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DEBRIS SLIDES AND RELATED FLOOD DAMAGE ASSOCIATED WITH THE SEPTEMBER 1,
1951, CLOUDBURST IN THE MT. LE CONTE-SUGARLAND MOUNTAIN
AREA, GREAT SMOKY MOUNTAINS NATIONAL PARK

A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

Donald Joseph Bogucki

December 1970

70 b
B437

71-17,713

BOGUCKI, Donald Joseph, 1944-
DEBRIS SLIDES AND RELATED FLOOD DAMAGE
ASSOCIATED WITH THE SEPTEMBER 1, 1951,
CLOUDBURST IN THE MT. LE CONTE-SUGARLAND
MOUNTAIN AREA, GREAT SMOKY MOUNTAINS
NATIONAL PARK.

The University of Tennessee, Ph.D., 1970
Geography

University Microfilms, A XEROX Company, Ann Arbor, Michigan

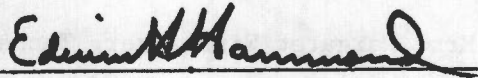
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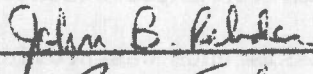
To the Graduate Council:

I am submitting herewith a dissertation written by Donald Joseph Bogucki entitled "Debris Slides and Related Flood Damage Associated with the September 1, 1951, Cloudburst in the Mt. Le Conte-Sugarland Mountain Area, Great Smoky Mountains National Park." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Geography.

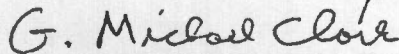

Major Professor

We have read this dissertation
and recommend its acceptance:









Accepted for the Council:


Vice Chancellor for
Graduate Studies and Research

ACKNOWLEDGMENTS

The writer wishes to express his sincere appreciation to all people who assisted in making this study possible. He especially wishes to express his gratitude to his committee chairman, Dr. Sidney R. Jumper, and to Dr. G. Michael Clark, under whom the writer worked as a Project THEMIS Research Assistant. The writer acknowledges indebtedness to the Department of Defense for the financial assistance which made this study possible. He also thanks committee members Dr. Edwin H. Hammond, Dr. Robert G. Long and Dr. John B. Rehder for their suggestions in the development of this dissertation.

In addition, the writer is grateful to numerous individuals who contributed to the study. Thanks go to Dr. Henry R. DeSelm, Department of Ecology, University of Tennessee; Mr. Edgar P. Menning and Mr. Glenn Cardwell, National Park Service; Mr. William Massa, Mr. John Scott, Mrs. Eleanor Southern, and Mrs. Margaret Wisecarver, Tennessee Valley Authority; and Mr. Richard Whiting, Environmental Science Services Administration. Invaluable field assistance was provided by Mr. Barry Wood, Mr. Carl Koch, Mr. Jeffery Neff, Mr. Brady Foust, Mr. Jay Tullos, and Mrs. Janice Clark.

Finally, inestimable thanks are extended to his wife for her assistance throughout the progress of this dissertation.

ABSTRACT

Numerous debris slides and considerable flood damage resulted from the September 1, 1951, cloudburst over the Mt. Le Conte-Sugarland Mountain area in Great Smoky Mountains National Park. Over 100 individual slide scar heads were found in the study area, 41 of them in the Alum Cave Creek watershed, area of detailed field study.

The movement is thought to have been initiated by sliding at the head of the scar, with the mass of moving rock, soil, forest debris, and water developing flow characteristics downslope. Mt. Le Conte-Sugarland Mountain slide tracks may be divided into three sections: (1) the scar head, (2) the middle zone, and (3) the area of deposition.

Slide dimensions vary considerably. Nineteen slides within the Alum Cave Creek watershed were surveyed with a Wild RDS self-reducing tachometer and sketched planimetrically at a scale of one inch to 50 feet. The scar head of Slide SB-10, largest within the study area, covers approximately 112,532 square feet and had an estimated removal of about 121,534 cubic feet of material. In contrast, the scar head of Slide ACC-3 occupies approximately 1,662 square feet and had about 2,160 cubic feet of material removed.

Slide scar heads in the Mt. Le Conte-Sugarland Mountain area are at elevations ranging from 4000 to 6300 feet. Field measurements in the Alum Cave Creek watershed indicate slope angles on individual scar heads range from approximately 35° to 44° , with a mean of 40° . Slides originated on all four quadrant exposures.

Slide location and distribution are controlled by the complex interaction of numerous physical and cultural factors. Because all known debris slides in the Appalachian Highlands south of the glacial border have been associated with heavy rainfall on steep slopes, intense or prolonged rainfall and slope angle must be considered the most important factors contributing to debris slide formation.

Precipitation is a critical localizing agent, but how much and how fast rain must fall to produce sliding is as yet unanswered; and computing an accurate recurrence interval for slide producing storms is nearly impossible. At best, a storm similar to the September 1, 1951, cloudburst probably has a recurrence interval of greater than 100 years, and possibly much longer, for the Mt. Le Conte-Sugarland Mountain area.

Detailed field investigation in the Alum Cave Creek watershed provided the basis for locating and mapping debris slides and related flood damage by using airborne imagery for the entire Mt. Le Conte-Sugarland Mountain area. Evaluation of the imagery indicated that Ektachrome Infrared Aero film is the best overall sensing medium for slope damage analysis in this particular area. Slide age and ground conditions vary considerably among the different slide areas in the Appalachian Highlands south of the glacial border, and other emulsions or sensing devices might prove better suited for investigating slope damage in these localities.

The need for further debris slide studies is apparent. All slopes are not hazardous; but few, if any, are stable in an absolute sense. If the various parameters of debris slide localization and distribution are understood, areas of slide potential can be determined.

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CHAPTER I

INTRODUCTION

I. STATEMENT OF THE PROBLEM

Many mountainous regions exhibit scars formed by debris slides. The location of these phenomena, however, is much too widespread to be investigated in depth on a global scale in this report. Within the unglaciated Appalachian Highlands physiographic division alone, 11 slide areas are known (Plate 1).¹ By concentrating on a single slide area, the Mt. Le Conte-Sugarland Mountain area in Great Smoky Mountains National Park, a detailed analysis of debris slides was made feasible.

Late in the afternoon of September 1, 1951, an intense, but relatively localized, thunderstorm precipitated at least four inches, and possibly six or more inches of rain in one hour on the Mt. Le Conte-Sugarland Mountain area. Debris slides occurred on many of the steeper slopes and substantial damage resulted from flooding of the several streams which drain the area. This study considers the causes, distribution, and effects of debris slides and related flood damage within the study area and evaluates the relative effectiveness of

¹The Appalachian Highlands physiographic division south of the glacial border includes portions of the Piedmont, Blue Ridge, Ridge and Valley, and Appalachian Plateau physiographic provinces. Nevin M. Fenneman, Physiography of Eastern United States (New York: McGraw-Hill Book Company, 1938), pp. 121-123; and William D. Thornbury, Regional Geomorphology of the United States (New York: John Wiley and Sons, Inc., 1965), p. 72.

various kinds of airborne remote sensing imagery in locating and identifying these landscape modifications.

Although interdisciplinary in nature, the present investigation is conducted within a geographical framework, with emphasis directed toward describing and interpreting detailed spatial interactions of the many factors connected with debris slide activity. The study strives to analyze the functional relationship between debris slide characteristics and location within the Mt. Le Conte-Sugarland Mountain area and the nature and distribution of pertinent physical and cultural phenomena.

Landslide investigations by engineers and geologists are relatively numerous, but geographers have not generally been concerned with the landslide problem. Reports by Mitchell, Putnam and Sharp, Ward, Gifford, Hepburn, and Johnson represent landslide studies published in geographical journals.² The present investigation is similar to the study by Gifford, which examined numerous slides caused by intense precipitation on Exmoor on August 15, 1952.³

²Guy E. Mitchell, "Landslides and Rock Avalanches," National Geographic Magazine, XXI (April, 1910), 278-287; William C. Putnam and R. P. Sharp, "Landslides and Earthflows Near Ventura, Southern California," Geographical Review, XXX (October, 1940), 591-600; William H. Ward, "The Stability of Natural Slopes," Geographical Journal, CV (May-June, 1945), 170-191; Joyce Gifford, "Landslides on Exmoor Caused by the Storm of 15th August, 1952," Geography, XXXVII (1953), 9-17; Nicholas Hepburn, "Southwestern Montana Earthquake and Landslide," Geographical Review, L (January, 1960), 109-111; and R. H. Johnson, "A Study of the Charlesworth Landslides Near Glossop, North Derbyshire," Institute of British Geographers Transactions, XXXVII (December, 1965), 111-126.

³Joyce Gifford, op. cit., 9.

Debris slides have received little attention from any discipline, and no geographers have, as yet, studied these phenomena. Debris slides in the White Mountains of New Hampshire, where more than 500 are known, are the best documented.⁴ Stringfield and Smith studied debris slides near Petersburg, West Virginia, and Hack and Goodlett described slides in the Little River area of Virginia.⁵ Flood damage around Watauga Lake, Tennessee, was reported by the United States Geological Survey.⁶ Other slide areas are known but have not yet been investigated.

⁴B. Silliman, C. Wilcox, and T. Baldwin, "Miscellaneous Notices of Mountain Scenery, and of Slides and Avalanches in the White and Green Mountains," American Journal of Science, XV (1829), 217-232; G. H. Perkins, "Notice of a Recent Landslide on Mt. Passaconaway," American Journal of Science, second series, XLIX (March, 1870), 158-161; W. G. Nowell, "Carter Dome and Vicinity," Appalachia, I (June, 1876), 76-86; C. Cutter, "The Slide at Tripyramid," Appalachia, III (June, 1884), 47-49; C. H. Hitchcock, "The Recent Landslide in the White Mountains," Science, VI (July, 1885), 84-87; M. V. B. Knox, "Notes on the Slide at Jefferson, New Hampshire," Appalachia, IV (March, 1886), 254-256; A. A. Butler, "The Trypyramid Slides of 1885," Appalachia, IV, (March, 1886), 177-190; L. V. Pirsson and W. N. Rice, "Geology of Trypyramid Mountain," American Journal of Science, fourth series, XXXI (May, 1911), 269-274; and Edward Flaccus, "Landslides and Their Revegetation in the White Mountains of New Hampshire" (unpublished Doctoral dissertation, Duke University, Durham, North Carolina, 1958).

⁵V. T. Stringfield and R. C. Smith, Relation of Geology to Drainage, Floods, and Landslides in the Petersburg Area, West Virginia, (Report of Investigations No. 13, Morgantown, West Virginia: Geological and Economic Survey, 1956); and John T. Hack and John C. Goodlett, Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians, Geological Survey Professional Paper 347 (Washington: Government Printing Office, 1960).

⁶United States Geological Survey, Floods of August, 1940, in the Southeastern United States, Geological Survey Water-Supply Paper 1066 (Washington: Government Printing Office, 1949).

Benefits that can be derived from study of debris slides are both academic and practical. It is of geomorphological interest to determine the overall effect of slides upon the landscape, but a knowledge of the factors responsible for the formation and localization of slides will permit planning and developmental agencies to take precautionary measures in areas susceptible to slides.

The study of debris slides and flooding in the Mt. Le Conte-Sugarland Mountain area leaves questions unanswered; it is hoped, however, that the information gained will contribute to a greater understanding of these phenomena. Several similar investigations are in progress at the University of Tennessee under a Department of Defense Project THEMIS grant, and it is hoped that still other students of geomorphology or remote sensing will become sufficiently challenged and interested by the topic to undertake the further research that is needed.

II. DATA COLLECTION AND ANALYSIS

Field investigation, interpretation of airborne imagery, and examination of historical records all provided valuable data for the present study. No single source of information yielded enough data to provide adequate information for debris slides in the area.

Field Research Data

The site selected for detailed field research was the Alum Cave Creek watershed located on the southwest slope of Mt. Le Conte. This area was chosen for several reasons. First, precipitation records for the September 1, 1951, storm indicate that it was situated close

to the area of maximum precipitation. Second, the watershed contains slides at various elevations and on different slope exposures. Finally, it is the most accessible area in this region of extremely steep slopes. A segment of the Alum Cave Bluffs Trail, which leads to the summit of Mt. Le Conte, is located within the drainage basin, and most of the debris slides and considerable flood damage along Alum Cave Creek and Styx Branch lie within close proximity to the trail.

The primary goal of field research was to determine the extent of slope and flood damage. Once this had been ascertained, the analysis then included the investigation of meteorological and climatological, geological, hydrological, vegetational, pedological, and cultural phenomena.

Nineteen slides within the field investigation area were surveyed with a Wild RDS self-reducing tachometer and Philadelphia rod, and sketched planimetrically at a scale of one inch to 50 feet. Longitudinal profiles for each slide were computed from the surveying notes and drawn at a scale of one inch to 50 feet. In order to portray true slope conditions, profiles were constructed with no vertical exaggeration. Once the slide areas within the Alum Cave Creek watershed were delimited the remaining field data were described and mapped.

Geological mapping involved plotting areas of bedrock, showing strike and dip of compositional layering and/or bedding, and areas of alluvial and colluvial deposits within the slide track. In addition, all characteristics believed relevant to the problem were noted and described, and studies of post-slide mass movement activity were made in several slide chutes.

The main hydrological features examined were the several small streams which drain the watershed. The nearest stream gauge to the area of study is located on the Little Pigeon River at Sevierville, Tennessee, and was too far from the slide area to have appreciable value in the investigation.

Because the study area is located in a densely vegetated region, forest ecology is an important parameter. The chief task was to distinguish the vegetation which was present prior to the September 1, 1951, storm from that which post-dated the slope damage. Each vegetative association has a particular set of identifying characteristics, and the edge of the slide tracks were, in part, plotted according to this differential make-up of the vegetation.

Only trees and stumps with a diameter of six inches or more were plotted individually on the planimetric maps. These were situated primarily outside the slide track, but, occasionally, trees of this diameter remained within the slide area. With respect to revegetation of the slide chute, areas were mapped collectively, with no attempt to portray the small individual trees, shrubs, or herbs. Plant specimens were collected to determine the important species in the revegetation process.

As living flora is of considerable importance in the field interpretation, so too are the remains of trees which once stood in the areas now damaged. It may be possible to obtain clues as to the mechanism of slide movement through the orientation of fallen trees.⁷

⁷ Anders Rapp, "The Debris Slides at Ulvadal, Western Norway - An Example of Catastrophic Slope Processes in Scandinavia," Nachrichten

In order to determine accurately their position and compass direction, all visible logs in and adjacent to the debris slide chutes were plotted to scale on the sketch maps.

Recent studies have shown that certain identifiable pedological characteristics may indicate the relative age and stability of a soils.⁸ Soil samples were collected from 11 pits within the Alum Cave Creek watershed, and investigation of soil properties included chemical and X-ray analyses. In order to determine relative age and development of the soils, tests were made for pH, extractable iron, extractable aluminum, extractable potassium, extractable phosphorus, and KCl extractable acidity.⁹ Selected samples were examined by X-ray diffraction

Der Akademie Der Wissenschaften in Gottingen II. Mathematisch-Physikalische Klasse, XIII (December, 1963), 200-201.

⁸D. P. Franzmeir and E. P. Whiteside, "A Chronosequence of Podzols in Northern Michigan. I. Ecology and Description of Pedons," Michigan State University Agricultural Experiment Station Quarterly Bulletin, XLVI (August, 1963), 1-20; D. P. Franzmeir and E. P. Whiteside, "A Chronosequence of Podzols in Northern Michigan. II. Physical and Chemical Properties," Michigan State University Agricultural Experiment Station Quarterly Bulletin, XLVI (August, 1963), 21-36; D. P. Franzmeir, E. P. Whiteside, and M. M. Mortland, "A Chronosequence of Podzols in Northern Michigan. III. Mineralogy, Micromorphology, and Net Changes Occurring During Soil Formation," Michigan State University Agricultural Experiment Station Quarterly Bulletin, XLVI (August, 1963), 37-57; P. H. T. Beckett, "Soil Formation and Slope Development I, A New Look at Walther Penck's Aufbereitung Concept," Zeitschrift Fur Geomorphologie, XII (1968), 1-24; and P. A. Furley, "Soil Formation and Slope Development II, The Relationship Between Soil Formation and Gradient Angle in the Oxford Area," Zeitschrift Fur Geomorphologie, XII (1968), 24-43.

⁹Testing for extractable iron, extractable aluminum, and KCl extractable acidity was done by the writer and Mrs. Janice Clark at the University of Tennessee, Knoxville, Tennessee. The analysis for pH, extractable phosphorus, and extractable potassium was done by the Soil Testing Laboratory, University of Tennessee Agricultural Extension Service, 5201 Marchant Drive, Nashville, Tennessee.

to determine the types of clays present in proximity to the various slide tracks.

Because the research site in Great Smoky Mountains National Park, cultural features are few. Within the field investigation area the only man-related item in the zone of damage was the Alum Cave Bluffs Trail with its several foot bridges. Damage from the storm of September 1, 1951, has since been repaired, however, and descriptions of the extent and nature of damage were obtained from historical records. The present trail is clearly visible on the airborne imagery and is helpful in locating several slope damage features within the Alum Cave Creek watershed.

Airborne Imagery

The main purpose for conducting airborne missions over the study area was to obtain up-to-date imagery of the slope and flood damage. So that complete coverage could be procured and the effectiveness studied under various ground conditions, three flights were made.

The University of Tennessee DC-3 research aircraft and Hasselblad 500EL quadricamera system were used to obtain simultaneous coverage utilizing four different emulsion/filter combinations. In addition to the photographic imagery, thermal imagery was obtained on one mission.

In the final evaluation, field research data collected from the Alum Cave Creek watershed were compared with corresponding portions of the airborne imagery. When the various damage features in the Alum Cave Creek watershed had been recognized and studied on the imagery,

slide scars throughout the Mt. Le Conte-Sugarland Mountain area were located and mapped from the imagery.

Historical Records

Field investigation and remote sensing portray slope damage features as they exist at present. Historical records were examined to obtain data concerning several factors of slide formation and information on how time has been related to various changes in the slide areas. Older aerial and ground photographs, maps, written reports, and personal communication were utilized. Primary sources for historical records were the Environmental Science Services Administration, National Park Service, Soil Conservation Service, Tennessee Valley Authority, United States Geological Survey, and United States Weather Bureau.

CHAPTER II

THE STUDY AREA

I. LOCATION

The Blue Ridge Province of the Appalachian Highlands extends from southern Pennsylvania to northeastern Georgia, a distance of approximately 550 miles (Plate I). North of Roanoke, Virginia, the province is linear in form and rarely exceeds 14 miles in width. To the south the province widens considerably, and the linear pattern is lost. The southern section is somewhat higher in elevation than the northern section and has a maximum width of about 70 miles.¹

Nomenclature in the Blue Ridge south of Roanoke is complex. The term "Blue Ridge" is generally restricted to the frontal scarp along the eastern portion of the province and to the mountains along the drainage divide immediately west of the front. The mountainous area west of the Blue Ridge is collectively referred to as the Unakas, and their best known range is the Great Smoky Mountains.²

Although the Great Smoky Mountains are imposing in height and magnitude, they do not form the main drainage divide between the Atlantic Ocean and Gulf of Mexico. The divide lies approximately 35

¹Nevin M. Fenneman, Physiography of Eastern United States (New York: McGraw-Hill Book Company, 1938), p. 163.

²John Rodgers, "Geologic Map of East Tennessee with Explanatory Text," Tennessee Division of Geology Bulletin, LVIII (1953), 6.

miles to the southeast at the Blue Ridge front. Two streams which cross the Unakas, the Pigeon River and the Little Tennessee River, mark the ends of the Great Smoky Mountains.

Great Smoky Mountains National Park was authorized by Congress in 1926 and formally dedicated on September 2, 1940, by President Franklin D. Roosevelt. It is located in eastern Tennessee and western North Carolina (Figure 1). Approximately 54 miles long and 19 miles wide at its broadest point, the park area comprises about 780 square miles. Sixteen peaks rise more than 6000 feet above sea level, and Clingmans Dome, at 6643 feet, is the highest point in the park. For 36 miles along the main divide of the mountain system the range has an elevation above 5000 feet.

Mt. Le Conte, with an elevation of 6593 feet, is the third highest peak in the park, and lies approximately three miles northwest of the main crest of the Great Smoky Mountains. It is connected to the main crest by a high ridge known as The Boulevard. Just southwest of Mt. Le Conte is Sugarland Mountain, whose highest elevations range from about 4280 feet in the northwest to slightly over 5600 feet where it joins the main divide. Mt. Le Conte and Sugarland Mountain are the primary features of study in this investigation.

The study area encompasses portions of the Mt. Le Conte, Gatlinburg, Silers Bald, and Clingmans Dome seven and one-half minute United States Geological Survey quadrangles (Figure 2). Approximately 34.3 square miles of the area lie in the Mt. Le Conte Quadrangle, 6.3 square miles in the Gatlinburg Quadrangle, 2.5 square miles in the Silers Bald Quadrangle, and 7.7 square miles in the Clingmans Dome Quadrangle.

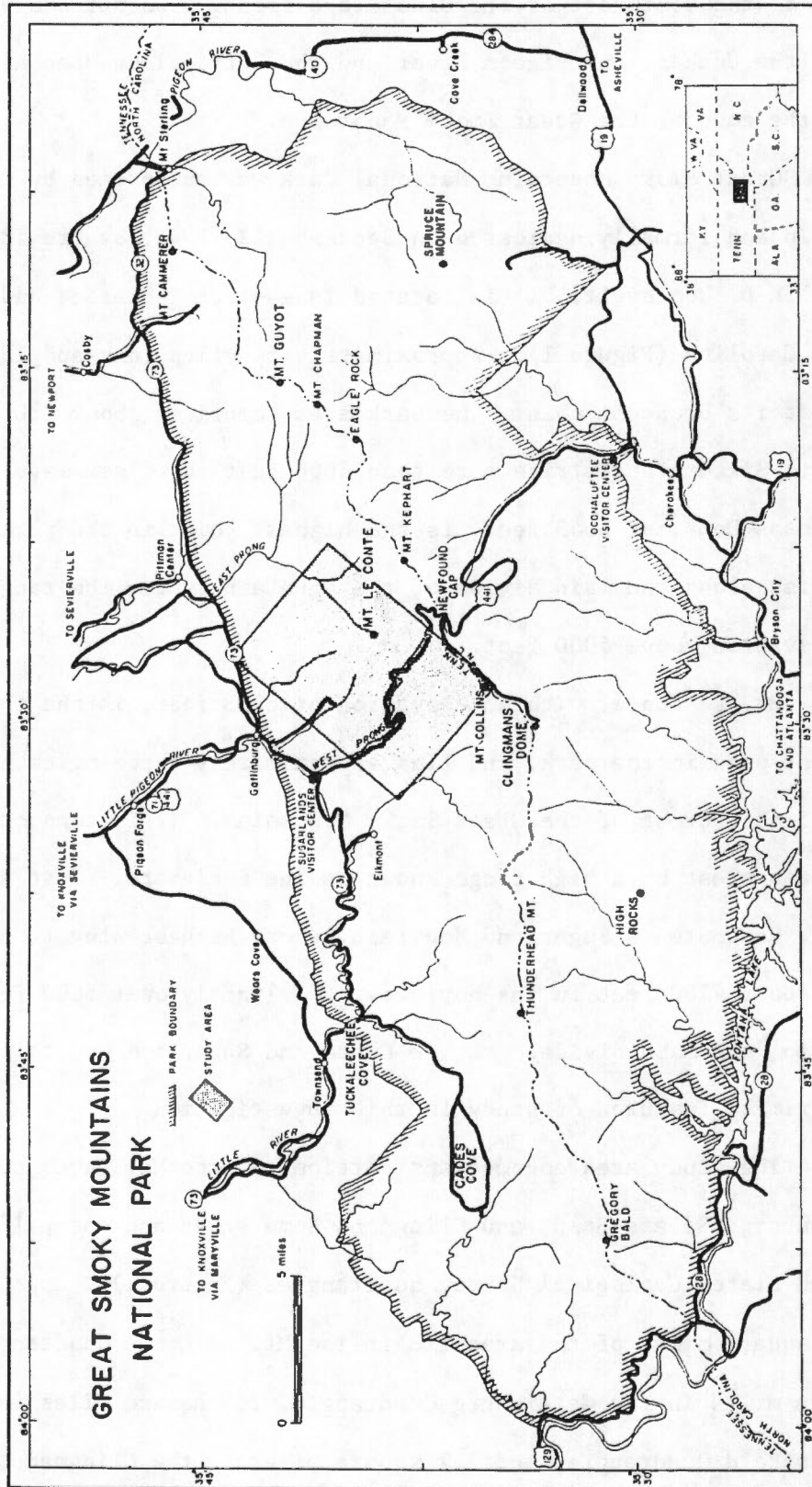


Figure 1. Great Smoky Mountains National Park

**MT. LE CONTE-SUGARLAND MOUNTAIN AREA
QUADRANGLE INDEX MAP**

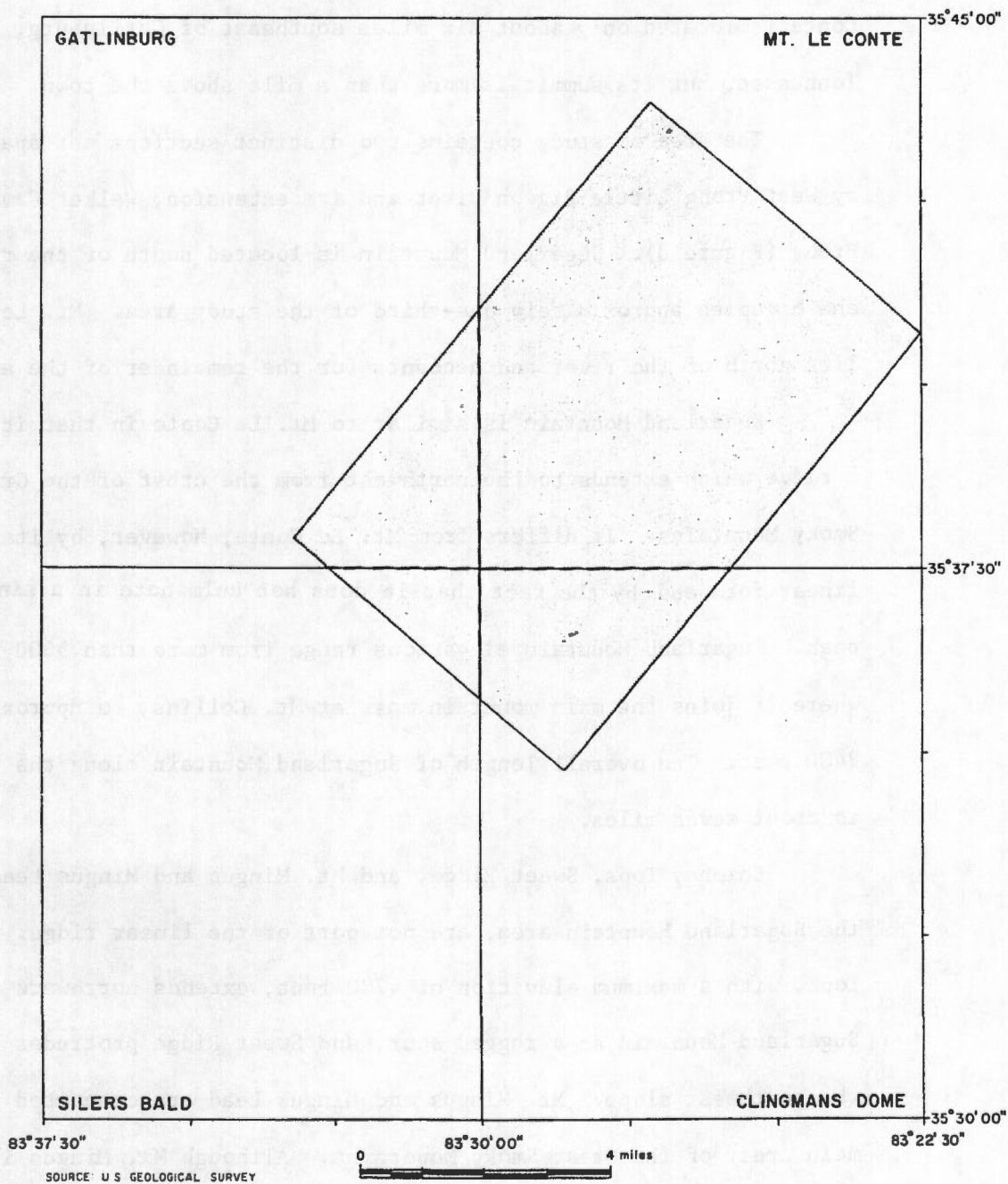


Figure 2. Index map, Mt. Le Conte-Sugarland Mountain Area.

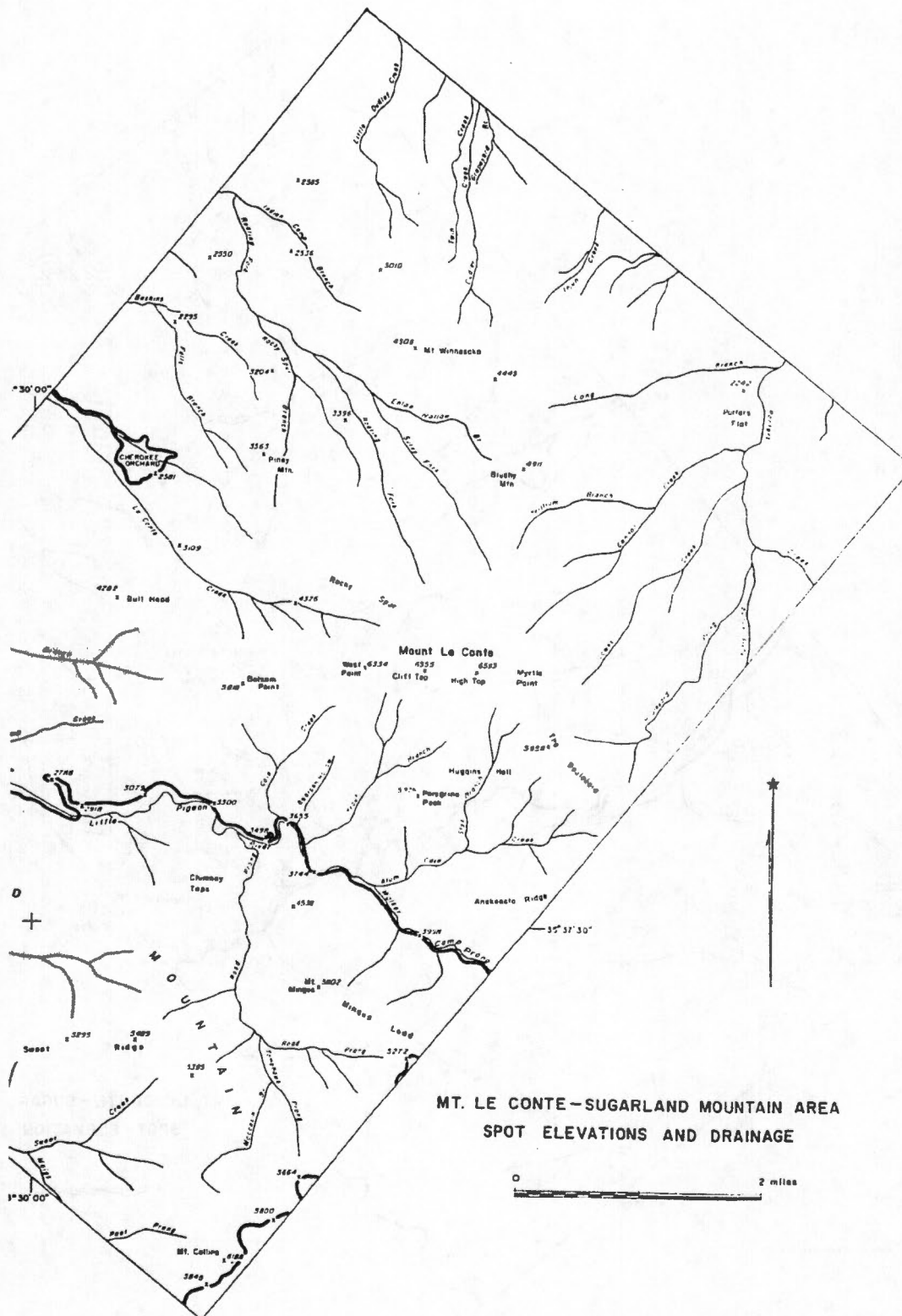
II. RELIEF AND DRAINAGE

The Mt. Le Conte-Sugarland Mountain area is characterized by steep slopes, sharp ridge crests, and narrow channelways. Mt. Le Conte is located only about six miles southeast of Gatlinburg, Tennessee, but its summit is more than a mile above the town.

The area of study contains two distinct sections set apart by West Prong Little Pigeon River and its extension, Walker Camp Prong (Figure 3). Sugarland Mountain is located south of the river and occupies approximately one-third of the study area. Mt. Le Conte lies north of the river and accounts for the remainder of the area.

Sugarland Mountain is similar to Mt. Le Conte in that it is a ridge which extends to the northwest from the crest of the Great Smoky Mountains. It differs from Mt. Le Conte, however, by its more linear form and by the fact that it does not culminate in a single high peak. Sugarland Mountain elevations range from more than 5600 feet where it joins the main mountain mass at Mt. Collins, to approximately 3400 feet. The overall length of Sugarland Mountain along the crest is about seven miles.

Chimney Tops, Sweet Ridge, and Mt. Mingus and Mingus Lead, in the Sugarland Mountain area, are not part of the linear ridge. Chimney Tops, with a maximum elevation of 4720 feet, extends northward from Sugarland Mountain as a rugged spur, and Sweet Ridge protrudes from the southwest slope. Mt. Mingus and Mingus Lead are connected to the main crest of the Great Smoky Mountains. Although Mt. Mingus is in topographic alignment with Sugarland Mountain, it is separated by the valley occupied by Road Prong.



ions and drainage, Mt. Le Conte-Sugarland Mountain Area.

The summit of Mt. Le Conte consists of four small peaks. From west to east these are West Point (6344 feet), Cliff Top (6555 feet), High Top (6593 feet), and Myrtle Point. The base of the mountain is 1200 feet above sea level near Gatlinburg. The slopes of Mt. Le Conte contain a number of ridges radiating in various directions and separated by deep valleys. Balsam Point Ridge, Rocky Spur, and The Boulevard are the largest ridges.

III. GEOLOGY

Geologists began studying the bedrock in the Great Smoky Mountains around the middle of the 19th century, but because of the inaccessibility of much of the area and the complex nature of the geology, progress has been slow.³ When compared with the surrounding regions, geological knowledge of the Great Smoky Mountains has lagged substantially. During the last several decades, however, numerous individuals have made valuable contributions to the understanding of the area's geologic history.

Bedrock Geology

Most of the rocks of the Great Smoky Mountains and large portions of the foothills belt consist of a thick mass of predominantly clastic metasedimentary rock belonging to the Ocoee Series of late Precambrian age. The lithology is mostly coarse thick-bedded

³ J. M. Stafford made the first attempt to classify the rocks of the Great Smoky Mountains. J. M. Stafford, A Geological Reconnaissance of the State of Tennessee, First Biennial Report (Nashville, Tennessee, 1856).

sandstone and interbedded slate, phyllite, and schist. Except along the northwest edge, where the Ocoee Series has been thrust over the Paleozoic rocks of the Ridge and Valley Province, the Ocoee rests largely upon a basement complex of granite and metasedimentary gneiss. The Ocoee Series has been internally folded and faulted.

Surface exposure of the Ocoee Series follows the trend of ranges from Asheville, North Carolina, to Cartersville, Georgia, a distance of more than 175 miles. Near the Great Smoky Mountains it reaches a width of about 30 miles.⁴

The rocks of the Great Smoky Mountains are younger than the Precambrian rocks of the Blue Ridge, but older than the early to middle Paleozoic rocks of the Ridge and Valley Province. The degree of metamorphism varies; generally, the rocks near the Ridge and Valley have been less altered than those near the Blue Ridge. Unlike the rocks of the Ridge and Valley, the Ocoee Series contains no known fossils.

Several relatively small areas of the Great Smoky Mountains have rocks which do not belong to the Ocoee Series. Chilhowee Mountain, a long narrow ridge which lies between the Great Smoky Mountains and the Ridge and Valley Province, is composed of sandstones of Cambrian age.⁵ Whiteoak Sink and Wear, Tuckaleechee, Big

⁴Philip B. King, Robert B. Neuman, and Jarvis B. Hadley, Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina, Geological Survey Professional Paper 587 (Washington: Government Printing Office, 1968), p. 3.

⁵Philip B. King and Arther Stupka, "The Great Smoky Mountains - Their Geology and Natural History," The Scientific Monthly, LXXI (July, 1950), 33.

Spring, and Cades Cove are fensters floored by limestones and calcareous shales of Ordovician age.⁶ Rocks of the basement complex occur in several localities in the eastern and southeastern parts of the park.⁷

The Ocoee Series is mostly sedimentary in origin, but other rocks were intruded at later times. Diorite sills and dikes, vein quartz, and granite gneiss are found in several locations.

Rocks of the Ocoee Series are similar in age and origin, but are divided into three groups, the Snowbird, Great Smoky, and Walden Creek, that contain related sequences of formations (Table I).⁸

The entire Mt. Le Conte-Sugarland Mountain area is located upon rocks of the Ocoee Series (Figure 4). Within the study area approximately 23 percent of the rocks are from the Snowbird Group and 77 percent are from the Great Smoky Group. The Snowbird Group is in the northern portion of the area below the Greenbrier fault. The Great Smoky Group is above and south of the Greenbrier fault. Several minor faults related to the Gatlinburg fault cross the area of the Snowbird Group, and the Mingus and Oconaluftee faults, also part of

⁶Philip B. King, Geology of the Central Great Smoky Mountains, Tennessee, Geological Survey Professional Paper 349-C (Washington: Government Printing Office, 1964), p. 9.

⁷Jarvis B. Hadley and Richard Goldsmith, Geology of the Eastern Great Smoky Mountains, North Carolina and Tennessee, Geological Survey Professional Paper 349-B (Washington: Government Printing Office, 1963), p. B5.

⁸Philip B. King, Jarvis B. Hadley, Robert B. Neuman, and Warren Hamilton, "Stratigraphy of the Ocoee Series, Great Smoky Mountains, Tennessee and North Carolina," Geological Society of America Bulletin, LXIX (August, 1958), 951.

TABLE I

STRATIGRAPHIC UNITS OF GREAT SMOKY MOUNTAINS
NATIONAL PARK AND VICINITY

Lower Cambrian	}	Chilhowee Group	{	Helenmode Formation Hesse Quartzite Murray Shale Nebo Quartzite Nichols Shale Cochran Formation
Later Precambrian	}	Ocoee Series	{	
Earlier Precambrian	}			
		Walden Creek Group	{	Sandsuck Formation Wilhite Formation Shields Formation Licklog Formation
		Great Smoky Group	{	Unnamed sandstone Anakeesta Formation Great Smoky Group, undivided Thunderhead Sandstone Elkmont Sandstone
				Formations of the Ocoee Series not assigned to groups - Cades Cove Sandstone, rocks of Webb Mountain and Big Ridge, and Rich Butt Sandstone
		Snowbird Group	{	Pigeon Siltstone Metcalf Phyllite Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation
				Basement Complex

Source: Philip B. King, Robert B. Neuman, and Jarvis B. Hadley, Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina, Geological Survey Professional Paper 587 (Washington: Government Printing Office, 1968), Plate 1.

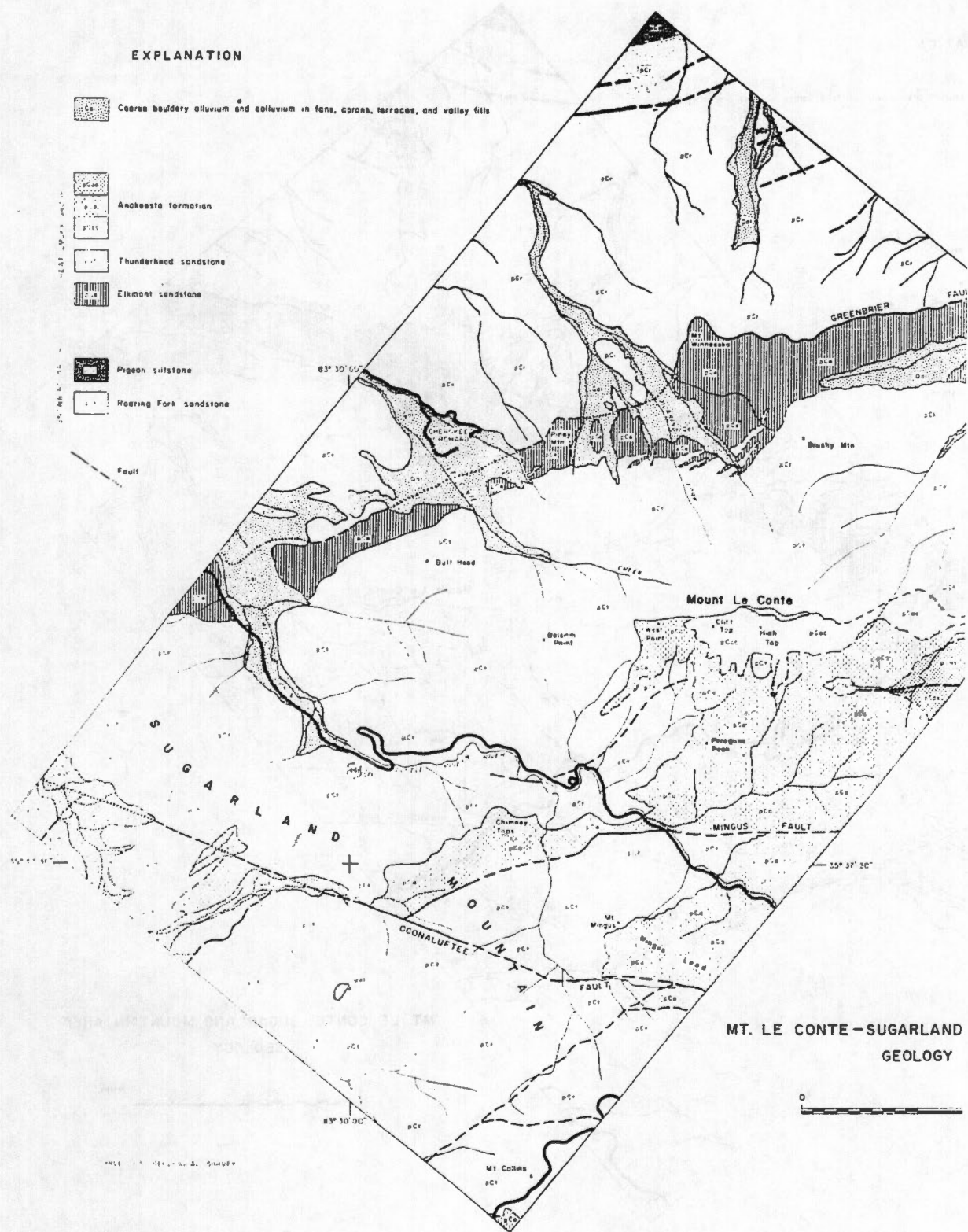


Figure 4. Geology, Mt. Le Conte-Sugarland Mountain Area.

Source: Jarvis B. Hadley and Richard Goldsmith, Geology of the Eastern Great Carolina and Tennessee, Geological Professional Paper 349-B (Washington: Government)

ATION

alluvium and colluvium in fans, aprons, terraces, and valley fills

granite

sedimentary

metamorphic

metamorphic

metamorphic

metamorphic

metamorphic

metamorphic

metamorphic

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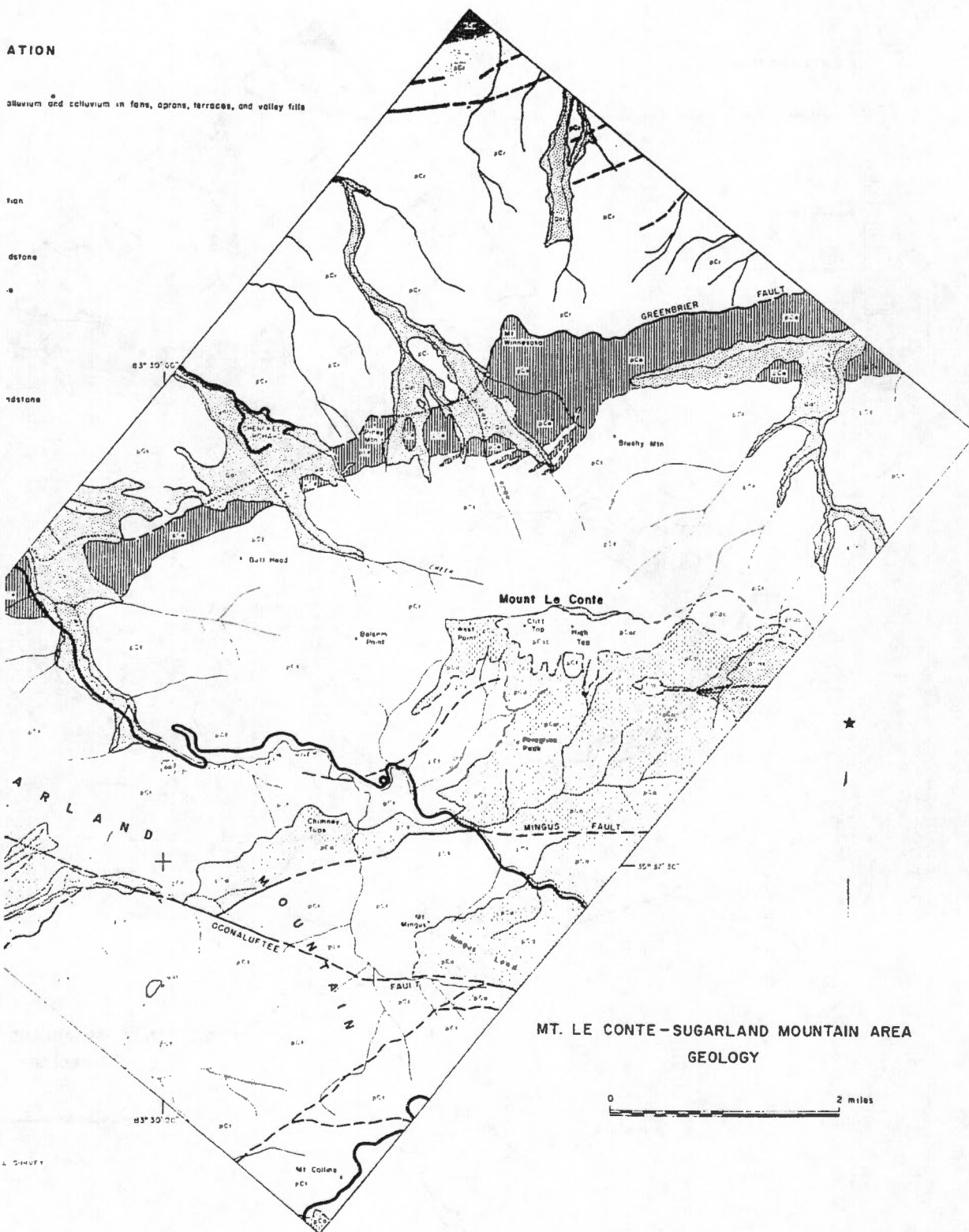
metamorphic

metamorphic

metamorphic

Geology, Mt. Le Conte-Sugarland Mountain Area.

B. Hadley and Richard Goldsmith, Geology of the Eastern Great Smoky Mountains, North, Geological Professional Paper 349-B (Washington: Government Printing Office, 1968).



the Gatlinburg fault system, occur in the Great Smoky Group in the southern section of the study area.

In this area the Snowbird Group consists almost entirely of Roaring Fork Sandstone. A small segment of the Pigeon Siltstone is found in the extreme northern corner.

Roaring Fork Sandstone is composed of moderately metamorphosed medium- and fine-grained feldspathic sandstone, metasiltstone, and minor amounts of slate and muscovite phyllite.⁹ The formation is about 7,000 feet thick and forms the lower portion of the north slope of Mt. Le Conte.

The Elkmont Sandstone, Thunderhead Sandstone, and Anakeesta Formation represent the Great Smoky Group within the study area. The Elkmont Sandstone occurs as a relatively narrow band just south of the Greenbrier fault. Mt. Winnesoka and Piney Mountain are located on the Elkmont. The bulk of Sugarland Mountain and much of the north slope and portions of the south slope of Mt. Le Conte are underlain by the Thunderhead Sandstone. The Anakeesta Formation is found on the summit and part of the south slope of Mt. Le Conte and in the vicinity of Mt. Mingus.

The Elkmont Sandstone consists of medium- to coarse-grained feldspathic sandstone and interbedded sandy siltstone and shale.¹⁰ Although the Elkmont is as much as 4,000 feet thick in certain localities, it varies from 1,000 feet thick in the western to 3,000 feet thick in the eastern portion of the study area.¹¹

⁹Jarvis B. Hadley and Richard Goldsmith, op. cit., p. B31.

¹⁰Ibid., Plate 1.

¹¹Ibid.

The thickest and most extensive stratigraphic unit in the Great Smoky Mountains is the Thunderhead Sandstone. In addition to underlying the imposing north-facing slope of Mt. Le Conte, it forms much of the crest of the range. Mt. Cammerer, 18 miles northeast of Mt. Le Conte, is underlain by the Thunderhead unit, as is Thunderhead Mountain, 16 miles southwest of Mt. Le Conte. Rugged topography is associated with the outcrop belt of this formation.

The Thunderhead Sandstone is described as a thick-bedded variously metamorphosed feldspathic sandstone and fine arkosic conglomerate. Gray slate, phyllite, feldspathic quartz-mica schist, and granite and quartzite cobble conglomerate are interbedded throughout the formation.¹² The thickness of the Thunderhead varies considerably because of extensive intertonguing with both the underlying and overlying formations. It is estimated to be approximately 5,000-6,000 feet thick on the north slope of Mt. Le Conte.¹³

The uppermost member of the Great Smoky Group in the study area is the Anakeesta Formation. Named for Anakeesta Ridge, a high spur between Mt. Le Conte and Newfound Gap, topography developed on the Anakeesta is characterized by exceptionally narrow and steep-sided ridges and craggy pinnacles. Peregrine Peak is typical of the former, and Chimney Tops is an excellent example of the latter. As mapped by Hadley and Goldsmith, the Anakeesta is divided into three members.¹⁴

¹²Ibid., p. B50 and Plate 1.

¹³Ibid., Plate 1.

¹⁴Ibid.

The uppermost of the three is the sandstone member. Only a small segment is found in the area of study. The middle member is composed of dark-gray to black slate and phyllite, medium- to coarse-grained feldspathic sandstone, and arkosic conglomerate. The south slope of Mt. Le Conte east of Alum Cave Bluffs lies upon this member as do Mingus Lead and Chimney Tops. The thickness varies from 0-2,000 feet.¹⁵ The third member of the Anakeesta, which occurs near the base of the formation, is exposed along the crest of Mt. Le Conte from Cliff Top to Myrtle Point as a 500 foot thick lens of light-colored chloritoid-bearing slate and argillite.¹⁶

Surficial Geology

The mantle of surficial material in the Great Smoky Mountains consists of saprolite, alluvium, and colluvium. This blanket of surficial material contains the record of a complex history of changing climate, weathering, soil formation, erosion, and deposition. Most researchers believe the surficial record in the Great Smoky Mountains may date as far back as the Tertiary Period.¹⁷

Saprolite is poorly preserved in the Mt. Le Conte-Sugarland Mountain area. Where present, it is usually thin and discontinuous.

¹⁵ Ibid.

¹⁶ Ibid., p. B61.

¹⁷ Ibid., p. B108; Philip B. King, op. cit., p. 131; and Robert B. Neuman and Willis H. Nelson, Geology of the Western Great Smoky Mountains, Tennessee, Geological Survey Professional Paper 349-D (Washington: Government Printing Office, 1965), p. D69.

Much of the slope surface is either fresh or slightly weathered bed-rock or colluvium. However, the basal portion of a saprolite layer is still preserved along the Clingmans Dome Road and may indicate that saprolite was more extensive at some former time.¹⁸ Saprolite is also found on the sandstones, siltstones, and argillaceous rocks of the foothills belt. Thicknesses of more than 100 feet have been reported in certain areas.¹⁹

Most of the stream valleys in the study area have steep sides and little alluvial fill. In areas of steep slopes, alluvium is generally limited to the stream bed or to a narrow strip along the stream. The alluvium is coarse and bouldery, with finer material usually becoming more common downstream. Two small deposits of alluvium occur in the vicinity of Roaring Fork and at Cherokee Orchard. According to Hadley and Goldsmith, the deposits are composed of large and small boulders mixed with smaller rock fragments and sandy or clay loam, and are poorly-sorted.

Slopes in the study area are mantled primarily with colluvial material. This unconsolidated debris, both fresh and weathered, is usually related to the underlying bedrock. The thickness of the colluvium is somewhat variable, but in slide areas the depth is generally thought to be inversely proportional to the steepness of the slope.

¹⁸ Jarvis B. Hadley and Richard Goldsmith, op. cit., p. 108.

¹⁹ Ibid.; and Philip B. King, op. cit., p. 133.

Very little is known of the mechanisms or rate of movement of the surficial mantle. No single hypothesis appears to satisfy all possible conditions. The presence of numerous large block fields and block streams, which are thought to be stable at present, and the existence of sizeable trees on slopes of 40° and more are evidence of at least relative stability. On the other hand, the accumulation of material on the upslope side of tree trunks, the bending of both large and small trunks upslope, and, of course, the debris slides on Mt. Le Conte and adjacent areas, do give credence to the idea that the mantle is not entirely stationary. Much research will be necessary before meaningful statements can be made concerning even the relative stability of natural slopes in the Great Smoky Mountains.

IV. CLIMATE

Because of elevation and exposure, mountains induce climates which differ markedly from those of adjacent lowlands. Within a mountainous area, the varieties of local or microclimates are almost infinite, and unless an extremely dense network of recording stations is present, the climate can only be described with generalities and with much conjecture.

According to Trewartha's modification of the Koppen climate classification, the Great Smoky Mountains share gross characteristics of the humid mesothermal climate of the Southeastern United States.²⁰

²⁰ Glenn T. Trewartha, An Introduction to Climate (New York: McGraw-Hill Book Company, Inc., 1954), pp. 232-237.

This indicates the coldest month is above 32°F. but below 64.4°F., and the warmest month is above 50°F. Although temperature records are not available, a humid microthermal climate probably prevails at the higher elevations. R. E. Shanks applied the Thornthwaite climate system to the area and concluded that the higher elevations of the Great Smoky Mountains possess a cool-temperate rain forest climate, whereas the lower elevations fall within a warm-temperate forest climate.²¹

Great Smoky Mountains National Park lies within the Tennessee River drainage basin, and weather events are monitored by the United States Weather Bureau, Tennessee Valley Authority, United States Department of the Interior, Aluminum Company of America, and other interested groups. Although the combined efforts of these observers have resulted in a large number of stations collecting data, most are located at the lower elevations, and many are concerned only with precipitation (Figure 5). Few long-term climatic records exist for any part of the Great Smoky Mountains (Table II).

The only rain gauge situated within the study area is located on the summit of Mt. Le Conte, but until 1960 readings were taken only during warm months when the lodge at the summit was occupied. Since 1960, however, Mr. Herrick Brown, operator of the lodge, has supplied the Tennessee Valley Authority with precipitation data for the entire year. Official temperature readings are not made.

²¹Royal E. Shanks, "Climates of the Great Smoky Mountains," Ecology, XXXV (July, 1954), 357-360.

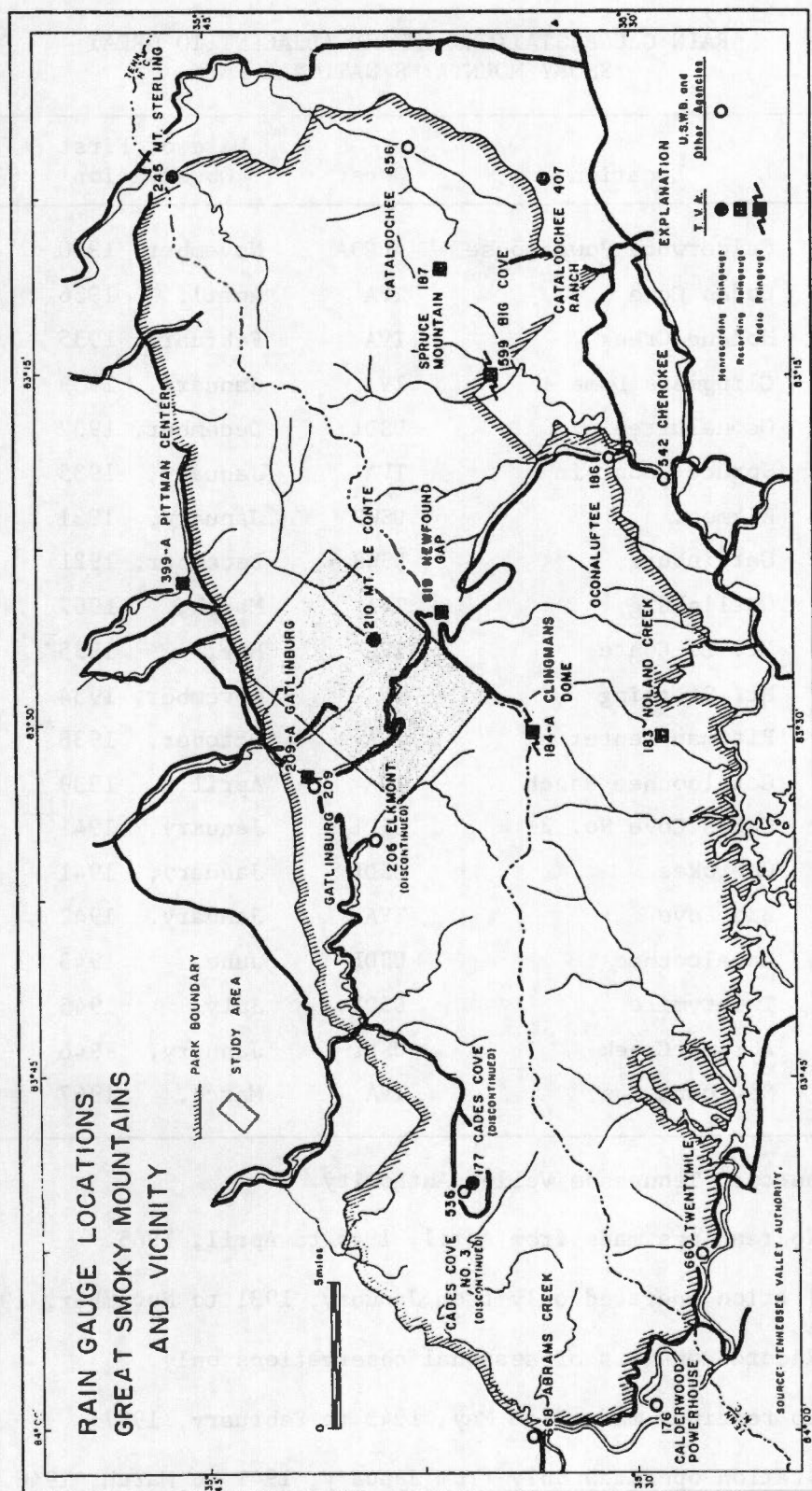


Figure 5. Rain gauge locations in and adjacent to Great Smoky Mountain National Park.

TABLE II
RAIN GAUGE STATIONS IN AND ADJACENT TO GREAT
SMOKY MOUNTAINS NATIONAL PARK

Station	Location	Owner	Date of First Observation	Elevation (feet)
176	Calderwood Powerhouse	ALCOA	November, 1930	950
177	Cades Cove	TVA	April, 1936 [*]	1964
183	Noland Creek	TVA	February, 1935	2520
184 A	Clingmans Dome	TVA	January, 1939	6250
186	Oconaluftee	USDI	December, 1932	2100
187	Spruce Mountain	TVA	January, 1935	4500
206	Elkmont	USWB	January, 1931 ⁺	2146
209	Gatlinburg	USWB	December, 1921	1460
209A	Gatlinburg	TVA	March, 1967	1460
210	Mt. Le Conte	TVA	May, 1935 ^x	6350
245	Mt. Sterling	TVA	November, 1934	2830
399A	Pittman Center	TVA	October, 1938 ^{**}	1350
407	Cataloochee Ranch	TVA	April, 1939	4800
536	Cades Cove No. 3	USDI	January, 1941 ⁺⁺	1800
542	Cherokee	USDI	January, 1941	1950
599	Big Cove	TVA	January, 1942	2620
656	Cataloochee	USDI	June, 1945	2590
660	Twentymile	USDI	July, 1945	1310
668	Abrams Creek	USDI	January, 1946	920
819	Newfound Gap	TVA	March, 1967	5000

Source: Tennessee Valley Authority.

^{*}No readings made from April, 1945 to April, 1965.

⁺Station operated only from January, 1931 to November, 1943.

^xRecord consists of seasonal observations only.

^{**}No readings made from May, 1943 to February, 1957.

⁺⁺Station operated only from January, 1941 to March, 1946.

Relatively long-term records are available from just two stations near the area of research. The Gatlinburg station has recorded both temperature and precipitation since December, 1921, but the Clingmans Dome station has recorded only precipitation since its establishment in September, 1935. The thirty-year record for these two stations offers some insight into the possible gamut of climatic conditions found in the Mt. Le Conte-Sugarland Mountain area (Table III).

The precipitation regime of the area is characterized by two maxima: one occurring in late winter and the other in the late summer. At Clingmans Dome maximum precipitation occurs during the winter, while a summer maximum prevails at Gatlinburg. Most winter precipitation is cyclonic in origin and falls as snow. The snow cover, however, rarely persists throughout the winter except in very sheltered locations. Rainfall during the summer months is primarily convectional. The thirty-year mean annual precipitation is 55.54 inches at Gatlinburg and 82.26 inches at Clingmans Dome.

Between 1946 and 1950 the United States Weather Bureau, the National Park Service, and the Tennessee Valley Authority conducted a study of the relationship between climatic variations and elevation.²² In addition to the standard non-recording gauges already situated near Gatlinburg, Smokemont, and Clingmans Dome, five new gauges were installed along 18 miles of U.S. Highway 441 at elevations ranging

²²James Smallshaw, "Some Precipitation - Altitude Studies of the Tennessee Valley Authority," American Geophysical Union Transactions, XXXIV (August, 1953), 583.

TABLE III
CLIMATIC DATA FOR GATLINBURG AND CLINGMANS DOME

Month	Gatlinburg		Clingmans Dome	
	Temperature (F.)	Precipitation (Inches)	Temperature (F.)	Precipitation (Inches)
January	39.1	5.05	Temperature readings are not taken.	6.74
February	40.9	5.14		9.11
March	47.6	5.64		8.34
April	57.0	4.60		6.92
May	64.9	4.11		5.20
June	72.0	5.17		6.69
July	74.4	6.53		8.18
August	73.6	5.29		6.75
September	68.2	3.04		5.03
October	57.6	3.05		5.24
November	46.3	3.74		6.97
December	39.5	4.18		7.09
Year	56.8	55.54		82.26

Source: Tennessee Valley Authority, Precipitation in Tennessee River Basin, Annual, 1968 (Knoxville: Tennessee Valley Authority, 1968).

from 1460 to 6400 feet (Figure 6). Results of the investigation show a decided increase in rainfall with increasing altitude, although a wide range in precipitation occurred from year to year (Figure 7). Altitude apparently has its greatest effect upon precipitation amounts at elevations below 3500 feet during the cyclonic storm period of the winter months (October-March). Similar results were obtained in the Snowbird Range in a 1938 study by the Tennessee Valley Authority.²³

Shanks noted that a water surplus exists throughout the year at all elevations above 3800 feet. Only at the 1460 foot level or below was precipitation less than potential evapo-transpiration, and then only by 0.49 inches in September.²⁴

Temperatures also vary with elevation. The Shanks' study indicated that temperatures decrease an average of 2.23°F. for each one thousand foot increase in elevation.²⁵ During the growing season temperatures in the spruce-fir forest at the summits average 10-13°F. cooler than at the base of the mountain.²⁶

Soil temperatures show conspicuous differences not only with elevational change, but also with different vegetational cover at the same elevation. Soil temperature differences between the spruce-fir

²³Tennessee Valley Authority, "Rainfall - Altitude Study, May 1, 1938 to October 31, 1938," (Knoxville: Tennessee Valley Authority, 1938).

²⁴Royal E. Shanks, op. cit., p. 360.

²⁵Ibid., p. 357.

²⁶Ibid.

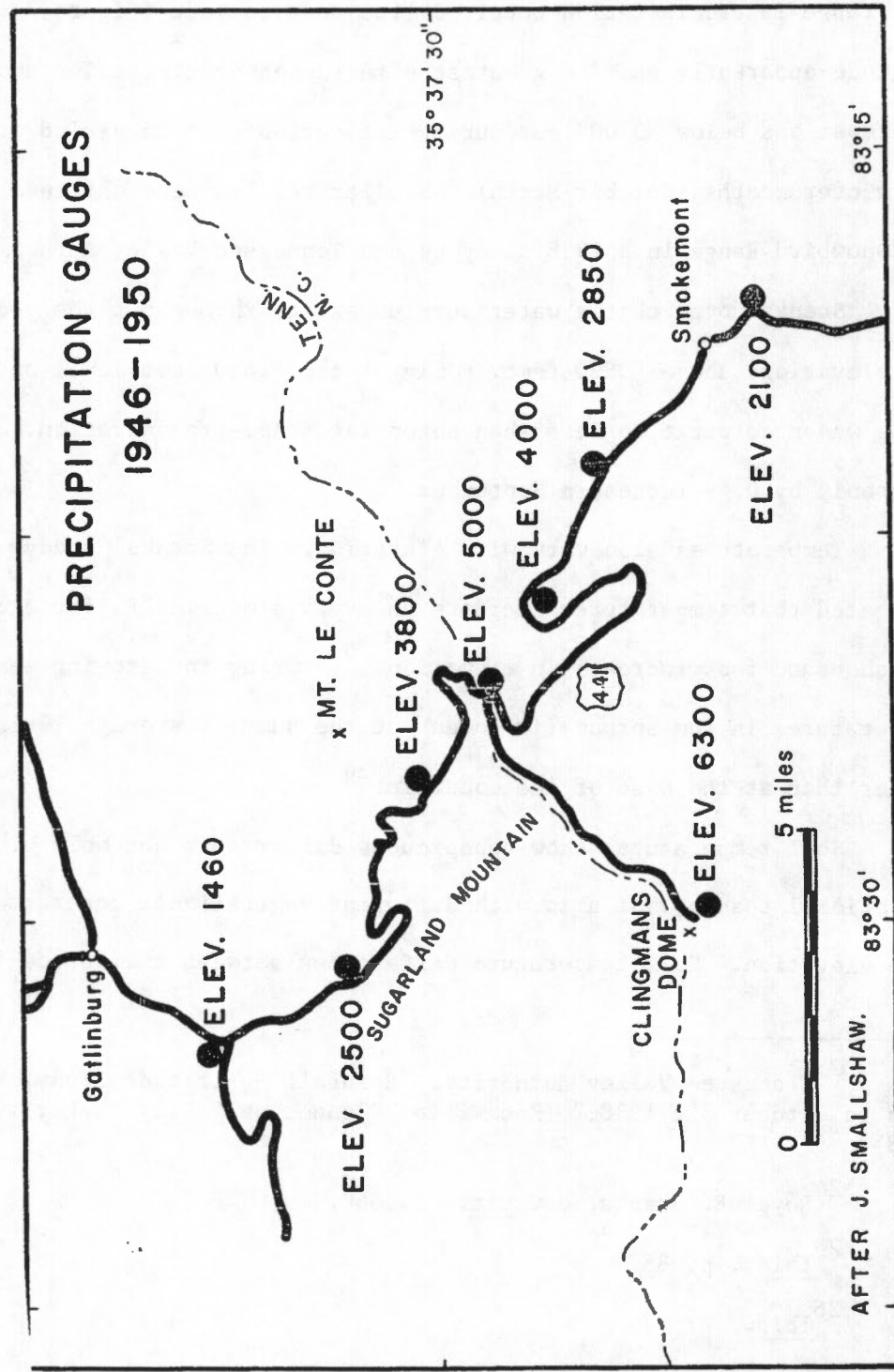


Figure 6. Rain gauge locations, 1946-1950.

Source: James Smallshaw, "Some Precipitation - Altitude Studies of the Tennessee Valley Authority," *American Geophysical Union Transactions*, XXXIV (August, 1953), 584.

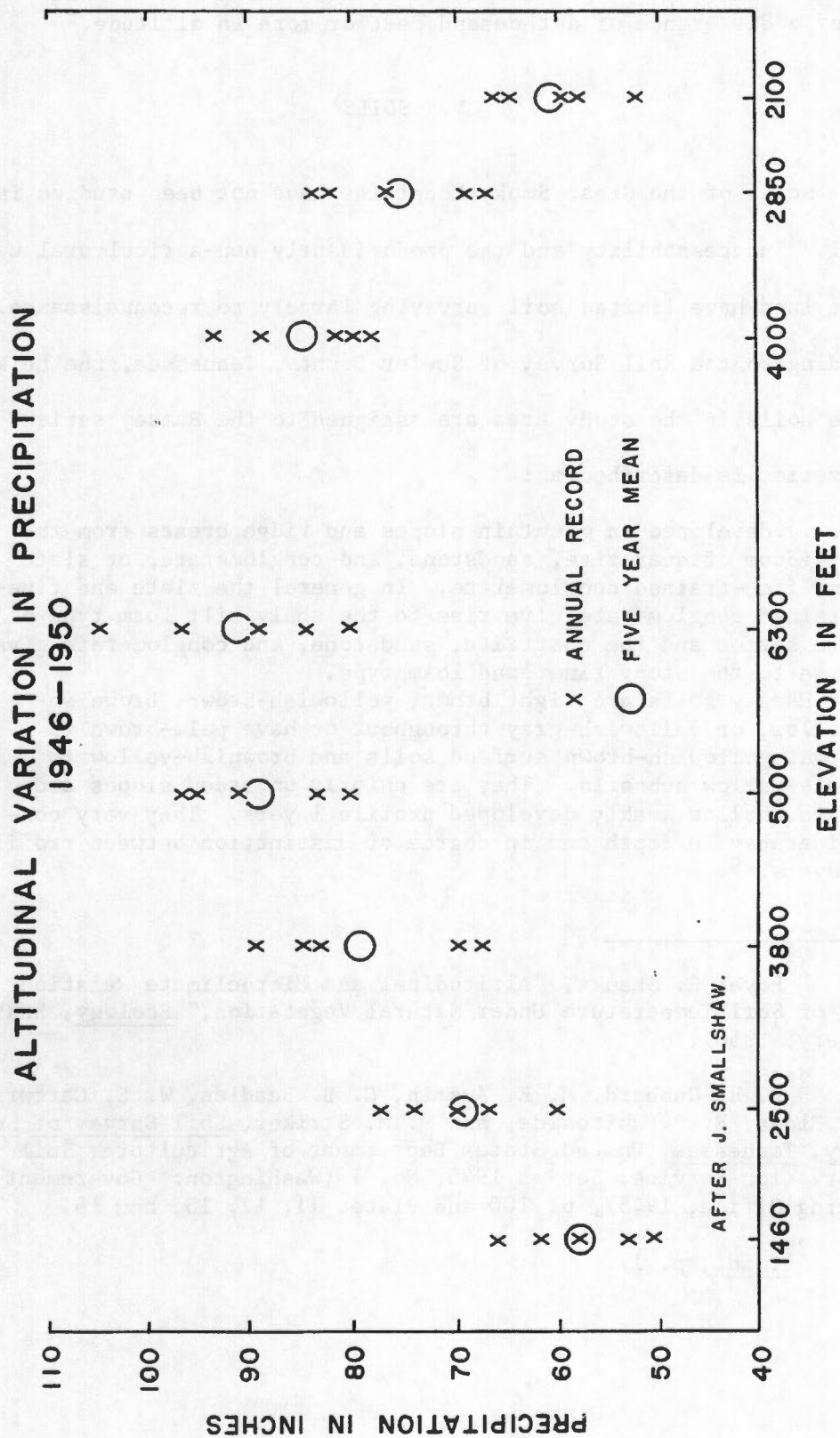


Figure 7. Precipitation increase with altitude.

Source: James Smallshaw, "Some Precipitation - Altitude Studies of the Tennessee Valley Authority," American Geophysical Union Transactions, XXXIV (August, 1953), 585.

forest and a beech stand adjacent to it may be as great as the equivalent of a difference of a thousand feet or more in altitude.²⁷

V. SOILS

Soils of the Great Smoky Mountains have not been studied in detail. Inaccessability and the predominantly non-agricultural use of the land have limited soil surveying largely to reconnaissance. According to the Soil Survey of Sevier County, Tennessee, the bulk of the soils in the study area are assigned to the Ramsey series.²⁸

This series is described as:

. . . developed on mountain slopes and ridge crests from the residuum of quartzite, sandstone, and conglomerate, or slate and fine-grained conglomerate. In general the slate and fine-grained conglomerate give rise to the shaly silt loam type of the series and the quartzite, sandstone, and conglomerate give rise to the stony fine sand loam type.

Ramsey soils are light brown, yellowish-brown, brownish-yellow, or yellowish-gray throughout or have pale-brown to light yellowish-brown surface soils and brownish-yellow to pale-yellow subsoils. They are chiefly on steep slopes and have shallow weakly developed profile layers. They vary considerably in depth and in degree of distinction between profile layers.²⁹

²⁷Royal E. Shanks, "Altitudinal and Microclimate Relationships of Soil Temperature Under Natural Vegetation," Ecology, XXXVII (January, 1956), 6.

²⁸E. H. Hubbard, M. E. Austin, C. B. Beadles, W. E. Cartwright, J. A. Elder, E. P. Whiteside, and M. M. Striker, Soil Survey of Sevier County, Tennessee, United States Department of Agriculture, Soil Conservation Service, Series 1945, No. 1 (Washington: Government Printing Office, 1945), p. 100 and Plates 11, 12, 15, and 16.

²⁹Ibid., p. 17.

Soils derived from the Anakeesta Formation are referred to as the Ramsey shaly silt loam. The Ramsey shaly silt loam is excessively drained and:

. . . consists mainly of residual materials weathered from slate and fine-grained quartzite. It is a light brown, yellowish-brown, or brownish-yellow friable shaly light silty clay loam or silt loam, 6-12 inches thick. In wooded areas, the 1- to 3-inch surface layer is stained dark with organic matter. Bedrock outcrops are common in most places.

Color and depth to bedrock are quite variable. The soil on the south-facing slopes is darker. . . . On the lower and milder slopes the soil is deeper and on the upper slopes it is shallower. . . . The soil is strongly acid. . . .

The soil is permeable to air, roots, and water. Runoff is very rapid and internal drainage is rapid. The water-holding capacity is low.³⁰

Soils derived from the Thunderhead Sandstone are referred to as the Ramsey stony fine sandy loam. The Ramsey stony fine sandy loam:

. . . is a light colored excessively drained stony soil on steep and very steep mountain slopes. It consists of residual materials weathered from quartzite, sandstone, and conglomerate.

The soil is medium to strongly acid in reaction and apparently low in content of organic matter except in the thin surface layer. It is moderately low in plant nutrients and very permeable to air, roots, and water. Runoff is very rapid and internal drainage is rapid. The water holding capacity is very low.³¹

Soils between 4500 and 6600 feet in the Great Smoky Mountains have been classified according to contrasting forest types. Soils beneath heath balds exhibit a Podzol profile, whereas soils under beech and spruce-fir vegetation are termed Sols Bruns Acides (Acid Brown Earths).³² The latter display no eluvial or illuvial horizons.

³⁰ Ibid., pp. 94-95.

³¹ Ibid., pp. 96-97.

³² R. J. McCracken, R. E. Shanks, and E. E. C. Clebsch, "Soil Morphology and Genesis at Higher Elevations of the Great Smoky Mountains," Soil Science Society of America Proceedings, XXVI (July-August, 1962), 384.

Wolfe has classified some soils at higher elevations in the Great Smoky Mountains according to the Seventh Approximation of the Soil Conservation Service.³³ Soils without development of eluvial or illuvial horizons are called Inceptisols and are classified as follows:

Great Group: Dystrochrepts
 Subgroup: Umbric Dystrochrepts
 Family: fine, loamy, mixed, mesic, permeable

According to Wolfe, the majority of forest soils at the higher elevations in the Great Smoky Mountains are Inceptisols (Sols Burns Acides) belonging to the Umbric Dystrochrept subgroup.³⁴

Although Podzols are associated with spruce-fir forests in other areas, records and descriptions of Podzols in the Great Smoky Mountains are not common. If present, the Podzols with albic (ashy grey A2) and spodic (illuvial humus and iron) horizons are termed Spodosols and are classified as follows:³⁵

Great Group: Normorthods
 Subgroup: Entic Normorthods
 Family: coarse, loamy, mixed, mesic, permeable, thin

³³J. A. Wolfe, "Forest Soil Characteristics as Influenced by Vegetation and Bedrock in the Spruce-fir Zone of the Great Smoky Mountains" (unpublished Doctoral dissertation, The University of Tennessee, Knoxville, Tennessee, 1967), p. 112; Soil Survey Staff, Soil Classification, A Comprehensive System - 7th Approximation (Washington: Government Printing Office, 1960); and Soil Survey Staff, Soil Classification, A Comprehensive System - 7th Approximation (Revisions) (Washington: Government Printing Office, 1964).

³⁴J. A. Wolfe, op. cit., p. 120.

³⁵Ibid., p. 113.

Wolfe reported that scattered profiles of Spodosols (Podzols) are present in the Great Smoky Mountains, but they are generally restricted to crests of higher domes or peaks under spruce-fir vegetation.

VI. VEGETATION

The Great Smoky Mountains have a great variety of vegetation, including approximately 1,300 species of flowering plants. Of these, 147 are native trees, and at least 20 are exotic to the region.³⁶ Investigators have also identified almost 350 mosses and liverworts, 50 ferns, 230 lichens, and more than 2,000 fungi.³⁷ The complexity of vegetation is primarily a function of recent earth history, physiography, and climatic diversity.

The Pleistocene Epoch apparently have had a marked influence upon the present make-up of the vegetation. Although it has been postulated that boreal types have been in the area since middle Tertiary,³⁸ investigators suggest that much of the vegetation in the higher elevations of the Great Smoky Mountains originated during the Pleistocene, when elements of the boreal forest were forced southward with the expansion of continental glaciers.³⁹ Geologic evidence

³⁶H. M. Jennison, "Flora of the Great Smokies," Journal of the Tennessee Academy of Science, XIV (July, 1939), 269.

³⁷Arthur Stupka, Great Smoky Mountains National Park, Natural History Handbook Series No. 5 (Washington: Government Printing Office, 1960), p. 10.

³⁸E. Lucy Braun, "Plant Distribution in Relation to the Glacial Boundary," Ohio Journal of Science, LI (May, 1951), 139-146.

³⁹E. S. Deevey, "Biogeography of the Pleistocene," Geological Society of America Bulletin, LX (August, 1949), 1315-1416; and P. S.

indicates the Great Smoky Mountains were not glaciated during the Pleistocene, but higher areas may have been above the forest limit.⁴⁰

Present climatic conditions range from a humid mesothermal climate in the lowlands to a humid microthermal climate at the summits. Local relief can exceed one mile, and relatively steep slopes are found on all exposures and at most elevations within the park. Under such diverse environmental parameters the gamut of local habitats varies from mesic slopes and valleys to extremely xeric slopes and ranges.

The floristic pattern in the Great Smoky Mountains includes two great vegetational systems. Temperate deciduous forests and related types are found in the lower elevations, whereas the boreal coniferous forest is present at elevations generally above 5500 feet.⁴¹ Numerous investigators have described the vegetation, but large-scale mapping of the plant associations has not received adequate attention. F. H. Miller mapped vegetative types in Great Smoky Mountains National Park, but the small scale of his map precludes

Martin, "Pleistocene Ecology and Biogeography of Eastern North America," Zoogeography (Washington: American Association for the Advancement of Science, 1958), pp. 375-420.

⁴⁰Philip B. King, op. cit., pp. 134-136; Jarvis B. Hadley and Richard Goldsmith, op. cit., p. 111B; and Robert B. Neuman and Willis H. Nelson, op. cit., p. D76.

⁴¹Robert H. Whittaker, "A Vegetational Analysis of the Great Smoky Mountains" (unpublished Doctoral dissertation, The University of Illinois, Urbana, Illinois, 1948), p. 6.

projecting his results to detailed analysis in the Mt. Le Conte-Sugarland Mountain area.⁴²

The mapping of discrete forest associations assumes, of course, that they do in fact exist. Whittaker is of the opinion that the various species are not organized into associational units, but that the vegetational pattern in the Great Smoky Mountains is one of continuous gradation.⁴³ Discontinuities which are present reflect such boundaries as the edges of fields or old burns. He stated that:

The climax vegetation of an area should be interpreted, not as one or more distinct associations, but as a broader or narrower section from a continuous complex, and often heterogeneous gradient system.⁴⁴

Whittaker believes moisture balance is the most critical factor for the lower, deciduous forests, whereas temperature is the most critical factor for the dominant trees of the boreal forest.⁴⁵

Most researchers, however, divide the forests of the Great Smoky Mountains into major tree associations. These include the spruce-fir forest, northern hardwood forest, hemlock forest, closed

⁴²F. H. Miller, "Vegetation Type Map, Great Smoky Mountains National Park" (unpublished Civilian Conservation Corps Project, 1935-1938). With the aid of airborne remote sensing, research on the mapping of vegetation in the Mt. Le Conte area is currently being conducted by the Department of Ecology, University of Tennessee, Knoxville, Tennessee.

⁴³Robert H. Whittaker, "Vegetation of the Great Smoky Mountains," Ecological Monographs, XXII (January, 1956), 32.

⁴⁴Robert H. Whittaker, "A Vegetational Analysis of the Great Smoky Mountains" (unpublished Doctoral dissertation, The University of Illinois, Urbana, Illinois, 1948), p. 274.

⁴⁵Ibid., pp. 271-272.

oak forest, open oak and pine forest, and cove hardwood forest.⁴⁶

In the eastern half of the Great Smoky Mountains the spruce-fir forest dominates at elevations above 5000 feet. The forest, characterized by red spruce, Fraser fir, mountain ash, yellow birch, serviceberry, pin cherry, beech, buckeye, and red maple, reaches its southernmost limit a few miles west of Clingmans Dome.

The northern hardwood forest consists primarily of yellow birch and beech and occurs generally above 4500 feet. Trees associated with this forest type are red spruce, red maple, sugar maple, pin cherry, black cherry, buckeye, mountain maple, striped maple, silverbell, and Fraser magnolia.

Eastern hemlock is generally found along high ridges to an elevation of 5000 feet on shaded slopes and along streams. Affiliated with the hemlock are beech, yellow birch, sweet (black) birch, Fraser magnolia, red maple, sugar maple, white ash, holly, northern red oak, yellow-poplar, and silverbell.

At middle and lower elevations and situated on relatively dry slopes is the closed oak forest. White oak, chestnut oak, northern red oak, black oak, pignut hickory, red hickory, mockernut hickory, red maple, sweet birch, sourwood, yellow-poplar, blackgum, black locust, and silverbell comprise this group. Before the blight, American chestnut was an important component of this forest.

⁴⁶ Arthur Stupka, op. cit., pp. 15-18; George B. Stevenson, Trees of the Great Smoky Mountains National Park (The Great Smoky Mountains Natural History Association, 1967), p. 30; and Royal E. Shanks, "Reference Lists of Native Plants of the Great Smoky Mountains," (Knoxville: Botany Department, University of Tennessee, 1954), pp. 4-14. (Mimeographed.)

Rocky, dry, exposed slopes and ridges are the usual habitat for the open oak and pine forest. Trees include white oak, chestnut oak, scarlet oak, black oak, white pine, pitch pine, Virginia (scrub) pine, red maple, black locust, sourwood, blackgum, sassafras, and mountain-laurel.

The cove hardwood forest is confined primarily to sheltered areas below 4500 feet. Associated with the cove hardwood forest are basswood, yellow-poplar, buckeye, beech, yellow birch, sugar maple, white ash, striped maple, holly, hornbeam, Fraser magnolia, and witch hazel.

Although there is no timberline in the Great Smoky Mountains, relatively small areas on some summits and slopes are forest free. Such localities are referred to as "balds", but vegetation is not necessarily lacking. If the predominant flora are grasses, ferns, or small shrubs, it is termed a "grass bald." If the vegetation is largely shrubs belonging to the heath family, the name "heath bald" is applied.

The origin of balds is still in question.⁴⁷ Ecological studies have attributed them to relics of some former climatic period, wind-fall, snow and ice storms, fire, and landslide.

All six types of forest associations are present within the Mt. Le Conte-Sugarland Mountain area. On Mt. Le Conte the spruce-fir forest is found between 4500 feet and the summit, northern hardwoods

⁴⁷ A. F. Mark, "The Ecology of the Southern Appalachian Grass Balds," Ecological Monographs, XXVIII (October, 1958), 330-332.

between 4500 and 5500 feet, and the remaining four are located between 1500 and 4500 feet.⁴⁸ A considerable portion of the slopes are covered with heath balds, but no grass balds are found within the study area.

VII. SETTLEMENT AND ECONOMY

The first Europeans who explored the Great Smoky Mountains found "Overhill" tribes of the Cherokee Indians living in permanent villages on alluvial bottoms of the larger streams of the foothills belt.⁴⁹ Except for an occasional hunting expedition, the Indians apparently did not venture into the high mountains. The first permanent white settlers came into the mountains in the late eighteenth century and established residence in Wear Cove. Shortly thereafter, White Oak Flats, later to be known as Gatlinburg, was settled, and pioneers began moving into the mountain valleys and coves to work farmsteads.⁵⁰ Isolated from the outside world, the mountaineers practiced a self-sufficient economy of farming, hunting, and some timber cutting. These early settlements were abandoned long before the establishment of Great Smoky Mountains National Park, and Cades Cove is the only part of the park now settled and cultivated.

⁴⁸Paul J. Adams, Mt. Le Conte (Knoxville: Holston Printing Company, 1966), p. 8.

⁴⁹Roderick Peattie, The Great Smokies and the Blue Ridge (New York: The Vanguard Press, 1943), p. 22.

⁵⁰E. J. Foscue, "Gatlinburg, A Mountain Community," Economic Geography, XXI (July, 1945), 196-197.

Logging in the Great Smoky Mountains is divided into two periods.⁵¹ The first period, prior to 1900, was characterized by mountaineers clearing land for farming and small enterprises engaged in selective cutting of the most valuable timber. Poplar, cherry, and ash were cut and some tanbark was peeled. The second period, 1900 to 1939, consisted of large-scale, systematic cutting on a commercial scale. Eighteen logging firms by 1939 had cut most of the merchantable timber in approximately 60 percent of the area which now comprises the park. However, logging is now history, and over 200,000 acres of virgin hardwood forest remain in the park.⁵² Most of Mt. Le Conte has never been logged.

Since the establishment of the park, emphasis has been upon developing appropriate park facilities and promoting the tourist industry. Much of the park perimeter can be traveled by road, and the transmountain road (U.S. Highway 441) follows the course of West Prong Little Pigeon River from Gatlinburg to Newfound Gap and then into Cherokee, North Carolina, in the valley of the Oconaluftee River. Within the park, access to most areas is generally by foot or horse trail, although roads do lead to Clingmans Dome and Cades Cove. The Appalachian Trail follows the Tennessee-North Carolina border along the crest of the Mountains.

⁵¹R. S. Lambert, "Logging in the Great Smoky Mountains National Park," (Report to the Superintendent, Great Smoky Mountains National Park, 1958). (Mimeographed.)

⁵²Arthur Stupka, Trees, Shrubs, and Woody Vines of Great Smoky Mountains National Park (Knoxville: University of Tennessee Press, 1964), p. 16.

Great Smoky Mountains National Park is the most visited national park in the United States, and the economy of several surrounding towns is based primarily upon the tourist industry generated by the park.⁵³ Gatlinburg, Tennessee, and Cherokee, North Carolina, are the two main points of focus for visitors to the mountains.

The Mt. Le Conte-Sugarland Mountain area has no permanent residents. With the coming of spring and the warm months, however, the area experiences a large influx of people. During this time numerous groups and individuals take advantage of the overnight facilities at Chimneys Campground, Le Conte Lodge, and the shelters located along several trails.

At one time, alluvial areas along West Prong Little Pigeon River, Roaring Fork, and at Cherokee Orchard furnished early settlers with the best agricultural land on the north slope of the higher mountains. These areas are now empty of people and are reverting back to forest.

Because of the park status, cultural features in the study area are few. The transmountain road, several unimproved roads, Le Conte Lodge, Chimneys Campground, three overnight shelters, a number of old cabins, and various trails are the only man-related features.

Gatlinburg is located less than four miles downstream from the Mt. Le Conte-Sugarland Mountain area on West Prong Little Pigeon

⁵³ National Park Service, Public Use of the National Parks - A Statistical Report (Washington: Government Printing Office, 1968), pp. 1-12.

River, and although it is not specifically included within the study area, it was affected by the floodwaters of the September 1, 1951, storm. Situated adjacent to the highest and most rugged area of the Great Smoky Mountains and surrounded by steep slopes on all sides, the unique site and situation of Gatlinburg is most interesting and will be discussed in later chapters.

CHAPTER III

MASS MOVEMENT

I. INTRODUCTION

The significance of downslope movement of rock, regolith, and soil under the influence of gravity, whether the rate be so slow that it is detectable only by indirect evidence or catastrophically rapid, has long been underestimated by students of slope processes. Only recently has erosion directly controlled by gravity begun to receive detailed attention.

II. CLASSIFICATIONS

The terms "mass movement" or "mass wasting" refer to the movement of material on slopes as a direct result of gravity, without significant contributions from transporting agents such as streams, waves, glaciers, or wind. This movement, whose velocities range from free rock fall to slow creep of material on very gentle slopes, occurs when internal resistance to downslope movement fails.

Although there are many types of mass movement, the various forms and processes are difficult to classify. Categorization is hindered because the changeover point between the forms of mass movement are generally transitional, and, in most instances, no one is present to observe and record the movement. Consequently, a completely workable classification of mass movement phenomena has not yet been designed.

Most early classifications came from European geologists and dealt primarily with landslides and catastrophic movement. As the significance of slow movement was not understood, no system provided a complete portrayal of this important agent of erosion.

C. F. S. Sharpe presented the first usable English-language classification dealing with mass movement phenomena.¹ Sharpe reviewed previous classifications and found them to be either incomplete, illogical, impractical, or lacking in a geological point of view.² He then presented a new system based upon (1) the kind and rate of movement, (2) the relative water or ice content, and (3) the kind of material involved. Sharpe divided mass movement into four groups based largely upon kind of movement. These he designated as slow flowage, rapid flowage, landslides, and subsidence (Table IV). Many studies have referred to and used this grouping.

D. J. Varnes developed a revised classification in 1958 which has attracted considerable attention.³ Basing his system partly upon the works of Heim and Sharpe,⁴ Varnes categorized mass movement

¹C. F. Stewart Sharpe, Landslides and Related Phenomena (New York: Columbia University Press, 1938).

²Ibid., p. 16.

³David J. Varnes, "Landslide Types and Processes," Landslides in Engineering Practice, Highway Research Board Special Report 29, E. B. Eckel, editor (Washington: Highway Research Board, 1958), pp. 20-47.

⁴A. Heim, "Bergsturz und Menschenleben," Vierteljahrsschrift der Naturforscher Gesellschaft Zurich, LXXII (1932), pp. 1-218; and C. F. Stewart Sharpe, op. cit.

TABLE IV

MASS MOVEMENT CLASSIFICATION BY C. F. STEWART SHARPE

I. Slow Flowage - usually imperceptible

Creep

Soil Creep

Talus Creep

Rock Creep

Rock-Glacier Creep

Solifluction

II. Rapid Flowage - relatively wet

Earthflow

Mudflow

Debris Avalanche

III. Landslide - relatively dry

Slump

Debris Slide

Debris Fall

Rockslide

Rockfall ..

IV. Subsidence - surface material displaced vertically downward

Source: C. F. Stewart Sharpe, Landslides and Related Phenomena,
(New York: Columbia University Press, 1938).

according to the material involved and the form of movement. Fall, slide, and flow are the three main divisions of the scheme (Table V).

More recently, L. H. Nobles proposed a classification based upon the bulk composition of the movement and utilized either a triangular diagram that has end members of water, snow, and rock fragments or a tetrahedron that has water, snow, coarse rock fragments, and fine rock fragments as the four end members.⁵ Because of the lack of quantitative data on mass movement at the time of its occurrence, Nobles stated that the absence of sharp boundaries in differentiating the various forms is beneficial to the classification.

III. TERMINOLOGY

The investigation of mass movement phenomena in the Mt. Le Conte-Sugarland Mountain area revealed characteristics similar to both the "debris avalanche" and the "debris slide" as defined by Sharpe and by Varnes report, the boundary between them is transitional. The almost infinite variations in combination and intensity of parameters involved dictates such a transition. Sharpe noted that water content is the prime distinguishing agent between debris slide and debris avalanche. He stated:

In humid regions with a good covering of vegetation the torrential mudflow of semiarid type is replaced by a sort of flowing slide here termed "debris avalanche." Were there a smaller water content the same material would move as a debris slide.⁶

⁵ Laurence H. Nobles, "Classification of Rapid Mass Movements," Geological Society of America Bulletin, LXX (December, 1959), 1652.

⁶ G. F. Stewart Sharpe, op. cit., p. 61.

TABLE V

MASS MOVEMENT CLASSIFICATION BY DAVID J. VARNES

I.	Falls	
		Bedrock
		Rockfall
		Soils
		Soilfall
II.	Slides	
		Bedrock
		Few Units
		Rotational Slump
		Planar Glide
		Many Units
		Rockslide
		Soils
		Planar Block Glide
		Rotational Block Slump
		Debris Slide
		Failure by Lateral Spreading
III.	Flows	
		All Unconsolidated Material
		Dry
		Rock Fragment Flow
		Sand Run
		Loess Flow
		Rapid Earth Flow
		Debris Avalanche
		Slow Earthflow
		Wet
		Sand or Silt Flow
		Debris Flow
		Mud Flow
IV.	Complex	
		Combinations of Material or type of movement

Source: David J. Varnes, "Landslide Types and Processes," Landslides in Engineering Practice, Highway Research Board Special Report 29, E. B. Eckel, editor (Washington: Highway Research Board, 1958).

Varnes also contended that water and velocity are factors in determining the form of movement. He concluded that:

With increase in water content or with increasing velocity, debris slides grade into the flowing movement of debris avalanches.⁷

Sharpe and Varnes agree that debris avalanches involve a wet, flowing movement whereas debris slides are more a function of dry, sliding movement. Sliding, as defined by Varnes, is present when:

. . .the movement results from shear failure along one or several surfaces, which are either visible or may be reasonably inferred.⁸

According to Varnes, flowage occurs when:

. . .the movement within the displaced mass is such that the form taken by the moving material or the apparent distribution of velocities and displacements resembles those of viscous fluids.⁹

Because no quantitative studies have been conducted on natural slides, however, neither the water content nor the velocity for either form is known. Consequently, one can only subjectively designate a particular occurrence as debris avalanche or debris slide.

In the Mt. Le Conte-Sugarland Mountain area, movement in the higher portion of the slide tracks was apparently sliding, whereas flowage was probably the main mechanism in the lower segments. Thus, even within each chute there exists an area of transition between flowage and sliding.

Because of lack of data and the transitional nature of the boundary separating the two forms, it is best, perhaps, not to try to

⁷David J. Varnes, op. cit., p. 29.

⁸Ibid., p. 23.

⁹Ibid., p. 32.

state whether the particular feature is a debris slide or debris avalanche. Since sliding probably initiated movement, the Mt. Le Conte-Sugarland mountain slope damage features will all be referred to as debris slides. Anders Rapp recommends that the term "debris avalanche" be wholly abandoned and the word "avalanche" used only for mass movement of snow, either pure or mixed with debris.¹⁰

IV. DEBRIS SLIDES

Although most debris slides are commonly associated with steep slopes and either prolonged or high intensity rainfall, little is actually known about specific causes and localizing factors. Long, relatively narrow tracks on steep, generally forested slopes are characteristic slide features. Slide scar heads are usually a short distance downslope from the drainage divide, but may originate at any point on the slope. As a rule, vegetation is almost entirely removed from the slide track. According to Hack and Goodlett, movement apparently begins as a result of concentrated runoff in the upper part of a channelway or hollow or from oversteepening at the base of a slope by a flooded stream.¹¹ The moving mass of slide material is

¹⁰ Anders Rapp, "The Debris Slides at Ulvadal, Western Norway - An Example of Catastrophic Slope Processes in Scandinavia," Nachrichten Der Akademie Der Wissenschaften in Gottingen II. Mathematisch - Physikalische Klasse, XIII (December, 1963), 200-201.

¹¹ John T. Hack and John C. Goodlett, Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians, Geological Survey Professional Paper 347 (Washington: Government Printing Office, 1960), p. 44.

composed primarily of rock, regolith, soil, forest debris and litter, and water.

Deposition may take place anywhere along the slide track, but usually occurs either where large immovable objects such as trees or boulders are present, on the outside bank of bends in the chute, or at a decrease in slope. The decrease in slope may occur either where the slide track meets the next order drainage feature or at some point before the junction.

If debris is deposited in such a manner that it is not swept away by flood waters, the resultant form is termed a debris fan. Hack and Goodlett defined this feature as:

Fan- or cone-shaped accumulations of sorted debris consisting mostly of stones and gravel, but also containing broken trunks and branches.¹²

If an exceptionally large pile of tree trunks is present, it is referred to as a log jam. Debris fans and log jams may occur separately or in combination in the slide track.

When debris slides occur in proximity to cultural features, considerable damage may result. Slides have been known to inundate residential and agricultural land, disrupt communications and transportation facilities, and take human lives. Slides can also damage recreational facilities and hinder land and water management. Trees are uprooted, and large scars are left upon the landscape. Debris entering rivers and lakes may cause flooding in nearby areas, reduce fish populations, and increase silting rates of reservoirs.

¹²Ibid., p. 53.

Activity within the slide track continues long after the debris slide has occurred. Factors in post-slide recovery are apparently complex. Revegetation operates to heal the slide scar, whereas mass movement, as well as other agents of erosion, continue at an accelerated rate within the slide track.

Geomorphically, the debris slide is an agent in valley formation.¹³ Sliding may initiate the formation of a first-order valley or modify the size and shape of an already existing higher-order valley. The relative importance, of course, is dependent upon the recurrence interval of the slide-producing storms. Only when enough evidence is gathered to reveal the frequency of debris slides in the unglaciated Appalachian Highlands can one begin to estimate their overall effect in valley origin.

¹³Ibid., p. 44.

CHAPTER IV

EVENTS OF SEPTEMBER 1, 1951

I. INTRODUCTION

Unusual meteorological conditions developed over Great Smoky Mountains National Park and nearby Gatlinburg, Tennessee, on September 1, 1951. For the afternoon temperatures were the hottest of the summer. At park headquarters in Gatlinburg a high of 95°F. was recorded, and at Knoxville an 80-year record was broken with a reading of 100°F.¹ Late in the afternoon an intense thunderstorm occurred in which four or more inches of rain fell in one hour in the vicinity of Mt. Le Conte and Sugarland Mountain.² Numerous debris slides and considerable flooding resulted.

II. THE STORM

Descriptions of the storm vary considerably. Several people driving along U.S. Highway 441 said showers began about 4:00 p.m. Two rangers reported that in the section of road between Alum Cave parking lot and the Chimneys parking area the hard rain began about 5:30 p.m. Information from the rain gauge record of the Mt. Le Conte

¹John C. Preston, "Great Smoky Mountains National Park, Superintendent's Monthly Report, September, 1951," p. 2.

²Tennessee Valley Authority, "Flood of September 1, 1951, in and Near Gatlinburg, Tennessee," Volume 1 (Knoxville: Tennessee Valley Authority, 1951), p. 1.

station indicates the storm duration was one hour, from 5:45 to 6:45 p.m., during which 4.00 inches of rain fell (Table VI).³

The storm was relatively small in areal extent but extremely intense, as evidenced by rain gauge records, bucket surveys, and the amount and distribution of slope damage. At Mt. Le Conte, Mrs. Jack Huff, wife of the former operator of Mt. Le Conte Lodge, reported that hailstones the size of marbles fell during the height of the storm. The Clingmans Dome recording rain gauge, located about seven miles south-southeast of Mt. Le Conte, showed rain beginning at 3:30 p.m., with 2.78 inches having fallen by 6:45 p.m.⁴ Approximately two inches of this fell between 5:00 and 6:45 p.m. (Figure 8). In Gatlinburg, six miles northwest of Mt. Le Conte, the rain gauge measured only 0.9 inches for the 24-hour period.⁵ A bucket survey was conducted after the storm, but additional information came only from the Chimneys Campground, where refuse cans and other receptacles showed a total catch of 4.2 inches.⁶ Precipitation records and the area of most intense slope damage place the storm center over the south face

³Tennessee Valley Authority, "Storm of September 1, 1951, Precipitation," (Knoxville: Tennessee Valley Authority, 1951), p. 1.

⁴Tennessee Valley Authority, "Flood of September 1, 1951, in and Near Gatlinburg, Tennessee," Volume 1 (Knoxville: Tennessee Valley Authority, 1951), p. 6.

⁵Tennessee Valley Authority, "Storm of September 1, 1951, Precipitation," (Knoxville: Tennessee Valley Authority, 1951), p. 1.

⁶Tennessee Valley Authority, "Flood of September 1, 1951, in and Near Gatlinburg, Tennessee," Volume 1 (Knoxville: Tennessee Valley Authority, 1951), p. 7.

TABLE VI
STORM PRECIPITATION OF SEPTEMBER 1, 1951

Station	Location	Storm Duration		Amount of Precipitation (Inches)	24 Hour Total at 7:00 a.m. September 2
		From	To		
184	Clingmans Dome	3:30 p.m.	6:45 p.m.	2.78	2.87
		3:30 p.m.	8:00 p.m.	2.84	
209	Gatlinburg				0.90
210	Mt. Le Conte	5:45 p.m.	6:45 p.m.	4.00	4.14
245	Mt. Sterling	5:25 p.m.	8:00 p.m.	1.55	
407	Cataloochee Ranch	5:00 p.m.	6:10 p.m.	4.85	
542	Cherokee				0.85
660	Twentymile				1.09
656	Cataloochee	6:00 p.m.	6:50 p.m.	2.46	

Source: Tennessee Valley Authority, "Storm of September 1, 1951, Precipitation" (Knoxville: Tennessee Valley Authority, 1951), p. 1.

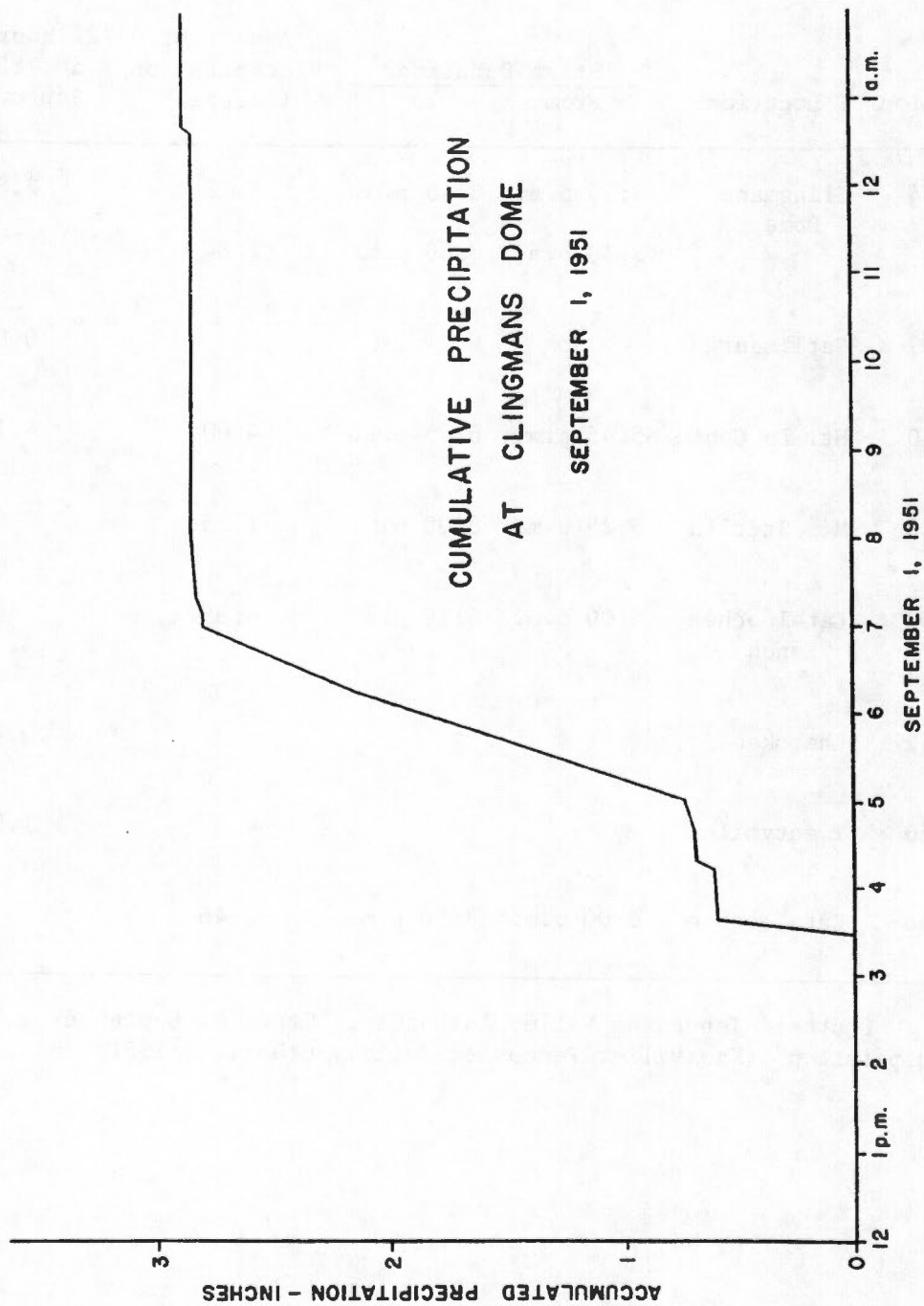


Figure 8. Cumulative precipitation at Clingmans Dome for the September 1, 1951, cloudburst.

Source: Tennessee Valley Authority, "Flood of September 1, 1951, in and near Gatlinburg, Tennessee," Volume 1 (Knoxville: Tennessee Valley Authority, 1951), Plate 4.

of Mt. Le Conte at the divide separating Alum Cave Creek and Trout Branch.

Another storm of nearly equal extent and intensity occurred at the same time in the Hemphill Creek watershed, about 22 miles east of Mt. Le Conte. Between 5:00 p.m. and 6:10 p.m. a total of 4.85 inches of precipitation was recorded at the Cataloochee Ranch rain gauge.⁷ A subsequent bucket survey indicated, however, that a maximum of 6.50 inches fell on the headwater area of Hemphill Creek. It is important to note that peak discharge rates for the small streams in the Hemphill Creek storm area were well under those calculated for Alum Cave Creek and Trout Branch. This indicates rainfall amounts for the Alum Cave Creek area may have been in excess of 6.50 inches.

Of the 11 known group occurrences of modern debris slides in the Appalachian Highlands south of the glacial border, eight have resulted from precipitation associated with extensive storm systems. The remainder were related to intense, localized storms.

The storm of September 1, 1951, was apparently not associated with any major cyclonic or frontal disturbance. Synoptic conditions at 12:30 Greenwich Mean Time show a quasi-stationary surface front trending in a northeast-southwest direction through western Tennessee (Figure 9).⁸ The synoptic weather map shows the front trending

⁷ Tennessee Valley Authority, Precipitation in Tennessee River Basin, September, 1951 (Knoxville: Tennessee Valley Authority, 1951), p. 11.

⁸ United States Weather Bureau, Daily Series Synoptic Weather Maps - Northern Hemisphere Sea Level and 500 Millibar Charts with Synoptic Data Tabulations (Washington: Government Printing Office, September, 1951), September 1, 1951.

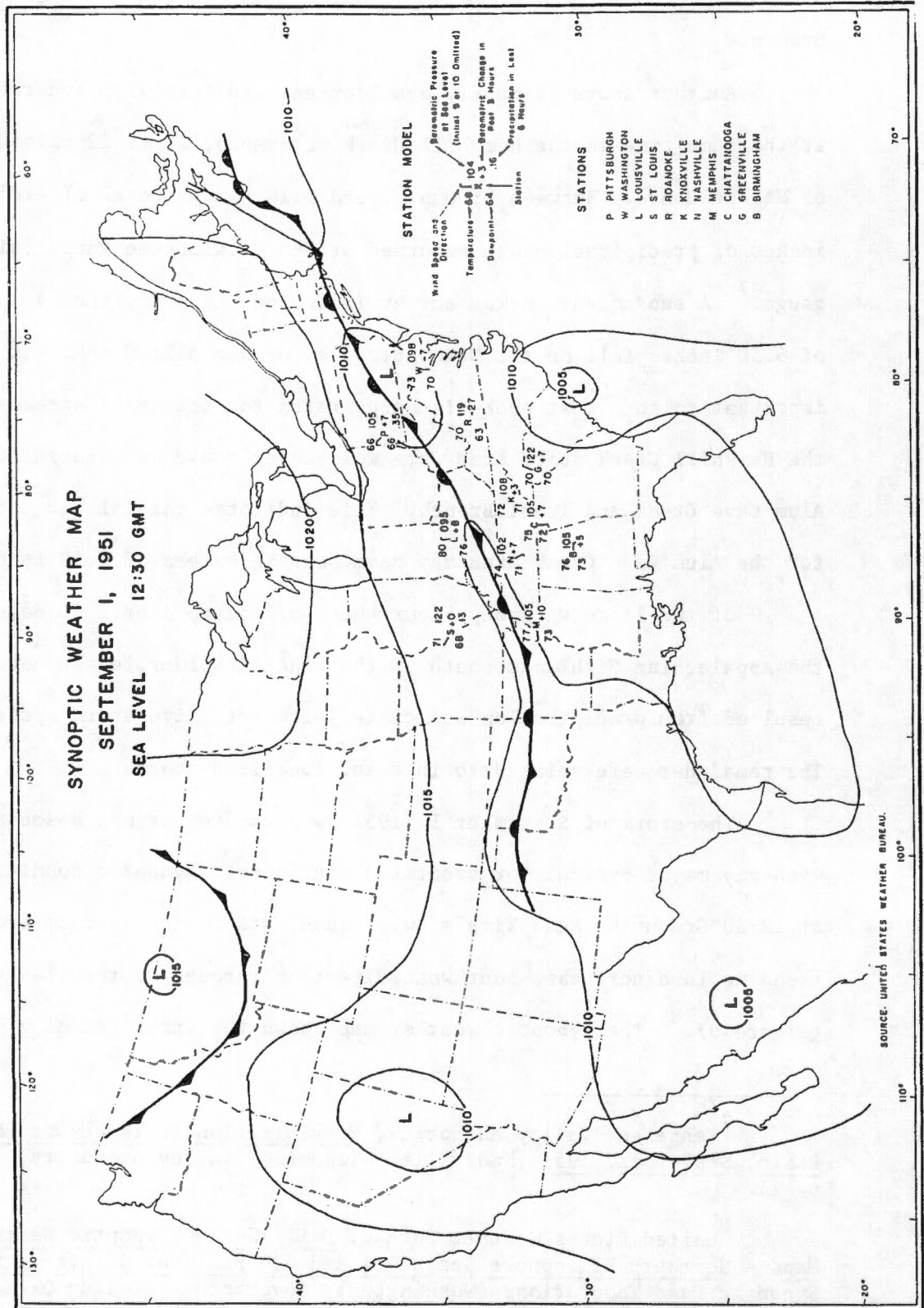


Figure 9. Synoptic map of the United States for September 1, 1951.

northeast-southwest through central Tennessee and advancing toward the southeast as a cold front at 12:30 Greenwich Mean Time on September 2, 1951. The front did not pass through the study area until late on the second or early on the third day of September, making it unlikely that frontal activity was involved in the formation of the storm. Although the distance between the front and study area on the afternoon of September 1, 1951, was approximately 100-150 miles, the storm's origin may have been associated with prefrontal thunderstorm activity.

Relatively intense rains are often spoken of as cloudbursts, but according to various meteorological organizations, a cloudburst (often termed "rain gush," "rain gust," or "gulley washer") is normally considered to have a rate of fall equal to or greater than 100 millimeters (3.94 inches) of rain per hour.⁹ By definition, the storm of September 1, 1951, qualifies as a true cloudburst.

III. THE FLOOD

Just as the storm came without warning, so did the flash flood which followed. The nearest stream gauge was located on the Little Pigeon River at Sevierville, approximately 20 miles downstream from the study area, but Tennessee Valley Authority engineers and United States Geological Survey personnel obtained estimates of the magnitude of

⁹United States Weather Bureau, Weather Glossary, Weather Bureau Report No. 1445 (Washington: Government Printing Office, 1946), pp. 75-76; Meteorological Office, Air Ministry, The Meteorological Glossary (New York: Chemical Publishing Co., Inc., 1940), pp. 45-46; and American Meteorological Society, Glossary of Meteorology (Boston: American Meteorological Society, 1959), p. 109.

flooding in the storm area by calculating peak discharge rates using the slope-area method.¹⁰

Stream channels in the headwater areas are exceptionally steep. Styx Branch drops approximately 1,500 feet per mile and Alum Cave Creek falls 1,000 feet per mile from Anakeesta Knob to where it joins West Prong Little Pigeon River. Walker Camp Prong has an average slope of 550 feet per mile. From Alum Cave Creek to Chimneys Campground, West Prong Little Pigeon River falls about 370 feet per mile. Trout Branch, another headwater stream, has a slope of 1,500 feet per mile. Stream gradients on Sugarland Mountain are considerably less steep. Road Prong drops slightly over 900 feet per mile while Rough Creek has a slope of 850 feet per mile.

The maximum measured peak discharge occurred on Alum Cave Creek with a rate of 2,980 cubic feet per second per square mile (Table VII). On a stream which usually has an average depth of one foot or less, the maximum depth during the flood was eight to ten feet.¹¹ The rate for Trout Branch could not be calculated, but measurements made on West Prong Little Pigeon River above and below where Trout Branch enters the river indicate that an even higher

¹⁰The slope-area method is used to determine peak discharges of streams on which no discharge data are available. The average slope over the reach of river in which the slope is measured is converted into an average velocity in that reach by means of a formula which expresses the relation of slope to velocity.

¹¹Tennessee Valley Authority, "Flood of September 1, 1951, in and Near Gatlinburg, Tennessee," Volume 1 (Knoxville: Tennessee Valley Authority, 1951), p. 11.

TABLE VII
PEAK DISCHARGES FOR WEST PRONG LITTLE PIGEON AREA,
SEPTEMBER 1, 1951

Location	Drainage Area Sq. Mi.	Average Discharge cfs	Estimated Peak Discharge	
			Amount cfs	Per Sq. Mile cfs
Walker Camp Prong	3.92	7.3	1,800	460
Alum Cave Creek	1.95	9.5	5,800	2,980
West Prong Little Pigeon River				
0.5 mile below Alum Cave Creek	6.39		7,000	1,090
Above Trout Branch	6.47		4,500	700
Below Trout Branch	7.60		8,500	1,120
Road Prong near mouth	3.50	16	3,400	970
West Prong Little Pigeon River				
Below Chimneys Campground	14.6		12,000	820
Above Gatlinburg	31.5	84	9,000	290
At Highway 71 below Gatlinburg	65.0		7,700	120
At Mill Dam below Gatlinburg	66.7		7,500	110
At former Pigeon Forge gauge	76.2	150	7,000	92
Little Pigeon River at Sevier- ville gauge	353	561	4,190	12

Source: Tennessee Valley Authority, "Flood of September 1, 1951 in and Near Gatlinburg, Tennessee," Volume 1 (Knoxville: Tennessee Valley Authority, 1951), p. 12.

peak occurred on Trout Branch.¹² The intense and severe slope damage in the Alum Cave Creek and Trout Branch watersheds confirm at least the relative findings of peak discharge.

Discharge rates correlate with the lower precipitation amounts recorded in the direction of Clingmans Dome. Walker Camp Prong had an estimated peak discharge of only 460 cubic feet per second per square mile and a flow depth of six to eight feet.¹³ Obtaining flood waters from both Alum Cave Creek and Walker Camp Prong, West Prong Little Pigeon River one-half mile below Alum Cave Creek had a maximum discharge of 1,090 cubic feet per second per square mile. A sharp reduction in discharge above Trout Branch on West Prong Little Pigeon River is accounted for by pooling in the somewhat wider section of the river and by the storing of water at the highway bridge. Maximum flow depth in this stretch was seven feet. Below Trout Branch, the estimated discharge once again increased, and flow was approximately 1,120 cubic feet per second per square mile. Peak depth was nine to ten feet.¹⁴ Below Chimneys Campground precipitation was light, and measurements on West Prong Little Pigeon River indicated a steady reduction in peak discharge downstream.

No mention has been made in the storm and flood reports or in other literature of the significant slope damage on the north face of Mt. Le Conte. Publications as recent as 1966 neglect to comment on

¹²Ibid., p. 12.

¹³Ibid.

¹⁴Ibid.

any damage in this area. Relative inaccessability probably prevented knowledge of this damage. Consequently, storm discharge rates for streams draining the area were never calculated.

The only estimate of peak discharge for the Sugarland Mountain area was made near the mouth of Road Prong. Accounting for most of the slope damage on Sugarland Mountain, this watershed had a peak flow calculated at 970 cubic feet per second per square mile.¹⁵

Gatlinburg residents had their first warning of the approaching flood when a loud roar was heard from the direction of Park Headquarters about 7:00 p.m. West Prong Little Pigeon River rose until the full force of the flood hit as a wave at about 7:15 p.m. The river rose 10 feet in approximately 15 minutes, and by 7:20 p.m. the crest had passed (Figure 10).¹⁶ Buildings were clear of flood waters by 8:00 p.m.

The overflow in Gatlinburg reached a maximum depth of about five feet and a width of nearly 600 feet (Figure 11). The maximum overflow width occurred in the vicinity of Baskins Creek. As the flood crest moved downstream toward Pigeon Forge, however, it flattened sufficiently so that, although the river went out of its banks in several localities, no damage resulted. Sevierville was not affected. Flood damage resulting from the September 1, 1951, cloudburst in Great

¹⁵Ibid.

¹⁶Tennessee Valley Authority, Floods on West Fork Little Pigeon River - Gatlinburg, Tennessee (Knoxville: Tennessee Valley Authority, 1966), p. 41.

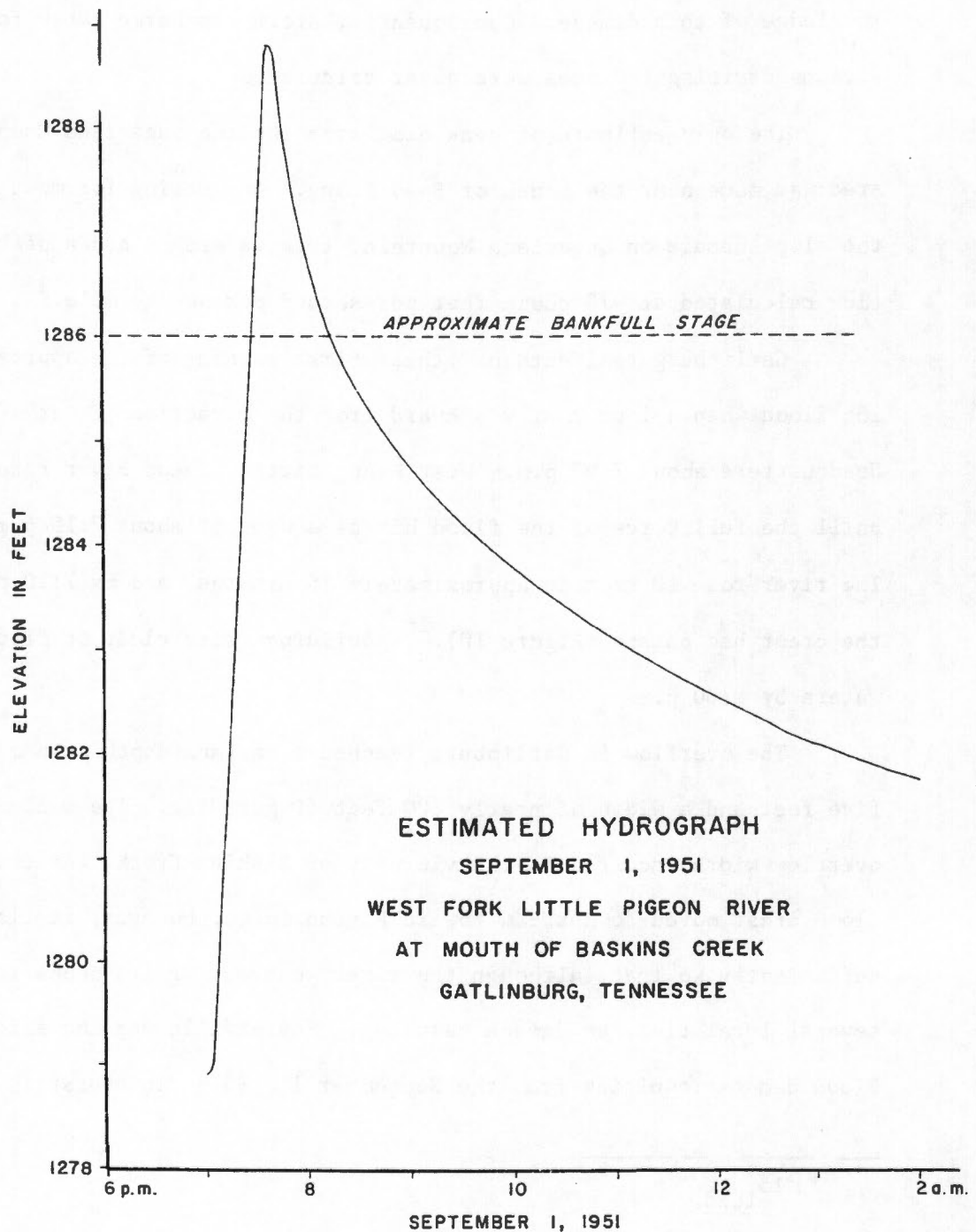


Figure 10. Estimated hydrograph for West Prong Little Pigeon River at mouth of Baskins Creek on September 1, 1951.

Source: Tennessee Valley Authority, Floods on West Fork Little Pigeon River - Gatlinburg, Tennessee (Knoxville: Tennessee Valley Authority, 1966), Plate 2.

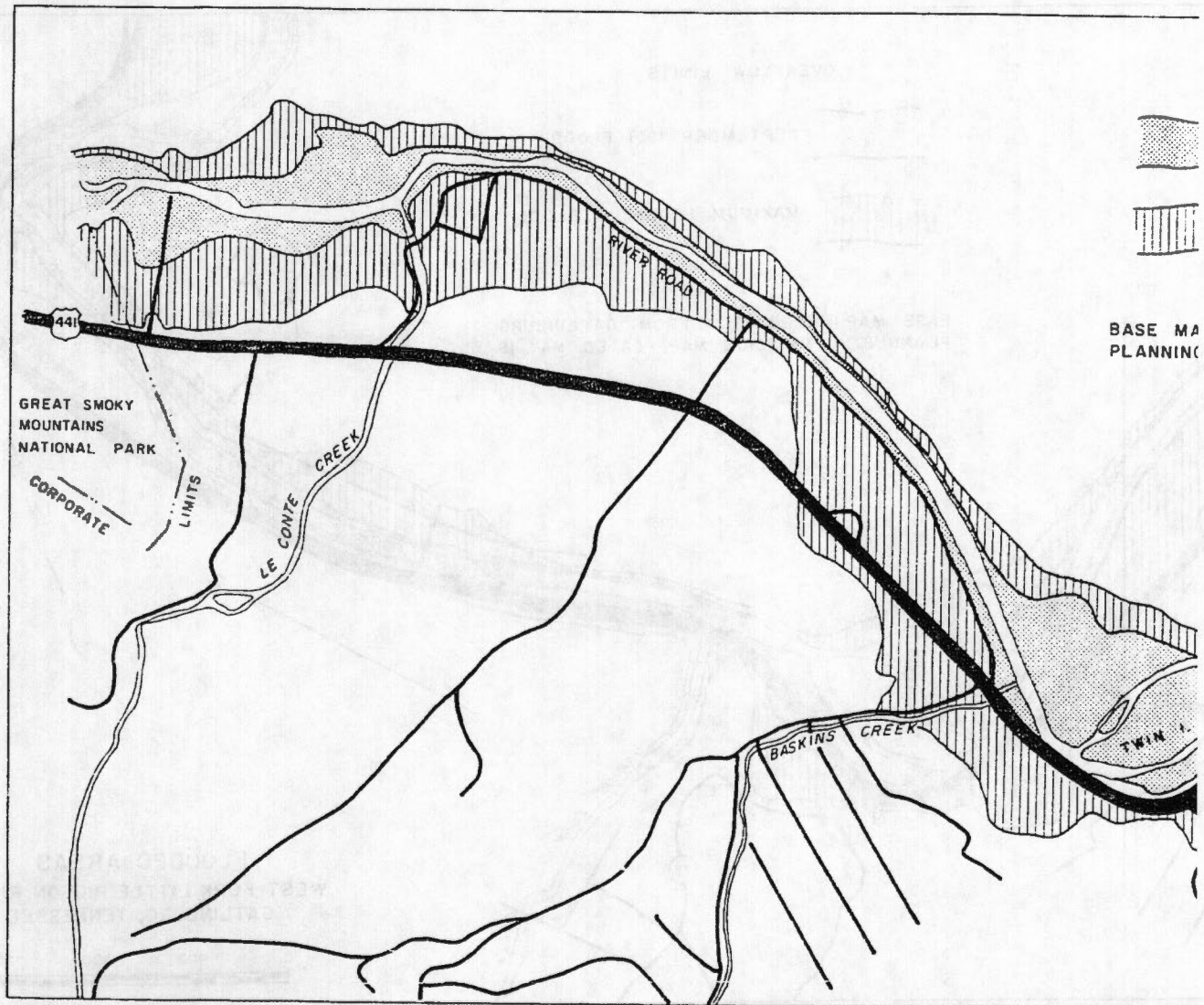
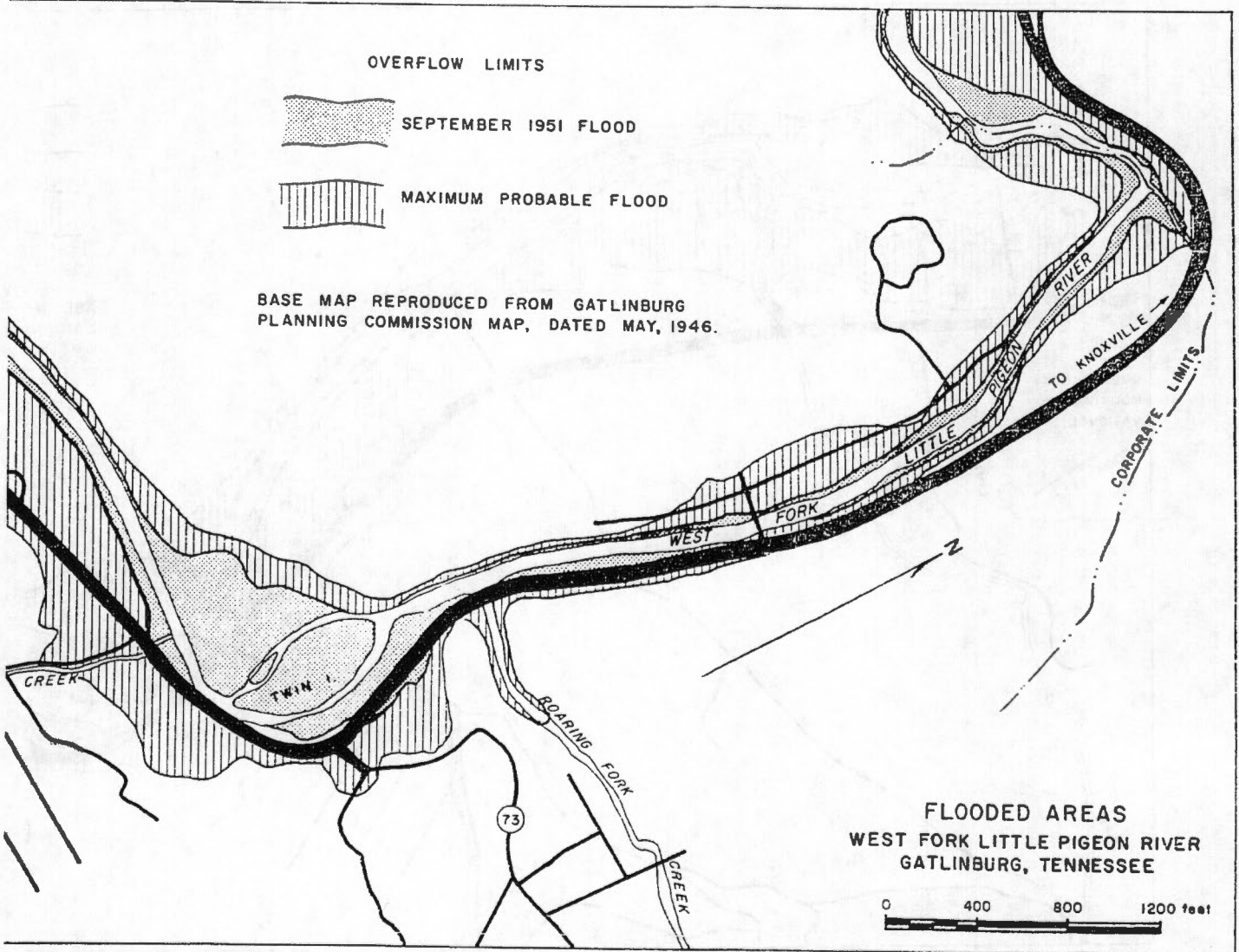


Figure 11. Flooded areas along West Prong Little Pigeon River, Gatlinburg, Tennessee.

Source: Tennessee Valley Authority, Floods on West Fork Little Pigeon River Tennessee (Knoxville: Tennessee Valley Authority, 1966), Plate 4.



igeon River, Gatlinburg, Tennessee.

Fork Little Pigeon River - Gatlinburg,
Plate 4.

Smoky Mountains National Park and Gatlinburg was estimated at \$252,000 (Table VIII). Approximately \$169,000, or 67 percent of the losses, occurred in the National Park, while \$52,000, or 21 percent of the damage, was in Gatlinburg. Tourists, trucking concerns, and the Smoky Mountain Trailways Bus Company lost about \$31,000, or 12 percent of the total.¹⁷ Although no lives were lost, a number of persons were briefly endangered by rising flood waters of West Prong Little Pigeon River and Little River.

IV. DAMAGE IN SLIDE AREAS

The numerous debris slide scars on the slopes of Mt. Le Conte and Sugarland Mountain are the most spectacular remains of the September 1, 1951, cloudburst. There are more than 100 individual slide head scars in the study area, 41 of them in the Alum Cave Creek watershed, site of detailed field study (Plate 2).

Alum Cave Creek Watershed

Alum Cave Creek watershed, on the south slope of Mt. Le Conte, is drained by Styx Branch and Alum Cave Creek. The drainage basin covers about 1.95 square miles; elevations range from approximately 3800 to 6593 feet.

Extent of slide damage. Debris slides in the Alum Cave Creek area are confined primarily to the western side of the watershed. Of

¹⁷ Tennessee Valley Authority, "Flood of September 1, 1951, in and Near Gatlinburg, Tennessee," Volume 1 (Knoxville: Tennessee Valley Authority, 1951), pp. 14-22.

TABLE VIII

DAMAGE SUMMARY FOR SEPTEMBER 1, 1951, FLOOD

Individual, Group, or Organization Claiming Loss	Direct	Indirect	Direct	Indirect
<u>Commercial</u>				
Graystone Hotel	\$ 5,000			
Twin Islands Court	7,100	\$3,000		
Waterlure Motel	500	100		
Lays Motor Court	3,600	1,000		
Pigeon River Cabins	300	500		
Park Tourist Court	1,500	200		
Riverview Cabins	600	100		
Smoky Heights Resort	100	100		
Clearwater Cabins	800	200		
Pioneer Trading Post	3,000	1,400		
Jays Photo Shop	100	500		
The Barkers Candy Shop	1,100	1,000		
Hackcraft Gift Shop	400	500		
Tsali Shop	2,000			
Thurman's Garage	200	200		
Robertson's Riding Stable	<u>100</u>	<u>100</u>		
Totals			\$ 26,400	\$8,900
<u>Urban Residential</u>				
6 homes and yards	1,400			
1 automobile	<u>1,500</u>			
Totals			2,900	-
<u>Municipal</u>				
1 bridge	3,000			
Cleanup	<u>1,000</u>			
Totals			4,000	-

TABLE VIII (continued)

Individual, Group, or Organization Claiming Loss	Direct	Indirect	Direct	Indirect
<u>Transportation</u>				
Smoky Mountain Trailways		1,000		
Added cost to through travellers and truckers	<u>30,000</u>			
Totals			30,000	1,000
<u>Great Smoky Mountains Park</u>				
Highway No. 441				
Temporary repair	10,500			
Permanent repair	132,000			
Other roads, trails, bridges	17,800			
Park facilities	<u>8,000</u>			
Totals			<u>168,600</u>	<u>-</u>
Totals			<u>231,900</u>	<u>9,900</u>
Totals direct and indirect			241,800	
Estimated intangible damage			<u>10,200</u>	
Grand Total			\$252,000	

Source: Tennessee Valley Authority, "Flood of September 1, 1951, in and Near Gatlinburg, Tennessee," Volume 1 (Knoxville: Tennessee Valley Authority, 1951), p. 22.

27 slide tracks located in the research area, 20 are on the southeast-facing slope of the spur separating the Trout Branch and Alum Cave Creek watersheds (Figure 12). Two slides occur on the west-facing slope just north of Arch Rock; five others are on southeast facing slopes in the Alum Cave Creek headwater area. Slide head elevations range from about 4200 feet (Slide ACC-3) to 6300 feet (Slide SB-10).

Slide dimensions - regolith volumes involved. Debris slide scars in the Alum Cave Creek watershed have various shapes and sizes, and 19 years after their formation most are still easily identified (Figure 13). Although slides share many common characteristics, each possesses unique physical traits. Some characteristic slide features are illustrated in Slides ACC-3, ACC-4, SB-2, SB-3, SB-6, and SB-10 (Plate 3).

Slide SB-10 in the Alum Cave Creek watershed is the largest slide in the study area (Figure 14). Map area of the slide scar head is approximately 88,675 square feet, and the slope area is about 112,532 square feet. Average slope for the scar head is 38° (Plate 4).

Because most material removed from the slide area was carried away by Styx Branch flood waters, the volume of regolith involved in sliding was estimated on the basis of soil depths in the non-slide area adjacent to the slide track. Depths ranged from 0 to 26 inches, with an estimated mean of 13 inches. Approximately 121,534 cubic feet of regolith is thought to have been removed from the scar head. Although not calculable, additional material was removed from the lower portions of the slide track. It was not possible to estimate the amount of bedrock removed.

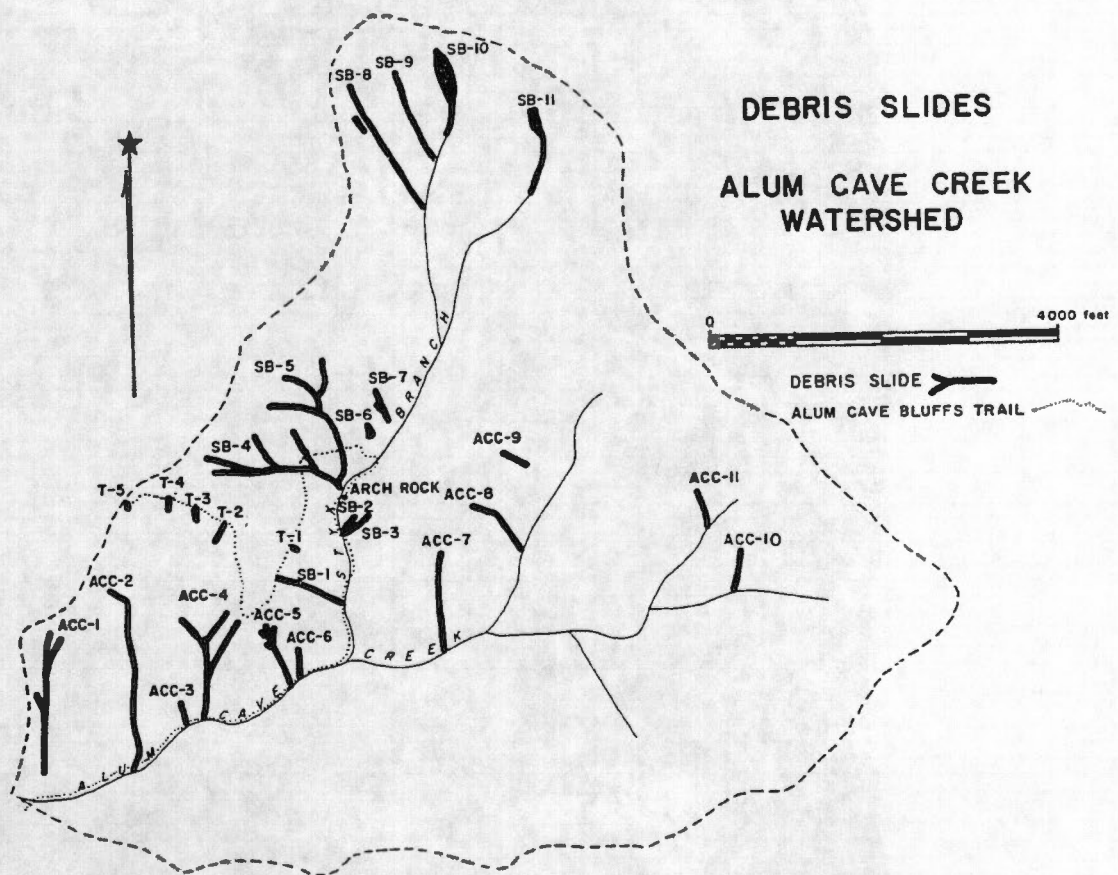


Figure 12. Debris slides in Alum Cave Creek Watershed.



Figure 13. Debris slides on the south slope of Mt. Le Conte.

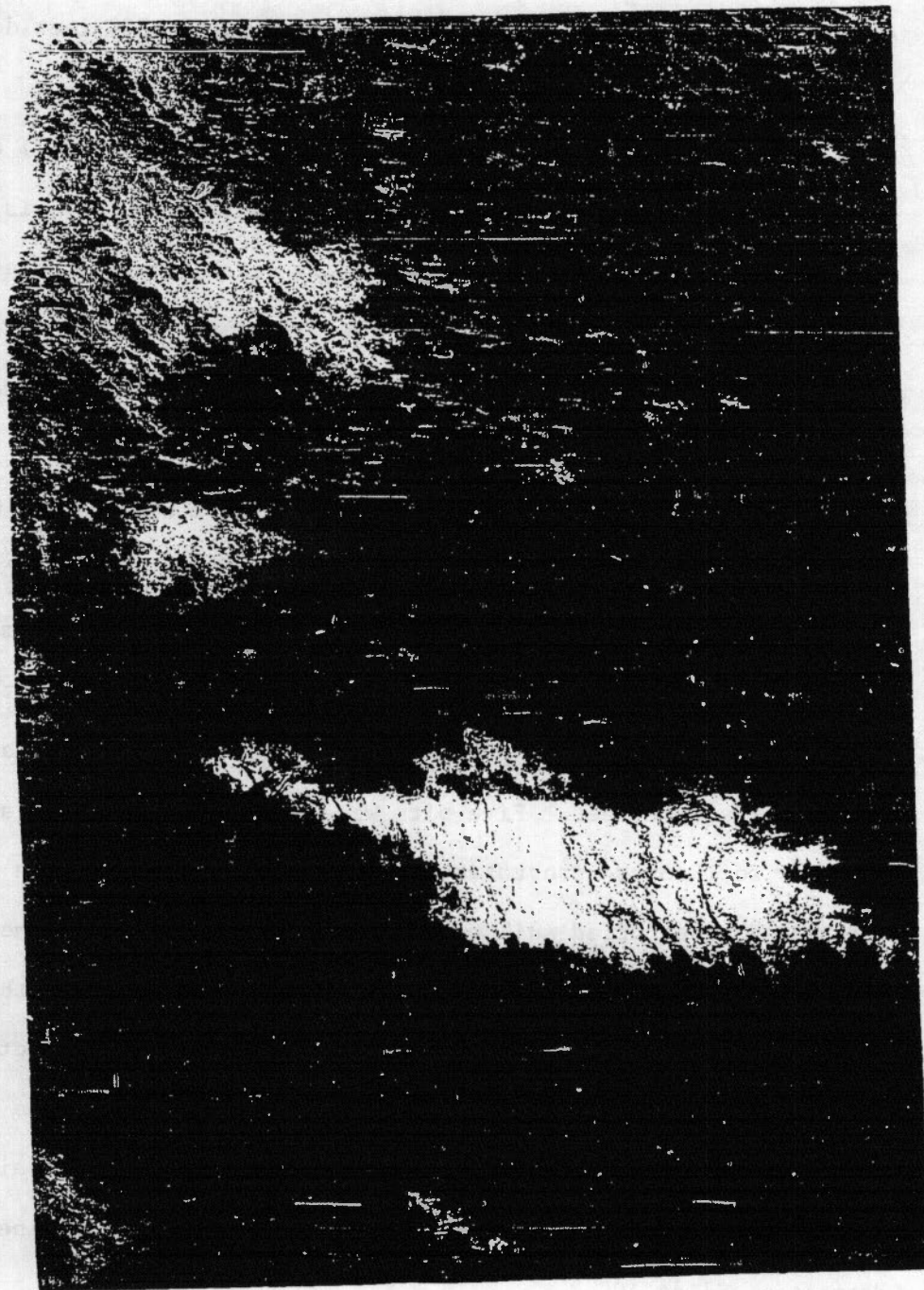


Figure 14. Aerial view of Slide SB-10.

The lower part of the SB-10 slide track is within a major valley axis, but the scar head is on a side slope with the valley axis situated to the east. The head lies approximately 300 feet downslope from the ridge crest.

Several small slippages (T-1, T-2, T-3, T-4, and T-5) are situated along the Alum Cave Bluffs Trail, but Slide ACC-3 is the smallest slide which occurs independently of the trail in the Alum Cave Creek watershed. The area of the slide head scar is estimated to be 1,235 square feet, with slope area estimated at 1,662 square feet. Average slope for the scar head is 42° .

Unlike Slide SB-10, material removed from Slide ACC-3 was not carried away by flood waters. Instead, the debris has been preserved as a small mound at the base of the slide (Figure 15). Volumetric measurements were made of the deposit and compared to estimates of regolith removed in sliding. The deposit covers an area of approximately 941 square feet. Five pits were dug in the deposit, and numerous soil cores were taken to learn if a contact between the deposit and the buried soil profile could be located. Volumetric computations could be more precisely determined if deposit thicknesses were based upon the location of the contact line. No contact could be found, however, and measurements of deposit volume were made by determining its size and relief above the adjacent flood plain. It is estimated that 1,122 cubic feet of slide material is contained in the deposit of Slide ACC-3.

Soil depths surrounding the slide track average approximately 16 inches. Estimated removal of regolith from the slide head scar is



Figure 15. Deposit and lower track of Slide ACC-3.

White ink dashes outline slide deposit.

2,160 cubic feet while about 538 cubic feet of additional material was removed from the entire slide track.

Several factors account for the discrepancy between the estimated amount of material removed from the slide track and the estimated volume of debris contained in the deposit. First, the deposit probably does not represent all the material involved in sliding. Some was presumably thrown out into the forest surrounding the slide track. Second, because water was associated with its transport, some material could have been washed away from the deposit area. Finally, soil depths adjacent to the slide track give only indirect estimates of the soil depths before movement in the slide area.

Slide ACC-4 is typical of slides with multiple scar heads. Unlike most slides with more than one scar head, however, none of the slide tracks originates in the main valley axis. All occur in small hollows or water collection areas on side slopes.

"Water blowouts" are features common to several debris slide areas in the Appalachian Highlands south of the glacial border. Hack and Goodlett described these as:

. . .semicircular in plan. The upslope side is a crescent-shaped scarp generally exposing the bedrock at its base. The downslope side is a pile of debris that has slumped or been thrown out of the cut or break.¹⁸

Slide SB-4 has size and shape characteristics which resemble a water blowout. The average slope of the slide head is 41°; in the

¹⁸ John T. Hack and John C. Goodlett, Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians, Geological Survey Professional Paper 347 (Washington: Government Printing Office, 1960), p. 45.

area of sliding, slide length is not much greater than slide width. Its shape is unlike that of other slides in the study area, for the usual long, linear slide track is not present.

Slides SB-2 and SB-3 are the only slides which occur on west facing slopes in the Alum Cave Creek watershed. Average slope at the slide head is 41° and 40° , respectively. Other than their small size and slope exposure, Slides SB-2 and SB-3 share gross characteristics of all slides in the watershed.

General slide characteristics. Although variations and modifications exist, most slides in the Alum Cave Creek watershed share common erosional and depositional characteristics. Three sections are generally distinguishable within each slide track: (1) the scar head, (2) the middle zone, and (3) the area of deposition. Flaccus divided White Mountain slide tracks into a slide section, gully section, and stream scour section; but this subdivision is not entirely applicable to the Mt. Le Conte-Sugarland Mountain area.¹⁹

Scar heads, in which the main mechanism of movement was probably sliding, are usually broad, relatively shallow features, devoid of pre-slide vegetation. Although a veneer of colluvial material may cover relatively large areas, exposed bedrock predominates. Original surficial material and vegetation completely surrounded by slide areas were found only in the scar head of slide SB-3.

¹⁹Edward Flaccus, "Landslides and Their Revegetation in the White Mountains of New Hampshire" (unpublished Doctoral dissertation, Duke University, Durham, North Carolian, 1960), p. 36.

Slide head scars generally occupy the steepest segments of the longitudinal profile. Most slides originate on slopes greater than 38° . Where slides have multiple scar heads, scars located in the main valley axis usually have slopes less steep than those forming on side slopes.

Shapes of debris slide heads vary considerably, but most taper at the top and the bottom and are widest in the middle. Although removal of material by sliding is the dominant process, some deposition occurs outside the scar head area, especially near the base of the scar head where it narrows. Some regolith and vegetational debris may be spewed into the surrounding forest, and debris piles or dams can often be seen behind trees or large rocks (Figure 16). Trees at the edge of the slide are frequently scarred from being hit by sliding material. Most such scars in the head area are generally no more than two or three feet above ground level.

The amount of bedrock contained in the various sliding masses could not be determined. The initial slide plane was probably located at the regolith-bedrock contact, and although large volumes of bedrock were probably not incorporated in the sliding debris, some may have been removed.

The middle zone is an area of transition, showing both erosion and deposition, and is almost always located in some form of valley axis. The change-over point from scar head to middle zone is generally clear when the scar head forms on side slopes. When the scar head forms in a valley axis, however, the change is transitional. Slope angles in the middle zone are less steep than in the head area,



Figure 16. Debris dam on upslope side of tree on Slide ACC-4.

Camera case is used for scale.

and flowage is considered to have been the chief mode of transport. The slide tracks in the middle zone are usually much narrower and considerably deeper than at the scar head. As most middle zones are located in valleys, width-depth characteristics are determined primarily by pre-existing valley dimensions and not by slide action.

Alluvial and colluvial material cover much of the slide track in the middle zone. Alluvium, often with blocks several feet across showing marked imbrication, generally occupies the valley bottoms, while colluvium mantles adjacent valley sides. Bedrock is usually exposed only in small patches.

Because the amount and distribution of surficial material in valleys prior to sliding is not known, it is impossible to quantify slide erosion and deposition. Removal of material, however, most commonly occurred in areas of locally steep slopes while deposition was confined ordinarily to areas of more gentle slopes (Plates 3 and 4). Most underbrush and some large trees were removed in the middle zone, but the tracks were not completely bared of vegetation as in the scar head.

Debris dams are common behind trees at the edge of the slide and in back of immovable objects, such as trees or rocks, in the track itself. Scarred trees are most numerous along upper portions of the middle zone and generally become less abundant farther downslope. Most scars on trees are two or three feet above the ground, but some have been observed as high as 15 feet above ground level. Numerous small log jams formed at constricted areas, breaks in slope, or on the outside banks of curves in the slide track.

The areas of deposition are located at significant breaks in slope, generally at the valley floor. In the Alum Cave Creek watershed they occur most commonly where the slide track meets the relatively flat, narrow bottom occupied by Alum Cave Creek or Styx Branch. Several slides have no preserved area of deposition.

The debris fans are generally triangular in shape, with one apex pointing up the slide track and the opposite side paralleling the main stream. Size is usually a function of slide magnitude, valley bottom width, and nearness to flood waters. Larger slides remove more regolith, but the size of the deposit may be more closely related to the width of the flood-plain. Considering regolith volumes equal, the greater the distance to flood waters along relatively level ground, the larger the resultant debris fan. In the Alum Cave Creek watershed all slides except SB-8, SB-9, and SB-10 have some form of recognizable deposit. Most, however, have had much of their material removed by flood waters.

Debris fans are ideal sites for log jam formation. The largest jam is located at the base of Slides SB-4 and SB-5, just north of Arch Rock along the right bank of Styx Branch. Over 100 logs, some more than three feet in diameter, were plotted on the sketch map, and many more are probably buried beneath the debris. Logs were often piled more than ten feet high. Most slides have at least small log jams near their bases, but many were altered by National Park Service workers when the Alum Cave Bluffs Trail was rebuilt after the 1951 storm.

Post-slide recovery. Since the formation of debris slides in the Alum Cave Creek watershed in 1951, two principal opposing processes have acted upon the slide tracks. Mass movement, as well as other agents of weathering and erosion, continues to operate long after the slide has occurred. Rock fall, block glide, sheet wash, gullying, and eolian movement have all been observed on various slide scars in the Alum Cave Creek watershed. Preliminary data from mass movement lines placed across selected slide tracks indicate that erosion is proceeding at an accelerated rate in the absence of vegetation.

Revegetation, occurring to some extent on all slide tracks, tends to stabilize surficial material and reduces erosion. Because of the almost infinite variety and intensity of ecological factors, the revegetation process is exceedingly complex. Moisture conditions, surficial material, soil nutrients, slope, elevation, exposure, and seed availability vary considerably.

The process of revegetation is generally most advanced in the area of deposition. Fire or pin cherry, sweet birch, yellow birch, red spruce, dog-hobble, and thornless blackberry are the predominant regrowth species in the deposition area.

Revegetation varies considerably in middle slide track zones, which are largely transitional in type and magnitude of vegetation cover. Species found in the lower portions of the middle slide tracks are generally the same found in the depositional areas, while those in the upper reaches of middle tracks are predominantly the same as those characteristic of the slide head scars.

Revegetation is usually relatively sparse in slide head scars. Crandell described various successional stages on precipitous rocky slopes below Myrtle Point and Cliff Top on Mt. Le Conte, but it is not clear whether her sample areas were slide scars or other bedrock outcrops.²⁰

According to Crandell, mosses and liverworts are the first plants to grow on bare rock surfaces in this area. Sand-myrtle appears soon after. Following sand-myrtle, or sometimes simultaneous with it, minnie-bush, Catawba rhododendron, or rosebay rhododendron may grow. If sufficient soil and support is available, red spruce or Fraser fir may germinate and grow in the center of this group of shrubs.²¹

Other surficial slope damage. Several valley areas, particularly on west-facing and north-facing slopes in the Alum Cave Creek watershed, show evidence of heavy wash and surficial slope damage. In several locations minor slippages of the surficial mantle have occurred and underbrush is absent. Small piles of forest litter and soil are dammed behind some large trees in these areas. No direct evidence, however, is available to confirm that the 1951 storm was responsible for this superficial damage.

Flood damage to valley bottoms. Evidence of severe flooding exists along Alum Cave Creek, Styx Branch, and Road Prong. Alterations

²⁰Dorothy L. Crandell, "Ground Vegetation Patterns of the Spruce-fir Area of the Great Smoky Mountains National Park," Ecological Monographs, XXVIII (October, 1958), 357.

²¹Ibid.

in channel width and location and abrupt vegetational changes are obvious effects of the flood.

Heavy discharges produced enlargements of stream channels. In many areas entire valley bottoms were damaged and the forest cover removed. Numerous stream bank failures occurred, especially on outsides of channel bends. Mass movement is still active in some of these areas.

Vegetation in valley bottom areas affected by the 1951 flood differs markedly from the generally undamaged northern hardwood forest adjacent to the flood areas. The damaged area is characterized by a growth of young trees, mostly fire cherry, sweet birch, and yellow birch, which give tree ring ages of 18 years or younger.

Mt. Le Conte-Sugarland Mountain Area

The investigation of slope and flood damage throughout the Mt. Le Conte-Sugarland Mountain area was based upon a comparison of field research data and airborne imagery. When the damage features in the Alum Cave Creek watershed had been recognized and studied on the imagery, slide scars in the entire study area were located and mapped from the imagery. Examination of recent photographic and thermal imagery, as well as older aerial photographs and field investigation, indicates a considerable amount of slope damage and related flood damage as a result of the 1951 storm (Plate 2).

Interpretation and Evaluation of Airborne Imagery

Three missions were made over the Mt. Le Conte-Sugarland Mountain area in the University of Tennessee DC-3 research aircraft to obtain

imagery of slope and related flood damage. On the first two flights the University of Tennessee Hasselblad 500EL quadricamera system, utilizing four different emulsion/filter combinations, was used to obtain simultaneous coverage of the entire study area (Table IX). These emulsions were selected because recent reports indicate great potential for their use in terrain, soil, and vegetation analysis.²²

The third mission consisted of three individual flights, and some modifications and additions were made to the sensing media. Thermal imagery was obtained on pre-dawn, mid-day, and post-sunset flights with a Daedalus thermal infrared line scanner equipped with roll compensation. By utilizing two detectors, data were received in the 1.0 to 5.5 micron and 8.0 to 14.0 micron bands. Photographic sensors were not employed on the pre-dawn or post-sunset flights. On the mid-day flight Ektachrome Infrared Aero and Ektachrome Aerographic film were used in Hasselblad Super Wide cameras (Table X). Plus X Aerecon and Infrared Aero emulsions were omitted. The thermal and photographic sensors were used primarily over the Alum Cave Creek, Trout Branch, and Road Prong watersheds.

Older aerial photographs covering all or portions of the Mt. Le Conte-Sugarland Mountain area were procured from the Agricultural Stabilization and Conservation Service, National Archives and

²² A. Anson, "The Use of Color Aerial Photography in the Reconnaissance of Soils and Rocks," Materials Research and Standards, VIII (February, 1968), 8-16; Arthur D. Kuhl, "Color and IR for Soils," Photogrammetric Engineering, XXXVI (May, 1970), 475-482; and Kenneth G. Northrop and Evert W. Johnson, "Forest Cover Type Identification," Photogrammetric Engineering, XXXVI (May, 1970), 483-490.

TABLE IX

EMULSION/FILTER COMBINATIONS USED ON THE APRIL 30, 1969,
AND NOVEMBER 6, 1969, REMOTE SENSING MISSIONS

April 30, 1969 - Spring coverage

November 6, 1969 - Fall coverage

Hasselblad 500EL quadricamera system - 80 millimeter lenses

Kodak Plus-X Aerecon Film Type 8401 - Hasselblad Haze Filter

Kodak Infrared Aerographic Film Type 5424 - Wratten 25 (red)
Filter

Kodak Ektachrome MS Aerographic Film Type 2448 (Estar base) -
Hasselblad Haze Filter

Kodak Ektachrome Infrared Aero Film Type 8443 - Wratten 15
(orange) Filter

TABLE X

EMULSION/FILTER COMBINATIONS AND SCANNER FACILITIES USED ON
THE APRIL 3, 1970, REMOTE SENSING MISSION

April 3, 1970 - Winter coverage

Two Hasselblad Super Wide C's - 38 millimeter lenses 90°
diagonal angle of view

Kodak Ektachrome MS Aerographic Film Type 2448 (Estar base) -
Hasselblad Haze Filter

Kodak Ektachrome Infrared Aero Film Type 8443 - Wratten 15
(orange) Filter

Daedalus Thermal Infrared Line Scanner System -

3600 RPM - 120 line scan per minute

Roll compensation - 120° field of view

Thermal resolution 1/4° Centigrade

In flight magnetic tape recorder (Two AM and two FM Channels)

1-5.5 micron band

8-14 micron band

Records Service, Soil Conservation Service, Tennessee Valley Authority, and United States Geological Survey (Table XI).

Although slope damage exists in a number of watersheds, Alum Cave Creek, Trout Branch, and Road Prong drainage basins contain approximately 71 percent of the individual slide scar heads. Damage appears to be concentrated in a swath about 1.2 miles wide extending from the summit of Mt. Le Conte southwest to the crest of Sugarland Mountain (Plate 3). Available precipitation and stream discharge data indicate this to have been the area of most intense rainfall.

Among the few debris slide scars found outside the area of greatest slope damage, several are located on the south slope of Sugarland Mountain and some are situated on the northeast slope of Mt. Le Conte. These occurrences are aligned with the northeast-southwest trending swath of debris slides already noted. Only isolated slide scars developed northwest or southeast of this area.

Preliminary analysis of the Mt. Le Conte-Sugarland Mountain imagery indicates some significant differences in slide detection capabilities of the various kinds of imagery. The first two flights, which utilized color (Ektachrome MS Aerographic), false color (Ektachrome Infrared Aero), panchromatic black-and-white (Plus-X Aerecon), and black-and-white infrared (Infrared Aerographic), revealed that both color emulsions were more useful than the black-and-white emulsions. Imagery from the April 30, 1969 mission shows that slide scars, flood damage, and vegetation patterns are more readily identifiable on the color emulsions (Figure 17). Although Ektachrome MS Aerographic appears to be the best emulsion for depicting slide head

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Kodak Ektachrome Infrared Aero Film Type 8443 - Wratten 15
(orange) Filter

Daedalus Thermal Infrared Line Scanner System -

3600 RPM - 120 line scan per minute

Roll compensation - 120° field of view

Thermal resolution 1/4° Centigrade

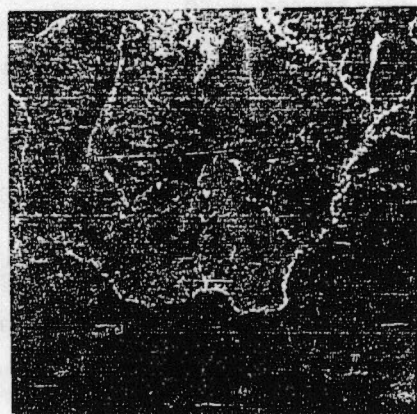
In flight magnetic tape recorder (Two AM and two FM Channels)

1-5.5 micron band

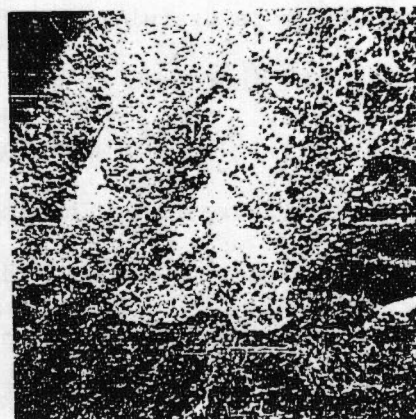
8-14 micron band

TABLE XI
AERIAL PHOTOGRAPHS AVAILABLE FOR ALL OR PORTIONS
OF THE MT. LE CONTE-SUGARLAND
MOUNTAIN AREA

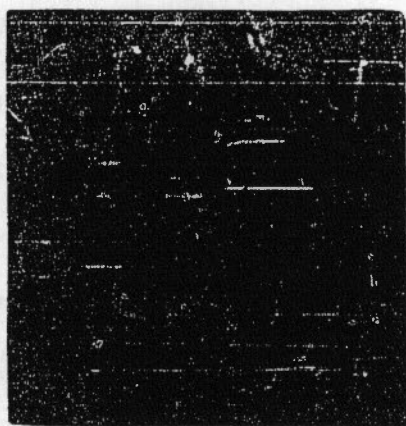
Dates	Scale	Film-holding Agency
1960	1:20,000	Agricultural Stabilization and Conservation Service, Department of Agriculture, 45 South French Broad Avenue, Asheville, North Carolina 28801.
1967	1:20,000	
1938	1:20,000	National Archives and Records Service Cartographic Branch, GSA 8th and Penn. Avenue, N. W., Washington, D.C. 20408.
1954	1:20,000	Soil Conservation Service, USDA Cartographic Unit, Federal Service Building, East-West Highway and Belcrest Road, Hyattsville, Maryland 20781.
1956	1:60,000	United States Geological Survey Washington, D. C. 20242.
1963	1:28,000	
Various	Various	Tennessee Valley Authority Maps and Surveys Branch Chattanooga, Tennessee 37401.



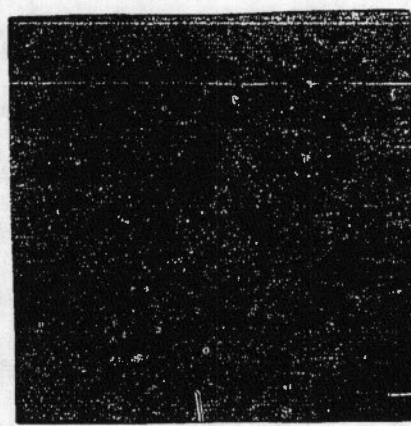
Ektachrome MS Aerographic



Ektachrome Infrared Acro



Plus-X Aerecon



Infrared Aerographic

Figure 17. Photographic Imagery of lower portion of Alum Cave Creek Watershed, April 30, 1969, Mission.

scars, slide tracks are usually more distinct on the Ektachrome Infrared Aero because contacts between pre- and post-slide vegetation are better defined. Among the black-and-white emulsions, Plus-X Aerecon provided more useful results than Infrared Aero.

The increased flight height and adoption of superwide cameras on the April 3, 1970 mission substantially reduced the scale of the imagery (Figure 18). The smaller debris slides, such as ACC-3 and ACC-6, were difficult to locate and probably would have been overlooked if their positions had not been already known. Again, slide head scars were more distinct on the Ektachrome MS Aerographic emulsion, whereas the Ektachrome Infrared Aero film permitted more precise delimitation of the lower portions of the slide tracks from vegetation patterns.

The main advantage of this combination of increased flight height and 38 millimeter superwide lens with a 90° diagonal angle of view is that suitable imagery may still be obtained even if considerable error is made in navigation. Flight lines are difficult to follow in highly mountainous regions with few landmarks. Gaps in the photographic coverage were common in the April 30, 1969, and November 6, 1969, flights when 80 millimeter lenses were used at an altitude of only 10,000 feet.

Thermal imagery was obtained on pre-dawn, mid-day, and post-sunset flights, but the results were disappointing. Scale, navigation, scanner, and processing difficulties combined to render most of the imagery unusable. Only one flight line of the 8-14 micron band pre-dawn imagery can be meaningfully analyzed (Figure 19). Identifying slide areas on the imagery is difficult, however, because of numerous bedrock outcrops along ridge crests and on steep valley sides. This



Ektachrome MS Aerographic



Ektachrome Infrared Aero

Figure 18. Photographic Imagery of Mt. Le Conte, April 3, 1970, Mission.



Figure 19. Pre-dawn 8-14 Micron Band Thermal Imagery of Trout Branch-Alum Cave Creek Watersheds, April 3, 1970, Mission.

thermal imagery, at least for the Mt. Le Conte-Sugarland Mountain area, appears to be of little importance as a basic tool for debris slide study.

A recent study on sensor detection capabilities by Wilson ranked various imaging and nonimaging sensor devices in identifying 98 earth resources targets. Although landslides were not included as a specific category, sensors were appraised for storm effects, including visible damage, soil moisture, and stream analysis (Table XII).²³ Black-and-white photography was considered the most effective sensor for the "storm effects" category.

In contrast to Wilson's conclusions, analysis of the imagery used in the Mt. Le Conte-Sugarland Mountain area indicates that color infrared photography is best for use in identifying slope damage, while thermal imagery is the least effective (Table XIII). Preliminary data indicate that months when vegetation is not in leaf are the best time to obtain aerial photographs of slope damage.

²³ John E. Wilson, Sensor Detection Capabilities Study, Geological Survey Circular 616 (Washington: Government Printing Office, 1969), p. 24.

TABLE XII

RANKING OF VARIOUS IMAGING AND NONIMAGING SENSORS FOR TARGET
IDENTIFICATION OF STORM EFFECTS (VISIBLE DAMAGE,
SOIL MOISTURE, STREAM ANALYSIS)

Sensor *	Daylight		Night
	Low	High	
Black and white photography	1	1	
Color photography	3	4	
Infrared color photography	2	2	
Black and white infrared photography	4	3	
2- to 4-micron thermal infrared photography	7		2
8- to 14-micron thermal infrared photography	6		1
Side-looking radar (SLAR) imagery			
Electro-optical (television) imagery	8		3
Imaging microwave imagery	5	5	
Nonimaging scatterometer	9		

Source: John E. Wilson, Sensor Detection Capabilities Study, Geological Survey Circular 616 (Washington: Government Printing Office, 1969), p. 24.

* The numerical ranking of sensors is in decreasing order of effectiveness, but even the highest rank (1) does not imply precision and optimum quality.

TABLE XIII
RANKING OF VARIOUS IMAGERY USED FOR MT. LE CONTE--SUGARLAND
MOUNTAIN SLOPE DAMAGE IDENTIFICATION

Sensor*	Slope Damage Feature			
	Slide Head Scar	Middle Zone of Slide Track	Deposit Area	Flood Damage to Valley Bottoms
Black and white photography	3	3	3	3
Color photography	1	2	2	2
Infrared color photography	2	1	1	1
Black and white infrared photography	4	4	4	4
Thermal Imagery	5	5	5	5

*The numerical ranking of sensors is in decreasing order of effectiveness, but even the highest ranking (1) does not imply precision and optimum quality.

CHAPTER V

PLAUSIBLE SLIDE LOCALIZING FACTORS

I. INTRODUCTION

Debris slides are rapid mass movement phenomena that occur on relatively steep slopes. A complex interaction of meteorological, climatological, slope, hydrological, geological pedological, vegetational, and cultural factors contribute to slope instability. Intense or prolonged precipitation and steep slopes appear to be the primary causes of debris slide activity, but other factors must not be overlooked. According to Varnes a slide can seldom be attributed to a single definite cause.¹

II. METEOROLOGICAL AND CLIMATOLOGICAL FACTORS

The importance of atmospheric factors in localizing debris slide activity is twofold. First, areas differ in the frequency with which severe storms can be expected to occur. Theoretically, any area had a characteristic recurrence interval for storms of debris slide capability. Second, the general size and character of the individual storms may affect the areal extent of slope damage. Locally intense storm cells generally affect only small watersheds, whereas major

¹David J. Varnes, "Landslide Types and Processes," Landslides in Engineering Practice, Highway Research Board Special Report 29, E. B. Eckel, editor (Washington: Highway Research Board, 1958), p. 42.

storm systems, although often containing locally intense cells, may result in widespread regional damage.

It is not possible to calculate accurately the recurrence interval for slide-producing storms in the Great Smoky Mountains. In the first place, the rate and amount of precipitation necessary to activate debris slides is unknown. Undoubtedly the critical values vary considerably from one site to another, depending upon the relative importance of the other controlling factors of slide development. Furthermore, rain gauge locations are too widely separated and the record is too short to permit determination of the frequency of severe storms in the area.

A relatively complete record of intense storms in the Tennessee River Basin is available only for the period since 1933. Large storm systems are usually well documented, but the widely spaced rain gauges do not record many locally intense storms.² Bucket surveys provide useful additional data for some isolated severe storms.

Records of storms known to have produced debris slides in the Appalachian Highlands south of the glacial border provide a starting point for determining the elementary characteristics of rainfall intensity and duration associated with slide occurrences. Although detailed precipitation data are lacking for several such storms, available information indicates that rainfall amount and duration

² Francis K. Schwarz and Norbert F. Helfert, Probable Maximum and TVA Precipitation for Tennessee River Basins up to 3,000 Square Miles in Area and Duration to 72 Hours, Weather Bureau Hydrometeorological Report No. 45 (Washington: Government Printing Office, 1969), p. 4.

have varied substantially (Table XIV). Because debris slides probably occurred before the storms ended, however, these values should exceed the necessary amounts required for the generation of debris slides in each area. As no one witnessed the actual sliding, it is impossible to determine how much rain had fallen at the time the slides occurred.

In order to arrive at some estimate of the recurrence interval for storms with debris slide capability an attempt was made to determine for the Great Smoky Mountains the frequency of occurrence for storms of the intensity and duration of those that produced slides elsewhere in the southern Appalachians. Rainfall intensity and frequency studies by Yarnell indicate that rainstorms of the intensity of those known to have been accompanied by slides elsewhere have recurrence intervals of more than 100 years in the Great Smoky Mountains (Table XV).³

According to Yarnell, a one-hour rainfall of 3.25 to 3.50 inches has a mean recurrence interval of 100 years for the Mt. Le Conte-Sugarland Mountain area.⁴ This amount is somewhat below the recorded four inches that fell on September 1, 1951, and only about one-half of the six inch fall estimated by using the slope area method. According to available records, a four inch per hour precipitation with a recurrence interval as short as 100 years is limited primarily to the Coastal Plain in the South Atlantic and Gulf states (Figure 20).

³David L. Yarnell, Rainfall Intensity-Frequency Data, United States Department of Agriculture Miscellaneous Publication No. 204 (Washington: Government Printing Office, 1935), pp. 29-56.

⁴Ibid., p. 43.

TABLE XIV
 RAINFALL AMOUNT-DURATION VALUES FOR APPALACHIAN
 DEBRIS SLIDE STORMS SOUTH OF
 THE GLACIAL BORDER*

Slide Area	Date	Amount (Inches)	Duration (Hours)
Webb Mountain Area	August 5, 1938	11-15	4
Watauga Area	August, 1940 (?)	?	?
Radford Area	August, 1940 (?)	?	?
Grandfather Mountain Area	August, 1940 (?)	?	?
Little River Area	June 17-18, 1949	9	several
Petersburg Area	June 17-18, 1949	16	24
Mt. Le Conte-Sugarland Mountain Area	September 1, 1951	4-6+	1
Cove Creek Area	June 30, 1956	12	1
Blue Ridge Area	August 22-24, 1967	?	?
Renick Area	August 19-20, 1969	?	?
Lovingston Area	August 19-20, 1969	?	?

*Compiled from various sources.

TABLE XV
RAINFALL TO BE EXPECTED ONCE IN 100 YEARS OVER
GREAT SMOKY MOUNTAINS

Duration (Hours)	Amount (Inches)
1	3.25 - 3.50
2	4.50 - 5.00
4	5.00 - 5.50
8	5.50 - 6.00
16	6.00 - 7.00
24	7.00 - 8.00

Source: David L. Yarnell, Rainfall Intensity-Frequency Data,
United States Department of Agriculture Miscellaneous Publication
No. 204 (Washington: Government Printing Office, 1935), pp. 29-56.

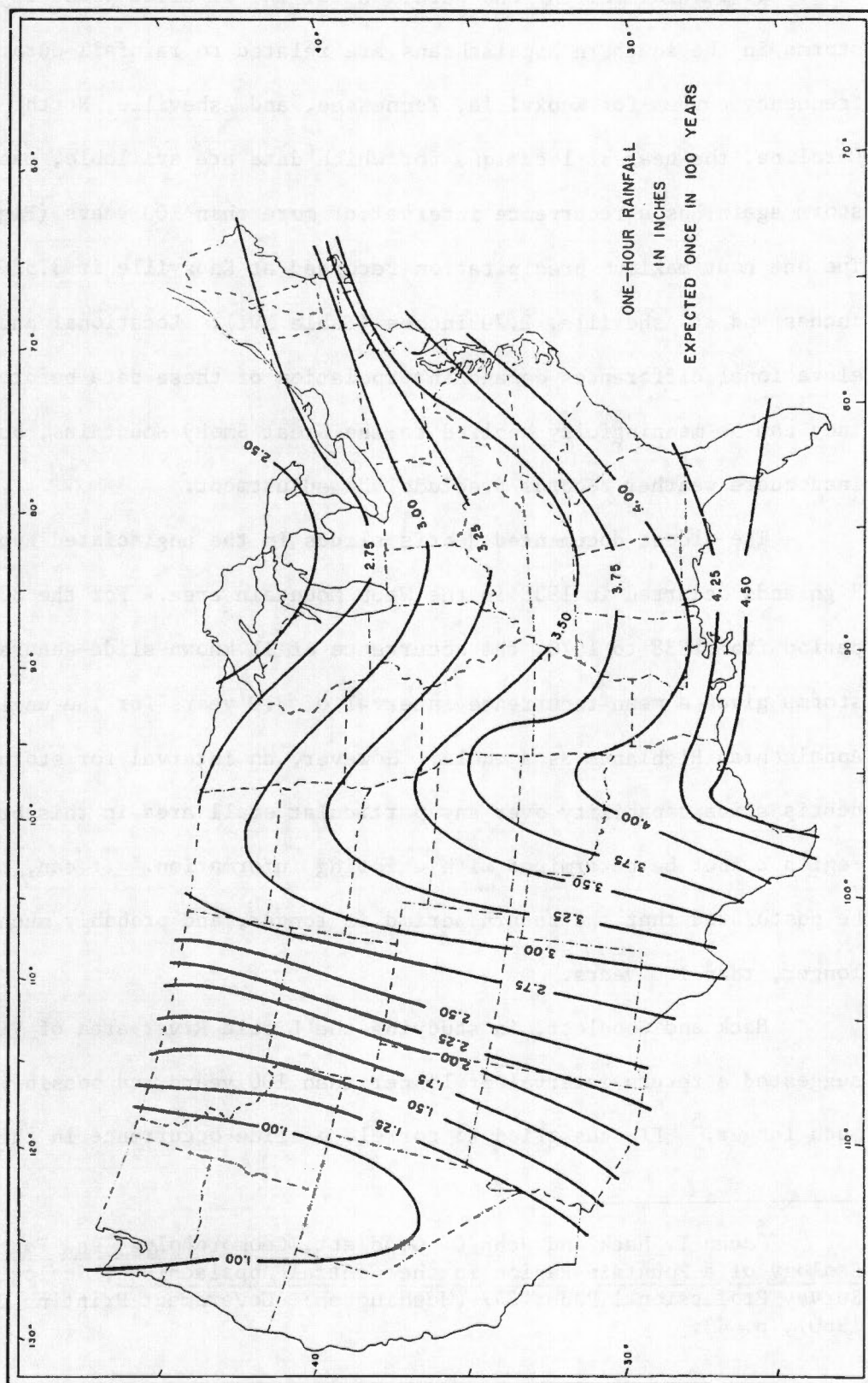


Figure 20. One-hour rainfall in inches expected once in 100 years in the United States.

Source: David L. Yarnell, Rainfall Intensity-Frequency Data, United States Department of Agriculture Miscellaneous Publication No. 204 (Washington: Government Printing Office, 1935), p. 43.

If rainfall amount and duration for the 11 slide-producing storms in the southern Appalachians are related to rainfall-duration-frequency curves for Knoxville, Tennessee, and Asheville, North Carolina, the nearest locations for which data are available, each storm again has a recurrence interval of more than 100 years (Figure 21). The one hour maximum precipitation recorded at Knoxville is 3.52 inches and at Asheville, 2.70 inches (Table XVI). Locational and elevational differences demand interpolation of these data before they can be meaningfully applied to the Great Smoky Mountains, but inadequate weather records preclude the adjustment.

The oldest documented debris slides in the unglaciated Appalachian Highlands occurred in 1938 in the Webb Mountain area. For the 33 year period from 1938 to 1970, the occurrence of 11 known slide-generating storms gives a mean recurrence interval of 3.0 years for the unglaciated Appalachian Highlands as a whole. However, an interval for storms of debris slide capability over any particular small area in this broad region cannot be determined with existing information. It can, however, be postulated that the return period is longer, and probably much longer, than 100 years.

Hack and Goodlett, in studying the Little River area of Virginia, suggested a return interval of longer than 100 years and possibly much longer.⁵ Flaccus tried to correlate slide occurrence in the

⁵ John T. Hack and John C. Goodlett, Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians, Geological Survey Professional Paper 347 (Washington: Government Printing Office, 1960), p. 43.

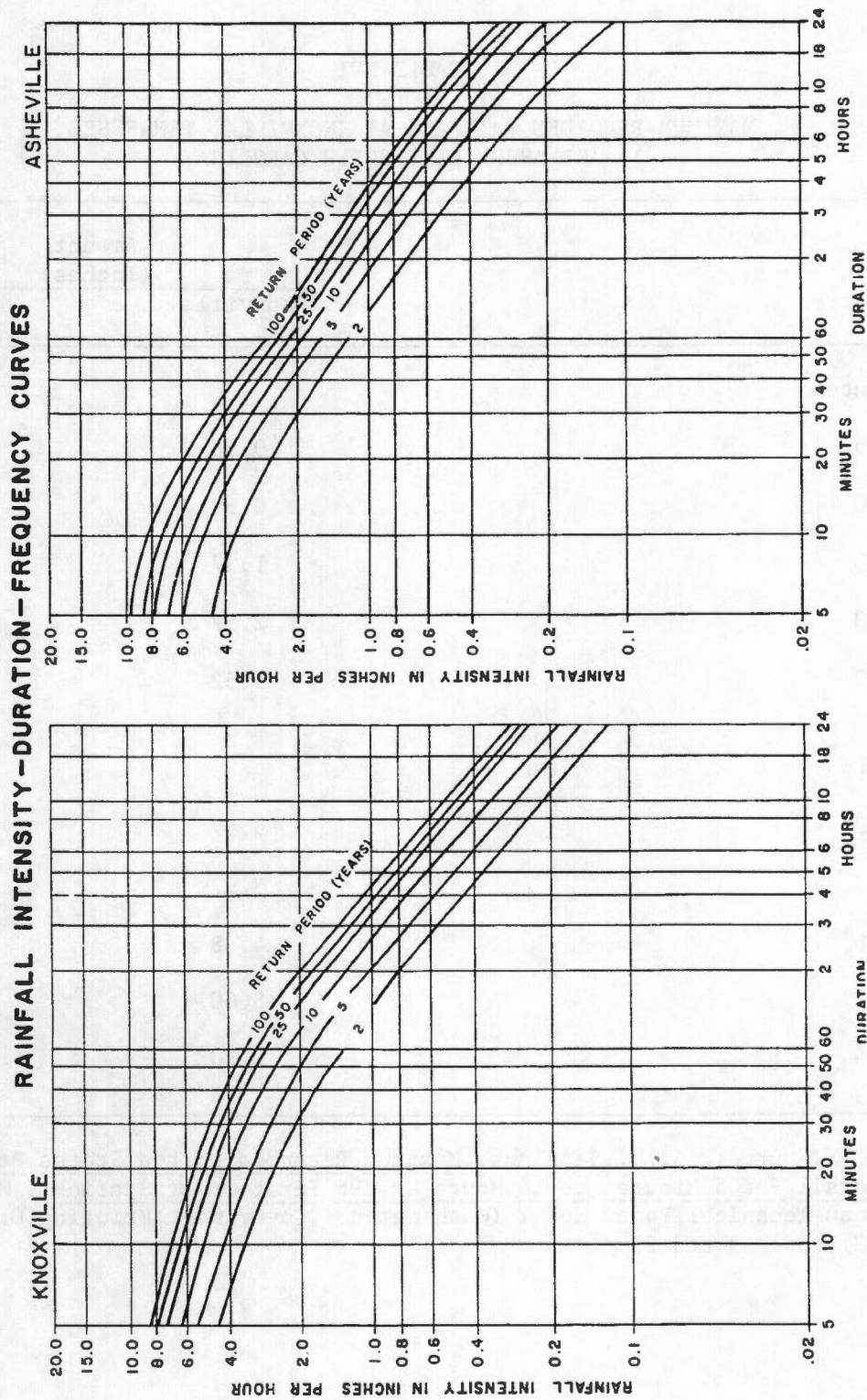


Figure 21. Rainfall intensity-duration-frequency curves for Asheville, North Carolina, and Knoxville, Tennessee.

Source: United States Weather Bureau, Rainfall Intensity-Duration-Frequency Curves for Selected Stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico, Weather Bureau Technical Paper No. 25 (Washington: Government Printing Office, 1955).

TABLE XVI
 MAXIMUM RECORDED RAINFALL AT KNOXVILLE, TENNESSEE,
 AND ASHEVILLE, NORTH CAROLINA

Duration	Amount (Inches)	
	Knoxville	Ashville
Minutes		
5	0.58	0.83
10	0.99	1.41
15	1.37	1.71
30	2.57	2.13
60	3.52	2.70
Hours		
2	3.57	2.82
3	3.97	3.00
6	4.88	4.18
12	5.60	5.51
24	6.20	7.92

Source: A. H. Jennings, Maximum Recorded United States Point Rainfall For 5 Minutes to 24 Hours at 296 First-Order Stations, Weather Bureau Technical Paper No. 2 (Washington: Government Printing Office, 1963), pp. 19 and 23.

White Mountains with an arbitrary intensity and duration of two inches or more of precipitation in 24 hours.⁶ Surmising that the record was too short and too easily distorted by large storms, however, he concluded that the calculation of how much rain must fall and at what rate to produce slides is practically impossible. Consequently, he did not estimate a recurrence interval.

Debris slides in the Appalachians have been associated with storms of short duration and great intensity and also with storms of long duration and only moderate to strong intensity. The Mt. Le Conte-Sugarland Mountain, Webb Mountain, and Cove Creek slides were the result of localized storms of short duration. Slides in the other eight areas formed during relatively extensive storms of long duration.

Although both types of intense storms may occur at any time, studies by Yarnell indicate that in the unglaciated Appalachians the number of intense rainstorms is greatest during June, July, August, and September.⁷ A United States Weather Bureau report, which also shows this to be true, states that over 50 percent of the intense rainstorms occur in the third quarter of the day (12 noon to 6:00 p.m.) both for the summer months and for the year.⁸

⁶Edward Flaccus, "Landslides and Their Revegetation in the White Mountains of New Hampshire" (unpublished Doctoral dissertation, Duke University, Durham, North Carolina, 1960), pp. 74 and 176.

⁷David L. Yarnell, op. cit., pp. 64-66.

⁸A. H. Jennings, Maximum Recorded United States Point Rainfall For 5 Minutes to 24 Hours at 296 First-Order Stations, Weather Bureau Technical Paper No. 2 (Washington: Government Printing Office, 1963), p. 55.

All known slide-producing storms of the unglaciated Appalachian Highlands occurred during June, July, August, or September (Table XIV, page 101). The approximate time of occurrence is known for five of the 11 areas. Of these, two occurred between 12 noon and 6:00 p.m. Flaccus found that all 127 White Mountain slides which could be dated by month occurred between June and November.⁹ The time of day was not noted.

The Tennessee Valley Authority has adopted a classification which defines an intense storm as one which has one or more inches of rainfall in one hour or three or more inches of rainfall in 24 hours. A record of such storms in and adjacent to Great Smoky Mountains National Park from 1936 to 1968 was compiled (Appendix A). Of the 341 intense rainfalls recorded, only the August 5, 1938, storm over Webb Mountain and the September 1, 1951, storm over Mt. Le Conte and Sugarland Mountain are known to have been associated with debris slide activity. Several of the intense storms were equal to or only slightly less severe than known slide-producing storms but apparently did not produce sliding because other factors were not favorable for slide formation.

Thunderstorm activity over Great Smoky Mountains National Park is greatest during the summer months (Table XVII).¹⁰ Frequency distribution of all intense rains by month, however, illustrates that extreme rainfall is not confined entirely to the summer period

⁹Edward Flaccus, op. cit., pp. 20-21.

¹⁰United States Weather Bureau, Mean Number of Thunderstorm Days in the United States, Weather Bureau Technical Paper No. 19 (Washington: Government Printing Office, 1952), pp. 8-23.

TABLE XVII

MEAN NUMBER OF THUNDERSTORM DAYS OVER GREAT
SMOKY MOUNTAINS NATIONAL PARK

Month	Days
January	0 - 1
February	1 - 2
March	2 - 4
April	4 - 6
May	6 - 8
June	10 - 12
July	10 - 14
August	10 - 12
September	4 - 6
October	1 - 2
November	1 - 2
December	0 - 1

Source: United States Weather Bureau, Mean Number of Thunderstorm Days in the United States, Weather Bureau Technical Paper No. 19 (Washington: Government Printing Office, 1952), pp. 8-23.

(Table XVIII). The hour of occurrence for storms was not available, but of the two slide-producing storms, only the Mt. Le Conte cloudburst occurred during the 12 noon to 6 p.m. quarter. The storm over Webb Mountain lasted from approximately 2:00 a.m. to 6:00 a.m.

Tennessee Valley Authority engineers, in determining the maximum probable flood in the vicinity of Gatlinburg, estimated that an 11.1 inch rainfall in two hours is a possibility.¹¹ Although storms of this magnitude have not officially been reported near Gatlinburg, estimates of the Webb Mountain cloudburst of August 4-5, 1938, indicate that such storms are possible. At least 11 inches of precipitation fell in four hours over a 27 square mile area, and rainfall of 12 to 15 inches was reported near the storm center.¹²

Theoretically, a storm of even greater proportions than that producing the maximum probable flood can occur. The Tennessee Valley Authority stated:

Storms greater than that which would produce the maximum probable flood can occur. Under extreme maximizing conditions it is estimated that the maximum possible storm would be approximately 1.7 times as great as the storm adopted as a basis for the maximum probable flood at Gatlinburg.¹³

¹¹Tennessee Valley Authority, Floods on West Fork Little Pigeon River - Gatlinburg, Tennessee, (Knoxville: Tennessee Valley Authority, 1966), p. 56.

¹²Berlen C. Money maker, "Erosional Effects of the Webb Mountain (Tennessee) Cloudburst of August 5, 1938," Tennessee Academy of Science Journal, XIV (April, 1939), pp. 190-196.

¹³Tennessee Valley Authority, Floods on West Fork Little Pigeon River - Gatlinburg, Tennessee, (Knoxville: Tennessee Valley Authority, 1966), p. 58.

TABLE XVIII

NUMBER OF DAYS BY MONTH INTENSE PRECIPITATION FELL IN
AND ADJACENT TO GREAT SMOKY MOUNTAINS NATIONAL
PARK FROM 1936 to 1968*

Month	Days
January	22
February	13
March	18
April	12
May	14
June	42
July	52
August	64
September	24
October	15
November	11
December	6

* No data for 1956.

If maximum storm conditions should ever develop in the Gatlinburg area, a storm precipitating 18.87 inches of rain in two hours could be expected. The Tennessee Valley Authority was unable to determine the return period for either the maximum probable or the maximum possible storm. Although such a storm would occur on the average at long intervals, it could conceivably occur in any year.¹⁴

III. SLOPE FACTORS

Slope influences the location of debris slides in two ways. First, slope angle is critical in the slide process. Although impossible to calculate, a theoretical minimum slope angle exists for debris slide formation at each potential slide area. Second, slope form is important to the distribution of slide activity. During intense precipitation, various slope segments react differently to excessive water. In the Mt. Le Conte-Sugarland Mountain area, where all slopes are relatively steep, slope form is apparently the more important slide localizing factor.

According to Sharpe, recorded debris slides have slopes that range from about 20° to 40° near the scar head and flatten out to 15° or less near their termini.¹⁵ Flaccus reported that in the area of his study movement begins on slopes which range from 25° to 35°, with an average of about 32°, and concluded that slides are not likely

¹⁴Ibid., p. 63.

¹⁵C. F. Stewart Sharpe, Landslides and Related Phenomena (New York: Columbia University Press, 1938), p. 61.

to occur on slopes which do not at any point exceed 25° .¹⁶

Field data from the Alum Cave Creek watershed indicate that slide head scars average about 40° , with a range of 35° to 44° . Many scars have short slope segments which are considerably steeper than 44° , and several have vertical cliffs near the head of the scar. The largest cliff, approximately 45 feet high, occurs on Slide SB-4. Slides formed over the Anakeesta Formation show no appreciable slope differences from those on the Thunderhead Sandstone.

Steep slopes are characteristic of most of the Mt. Le Conte-Sugarland Mountain area and were of considerable importance in the formation of debris slides within the study area. If slopes had averaged only 15° to 20° , it is unlikely that sliding would have occurred. However, slope conditions other than angle must be investigated in assessing localization, for many unaffected slopes within the areal limits of the 1951 storm have inclinations equal to or greater than those which slid.

Debris slides are most numerous in the valley areas. Nearly all of the slide scars originate at valley heads or are associated with small or incipient hollows on side slopes where runoff is concentrated. Several small slides occur in non-valley areas near the slope bases, but stream undercutting is a possible explanation for these features.

Using the slope segment terminology of Leopold, Wolman, and Miller, most slides originate either in the mid-slope segment or

¹⁶ Edward Flaccus, op. cit., p. 63.

somewhere near the contact between the crest-slope and mid-slope areas.¹⁷ Deposition is usually confined to the foot-slope segment.

Elevation shows no clear relationship to debris slide formation in the area. Slide heads range from about 4000 feet to 6300 feet. Debris slides are found on all exposures, but are notably less frequent on west-facing slopes. This condition, however, is primarily a function of geological control and will be discussed under geological factors.

IV. HYDROLOGICAL FACTORS

Runoff and infiltration exert poorly understood influences upon localization of debris slides. Several hypotheses have been advanced to explain the relationship between rapid mass movement and excessive amounts of water on steep slopes. Briefly, these are concerned with (1) water as a lubricant, (2) elimination of surface tension, (3) the weight of water, (4) hydrostatic or pore pressure, and (5) overland flow.

Water was originally thought to act as a lubricant when it infiltrated the ground. Terzaghi, however, found this unacceptable for two reasons:

First of all, water in contact with many common minerals, such as quartz, acts as an anti-lubricant and not as a lubricant. . . . Second, only an extremely thin film of any lubricant is required to produce the full static lubricating effect

¹⁷ Luna B. Leopold, M. Gordon Wolman, and John F. Miller, Fluvial Processes in Geomorphology (San Francisco: W. H. Freeman and Company, 1964), p. 334.

characteristic of the lubricant . . . since practically all the sediments located beneath slopes are permanently "lubricated" with water, a rainstorm cannot possibly start a slide by lubricating the soil or boundaries between soil strata.¹⁸

In most unconsolidated deposits the pore spaces between individual grains are filled partly with moisture and partly with air. The surface tension of the moisture gives a certain degree of cohesion to the soil as long as this condition exists. When air is forced out of the soil by excessive water accumulations, cohesion is reduced and the mass becomes more susceptible to downslope movement. Water also increases the unit weight of the soil, but Terzaghi believes that this increase is not an important factor in promoting mass movement.¹⁹ Nevertheless, Moneymaker attributed the Webb Mountain debris slides of 1938 to the saturation of residual soils, with the water increasing their weight and serving as a lubricant.²⁰

Water which soaks into the ground beneath a slope also contributes to instability by causing a rise in the hydrostatic pressure and decreasing the shearing resistance of the soil. As the piezometric surface rises, the action of pore water pressure is analogous to that of a hydraulic jack.²¹ As pore pressure increases, the shearing resistance decreases and theoretically can become equal to zero. Another process

¹⁸Karl Terzaghi, "Mechanisms of Landslides," The Geological Society of America Engineering Geology (Berkey) Volume (New York: Geological Society of America, 1950), p. 91.

¹⁹Ibid.

²⁰Berlen C. Moneymaker, op. cit., 192.

²¹Karl Terzaghi, op. cit., p. 91.

occurring on slopes is erosion and movement of material by surface runoff. Although overland flow is not thought to be directly responsible for debris slide formation, runoff concentrates in valleys, hollows, and small indentations and may supply the necessary amounts of water needed for slide formation. Once sliding has occurred, however, runoff causes additional erosion within the slide track.

Debris slides in the Alum Cave Creek watershed are generally associated with areas of concentrated runoff. Main chutes of most slides are confined to major valley axes, and slides with multiple chutes usually have secondary slide heads formed in lower order valleys. In some instances, secondary chutes may develop by a local oversteepening of the slope through the erosive action of the main slide mass.

Water blowouts, a feature common to several Appalachian debris slide areas, are small, semicircular holes in the surficial mantle. The upslope side is generally crescent-shaped, while debris is accumulated at the base. Bedrock may or may not be exposed. Eisenlohr concluded that hydrostatic pressure at geologically favorable horizons where water was concentrated was responsible for their formation in Pennsylvania.²² Hack and Goodlett also described blowouts in the Little River area and stated that they may have had a hydrostatic pressure origin.²³

²²W. S. Eisenlohr, Floods of July 18, 1942, in North Central Pennsylvania, Geological Survey Water-Supply Paper 1134-B (Washington: Government Printing Office, 1952), pp. 77-78.

²³John T. Hack and John C. Goodlett, op. cit., p. 45.

Only one feature which resembles a blowout was found in the study area (Slide SB-6). However, several slope damage features seem to be transitional between blowout and debris slide. Identical processes may be responsible for both forms, with other factors controlling the ultimate shape and magnitude of the damage area. Debris slides may be blowouts which were able to gather sufficient momentum to carry the moving mass a considerable distance downslope. Conversely, blowouts may be small chutes in which the material was unable to maintain downslope movement.

Some slopes which did not slide apparently experienced superficial damage from heavy runoff. Small piles of debris behind large trees, the lack of underbrush, and minor breaks in the surficial mantle all indicate unusually heavy wash.

Areas of severe flood damage were confined to the valleys of streams which drain the slide area. Watersheds containing the greatest slope damage also experienced the most severe flooding. High initial infiltration capacity is characteristic of relatively dry soil of low coherence; thus little surface detention or runoff occurs during the interval of time during which the storm reaches maximum intensity.²⁴ On low capacity or moist soils, runoff begins soon after the onset of precipitation.

The month of August, 1951, was considerably drier than normal for the area affected by the September 1, 1951, storm. At Clingmans

²⁴R. E. Horton, "Erosional Development of Streams and Their Drainage Basins; Hydrophysical Approach to Quantitative Morphology," Geological Society of America Bulletin, LVI (March, 1945), 326-329.

Dome only 1.79 inches of precipitation was recorded as compared to a 16-year August mean of 7.80 inches. The mean at Mt. Le Conte for August is 8.20 inches, but the summit station only received 4.34 inches in August, 1951.²⁵ The last rain preceding the September storm fell from 2:00 a.m. to 9:00 a.m. on August 29, with a total of 1.1 inches recorded at Mt. Le Conte.

Although no soil moisture data are available, the sparse precipitation and high August temperatures may have left soils in the study area relatively dry. The resulting high initial infiltration capacity and reduced surface detention may be connected with slide formation. Had the soil been moist, the intense precipitation might have produced less severe forms of slope damage.

V. GEOLOGICAL FACTORS

Field data indicate that geological control was a significant factor in localizing debris slides within the study area. Variables investigated include type of bedrock, degree of weathering, and attitude of compositional layering.

All debris slides in the Mt. Le Conte-Sugarland Mountain area are underlain by either the Anakeesta Formation or the Thunderhead Sandstone. Of the known slides, 63 percent occur on the Anakeesta and 37 percent on the Thunderhead. This distribution suggests bedrock

²⁵Tennessee Valley Authority, Precipitation in Tennessee River Basin, Annual 1951 (Knoxville: Tennessee Valley Authority, 1951), pp. 22-23.

type has no outward visible influence on the location of slides. No slides were found on the Elkmont Sandstone, Pigeon Siltstone, or Roaring Fork Sandstone, but lesser amounts of precipitation probably account for the absence of slides in these areas.

Degree of bedrock weathering in the study area varies substantially. Conditions range from relatively unweathered outcrop to predominantly saprolitized rock. No relationship, however, was found between degree of weathering and slide occurrence. Slide chutes originate on predominantly unweathered rock as well as on those which are considerably weathered.

Compositional layering, however, apparently has considerable importance in the localization process, especially in the area underlain by the Anakeesta Formation. The predominant dip of compositional layering within the Alum Cave Creek watershed is south-southeast. Correspondingly, 20 of the 22 main slide tracks within the field research area are located on south or southeast facing slopes, and 34 of the 41 individual slide scar heads have downslope slide track axes trending between south and east (Figure 12, page 72). The two slides which occur on the west facing slope of Alum Cave Creek watershed (Slides SB-2 and SB-3) have southwest downslope slide track axes.

Field measurements in the watershed reveal that compositional layering of exposed bedrock strikes between $N31^{\circ}E$ and $N82^{\circ}E$ in slide scar heads. The dip is generally southeast and varies from 26° to 55° , with a mean of 42° for slide scar heads. Strikes and dips representative of slide scar heads in Alum Cave Creek watershed are shown on Plate 3. Debris slides in Trout Branch watershed also formed on the

dip slope of the Anakeesta Formation. Most slides developed on the east or south facing slopes and have downslope slide track axes oriented between south and east. One slide formed on the west-facing slope, but the downslope axis is to the south.

The relationship of slide occurrence with compositional layering is less pronounced in the areas of Thunderhead Sandstone. Slides in the Mt. Mingus area, for example, occur more commonly on west-facing slopes.

Field investigation of bedrock exposed in slide tracks and examination of small pits dug along the edges of slide tracks indicate that movement was probably initiated at the regolith-bedrock contact. The bedrock surface in most instances continues under the regolith surrounding the track with no appreciable change. Some slide scars, however, show evidence that bedrock layers may have been involved in sliding. If the regolith does slide on the bedrock surface, it apparently has less resistance to movement on the relatively smooth surface of the dip slope than on the rough and often step-like surface of the obsequent slope.

VI. PEDOLOGICAL FACTORS

Because soil chemistry and mineralogy may provide some information on slope stability, soil analyses were conducted to provide data on the types of soils present in the study area and their bearing upon the formation and distribution of debris slides. Soil samples were collected from 11 pits dug adjacent to four selected slide tracks in the Alum Cave Creek watershed (Figure 22). The main criteria in

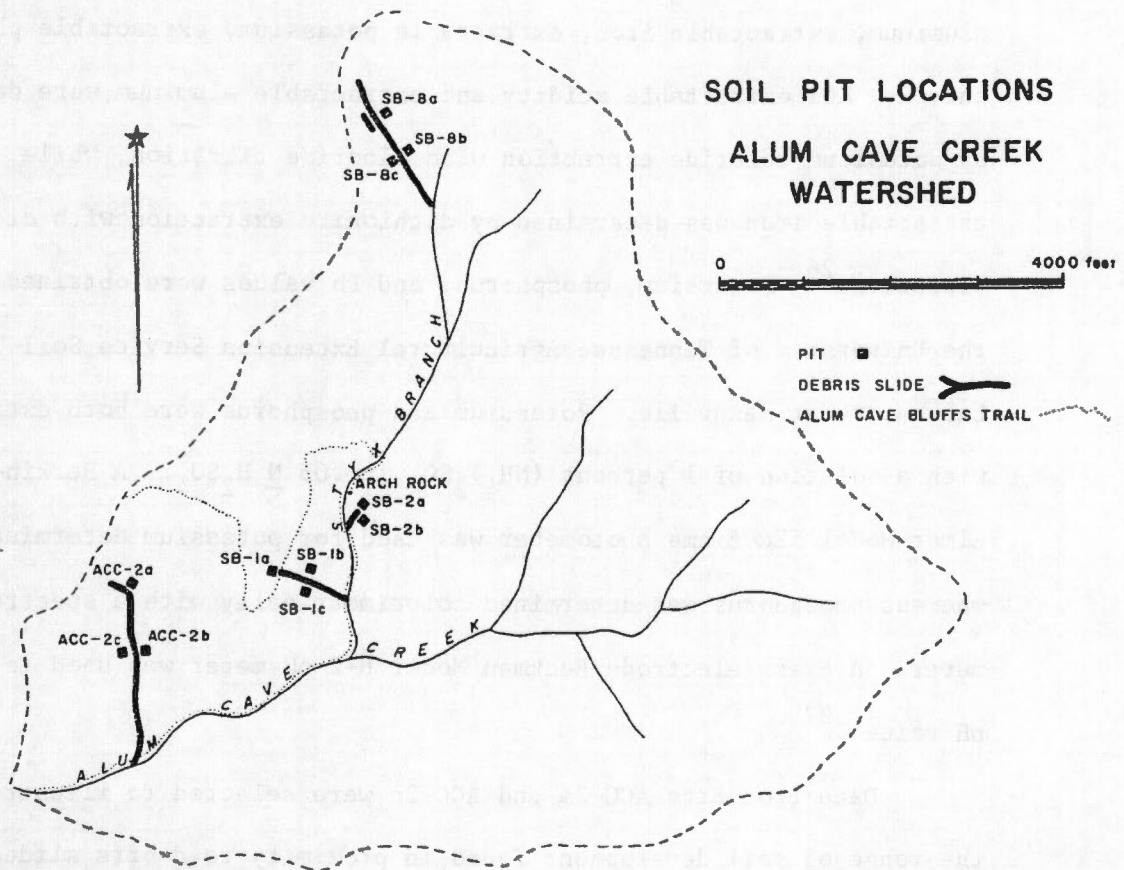


Figure 22. Soil pit locations in Alum Cave Creek Watershed.

determining the location for these pits were elevation and exposure. Samples were taken from each pit at interval depths of 10 centimeters with a sample thickness of plus or minus one centimeter. Sampling was continued to bedrock or to where no further visual change in the soil characteristics appeared. Mean depth of the 11 pits was 90 centimeters.

Chemical analyses included KCl extractable acidity, extractable aluminum, extractable iron, extractable potassium, extractable phosphorus, and pH. KCl extractable acidity and extractable aluminum were determined by potassium chloride extraction with fluoride titration, while extractable iron was determined by dithionite extraction with dichromate titration.²⁶ Potassium, phosphorus, and Ph values were obtained from the University of Tennessee Agricultural Extension Service Soil Testing Laboratory at Nashville. Potassium and phosphorus were both extracted with a solution of 1 percent $(\text{NH}_4)_2\text{SO}_4$ in .05 N H_2SO_4 . A Perkin-Elmer Model 52C flame photometer was used for potassium determination whereas phosphorus was determined colorimetrically with a spectrophotometer. A glass electrode Beckman Model H-2 pH meter was used to derive pH values.²⁷

Data from pits ACC-2a and ACC-2c were selected to illustrate the range of soil development found in proximity to debris slides in the study area. Profile ACC-2a represents minimum development while

²⁶United States Department of Agriculture, Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples, (Washington: Government Printing Office, 1967), pp. 26, 30-31.

²⁷University of Tennessee, "Tennessee Soil Testing Methods and Procedures" (Nashville: University of Tennessee, 1956).

profile ACC-2c typifies more advanced development (Figure 23). Complete results of chemical analyses are presented in Appendix B.

Chemical analyses supported field observation by showing that soils formed over phyllite of the Anakeesta Formation are Inceptisols. Analyses also show that soils are in various stages of development.

These determinations are in close agreement with the findings of Wolfe. He classified most forest soils at higher elevations in the Great Smoky Mountains as Inceptisols, but noted some Spodosols were present on crests of some higher domes or peaks under spruce-fir vegetation.²⁸ Similarly, McCracken, Shanks, and Clebsch reported that most soils at higher elevations contained no eluvial or illuvial horizons (Sols Bruns Acides).²⁹ Podzols were recognized under heath, but these were restricted to crest or ridge top areas.

Inceptisols are most often found on young, but not necessarily recent land surfaces.³⁰ In the Mt. Le Conte-Sugarland Mountain area slopes are apparently sufficiently steep to prevent horizon development, and although detailed studies are needed to confirm soil behavior on

²⁸J. A. Wolfe, "Forest Soil Characteristics as Influenced by Vegetation and Bedrock in the Spruce-fir Zone of the Great Smoky Mountains" (unpublished Doctoral dissertation, The University of Tennessee, Knoxville, 1967), p. 120.

²⁹R. J. McCracken, R. E. Shanks, and E. E. C. Clebsch, "Soil Morphology and Genesis at Higher Elevations of the Great Smoky Mountains," Soil Science Society of America Proceedings, XXVI (July-August, 1962), 384-388.

³⁰Soil Survey Staff, Soil Classification, A Comprehensive System - 7th Approximation (Washington: Government Printing Office, 1960), p. 136.

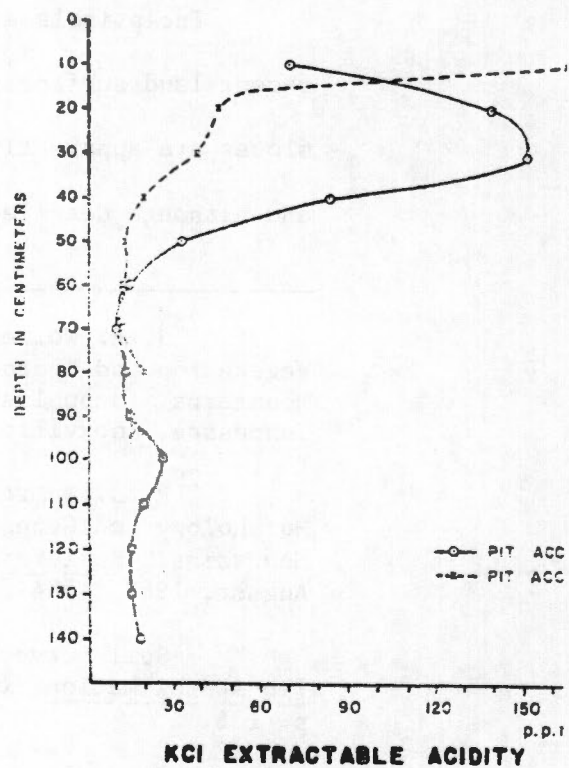
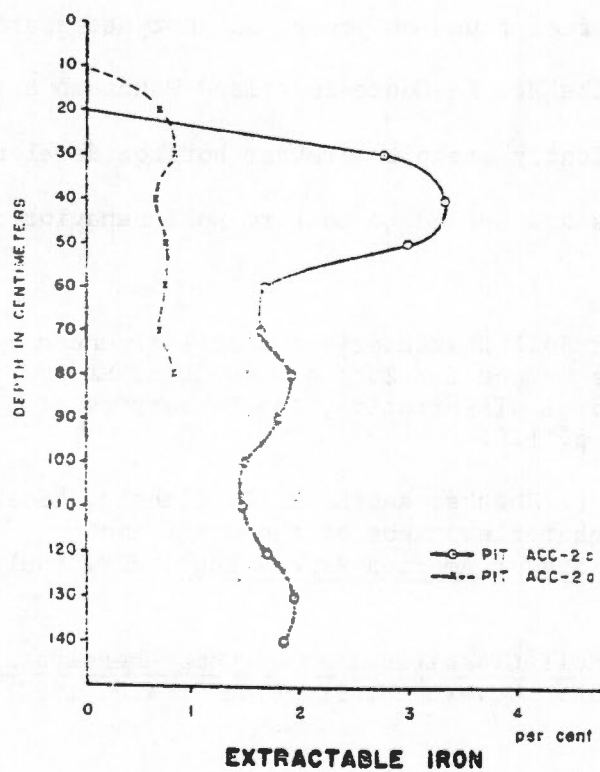
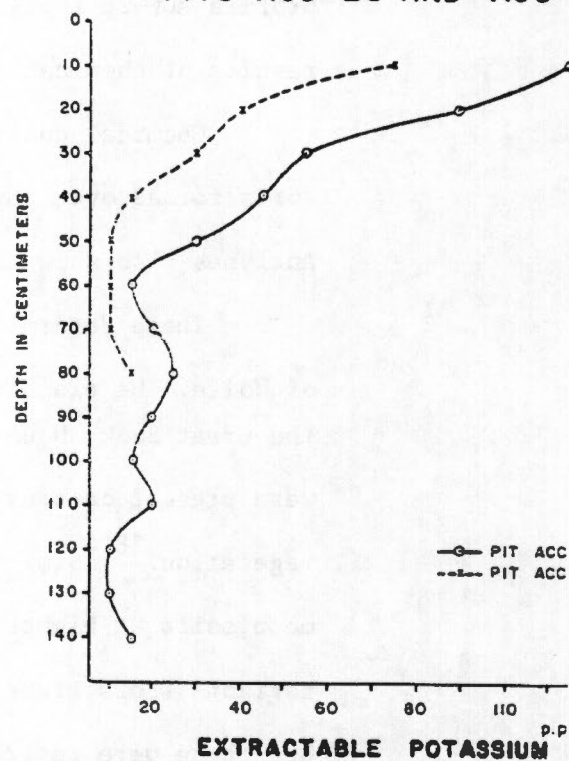
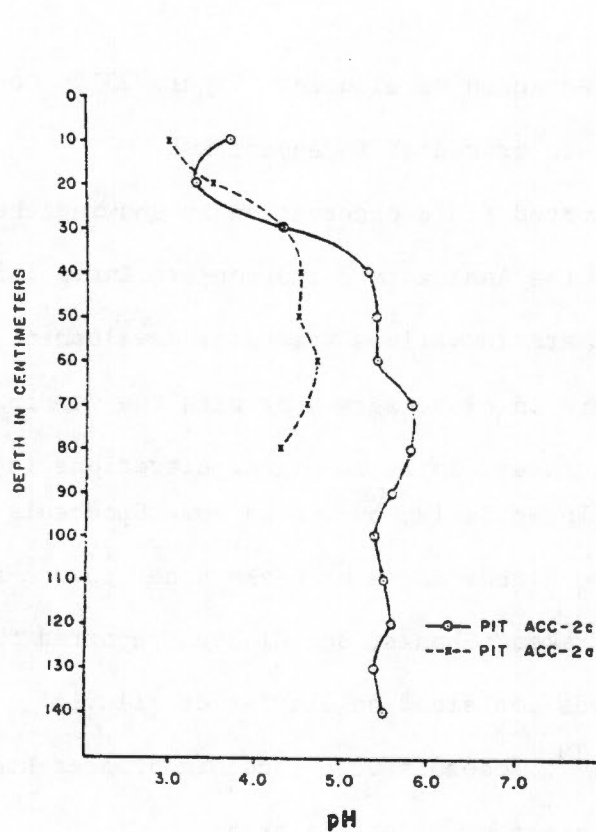
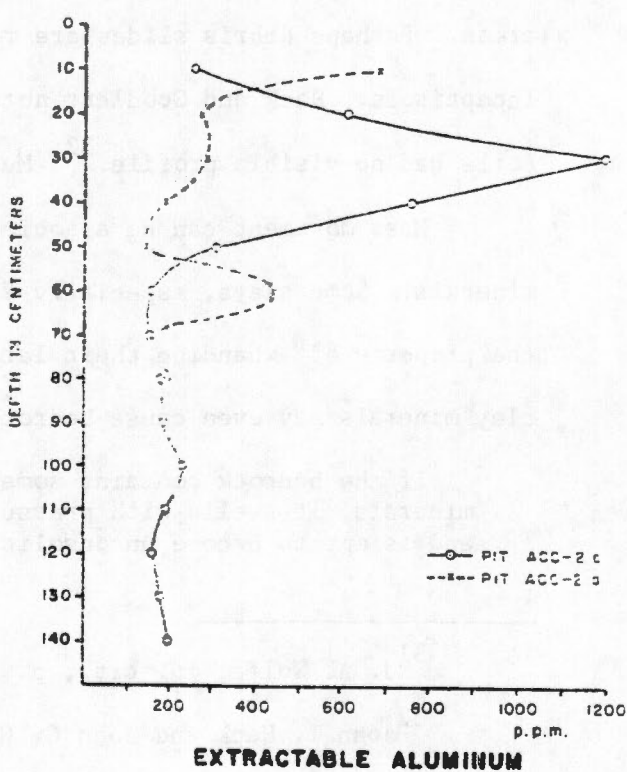
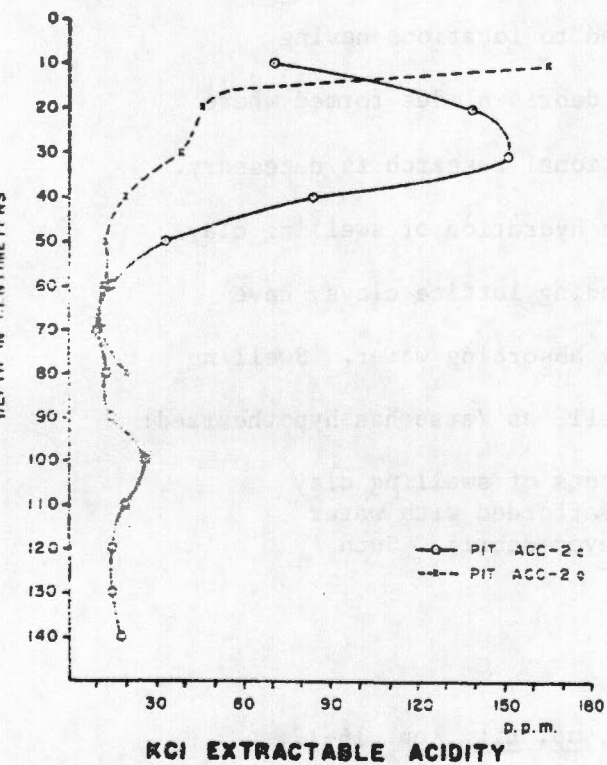
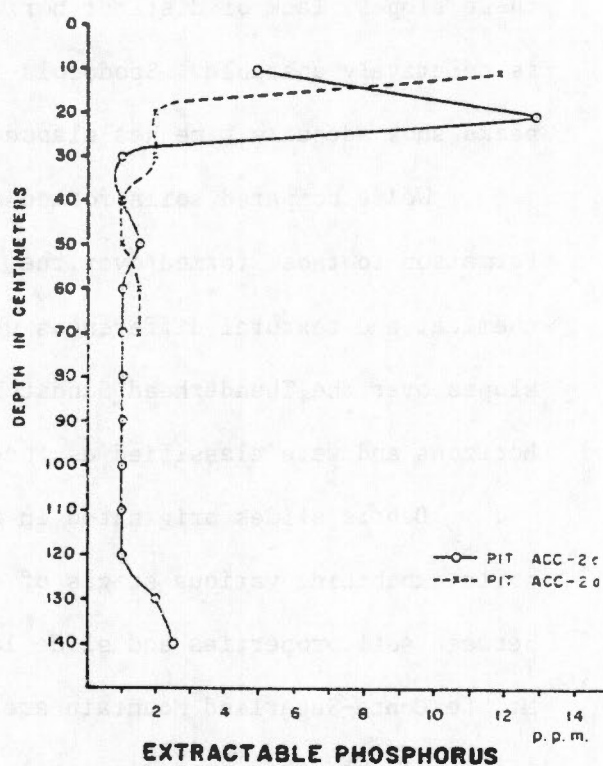
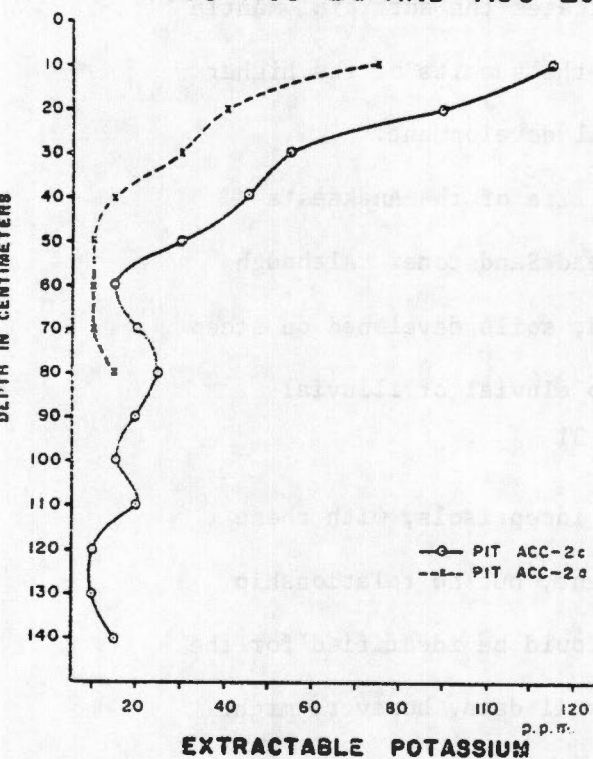


Figure 23. Chemical analyses - pits ACC-2a and ACC-2b.

CHEMICAL ANALYSES PITS ACC-2a AND ACC-2c



these slopes, lack of distinct horizons indicates the surficial mantle is relatively unstable. Spodosols found on the summits of the higher peaks show adequate time has elapsed for soil development.

Wolfe compared soils formed over phyllite of the Anakeesta Formation to those formed over the Thunderhead Sandstone. Although chemical and textural differences were noted, soils developed on steep slopes over the Thunderhead Sandstone had no eluvial or illuvial horizons and were classified as Inceptisols.³¹

Debris slides originated in areas of Inceptisols, with these soils exhibiting various stages of development; but no relationship between soil properties and slide location could be identified for the Mt. Le Conte-Sugarland Mountain area. The soil data, however, might prove valuable when comparing soil characteristics with other slide areas. Perhaps debris slides are restricted to locations having Inceptisols. Hack and Goodlett noted that debris slides formed where soils had no visible profile.³² Much additional research is necessary.

Mass movement can be associated with hydration of swelling clay minerals. Some clays, especially 2:1 expanding lattice clays, have the property of expanding their lattices by absorbing water. Swelling clay minerals may even cause bedrock to swell, as Yatsu has hypothesized:

If the bedrock contains some components of swelling clay minerals, it swells with pressure when afforded with water and is apt to become unconsolidated clayey debris. Such

³¹J. A. Wolfe, op. cit., p. 19.

³²John T. Hack and John C. Goodlett, op. cit., pp. 16-17.

clayey detritus is easily affected by mass movements of slip or flow type.³³

According to Wolfe, soils developed over sandstone contained more sand and less silt and clay than those over phyllite, with the amount of clay decreasing as bedrock is approached. X-ray diffractions indicated clay sized minerals consist chiefly of illite, intergrading toward vermiculite, with smaller amounts of kaolinite present.³⁴ McCracken, Shanks, and Clebsch reported that vermiculite predominates at higher elevations in the Great Smoky Mountains with intergradational vermiculite-chlorite and small amounts of kaolinite and gibbsite present.³⁵

X-ray diffraction of soil samples from the Alum Cave Creek watershed also showed illite, vermiculite, and kaolinite to be the dominant clay minerals. As 2:1 expanding lattice clays were not found, slides in the Mt. Le Conte-Sugarland Mountain area are apparently not associated with hydration of swelling clay minerals.

VII. VEGETATIONAL FACTORS

Vegetation within the area of study, although complex in makeup, is essentially virgin. Some timber was cut in valley areas at lower elevations, and one documented burn is located on the north slope of

³³ Ei-ju Yatsu, "Some Problems on Mass Movements," Geografiska Annaler, XLIX (1967), 399.

³⁴ J. A. Wolfe, op. cit., p. 121.

³⁵ R. J. McCracken, R. E. Shanks, and E. E. C. Clebsch, op. cit., p. 387.

Mt. Le Conte near Mt. Winnesoka.³⁶ All debris slides, however, head in virgin forest.

According to the general vegetation patterns as mapped by Miller, debris slides originate in several different tree association areas.³⁷ The spruce-fir forest, northern hardwood forest, hemlock forest, and cove hardwood forest each contain debris slide scars. In addition, several scars begin in areas of heath bald. Vegetative type apparently has no relationship to the distribution of debris slides in the study area.

Windthrow or tree blowdown is common in the Mt. Le Conte-Sugarland Mountain area and may have been a significant factor in slide formation. Crandell reported:

On steep slopes at higher elevations fir is subject to windthrow and may be blown down in great numbers, resulting in an entire slope being covered with criss-cross stems. This is very evident on the upper slopes of Mt. Le Conte where large expanses are sometimes leveled by violent storms that sweep across the mountain.³⁸

Although wind velocities were not recorded during the 1951 cloudburst, intense convectional storms generally have strong movements of air. No mention, however, has been made in the various storm reports of windthrow caused by this particular storm. With

³⁶F. H. Miller, "Vegetation Type Map, Great Smoky Mountains National Park" (unpublished Civilian Conservation Corps Project, 1935-1938).

³⁷Ibid.

³⁸Dorothy L. Crandell, "Ground Vegetation Patterns of the Spruce-fir Area of the Great Smoky Mountains National Park," Ecological Monographs, XXVIII (October, 1958), 337-360.

all the destruction from landsliding and flooding, it may have gone unnoticed. If widespread tree blowdown did occur during the storm period, throw pits could well serve as inception points for slide formation. Root-prying as the result of strong winds may also have some importance as an initiating factor in slide development.

Logging, overgrazing, burning, and other unwise land uses have long been credited with increased incidence of landslides.³⁹ Flaccus, on the other hand, advanced the idea that mature forests might tend to increase slide susceptibility.⁴⁰ He stated that a mature forest cover increases infiltration, reduces runoff, allows greater water retention during storms, and adds appreciable weight to the slope.

VIII. CULTURAL FEATURES

Cultural features within the study area are few, but, nevertheless, some have an apparent influence upon debris slide location. Six slide scars cross or contact the Alum Cave Bluffs trail which leads to the summit of Mt. Le Conte (Figure 12, page 72). Slides T-1, T-2, T-3, T-4, and T-5 are relatively small and do not extend more than 25 or 50 feet downslope from the trail. Slide SB-1, however, begins at the trail and covers approximately 1,400 slope feet before entering Styx Branch. Other slides which contact the trail are located in Trout Branch watershed.

³⁹ John T. Hack and John C. Goodlett, op. cit., p. 56.

⁴⁰ Edward Flaccus, op. cit., p. 86.

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³⁹ John T. Hack and John C. Goodlett, op. cit., p. 56.

⁴⁰ Edward Flaccus, op. cit., p. 86.

The exact relationship between trail location and slide formation is not entirely clear. Slide T-4 heads a short distance upslope from the trail while the others begin at the trail. The trail was certainly not the sole cause of slide activity in these areas, but might have contributed to their formation. As with nearly all slides, the origin is probably polygenetic.

Although an apparent visual relationship exists between trail location and slide formation, it is possible that the relation is coincidental. The slides are small and were observed from the trail. They cannot be identified from the airborne imagery, and unless detailed reconnaissance were applied to all forested slopes in the study area, similar slides would be overlooked. Considerable time, however, was spent investigating forested slopes without slides, and the relationship between trail location and the occurrence of small slides is considered to be reasonably significant.

IX. OTHER FACTORS

A number of other factors have been noted as being responsible for landslide activity. Terzaghi mentioned construction operations, tectonic movements, earthquakes or blasting, melting snow, frost, lightning, and seepage from artificial sources.⁴¹ None, however, is considered relevant to the present investigation.

⁴¹Karl Terzaghi, op. cit., pp. 106-108..

CHAPTER VI

SUMMARY AND CONCLUSIONS

Numerous debris slides and considerable flood damage resulted from the September 1, 1951, cloudburst over the Mt. Le Conte-Sugarland Mountain area in Great Smoky Mountains National Park. Nineteen years after their formation debris slides are still prominent features of the landscape.

According to precipitation and stream discharge data, and judging from the extent and intensity of slope damage, the storm center was probably located near the Trout Branch-Alum Cave Creek drainage divide on the southwest slope of Mt. Le Conte. Over 100 individual slide scar heads were found in the study area, of which 41 occur in the Alum Cave Creek watershed, the area of detailed field study.

Movement is thought to be initiated by sliding at the head of the track with the mass of moving rock, soil, forest debris, and water developing flow characteristics downslope. Mt. Le Conte-Sugarland Mountain slide tracks may be divided into three sections: (1) the scar head, (2) the middle zone, and (3) the area of deposition.

Slide dimensions vary considerably. The scar head of Slide SB-10, largest within the study area, covers approximately 112,532 square feet and had an estimated removal of about 121,534 cubic feet of material. In contrast, the scar head of Slide ACC-3 occupies approximately 1,662 square feet and had about 2,160 cubic feet of material removed. An additional 538 cubic feet of material is estimated to have been removed from the lower portion of the slide track.

Slide scar heads in the Mt. Le Conte-Sugarland Mountain area are at elevations ranging from 4000 feet to 6300 feet. Field measurements in the Alum Cave Creek watershed indicate that slope angles on individual scar heads range from approximately 35° to 44°, with a mean of 40°. Slides originated on slopes facing all four quadrants.

Geomorphically, the debris slide is an agent in valley formation. Sliding may instigate first-order valley development or may modify the size and shape of already existing higher-order valleys. The relative importance of debris slides in valley modification will depend largely upon the recurrence interval of slide-producing storms. The recurrence interval is based upon present climatic conditions; climatic change through time may have altered this considerably.

According to available precipitation data, severe rainstorms with debris slide capability are most likely to occur in the southeastern United States. Hence, debris slides should probably be a relatively more important geomorphic agent in the southern Appalachian Highlands than in the New York-New England area, for example. But the more than 500 slide scars located by Flaccus in the White Mountains suggests this might not be true. Factors other than precipitation may make the New England area more susceptible, so that lesser storms may be adequate to set off sliding. Much more data is necessary before a valid comparison can be made.

Slide location and distribution are controlled by the complex interaction of numerous physical and cultural factors. Because all known debris slides in the unglaciated Appalachian Highlands have been associated with heavy rainfall on steep slopes, intense or

prolonged precipitation and slope angle must be considered the most important factors contributing to slide activity in that region.

Precipitation is a critical localizing agent, but how much and how fast rain must fall to produce sliding is as yet unanswered, and computation of an accurate recurrence interval for slide-producing storms is nearly impossible. At best, a storm similar to the September 1, 1951, cloudburst probably has a recurrence interval of greater than 100 years, and possibly much longer, for the Mt. Le Conte-Sugarland Mountain area.

Slope form and inclination is the second critical factor in slide localization. Slide scars are most numerous in low-order valleys or incipient water collection areas. All slides head on the mid-slope segment or near the contact between the mid-slope and crest-slope segments. Minimum slope angle for debris slide formation is difficult to define. Steep slopes are characteristic of most of the study area and were probably of considerable importance in the formation of debris slides. If slopes had averaged only 15° to 20° , it is doubtful that slides would have formed. To illustrate the complexity of localizing factors, no sliding occurred on many slopes with inclinations greater than those which experienced debris slides.

Runoff and infiltration are undoubtedly important factors of slide formation, but their working is poorly understood. Hydrostatic or pore pressure and elimination of surface tension by excessive amounts of water on steep slopes may be instrumental in producing debris slides.

Compositional layering of the bedrock appears to be the most significant geological control. Predominant dip of the compositional layering is southeast. Few slides originated on the obsequent slope. Bedrock type and degree of weathering apparently had little influence upon slide location. Scar heads formed on both the Anakeesta Formation and the Thunderhead Sandstone. Slide heads exhibit relatively unweathered as well as saprolitized bedrock.

Field investigation and laboratory analyses indicated that soils in proximity to selected slide tracks within Alum Cave Creek watershed are Inceptisols in various stages of development. No relationship between soil properties and slide location could be identified. Mass movement initiated by hydration of swelling clay minerals is not applicable. X-ray analyses revealed that 2:1 expanding lattice clays are not present in the study area.

Vegetation type apparently has no relationship to the distribution of debris slides. Slides originate in spruce-fir forest, northern hardwood forest, hemlock forest, cove hardwood forest, and heath bald. Strong winds acting upon the forest, however, may instigate sliding through windthrow or root-prying.

Because of the National Park status, cultural features are at a minimum within the study area. Six slide heads in the Alum Cave Creek watershed begin in proximity to the Alum Cave Bluffs trail, but the relationship between trail location and slide formation is not understood. Perhaps the trail permits a greater rate of infiltration or contributes to slide formation through the local oversteepening of slopes.

Other possible causes of landslides that have been proposed by various authors for occurrences elsewhere have no bearing upon debris slide activity in the study area.

Detailed field investigation in the Alum Cave Creek watershed provided the basis for locating and mapping debris slides and related flood damage through the use of airborne imagery for the entire Mt. Le Conte-Sugarland Mountain area. Evaluation of the imagery indicated that Ektachrome Infrared Aero film is the best overall sensing medium for slope damage analysis in this particular area. Slide age and ground conditions vary considerably among the different slide areas in the unglaciated Appalachian Highlands, and other emulsions or sensing devices might prove better suited for investigating slope damage in these localities.

The need for further research is apparent. Particular attention should be directed toward obtaining a more precise account of slide localizing factors. Considerable research is needed to learn more about the nature and occurrence of intense precipitation, and quantitative studies of slope angles and slope form are needed for each of the known slide areas. Chemical and mechanical analyses of soils in various slide areas may provide a better understanding of pedological factors involved in slide formation, and permeability studies may yield significant information. Although slide location in the study area was not greatly influenced by vegetational or cultural factors, researchers should examine these variables as they may have an affect on slide formation in other areas.

All slopes are not hazardous, but few, if any, are stable in an absolute sense. If the various parameters of debris slide localization and distribution are understood, areas of slide potential can be determined. As the number of homes, chalets, and villages in mountainous areas has increased rapidly in recent years, the ability to recognize areas of slide potential is becoming increasingly important. Personal communication with several developers indicated that few had considered the problem of slope stability.

Little can be done to prevent debris slides, but many precautionary measures can be initiated to reduce the extent and severity of damage. People can be warned against building near possible slide sites, transportation and communications facilities can be constructed away from suspected future slide locations, and culverts and flood prevention structures can be installed in particularly dangerous areas.

Debris slides have occurred in the past and will certainly occur in the future. The greatest benefit to be derived from an understanding of the nature and occurrence of debris slides will be the ability to plan for such phenomena.

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APPENDIXES

APPENDIX A

TABLE XIX

RECORD OF INTENSE STORMS AT RAIN GAUGE STATIONS IN AND
ADJACENT TO GREAT SMOKY MOUNTAINS NATIONAL PARK,
1937-1968

Date	Station	Location	Amount (Inches)	Duration (Hours)	
January	2-3, 1937	184	Clingmans Dome	3.03	24.0
May	19, 1937	209	Gatlinburg	.80	0.75
June	17, 1937	210	Mt. Le Conte	2.74	0.75
July	19, 1937	187	Spruce Mountain	1.19	1.0
August	6, 1937	187	Spruce Mountain	2.19	1.0
October	19, 1937	184	Clingmans Dome	3.25	24.0
June	20, 1938	108	Cades Cove	3.02	*
July	8, 1938	209	Gatlinburg	2.11	1.0
July	15, 1938	245	Mt. Sterling	1.18	0.83
August	4-5, 1938	209	Gatlinburg	3.34	*
August	5, 1938	176	Calderwood	6.90	*
August	5, 1938	177	Cades Cove	5.26	*
August	5, 1938	210	Mt. Le Conte	3.92	*
August	8-9, 1938	184	Clingmans Dome	1.50	1.0
September	7, 1938	245	Mt. Sterling	1.85	1.25
April	28, 1939	210	Mt. Le Conte	4.75	*
May	25, 1939	245	Mt. Sterling	1.70	0.42
June	3, 1939	245	Mt. Sterling	1.10	0.58
June	9, 1939	399	Pittman Center	2.08	1.25
July	4, 1939	177	Cades Cove	2.45	0.92
July	30, 1939	209	Gatlinburg	1.73	1.0
August	14-15, 1939	187	Spruce Mountain	1.05	1.0
June	25, 1940	177	Cades Cove	1.10	1.0
July	3, 1940	210	Mt. Le Conte	3.19	*
August	13-14, 1940	184	Clingmans Dome	6.24	*
August	13-14, 1940	187	Spruce Mountain	3.89	*

TABLE XIX (continued)

Date		Station	Location	Amount (Inches)	Duration (Hours)
August	13, 1940	407	Cataloochee Ranch	3.34	1.0
August	15, 1940	210	Mt. Le Conte	4.80	*
August	29-30, 1940	184	Clingmans Dome	1.50	1.0
August	29-30, 1940	187	Spruce Mountain	4.32	*
August	30, 1940	186	Oconaluftee	4.60	*
August	30, 1940	245	Mt. Sterling	4.50	*
August	30, 1940	210	Mt. Le Conte	3.54	*
July	7, 1941	210	Mt. Le Conte	3.20	*
July	20, 1941	177	Cades Cove	2.10	1.0
July	23-24, 1941	184	Clingmans Dome	1.08	1.0
July	26, 1941	184	Clingmans Dome	1.34	1.0
August	4, 1941	187	Spruce Mountain	1.04	1.0
August	4-5, 1941	184	Clingmans Dome	1.00	1.0
February	17, 1942	183	Noland Creek	3.27	*
June	3, 1942	177	Cades Cove	1.85	0.5
June	23, 1942	184	Clingmans Dome	1.21	1.0
July	9, 1942	177	Cades Cove	3.08	*
August	4, 1942	184	Clingmans Dome	1.69	1.0
September	7, 1942	184	Clingmans Dome	1.10	1.0
September	27-28, 1942	184	Clingmans Dome	4.01	24.0
September	27-28, 1942	187	Spruce Mountain	4.05	24.0
December	29, 1942	184	Clingmans Dome	3.92	24.0
May	21, 1943	245	Mt. Sterling	3.66	10.08
July	5, 1943	536	Cades Cove No. 3	3.00	*
July	19, 1943	177	Cades Cove	0.99	0.5
July	26, 1943	209	Gatlinburg	5.34	*
July	26, 1943	210	Mt. Le Conte	5.07	*
July	26, 1943	536	Cades Cove No. 3	3.33	21.0
July	30, 1943	536	Cades Cove No. 3	3.64	*
July	30-31, 1943	177	Cades Cove	3.83	*
July	31, 1943	184	Clingmans Dome	1.31	1.0

TABLE XIX (continued)

Date	Station	Location	Amount (Inches)	Duration (Hours)
February 17-18, 1944	184	Clingmans Dome	3.02	24.0
March 19-20, 1944	184	Clingmans Dome	3.52	24.0
March 19-20, 1944	186	Oconaluftee	3.13	*
May 20, 1944	184	Clingmans Dome	1.91	1.0
August 17, 1944	210	Mt. Le Conte	3.20	*
August 17-18, 1944	184	Clingmans Dome	1.20	1.0
September 29-30, 1944	184	Clingmans Dome	6.29	24.0
September 29-30, 1944	187	Spruce Mountain	3.91	24.0
September 30, 1944	186	Oconaluftee	3.30	*
September 30, 1944	183	Noland Creek	3.15	*
April 16, 1945	186	Oconaluftee	1.72	1.0
July 26, 1945	536	Cades Cove No. 3	3.00	*
July 28-29, 1945	184	Clingmans Dome	1.20	1.0
August 6-7, 1945	187	Spruce Mountain	1.72	1.0
August 16, 1945	187	Spruce Mountain	1.37	1.0
August 16-17, 1945	184	Clingmans Dome	1.33	1.0
August 24, 1945	210	Mt. Le Conte	3.17	*
August 24-25, 1945	184	Clingmans Dome	1.35	1.0
September 14-15, 1945	184	Clingmans Dome	3.57	24.0
January 6-7, 1946	656	Cataloochee	3.10	*
June 27, 1946	407	Cataloochee Ranch	1.50	1.0
January 14-15, 1947	184	Clingmans Dome	3.25	24.0
January 19-20, 1947	184	Clingmans Dome	3.61	24.0
January 19-20, 1947	187	Spruce Mountain	3.16	24.0
January 19-20, 1947	656	Cataloochee	3.35	*
January 19-20, 1947	660	Twentymile	3.28	*
January 19-20, 1947	407	Cataloochee Ranch	3.10	*
January 19-20, 1947	183	Noland Creek	3.08	24.0
June 30, 1947	184	Clingmans Dome	1.09	1.0
August 7, 1947	184	Clingmans Dome	1.10	1.0
August 7, 1947	210	Mt. Le Conte	2.02	1.0
August 18, 1947	407	Cataloochee Ranch	1.00	1.0

TABLE XIX (continued)

Date		Station	Location	Amount (Inches)	Duration (Hours)
August	18-19, 1947	184	Clingmans Dome	1.08	1.0
August	20, 1947	184	Clingmans Dome	1.00	1.0
August	22-23, 1947	210	Mt. Le Conte	3.00	*
September	8, 1947	184	Clingmans Dome	1.18	1.0
September	13-14, 1947	187	Spruce Mountain	1.00	1.0
April	7-8, 1948	184	Clingmans Dome	1.05	1.0
June	21-22, 1948	184	Clingmans Dome	1.94	1.0
June	23-24, 1948	187	Spruce Mountain	1.34	1.0
July	11-12, 1948	184	Clingmans Dome	1.60	1.0
July	12, 1948	245	Mt. Sterling	1.41	1.21
August	16, 1948	407	Cataloochee Ranch	1.98	1.5
August	17, 1948	542	Cherokee	1.57	1.0
November	6, 1948	184	Clingmans Dome	3.20	9.0
November	28, 1948	184	Clingmans Dome	4.53	22.0
November	28-29, 1948	187	Spruce Mountain	3.93	23.0
November	28-29, 1948	660	Twentymile	4.40	*
January	4-5, 1949	184	Clingmans Dome	4.12	24.0
January	4-5, 1949	187	Spruce Mountain	3.48	24.0
June	13, 1949	187	Spruce Mountain	1.97	1.0
June	15-16, 1949	184	Clingmans Dome	5.18	17.0
June	15-16, 1949	210	Mt. Le Conte	3.94	*
June	15-16, 1949	245	Mt. Sterling	4.38	15.0
June	15-16, 1949	542	Cherokee	3.40	*
June	16, 1949	209	Gatlinburg	3.01	*
July	12-13, 1949	184	Clingmans Dome	3.48	24.0
July	15, 1949	187	Spruce Mountain	1.30	1.0
August	11, 1949	184	Clingmans Dome	1.03	1.0
August	16, 1949	187	Spruce Mountain	1.60	1.0
August	16-17, 1949	660	Twentymile	3.67	*
August	28-29, 1949	209	Gatlinburg	3.05	*
August	28-29, 1949	210	Mt. Le Conte	4.01	*
September	6, 1949	184	Clingmans Dome	3.92	16.0
October	30-31, 1949	176	Calderwood	3.50	*
October	30-31, 1949	184	Clingmans Dome	5.08	22.0
October	30-31, 1949	187	Spruce Mountain	3.90	23.0

TABLE XIX (continued)

	Date	Station	Location	Amount (Inches)	Duration (Hours)
October	30-31, 1949	209	Garlinburg	3.45	*
October	30-31, 1949	660	Twentymile	4.40	*
January	18-19, 1950	660	Twentymile	3.04	*
March	12-13, 1950	184	Clingmans Dome	3.08	19.0
May	2, 1950	184	Clingmans Dome	1.15	1.0
May	10, 1950	184	Clingmans Dome	1.00	1.0
May	10, 1950	187	Spruce Mountain	1.10	1.0
October	19-20, 1950	407	Cataloochee Ranch	4.02	*
March	28-29, 1951	176	Calderwood Powerhouse	4.00	*
March	28-29, 1951	186	Oconaluftee	3.78	*
March	28-29, 1951	184	Clingmans Dome	3.11	12.0
March	28-29, 1951	184	Clingmans Dome	5.34	29.0
March	28-29, 1951	660	Twentymile	4.15	*
June	4-5, 1951	209	Garlinburg	3.00	*
July	23-24, 1951	660	Twentymile	3.08	*
July	25, 1951	184	Clingmans Dome	1.50	1.0
July	25, 1951	184	Clingmans Dome	2.31	5.0
September	1, 1951	184	Clingmans Dome	1.60	1.0
September	1, 1951	184	Clingmans Dome	2.84	5.0
September	1, 1951	210	Mt. Le Conte	4.00	1.0
September	1, 1951	210	Mt. Le Conte	4.14	*
September	1, 1951	407	Cataloochee Ranch	4.80	1.2
September	1, 1951	656	Cataloochee	2.46	0.8
October	31, 1951	660	Twentymile	3.50	*
November	1, 1951				
October	31, 1951	668	Abrams Creek	5.85	*
November	1, 1951				
March	10, 1952	184	Clingmans Dome	3.36	14.0
March	10-11, 1952	660	Twentymile	3.11	*
June	10, 1952	187	Spruce Mountain	1.20	1.0
June	10, 1952	187	Spruce Mountain	2.01	3.0

TABLE XIX (continued)

	Date	Station	Location	Amount (Inches)	Duration (Hours)
June	12-13, 1952	660	Twentymile	3.23	*
August	1, 1952	184	Clingmans Dome	1.68	1.0
August	1, 1952	184	Clingmans Dome	2.52	2.0
August	5, 1952	660	Twentymile	3.27	*
November	21-22, 1952	668	Abrams Creek	3.37	*
February	20-21, 1953	184	Clingmans Dome	3.18	24.0
February	20-21, 1953	187	Spruce Mountain	3.51	24.0
May	18-19, 1953	668	Abrams Creek	3.18	*
July	2, 1953	245	Mt. Sterling	3.00	6.8
July	18, 1953	184	Clingmans Dome	1.00	1.0
July	30, 1953	184	Clingmans Dome	1.35	1.0
August	8, 1953	184	Clingmans Dome	1.03	1.0
January	15-16, 1954	176	Calderwood Powerhouse	3.58	*
January	15, 1954	184	Clingmans Dome	4.71	24.0
January	14-16, 1954	184	Clingmans Dome	6.82	48.0
January	15-16, 1954	209	Gatlinburg	3.35	*
January	15-16, 1954	186	Oconaluftee	3.88	*
January	15-16, 1954	407	Cataloochee Ranch	3.07	*
January	15-16, 1954	660	Twentymile	3.19	*
January	15-16, 1954	668	Abrams Creek	4.07	*
January	20-21, 1954	176	Calderwood Powerhouse	3.21	12.0
January	20-21, 1954	186	Oconaluftee	3.04	*
January	20-21, 1954	660	Twentymile	3.04	*
January	20-21, 1954	668	Abrams Creek	3.15	*
January	22, 1954	187	Spruce Mountain	3.53	20.0
August	25, 1954	184	Clingmans Dome	1.90	1.0
December	29, 1954	184	Clingmans Dome	3.31	*
April	6-7, 1955	176	Calderwood Powerhouse	3.19	*
April	6-7, 1955	660	Twentymile	3.37	*
June	8, 1955	184	Clingmans Dome	3.50	16.0
July	8, 1955	187	Spruce Mountain	1.70	1.0

TABLE XIX (continued)

Date	Station	Location	Amount (Inches)	Duration (Hours)
July	8, 1955	187 Spruce Mountain	3.26	6.0
August	1, 1955	183 Noland Creek	1.85	1.0
August	3, 1955	187 Spruce Mountain	1.20	1.0
August	6, 1955	184 Clingmans Dome	1.45	1.0
October	7-8, 1955	184 Clingmans Dome	3.37	19.0

Data for 1956 not available

January	22-23, 1957	184	Clingmans Dome	3.84	16.0
January	31, 1957	184	Clingmans Dome	3.35	8.0
January	30-31, 1957	184	Clingmans Dome	6.48	24.0
January	31, 1957	183	Noland Creek	5.54	24.0
January	30-31, 1957	176	Calderwood Powerhouse	3.87	*
January	30, 1957	176	Calderwood Powerhouse	5.98	48.0
February	1, 1957	245	Mt. Sterling	3.29	24.0
January	31, 1957	187	Spruce Mountain	4.69	47.0
February	1, 1957	209	Gatlinburg	3.10	*
January	31, 1957	407	Cataloochee Ranch	5.22	*
February	1, 1957	668	Abrams Creek	3.20	*
April	4-5, 1957	186	Oconaluftee	3.63	*
April	4-5, 1957	187	Spruce Mountain	3.53	23.0
April	4-5, 1957	184	Clingmans Dome	3.91	23.0
April	4-5, 1957	245	Mt. Sterling	4.10	22.0
April	4-5, 1957	656	Cataloochee	3.50	*
April	4-5, 1957	660	Twentymile	3.10	*
June	24-25, 1957	660	Twentymile	3.05	*
June	24-25, 1957	668	Abrams Creek	3.05	*
November	17-18, 1957	176	Calderwood Powerhouse	3.48	*

TABLE XIX (continued)

Date	Station	Location	Amount (Inches)	Duration (Hours)
July 7-8, 1958	184	Clingmans Dome	3.77	24.0
September 20-21, 1958	184	Clingmans Dome	3.44	13.0
September 30, 1958	184	Clingmans Dome	3.00	15.0
October 1, 1958				
May 22-23, 1959	668	Abrams Creek	3.11	*
June 5, 1959	184	Clingmans Dome	1.08	1.0
June 23-24, 1959	660	Twentymile	3.12	18.0
June 24-25, 1959	210	Mt. Le Conte	3.46	*
June 26, 1959	184	Clingmans Dome	1.85	1.0
June 25-26, 1959	184	Clingmans Dome	4.46	24.0
July 1, 1959	184	Clingmans Dome	1.49	1.0
August 17-18, 1959	184	Clingmans Dome	3.57	24.0
September 29-30, 1959	210	Mt. Le Conte	3.10	*
September 29-30, 1959	407	Cataloochee Ranch	3.08	19.1
September 30, 1959	399A	Pittman Center	3.04	17.0
October 1, 1959	210	Mt. Le Conte	3.19	*
November 27, 1959	184	Clingmans Dome	3.50	12.0
June 23, 1960	184	Clingmans Dome	1.03	1.0
September 8, 1960	187	Spruce Mountain	1.05	1.0
September 11-12, 1960	245	Mt. Sterling	3.86	*
March 7-8, 1961	660	Twentymile	3.18	*
June 19, 1961	210	Mt. Le Conte	1.13	0.6
June 20-21, 1961	176	Calderwood Powerhouse	4.09	*
June 22, 1961	210	Mt. Le Conte	3.50	1.8
August 2, 1961	210	Mt. Le Conte	.75	0.4
August 3, 1961	187	Spruce Mountain	1.40	1.0
October 3, 1961	184	Clingmans Dome	3.06	11.0
October 3, 1961	210	Mt. Le Conte	3.37	21.5
December 11, 1961	184	Clingmans Dome	3.20	11.0
December 11-12, 1961	184	Clingmans Dome	5.54	24.0
December 11-12, 1961	176	Calderwood Powerhouse	3.24	*
December 11-12, 1961	186	Oconaluftee	4.08	*

TABLE XIX (continued)

Date	Station	Location	Amount (Inches)	Duration (Hours)
December 11-12, 1961	542	Cherokee	3.48	*
December 11-12, 1961	599	Big Cove	3.40	14.0
December 11-12, 1961	656	Chataloochee Ranch	3.50	*
December 17-18, 1961	176	Calderwood Powerhouse	3.01	*
December 17-18, 1961	184	Clingmans Dome	3.10	16.0
December 17-18, 1961	660	Twentymile	3.12	*
February 22-23, 1962	184	Clingmans Dome	3.95	24.0
February 23, 1962	187	Spruce Mountain	3.24	24.0
June 19, 1962	184	Clingmans Dome	1.16	1.0
June 19, 1962	299A	Pittman Center	1.03	1.0
June 26, 1962	210	Mt. Le Conte	1.85	1.5
July 8, 1962	187	Spruce Mountain	1.20	1.0
July 24-25, 1962	184	Clingmans Dome	3.90	24.0
July 24-25, 1962	187	Spruce Mountain	3.45	24.0
July 25-26, 1962	210	Mt. Le Conte	3.83	*
July 25-26, 1962	599	Big Cove	3.30	19.0
July 30, 1962	187	Spruce Mountain	1.08	1.0
August 6-7, 1962	668	Abrams Creek	3.06	*
August 7, 1962	210	Mt. Le Conte	0.75	0.25
September 16, 1962	184	Clingmans Dome	3.08	12.0
September 16-17, 1962	184	Clingmans Dome	5.22	24.0
September 16-17, 1962	599	Big Cove	3.10	24.0
March 5, 1963	184	Clingmans Dome	3.10	12.0
March 5, 1963	184	Clingmans Dome	5.20	24.0
March 5-6, 1963	186	Oconaluftee	4.76	*
March 5-6, 1963	176	Calderwood Powerhouse	4.02	*
March 5-6, 1963	187	Spruce Mountain	3.14	13.0
March 5-6, 1963	187	Spruce Mountain	5.01	24.0
March 5-6, 1963	209	Gatlinburg	3.05	*
March 5-6, 1963	245	Mt. Sterling	4.06	*
March 5-6, 1963	399A	Pittman Center	2.97	24.0
March 5-6, 1963	656	Cataloochee	5.96	*
March 5-6, 1963	660	Twentymile	3.14	*
March 5-6, 1963	668	Abrams Creek	3.55	*
March 11-12, 1963	176	Calderwood Powerhouse	3.80	*
March 11-12, 1963	184	Clingmans Dome	3.00	7.0

TABLE XIX (continued)

Date		Station	Location	Amount (Inches)	Duration (Hours)
March	11-12, 1963	184	Clingmans Dome	5.84	24.0
March	11-12, 1963	245	Mt. Sterling	4.72	*
March	11-12, 1963	299A	Pittman Center	3.65	23.0
March	11-12, 1963	668	Abrams Creek	3.65	*
April	29-30, 1963	184	Clingmans Dome	3.14	23.0
July	28, 1963	210	Mt. Le Conte	1.40	0.7
August	25, 1963	184	Clingmans Dome	1.17	1.0
November	28-29, 1963	184	Clingmans Dome	3.54	24.0
March	14-15, 1964	176	Calderwood Powerhouse	3.30	*
March	14-15, 1964	210	Mt. Le Conte	3.20	*
March	14-15, 1964	599	Big Cove	3.10	24.0
March	14-15, 1964	660	Twentymile	3.83	*
March	14-15, 1964	668	Abrams Creek	3.30	*
April	7, 1964	187	Spruce Mountain	3.08	12.0
May	12, 1964	399A	Pittman Center	1.10	1.0
June	12, 1964	399A	Pittman Center	1.23	1.0
June	13, 1964	399A	Pittman Center	1.37	1.0
July	20, 1964	210	Mt. Le Conte	1.11	0.5
July	28, 1964	187	Spruce Mountain	1.22	1.0
August	3, 1964	184	Clingmans Dome	1.15	1.0
August	12, 1964	210	Mt. Le Conte	1.11	1.0
August	15-16, 1964	184	Clingmans Dome	4.04	24.0
August	16, 1964	187	Spruce Mountain	3.01	24.0
August	29-30, 1964	245	Mt. Sterling	3.18	*
August	29-30, 1964	656	Cataloochee	3.14	24.0
October	3-4, 1964	184	Clingmans Dome	3.04	23.0
March	25-26, 1965	183	Noland Creek	3.88	24.0
March	25-26, 1965	184	Clingmans Dome	4.65	24.0
March	25-26, 1965	186	Oconaluftee	4.07	*
March	25-26, 1965	187	Spruce Mountain	3.60	24.0
March	25-26, 1965	209	Gatlinburg	4.48	*
March	25-26, 1965	245	Mt. Sterling	3.27	*
March	25-26, 1965	656	Cataloochee	3.50	*
March	25-26, 1965	668	Abrams Creek	4.08	*
May	25, 1965	210	Mt. Le Conte	1.52	0.8
May	27, 1965	210	Mt. Le Conte	0.98	0.4
July	27, 1965	210	Mt. Le Conte	1.30	1.0

TABLE XIX (continued)

Date		Station	Location	Amount (Inches)	Duration (Hours)
February	13, 1966	399A	Pittman Center	1.10	1.0
February	12-13, 1966	299A	Pittman Center	3.37	24.0
February	12-13, 1966	542	Cherokee	4.54	*
June	29, 1966	399A	Pittman Center	1.20	1.0
June	29-30, 1966	209	Gatlinburg	4.59	*
July	29-30, 1966	209	Gatlinburg	3.03	*
July	29-30, 1966	399A	Pittman Center	3.73	24.0
August	2, 1966	184	Clingmans Dome	1.40	1.0
August	9, 1966	187	Spruce Mountain	1.05	1.0
August	9-10, 1966	209	Gatlinburg	3.45	*
August	19-20, 1966	660	Twentymile	7.35	*
October	18-19, 1966	184A	Clingmans Dome	3.20	21.0
February	6-7, 1967	819	Newfound Gap	3.02	23.0
February	17, 1967	187	Spruce Mountain	3.18	24.0
June	3-4, 1967	183	Noland Creek	3.02	22.0
June	3-4, 1967	187	Spruce Mountain	3.30	24.0
June	3-4, 1967	210	Mt. Le Conte	3.70	21.0
June	3-4, 1967	656	Cataloochee	3.26	*
June	3-4, 1967	660	Twentymile	3.08	*
June	4, 1967	184A	Clingmans Dome	3.20	18.0
July	1, 1967	209A	Gatlinburg	1.22	1.0
July	6-7, 1967	184A	Clingmans Dome	3.30	*
July	28, 1967	210	Mt. Le Conte	1.12	1.0
August	31, 1967	210	Mt. Le Conte	3.40	1.5
April	23, 1968	187	Spruce Mountain	1.02	1.0
July	13, 1968	209A	Gatlinburg	1.10	1.0
July	19, 1968	399A	Pittman Center	1.05	1.0
July	18-19, 1968	668	Abrams Creek	4.61	*
August	4, 1968	209A	Gatlinburg	1.62	1.0
August	19, 1968	187	Spruce Mountain	1.18	1.0
August	19, 1968	819	Newfound Gap	1.50	1.0

Information compiled from Tennessee Valley Authority, Hydraulic Data Branch records.

* Occurred in 24 hours or less--exact duration unknown.

APPENDIX B

TABLE XX

SOIL ANALYSIS DATA, ALUM CAVE CREEK WATERSHED

Depth (centimeters)	pH	Extractable Potassium (ppm)	Extractable Phosphorus (ppm)	Extractable Aluminum (ppm)	Exchange Acidity (ppm)	Extractable Iron (percent)
Slide ACC-2						
Profile ACC-2a						
10	3.0	75	12	687	164	0
20	3.5	40	2	277	45.6	0.70
30	4.3	30	2	297	38.2	0.84
40	4.5	15	1	193	19.1	0.67
50	4.5	10	1	147	13.3	0.75
60	4.7	10	1	440	12.9	0.75
70	4.6	10	1.5	163	12.1	0.70
80	4.3	15	1.5	208	19.5	0.84
Profile ACC-2b						
10	3.5	110	7	312	74.5	0.08
20	4.0	35	2.5	307	41.7	1.46
30	5.0	35	1	480	53.0	3.70
40	5.2	25	1	376	38.6	3.16
50	5.0	25	1	322	32.8	2.85
60	5.0	30	1.5	480	51.9	3.13
Profile ACC-2c						
10	3.7	115	5	257	70.6	0
20	3.3	90	13	613	138	0
30	4.3	55	1	1193	150	2.68
40	5.3	45	1	757	83.8	3.36
50	5.4	30	1.5	310	33.6	2.80
60	5.4	15	1	158	14.4	1.68
70	5.8	20	1	153	10.6	1.65

TABLE XX (continued)

Depth (centimeters)	pH	Extractable Potassium (ppm)	Extractable Phosphorus (ppm)	Extractable Aluminum (ppm)	Exchange Acidity (ppm)	Extractable Iron (percent)
80	5.8	25	1	178	13.4	1.93
90	5.6	20	1	183	14.4	1.82
100	5.4	15	1	233	26.0	1.48
110	5.5	20	1	193	18.7	1.46
120	5.7	10	1	163	14.4	1.71
130	5.4	10	2	178	14.4	1.96
140	5.5	15	2.5	198	17.8	1.84
Slide SB-1						
Profile SB-1a						
10	3.8	85	8	435	136	0
20	3.7	65	5.5	767	136	0
30	4.3	10	2.5	109	8.9	0.20
40	4.5	10	2	401	43.0	0.53
50	4.8	10	2.5	317	33.6	0.73
60	5.4	10	2	64	3.9	0.61
70	5.7	10	2	30	0	0.61
80	5.7	10	6	30	0	1.50
90	5.5	10	9	25	0	0.89
100	5.7	10	10.5	35	0	0.95
Profile SB-1b						
10	4.1	95	3.5	1130	156	0.73
20	4.3	45	2	881	116	2.24
30	4.3	30	2	802	105	2.82
40	4.3	30	1.5	772	100	4.64
50	4.7	10	1	242	27.3	7.28

TABLE XX (continued)

Depth (centimeters)	pH	Extractable Potassium (ppm)	Extractable Phosphorus (ppm)	Extractable Aluminum (ppm)	Exchange Acidity (ppm)	Extractable Iron (percent)
60	5.2	5	2.5	30	1.6	5.32
70	5.2	5	8	35	0	5.64
Profile SB-1c						
10	3.6	50	10	381	107	0.11
20	3.7	25	2	386	64.4	0.92
30	4.0	10	2	153	16.8	0.81
40	4.0	10	1	139	14.0	1.01
50	4.5	5	1	158	18.0	-
60	4.3	5	2.5	183	19.9	1.45
70	4.5	25	2	376	46.8	1.84
Slide SB-2						
Profile SB-2a						
10	3.8	80	12	603	137	0.08
20	3.3	40	3.5	1235	212	0.08
30	4.0	15	1	84	10.5	0.67
40	4.0	15	2	134	16.8	0.84
50	4.0	20	1	835	97.5	0.98
60	4.5	40	1	1125	130	1.68
70	4.7	30	1	830	92.5	2.18
80	5.2	10	1.5	238	20.7	1.62
Profile SB-2b						
10	3.7	75	15	623	126	0.16
20	3.8	30	1	257	37.0	0.95
30	4.3	30	1	317	45.2	2.24

TABLE XX (continued)

Depth (centimeters)	pH	Extractable Potassium (ppm)	Extractable Phosphorus (ppm)	Extractable Aluminum (ppm)	Exchange Acidity (ppm)	Extractable Iron (percent)
40	4.7	20	1	306	26.5	2.74
50	4.8	15	1	247	26.5	3.08
60	4.7	15	1	252	24.2	3.69
70	5.0	15	1	247	25.4	3.94
Slide SB-8						
Profile SB-8a						
10	3.7	75	9	332	75.0	0.15
20	3.7	70	1.5	644	102	2.77
30	4.8	20	1.5	441	49.9	4.39
40	4.7	10	1.5	322	34.7	5.18
50	4.8	10	2	213	21.4	3.78
60	4.9	10	2.5	223	21.8	4.17
70	4.8	10	1.5	157	15.6	3.72
80	4.8	10	1.5	114	12.9	4.37
90	4.8	10	1.5	109	11.3	4.12
100	4.8	10	1.5	119	11.7	4.00
Profile SB-8b						
10	4.0	60	10	638	13.7	0.11
20	4.3	15	1	183	23.8	1.32
30	4.3	15	1	342	40.5	0.98
40	4.5	25	1	727	88.8	2.16
50	4.7	25	2.5	707	84.1	3.22
60	5.4	15	1	352	34.7	3.38
70	5.4	10	1	148	11.3	2.86
80	5.2	5	1	119	7.4	2.27

TABLE XX (continued)

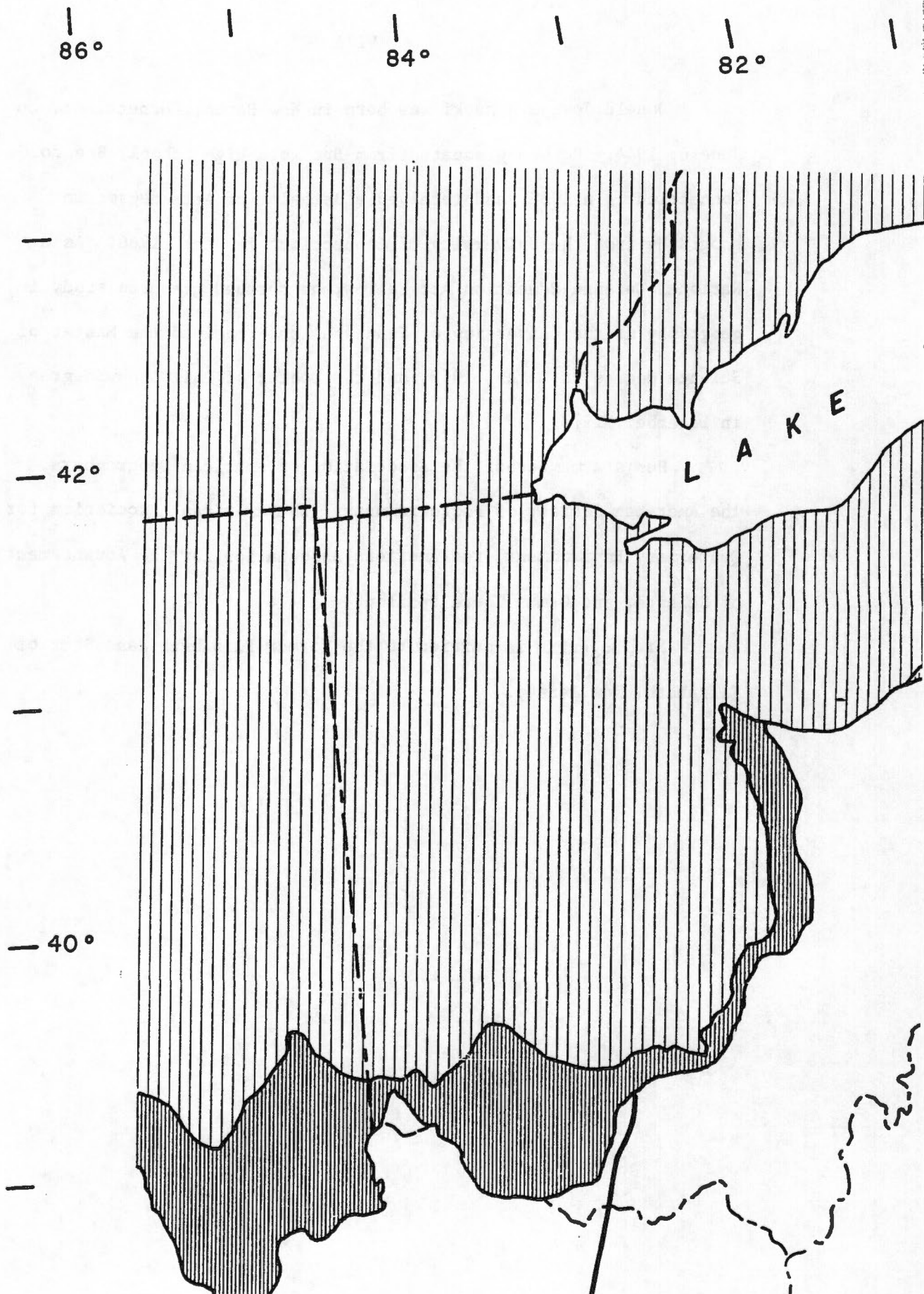
Depth (centimeters)	pH	Extractable Potassium (ppm)	Extractable Phosphorus (ppm)	Extractable Aluminum (ppm)	Exchange Acidity (ppm)	Extractable Iron (percent)
Profile SB-8c						
10	3.8	75	2.5	366	54.2	1.93
20	4.4	35	2.5	366	44.1	2.46
30	4.5	35	2.5	352	41.7	2.68
40	4.3	30	2.5	317	33.2	2.99
50	4.8	25	2.5	2.3	24.2	3.50
60	4.7	15	3	178	18.3	3.61
70	5.0	10	3.5	139	13.3	3.55
80	5.2	20	5	79.2	6.6	3.44

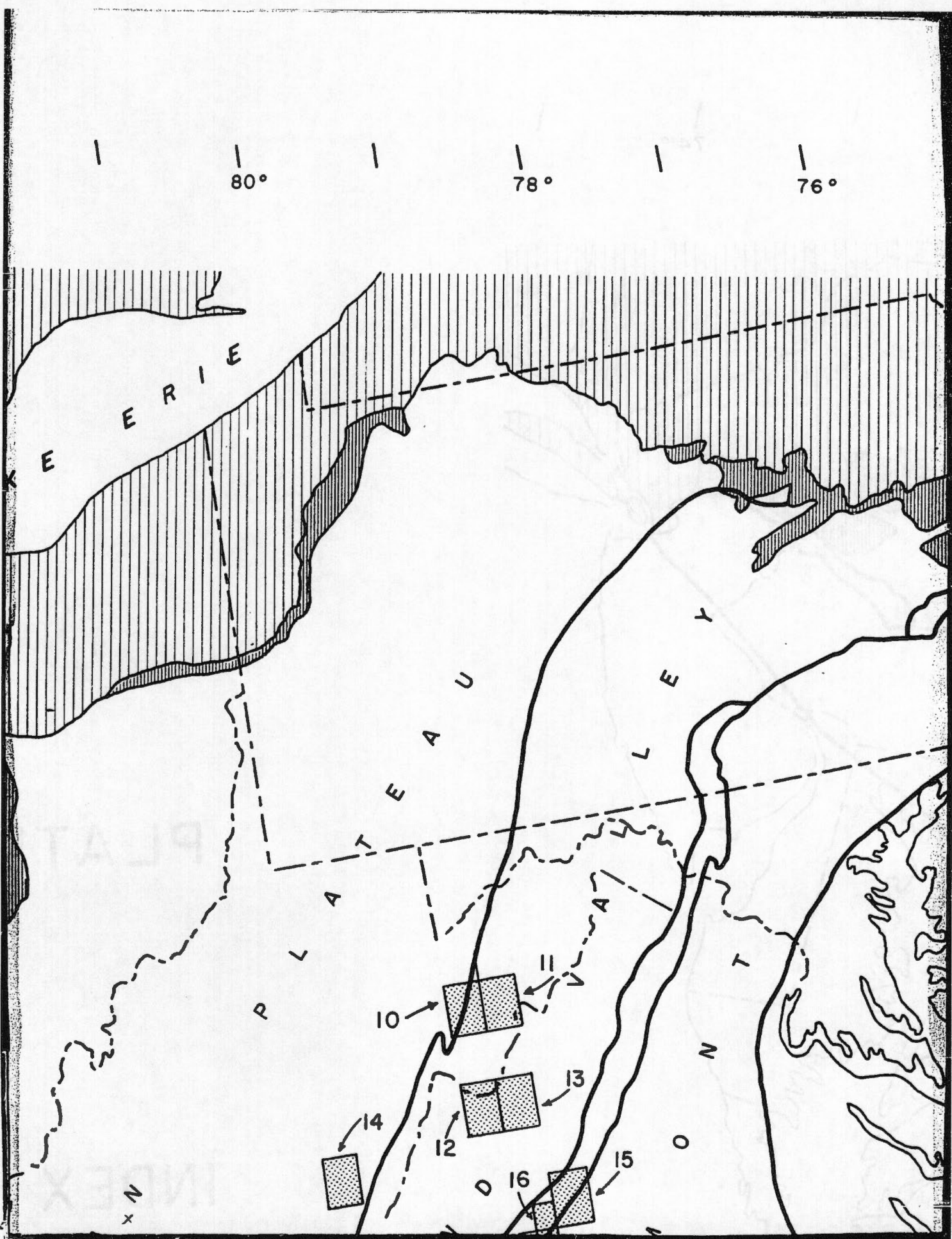
VITA

Donald Joseph Bogucki was born in New Haven, Connecticut, on June 6, 1944. He was graduated from Branford High School, Branford, Connecticut, in 1962, and received a Bachelor of Arts degree in geography from the University of Connecticut in June, 1966. As a National Defense Education Act Fellow, he pursued graduate study in geography at the University of Tennessee and received the Master of Science degree in March, 1968, and the Doctor of Philosophy degree in December, 1970.

He is a member of the Association of American Geographers, the American Society of Photogrammetry, the American Association for Quaternary Environment, the American Association for the Advancement of Science, and Gamma Theta Upsilon.

Mr. Bogucki is married to the former Elizabeth Jane Baer of Elizabeth, New Jersey.





74°

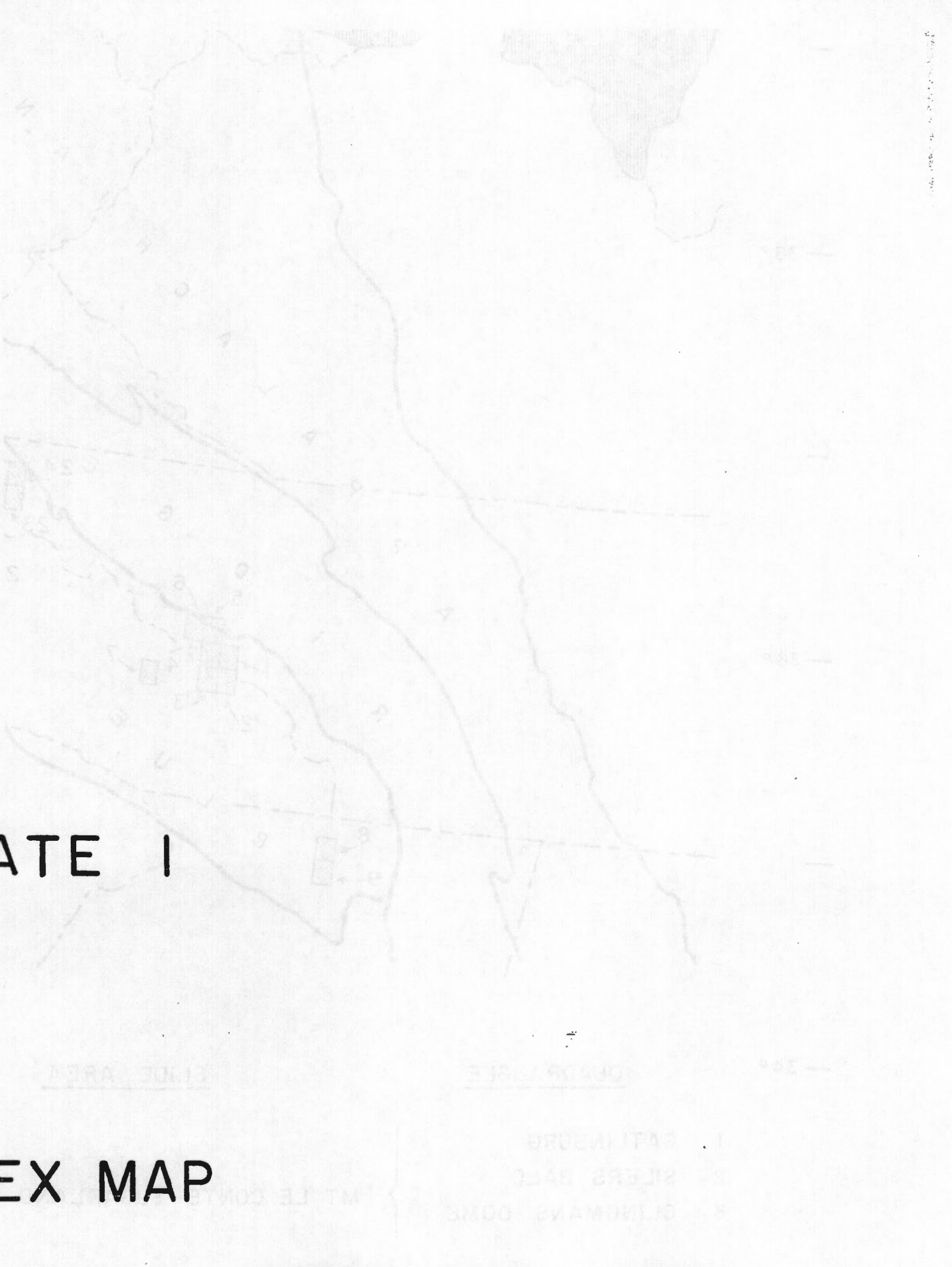


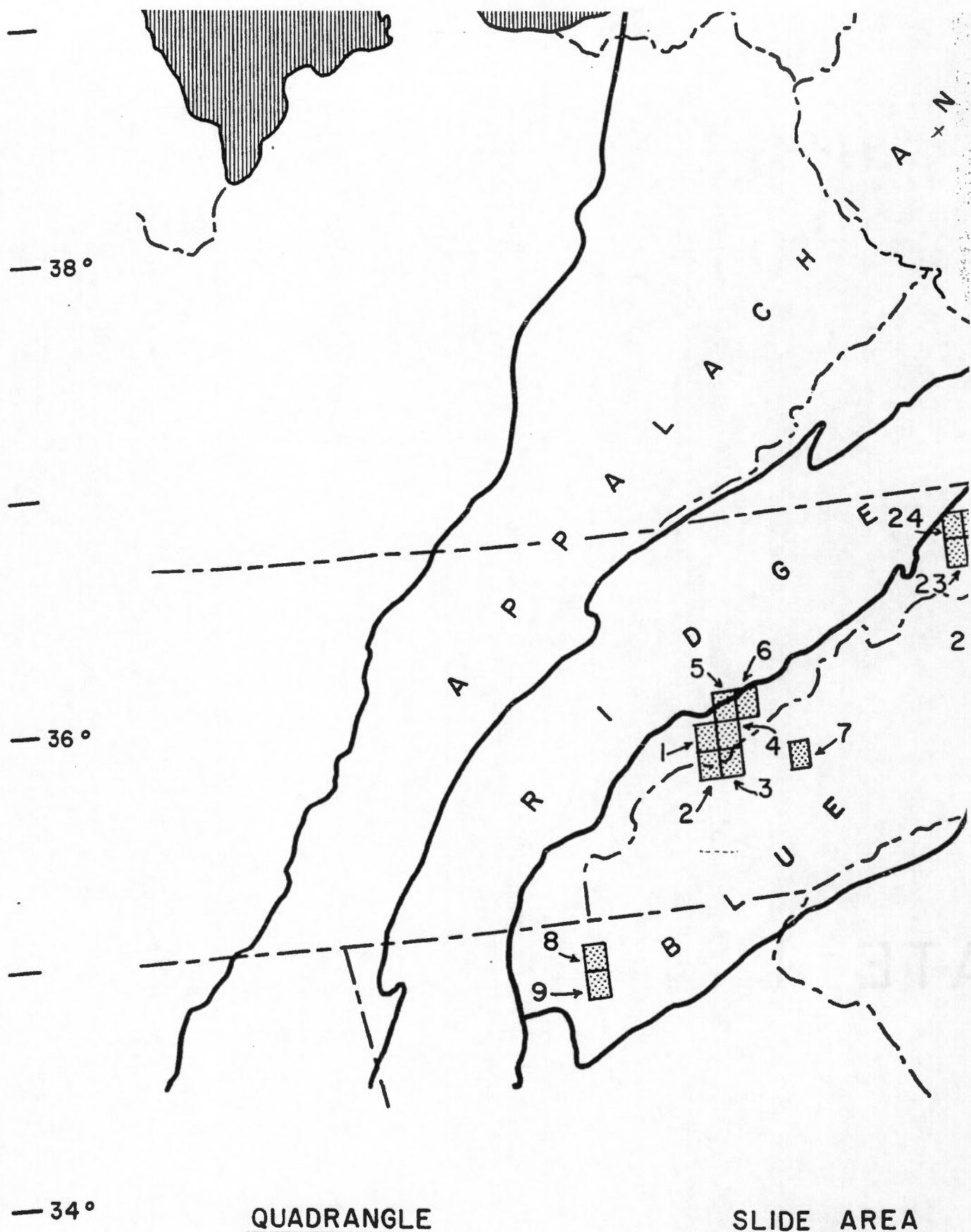
PLATE

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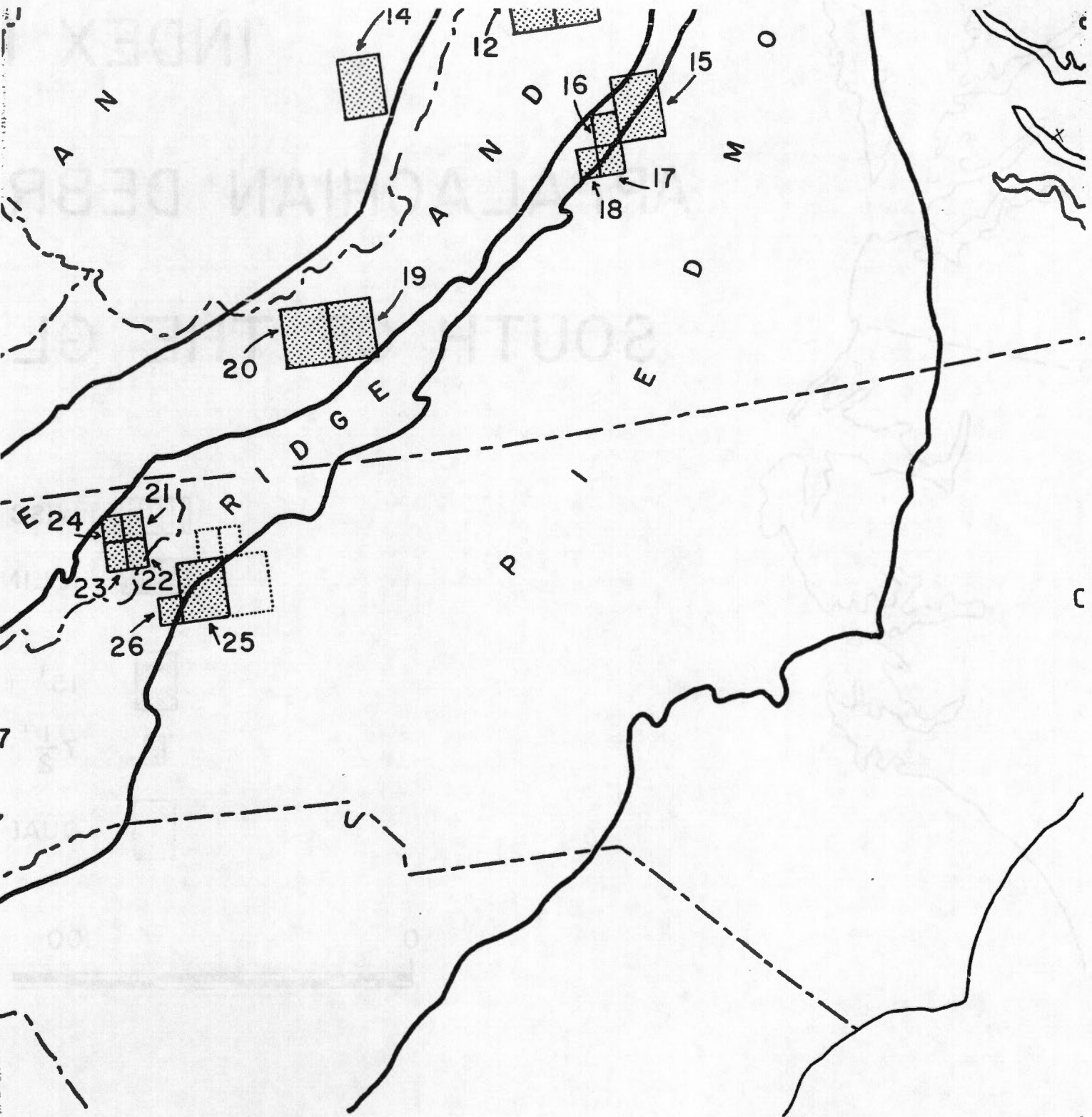
ATE I

EX MAP





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| 1 | GATLINBURG | } | MT LE CONTE-SUGARLAND |
| 2 | SILERS BALD | | |
| 3 | CLINGMANS DOME | | |



AREA

QUADRANGLE

SLI

GARLAND MOUNTAIN AREA

14 LOBELIA

15 LOVINGSTON

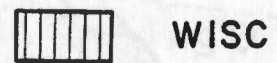
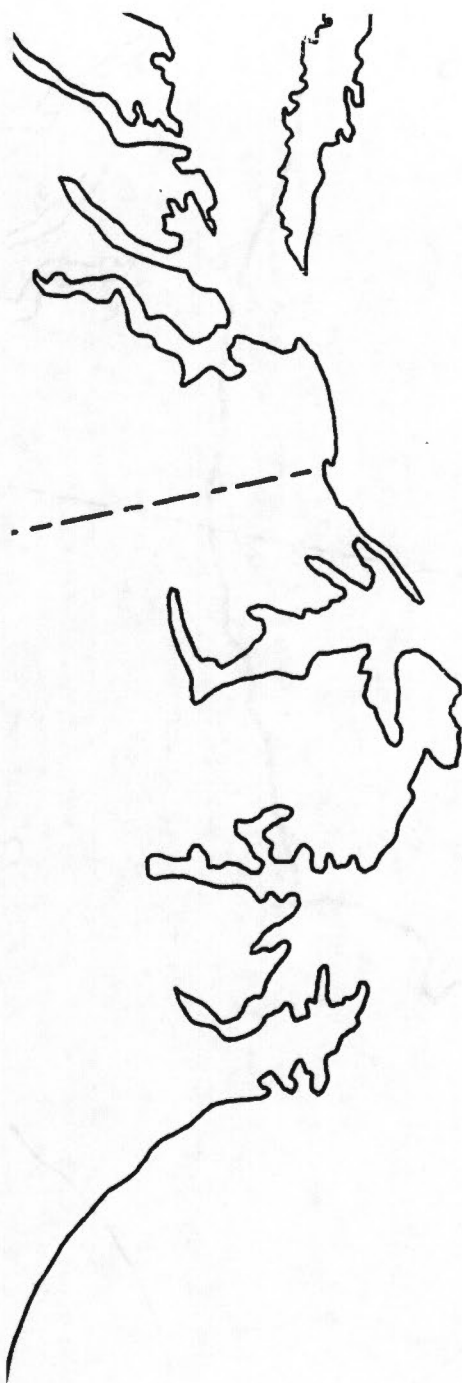
16 MASSIE MILL

} RENICK

INDEX I

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ILLIN



15'



7 1/2'



QUAT



SLIDE AREA

RENICK AREA

X MAP

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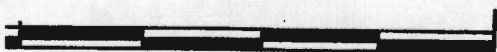
ILLINOIAN DRIFT

15' QUADRANGLE

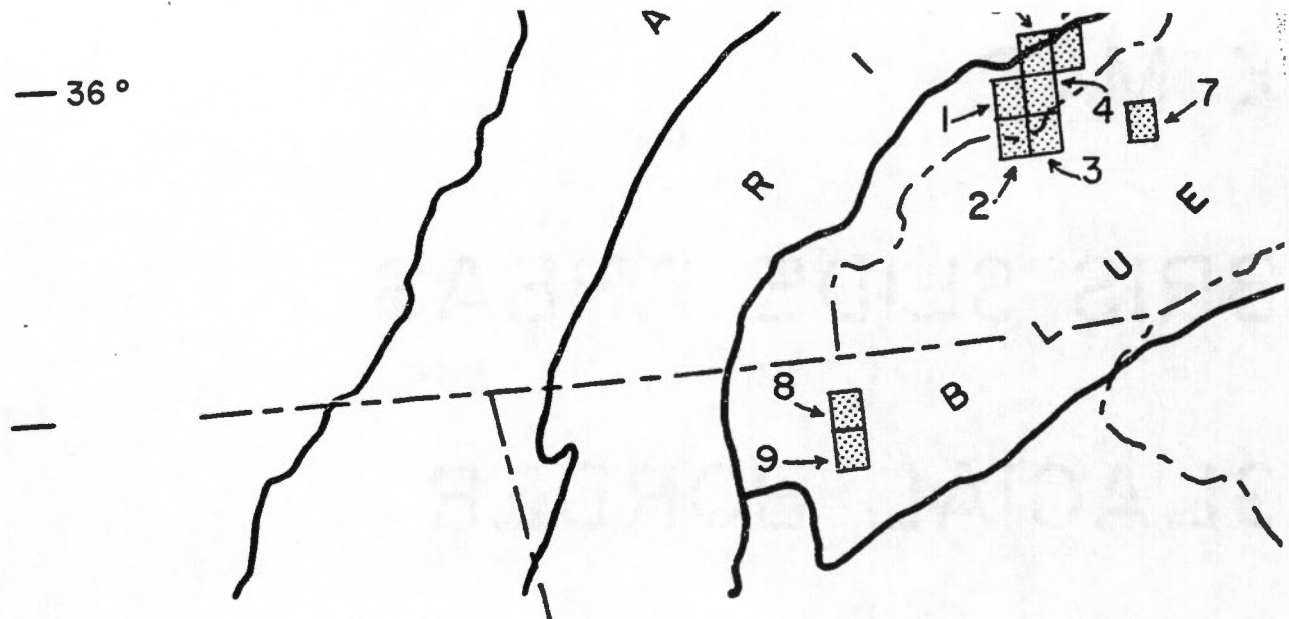
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QUADRANGLE UNMAPPED

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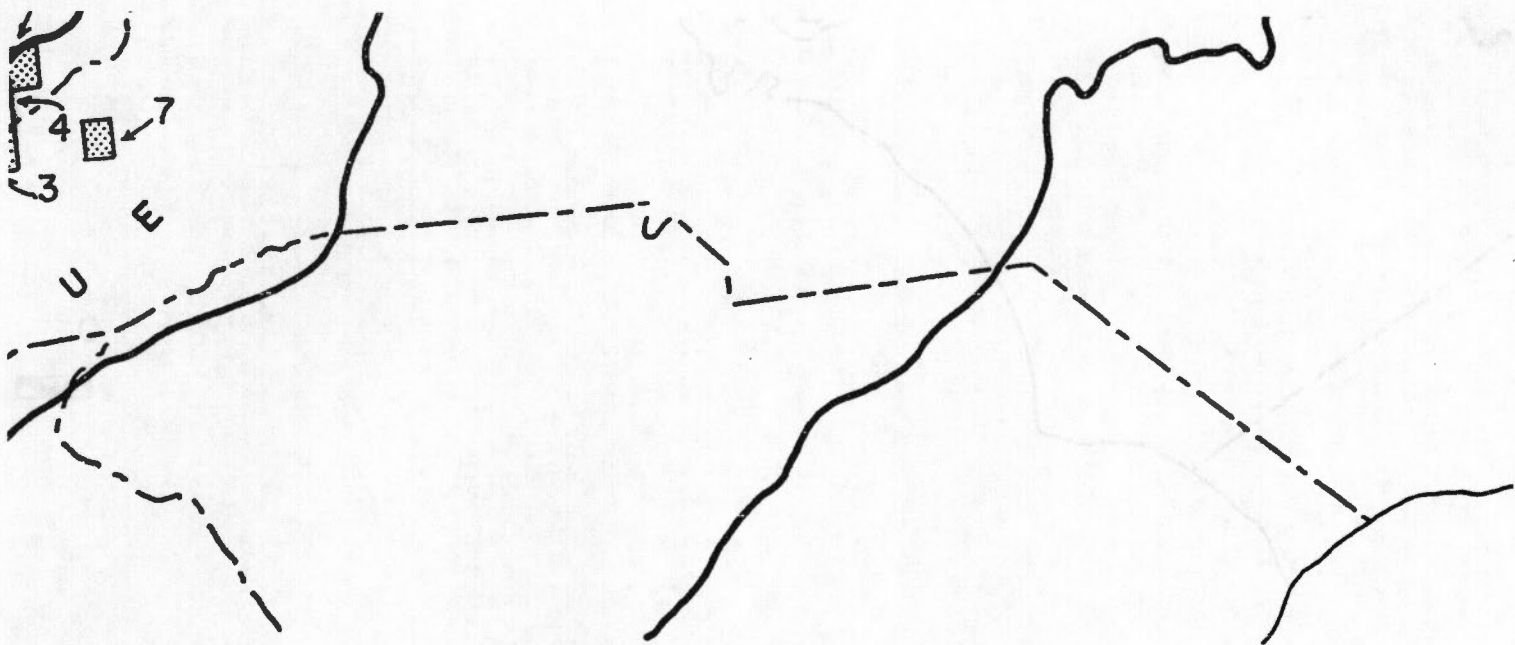


— 34°

QUADRANGLE

SLIDE AREA

1	GATLINBURG	}	MT LE CONTE—SUGARLA
2	SILERS BALD		
3	CLINGMANS DOME		
4	MT LE CONTE		
5	RICHARDSON COVE	}	WEBB MOUNTAIN AREA
6	JONES COVE		
7	DELLWOOD	}	COVE CREEK AREA
8	LAKE TOCCOA		
9	TICKANETLEY	}	BLUE RIDGE AREA
10	ONEGO		
11	PETERSBURG	}	PETERSBURG AREA
12	MC DOWELL		
13	PARNASSUS	}	LITTLE RIVER AREA



SLIDE AREA

QUADRANGLE

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|----|------------------|---|
| 14 | LOBELIA | } |
| 15 | LOVINGSTON | } |
| 16 | MASSIES MILL | |
| 17 | PINEY RIVER | |
| 18 | FORKS OF BUFFALO | |
| 19 | RADFORD | } |
| 20 | PULASKI | |
| 21 | DOE | } |
| 22 | ELK MILLS | |
| 23 | WATAUGA DAM | |
| 24 | CARTER | |
| 25 | BLOWING ROCK | } |
| 26 | GRANDFATHER MTN | |



QUADRANGLE

SLIDE AREA

BELIA



RENICK AREA

LOVINGSTON

WATKINS MILL

WATKINS RIVER

WATKINS OF BUFFALO



LOVINGSTON AREA

WATKINS

WATKINS



WATKINS AREA

WATKINS

WATKINS

WATKINS DAM

WATKINS



WATKINS LAKE AREA

WATKINS ROCK

WATKINS MTN



WATKINS MTN AREA



10 QUADRANGLE



$7\frac{1}{2}$ QUADRANGLE

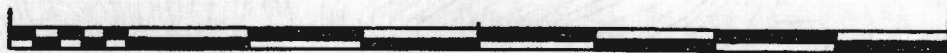


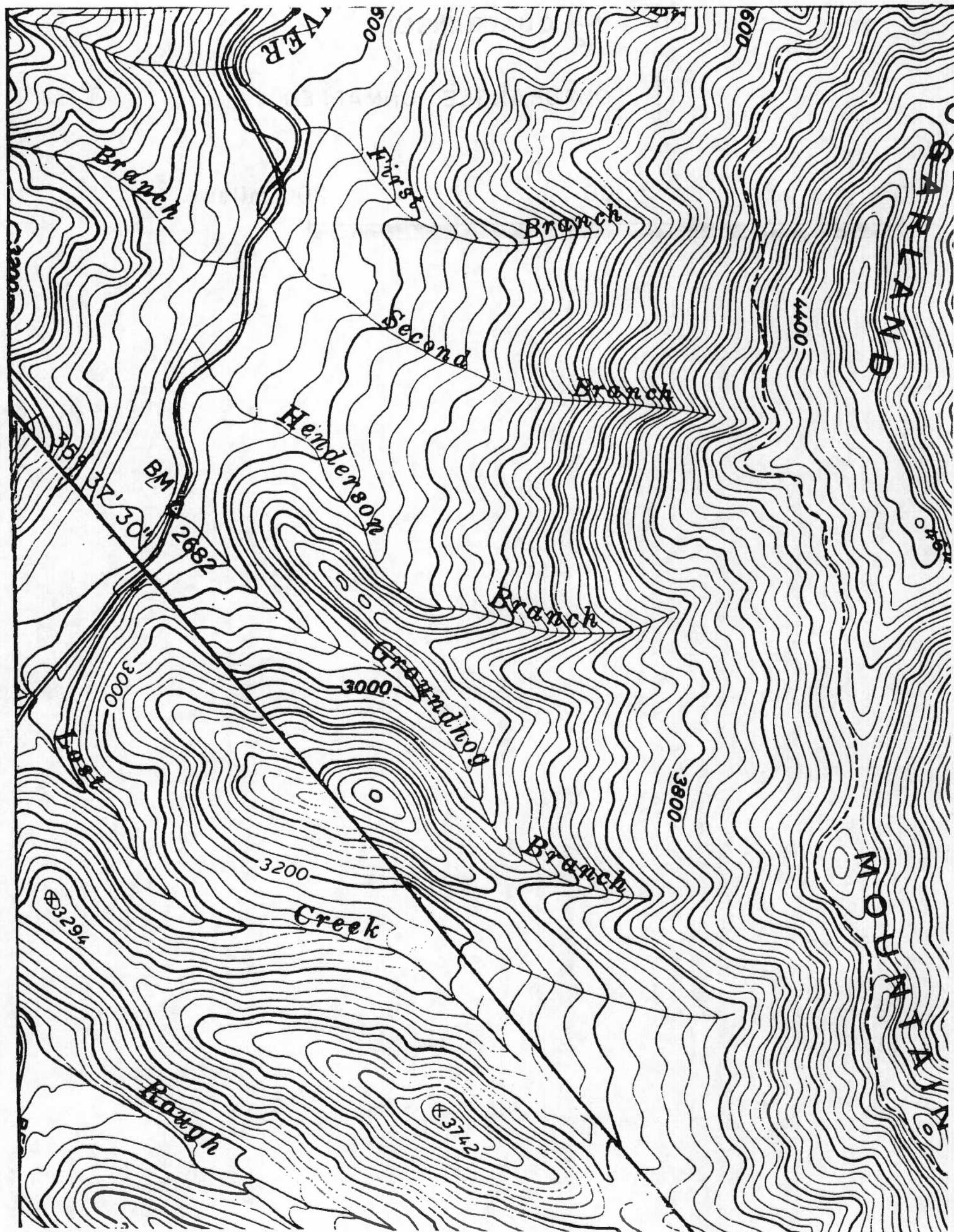
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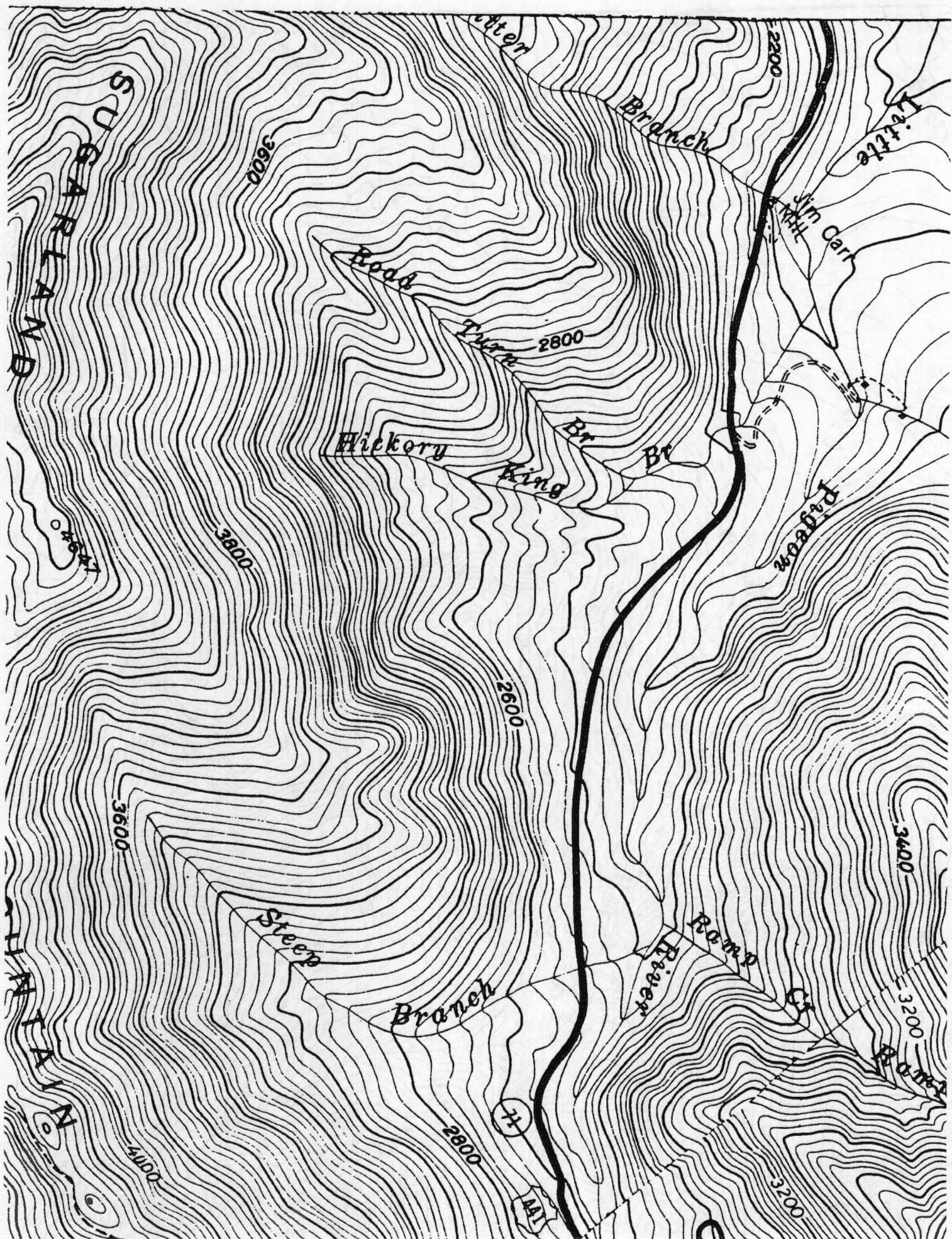
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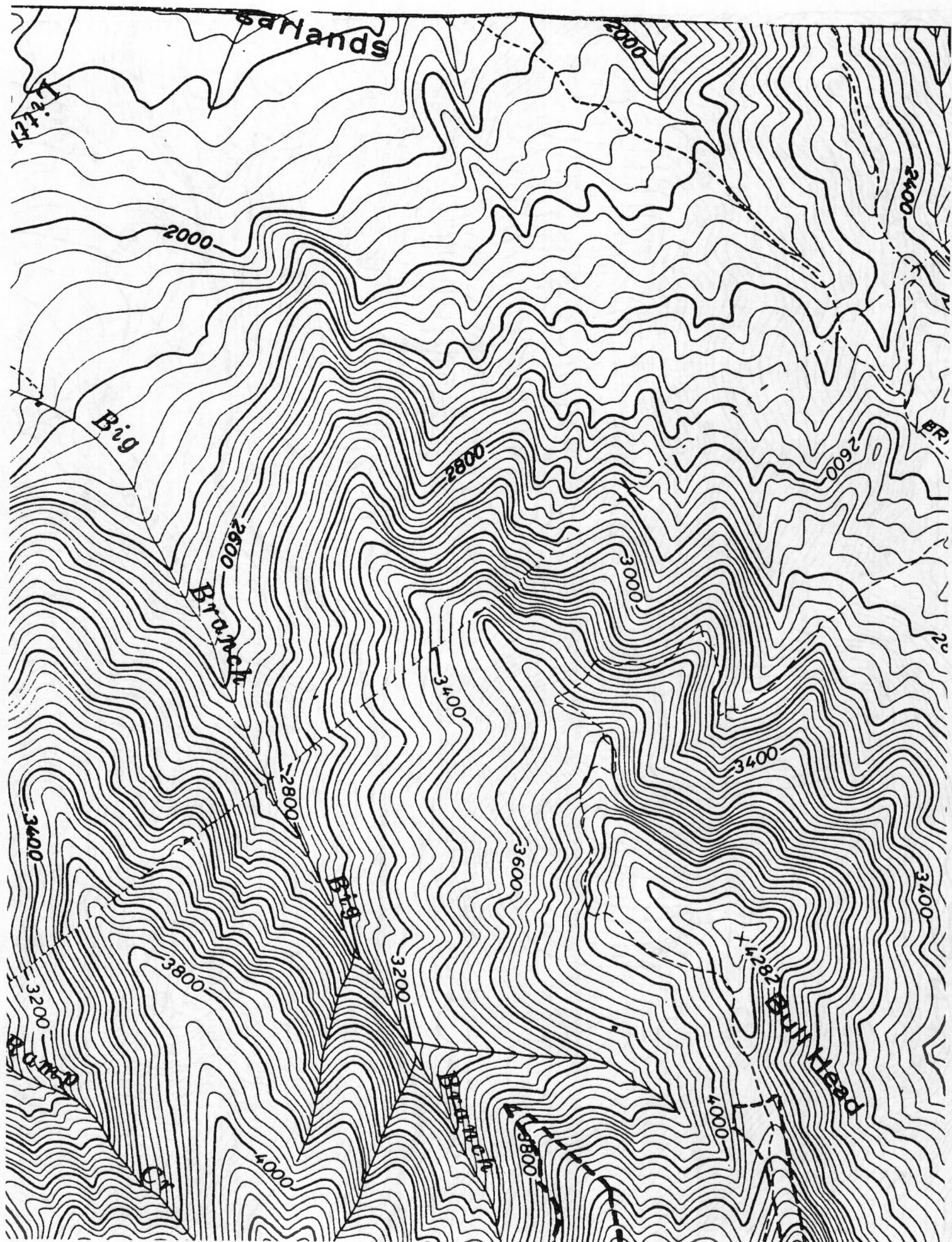
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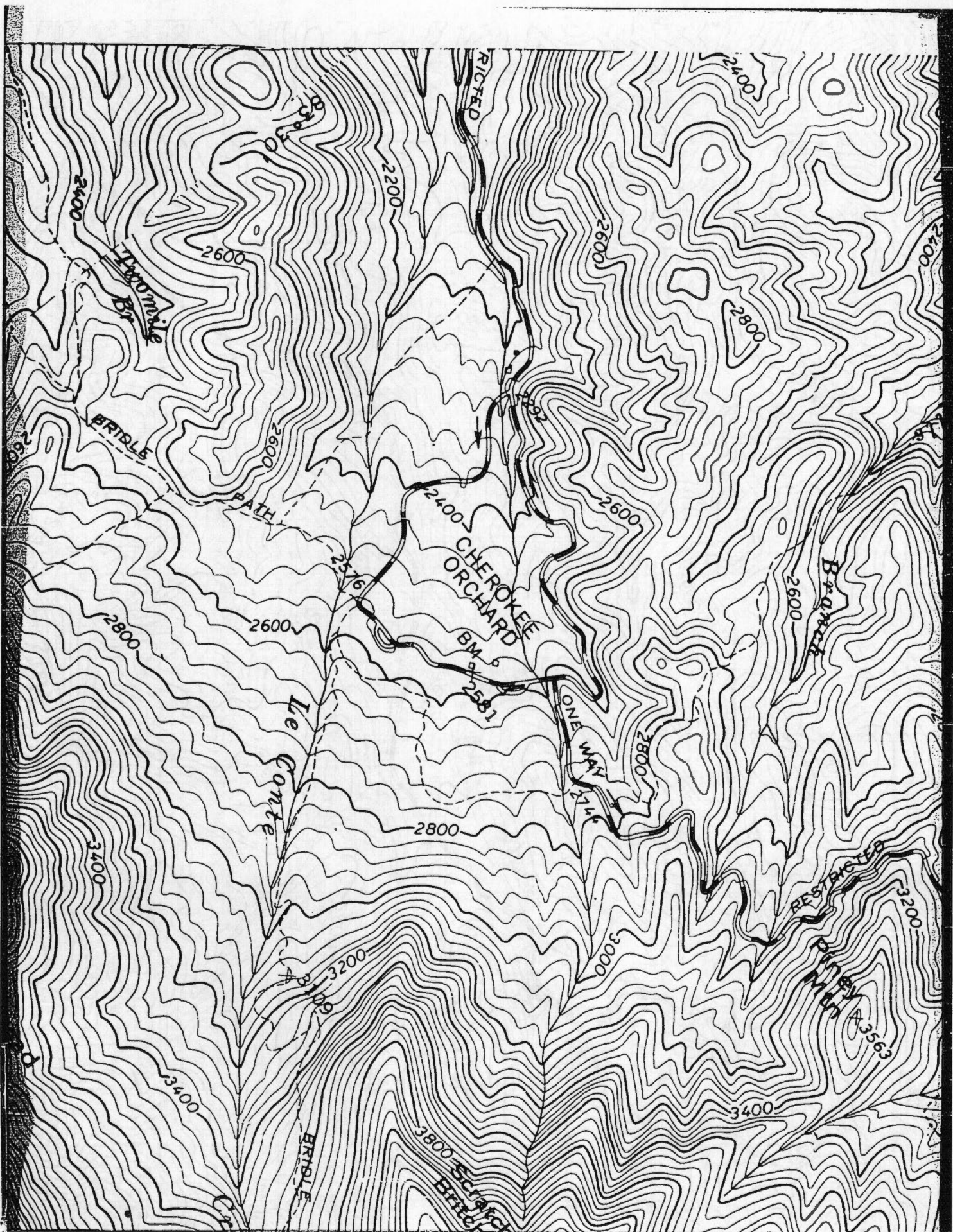
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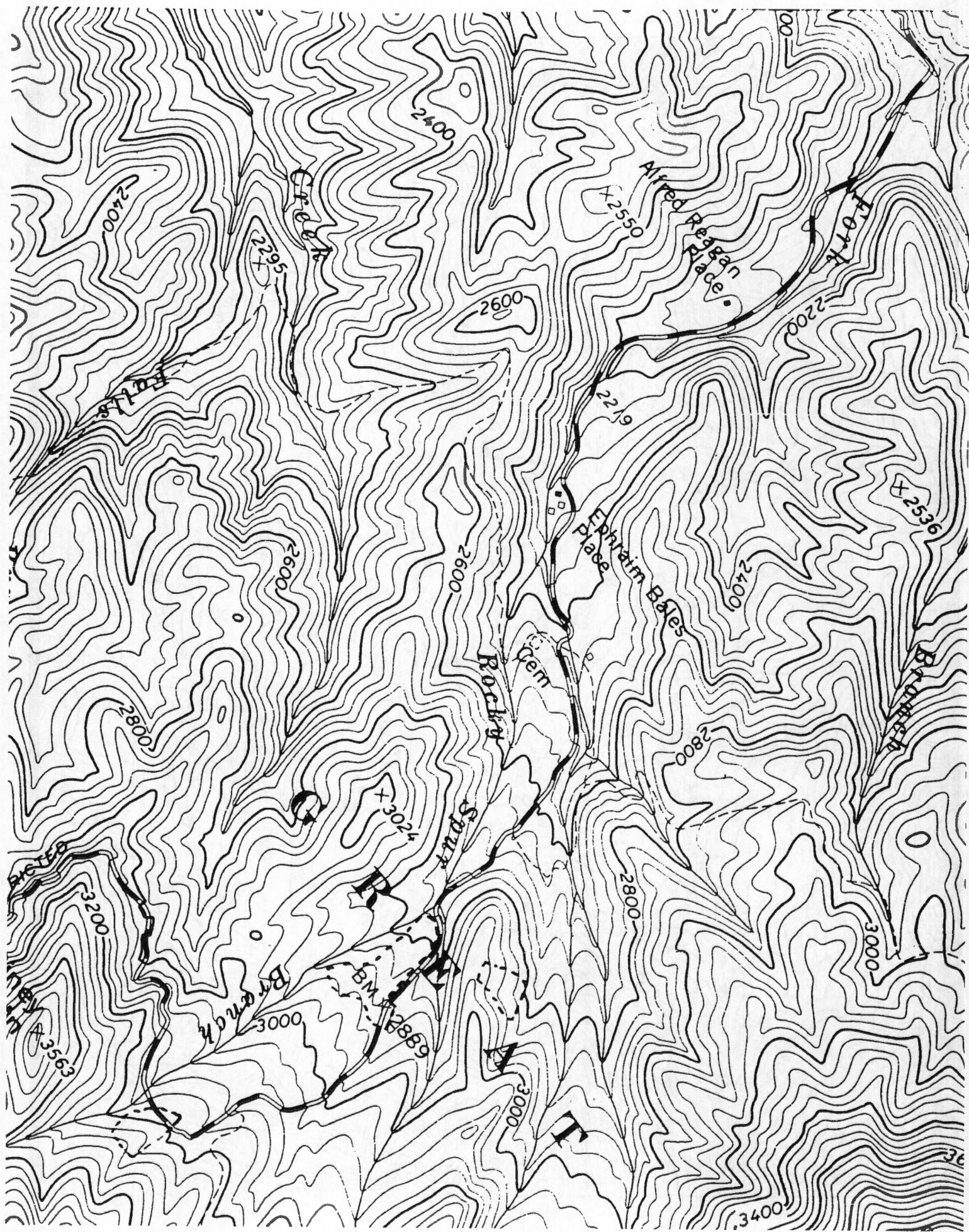


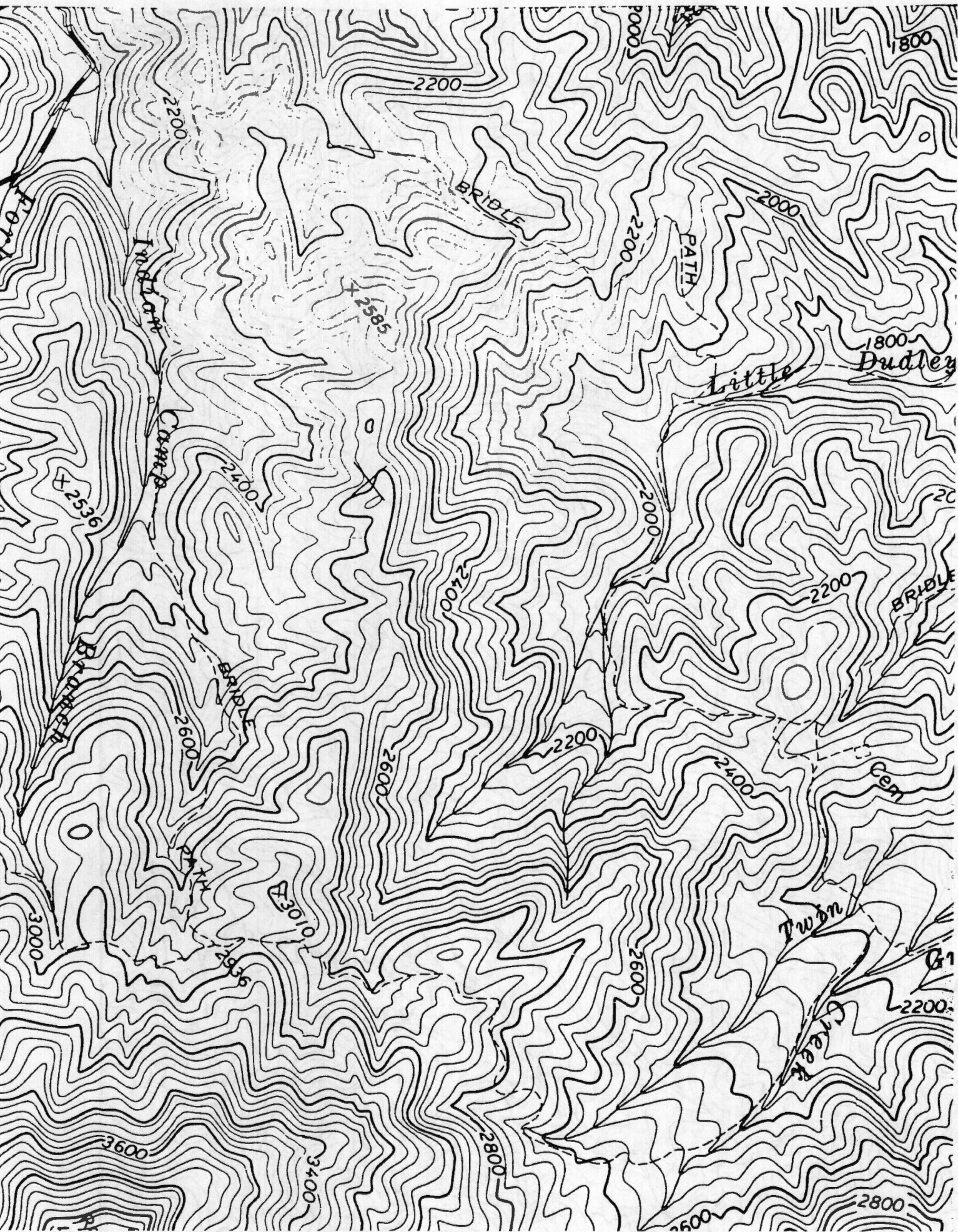




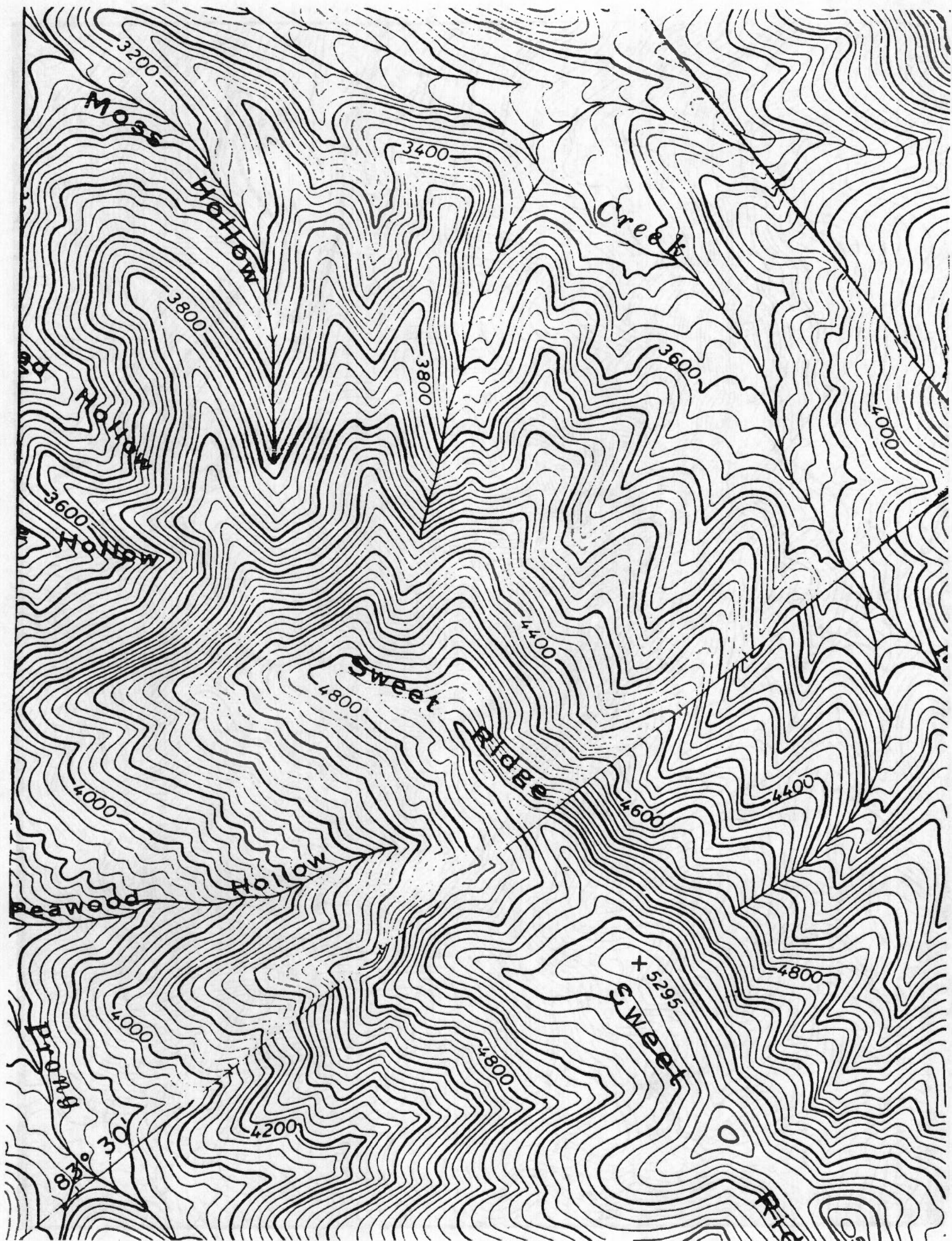


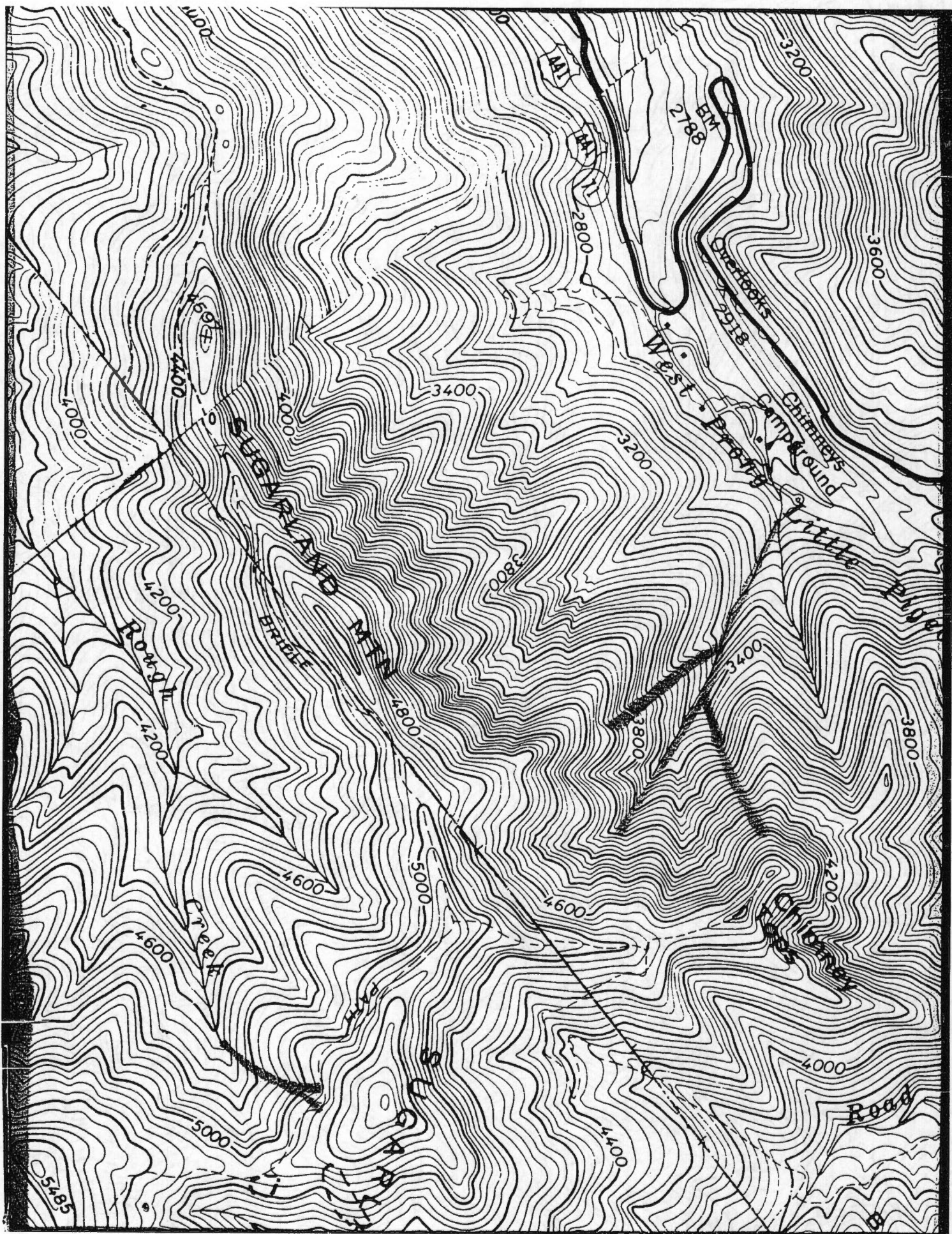


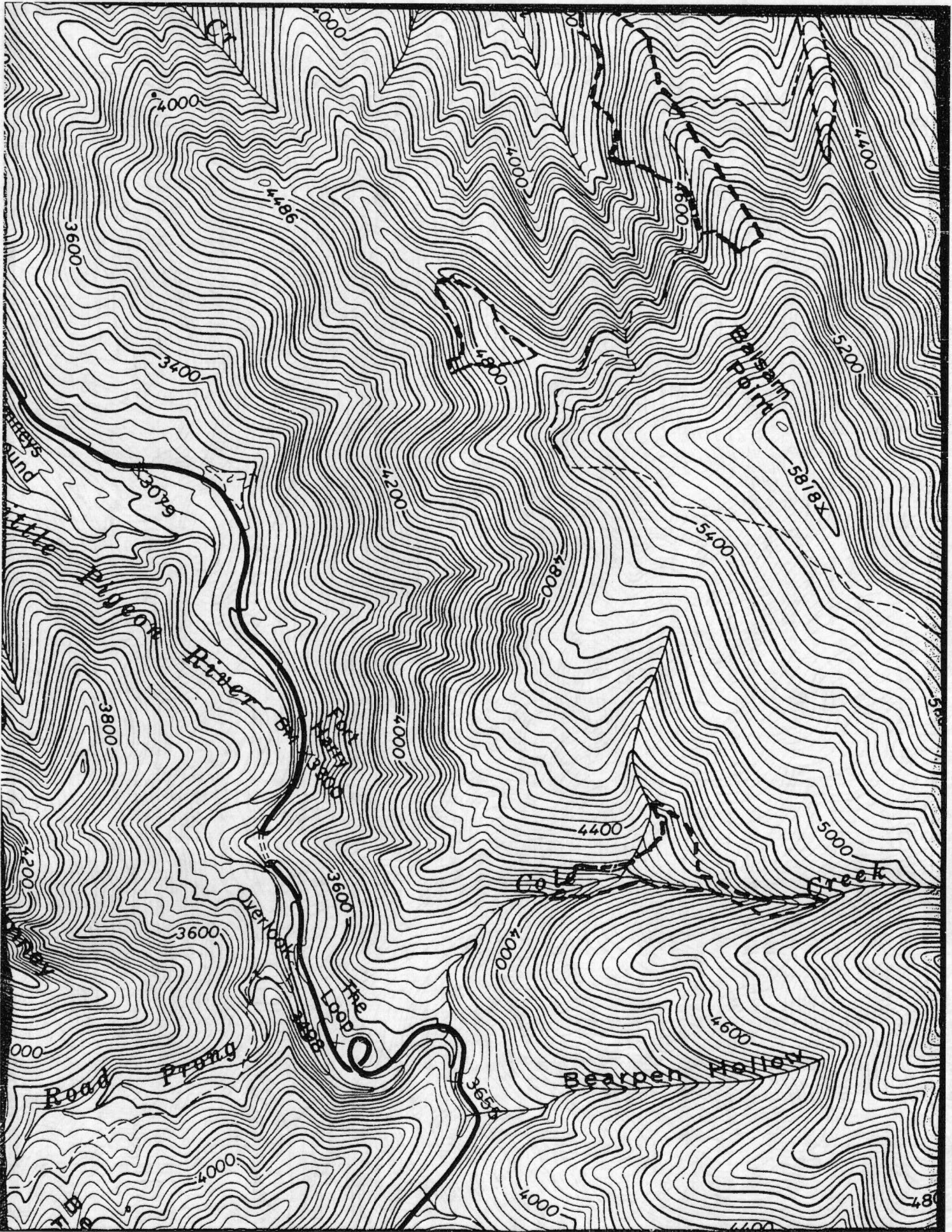


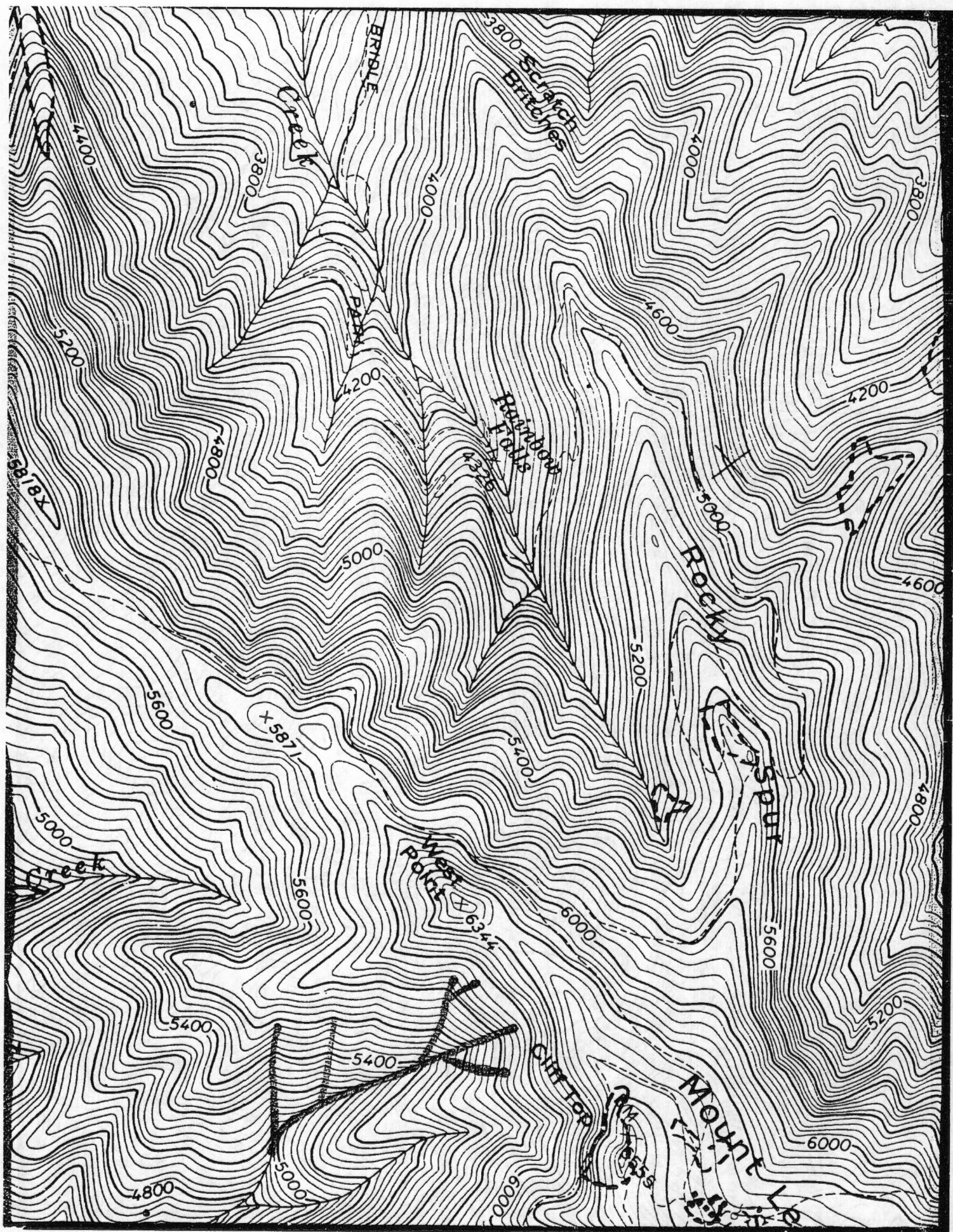


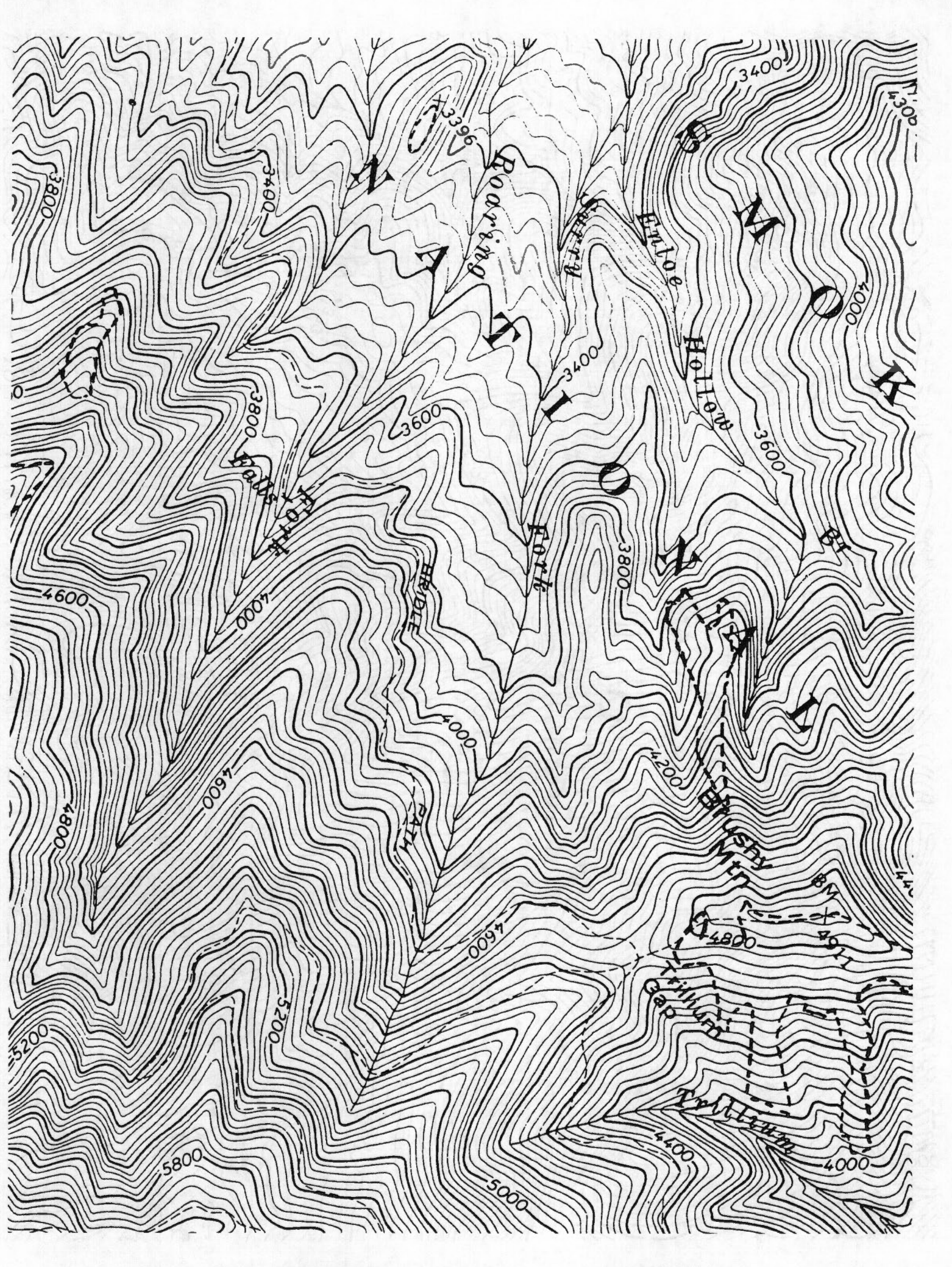


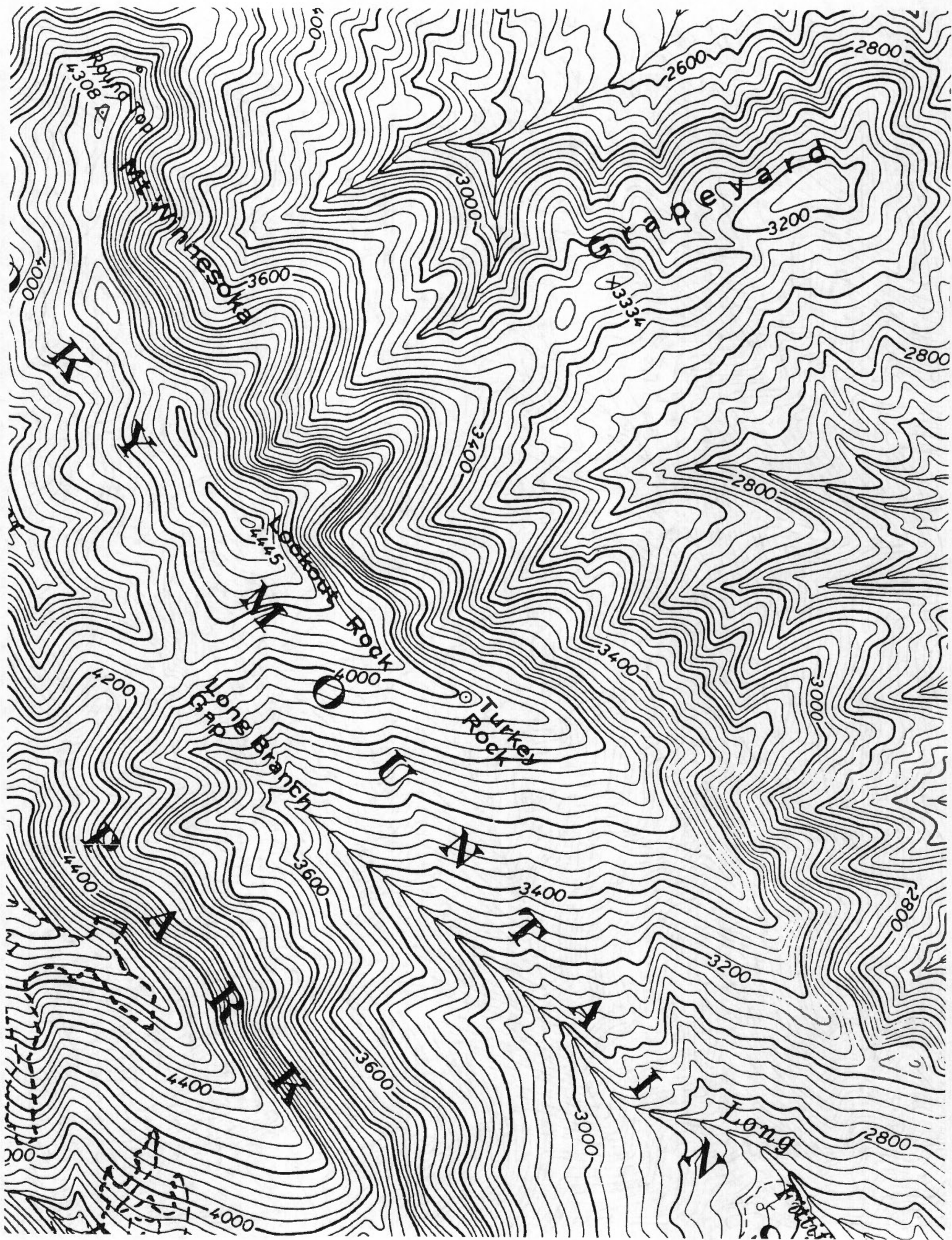


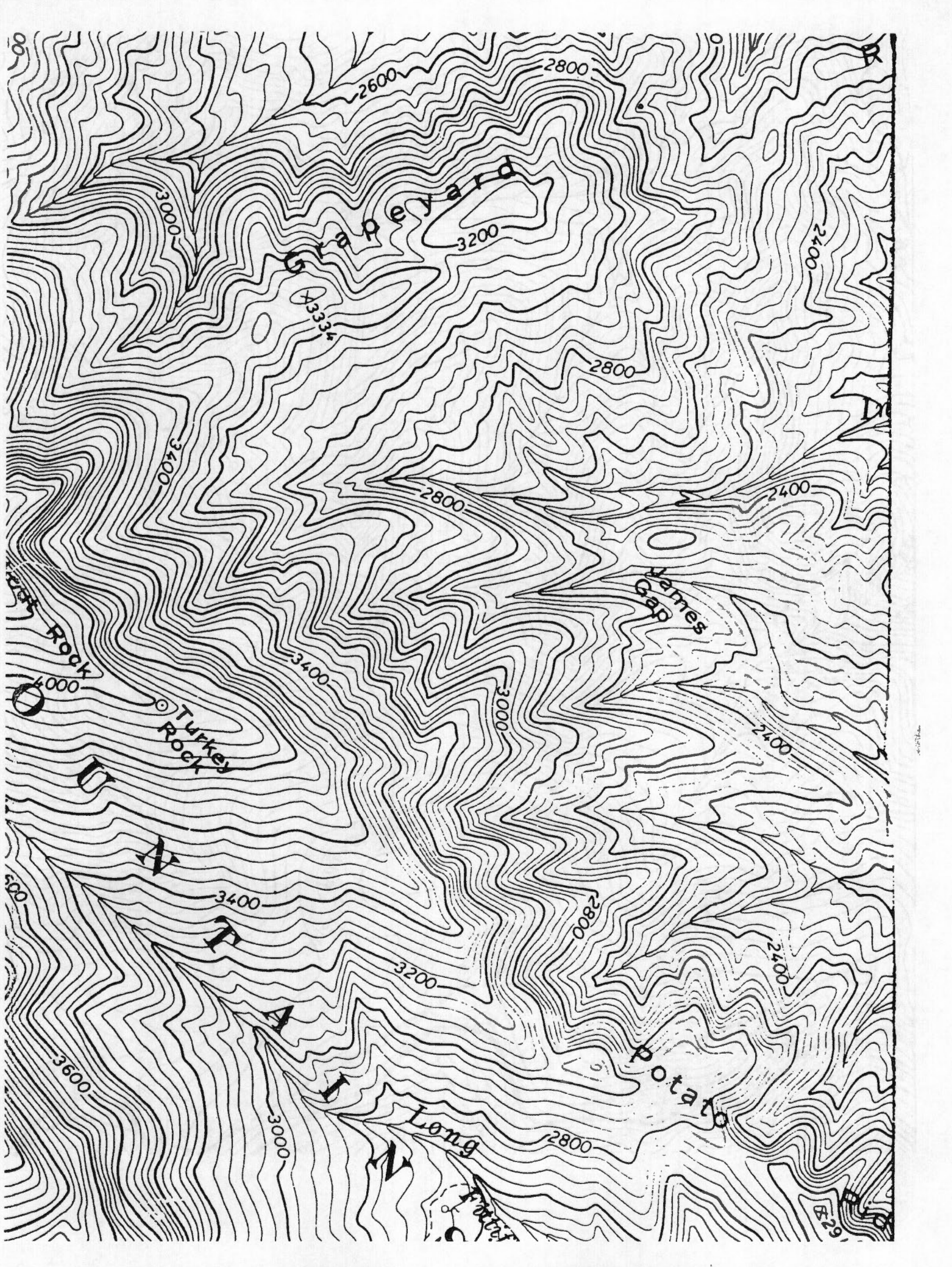


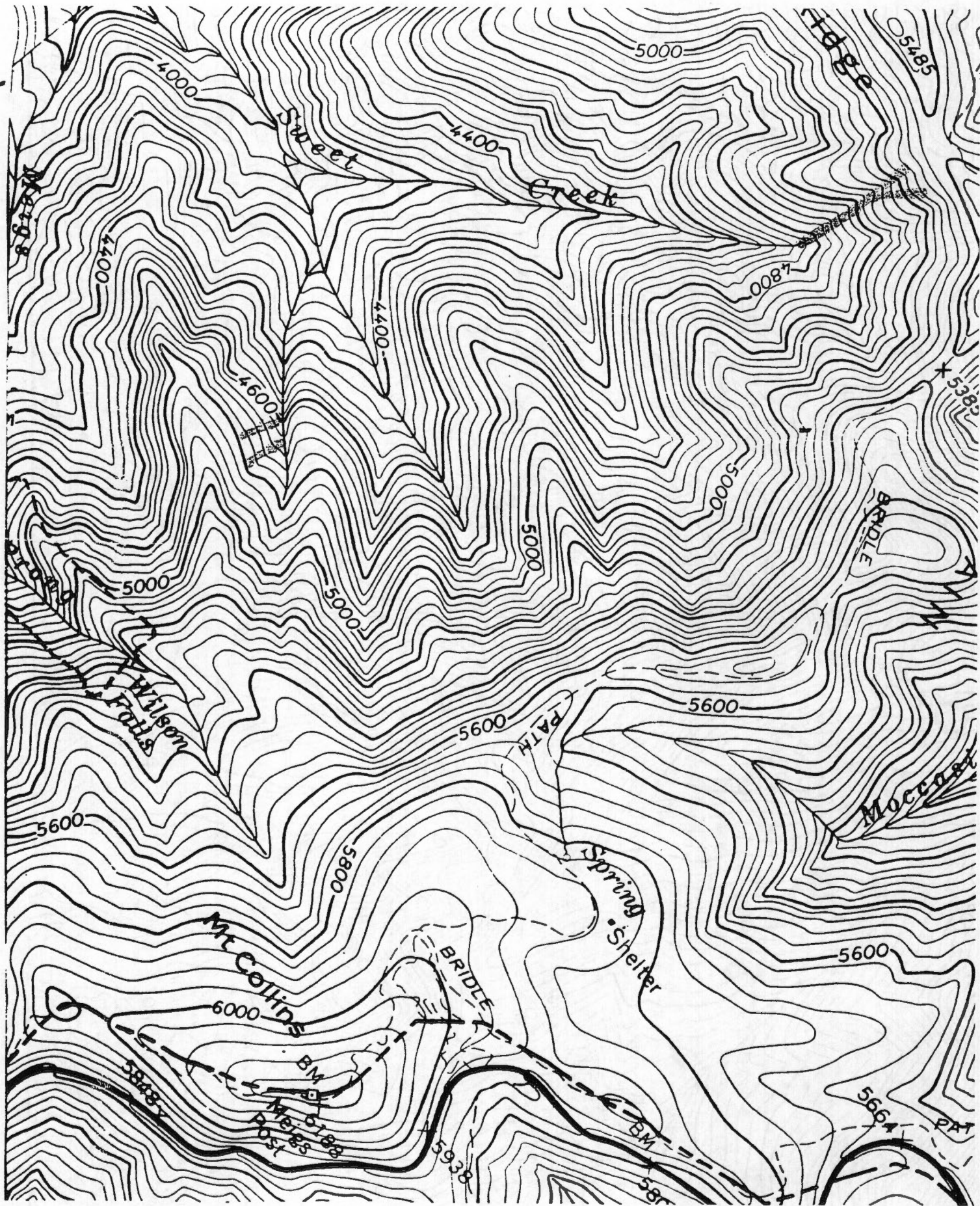


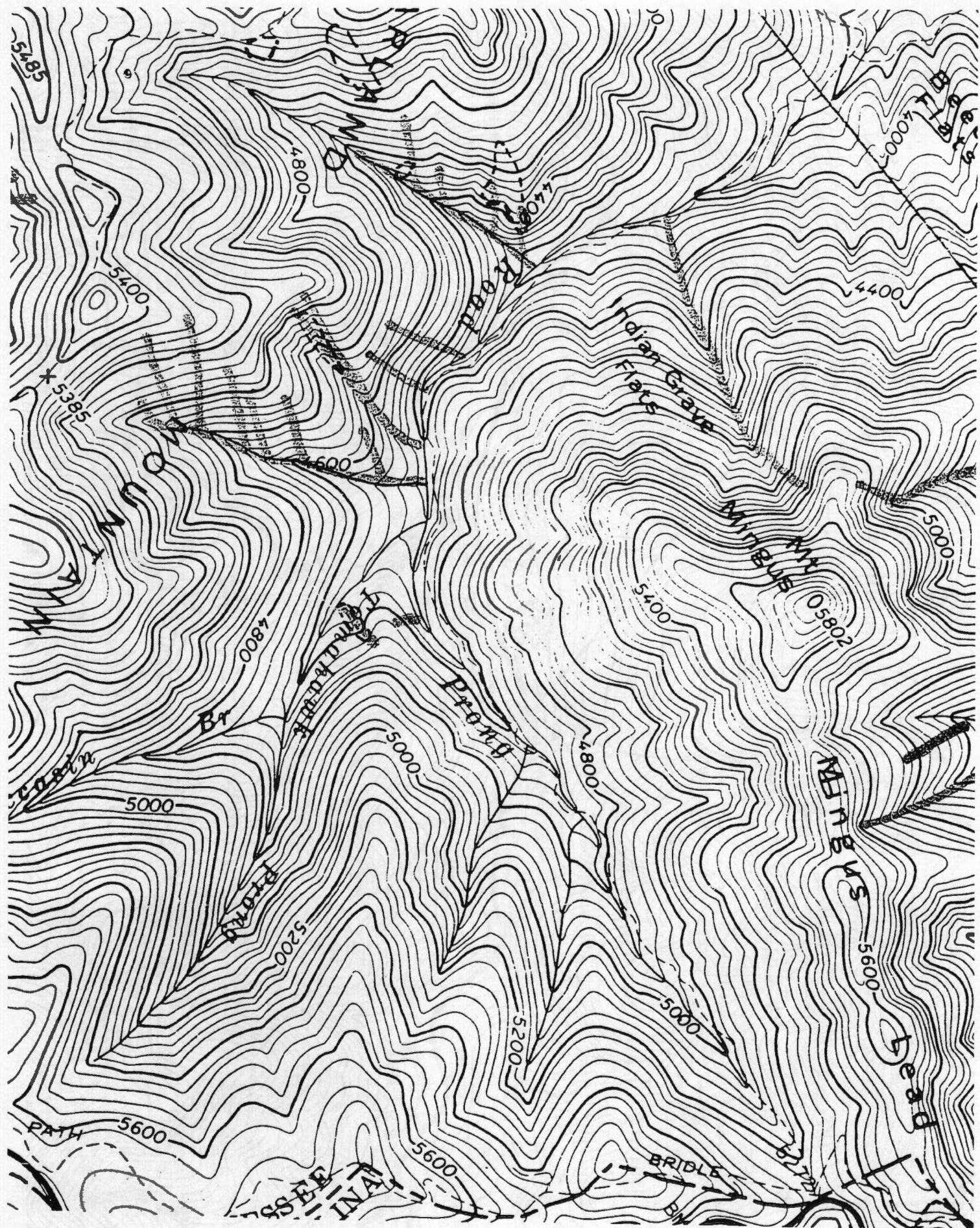


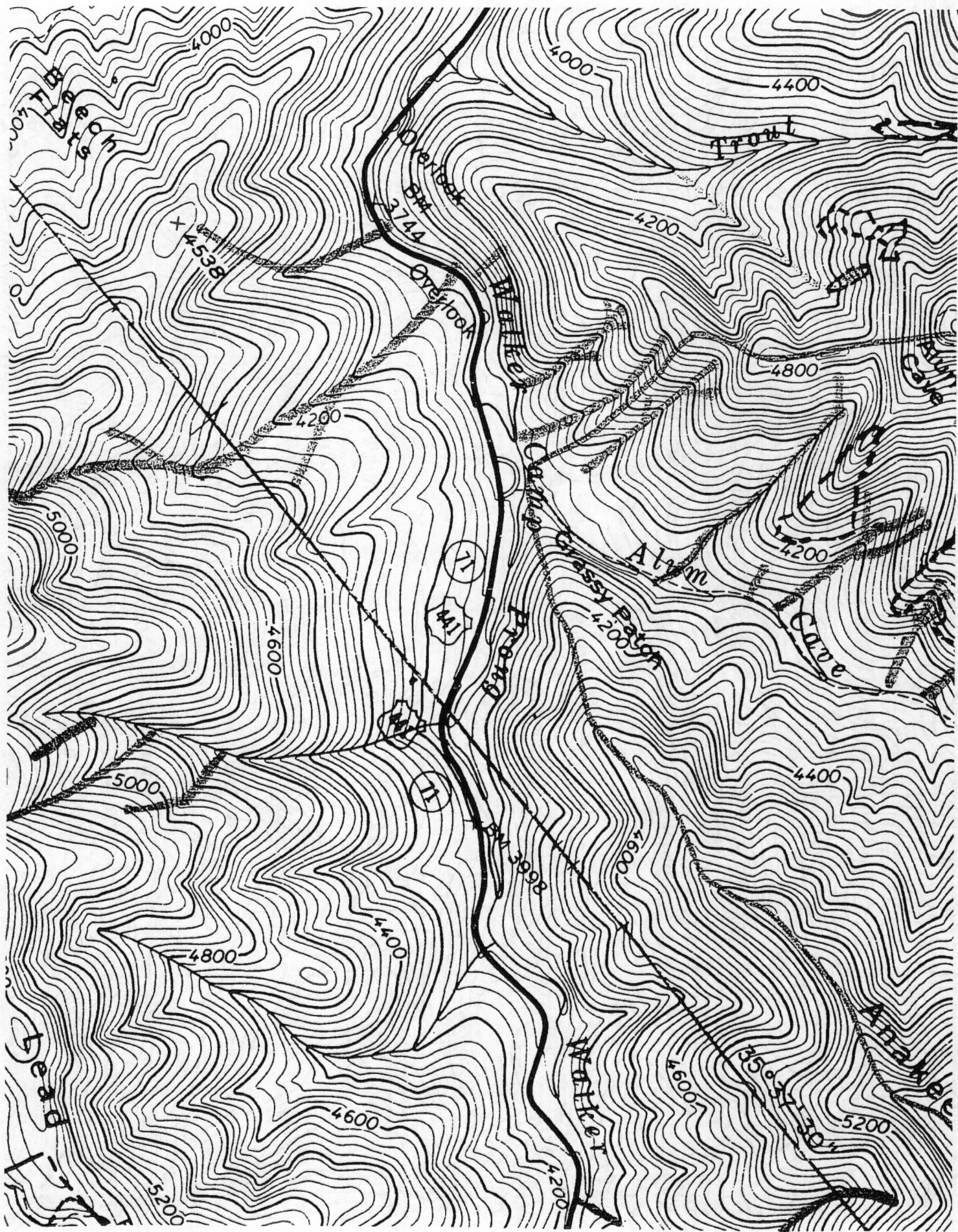


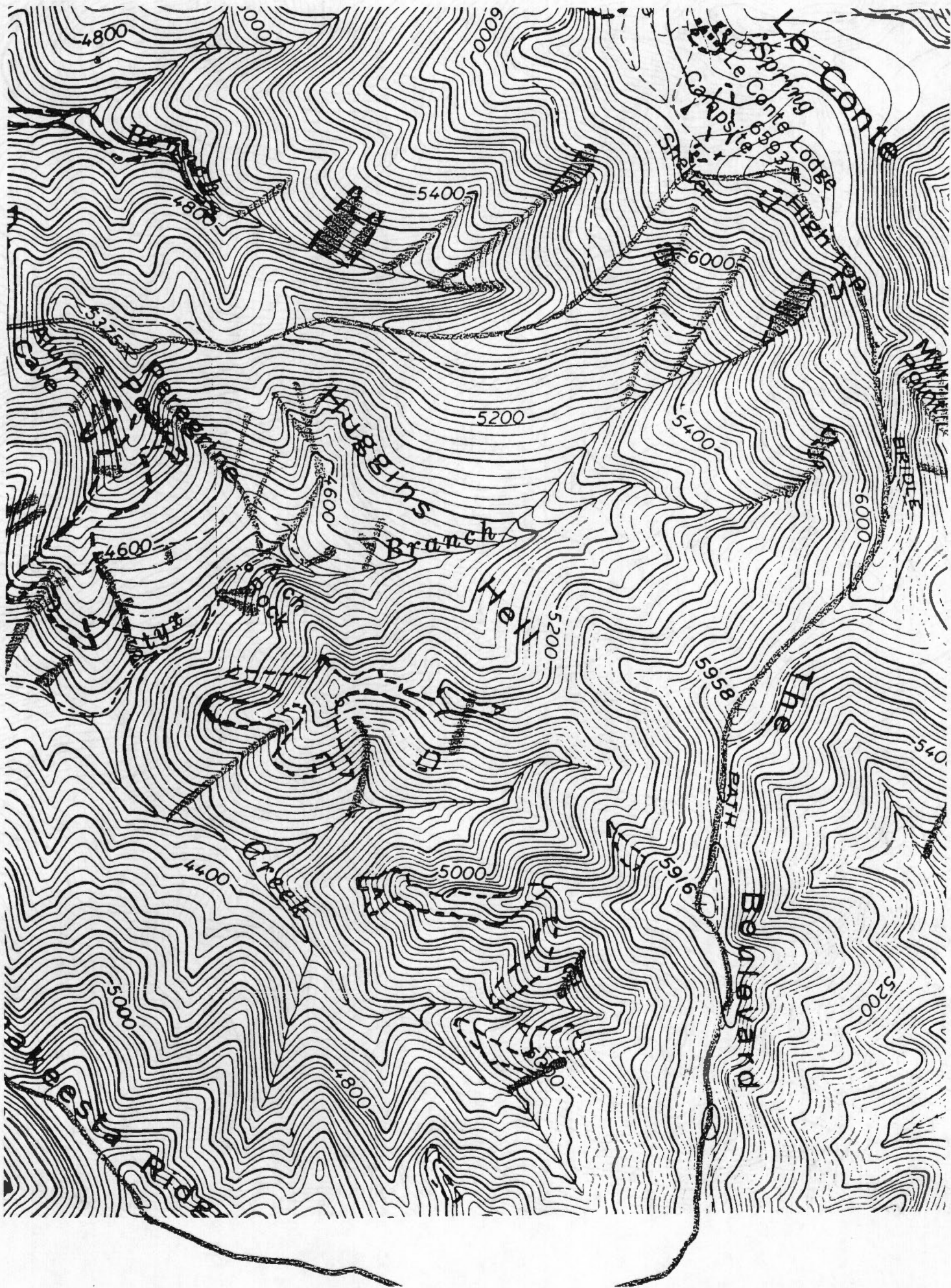


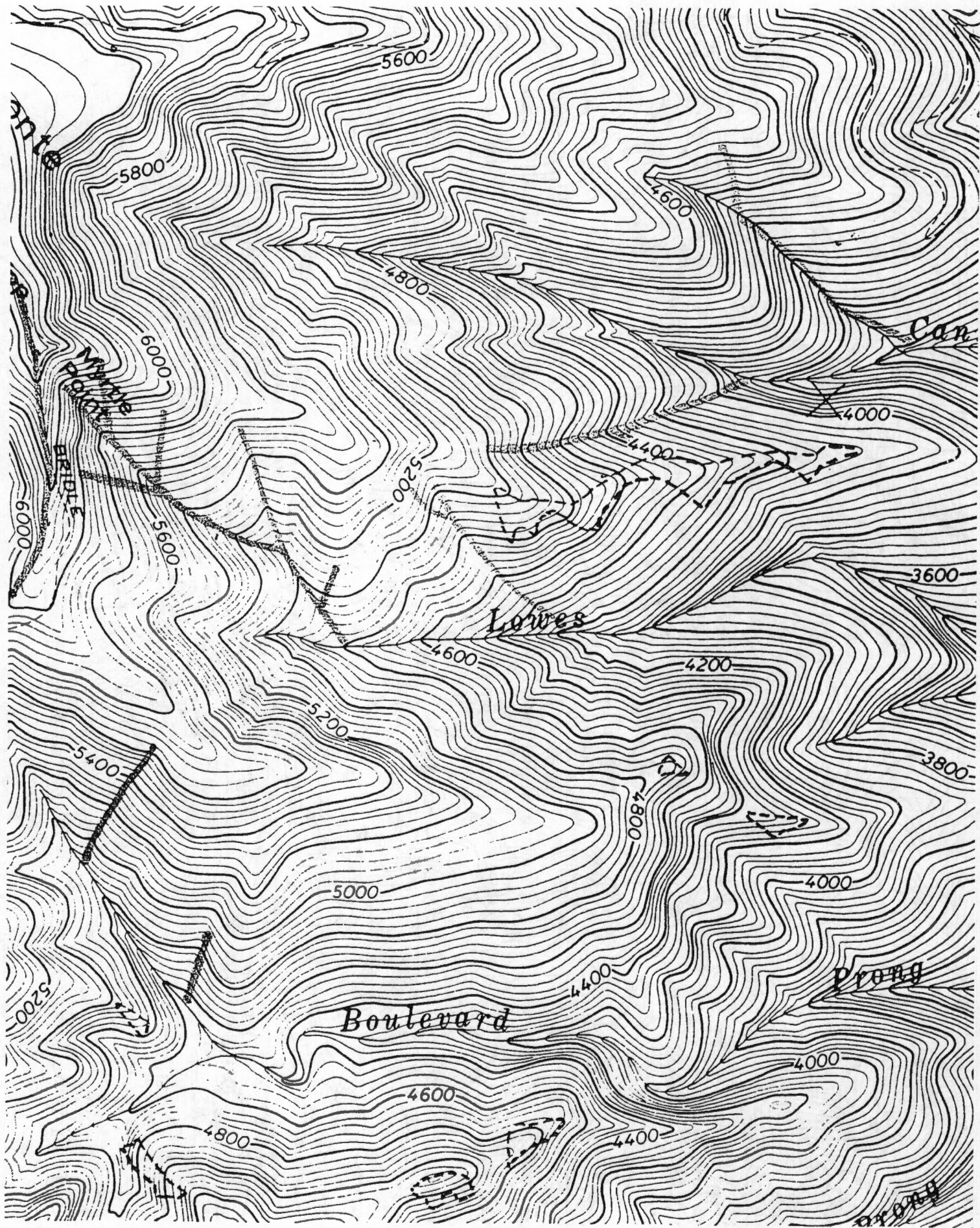


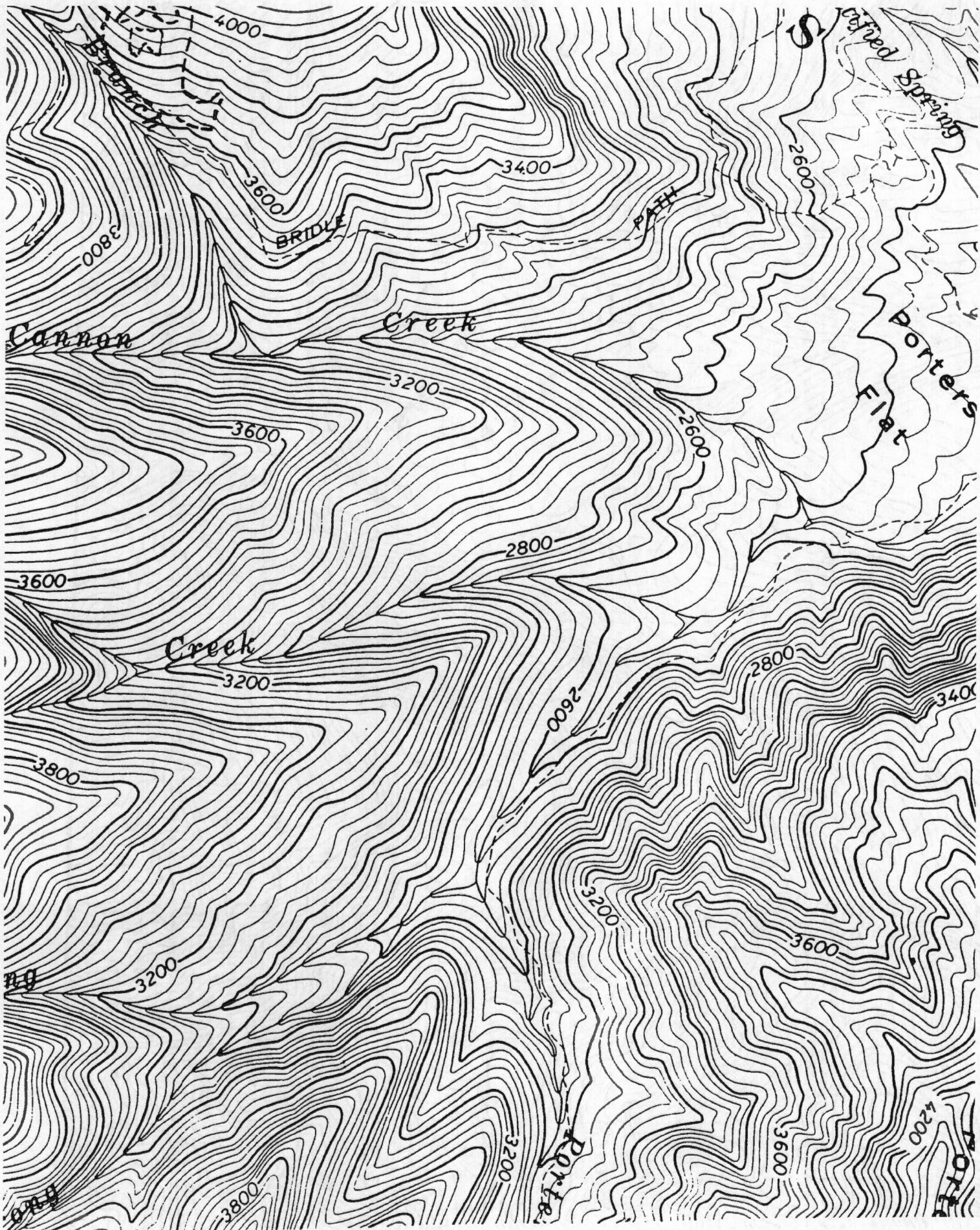


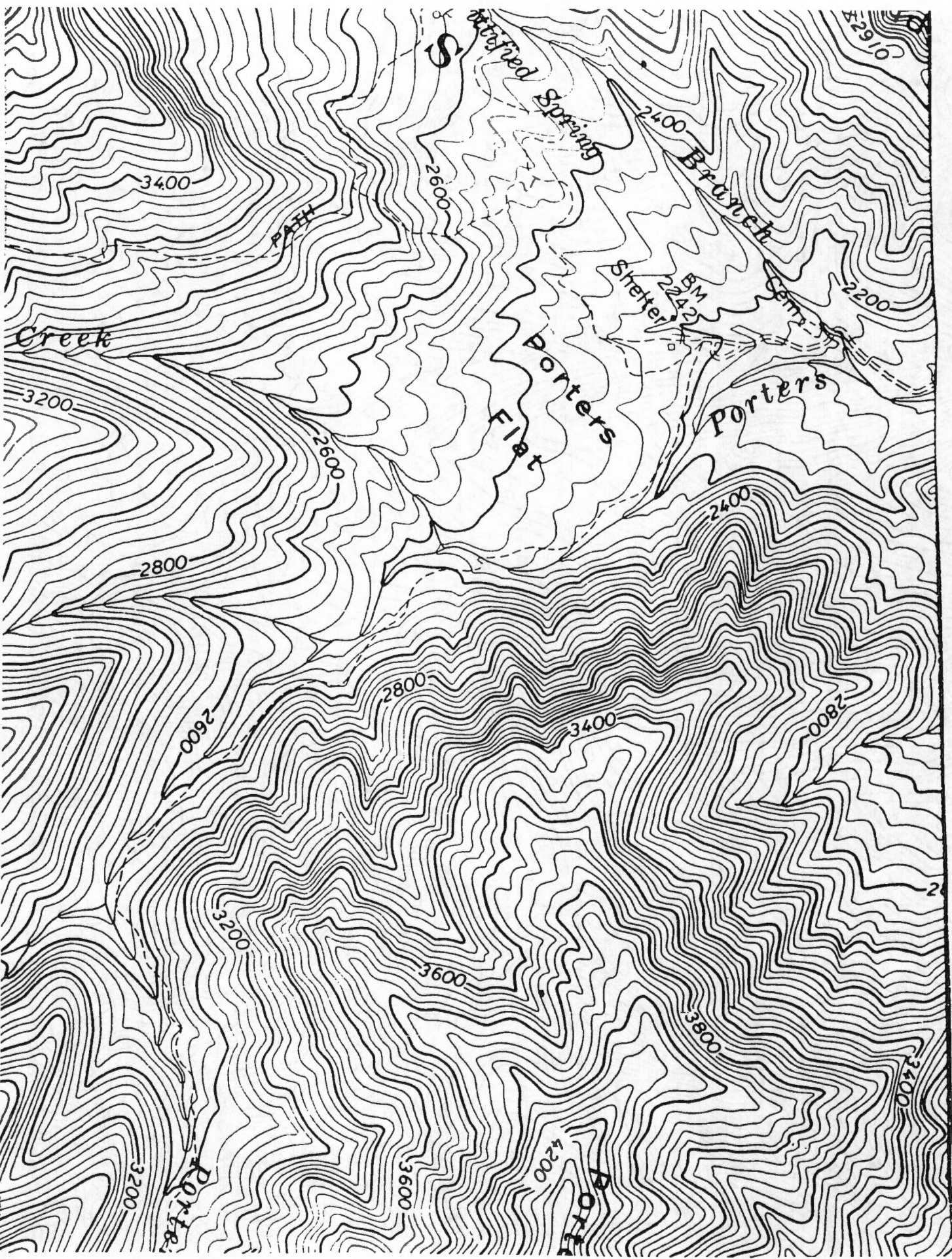


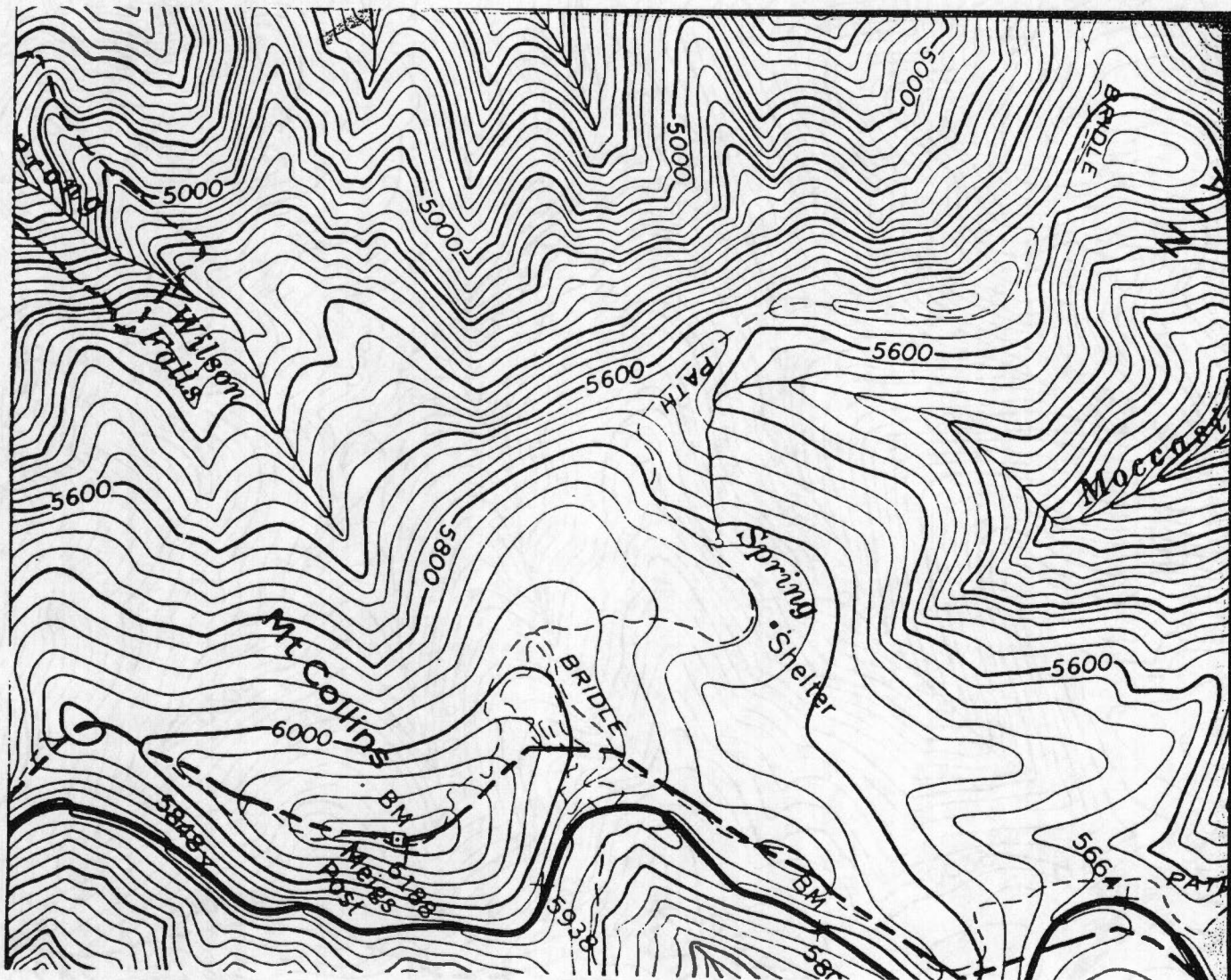








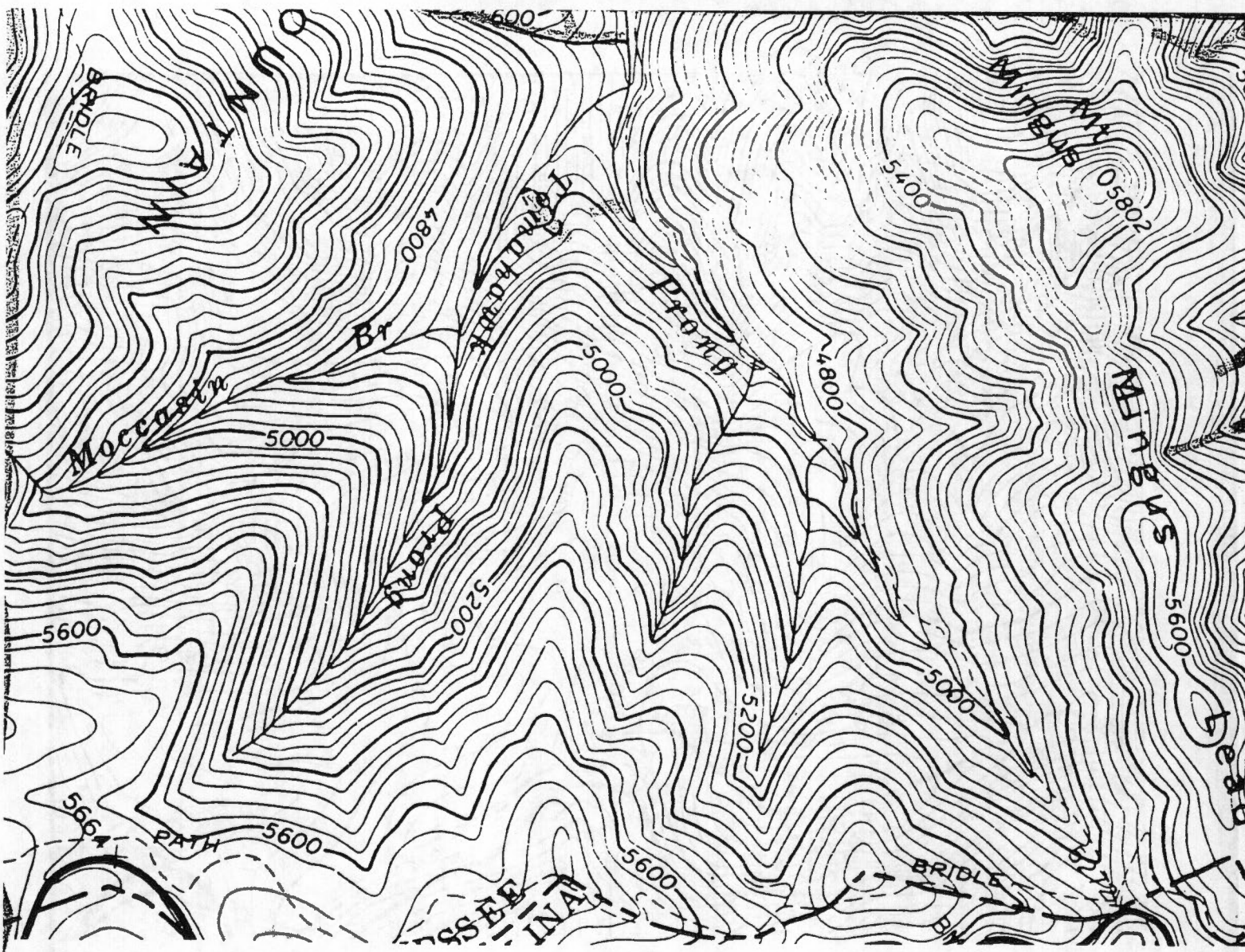




DEBRIS SLIDE

FLOOD DAM

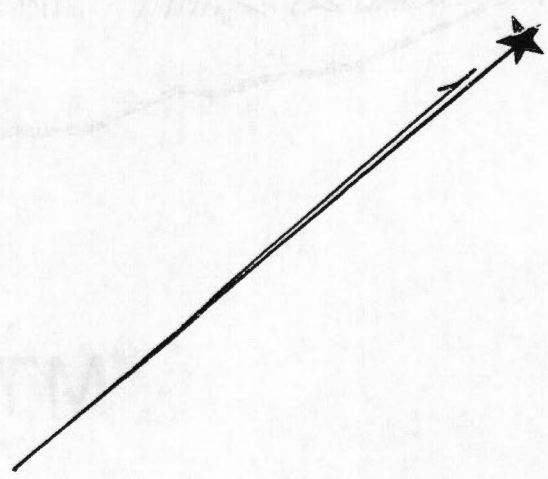
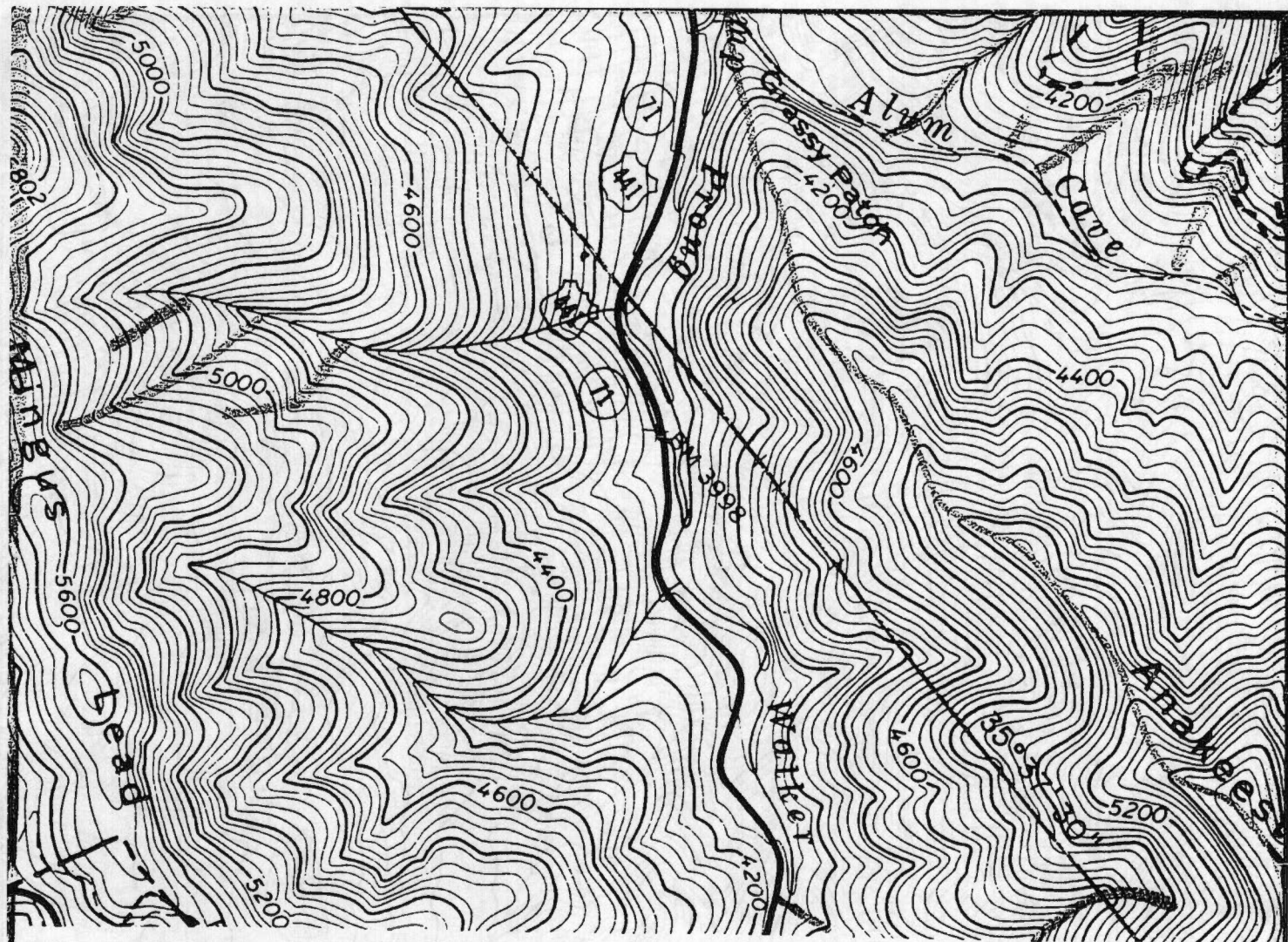
ALUM CAVE
WATERSHED



S SLIDES

DAMAGE AREAS

CAVE CREEK
ERSHED BOUNDARY



CONTOUR INTERVAL 40 FEET

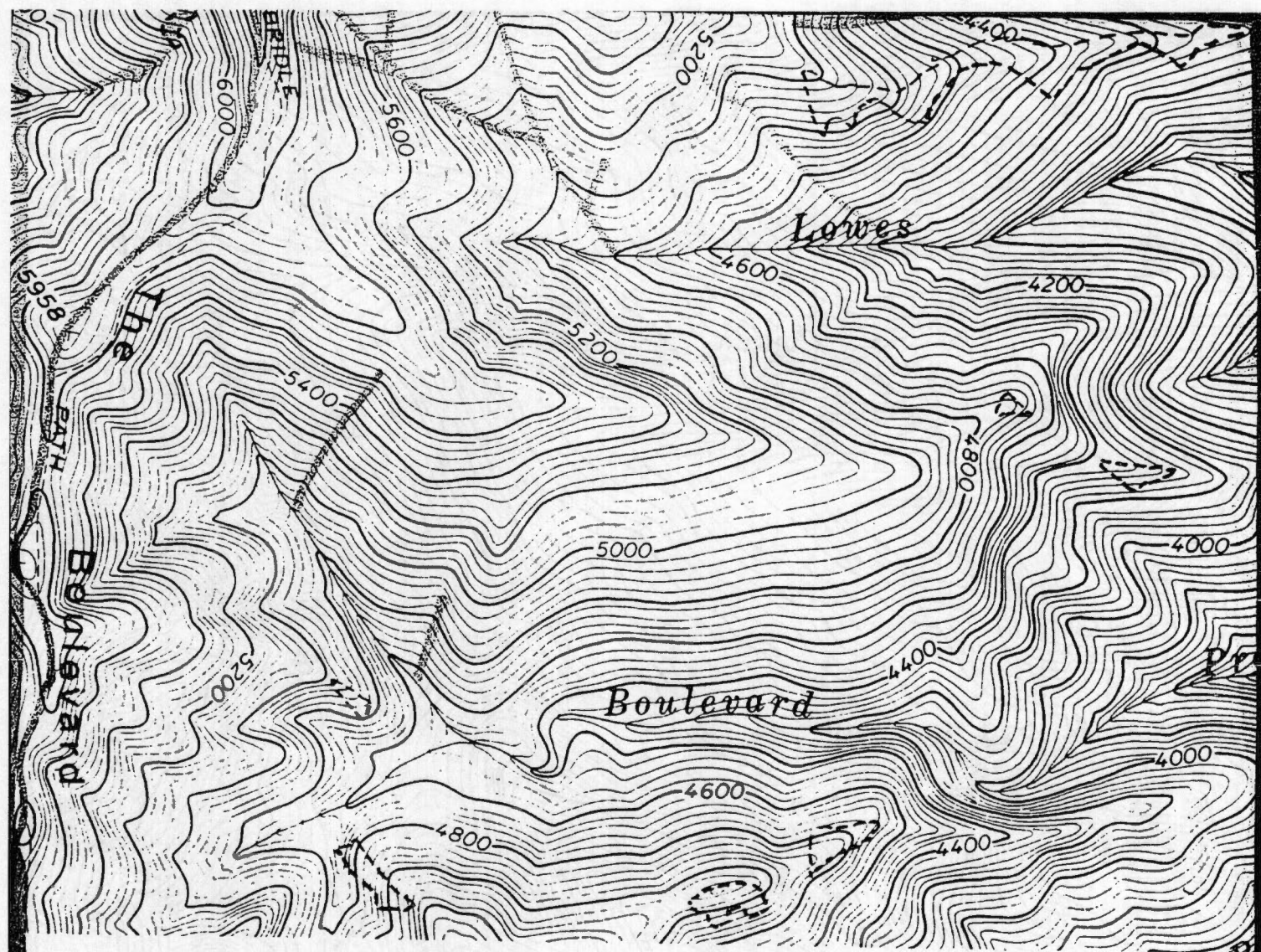
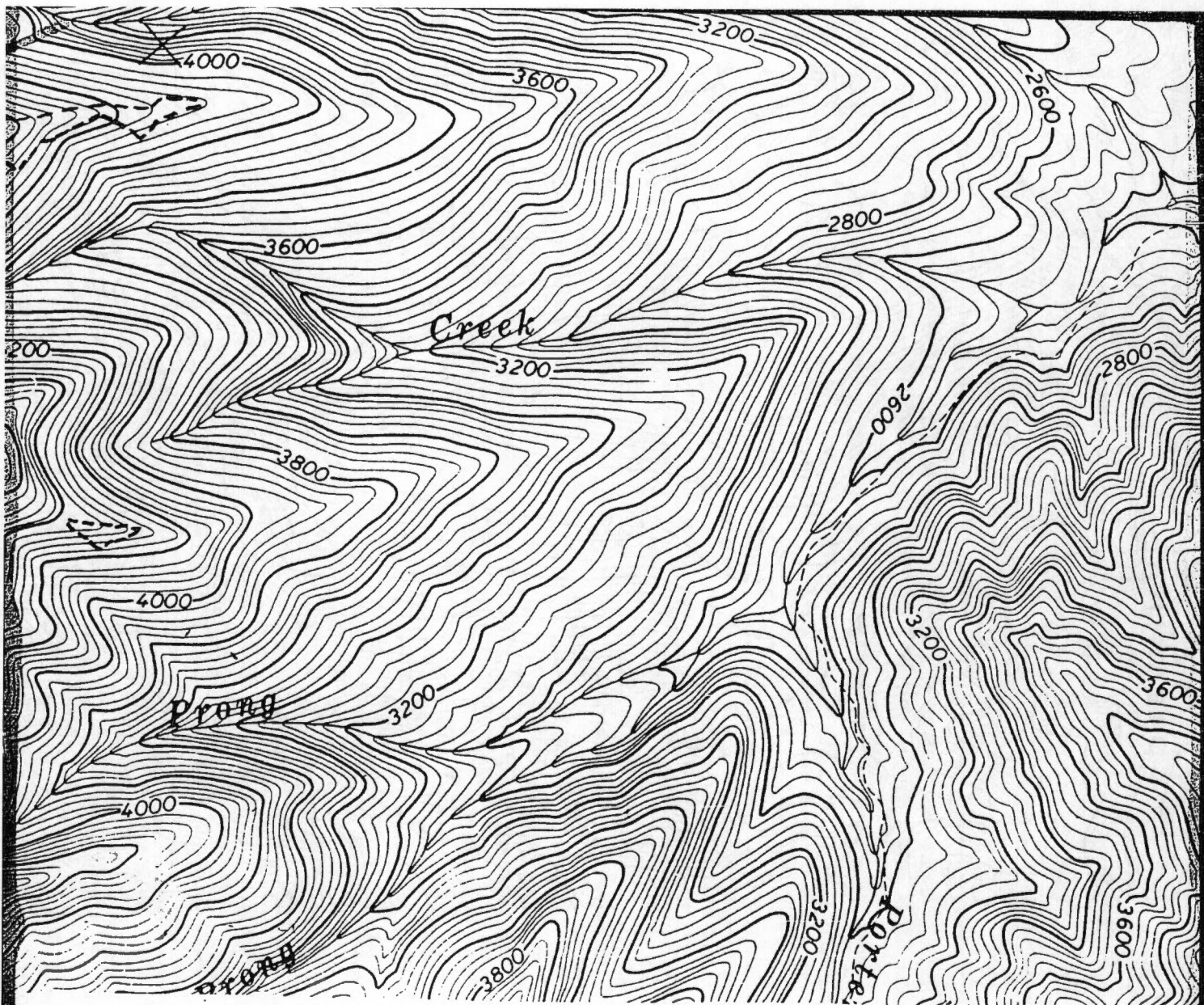
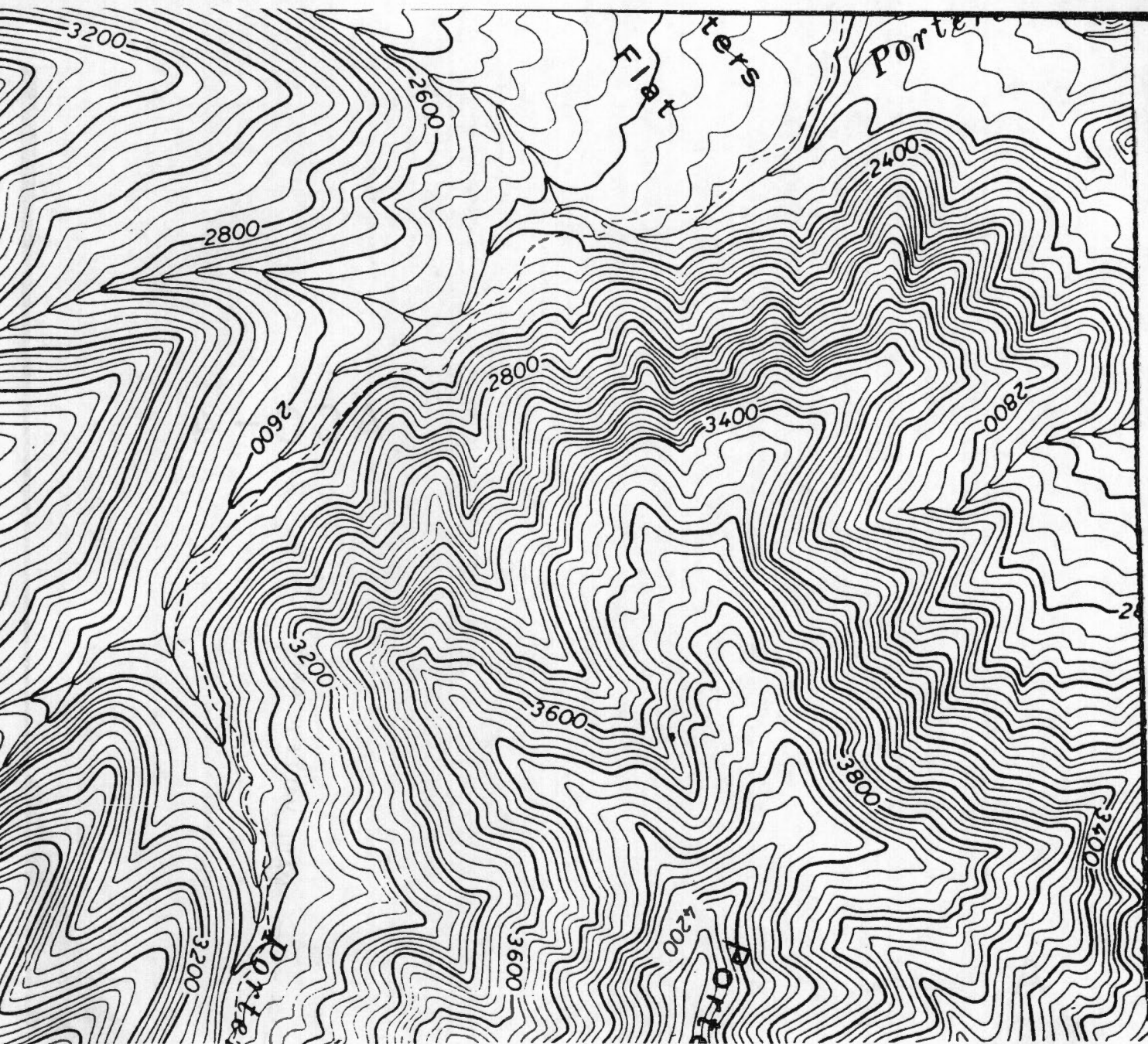


PLATE 2

MONTE-SUGARLAND MOUNTAIN
SLIDES AND RELATED FLOOD DAMAGE



TAIN AREA
OD DAMAGE

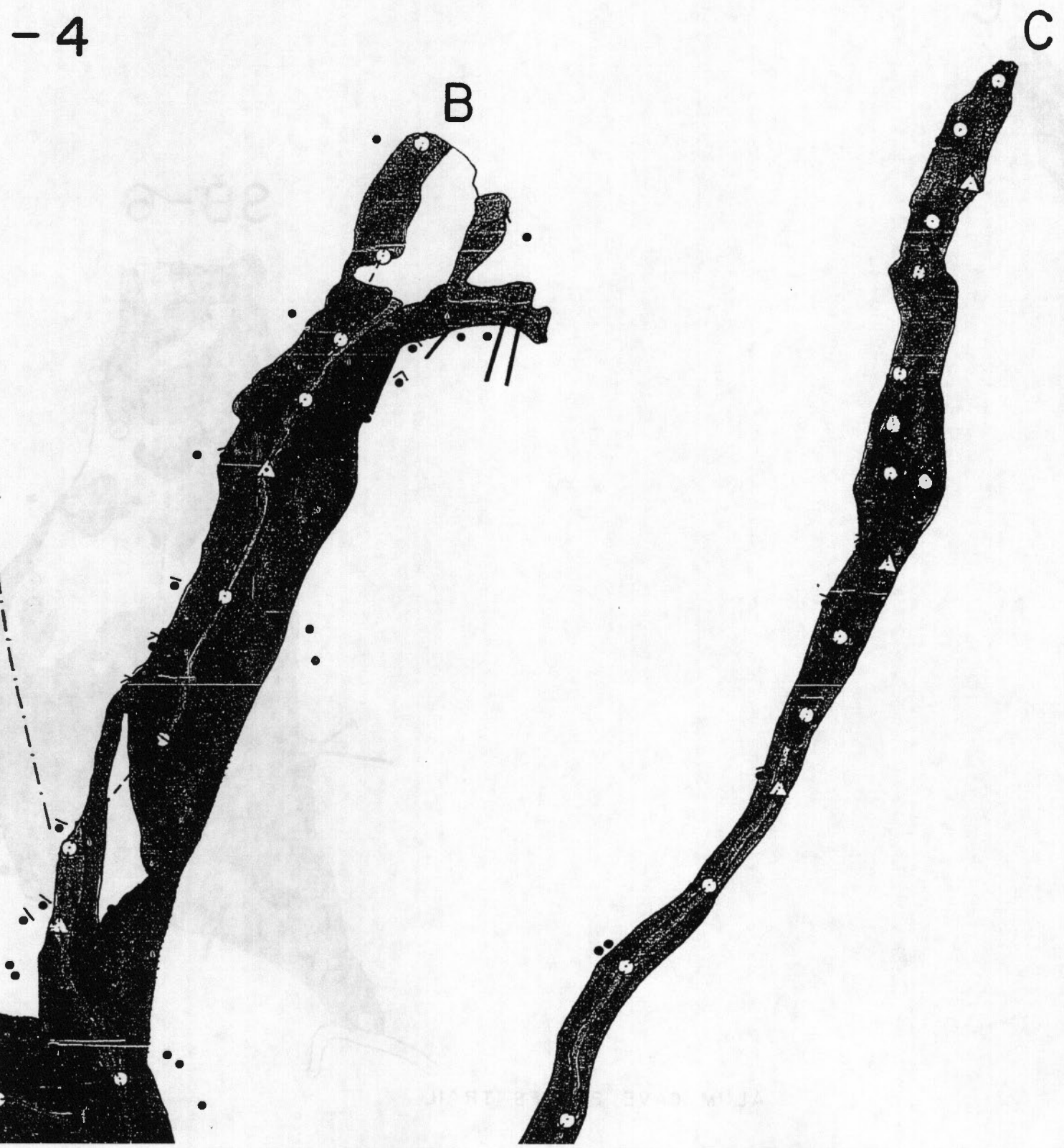


ACC-4

MAIN VALLEY AXIS

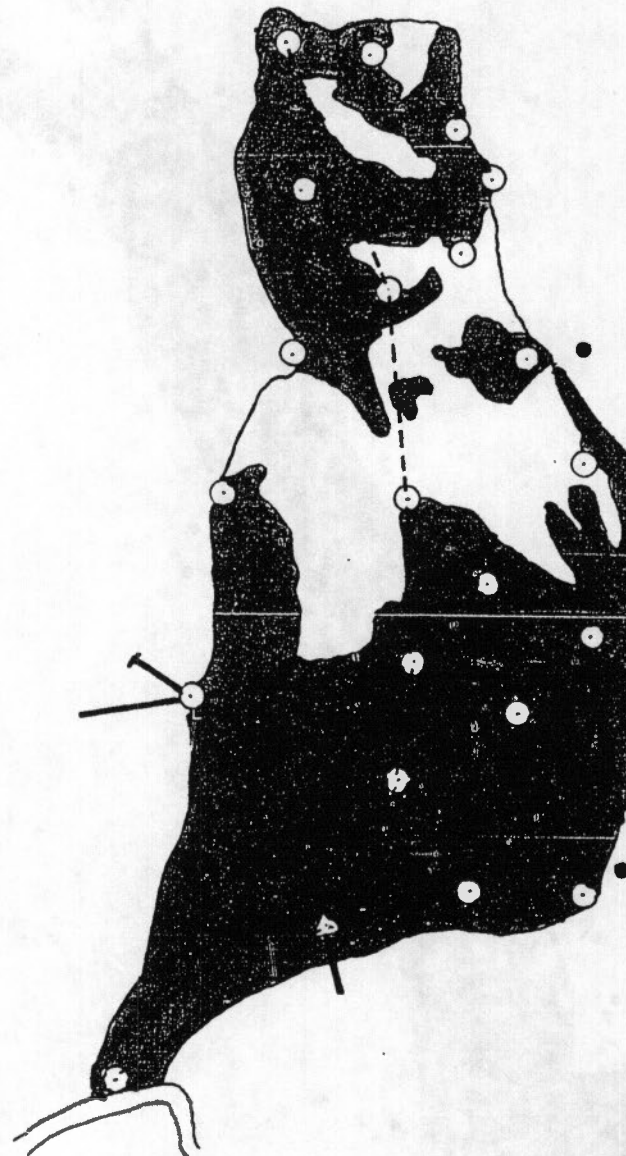
A





C

SB-6



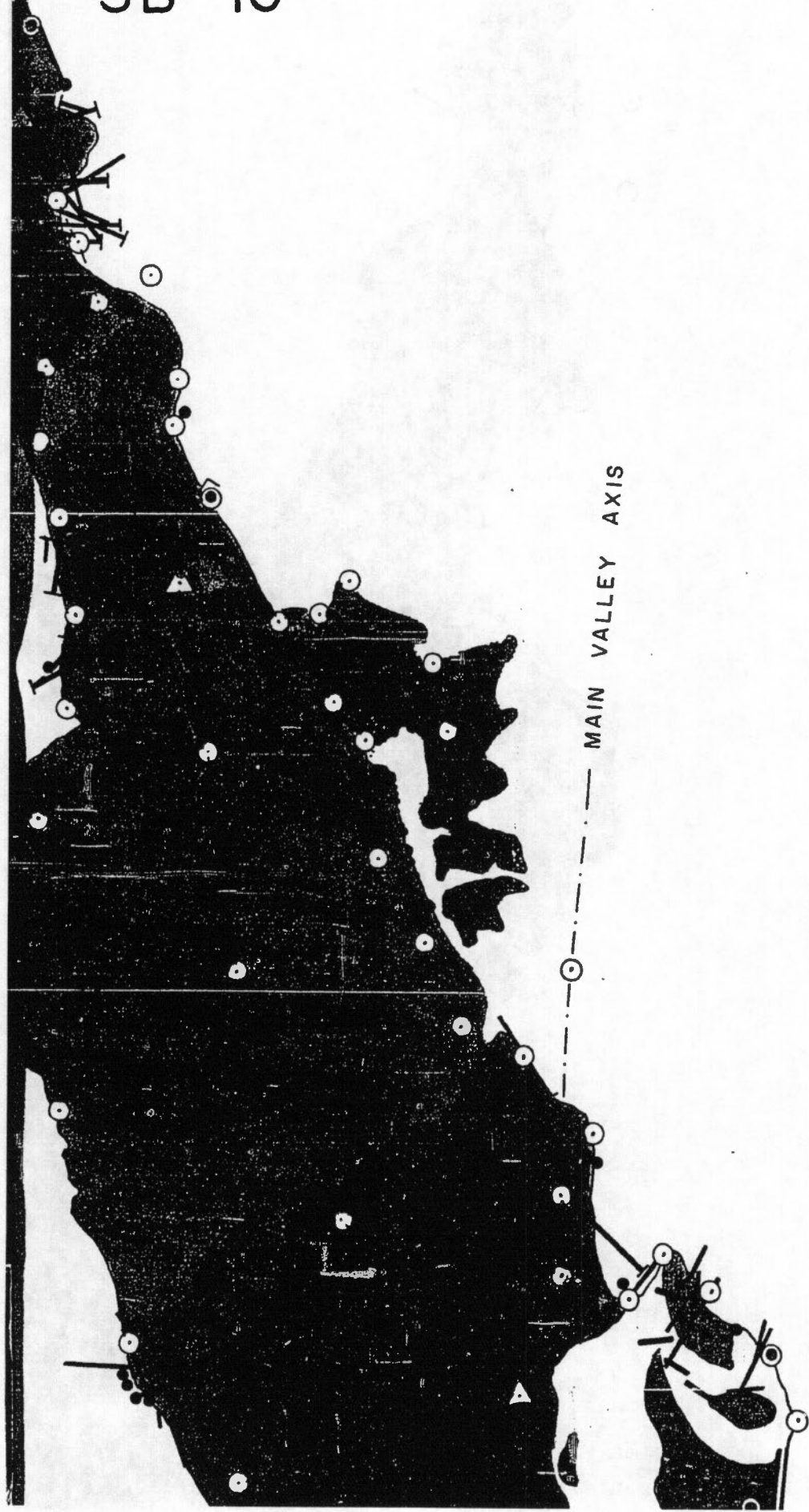
ALUM CAVE BLUFFS TRAIL

SB-10

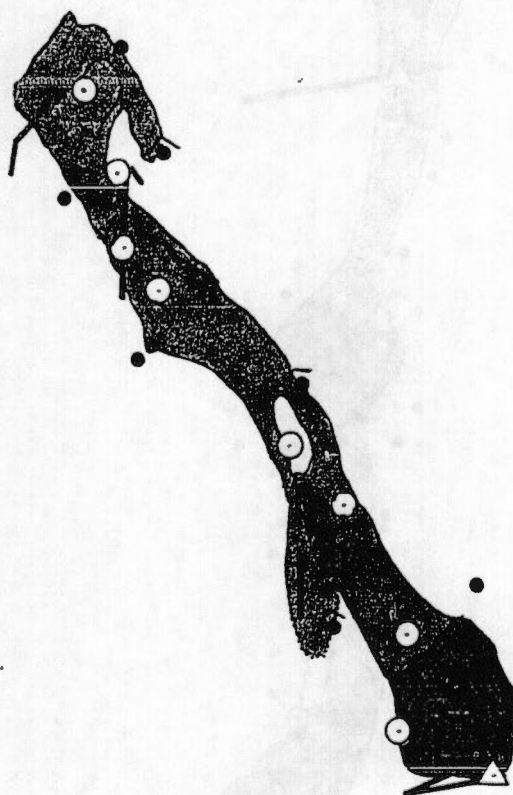
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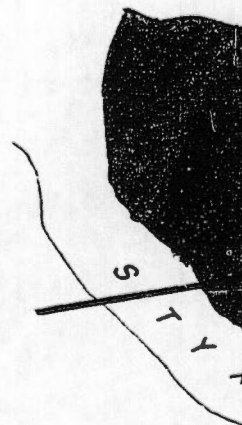
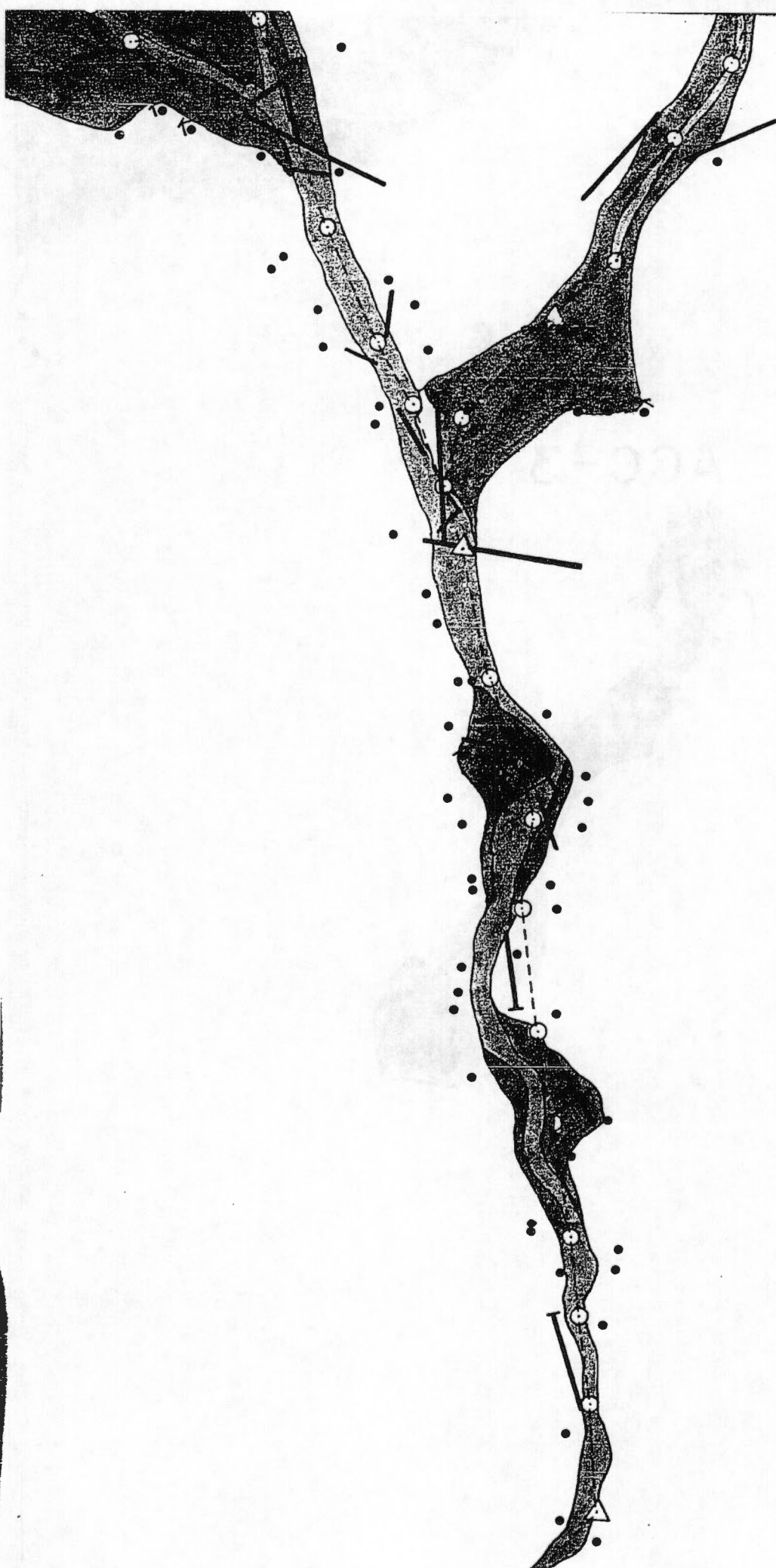


SB-10

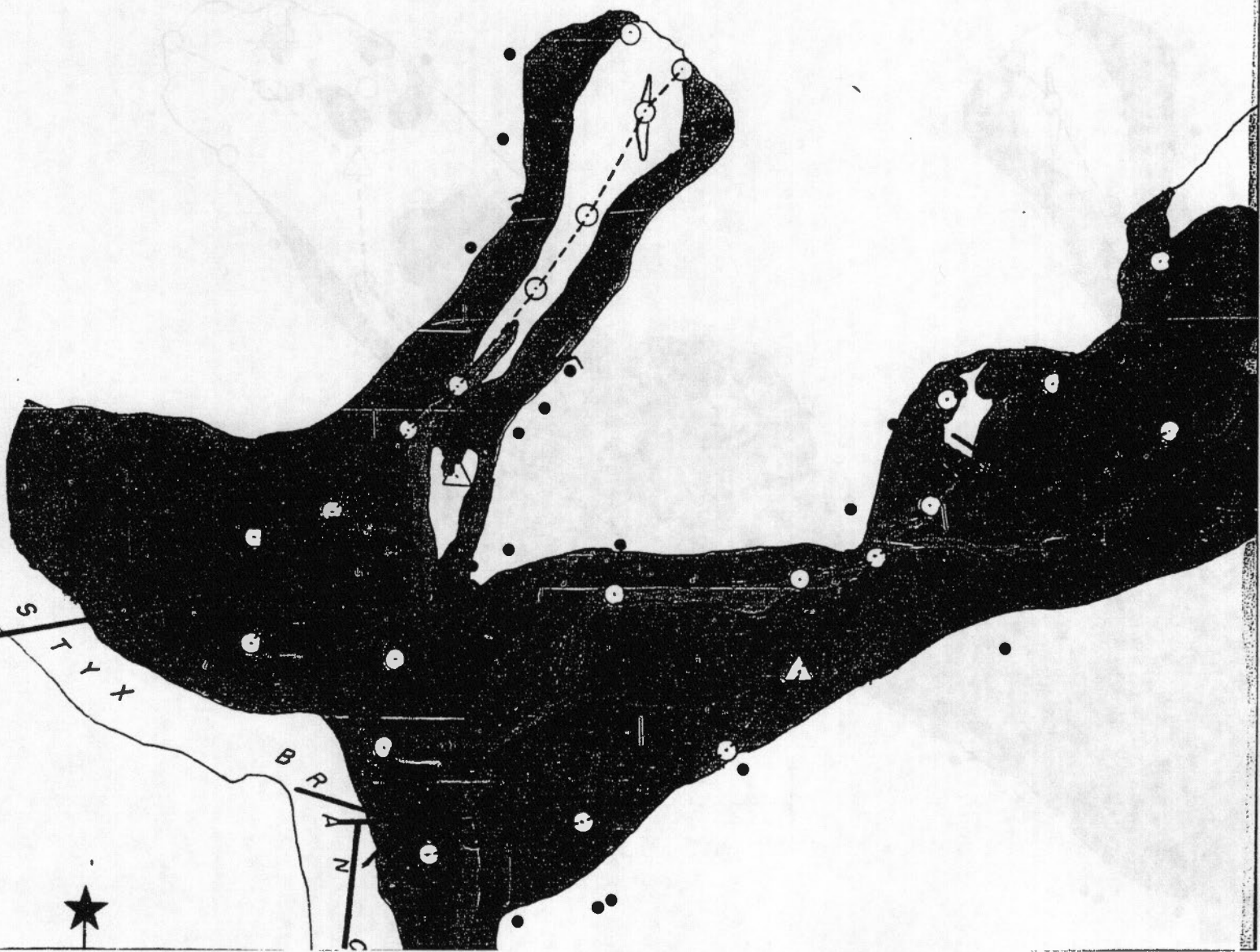


ACC-3





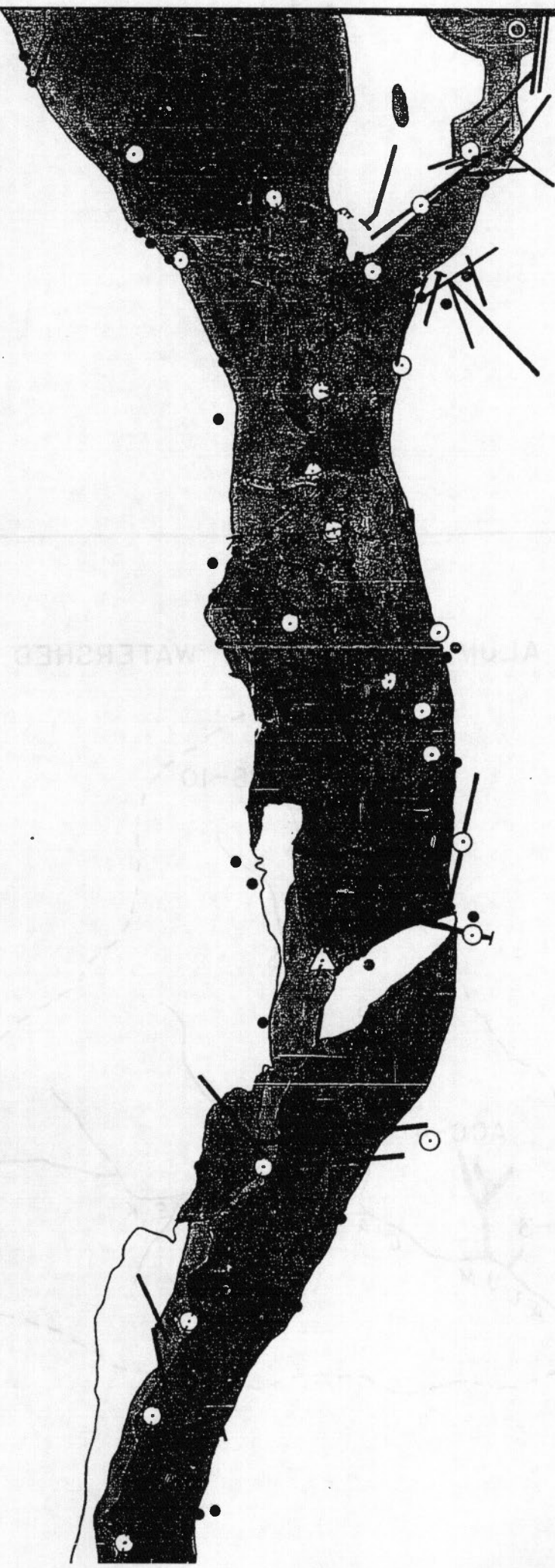
SB-2



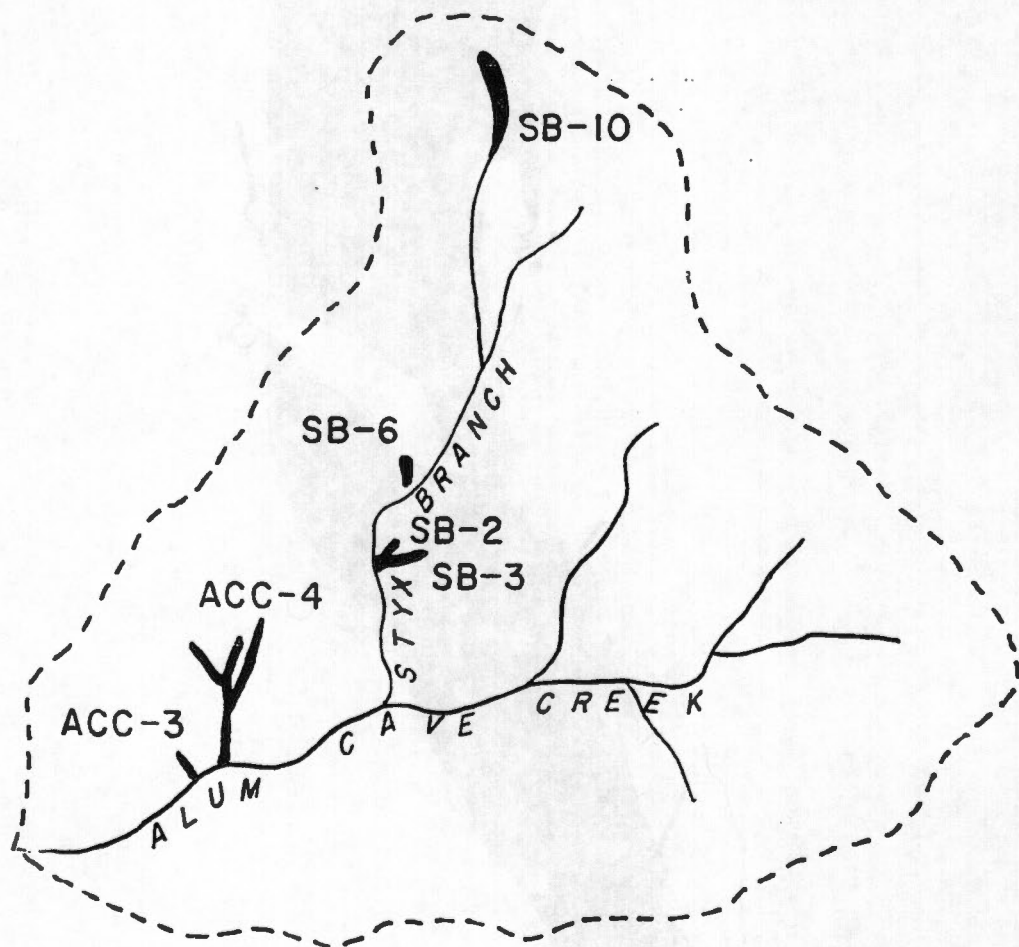
SB-2

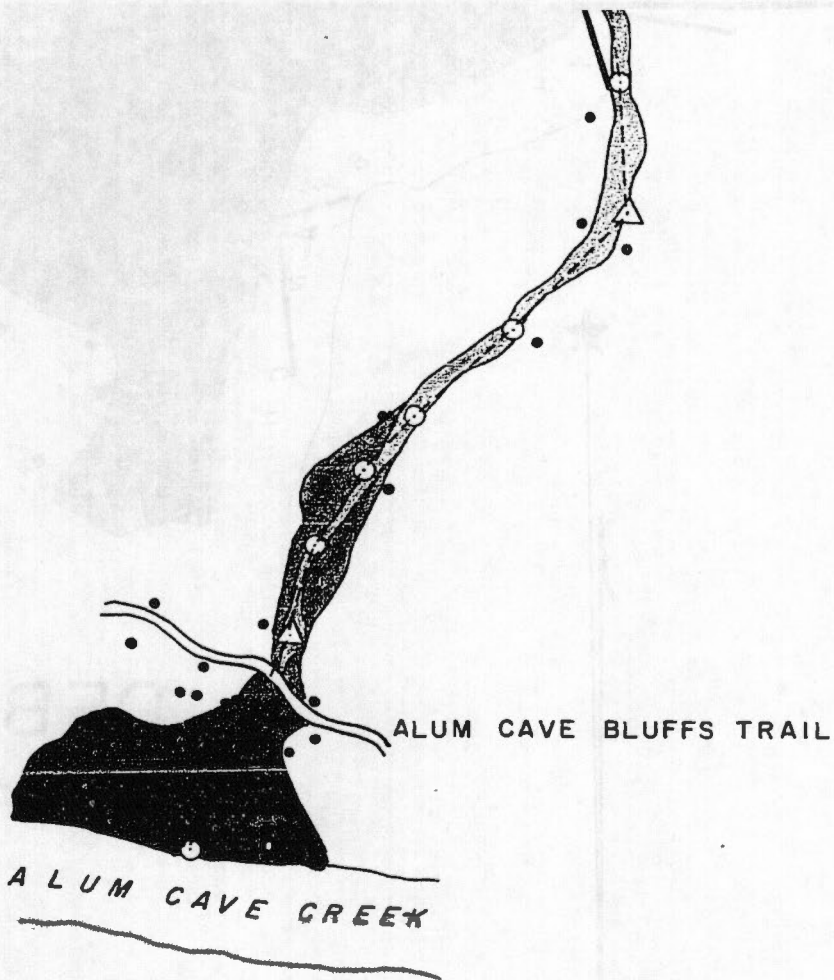
SB-3

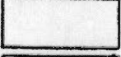
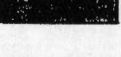


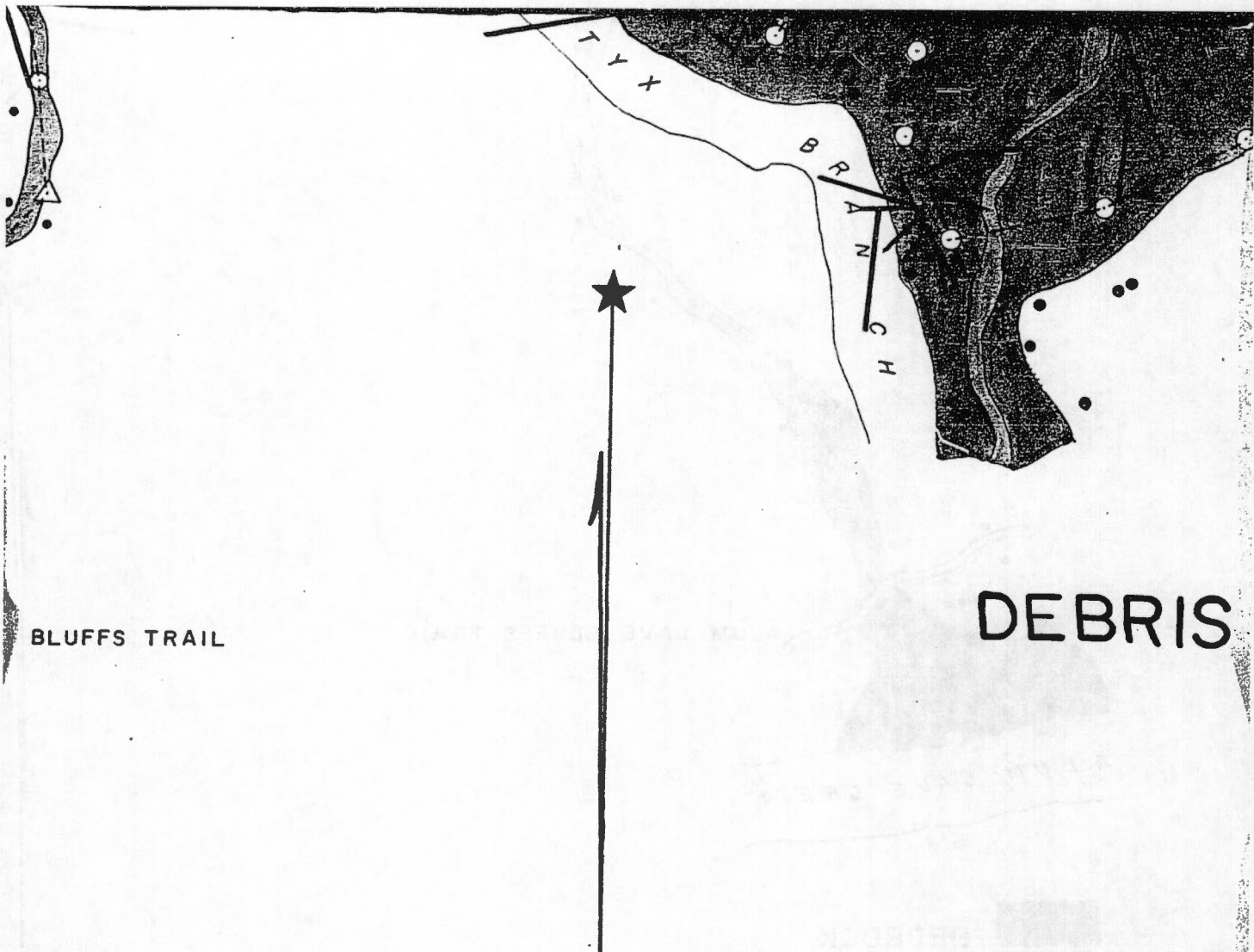


ALUM CAVE CREEK WATERSHED





- | | | |
|---|---|-----------------|
|  | BEDROCK | |
|  | COLLUVIUM | |
|  | ALLUVIUM | |
|  | REVEGETATION OVER BEDROCK | |
|  | REVEGETATION OVER COLLUVIUM | |
|  | REVEGETATION OVER ALLUVIUM | |
|  | COLLUVIUM LESS THAN 15 CENTIMETERS THICK | |
|  | OVER BEDROCK | |
|  | PRE-SLIDE VEGETATION IN SLIDE TRACKS | |
|  | TACHEOMETER STATION | } SURVEY POINTS |
|  | ROD STATION | |
|  | TREE OR STUMP GREATER THAN 6 INCHES IN DIAMETER | |
|  | TREE OR STUMP WITH DEBRIS SCAR | |
|  | TREE OR STUMP WITH DEBRIS DAM | |
|  | LOG GREATER THAN 6 INCHES IN DIAMETER | |



BLUFFS TRAIL

DEBRIS

R BEDROCK

R COLLUVIUM

R ALLUVIUM

AN 15 CENTIMETERS THICK

TION IN SLIDE TRACKS

ION } SURVEY POINTS

EATER THAN 6 INCHES IN DIAMETER

TH DEBRIS SCAR

TH DEBRIS DAM

6 INCHES IN DIAMETER

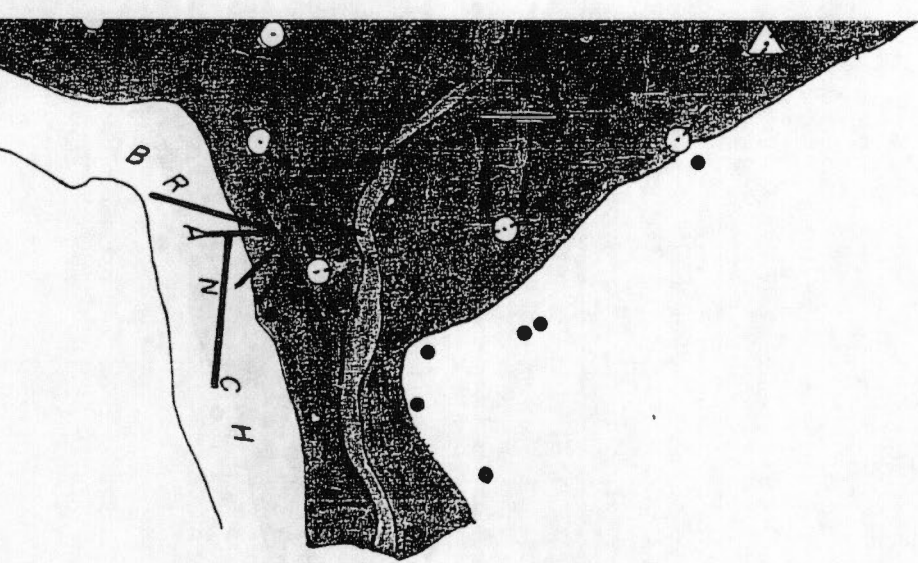


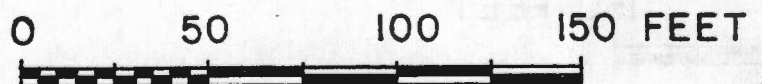
PLATE 3

DEBRIS SLIDE SKETCH MAP

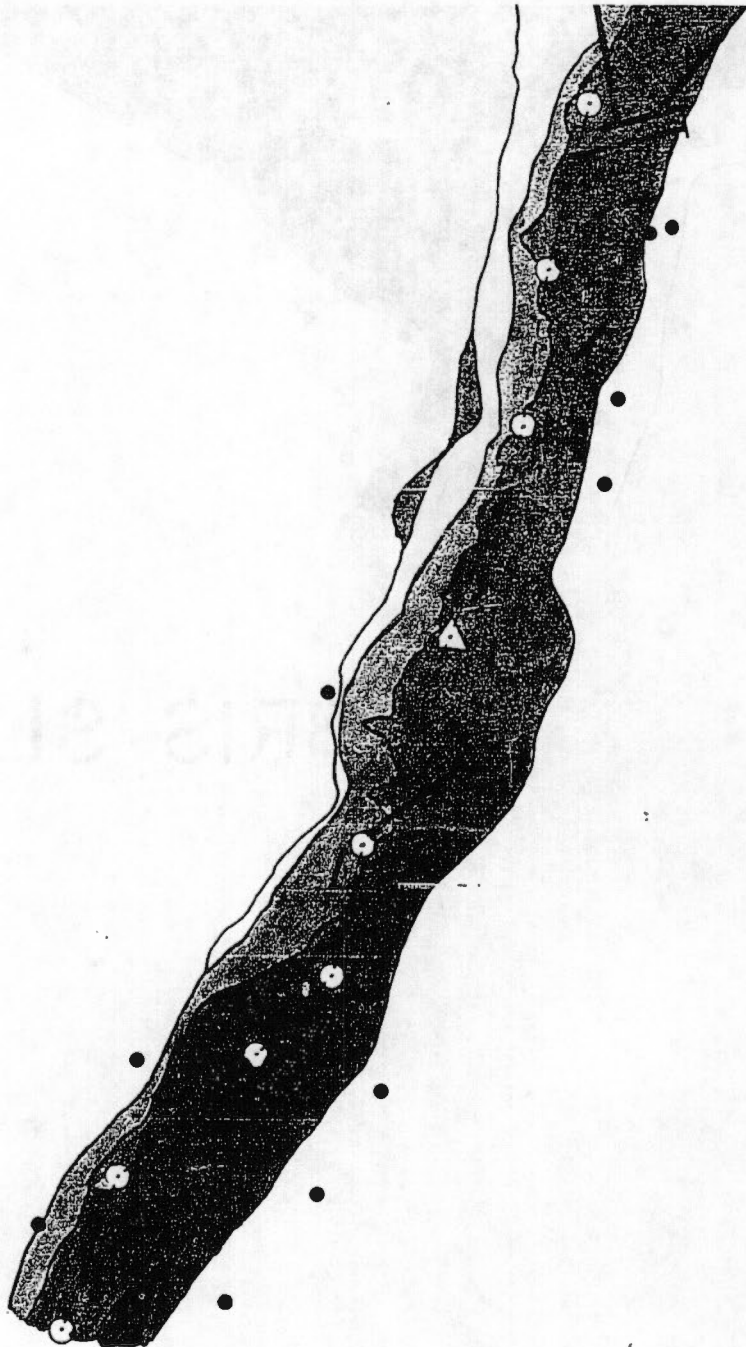
SLIDES

SB-10
SB-6
SB-3
SB-2
ACC-4
ACC-3

1 INCH = 50 FEET

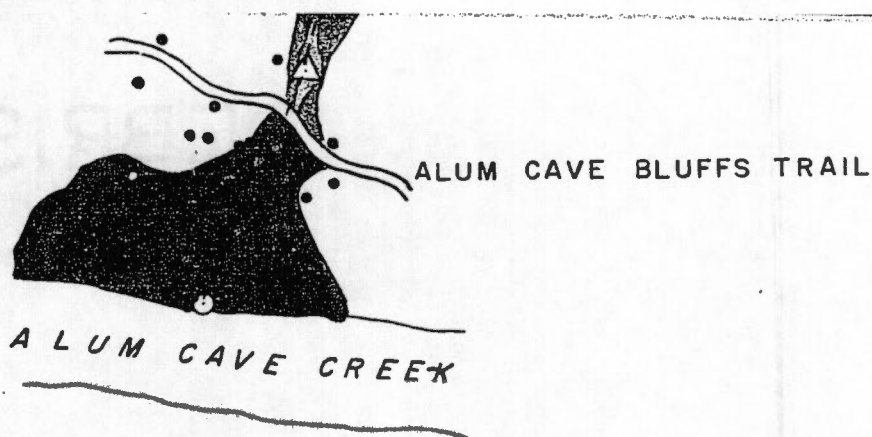


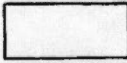
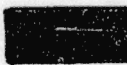
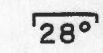
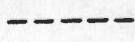
3 SKETCH MAPS



FEET

00 150 FEET



-  BEDROCK
 -  COLLUVIUM
 -  ALLUVIUM
 -  REVEGETATION OVER BEDROCK
 -  REVEGETATION OVER COLLUVIUM
 -  REVEGETATION OVER ALLUVIUM
 -  COLLUVIUM LESS THAN 15 CENTIMETERS THICK OVER BEDROCK
 -  PRE-SLIDE VEGETATION IN SLIDE TRACKS
 -  TACHEOMETER STATION
 -  ROD STATION
 -  TREE OR STUMP GREATER THAN 6 INCHES IN DIAMETER
 -  TREE OR STUMP WITH DEBRIS SCAR
 -  TREE OR STUMP WITH DEBRIS DAM
 -  LOG GREATER THAN 6 INCHES IN DIAMETER
 -  STRIKE AND DIP OF COMPOSITIONAL LAYERING IN THE
 -  LEDGE GREATER THAN 2 FEET HIGH
 -  LONGITUDINAL PROFILE LINE (PLATE 4)
- } SURVEY POINTS

DEBRIS

UFFS TRAIL

BEDROCK
COLLUVIUM
ALLUVIUM
15 CENTIMETERS THICK

ON IN SLIDE TRACKS

} SURVEY POINTS

TER THAN 6 INCHES IN DIAMETER

DEBRIS SCAR

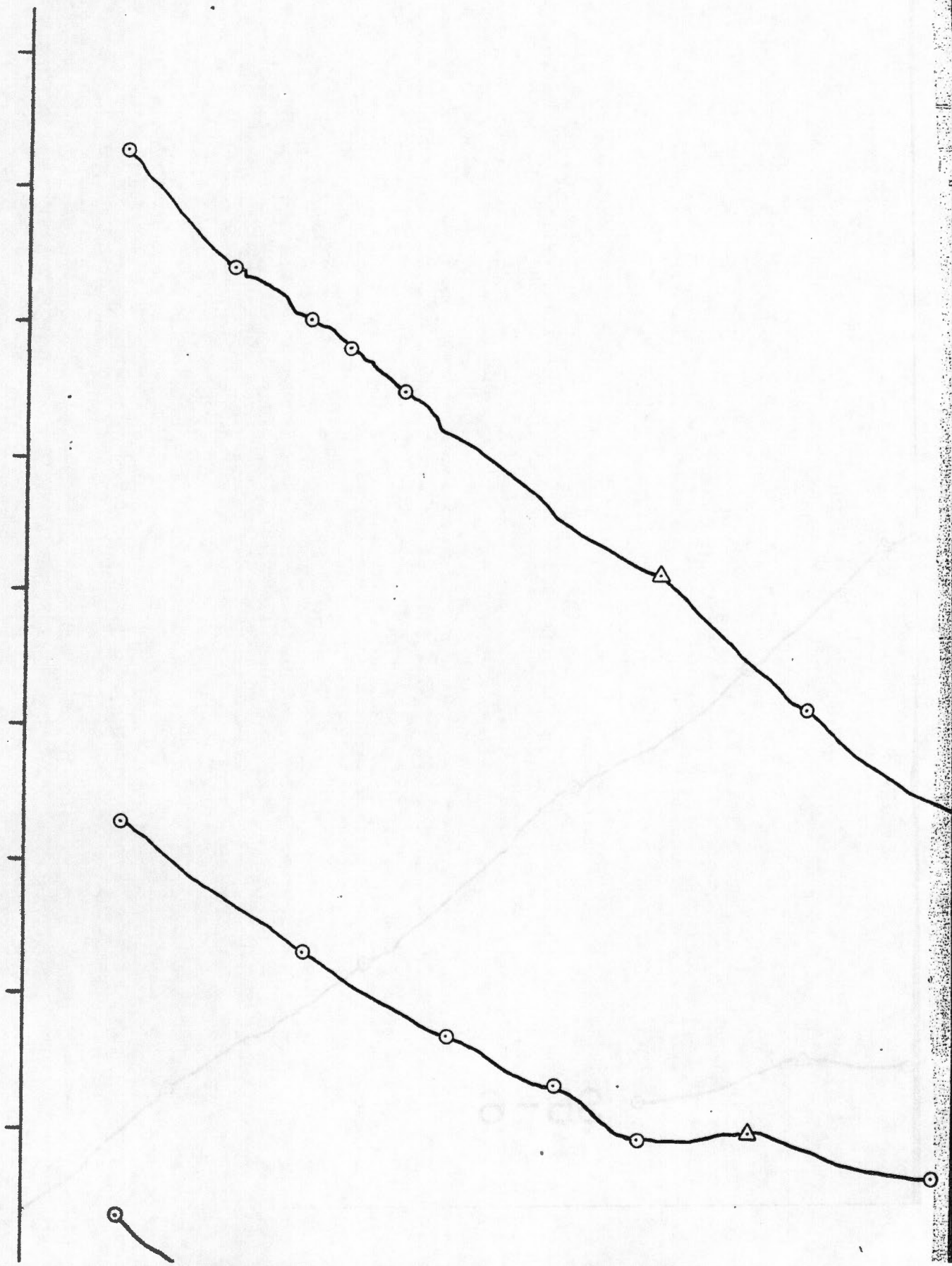
DEBRIS DAM

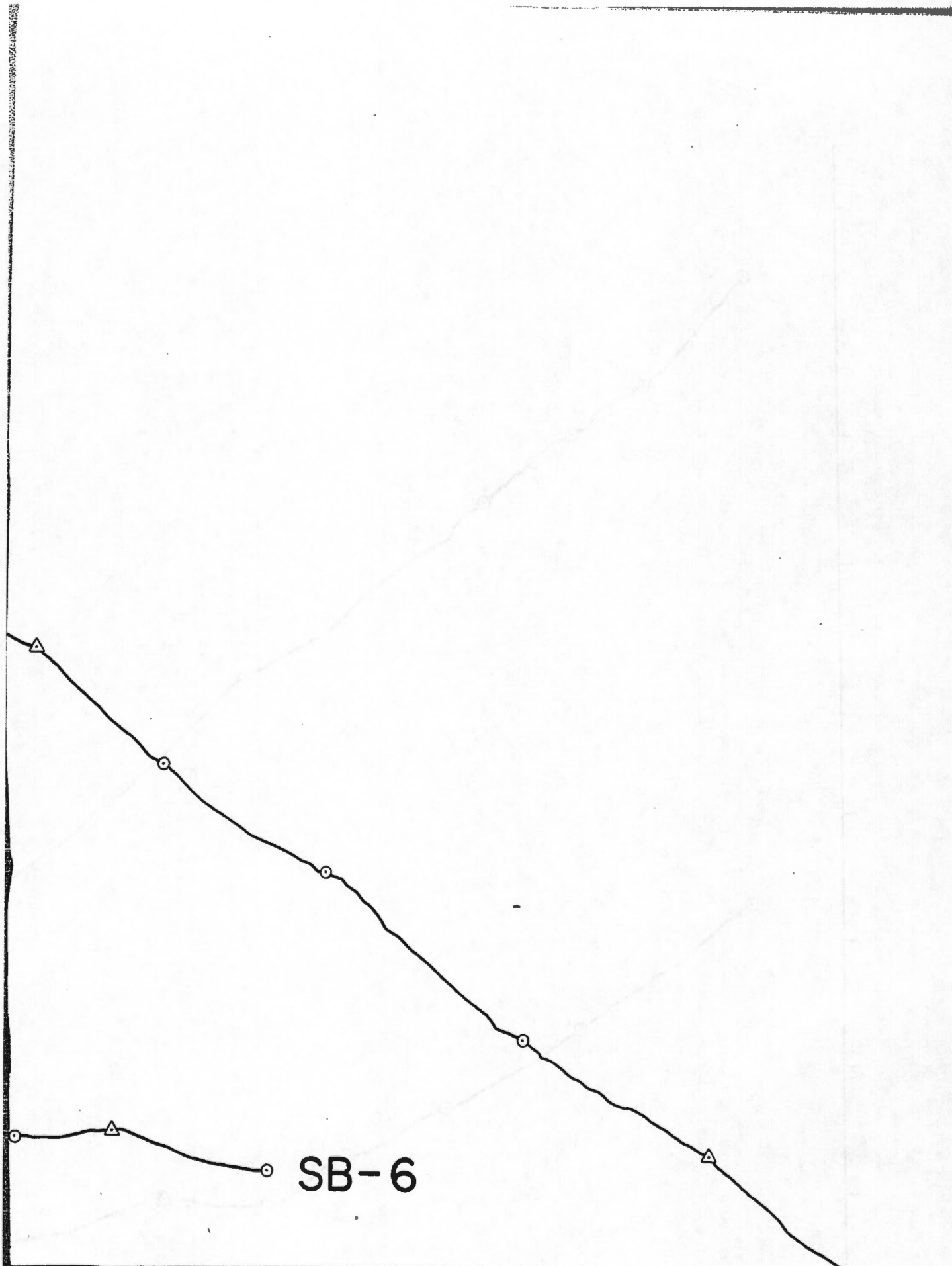
INCHES IN DIAMETER

COMPOSITIONAL LAYERING IN THE ANAKEESTA FORMATION

2 FEET HIGH

LINE (PLATE 4)





SB-6

01

PLATE 4

LONGITUDINAL PROFILES

SLIDES

SB-10

SB-6

SB-5

SB-3

ACC-4

ACC-3

PLATE 4

LONGITUDINAL PROFILES

SLIDES

SB-10

SB-6

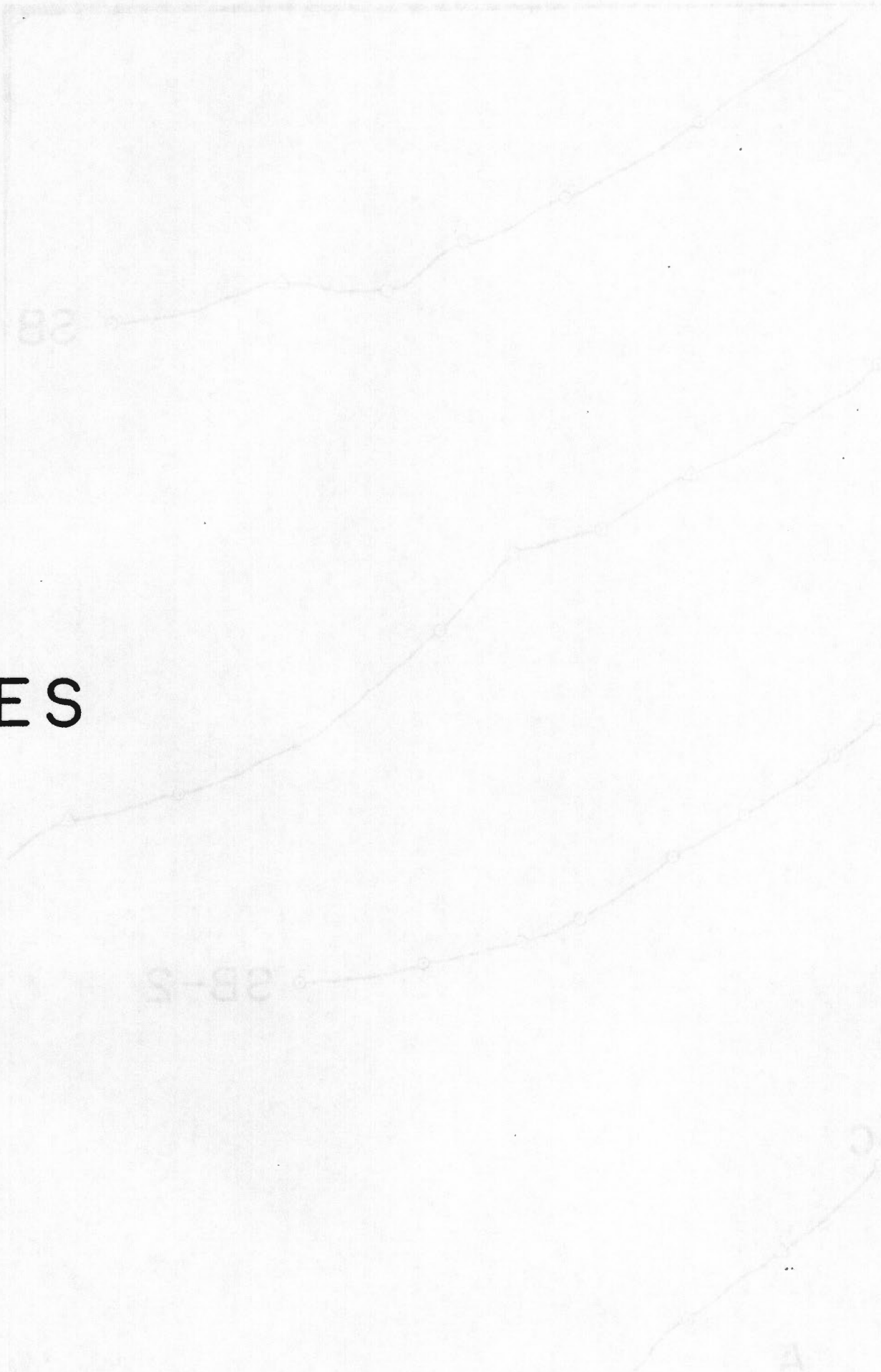
SB-3

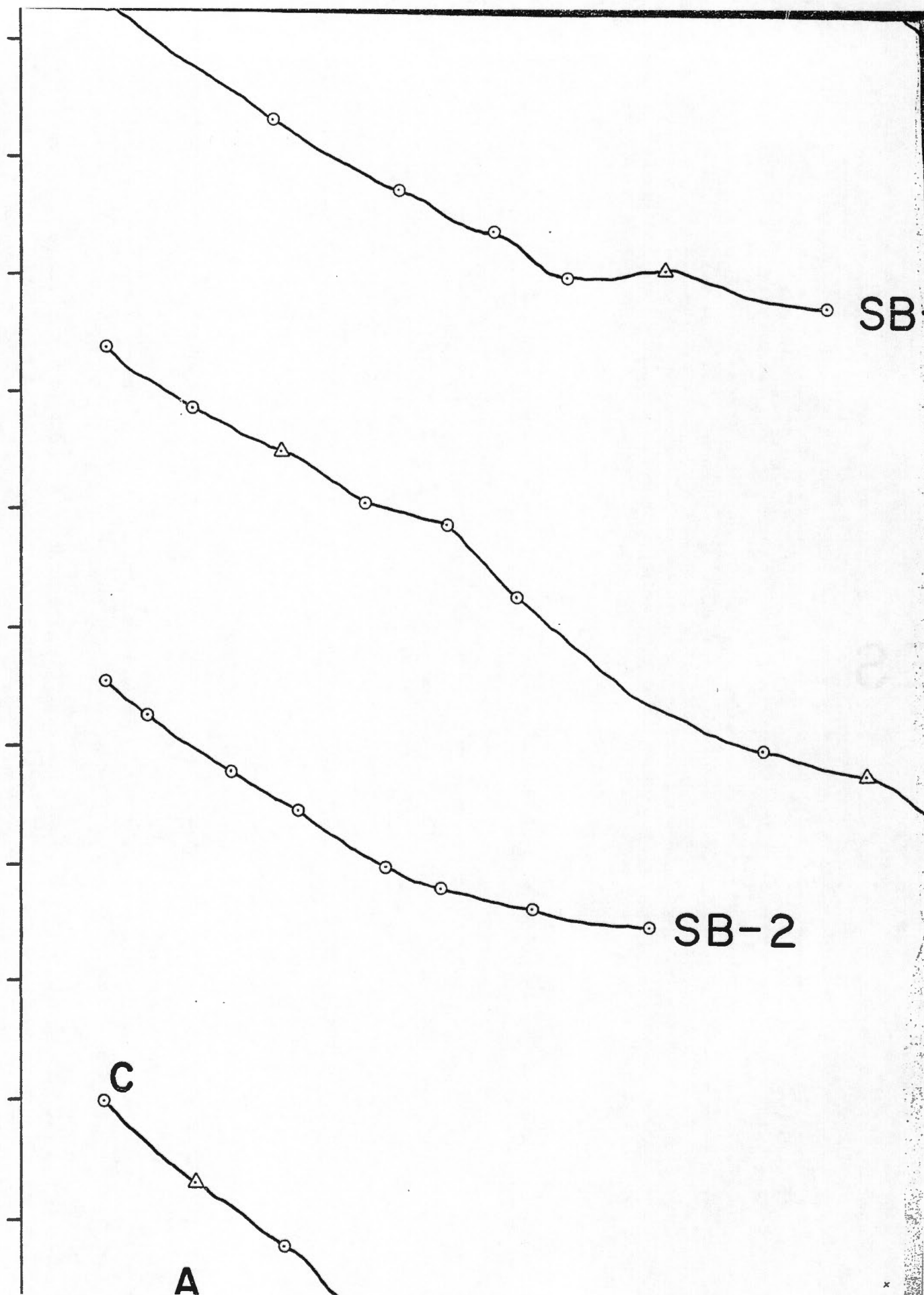
SB-2

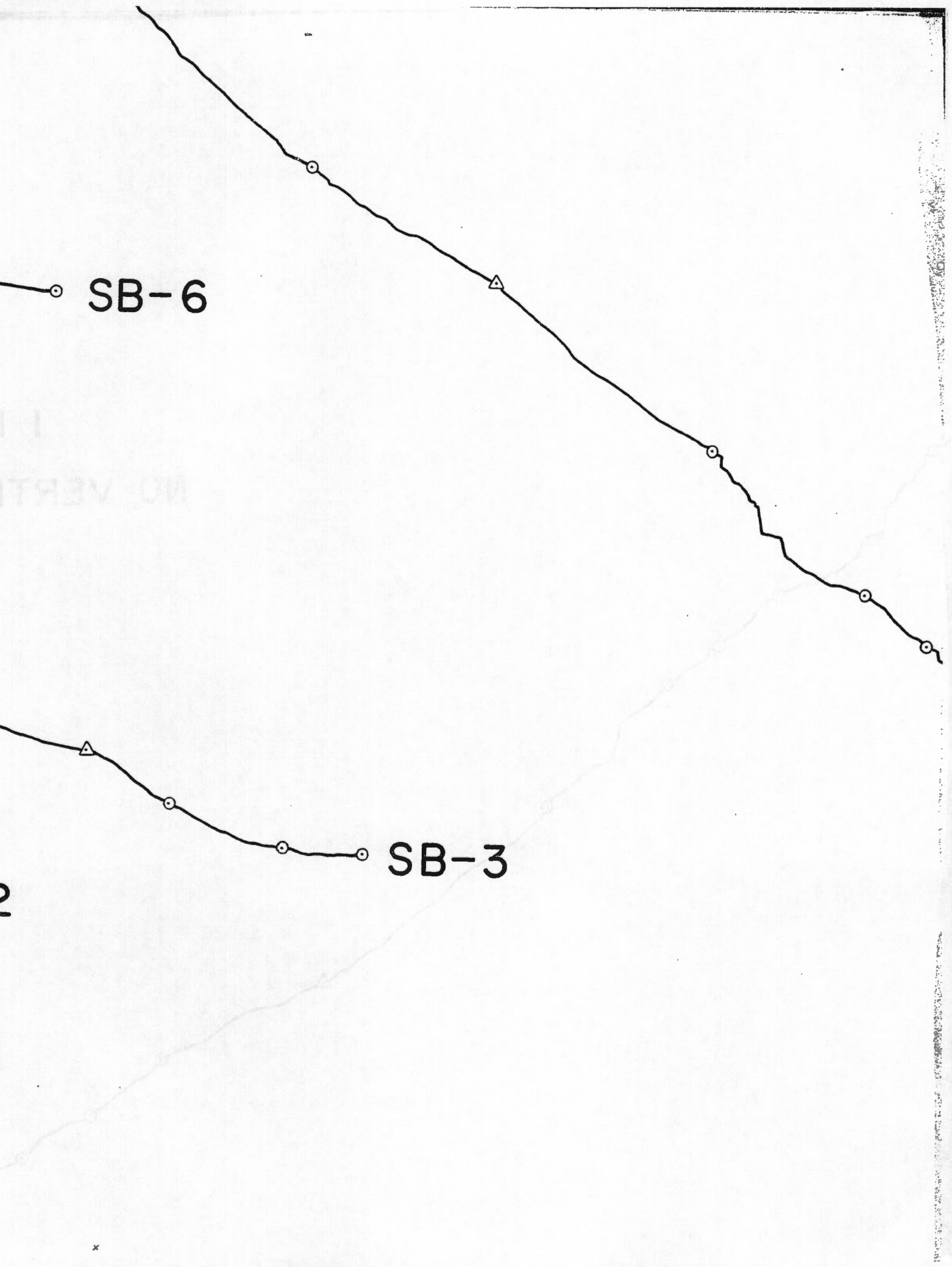
ACC-4

ACC-3

ES



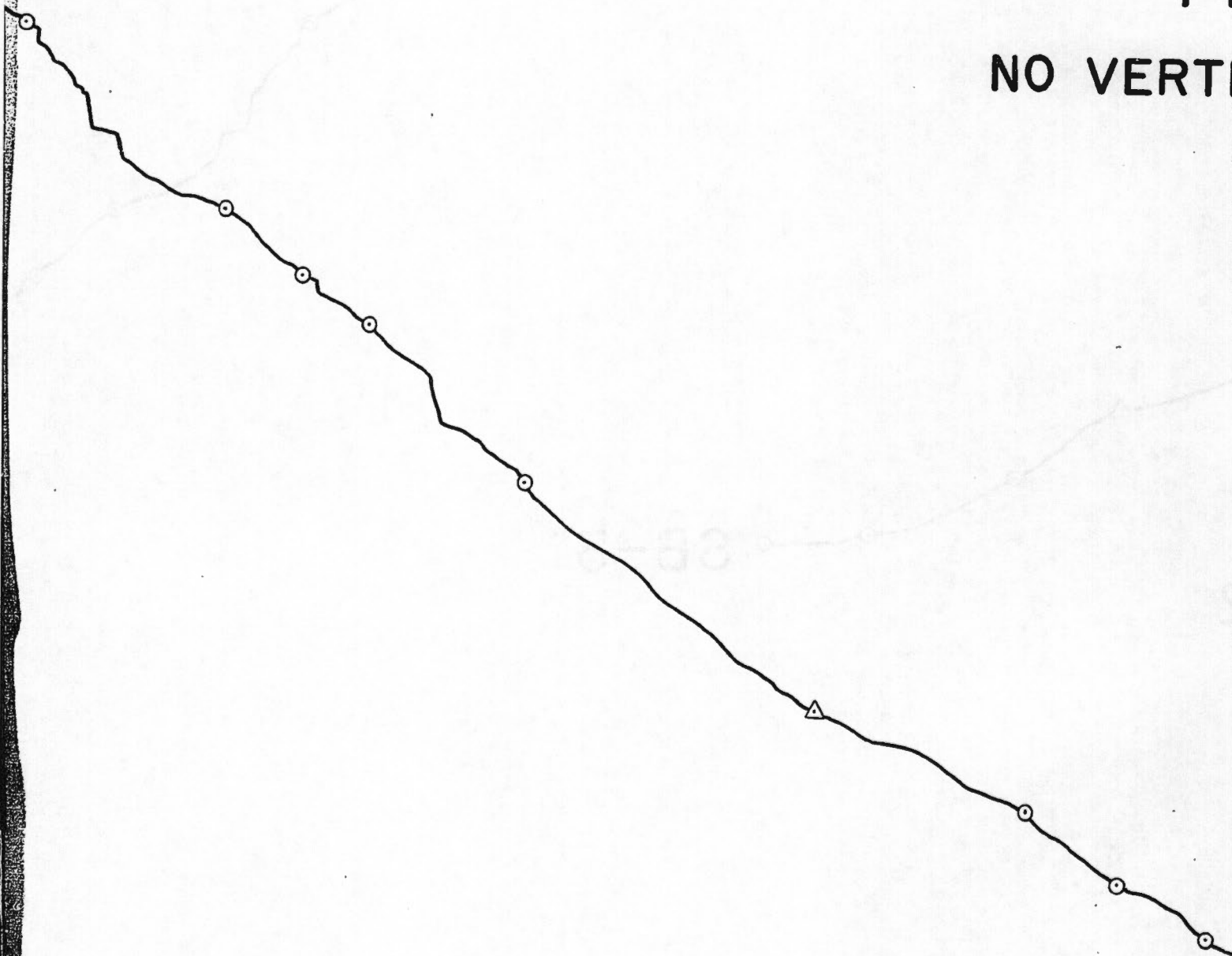




SB-6

SB-3

I
NO VERT

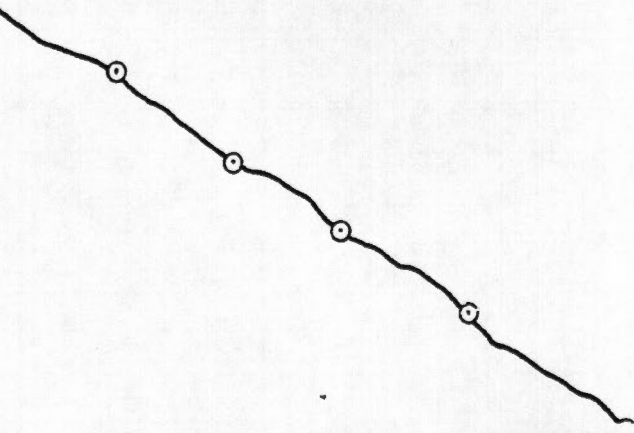


SB-10
SB-6
SB-3
SB-2
ACC-4
ACC-3

1 INCH = 50 FEET

NO VERTICAL EXAGGERATION

△ TACHEOMETER STATION
○ ROD STATION



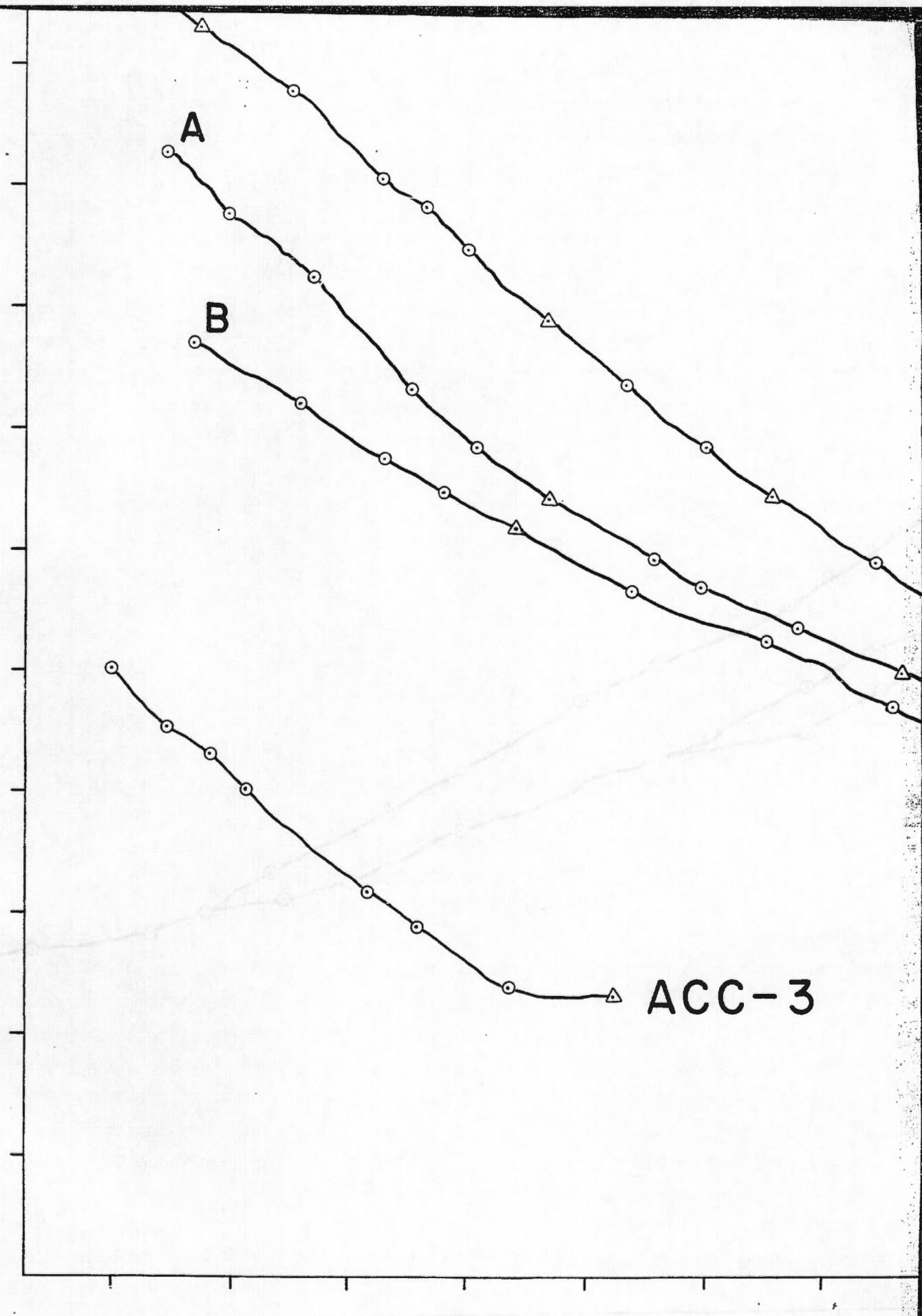
6
3
2
4
3

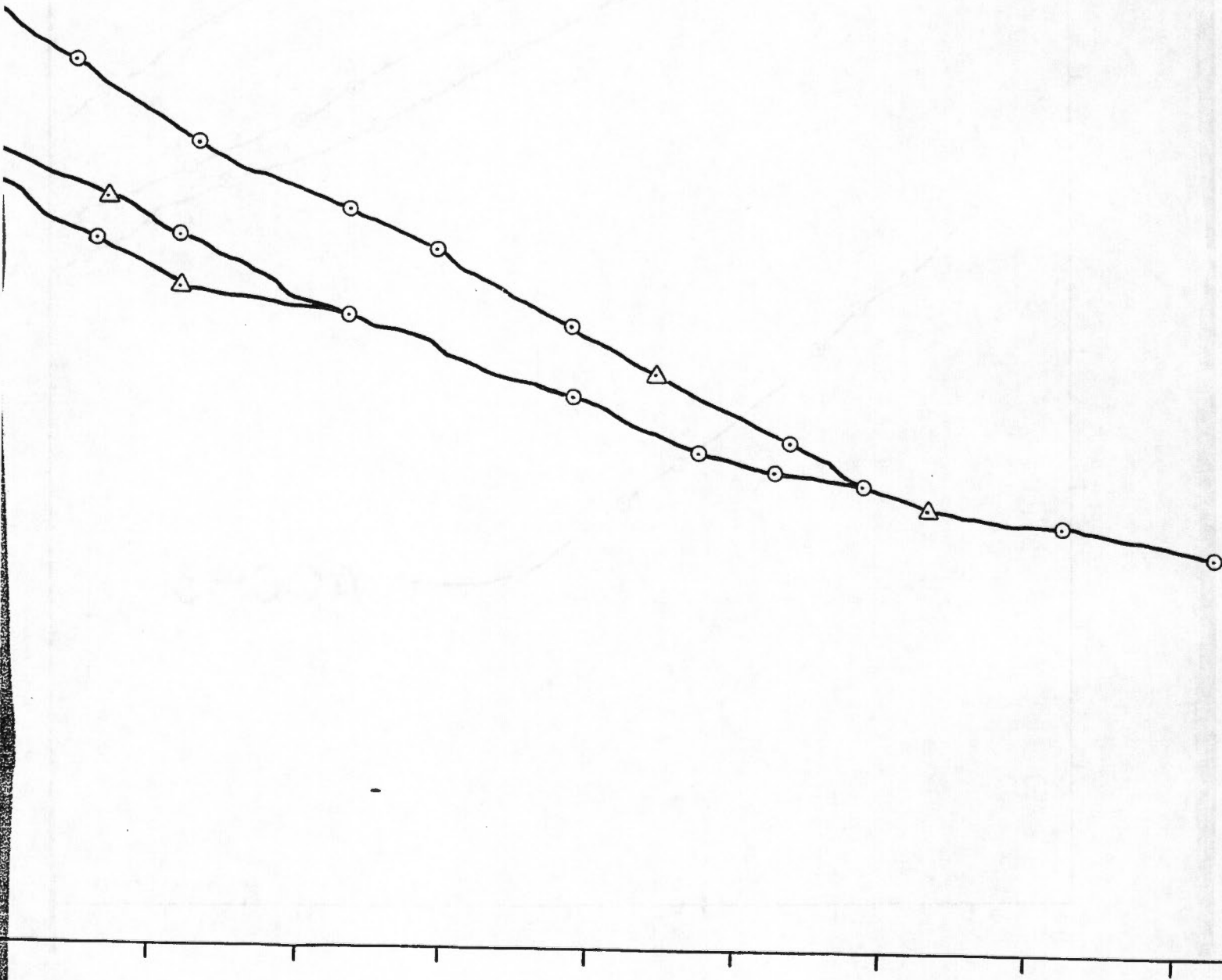
0 FEET

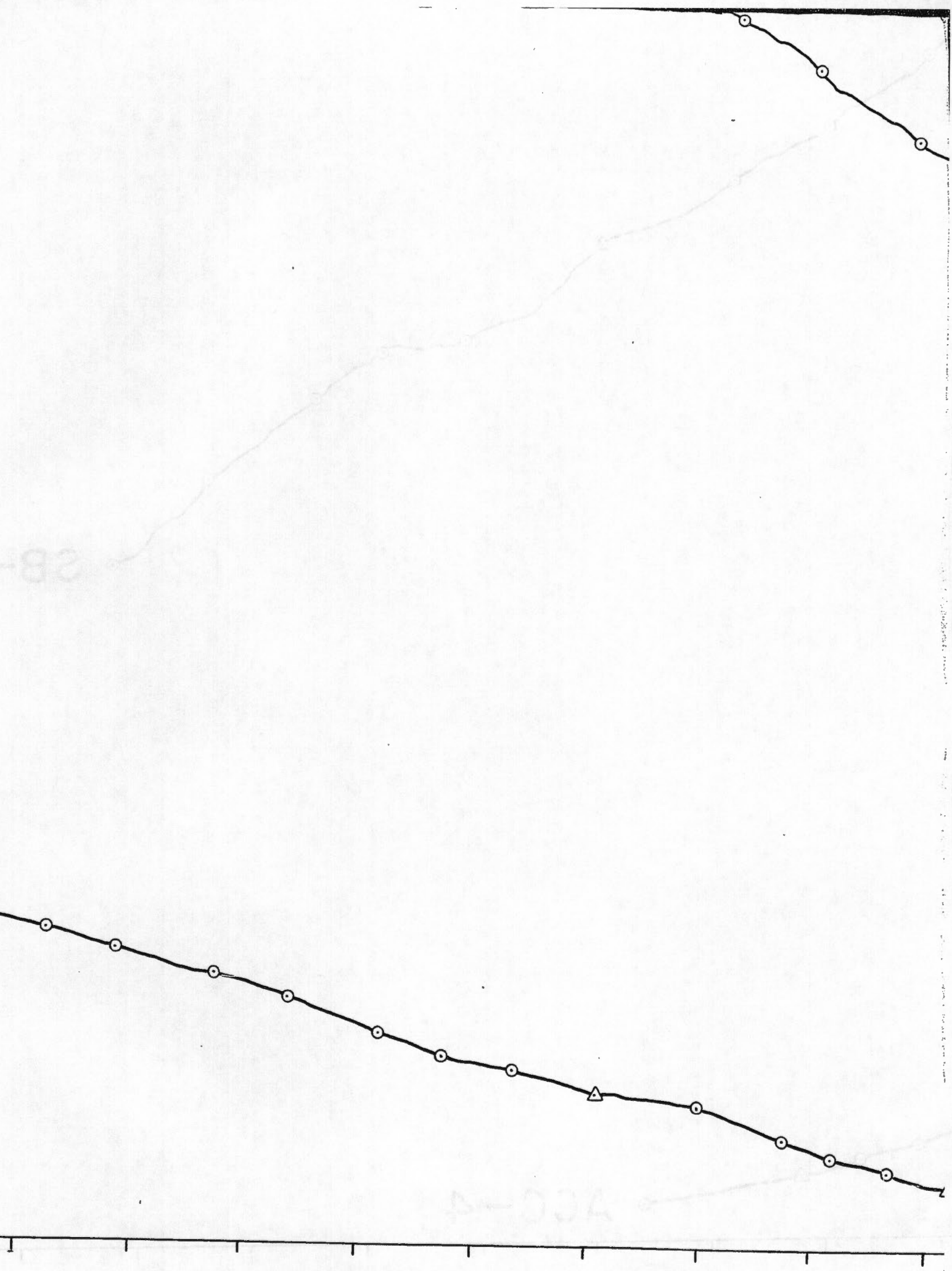
AGGERATION

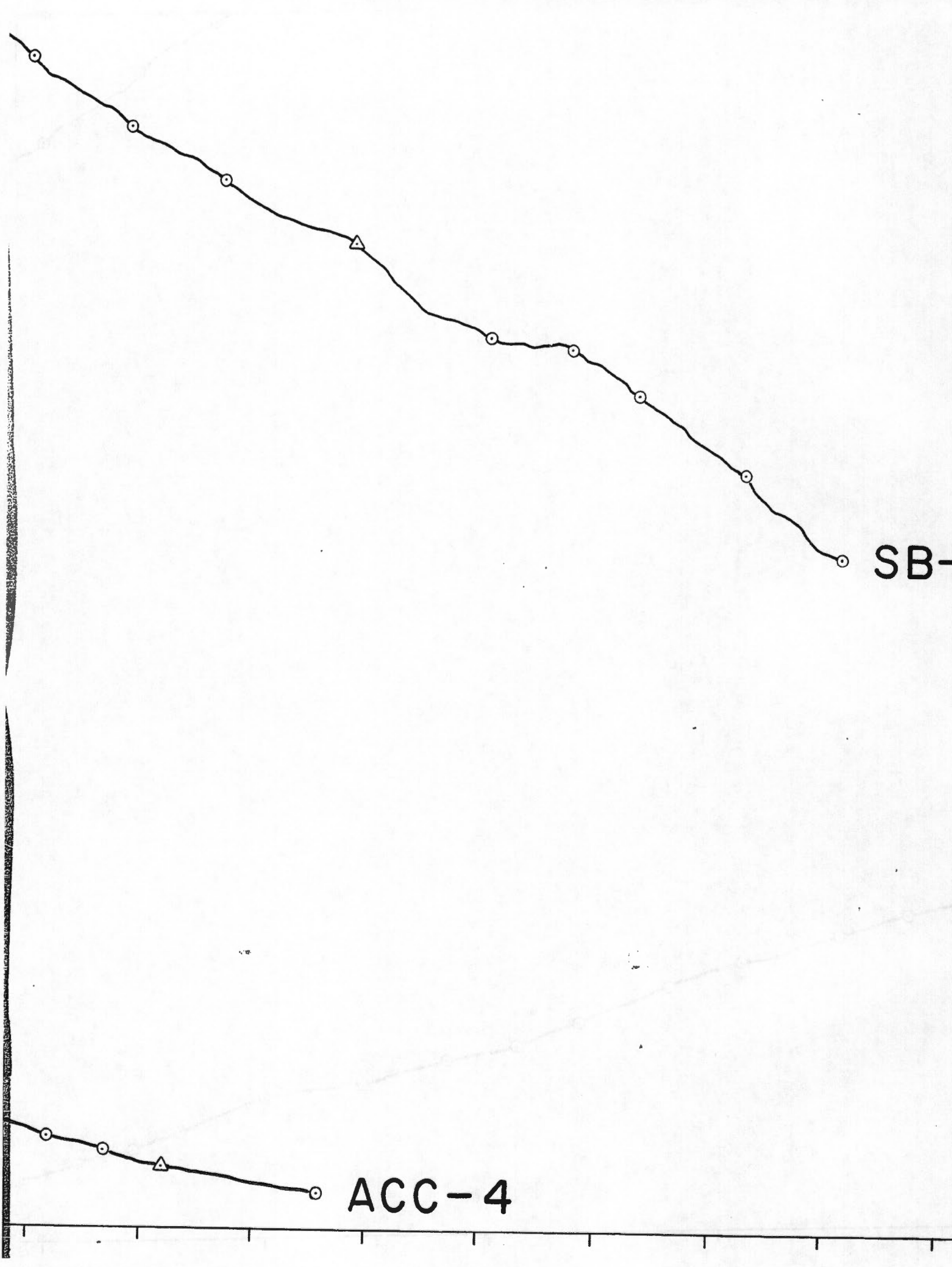
△ TACHEOMETER STATION

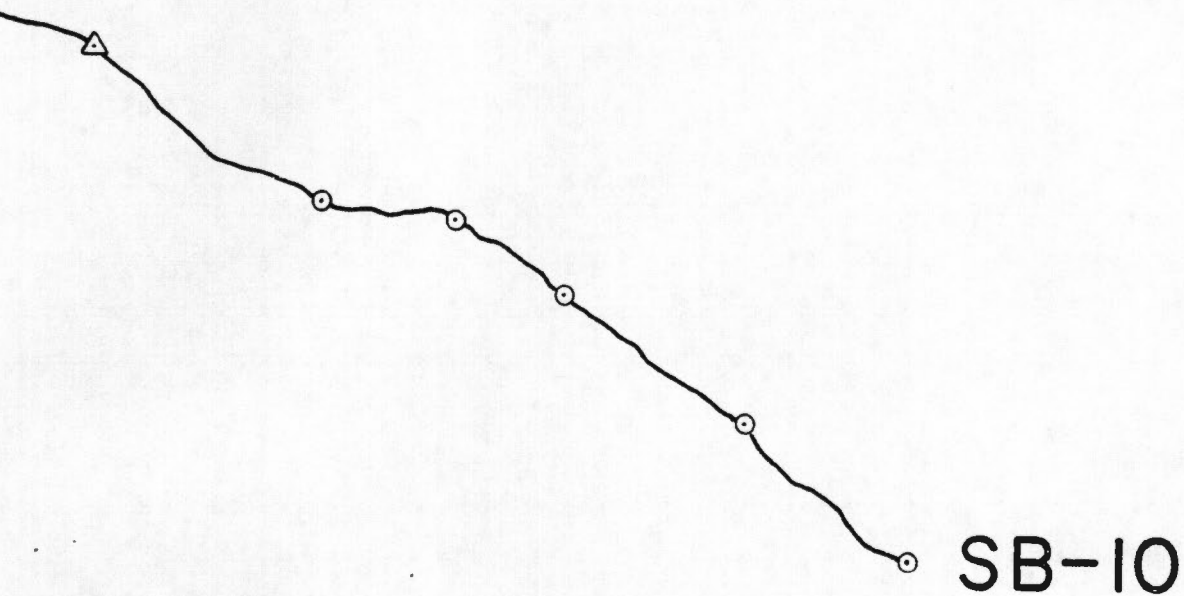
○ ROD STATION











ACC-4

848V21 6420
04/13/09 12838

SH Group