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Small scale, space-order studies using the quantifiable aspects of drainage basins to differentiate the earth's surface have proven to be viable. Generic regionalizations that are continental in scope would be comparisons of drainage basins having similar morphometric parameters. In this study, multiple discriminant analysis tests the hypothesis that drainage basins defined by their morphometric characteristics will group in fashions reflective of their genetic provinces. The results of statistical tests support the null hypothesis. Interpretation of the test statistics indicates results which differ from previous literature as to the importance of certain morphometric parameters.

SELECTED MORPHOMETRIC CHARACTERISTICS AND THEIR RELATIONSHIP TO THE GENETIC PROVINCES OF THE SOUTHERN APPALACHIAN HIGHLANDS

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James Michael McCluskey
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by

James M. McCluskey

APPROVED BY:

DIRECTOR OF THESIS Richard A. Stephenson
Richard A. Stephenson

CHAIRMAN OF THE DEPARTMENT OF GEOGRAPHY
Ennis L. Chestang

DEAN OF THE GRADUATE SCHOOL
Joseph G. Boyette
Joseph G. Boyette

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CHAPTER I

INTRODUCTION

Statement of Problem

American geomorphologists have developed two distinct methodologies to analyze land forms. These are the genetic and generic approaches (Zakrzewska, 1967). The genetic approach is qualitative and uses verbal descriptions to portray landscapes in an evolutionary context. The generic approach is statistical and uses numerical data to analyze surface forms of the earth. The theoretical framework upon which genetic studies are based is related to closed systems analysis, while generic studies are linked to open systems analysis. The two systems are comparable through general systems theory (Strahler, 1952A).

Geographers during the past century have used both approaches to regionalize land forms. Genetic regionalizations reached their peak in the first half of the twentieth century. They are typified by studies that are continental in scope, such as Fenneman's (1916, 1928, 1931, 1938) delineation of the physiographic provinces of the United States. Generic regionalizations are more recent. They normally examine small geographic areas such as the study by Eyles (1971) of West Malaysian drainage basins or the work of Mather and Doornkamp (1970) in Uganda.

There has been a lack of research which tests the conformity of the spatial organization of landscapes when they are defined according to the different modes of land form analysis. The purpose of this investigation is to test for such conformity. A comparison is made between an established genetic regionalization and a generic analysis of the same terrain.

Significance of Research

Numerous geographers have expressed the need for generic land form studies. Kesseli (1946) criticized the genetic approach. He stated that too much concern was placed upon the origin of the land instead of upon numerical analysis which can render an accurate portrait of the land surface. Russell (1949) suggested that geomorphology really becomes geographical when it ascertains what is actually present in the landscape and where each form may be found. Strahler (1954A) noted that genetic methods of land form interpretation are devices adequate to teach general principles in introductory courses, but are not sufficient to meet the needs of research specialists. Salisbury (1971: 6), while tracing the quantitative thread for the descriptive analysis of land forms, summarized numerous criticisms of the genetic approach and offered a rationale for numerical analysis. He stated that:

> ... the thread found its roots in the dissatisfaction of geographers with an historical-genetic geomorphology that concentrated its efforts upon the search for peneplains and gave forth laborious accounts of the evolution of landscapes. It is possible to explain any spatial distribution by tracing its evolution, of course. Thus in explaining the population of the Middle West we might examine the surge of immigration across the land, consider the actual origin of the immigrants, and concern ourselves with the details of birth and death rates on a decennial basis. But this is an inefficient intellectual device for the development of laws and generalizations, particularly so if the examination of genesis is confined by imaginary regional boundaries.

> Geographers needed data about the land that could be used in studies of man-land relationships, or where land was simply one more variable in a more complex mix. To be useful, the information required should be more descriptive than were traditional references to this or that peneplain. The call for a more descriptive landform study came before the advent of the "quantitative revolution" in geography, but the answer to that call developed in full stride with the methodological swing to numbers.

The work of Eyles (1971) and Mather and Doornkamp (1970) in relatively small geographic areas points to the validity of generic regionalizations in concept. However, the development of a macroscale generic regionalization has not yet been undertaken. Such a task would be similar to the efforts of geographers to develop world climatic classifications.

The present investigation differs from previous work in that hypotheses are developed and tested comparing the spatial organization of a landscape defined generically to an established genetic regionalization. The area chosen to test the hypotheses is the southern Appalachian Highlands. The desirability of such an endeavor is twofold. First, if the spatial organization of landscapes defined by generic methods reflects an established genetic regionalization, then the usefulness of the genetic method will be reinforced. Second, if this is not the case, then possible alternatives for a generic land form classification can be considered.

CHAPTER II

A COMPARISON OF THE THEORETICAL FRAMEWORKS OF GENETIC AND GENERIC LAND FORM CLASSIFICATION SYSTEMS

Introduction

In order to test the conformity in the spatial organization of land forms as defined by the genetic and generic approaches of land form classification, a comparison must be made between their theoretical frameworks to determine the appropriate variables to be used in the analytical model. Strahler (1952A) suggested that this can be done in terms of general systems theory. Hall and Fagan (1956: 18) defined a system as "a set of objects together with relationships between their attributes." Genetic studies with their evolutionary orientation are linked to "closed systems", while generic studies with their quantitative considerations are related to "open systems".

Genetic Studies and Closed Systems Analysis

Von Bertalanffy (1956) defined a closed system as one in which no import or export of energy occurs. Davis (1899) provided an early approach to a closed system study of land forms. His approach formed the basis for the majority of the genetic regionalizations. These include: Fenneman (1916, 1928, 1931, 1938), Atwood (1940), Lobeck (1950), Thornbury (1965), and Hunt (1974).

In the Davisian approach to landscape development, the concept of stage or length of time is stressed. Davis (1899) postulated that after the initial uplift of the land the interaction of geomorphic processes and structures would produce sequential landscapes. The sequential landscapes are identified as the stages of youth, maturity, and old age. As the land evolves through time, there is a continuous volumetric reduction in the surface of the earth ending in a state of peneplanation. Davis defined a peneplain as a condition where a featureless plain is developed through the processes of subaerial erosion. The various stages of Davis' "geographical cycle" are not of the same time duration, and the process of evolution can be reinitiated if there is another uplift of the land. Davis thought that landscapes could be regionalized according to the various stages of his geographical cycle (Bryan, 1941).

Davis (1899) formulated his cyclical theory of landscape evolution primarily for humid environments, where fluvial processes dominate. However, he also considered the implications in arid and glaciated areas.

Davis' cyclical viewpoint of landscape evolution is associated with the concept of "entropy" as it is related to closed systems. Entropy has been defined as the degree to which energy has become unable to perform work; an increase in entropy denotes a trend towards minimum free energy (Von Bertalanffy, 1956). Therefore, in closed systems there is a tendency to level down existing differentiation within the system or toward a progressive degradation of energy to its lowest form. This situation is analogous to the volumetric reduction of the land surface from its initial uplift to the state of peneplanation (Chorley, 1962). The uplift of the land provides the initial potential energy to the system, while the degradation of the land through the processes of subaerial erosion constitutes the tendency towards entropy. Entropy is maximized in the peneplanation state.

The state of any closed system is largely dependent on the amount of time that has elapsed since its inception. Thus, closed systems may be thought of as being time-dependent, since the basis for their study is the historical evolution of the surface of the earth.

The closed system approach formed the basis for numerous land form regionalizations. Davis' (1899) geographical cycle was the dominant guide in their formulation. Other similar theories of landscape development are Penck's (1953) theorem of parallel slope retreat and King's (1953) "epigene cycle of erosion".

Generic Studies and Open Systems Analysis

Generic regionalizations have only recently appeared in the literature. They are linked to open systems analysis. Open systems contrast sharply with closed systems. In the open system, there are exchanges of energy and materials with outside environments (Von Bertalanffy, 1950). A balance exists between the rates of import and export of energy and material (Doornkamp and King, 1970). This balance acts as a steady state (Strahler, 1952A). Once equilibrium is established, an open system becomes time-independent because of its self-regulating mechanism (Strahler, 1952).

Hack (1965: 5) formulated these ideas in relation to the development of landscapes in his principle of "dynamic equilibrium".

He stated that:

> As applied to the landscape, the principle of dynamic equilibrium states that when in equilibrium a landscape may be considered a part of an open system in a steady state of balance in which every slope and every form is adjusted to every other. Changes in topographic form take place as equilibrium conditions change, but no particular cycle or succession of changes occurs through which the forms inevitably evolve, as was assumed by Davis and most later workers in geomorphology. Differences in form from place to place are explained by differences in the bedrock or in processes acting upon the bedrock. Changes which take place through time are a consequence of climatic or diastrophic changes in the environment or of changes in the pattern and the structure of the bedrock as the erosion surface is lowered.

Numerous geomorphologists view a drainage basin as an open system. These include Chorley (1962), Strahler (1964), Schumm and Lichty (1965), and Morisawa (1968). Strahler (1964) reviewed the application of open systems analysis to the drainage basin. He stated that in a graded drainage basin equilibrium manifests itself in the development of certain topographic forms which are time-independent. Over a long time span, however, there are continuous readjustments in components as relief lowers and available energy decreases. Topographic forms show a correspondingly slow evolution. Validity for the drainage basin acting as an open system depends on the principle that: when a given intensity of erosion acts upon a mass of given physical properties, conditions of surface relief, slope, and channel configuration exist within a steady state. The morphologies of these forms are adjusted to transmit through the system the quantity of debris and excess water which is characteristically produced under the controlling regime of climate. Changes in the controlling factors of climate and geology upset steady state conditions. If this is the case, a rapid series of readjustments will take place to reestablish a steady state. New values of basin geometry are then developed.

Systems of Stream Ordering

A concept that is basic to any numerical analysis of drainage basin characteristics is a system of stream ordering. One such system was proposed by Gravelius (1914), but it was not until the work of Horton (1945) that the use of stream ordering systems became widely used in geomorphology. The system that is most widely used today is Strahler's (1952B) modification of the Horton method. According to Strahler, all unbranched tributaries are first-order streams. The joining of two first-order streams forms a second-order stream and so on. Increases in stream order occur only when two streams of the same magnitude join together. The head of a second-order stream is at the junction of two first-order streams. This is also true for streams of successively higher orders.

Strahler's system differs from that of Horton in that the Hortonian method extends the second-order designation back to the head of the longest first-order tributary and likewise for streams of higher orders (see Figure 1). Other stream ordering systems have been advanced by Scheidegger (1965), Woldenburg (1966), and Shreeve (1967). They attempt to account for the total magnitude of all tributaries within a given system. These methods of stream ordering are not widely used.

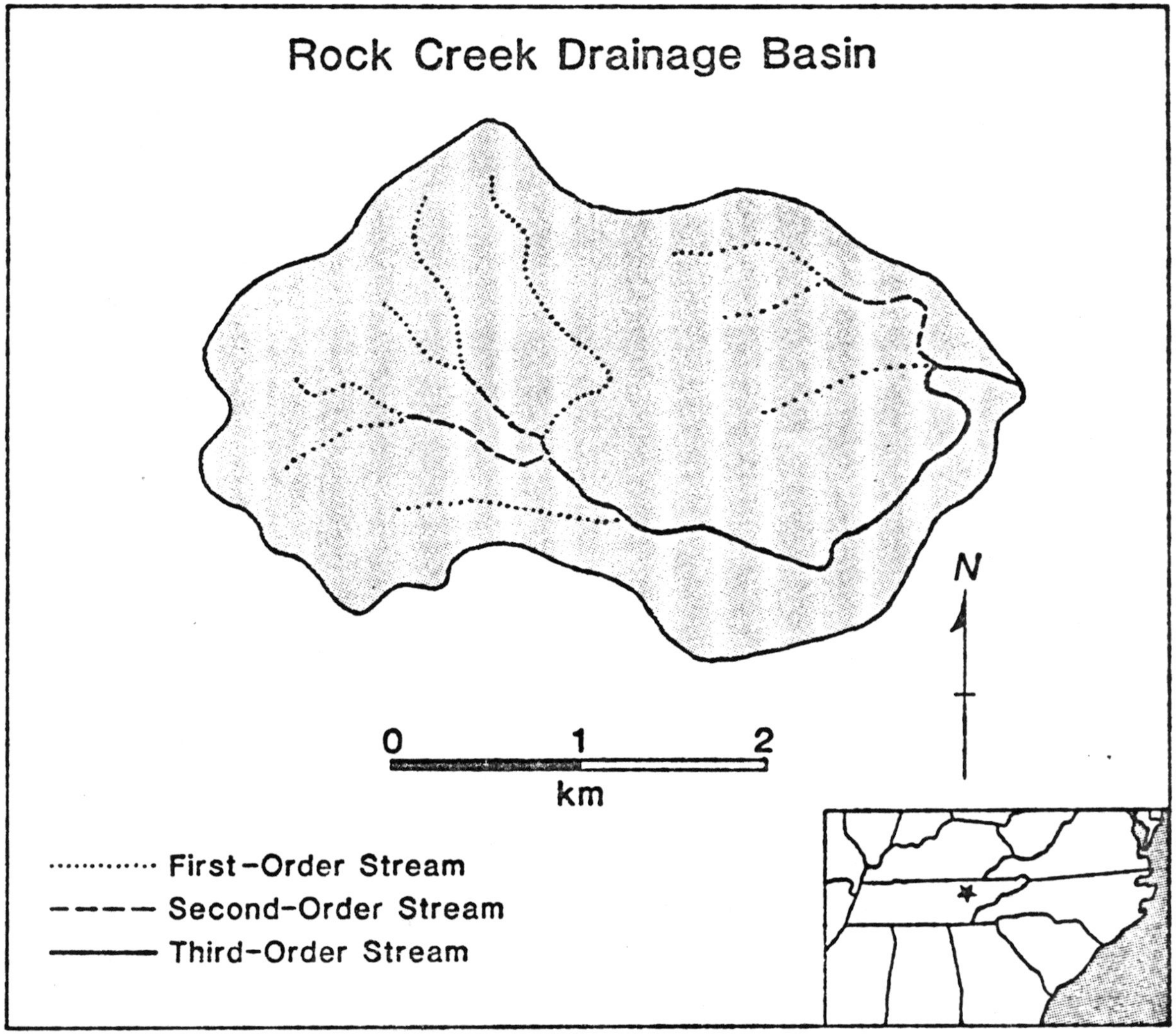

Figure 1: Strahler's method of stream-ordering.

Laws of Drainage Basin Composition

Horton proposed three laws of drainage basin composition which relate stream order to the number, length and slope of streams in any given system. The first of these is the law of stream numbers. Horton (1945: 287) stated:

> The number of streams of different orders in a given drainage basin tends to approximate an inverse series in which the first term is unity and the ratio is the bifurcation ratio.

This means that within a given drainage basin there is a decrease in the number of streams at correspondingly higher orders. The geometric series may be demonstrated by plotting the number of streams on a logarithmic scale against stream order on an arithmetic scale. The validity of this relationship has been demonstrated in field studies conducted by Strahler (1952B; 1957) and Leopold and Miller (1956). Some researchers including Shreeve (1963), Bowden and Wallis (1964), and Milton (1966) have stated that the law may be a statistical relationship rather than due to the random development of drainage networks. Other researchers such as Shreeve (1966), Smart (1967), and Scheidegger (1968) have explored the theoretical relationship between stream order and stream number.

Horton's second law of drainage composition denotes the relationship between stream order and stream length. Horton (1945: 287) stated:

> The average length of streams of each of the different orders in a drainage basin tend to closely approximate a direct geometric series in which the first term is the average length of streams of the 1st order.

This law states as stream order increases so does stream length. Again this relationship may be demonstrated by plotting mean stream length on a logarithmic scale against stream order plotted on an arithmetic scale. Melton (1957) and Maxwell (1960) question the validity of the law of stream lengths when the Strahler ordering system is used rather than the Horton method. Broscoe (1959) proposed a modification of the stream length law for use with the Strahler system. Cumulative stream length would be substituted for Horton's mean stream length. The improvement of Broscoe, however, fits Horton's definition of length better than Strahler's uncumulated mean lengths (Bowden and Wallis, 1964). Milton (1966) suggested that the law of stream lengths is a statistical probability function similar to the law of stream numbers.

Horton's third law of drainage basin composition relates stream order to stream slope. Horton (1945: 295) stated:

> ...there is a fairly definite relationship between slope of streams and stream order, which can be expressed by an inverse geometric-series law.

This law states that as there is an increase in the order of streams there will be a decrease in stream slope. It may be demonstrated like Horton's other laws of drainage composition by plotting the logarithmic mean stream slope against stream order. Morisawa (1962) found in the Appalachian Plateau that all drainage basins do not have straightline plots when stream slope is related to stream order. It was felt that the anomalies were caused by differential resistance to erosion and rejuvenation. Broscoe (1959) restated this law to conform to the Strahler ordering system by substituting cumulative mean slope for

Horton's average slope. Bowden and Wallis (1964) have substantiated Broscoe's use of cumulative mean slope.

Two other laws regarding drainage basin composition have been formulated. A law of basin areas inferred by Horton was formalized by Schumm (1956: 606). He stated:

> ...the mean drainage basin areas of streams of each other tend to approximate closely a direct geometric series in which the first term is the mean of the first-order basins.

Field studies by Morisawa (1959) and Leopold and Miller (1956) have substantiated this law.

Morisawa (1962: 1035) formulated a law for basin relief. She noted that:

> ...the average relief of basins of each order forms a direct geometric series in which the first term is average relief of the first order.

Fok (1971) used Horton's laws of stream lengths and stream slopes to derive a law which is similar to that of Morisawa. This was substantiated from field data from drainage basins of the third-order and higher.

A Comparison of Open and Closed Systems

Schumm and Lichty (1965: 115) considered the comparability of open and closed systems with regard to the study of land forms. They stated:

> Landscapes can be considered...either as a result of past events or as a result of modern erosional agents. Depending upon one's viewpoint the landform is one stage of the erosional cycle of erosion or a feature in dynamic equilibrium with the forces

> operative. These views are not mutually exclusive. It is just the more specific we become the shorter is the time span with which we deal and the smaller is the space we consider. Conversely when dealing with geologic time we generalize. The steady state concept can fit into the cycle of erosion when it is realized that the steady state can be maintained for a fraction of the total time involved.

Schumm and Lichty (1965) also considered the status of drainage basin variables during time spans of decreasing duration. They designated variables as being independent, dependent, or not relevant. Variables are arranged in a hierarchy approximating increasing degrees of dependence. For example, over the long span of cyclical time, geology, initial relief, climate, and time are independent variables. Time, simply the duration since the inception of the erosional cycle, perhaps is the most important variable in the cyclical time span. It determines the accomplishments of the erosional agents, and therefore, the progressive morphological changes within the system. The graded time span refers to a short span of cyclical time where conditions of dynamic equilibrium exist. There are continuous adjustments between elements within the system and negative feedback and self-regulation dominate. From the viewpoint of graded time, time and initial relief are not considered to be relevant variables. There are no restrictions placed on space or area because the graded time span considers components of the landscape in smaller units (see Table I).

Summary

When viewing the theoretical frameworks by which genetic and generic regionalizations are formulated, it is seen that one of the

Table I

The Status of Basin Variables During Time Spans of Decreasing Duration

Drainage Basin Variables	Status of Variables During Designated Time Spans	
	Cyclic	Graded
1. Time	Independent	Not relevant
2. Initial Relief	Independent	Not relevant
3. Geology (lithology and structure)	Independent	Independent
4. Climate	Independent	Independent
5. Vegetation	Dependent	Independent
6. Relief or volume of system above base level	Dependent	Independent
7. Hydrology (runoff and sediment yield per unit area within system)	Dependent	Independent
8. Drainage network morphology	Dependent	Dependent
9. Hillslope morphology	Dependent	Dependent
10. Hydrology (discharge of water and sediment from system)	Dependent	Dependent

Source: Schumm, S.A. and R.W. Lichty 1965. Time, space, and causality in geomorphology. American Journal of Science, 263, 110-119.

fundamental differences is the consideration of time. Genetic studies, such as that of Fenneman, are based upon the closed system Davisian approach where broad expanses of land are designated according to stage. Generic regionalizations use Hortonian analysis and relate the quantifiable forms of the drainage basin to the processes by which they form while holding time constant.

Open systems are considered to be a special case of the closed systems, since the transport of material and energy into and from the system becomes zero (Von Bertalanffy, 1956). Therefore, there should be similar spatial organizations of the landscape when the dependent variables of drainage network and hillslope morphology are considered. This similarity is based on the fact that while genetic regionalizations designate specific areas according to their stage in the evolutionary cycle and generic regionalizations have no such cyclical reference, both classify land forms according to the resultant form which occurs through the interaction of geomorphic structures and processes.

CHAPTER III

A REVIEW OF GENETIC AND GENERIC REGIONALIZATIONS

Genetic Regionalizations

The first attempt at a regional classification of the United States was made by Powell (1896). The basis for his regionalization was the common history by which geomorphic features developed. Physiographic provinces were defined by map and verbal description. In the twenty years following Powell, numerous other attempts were made at a regional classification of the United States. Thornbury (1965) outlined these studies which included: Davis in 1899, Brooks in 1906, Bowman in 1911, Blackwelder and Dryer in 1912, Fair and Von Engelen in 1913, and Fenneman in 1916. Some studies were based on physiographic considerations, while others were based on combinations of physiography, soils, climate, vegetation, and other factors. Thornbury (1965) also considered the numerous regionalizations made at the state level and identified the basis for each (see Table II).

Fenneman's (1916, 1928, 1931, 1938) classification of the United States into physiographic provinces is the most widely known of the genetic studies. It was officially accepted by the United States Geological Survey after its initial presentation at the 1919 meeting of the Association of American Geographers. The system has three categories or levels of differentiation for classifying geomorphic provinces. The division is the most general category, followed by increasing levels of

Table II

Explanatory Regionalizations at the State level and the Stated Basis for Division

Date	Author	State	Basis for Division
1896	Marbut	Missouri	Principally geologic structure
1898	Salisbury	New Jersey	Geologic structure, and topography
1899	Abbe	Maryland	Geology and topography
1900	Hill	Texas	Soil, climate, geologic structure, drainage, and human culture
1902	Tarr	New York	No clear statement
1916	Martin	Wisconsin	Constrasting topographic form
1922	Mallot	Indiana	Altitude, relief, and type and relationships of land forms
1925	La Force, et al.	Georgia	Altitude and relief, grouping of the features or relief patterns, size and scale of features, nature of surface
1952	Hinds	California	Geologic history

Source: Thornbury, W.D. 1965. Regional Geomorphology of the United States, New York: John Wiley and Sons.

differentiation, by the province and section. The dominant features of topography are explained by Davis' theoretical considerations of process, structure, and stage (Fenneman, 1928).

Other classifications similar to that of Fenneman are Loomis (1937) and Atwood (1940). Later researchers such as Thornbury (1965) and Hunt (1974) departed from the Davisian concept of Stage by substituting the idea of length of time as it relates to the evolution of landscapes.

Murphy's (1967; 1968) classification of land forms on a world scale combines the genetic and generic approaches. He used three levels or categories of information to regionalize land forms. Structural regions identified a landscape in terms of its geologic origin and rock composition. Topographic regions, using numerical observations for elevation, denoted the surface configuration of the earth. The means by which landscapes were formed are regionalized in terms of various erosional and depositional processes. Structure and process regions are defined genetically, while topographic regions are defined generically. When the three regional types are superimposed, a landscape may be considered in terms of process, structure, and stage as well as by differences in surface configuration.

Other classifications which combine aspects of the genetic and generic methods of terrain evaluation are the land-systems approaches (Cooke and Doornkamp, 1977). For example, the model developed by the Commonwealth Scientific and Industrial and Industrial Research Organization (CSIRO) of Australia is physiographic in nature and considers the genetically interrelated components of the land surface which include vegetation, soils, bedrock, and slope. The hierarchy of units within the classification are similar to those of Fenneman; however, a more refined level of detail is reached. The CSIRO method developed as a rapid method of reconnaissance survey of unmapped or poorly mapped areas. The method has been adopted by the Land Resource Division (LRD) of the Overseas Development Administration, Foreign and Commonwealth Office in Britain. Reports have been produced for parts or all of the countries of Bechuanaland, Tanzania, Nigeria, Lesotho, Botswana, and Gambia (Ministry of Overseas Development, 1970). Similar mapping techniques were put forward by Hunt (1950) as applicable to military purposes for assessing the difficulties of passing across different types of ground. In the United States, the Soil Conservation Service of the Department of Agriculture formalized a land-capability classification for agriculture which resembles the land-systems method. The United States system recognizes a threefold hierarchy from smaller to larger groupings of 1) capability units, 2) capability subclasses, and 3) capability classes (Klingebiel and Montgomery, 1961).

Mabbutt (1968: 12) outlined the considerations that support the genetic framework and the reasons for its relative dominance. He stated:

> 1) It is a logical breakdown, and similarities between widely separated areas should be predictable when the basic controls are similar. 2) It offers a rational hierarchy and should allow further investigation and subdivision within the framework. 3) It has the promise of universality.

Generic Regionalizations

The advent of the "quantitative revolution" in geography of the 1950's ushered in a new era of land form analysis. Hammond (1962: 71-72) emphasized the need for a shift in geographic geomorphology from the previously dominant genetic approach. He stated that:

> System in any expository presentation requires the use of some organizing principle, but genesis is not the only such device available. Function, for example, is an equally valid one. Another is to hold inherent characteristics, resolving the complexity of the phenomenon into elements, component parts or attributes that can be characterized separately. This is a familiar scheme, regularly utilized, for example, in the description of climates, plants, and to an increasingly exclusive degree of soils. Indeed at the moment land form description stands alone in its stubborn adherence to a genetic rather than a component-characteristic organization. Possibly this slowness to venture into empirical description stems in part from the fact land form data are not normally assembled in specific numerical form, element by element.

Kesseli (1954: 220) summarized the form that such a component-characteristic organization in geographic geomorphology should take. He stated:

> ...a) that this desired geomorphology need not concern itself with the origin of landforms; b) that this geographic geomorphology should divorce itself from an explanatory descriptive terminology instead; c) that this geomorphology could be developed by recognizing and defining landform types, a procedure which would follow the methods applied in the investigation of climate, vegetation, and soils; d) that the landforms themselves should be mapped by use of appropriate symbols, following methods used by European geomorphologists in constructing morphometric maps; e) that physical as well as human geographers could contribute to this desired geographic geomorphology.

The earliest studies to follow these lines differentiated between aspects of slope or relative relief. Studies were often of small geographic areas, such as those conducted by Wentworth (1930), Smith (1935), Raisz and Henry (1937), and Calef and Newcomb (1954). In contrast to these studies on a small scale, Hammond (1964) produced a map of land-surface form for the United States based upon aspects of slope. He considered three aspects: 1) amplitude of relief, 2) percent of near level land, and 3) profile type.

The majority of empirical regionalizations concentrate upon the differentiation of fluvially eroded topography. The drainage basin came to be considered the logical unit of analysis, since streams are integrated and thus orderly (Scheidegger, 1961). Doornkamp and King (1971: 3) gave a rationale for the use of drainage basins in the regionalization of landscapes. They stated:

> The analysis of drainage basins, either as single units or as a group of basins which, taken together comprise a distinct morphological region, has particular relevance to geomorphology. Fluvially eroded landscapes are comprised of drainage basins, and these provide convenient units into which an area can be subdivided. The development of a landscape is equal to the sum total of each individual drainage basin of which it is composed. The fact that morphological regions can be recognized suggests not only within each region the drainage basins have forms similar to each other but also that the basins are evolving in a similar way to each other. Thus, by analyzing the development of each drainage basin, greater understanding of the landscape as a whole may be achieved. This is possible if there are definable relationships between the form of the drainage basin and the processes at work within it.

The pioneering work of Horton (1945) concerning the development of drainage basins and the resulting basin forms led others to follow in this vein. Strahler (1952A, 1952B, 1954B, 1957, 1958; 1964) enlarged upon the work of Horton. Others such as Schumm (1956), Smith (1950), and Miller (1953) also contributed. Their basic research has been used for the comparison and regionalization of land forms using drainage basin morphometry.

Early studies which used aspects of drainage basin morphometry to compare land forms in different regions were important building blocks in the body of theory and techniques eventually used in generic regionalizations. A complete review of all the comparative studies is beyond the scope of this investigation, since the primary concern is with the regionalization of land forms. However, a few specific examples are given. Chorley (1957) compared the morphometry of the Exmoor region of England, north central Pennsylvania, and northern Alabama. Melton (1958) analyzed the differences in drainage density in the American southwest. Chorley and Morgan (1962) compared the morphometric characteristics of the Unaka Mountains of North Carolina and Tennessee with the Dartmoor region of England. Woodruff (1964) compared the mean values of five morphometric variables for four geographically separate regions of the United States. Milling and Tuttle (1965) conducted a study of two east-flowing tributaries of the Iowa River. Woldenburg (1971) expanded upon the work of Milling and Tuttle. Folsom and Winters (1970) analyzed the spatial variation of basin properties in the southern shoreline of Michigan. Stephenson (1971) considered the previous classifications of stream types in the Des Moines River basin using five channel response variables. These comparative studies added to the knowledge about spatial differences in drainage basin morphometry and permitted regionalizations in such terms.

Landscape regionalization using aspects of morphometry share two common characteristics. First, drainage basins are all of the same order or dimensionless parameters are used for purposes of standardization. Second, some form of multivariate analysis is used for classification purposes. Three studies are used to demonstrate this regionalization process: 1) Mather and Doornkamp (1970), 2) Eyles (1971), and 3) Giles (1974). Similar studies were conducted by Lewis (1969) and Gardner (1972).

Mather and Doornkamp (1970) in their study of 130 third-order Ugandan drainage basins used cluster analysis as the method of classification. They identified five distinct drainage basin types based upon eight morphometric variables which were shown to be significant by factor analysis. The eight morphometric variables are: 1) relative relief, 2) drainage density, 3) stream frequency, 4) relief ratio, 5) basin area, 6) total stream length, 7) number of streams, and 8) bifurcation ratios. The five morphometric groups were in contrast to eight morphological regions which had been subjectively defined by the authors prior to their research. The strength of their classification scheme was tested by discriminant analysis.

Eyles (1971) also used cluster analysis in his classification of a random sample of fourth-order West Malaysian drainage basins. He used five morphometric variables for purposes of differentiation. These included: 1) the hypsometric integral, 2) average slope, 3) basin relief, 4) drainage density, and 5) basin area. The identification of six distinct drainage basin types by multivariate analysis was said to decrease the degree of subjectivity found in earlier studies.

Giles (1974) used factor analysis to regionalize the Coastal Plain of North Carolina. He used a sample of 170 third-order drainage basins and twenty-eight morphometric variables for purposes of classification. He found similarities in the grouping of drainage basins and the incidence of marine terraces.

CHAPTER IV

THE STUDY AREA

Introduction

The study area chosen for this investigation is the southern Appalachian Highlands which includes the physiographic provinces of the Piedmont, the Blue Ridge Mountains, the Ridge and Valley, and the Appalachian Plateau. This area was selected because: 1) the topography of the area is largely the result of fluvial processes; 2) there are several distinct geomorphic units within a compact geographic area; and 3) the dominant climatic controls are relatively uniform.

Delineation of the Study Area

A linear transect roughly parallel to the northern borders of North Carolina and Tennessee is used to take a systematic sample of fifty third-order drainage basins. The 560 kilometer transect extends along 36^{o} 3' 45" North latitude between 79^{o} and 85^{o} West longitude. The eastern margin of the transect is the Durham Triassic basin and the western margin is the Highland Rim of Tennessee (see Figure 2). The sample drainage basins are taken from 7.5 minute series topographic quadrangles, which conform to national map accuracy standards (United States Geological Survey, 1976). One third-order drainage basin is selected from an area which corresponds to the center of each of the quadrangles (see Appendix A).

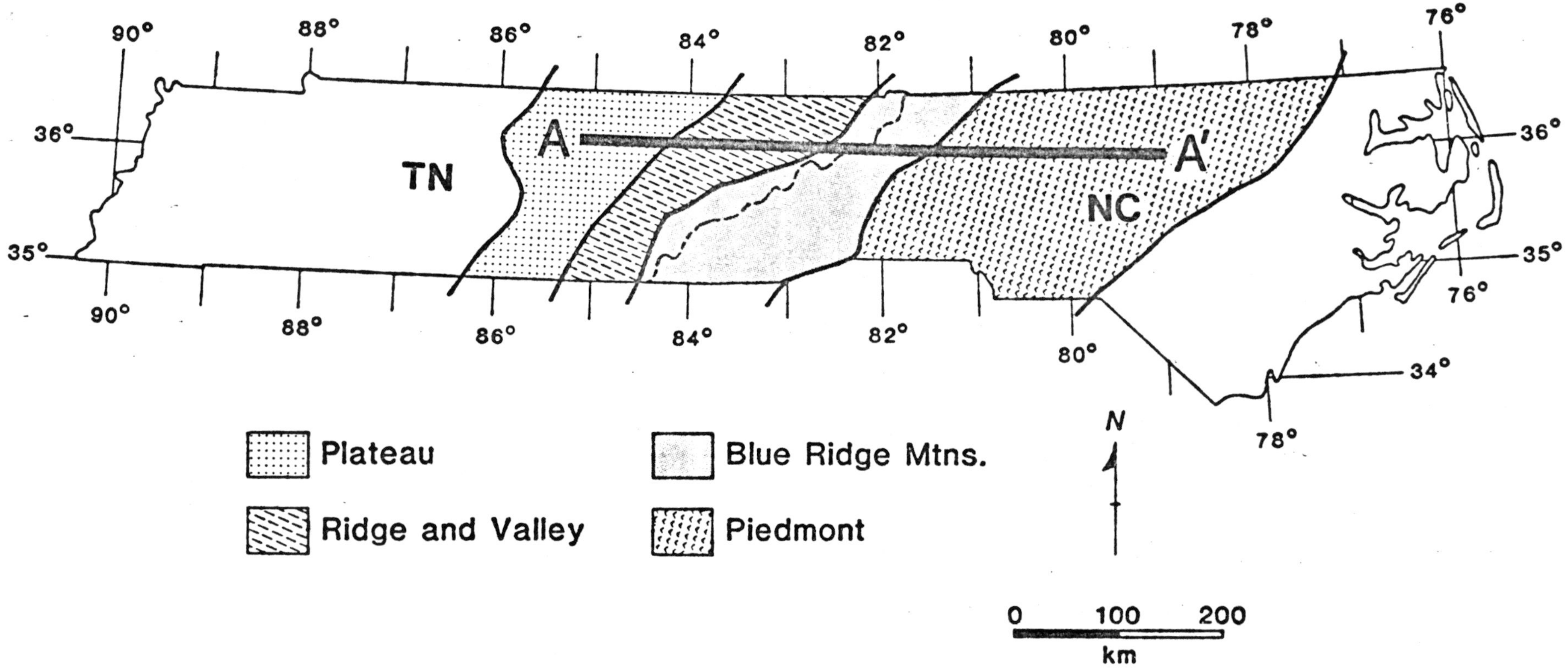

Figure 2: The study area.

Third-order drainage basins are used because they are large enough to demonstrate relationships between morphometric parameters and small enough not to become unwieldly for data collection. Also, it is useful to have all drainage basins of the same magnitude for purposes of uniformity.

Description of the Study Area

Since both genetic and generic regionalizations concentrate upon geologic structure, local lithology, and topographic expression to classify land forms, the study area is described in such terms. Appendix B lists the percentage of rock types found in each of the drainage basins, while Figure 3 shows the topographic cross-section of the study area.

The Piedmont Province

The Piedmont Province attains its maximum width of 200 kilometers near the North Carolina - Virginia border. It is the least mountainous of the southern Appalachian provinces. The surface of the Piedmont is undulating. Relief may be increased locally by low knobs. Small areas of downfaulted Triassic sedimentary rocks give rise to lowland tracts. Structural and lithologic controls of drainage is observed locally, but regionally it is lacking.

Except for the sediments of the Triassic basins, Piedmont rocks are predominantly metamorphic (schists, gneisses, quartzites, and slates) or plutonic (granites, granodiorites, gabbros, and dunites). The metamorphic and plutonic rocks of the Piedmont have a highly complex

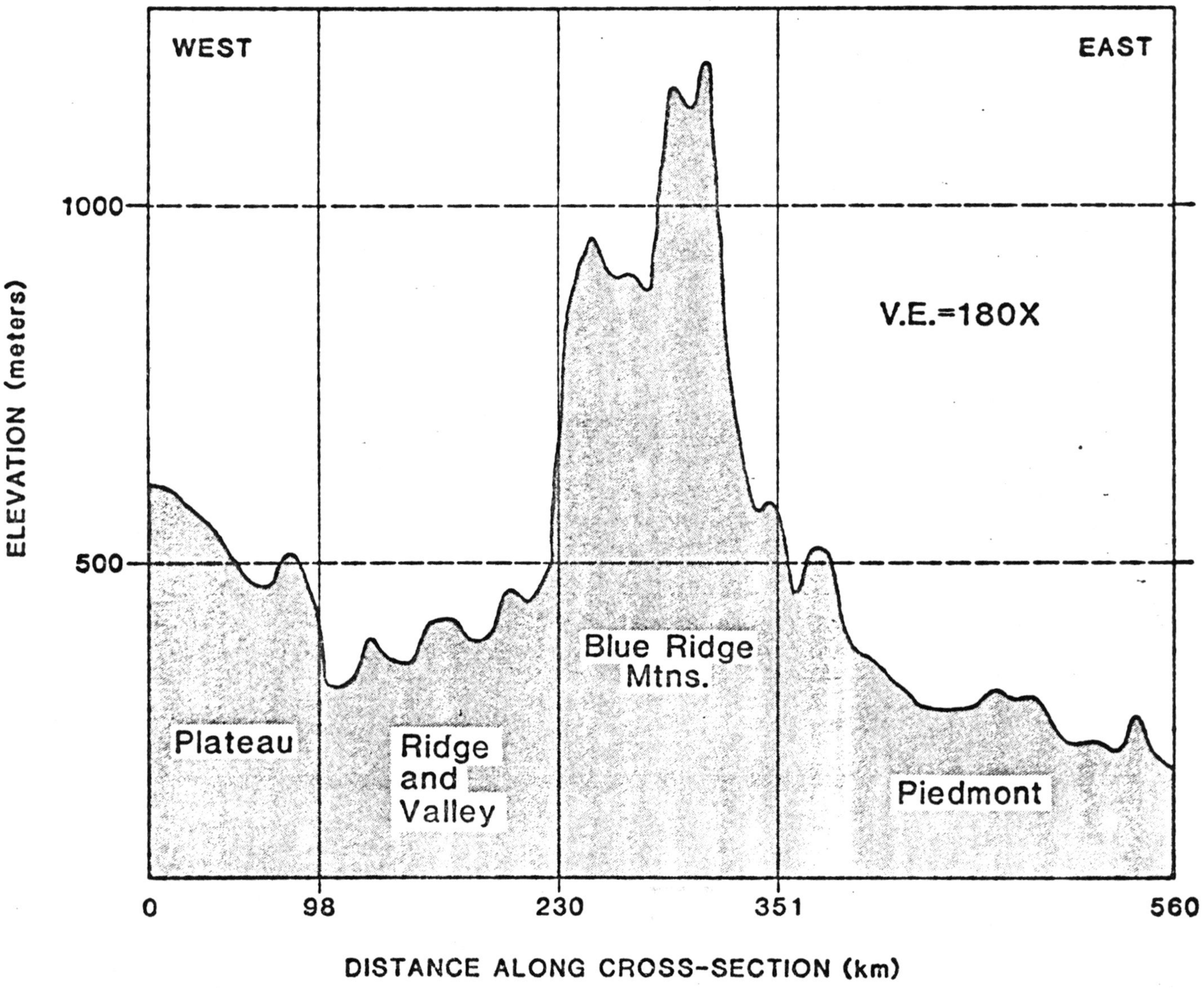

Figure 3: Topographic cross-section of the study area.

structure. The latest episode of regional metamorphism in the Piedmont dates from the early Paleozoic. Plutonic rocks were emplaced at intervals ranging from the early Precambrian to the late Paleozoic. The Triassic sediments are mainly continental red sandstones, shales, and conglomerates, which accumulated in down faulted troughs with dimensions somewhat greater than their present outcrop areas.

The Blue Ridge Mountain Provinces

The Blue Ridge Mountain Province attains its maximum width of 130 kilometers in North Carolina. Massive mountains and high peaks characterize the southern portion of this province. Several peaks exceed 1800 meters in elevation. Angularity and lineation of topography are lacking. Mountain tops which have grassy or heath summits are known as balds. They are common in the Great Smoky and Unaka Mountains. The eastern front of the Blue Ridge escarpment is the most striking feature of the region. The eastern continental drainage divide is very near the eastern edge of this portion of the Blue Ridge province. Streams flowing into the Piedmont are short and steep compared to those with a westward flow. Stream piracy is common.

The Blue Ridge is underlain by Lower Cambrian sedimentary rocks, Upper Precambrian sedimentary and metamorphic rocks, and a Precambrian basement complex. The sedimentary rocks are of the Precambrian Ocoee series and the Lower Cambrian Chilhowee series. These rocks are predominantly clastics which have undergone varying degrees of metamorphism. Metasedimentary rocks are found on the western side of the province. East of these are basement rocks similar to those found in the Piedmont, but the Paleozoic igneous plutons of the Piedmont are not found in the Blue Ridge. A series of overthrust faults separates the western Blue Ridge from the Ridge and Valley.

The Ridge and Valley Province

A series of weak and strong rocks controls the topography of this province. Less resistant limestones and shales form the valleys, while more resistant sandstones, shales, cherts, and dolomites compose the ridges. Varying degrees of karst development occur within the limestone valleys.

The structure of the Ridge and Valley province varies from south to north. In the southern section folds are compressed, overturned, and often broken by thrust faults, which themselves have been folded. Except for the Blue Ridge border faults, the thrusts are shallow and do not involve the basement complex. In the northern section, steep folds with minor amounts of faulting are characteristic.

Due to the differential erosion of folded structures, the Ridge and Valley Province is marked by several geomorphic features. The most outstanding of these are: 1) a marked parallelism of ridges and valleys having a northeast-southwest orientation; 2) a few major streams with the notable development of subsequent streams forming a trellis drainage pattern; 3) numerous ridges displaying accordant summit levels; and 4) hundreds of water gaps through hard rock ridges and an equal number of wind gaps, testifying to stream diversion.

The Appalachian Plateaus Province

The southern section of the Appalachian Plateaus Province is known as the Cumberland. Altitudes there are not as high as in the southern Blue Ridge. The province is essentially a broad syncline of rocks of Pennsylvanian and Mississippian age. Rocks of the plateau are mostly clastic in nature: conglomerates, sandstones, shales; with some limestones and some interbedded coal seams. The Appalachian Plateaus have not been subjected to the intense deformation which has occurred in the other provinces. In the eastern portion of the province there are local gentle folds contrasting with the steep folds of the Ridge and Valley Province. The plateau is bounded on all sides by outfacing escarpments. Most of the region has undergone extreme dissection. This is so great in the eastern portion of the province that locally the upland surface of the plateau has been reduced to narrow interfluves so that the terrain is designated as mountainous.

Interpretation of the Erosional History of the Southern Appalachians

There is a wide diversity of opinion as to the age and the number of erosional surfaces found in the Appalachians. Bascom (1921) believed that there are as many as five peneplains, with an equal number of strath terraces below the youngest peneplain. She suggested ages ranging from the Jurassic to the Pleistocene for these erosion surfaces.

Ashley (1935) thought that only one peneplain is present and that the other topographic surfaces which have been called peneplains are the result of the differential lowering of the one peneplain upon rocks of varying resistance, local baseleveling of areas of weak rocks, or the stripping of areas of less resistant rocks.

Hack (1960, 1965) questioned the existence of any remnants of surfaces having cyclical significance within the Appalachians. He believed that it is not necessary to postulate a Mesozoic or Cenozoic history of the Appalachian region to explain the existing topographic forms. Present topography is explained as the result of recent processes acting on rocks of unequal resistance.

The conventional interpretation of the geomorphic history of the Appalachians acknowledges the remnants of two erosional surfaces (Thornbury, 1965). These are known as the Schooley and Harrisburg peneplains. The Schooley peneplain is now thought to date from the early to middle Tertiary, while the Harrisburg peneplain is believed to date from the late Tertiary. Evidence for the Schooley peneplain is not strongly convincing. The accordance and subaccordance of numerous ridge crests in the Ridge and Valley province are offered to explain its existence. It is argued that similarities in ridge crest altitudes may be the result of the uniform downwasting of rocks of unequal resistance. Evidence for the Harrisburg peneplain is more convincing. In the Piedmont there are extensive tracts of rolling topography having deeply weathered soils which conform to Davis' initial conception of a peneplain.

The Harrisburg surface is thought to be represented in the Ridge and Valley Province strath terraces in the Great Valley at the east side of the province. Some geomorphologists feel that there has been a subcycle following the Harrisburg cycle that is represented locally by straths given local names. Another interpretation of these surfaces is that they represent areas lower than the typical Harrisburg surface which developed on belts of weak rocks. However, if they do represent local post-Harrisburg erosional surfaces then their age is very late Pliocene or early Pleistocene.

CHAPTER V

HYPOTHESIS AND MODEL FORMULATION

Hypothesis Formulation

The Fenneman (1938) regionalization of land forms is an established genetic classification scheme. The problem is to test if such a regionalization has conformity in its spatial organization when the morphometric variables of drainage basins are used as distinguishing characteristics.

The working hypothesis of this investigation is that when drainage basins are defined on the basis of their morphometric parameters they will group in a similar fashion to an a priori genetic regionalization. The rationale for this statement is that morphometric parameters reflect geomorphic processes acting differentially upon varied structures and lithologies, and need not be tied to any particular time element, whether cyclic or graded.

Drainage basins are initially assigned to one of Fenneman's four physiographic provinces of the southern Appalachian Highlands. They are defined by a set of morphometric parameters which are measurements of the drainage basin as an open system. Appropriate statistical tests are made which test hypotheses concerning similarities in the spatial organization of drainage basins when they are defined according to the two modes of landform analysis.

Model Formulation

Discriminant analysis is employed for a set of observations which are already classified in some manner. The technique was originally developed to allocate new observations to a set of pre-established classes on the basis of certain characteristics. Its most common use in geography has been as an aid for the classification of variables (King, 1970).

In discriminant analysis the term allocation is used to refer to some aspects of the discrimination problem which focus on the assignment of individuals to populations and the related issues of the probabilities of wrong assignment. By contrast, the classification problem concerns itself with deciding how observation units fall into groups, how many groups are needed for proper classification, and the delimitation of groups.

Kendall (1966) suggests three situations which give rise to the statistical discrimination problem. These are: 1) where there are missing or lost data such that it is impossible to choose between different populations precisely, 2) where it is essential for some decision to be made as to the nature of the condition of certain observed symptoms, and 3) where certain problems of prediction need to be approached by means of discriminating between particular conditions before they actually occur. This investigation concerns itself with the second of Kendall's situations and the related allocation problems of the assignment of individuals to populations and the probabilities of wrong assignment.

The allocation problem is handled within the framework of the theory of statistical decision functions. Rao (1965) noted that a decision rule may be nonrandomized or randomized. The sample space of the former case is divided into mutually exclusive k regions with x measurements allocated to the one region.

$$w_i, \text{ if } x \Sigma w_i \tag{1}$$

Using the randomized rule, the observation is allocated to population i with a probability

$$\lambda_i(x), \; i = 1, 2, \; . \; . \; . \; k \tag{2}$$

The nonrandomized rule would be for those which

$$\gamma = 0 \tag{3}$$

Any allocation problem has numerous alternative hypotheses, where k is the number of populations. Using either of the allocation rules, there is a loss associated with an incorrect hypothesis. For each rule there is a loss vector

$$(L_1, L_2, \; . \; . \; . \; L_k) \tag{4}$$

corresponding to the alternative hypotheses. The problem is choosing between the different decision rules with respect to their loss vectors. A decision rule ζ_1 is admissable if in comparison to any other decision rule ζ_2 when

$$L_i \leq L_{i2}, \; i = 1, 2, \; . \; . \; . \; k \tag{5}$$

for at least one i,

$$L_{i1} < L_{i2} \tag{6}$$

Not all decision rules, however, are directly comparable and the class for admission may be large. The class is complete if for any rule outside the class there is a better one in the class. A minimal complete class implies that the class contains no complete subsets.

The selection of a decision rule is straightforward when the a priori probabilities of the k populations are known (King, 1970). The optimum solution is one which allocates the observations to populations such that the a posteriori risk is minimized. This is the case with the present study. The groups of drainage basins in each of the physiographic provinces are assumed to be non-randomized complete populations with known a priori probabilities.

The multiple discriminant analysis procedure computes a set of linear functions for the purpose of allocating observations into several groups or populations. The input data consist of a set of observations for a set of variables, and each observation contains a value for each of the variables.

The allocation criterion developed is determined by a measure of generalized squared distance (Barr et al, 1976). It is based upon the within group covariance matrices. The generalized squared distance is

$$D_t^2\ (X) = g_1\ (X,\ t) + g_2\ (X,\ t) \tag{7}$$

where

$$g_1 (X,t) = (X - X_t)^1 S_t^{-1} (X - X_t) + \log_e |S_t| \qquad (8)$$

and

$$g_2 (X, t) = -2 \log (\text{prior probability for e group } t) \qquad (9)$$

with

t	A subscript to distinguish groups,
$\lvert S_t \rvert$	The covariance matrix for observations within group t,
S_t	The determinant of S_t,
X	A vector of values of the variables being analyzed,
X_t	The vector of means of the variables being analyzed.

The posterior probability of membership in group u for a vector of values x based upon the expected probabilities of assignment (exp) was formulated by Barr et al (1976) such that

$$\frac{\exp (-0.5\ D^2 (X))}{\underset{t}{\text{sum}} (\exp (-0.5\ D_t^2 (X)))} \qquad (10)$$

In the case of k groups a maximum of (k-1) discriminant axes is necessary. Fewer than (k-1) axes may suffice if they account for a higher proportion of the total intergroup differences, or if p, the number variables, is less than k, the number of groups, in which case a maximum of p discriminant axes will be required irrespective of the number of groups. The first discriminant axis is the line of closest fit to the means of the k groups in p dimensional space defined by the variables. The second discriminant axis is orthogonal to the first and subsequent discriminant axes.

The coefficients which define the discriminant axes are termed canonical vectors. The canonical vectors are eigenvectors of the matrix $W^{-1}A$, where W^{-1} is the inverse of the pooled within groups sums of squares and cross products matrix of the k groups and A is the between groups sums of squares and cross products matrix. The matrix $W^{-1}A$ is a ratio of the within groups to between groups sums of squares and cross products. The first canonical vector maximizes the ratio, while the second canonical axis minimizes the ratio being orthogonal to the first.

The discriminating power of each eigenvector is given by the corresponding eigenvalue. The eigenvalue, λ^{i} is the square of the canonical correlation coefficient r. The results are expressed as a percentage.

The relative contribution of each variable in the separation between groups is determined by scaling their characteristic values associated with each of the eigenvectors. The variables are scaled in such a manner that the largest value is equal to one. If the value assigned to a variable approaches one, then its relative contribution in separating between groups is large. There is a range of values associated with each of the k-1 eigenvectors.

The null hypothesis that the discriminating power of the canonical vectors above the gth group is due to chance may be tested. The Chi square test of the null hypothesis is

$$X^2 = -N - 0.5\ (p + k) - 1 \log_e \Lambda' \qquad (11)$$

where

$$\Lambda' = \overset{n}{\pi} \quad \frac{1}{1 + j}$$

$$j = g + 1 \qquad (12)$$

with

$$d.f. = (p - g)\ (k - g - 1) \qquad (13)$$

If the calculated Chi square exceeds the selected significance level then the null hypothesis is not accepted. The test is repeated with g incremented by 1 until all n functions have been tested or until Chi square is not significant.

A plot of the separation of the k groups in p dimensional space can be derived based upon the canonical variables. The separation between groups as well as areas of overlap between groups may be observed.

Model Assumptions

The main assumptions of discriminant analysis are: 1) that each of the k samples are drawn from separate populations; 2) that the variables upon which the measurements are made are normally distributed; 3) that the multivariate means of the k populations are not equal; and 4) that the within group variance-covariance matrices of the k populations are equal (Mather, 1976).

Satisfaction of the first assumption of discriminant analysis, that each of the samples are drawn from distinct populations, is met by a systematic sampling of third-order drainage basins from each of the four physiographic provinces. Drainage basins selected are located at approximately 11.0 kilometer intervals.

In order to test the second assumption of discriminant analysis, that the variables are normally distributed, a Kolmogrov-Smirnov test is employed. The null hypothesis that the sample data come from a population that is normally distributed.

The Kolmogrov-Smirnov test concentrates upon the greatest difference between frequencies of a given class interval. Cummulative frequency distributions are produced for both the observed data and the heights of ordinates on the normal curve. By inspection, the largest difference in frequency, for a given class, between the two distributions is

$$D = \text{maximum } (F_1 (x_i) - F_2 (x_i)) \qquad (14)$$

where F_1 is the frequency of heights of ordinates on the normal curve, F_2 is the frequency of the observed data, and i is the class for which D is a maximum. With the null hypothesis, D follows Chi square with two degrees of freedom, such that

$$D > 1.36 \ \frac{n_1 + n_2}{n_1 n_2}^{\frac{1}{2}} \qquad (15)$$

Successive applications are made using various data transformations until normality is attained (Till, 1974).

The third assumption of discriminant analysis, that the multivariate means of the k populations are not equal is tested by the Hotelling-Lawley trace statistic

$$T^2 = TR\ (E^{-1} \times H) \qquad (16)$$

in comparison to an approximation of Fisher's F, such that

$$F = \frac{2(S \times N + 1) \times TR\ (E^{-1} \times H)}{(S \times S\ (2M + S + 1))} \qquad (17)$$

with F having degrees of freedom

$$S\ (2M + S + 1) \qquad (18)$$

and

$$2\ (S \times N + 1) \qquad (19)$$

where

TR	is a trace of the addition of eigenvalues along the diagonal of the multivariate matrix
E	is the error associated with the sum of squares and cross products of the within group matrix
H	is the between group sum of squares and cross-products matrix
S	is the minimum (P,Q)
M	equals 0.5 (ABS (P - Q) - 1)
N	equals 0.5 (NE - P - 1)

and

P is the number of dependent variables

Q is the degrees of freedom specified by the hypothesis

NE is the degrees of freedom associated with E.

If the F approximation exceeds T^2, the the null hypothesis that the multivariate means of the k populations are equal is rejected (Mather, 1976).

The final assumption of discriminant analysis, that the within group variance-covariance matrices of the k populations are equal is tested using the null hypothesis that

$$-2.0 \text{ RHO } \log_e \frac{N^{PN/2} \qquad V}{N_{(I)}{}^{PN(I)/2}} \tag{20}$$

is distributed approximately as Chi square with

$$\text{d.f.} = 0.5\ (K - 1)\ P\ (P + 1) \tag{21}$$

where

K is the number of groups

P is the number of dependent variables

N is the total number of observations

N(I) is the number of observations in the Ith group

with

$$V = \frac{(\text{within SS matrix } (I))^{N(I)/2}}{(\text{pooled SS matrix})^{N/2}} \tag{22}$$

and

$$\text{RHO} = 1.0 - \text{sum} \quad \frac{1}{N(i) - 1} - \frac{1}{N - K} \quad \frac{2P^2 + 3P - 1}{6\ (P+1)\ (K - 1)} \qquad (23)$$

If the Chi square is small then the null hypothesis that the within group variances and covariances are unequal is not accepted. If the Chi Square is greater than the tabled value at the appropriate significance level, then either or both the following conclusions apply: 1) the variances and covariances are truly unequal, or 2) the distributions are not normal (Barr *et al.*, 1976).

Summary

The application of discriminant analysis to the present problem allows for the direct comparison of the spatial organization of landscapes when they are defined according to the different modes of land form analysis. The hypotheses that are tested give insight into the relationships of the two methodologies. The technique also permits the analysis of the relative contribution of the various morphometric variables in the allocation procedure.

CHAPTER VI

THE MORPHOMETRIC VARIABLES

The four types of morphometric variables used in this study are: 1) measurements of the drainage network; 2) the basin geometry; 3) the intensity of dissection; and 4) those involving height. Morphometric variables fall into several distinct groups. Some, such as lengths, are measured directly from maps, while others, such as ratios, are derived from several direct measurements. Variables also differ in their dimensions. Stream length, for example, is a one-dimensional measurement, while basin area is a two-dimensional measurement. Drainage density is the reciprocal of a one-dimensional measure, and variables involving length and area in their denominator are considered dimensionless. The seven morphometric variables used in this study are: 1) the bifurcation ratio; 2) the stream length ratio; 3) the basin elongation ratio; 4) drainage density; 5) basin relief; 6) the elevation-relief ratio; and 7) the mean ground slope.

Bifurcation Ratio

Horton (1945: 286) defined the bifurcation ratio (R_b) as being the "ratio of the average number of branchings or bifurcations of streams of a given order to that of streams of the next higher order." Several methods may be used to determine the bifurcation ratio. It can be computed for pairs of stream orders using the formula

$$R_b = N_u / N_{u+1} \qquad (24)$$

where R_b is the bifurcation ratio and N_u is the number of streams of a given order. The average mean bifurcation ratio can be calculated from all individual bifurcation ratios within a basin. The geometric mean bifurcation ratio may be determined from the slope of a line passing through the two end points on a Horton diagram (Shreeve, 1966). A weighted mean bifurcation ratio can be determined by multiplying each individual bifurcation ratio by the total number of streams of each order involved in the ratio and taking the mean sum of these values (Schumm, 1956). Also, the antilog of a regression line relating log number of streams to stream order may be used (Maxwell, 1955). This study uses the bifurcation ratio between the number of first-order streams and second-order streams.

The minimum bifurcation ratio is 2.0. Normally the ratio ranges between 3.0 and 5.0 where geologic structures do not distort the drainage pattern. Because the bifurcation ratio is a dimensionless parameter, and because drainage systems of homogeneous materials display geometrical similarity, the ratio usually shows only a small variation from region to region. High bifurcation ratios can be expected in areas of steeply dipping strata where narrow strike valleys are confined between hogback ridges (Strahler, 1964).

The rationale for using the bifurcation ratio as a variable is that it is a measurement of Horton's first law of drainage composition, the law of stream numbers. The bifurcation ratio should show where the drainage patterns are structurally such as in the Ridge and Valley province. Additionally, it has been used in a positive manner in several generic studies of land forms such as by Woodruff (1964), Mather and Doornkamp (1970), and Giles (1974).

Stream Length Ratio

The stream length ratio was formulated by Horton (1945: 286-287) as the "...ratio of the average length of streams of a given order to that of streams of the next lower order." The formula is

$$R_1 = \bar{L}_u / \bar{L}_{u-1} \qquad (25)$$

where R_1 is the stream length ratio and $\bar{L}_u$ is the mean length of stream segments of a given order. This study uses the stream length ratio between second-order and first-order streams as a variable.

The stream length ratio is selected as a variable because it is a measurement of Horton's second law of drainage composition, the law of stream lengths. It is expected that the stream length ratio will vary regionally, dependent upon local structures and lithologies. Giles (1974) used the stream length ratio successfully to distinguish fluvially eroded terrain in the North Carolina Coastal Plain.

Basin Elongation Ratio

The basin elongation ratio is a measurement of basin shape proposed by Schumm (1956). The basin elongation ratio (R_e) is defined as the ratio of a circle equal to the perimeter of the drainage basin to the maximum basin length. This is formulated

$$R_e = C_d / L_b \tag{26}$$

where R_e is the elongation ratio, C_d is the circumference of a circle equal to the perimeter of the drainage basin, and L_b is the maximum basin length.

This dimensionless parameter varies between 0.6 and 1.0 over a wide variety of climatic and geologic types. Values near 1.0 are common to areas of very low relief. Values in the range of 0.6 to 0.8 are associated with regions of steep ground slopes (Strahler, 1964). Morisawa (1958) found the basin elongation ratio to be a good measure of basin outline form in the Appalachian Plateau.

The basin elongation ratio is used as a variable because it is an indicator of drainage basin shape. Morisawa (1959) and Stephenson (1967) related the importance of drainage basin shape to runoff conditions. Woodruff (1964), Mather and Doornkamp (1970), and Giles (1974) successfully used the basin elongation ratio as a variable in generic land form regionalizations.

Drainage Density

Horton (1945) used drainage density (D_d) in his landmark hydrologic study. Defined simply, it is the ratio of the total channel-segment length cumulated for all orders within a drainage basin to the drainage basin area. The formula for drainage density is

$$D_d = \sum_{i=1}^{k} \sum_{i=1}^{n} L_u / A_u \tag{27}$$

where D_d is drainage density, L_u is the stream lengths of channels of a given order, and A_u is the area of the drainage basin.

Several measurements of drainage density have been made over a wide area of the United States. The lowest observed values, 4.8 and 6.4 (km. / km.^2), are found to occur in the resistant sandstone strata of the Appalachian Plateau province (Smith, 1950 and Morisawa, 1959). Values ranging from 12.9 to 25.7 are typical in the humid regions of the central and eastern United States where rocks are of a moderate resistance and exist under a deciduous forest cover (Strahler, 1952; Coates, 1958; and Stephenson, 1967). Similar values are found in the Rocky Mountain region, but in the drier portions of this area they may range from 80.5 to 160.9 (Melton, 1957). The strongly fractured and deeply weathered igneous and metamorphic rocks under the dry climate of the coast ranges of Southern California exhibit drainage densities in the range of 32.2 to 48.3; however, where Pleistocene sediments have been exposed drainage densities range from 48.3 to 64.4 (Smith, 1950; Strahler, 1952; and Maxwell, 1960). The highest values which have been observed for drainage density are found in badlands topography, which are developed on weak clays barren of vegetation. Smith (1950) encountered densities ranging from 321.9 to 643.7 in the badlands national monument of South Dakota, while Schumm (1956) found values as high as 1,609.3 to 2,092.1 in the badlands at Perth Amboy, New Jersey. Generally, a low drainage density is associated with areas of highly resistant or highly permeable subsoil materials, under a dense vegetation cover where relief is low. A high drainage density is indicative of regions of weak or impermeable subsurface materials, sparse vegetation, and mountainous relief (Strahler, 1964). Drainage densities may be related to the relative term "texture", the spacing of drainage lines. A low drainage density indicates a coarse texture, while a high drainage density indicates a fine texture (Strahler, 1964).

Drainage density is selected as a variable because it is an important indicator of the intensity of dissection within the drainage basin. It is expected that drainage densities will vary across the study area depending upon local lithologies and structures. The generic land form regionalizations of Mather and Doornkamp (1970), Eyles (1971), and Giles (1974) demonstrated the primary importance of drainage density for the differentiation of fluvially eroded topography.

Basin Relief

Basin relief (H) is obtained by finding the difference between the highest and lowest points within the drainage basin. This is formulated

$$H = Z - z \tag{28}$$

where H is the basin relief, Z is the highest elevation within the drainage basin, and z is the lowest elevation in the drainage basin.

The rationale for using basin relief as a variable is twofold. First, it is a quantified expression of altitudinal differences used in several genetic studies such as Fenneman. Second, it is a measurement suggested by Morisawa's law of basin relief. The highest values are expected in mountainous terrain. Woodruff (1964), Eyles (1971), and Giles (1974) successfully used basin relief to differentiate stream eroded topography.

Elevation-Relief Ratio

The elevation-relief ratio (E) was derived by Wood and Snell (1960). It is an expression of the relative proportion of upland to lowland within a sample region. The ratio is formulated

$$E = \frac{\text{mean elevation - minimum elevation}}{\text{maximum elevation - minimum elevation}} \qquad (29)$$

High values indicate broad, level surfaces occasionally broken by depressions, while low values characterize isolated relief features standing above extensive level surfaces.

Pike and Wilson (1971) demonstrated that the elevation-relief ratio is mathematically identical to the hypsometric integral developed by Strahler (1952B). Calculation of the hypsometric integral is a lengthy process due to the planimetry required for its derivation. Despite simplified procedures which have been developed to approximate the hypsometric integral (Chorley and Morley, 1959), the elevation-relief ratio is the more practical of the two since it can be calculated rapidly and with greater ease.

The elevation-relief ratio is selected as a variable because it is a quantified expression of the degree of erosion within the drainage basin. Strahler (1958), using the hypsometric integrals, suggested that drainage basins may be designated as youthful, mature, or old depending upon their characteristic curves. Eyles (1971) and Giles (1974) used such altitude-to-area measurements to successfully distinguish fluvially eroded terrain.

Mean Ground Slope

Random point smapling of drainage basin ground slope can yield essentially the same information as that obtained from a slope map (Strahler, 1956). Salisbury (1957) suggests that a minimum of five sample points be selected for every 1.6 km^2 of area. Mean ground slope may be calculated as

$$\Theta_g = \sum_{i-1}^{n} (H / L)(100)_i / n \qquad (30)$$

where Θ_g is mean ground slope expressed in percent, H is the elevation difference between the highest and lowest points on a line orthogonal to the contour where the sample point is found, and n is the size of the sample.

Mean ground slope is selected as a variable because it depicts the important aspect of grade within the drainage basin. Although mean ground slopes are higher than stream slopes, it can be used as a surrogate measure for that parameter. Hence, it also serves to demonstrate aspects of Horton's law of stream slopes. The highest mean ground slopes are expected to be found in the more mountainous areas. Eyles (1971) and Giles (1974) used mean ground slope in a positive manner in generic regionalizations.

CHAPTER VII

RESULTS OF HYPOTHESES TESTING

Satisfaction of Model Assumptions

The multiple discriminant analysis model has four major assumptions: 1) that each of the k samples are drawn from separate populations; 2) that the variables upon which the measurements are made are normally distributed; 3) that the multivariate means of the k populations are not equal; and 4) that the within group variance-covariance matrices of the k populations are equal (Mather, 1976).

The first assumption of multiple discriminant analysis is satisfied by the nature of the sampling procedure. A systematic sample of third-order drainage basins was taken from each of the four physiographic provinces. Drainage basins within each province are assumed to belong to k mutually exclusive populations as defined by Fenneman (1938).

The second assumption of multiple discriminant analysis, that the variables are normally distributed, was verified by the use of the Kolmogrov Smirnov test. The selected alpha level for acceptance of the null hypothesis that the variables are normally distributed was 0.05. This same significance level is used in all subsequent tests.

It was found that the distributions of bifurcation ratios, stream length ratios, basin elongation ratios, elevation-relief ratios, and drainage densities were normally distributed in their original forms. The distributions of mean ground slopes and basin reliefs were found to be normal upon transformation to $\log_{10}$ distributions (Eq. 14 and 15).

The third assumption of multiple discriminant analysis, that the multivariate means of the k populations are not equal, was tested by the Hotelling-Lawley trace statistic. The null hypothesis that the multivariate means of the k populations are equal was rejected. It was found that the multivariate means of the k populations were unequal at $F_{0.0001}$ with 21 and 116 degrees of freedom (Eq. 16, 17, 18, and 19).

The fourth assumption of multiple discriminant analysis, that the within group variance-covariance matrices are equal, was tested using the Box test for homogeneity. The null hypothesis that the within group variance-covariance matrices were unequal was rejected. It was found that the within group variance-covariance matrices were equal at $X^2_{0.0070}$ with 84 degrees of freedom (Eq. 20, 21, 22, and 23).

Results of Multiple Discriminant Analysis

The multiple discriminant analysis procedure reallocated drainage basins to different groups based upon the generalized squared distance between groups (Eq. 7, 8, and 9). The generalized squared distance between groups is given in Table III. Along the diagonal, there are similar distances to the centroids for each group. The relatively large values, such as between the Ridge and Valley province and the Appalachian Plateau province, indicate the distinct nature of the two groups from one another. The posterior probability of membership in each group indicated that five drainage basins were significantly different from the groups to which they were initially assigned (Eq. 10). This is shown in Table IV. Two drainage basins from the Piedmont province were reassigned, while three drainage basins from the Ridge and Valley province were reassigned.

Table III

Generalized Squared Distance Between Groups

From ID	Generalized Squared Distance to ID 1	2	3	4
1	-13.826	75.596	- 3.833	858.456
2	4.770	-15.274	29.641	145.012
3	- 9.165	50.990	-11.837	401.548
4	- 5.495	9.382	6.962	-17.429

ID 1 = Piedmont Province
ID 2 = Blue Ridge Mountain Province
ID 3 = Ridge and Valley Province
ID 4 = Appalachian Plateaus Province

Table IV

Posterior Probability of Membership to Different Groups

Observation	ID	To ID	1	2	3	4
Piedmont Province						
1	1	1	1.0000	0.0000	0.0000	0.0000
2	1	1	1.0000	0.0000	0.0000	0.0000
3	1	1	1.0000	0.0000	0.0000	0.0000
4	1	1	1.0000	0.0000	0.0000	0.0000
5	1	1	1.0000	0.0000	0.0000	0.0000
6	1	1	1.0000	0.0000	0.0000	0.0000
7	1	1	1.0000	0.0000	0.0000	0.0000
8	1	1	1.0000	0.0000	0.0000	0.0000
9	1	1	0.9827	0.0000	0.0173	0.0000
10	1	1	0.9995	0.0000	0.0005	0.0000
11	1	1	0.9738	0.0000	0.0262	0.0000
12	1	1	0.9411	0.0000	0.0589	0.0000
13	1	1	0.9936	0.0000	0.0064	0.0000
14	1	1	0.9854	0.0000	0.0146	0.0000
15	1	1	019948	0.0000	0.0052	0.0000
16	1	3*	0.2297	0.0000	0.7703	0.0000
17	1	4*	0.0317	0.1083	0.0000	0.8600
18	1	1	1.0000	0.0000	0.0000	0.0000
19	1	1	0.8011	0.0000	0.1989	0.0000
Blue Ridge Mountain Province						
20	2	2	0.0234	0.9666	0.0000	0.0000
21	2	2	0.0025	0.9974	0.0000	0.0000
22	2	2	0.0000	1.0000	0.0000	0.0000
23	2	2	0.0004	0.9996	0.0000	0.0000
24	2	2	0.0117	0.9883	0.0000	0.0000
25	2	2	0.0051	0.9949	0.0000	0.0000
26	2	2	0.0155	0.9845	0.0000	0.0000
27	2	2	0.0000	1.0000	0.0000	0.0000
28	2	2	0.0000	1.0000	0.0000	0.0000
29	2	2	0.0000	1.0000	0.0000	0.0000
30	2	2	0.0000	1.0000	0.0000	0.0000

Table IV

(Continued)

Observation	ID	To ID	1	2	3	4
Ridge and Valley Province						
31	3	3	0.0000	0.0000	1.0000	0.0000
32	3	3	0.0058	0.0000	0.9942	0.0000
33	3	3	0.0000	0.0000	1.0000	0.0000
34	3	3	0.0000	0.0000	1.0000	0.0000
35	3	1*	0.8427	0.0000	0.1573	0.0000
36	3	1*	0.8701	0.0000	0.1299	0.0000
37	3	3	0.0221	0.0000	0.9779	0.0000
38	3	3	0.0028	0.0000	0.9972	0.0000
39	3	1*	0.7449	0.0000	0.2551	0.0000
40	3	3	0.0161	0.0000	0.9839	0.0000
41	3	3	0.1784	0.0000	0.8216	0.0000
42	3	3	0.0590	0.0000	0.9410	0.0000
Appalachian Plateau Province						
43	4	4	0.0002	0.0000	0.0000	0.9998
44	4	4	0.0080	0.0127	0.0000	0.9794
45	4	4	0.0000	0.0271	0.0000	0.9721
46	4	4	0.0149	0.0047	0.0000	0.9805
47	4	4	0.0003	0.0000	0.0000	0.9997
48	4	4	0.0031	0.0000	0.0000	0.9969
49	4	4	0.0000	0.0000	0.0000	1.0000
50	4	4	0.0719	0.0000	0.0000	0.9281

ID 1 = Piedmont Province
ID 2 = Blue Ridge Mountain Province
ID 3 = Ridge and Valley Province
ID 4 = Appalachian Plateau Province

An * indicates a drainage basin which has been reassigned.

There was no change in the prior probabilities for the Blue Ridge Mountain and Appalachian Plateau provinces (see Table V).

The relative dispersion of drainage basins before reallocation in p dimensional space may be seen by plotting the first two canonical vectors or variables (see Figure 4). It was found that the first canonical vector with an associated eigenvalue of 0.8765 explained 76.83 percent of the overall discriminating power of the model with $X^2_{0.0001}$ at 21 degrees of freedom (Eq. 11, 12, and 13). The second canonical vector with an associated eigenvalue of 0.6014 accounted for 36.17 percent of the total discriminating power of the model with $X^2_{0.0281}$ at 12 degrees of freedom. A third canonical vector was calculated, but it was found not to be significant in the model formulation with $X^2_{0.6334}$ at 5 degrees of freedom (Eq. 11, 12, and 13).

The relative contribution of each variable in the separation of groups is seen by the scaling of their characteristic values associated with each of the eigenvectors. The scaling is accomplished by dividing the score of all of the values by the score of the largest value. The rank of each value then determines its relative contribution in the overall separation between groups. The higher a rank that a variable holds, then the greater its importance. The range between the highest and lowest values is important in determining the causation of the separation in p dimensional space of the different groups. Each canonical vector has a set of characteristic values associated with each variable. The rank and scaled value for the first two canonical vectors is seen in Tables VI and VII. It is seen that for the first two canonical vectors that the

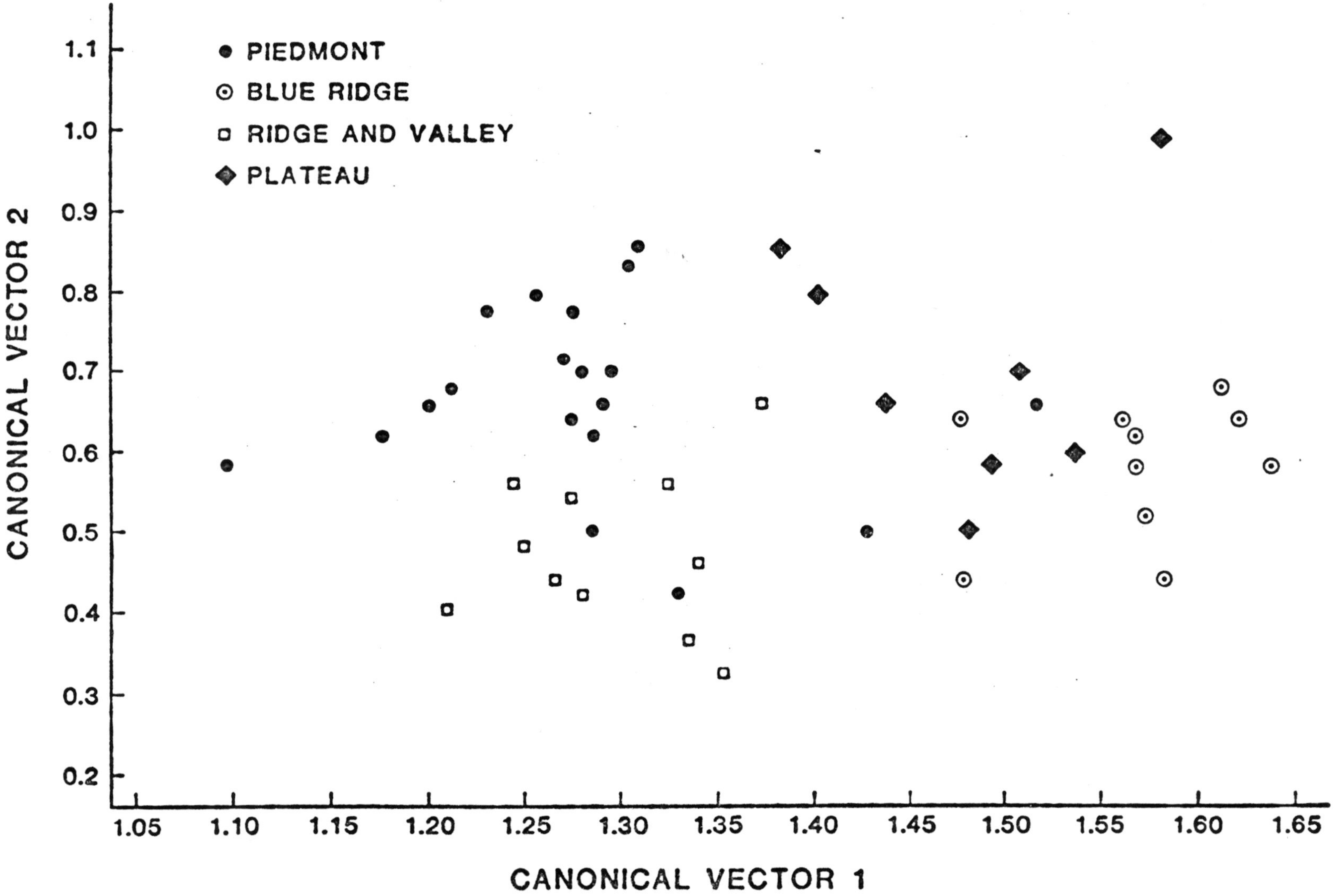

Figure 4: Plot of canonical variables in P dimensional space.

Table V

Posterior Probability of Classification into Different Groups

From Group	Into Group Piedmont	 Blue Ridge Mountains	 Ridge and Valley	 Appalachian Plateau	 Total
Piedmont	89.47 (17)	0.00 (0)	5.26 (1)	5.26 (1)	100.00 (19)
Blue Ridge Mountains	0.00 (0)	100.00 (11)	0.00 (0)	0.00 (0)	100.00 (11)
Ridge and Valley	25.00 (3)	0.00 (0)	75.00 (9)	0.00 (0)	100.00 (12)
Appalachian Plateau	0.00 (0)	0.00 (0)	0.00 (0)	100.00 (8)	100.00 (8)
Total	40.00 (20)	22.00 (11)	20.00 (10)	18.00 (9)	100.00 (50)

Table VI

Characteristic Values of the First Canonical Vector

Variable	Scaled Value	Rank
Bifurcation ratio	0.0379	5
Stream length ratio	0.0015	6
Basin elongation ratio	0.2104	3
Drainage density	-0.0119	7
Relative basin relief	0.2268	2
Elevation-relief ratio	1.0000	1
Mean ground slope	0.0687	4

Table VII

Characteristic Values of the Second Canonical Vector

Variable	Scaled Value	Rank
Bifurcation ratio	0.0275	3
Stream length ratio	-0.0548	5
Basin elongation ratio	-0.1080	6
Drainage density	-0.0065	4
Relative basin relief	0.1069	2
Elevation-relief ratio	1.0000	1
Mean ground slope	-0.1532	7

elevation-relief ratio and relative relief are the most important distinguishing variables. The lowest value for the first canonical vector is drainage density, while for the second canonical vector the lowest value is mean ground slope.

Interpretation of Test Statistics

The working hypothesis for the present study is that when drainage basins are defined on the basis of their morphometric parameters they will group in a similar fashion to an a priori genetic regionalization. The results of the discriminant analysis model must be interpreted in such a manner that it may be related back to the working hypothesis and the applicable theory.

It was found that 90.0 percent of all the drainage basins were in accord with their initial assignments. This high degree of spatial cohesion supports the premise of the working hypothesis; however, five anomalous drainage basins were identified. These drainage basins were more aligned with the new groups to which they were allocated. Inspection of the posterior probabilities of membership to different groups by province illuminates the results of the multiple discriminant analysis model.

Piedmont Province

Sixteen of the nineteen Piedmont drainage basins, on the basis of their generic characteristics, had posterior probabilities of greater than 0.9400 of being classified as Piedmont types. The first eight drainage basins within the eastern portion of the transect had posterior probabilities of belonging to that group of 1.000, a fact that indicates a high degree of spatial conformity. The far western Piedmont drainage basin had a lower posterior probability of membership of 0.8011. This lower probability was expected, since the basin is at the boundary with the Blue Ridge Mountain province.

Two of the Piedmont drainage basins were reallocated to different groups. These are the Osborn Creek drainage basin of the Osbornville quadrangle and an unnamed third-order drainage basin of the Gilreath quadrangle. Both of these drainage basins are in the Brushy Mountains of North Carolina. Fenneman (1938) identified the Brushy Mountains as being genetically similar to the Piedmont, but as being dissimilar in terrain characteristics.

Osborn Creek is underlain by a Precambrian mica gneiss complex. The drainage basin was found to have similar morphometric characteristics to the drainage basins of the Ridge and Valley province. However, there is a dissimilarity between the metamorphic rocks of this basin and the overall sedimentary structures of the Ridge and Valley province. The similarity is seen to exist in the overall topographic form of the drainage basin. Several resistant ridges increase the relative relief of the drainage basin to 160 meters, which is well above the mean for the Piedmont province as a whole but is very similar to that of the Ridge and Valley province (see Appendix C). Additionally, the elevation-relief ratio for the basin is 37.0 percent, well below the mean of the Piedmont province, but very near to the mean of 36.5 percent of the Ridge and Valley province. Since the elevation-relief ratio and the relative relief of drainage basins were found to be the two most important parameters in the distinguishing of groups, such findings are reasonable.

A similar situation exists with the unnamed third-order drainage basin of the Gilreath quadrangle. This basin is underlain by a granitic complex, which is unlike the overall sedimentary structures of the Appalachian Plateau province with which the drainage basin has greater similarities. Again the explanation is seen in the overall topographic expression of the drainage basin. The drainage basin is highly dissected in a manner similar to that of the basins of the eastern portion of the Appalachian Plateau province. The mean relative relief of the drainage basin is 347 meters which is very close to the mean relative relief of the Plateau province of 312 meters. The elevation-relief ratio of the drainage basin being 53.0 percent is also similar to the elevation-relief ratio for the Plateau province as a whole of 52.8 percent.

The difference in the lithologies of the two drainage basins from the predominant lithologies of the provinces with which they are similar, may be accounted for by the fact that despite the difference in rock types the erodibility of the structures are similar.

The identification of these two drainage basins as anomalies illustrates the classic dichotomy of the two systems of land form classification. Genetically the two basins are related to the Piedmont, but there are dissimilarities in their terrain characteristics with the province as a whole. This factor, however, was pointed out by Fenneman (1938) more than forty years ago.

Blue Ridge Mountain Province

The drainage basins of the Blue Ridge Mountain province exhibited a high degree of similarity between being classified by the two modes of land form analysis. Each drainage basin had a posterior probability of membership to the Blue Ridge Mountain group of greater than 0.9500. Five drainage basins of the total eleven had posterior probabilities of 1.0000. The distinct nature of the physiographic province predicates such conformity between the two classification schemes.

Ridge and Valley Province

The Ridge and Valley Province showed the greatest disparity in the comparison of the two classification schemes. Three of the twelve sample drainage basins were reallocated. In each instance the reallocation was from the Ridge and Valley province type drainage basin to Piedmont type drainage basins. However, eight drainage basins did have posterior probabilities of membership to the Ridge and Valley Province of greater than 0.9400 and three of these drainage basins had probabilities of 1.0000.

The three Ridge and Valley drainage basins that were reallocated were the Leadville Creek drainage basin of the White Pine quadrangle, the Goose Creek drainage basin of the Jefferson City quadrangle, and the Legg Creek drainage basin of the John Sevier quadrangle.

The Leadville Creek drainage basin of the White Pine quadrangle is underlain by Knox dolomite and Sevier shale. The sedimentary structure of this drainage basin is dissimilar to the metamorphic and igneous structures of the Piedmont, but since these sedimentary structures are massive similar erodibility functions are thought to exist with the lithologies of the Piedmont province. The elevation-relief ratio of the drainage basin is 46.0 percent which is very close to the mean of 49.0 percent of the Piedmont province. Additionally the 70 meter relative relief of the drainage basin is equal to the relative relief of the Piedmont province.

The Goose Creek drainage basin of the Jefferson City quadrangle is completely underlain by Knox dolomite, which is dissimilar to the metamorphic and igneous structure of many Piedmont drainage basins. However, since Knox dolomite is a massive structure, it is felt that the erodibility of the formation will be less and of similar nature to those rock types found within the Piedmont province. The causative factor of this drainage basin being reallocated to the Piedmont type group is its elevation-relief ratio of 52.0 percent, which is comparable to the mean of the Piedmont of 49.0 percent.

The Legg Creek drainage basin is underlain by shales, limestones, and dolomites. The upper portion of the drainage basin at MacNally Ridge is composed of shales. The middle portion of the drainage basin is limestone, while the lower portion of the drainage basin is composed of dolomite. The main third-order stream traverses MacNally Ridge. Again the rock types of this drainage basin have similar erodibility to those rock types of the Piedmont. The only common link which was found between this drainage basin and those of the Piedmont was a similarity in drainage densities. The drainage density for Legg Creek is 2.37, while the mean drainage density for the Piedmont province is 2.40.

Appalachian Plateau Province

The Appalachian Plateau Province like the Blue Ridge Province showed complete conformity according to the two different systems of terrain evaluation. Seven of the eight sample drainage basins of the Appalachian Plateau Province had posterior probabilities of membership of belonging to the group of greater than 0.9700. One drainage basin had a probability of 0.9200.

CHAPTER VIII

CONCLUSIONS

Several conclusions can be drawn from the results of this study: 1) that the classification of terrain by either genetic or generic schemes will yield similar results; 2) that a simplified generic approach can be applied to terrain analysis that incorporates the essential elements of both systems; and 3) that morphometric studies are pertinent to more applied geomorphic analyses.

The classification of terrain by either the genetic or generic approaches has been shown to have similar results spatially. Ninety percent of the sample drainage basins fell within the original groups to which they were assigned. The five drainage basins which were reallocated had differences in their morphometric characteristics. The two Piedmont drainage basins which were reallocated are in the Brushy Mountains of North Carolina. This area, an outlier of the Blue Ridge Mountain province, was noted by Fenneman (1938) as being dissimilar from the rest of the Piedmont province. This anomaly judged qualitatively by Fenneman has been confirmed quantitatively here. The remaining drainage basins that were reallocated are in the Ridge and Valley province. This highly complex geologic area, while unified genetically, has great diversity in the individual topographic expression of drainage basins due to varied structures and lithologies. When the scale of morphometric analysis used for individual drainage basins is considered, the work of Fenneman stands as an example of the thoroughness of an earlier generation of American geomorphologists. The point of view taken by Schumm and Lichty (1965) that open and closed systems analysis focus on different variables but can yield similar results is confirmed.

The drainage basin as a unit of study offers the advantage of a more complex picture of the essential elements of terrain. However, multivariate studies thus far have been complicated in procedure and have not been duplicable in other areas. It is suggested that the elevation-relief ratio and basin relief offer the simplest means of classifying terrain, since these variables were found to be of predominant importance. These variables, while being quantitative in nature, are expressions of Davis' concept of stage and of elements of topographic form. The use of these two variables in future studies would combine the best attributes of the two approaches to land form analysis.

While it was found that mean ground slopes and drainage density as variables did not play a key role in the grouping of drainage basins, the value of these parameters as well as other morphometric variables has not been undermined. Such morphometric parameters are of extreme importance to applied geomorphic studies where the specific information which they yield can be applied directly to problem solving.

Since it has been demonstrated that genetic regionalizations are more than adequate in defining the surface features of the earth into spatial groupings, large scale generic regionalizations aimed in the same vein might very well be fruitless endeavors. However, it is stressed that before such a conclusion can be reached, studies similar to the present one must be conducted in different regions. Additionally, such studies could be used to determine the geographic significance of the several morphometric parameters as well as their role in the spatial ordering of landscapes.

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APPENDIX A

Quadrangle	State	Basin	Section	Area (KM^2)
Piedmont Province:				
Hillsborough	NC	Little Creek	N	3.52
Efland	NC	No Name	C	4.86
Mebane	NC	No Name	C	7.82
Burlington	NC	No Name	W	3.28
Gibsonville	NC	No Name	C	2.35
McLeansville	NC	No Name	NE	11.12
Greensboro	NC	No Name	NW	6.34
Guilford	NC	Long Branch	C	5.62
Kernersville	NC	No Name	C	5.36
Winston-Salem East	NC	Soakas Creek	SW	7.77
Winston-Salem West	NC	Side Branch	SE	1.62
Clemmons	NC	Ellison Creek	C	8.22
Farmington	NC	No Name	C	12.66
Lone Hickory	NC	Fisher Creek	C	4.86
Brooks Crossroads	NC	Walkers Branch	W	4.01
Osbornville	NC	Osborn Creek	NE	8.51
Gilreath	NC	No Name	C	6.44
Moravian Falls	NC	Moravian Creek	C	10.22
Boomer	NC	Little Warrior Creek	C	9.65
Blue Ridge Mountain Province:				
Grandin	NC	No Name	W	9.70
Buffalo Cove	NC	Green Park Branch	SE	3.11
Globe	NC	Johns River	N	7.21
Grandfather Mtn.	NC	Wilson Creek	N	5.91
Newland	NC	No Name	C	6.45
Carvers Gap	NC/TN	Henson Creek	S	8.74
Bakersville	NC/TN	Sweet Creek	S	5.21
Huntdale	NC/TN	Brummett Creek	E	3.23
Chestoa	NC/TN	No Name	C	1.71
Flag Pond	NC/TN	Big Branch	C	3.09
Greystone	NC/TN	No Name	C	1.51
Ridge and Valley Province:				
Davey Crockett Lake	NC/TN	Flag Branch	C	2.74
Cedar Creek	TN	Gregg Creek	C	3.77
Parrotsville	TN	Sinking Creek	C	1.75
Rankin	TN	McCowan Creek	C	4.26
White Pine	TN	Leadvosle Creek	NE	3.67

APPENDIX A (Continued)

Quadrangle	State	Basin	Section	Area (KM^2)
Ridge and Valley Province (Continued):				
Jefferson City	TN	Goose Creek	S	4.05
New Market	TN	Dance Branch	SE	2.40
Mascot	TN	Clift Creek	S	6.31
John Sevier	TN	Legg Creek	C	5.20
Fountain City	TN	Cox Creek	E	5.97
Powell	TN	Patt Branch	W	2.65
Clinton	TN	No Name	C	5.28
Appalachian Plateau Province:				
Wind Rock	TN	Hoskins Creek	C	5.28
Petros	TN	Middle Creek	E	2.49
Camp Austin	TN	Hall Branch	C	4.41
Lancing	TN	Rock Creek	C	4.97
Hebbertsburg	TN	Hawn Spring Branch	NW	1.77
Fox Creek	TN	South Fork	NW	5.26
Isoline	TN	Scott Creek	E	12.08
Campbell Junction	TW	Clear Creek	E	10.15

APPENDIX B

Geologic Formations

Hillsborough (Little Creek)

Carolina Slate Belt: chiefly acid tuffs, breccias, and flows, in part of sedimentary origin; also mafic fragmentals and flow materials and lenses of bedded slate (Precambrian or Lower Paleozoic).

Efland (Unnamed)

Carolina Slate Belt: chiefly basic tuffs, breccias, and flows, in part of sedimentary origin; also felsic fragmental and flow materials and lenses of bedded slate (Precambrian or Lower Paleozoic).

Mebane (Unnamed)

Carolina Slate Belt: chiefly acid tuffs, breccias, and flows, in part of sedimentary origin; also mafic fragmentals and flow materials and lenses of bedded slate (Precambrian or Lower Paleozoic).

Burlington (Unnamed)

Massive to weakly foliated even-grained to porphyritic granitic rocks (Paleozoic).

Gibsonville (Unnamed)

Carolina Slate Belt: chiefly basic tuffs, breccias, and flows, in part of sedimentary origin; also mafic fragmentals and flow materials and lenses of bedded slate (Precambrian or Lower Paleozoic).

McLeansville (Unnamed)

Massive to weakly foliated even-grained to porphyritic granitic rocks (Paleozoic).

Greensboro (Unnamed)

Massive to weakly foliated even-grained to porphyritic granitic rocks (Paleozoic).

APPENDIX B

(Continued)

Guilford (Long Branch)

Carolina Slate Belt: chiefly basic tuffs, breccias, and flows, in part of sedimentary origin; also felsic fragmental and flow materials and lenses of bedded slate (Precambrian or Lower Paleozoic).

Kernersville (Unnamed)

Massive to weakly foliated even grained to porphyritic granitic rocks (Paleozoic).

Winston-Salem East (Sokas Creek)

Chiefly mica gneiss; includes mica schist and a wide variety of other gneisses and schists (Precambrian).

Winston-Salem West (Side Branch)

Chiefly mica gneiss; includes mica schist and a wide variety of other gneisses and schists (Precambrian).

Clemmons (Ellison Creek)

Diorite-Gabbro: massive to weakly foliated; gray to dark greenish gray rocks, composed mostly of plagioclase, hornblende, and pyroxene (Paleozoic).

Farmington (Unnamed)

Diorite-Gabbro: massive to weakly foliated; gray to greenish gray rocks, composed mostly of plagioclase, hornblende, and pyroxene (Paleozoic).

Lone Hickory (Fisher Creek)

Chiefly mica gneiss, includes mica schist and a wide variety of other gneisses and schists (Precambrian).

Brooks Crossroads (Walkers Branch)

Chiefly mica gneiss, includes mica schist and a wide variety of other gneisses and schists (Precambrian).

APPENDIX B

(Continued)

Osbornville (Osborn Creek)

Chiefly mica gneiss, includes mica schist and a wide variety of other gneisses and schists (Precambrian).

Gilreath (Unnamed)

Massive to weakly foliated, even grained to porphyritic granitic rocks (Paleozoic).

Moravian Falls (Moravian Creek)

Chiefly mica schist, includes mica gneiss and a wide variety of other gneisses and schists (Precambrian).

Boomer (Little Warrior Creek)

Cheifly mica gneiss, includes mica schist and a wide variety of other gneisses and schists (Precambrian).

Grandin (Unnamed)

Chiefly mica gneiss, includes mica schist and a wide variety of other gneisses and schists (Precambrian).

Buffalo Cove (Green Park Branch)

Chiefly mica gneiss, includes mica schist and a wide variety of other gneisses and schists (Precambrian).

Globe (Johns River)

Light reddish, coarse or porphyritic granite gneiss (Precambrian).

Grandfather Mtn. (Wilson Creek)

Unicoi: feldspathic sandstone and conglomerate; some siltstone and shale (Lower Cambrian).

APPENDIX B

(Continued)

Newland (Unnamed)

Cranberry: granite gneiss of varying colors and textures containing lenses of hornblende gneiss, mica gneiss, and mica schist (Precambrian).

Carvers Gap (Henson Creek)

Precambrian crystalline complex: granite and gneissic rocks with inclusions of mica and hornblende schist (Precambrian).

Bakersville (Sweet Creek)

Precambrian crystalline complex: granitic and gneissic rocks with inclusions of mica and hornblende schist (Precambrian).

Huntdale (Brummett Creek)

Snowbird: shale, siltstone, arkose, and comglomerate (Precambrian).

Chestoa (Unnamed)

Unicoi: feldspathic sandstone and conglomerate; some siltstone and shale (Lower Cambrian).

Flag Pond (Big Branch)

Precambrian crystalline complex: granitic and gneissic rocks with inclusions of mica and hornblende schist (Precambrian).

Greystone (Unnamed)

Unicoi: feldspathic sandstone and conglomerate; some siltstone and shale (Lower Cambrian).

Davy Crockett Lake (Flag Branch)

Conococheague: blue limestone ribboned with dolomite (Upper Cambrian).

Cedar Creek (Gregg Creek)

Knox: siliceous dolomite (Lower Ordivician).

APPENDIX B

(Continued)

Parrotsville (Sinking Creek)

Sevier: blueish calcareous shale with sandstone beds and blue limestone at base (Middle Ordivician).

Rankin (McCowan Creek)

Sevier: blueish calcareous shale with sandstone beds and blue limestone at base (Middle Ordivician).

White Pine (Leadvale Creek)

Sevier: blueish calcareous shale with sandstone beds and blue limestone at base (Middle Ordivician).

Knox: siliceous dolomite (Lower Ordivician).

Jefferson City (Goose Creek)

Knox: siliceous dolomite (Lower Ordivician).

New Market (Dance Branch)

Copper Ridge: dark crystalline siliceous dolomite (Upper Cambrian).

Chepultepic: siliceous dolomite and sandstone beds near base (Lower Ordivician).

Mascot (Clift Creek)

Holston: red crystalline limestone (marble), quartzose crystalline limestone, and limy sandstone (Middle Ordivician).

Lenoir: limestone (Ordivician).

John Sevier (Legg Creek)

Pumpkin Valley: greenish silty shale (Middle Cambrian).

Rutledge, Rogersville; Maryville: blue limestone with middle shale units (Middle Cambrian).

APPENDIX B

(Continued)

John Sevier (Legg Creek cont.)

Conasauga: limestone and dolomite above and shale below (Upper Cambrian).

Copper Ridge: dary crystalline siliceous dolomite (Upper Cambrian).

Chepultepec: siliceous dolomite with sandstone beds near base (Lower Ordivician).

Longview: very siliceous dolomite with limestone beds near top (Lower Ordivician).

Kingsport: siliceous dolomite with thick limestone bed near base (Lower Ordivician).

Mascot: siliceous dolomite (Lower Ordivician).

Fountain City (Cox Creek)

Copper Ridge: dary crystalline siliceous dolomite (Upper Cambrian).

Conasauga: shale with some limestone (Middle Cambrian).

Rome: varicolored shale, siltstone, and sandstone; some dolomite and limestone layers (Lower Cambrian).

Powell (Patt Branch)

Rome: varicolored shale, siltstone, and sandstone; some dolomite and limestone layers (Lower Cambrian).

Chickamauga: blue limestone of several kinds and yellow silty limestone (Middle Ordivician).

Clinton(Unnamed)

Knox: siliceous dolomite (Lower Ordivician).

Windrock (Hoskins Creek)

Undifferentiated sandstones and shale with coal beds (Pennsylvanian).

APPENDIX B

(Continued)

Petros (Middle Creek)

Undifferentiated sandstones and shale with coal beds (Pennsylvanian).

Camp Austin (Hall Branch)

Undifferentiated sandstones and shale with coal beds (Pennsylvanian).

Lancing (Rock Creek)

Undifferentiated sandstones and shale with coal beds (Pennsylvanian).

Hebbertsburg (Hawn Spring Branch)

Undifferentiated sandstones and shale with coal beds (Pennsylvanian).

Fox Creek (South Creek)

Undifferentiated sandstones and shale with coal beds (Pennsylvanian).

Isoline (Scott Creek)

Undifferentiated sandstones and shale with coal beds (Pennsylvanian).

Campbell Junction (Clear Creek)

Undifferentiated sandstones and shales with coal beds (Pennsylvanian).

Sources: Geologic Map of North Carolina compiled by the North Carolina Department of Conservation and Development, Division of Mineral Resources in 1958 at a scale of 1:500,000.

Geologic Map of East Tennessee compiled by the Tennessee Department of Conservation, Division of Geology in 1952 at a scale of 1:125,000.

APPENDIX C

Summary of Morphometric Variables

Quadrangle	Drainage Basin	R_b	R_l	R_e	D_d	H	E	θ_g
Piedmont:								
Hillsborough	Little Creek	3.50	1.98	0.90	2.53	55	0.67	5.22
Efland	No Name	6.00	2.45	0.94	3.19	52	0.54	4.52
Mebane	No Name	2.00	1.39	0.76	4.86	58	0.60	6.08
Burlington	No Name	3.00	2.24	0.77	2.04	49	0.54	6.36
Gibsonville	No Name	3.00	1.55	0.77	1.46	40	0.42	5.68
McLeansville	No Name	4.75	1.62	0.86	6.91	55	0.62	5.83
Greensboro	No Name	5.50	4.63	0.97	3.94	55	0.50	8.24
Guilford	No Name	4.00	2.98	0.76	3.49	58	0.59	6.38
Kernersville	No Name	4.50	0.85	0.85	3.33	46	0.49	7.92
Winston-Salem East	Sokas Creek	5.00	0.28	0.61	4.83	64	0.51	9.12
Winston-Salem West	Side Branch	2.50	0.63	0.79	1.02	55	0.48	9.17
Clemmons	Ellison Branch	4.33	1.39	0.79	5.11	83	0.46	11.04
Farmington	No Name	6.33	2.69	0.70	7.87	80	0.45	8.02
Lone Hickory	Fisher Creek	3.00	0.92	0.70	3.02	82	0.55	13.37
Brooks Crossroads	Walkers Branch	2.50	1.40	0.71	2.49	85	0.55	10.06
Osbornville	Osborn Creek	3.25	1.24	0.84	5.29	158	0.37	9.34
Guilreath	No Name	3.00	1.09	0.83	4.00	347	0.53	31.90
Moravian Falls	Moravian Creek	2.60	0.76	0.81	6.35	469	0.32	31.58
Boomer	Little Warrior Creek	3.25	1.74	0.85	6.00	246	0.29	20.07
$\bar{x}$		3.79	1.68	0.80	4.09	112	0.50	11.05
s		1.26	1.01	0.09	1.87	117	0.10	8.10

APPENDIX C

(Continued)

Quadrangle	Drainage Basin	R_b	R_l	R_e	D_d	H	E	θ_g
Blue Ridge Mountains:								
Grandin	No Name	4.50	1.81	0.74	1.78	472	0.48	37.98
Buffalo Cove	Green Park Branch	2.00	1.49	0.85	1.95	427	0.57	47.50
Globe	Johns River	6.50	2.84	0.84	2.62	658	0.43	45.74
Grandfather Mtn.	Wilson Creek	2.50	0.69	0.77	2.19	963	0.47	41.60
Newland	No Name	3.50	0.94	0.94	1.50	372	0.42	20.93
Carvers Gap	Hanson Creek	3.00	0.73	0.92	2.01	785	0.39	41.28
Bakersville	Sweet Creek	4.50	2.21	0.98	2.26	399	0.33	33.12
Huntdale	Brummett Creek	6.33	2.91	0.82	4.28	561	0.38	65.42
Chestoa	No Name	5.00	3.44	0.74	5.42	732	0.50	21.88
Flag Pond	Big Branch	5.20	1.62	0.74	5.28	764	0.47	50.00
Greystone	No Name	3.50	3.39	0.70	3.77	524	0.52	50.00
$\bar{x}$		4.23	2.01	0.82	3.01	605	0.45	42.31
s		1.48	1.02	0.09	1.43	190	0.07	11.59
Ridge and Valley:								
Davy Crockett Lake	Flag Branch	4.50	3.58	0.78	3.21	259	0.27	17.71
Cedar Creek	Gregg Creek	7.00	1.71	0.82	3.45	116	0.29	11.41
Rankin	McCowan Creek	6.00	3.15	0.95	3.67	125	0.35	32.22
Parrotsville	Sinking Creek	3.17	1.20	0.84	5.10	88	0.53	41.25
White Pine	Leadvale Creek	3.50	1.82	0.89	2.24	69	0.46	10.42
Jefferson City	Goose Creek	3.00	1.23	0.88	2.12	139	0.52	15.31
New Market	Dance Branch	2.00	1.27	0.74	3.31	163	0.43	11.50

APPENDIX C

(Continued)

Quadrangle	Drainage Basin	R_b	R_l	R_e	D_d	H	E	θ_g
Mascot	Clift Creek	7.00	1.86	0.70	2.45	126	0.23	17.04
John Sevier	Legg Creek	3.00	0.68	0.87	2.37	200	0.36	15.36
Fountain City	Cox Creek	5.00	3.24	0.66	1.71	152	0.30	14.90
Powell	Patt Branch	2.33	1.60	0.95	2.89	119	0.30	13.27
Clinton	No Name	3.00	0.86	0.89	1.95	119	0.34	14.79
$\bar{x}$		4.13	1.85	0.83	2.87	140	0.37	17.93
s		1.75	0.96	0.09	0.95	51	0.10	9.26
Appalachian Plateau:								
Windrock	Hoskins Creek	5.00	0.45	0.75	3.03	600	0.27	45.63
Petros	Middle Creek	2.00	0.71	0.80	2.92	506	0.44	37.08
Camp Austin	Hall Branch	6.00	0.91	0.95	3.70	521	0.35	32.05
Lancing	Rock Creek	3.00	0.85	0.85	2.93	323	0.54	27.38
Hebbertsburg	Hawn Spring Branch	2.50	2.35	0.94	2.46	119	0.66	20.00
Fox Creek	South Fork	6.00	2.46	0.71	2.69	110	0.58	9.80
Isoline	Scott Creek	6.00	2.07	0.86	2.09	165	0.75	12.03
Campbell Junction	Clear Creek	4.60	0.85	0.80	2.90	84	0.64	11.13
$\bar{x}$		4.39	1.33	0.83	2.84	304	0.53	24.39
s		1.67	0.82	0.08	0.47	212	0.16	13.31