning to form where Bluff Creek enters the Warrior River. Its surface area is approximately 419 square meters. No sediment is evident in the creek channel. Width of channel is not measurable due to shadows of trees blocking the creek.

DATE: 10/28/60
FRAME: AXO-3BB-191 & AXO-3BB-138
SCALE: 1/20,000
SOURCE: Geological Survey of Alabama, Remote Sensing Division

The upper end of the basin is shown on these photographs. Mining is slightly more extensive and extends to within 91 meters of the creek.

During the period 1960 to 1973, a lock was constructed downstream from the Bluff Creek area on the Warrior River (Holt Lock and Dam, late 1966). The lock raised the river level upstream and flooded many of the tributaries to the river, Bluff Creek included. This situation created a slough in the former creek valley and formed the low energy environment (needed for delta growth) upstream. Since that time a delta has developed upstream from the point where Bluff Creek and the Warrior River actually merge.

DATE: 2/22/73
FRAME: 876 NASA U-2 Flight
SCALE: 1/131,000
SOURCE: Geological Survey of Alabama, Remote Sensing Division

Detail is good considering the scale of 1/131,000. Although only approximate measurements can be made, due to the photograph scale, this photograph is important in calculating the rate of advance of the lower sediment wedge.

A reference point was also established so later photographs of the area could be measured from the same point of reference. This "point" is the extreme northern portion of the cutback that occurs in the apex of the first major meander in the creek going upstream from the river. This point is approximately 1000 meters from the intersection of Bluff Creek and the Black Warrior River. (Measurements taken from 12/18/73 NASA Photo #028-2-173.)

This point can be easily located or approximated on all photographs and maps studied. In this text, it will be referred to as the "arbitrary reference point". (See Figure)

The delta plain (subaerial portion of the delta) appears to end about 45.7 meters upstream from the arbitrary reference point. The prodelta (submerged portion of the delta) appears to extend to approximately the same position as the arbitrary reference point on the photographs.

The upper limit of the sediment wedge appears to be visible just downstream of the apex of the second major meander visible on the photograph. This is about 490 meters upstream from the reference point. It may extend further upstream, however, and be blocked from view.

Upper reaches of the creek are extremely vivid, considering the scale. However, they are too small to measure accurately. One interesting feature seen only on this photograph is the braided nature of the creek in the central to upper portions of it.

Also worthy of note is the fact that mining spoils were not in contact with the major mined tributary along its western banks. These spoils (present now) are presently a major source of sediment for the Bluff Creek system.

DATE: 12/18/73
FRAME: 028-2-0173
SCALE: 1/25,000
SOURCE: NASA MSFC

Quality of the photograph's detail is excellent. Individual trees can be noted and provide good control points for future reference. The lower, delta-like sediment wedge is easily identified on the photograph. From the arbitrary reference point, the delta plain extends downstream approximately 94.5 meters. The prodelta extends approximately 64 meters past the delta plain. This measure is an approximation however, in that the exact extent of the prodelta is not easily recognized on the photographs. There is also what appears to be a sediment wedge located further downstream, apparently detached from the present delta. It is possibly an old delta that has been submerged by the rise in river level.

Extending approximately 580 meters upstream from the arbitrary reference point, the sediment wedge is still clearly visible. Beyond this point, the wedge is obscured, as is the entire valley floor, by shadows of trees lining the creek's banks. These shadows eliminate the photography as a tool in evaluating the sediment distribution in the creek except in areas of wide sediment distribution (greater than 30 meters), or in areas where the shadows do not obscure details of the valley floor.

DATE: 12/18/73
FRAME: 028-2-0170
SCALE: 1/25,000
SOURCE: NASA, MSFC

On this photograph the entire upper reaches of the Bluff Creek drainage basin are visible. Strip mining is extensive and extends to the creek itself in some areas. The major mined tributary (Figure I) is clearly visible and provides enough detail to make accurate measurements of it and its sediment distribution, from which some measurements to calculate volume were made.

DATE: 2/20/74
FRAME: 4-50
SCALE: 1/23,000
SOURCE: Geological Survey of Alabama, Remote Sensing Division

The lower sediment wedge is shown in excellent detail. The lower extent of the delta plain extends about 100.6 meters from the arbitrary reference point. The prodelta extends past the delta plain an additional 76.2 meters.

The upper end of the lower sediment wedge is visible approximately 594.4 meters upstream from the arbitrary reference point where it then tapers to apparently "normal" stream width. This distance extends completely around the second obvious meander (mentioned before).

No photographs of the upper end of the basin were available from this mission.

APPENDIX IV
GEOCHEMISTRY SAMPLE PROCEDURE
Geochemistry

Preliminary Report

SAMPLING AND SAMPLE PREPARATION

Sampling sites are positioned at 20 places (See Figure 1) along Bluff Creek and its' tributaries. These sample stations were chosen at the most advantageous places for monitoring the water properties of Bluff Creek. Samples from 14 stations have been supplied to NASA for analyses (See Figure 2).

Three samples are taken at each station: Sample 1 for analysis of Cr, Mn, Fe, Ni, Cu, Zn, Cd, & Co; Sample 2 for analysis of total sulfide; and Sample 3 for analysis of SO_4 and total alkalinity.

Sample 1 is taken, unfilitered and mixed 50-50 with a sulfide anti-oxidant buffer solution (SAOB) and poured into a 50 ml airtight polyethylene bottle. SAOB is a highly reducing, high pH solution. SAOB reduces air oxidation of sulfide and ensures that all sulfide present is present in the free form.

Sample 3 is taken, unfiltered and treated with a drop of formalin which kills any sulfide oxidizing bacteria that might be present. This sample is poured into a 50 ml polyethylene bottle.

ON SITE DETERMINATION

Eh and pH are determined on site at each station with a Model 407 Orion specific ion meter.

Stream discharge is measured at 8 of the sample stations. Method: Channel width is measured. Average channel depth is estimated by measuring the depth of the water at 4 inch intervals across the width of the stream. These values are averaged on site with a calculator to determine the streams average depth. Water velocity is determined with the aid of a flow meter and

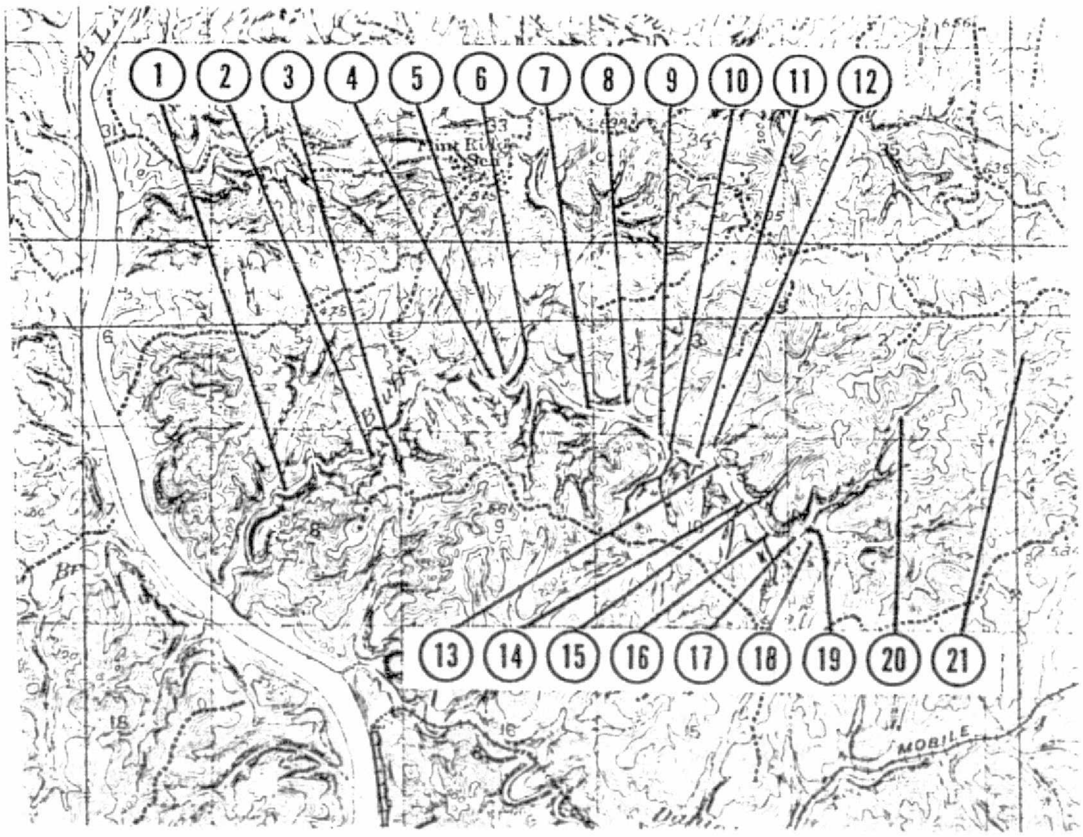


Figure 40

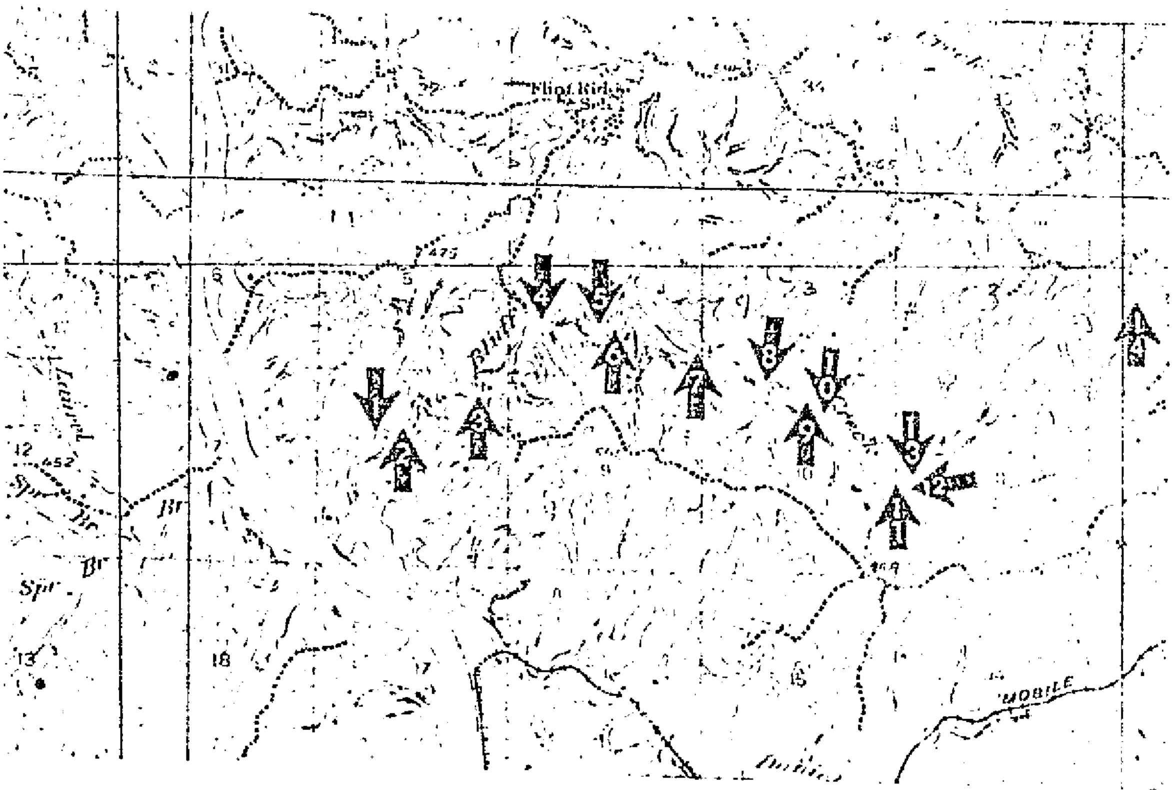


Figure 41

a watch. The flow meter which registers in centimeters is placed in the water for 30 seconds. The value in cm that has registered on the flow meter is divided by 30 to give velocity in cm/sec. Discharge is computed = velocity x depth x width.

ANALYSIS - SAME DAY AT LAB - SAMPLE 3

ALKALINITY is determined by titrating a 10 ml water sample with 0.020 N Sulfiric acid to an end point determined by a color change due to the addition of one Brom Cresol Green - Methyl Red Indicator powder pillow (HACH). The total alkalinity (as mg/l $CaCO_3$) is calculated by multiplying the number of ml of -.020N sulfuric acid necessary to effect a color change from green to pink.

SULFATE - The sample used for sulfate determination is filtered through a 0.45 micron semi-permeable membrane filter to remove all turbidity due to sediment. 25 ml of this sample is immediately pipetted into a colorimeter bottle. The contents of one Sulfa VER IV reagent powder pillow (HACH - contains $BaCl_2$) is added to the sample. The sample is then allowed to stand undisturbed for 5-10 minutes for the turbidity (due to $BaSO_4$ percipitation) to develope. The sample is then placed into a light cell of a colorimeter to measure % light transmission which is proportional to SO_4 concentration. SO_4 is registered on the colorimeter cell in ppm.

ANALYSIS - NEXT DAY AT LAB - SAMPLE 2

SULFIDE(S^{-2}) concentration is measured with an Orion 407 specific ion meter equipped with a Ag/S solid state electrode, and a double junction reference electrode. The Orion 407 is calibrated with 2 standards whose known S^{-2} concentrations are exactly one decade apart and whose concentrations bracket the $[S^{-2}]$ of the unknown sample.

ANALYSIS - SAMPLE 1

Sample 1 is brought immediately from the field and is filtered through a 0.45 micron semi-permeable membrane filter to remove all solids. The filtrate is then acidified with concentrated HCl to pH =1. This sample is poured into a clean 250 ml polyethylene bottle for storage until it is analyzed for Cr, Mn, Fe, Ni, Cu, Zn, Cd, & Co by atomic absorption spectroscopy.

Standard solutions of the above elements are prepared from a concentrate at the beginning of each run. These solutions are used to prepare a working curve showing the relation between absorbance and concentration in ppm. for each element.

Each sample is aspirated twice. The average of the 2 runs is taken as the concentration. The null indicator is centered to zero with the aspiration of a blank (which contains the same amount of the same acid used to preserve the samples) between each run. % absorption is read and converted to absorbance which gives the corresponding concentration in ppm on the working curve.

CLEANING OF THE SAMPLE BOTTLES

After use, the sample bottles are filled with 20% HNO_3 and allowed to soak about a week before thay are rinsed, drained and used again.

PREPARATION OF SAOB

SAOB is prepared the day before sampling by adding 80 g of NaOH, 320g sodium salicylate, and 72 g of ascorbic acid to approximately 500 ml of distilled water in a 1 liter volumetric flask. This mixture is swirled to dissolve, cooled rapidly to room temperature and brought to volume (1 liter) with distilled water. The solution, if stored in a tightly stoppered bottle, has a shelf life of approximately 2 weeks. When SAOB turns dark brown it has oxidized and must not be used. Prevents oxidation and preserves $S^{=}$.

PREPARATION OF S^{-2} STANDARDS

Sulfide standardizing solutions are prepared from reagent grade sodium sulfide hydrate, $Na_2S \cdot 9H_2O$. Precise standards cannot be preapred by weighing the salt because of the large and variable water of hydration. An approximately 0.01N sodium sulfide standard solutions prepared by dissolving 2.4 g of $Na_2S \cdot 9H_2O$ in 1000 ml of 25% SAOB (1 part SAOB diluted with 3 parts of H_2O). This approximate solution is standardized by titration with 0.1M lead perchlorate, $Pb(ClO_4)_2$ or 0.1 M lead nitrate, $Pb(NO_3)_2$. The Orion Model 94-16 silver/sulfide ion electrode is used as an end point indicator of the sulfide solution when the Orion Model 407 specific ion meter is set to the millivolt function switch. 50 ml of the approximately 0.01N sodium sulfide solution is pipetted into a beaker. The titrant is added in increments of 0.5 to 1.0 ml in the beginning of the titration and about 0.1 to 0.25 ml in the region of the end point. The solution potential is recorded after each addition of titrant. The titration is continued past the end point. Milliliters of titrant versus millivolt reading are plotted on standard coordinate graph paper. The point of greatest inflection is taken as the end point. Sulfide molatity is calculated by miltiplying the volume of titrant at the end point by the concentration of the titrant and dividing the product by the volume of the unknown solution. Once the true molarity of the approximately 0.01 N sodium sulfide solution has been established, the concentration in ppm S^{-2} can be calculated by multiplying molarity by 32,064. The solution can be diluted to obtain a concentration of some whole power of 10 parts per million. Serial dilutions are then made by pipetting 10 ml of the solution into a 100 ml bolumetric flask and bringing to volume. All dilutions are made with 25% SAOB. This procedure is repeated for further serial dilutions.