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RELICT PERIGLACIAL MORPHOSEQUENCES
IN THE NORTHERN BLUE RIDGE

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RELICT PERIGLACIAL MORPHOSEQUENCES
IN THE NORTHERN BLUE RIDGE

By

Bryon Douglas Middlekauff

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ABSTRACT

RELICT PERIGLACIAL MORPHOSEQUENCES IN THE NORTHERN BLUE RIDGE

By

Bryon Douglas Middlekauff

Isolated bouldery deposits in the Central Appalachians have been documented in the literature and attributed to freeze-thaw processes of the Pleistocene cold phases. But these deposits have never before been examined regionally as a suite of landforms. This thesis documented the character and distribution of the landform continuum, including block streams, block-covered slopes, tors, and scarps, and examined the degree of morphoclimatic change between the Pleistocene and the Present.

Data supporting a Pleistocene periglacial paleoclimate were synthesized from the paleobiological and geomorphic literatures and coupled with field data. Standard morphometric techniques were utilized to document the character, distribution, mode of deposition, stability, and relict nature of the major deposits.

Major findings include the distributional characteristics of the landform continuum, current stability, and the degree of morphoclimatic change between the Pleistocene and the Present. Geologic structure played a dominant role in the distribution of the landforms and deposits. The slightly inclined quartzite strata produced a steep,

west-facing scarp and a gentler east-facing dip slope each with a characteristic landform association.

The general lack of damage to trees from falling and rolling boulders, lichen encrustation, weathering pits on exposed block surfaces, and thick organic soil accumulations on top of blocks suggest that the major landforms and structures are both relict and stable.

Geomorphic and paleobiologic evidence allowed the reconstruction of a late-Wisconsinan Mean Annual Air Temperature of around 0° C to 2° C, and a maximum Wisconsinan tree line at about 500m.

To Catherine and Kirk

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Several individuals were instrumental in the evolution of this thesis. The original committee chair, Dr. Dieter Brunnschweiler, provided me with ideas, skillful editing, and patient discussion. After Dr. Brunnschweiler's passing, Dr. Jay Harman and Dr. David Lusch invested uncountable hours reading, editing, and advising. Special thanks are extended to Dr. Harold Winters and Dr. Larry Sommers. Their helpful advice was welcomed and appreciated. Dr. Gary Manson, Chairperson of the Geography Department, provided valuable assistance which facilitated completion of the degree program.

A special acknowledgment must be made of the efforts of the cartographer, Julie DeGalan, who prepared the final maps and figures, skillfully edited the numerous drafts, and word processed the text.

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CHAPTER I

INTRODUCTION

Background

The tectonics, stratigraphy, and geomorphic development of the Northern Blue Ridge have received much attention in the literature (Stose, 1909; Davis, 1922; Cloos, 1941, 1957; King, 1950; Whitaker, 1955; Fauth, 1968; Espenshade, 1970), but the question of morphogenesis resulting from intensive freeze-thaw processes operating during the Quaternary has not been thoroughly examined (Fauth, 1968; Godfrey, 1975; Hedges, 1975). Brunnschweiler (1962), an early advocate of a periglacial realm in the Appalachians during the Pleistocene, suggested that cold climates were much more widespread in North America than formerly believed. His map shows the Northern Blue Ridge study area under the influence of a tundra-type climate during the Wisconsinan Glacial Maximum.

Other researchers have identified several types of bouldery material mantling the slopes in the Appalachian system and have attributed their development to increased frost action of the Pleistocene (Kerr, 1881; Smith, 1945, 1949; Denny, 1951; Brunnschweiler, 1962; Michalek, 1969; Godfrey, 1975; Hedges, 1975; Mills, 1980; Kite, 1987). This interpretation has created some controversy because Hack (1965) and French (1976) concluded that a portion of the bouldery alluvial and colluvial deposits in the Appalachians may have been emplaced by processes operating in the present environment.

Additional documentation and correlation of the Cenozoic deposits and landforms are necessary to arrive at a better understanding of the Pleistocene history of this region. Specifically, Clark (1975, 1987) noted that an examination of block fields, block streams, and bouldery colluvial/alluvial sediments in the Appalachians holds great promise for extending our knowledge of Pleistocene chronology because few of these deposits have been examined in detail. Descriptions of block fields, scree, and bouldery deposits do exist in the literature (Smith, 1949; Hack, 1965; Pierce, 1966; Potter and Moss, 1968; Godfrey, 1975; Mills, 1980; Kite, 1987), but these landforms and deposits have never before been examined in detail as a suite of landforms in a regional context.

Two basic types of sediments have been identified in the Central Appalachians that may be related to cryic processes of the Pleistocene. Accumulations of angular boulders have been noted in the literature and described as block streams, block fields, frost rubble, scree and talus (Smith, 1949; Denny, 1951; Hack, 1965; Pierce, 1966; Godfrey, 1975; Kochel, 1976; Mills, 1980). These accumulations usually include blocks of metabasalt, sandstone, or quartzite, and occur on slopes ranging from 2 - 30°. The other deposit type consists of angular or subrounded clasts within a matrix of fines (i.e., diamictons)[1] that mantles the slopes of the mountain flanks to a thickness of more than 50m (Pierce, 1966; Godfrey, 1975). The diamictons may have been produced by solifluction during the Pleistocene. Neither the origin of the diamictons nor the possible genetic affiliation with the block accumulations has been satisfactorily explained.

Problem Statement

On the basis of the literature and field investigations, it is postulated that a variety of erosional and depositional features found in the Central Appalachians consist of fossil periglacial deposits in various stages of decay. These landforms and depositsl include certain types of bedrock scarps, stepped terraces, summit tors, and boulder accumulations of great thickness and expanse. With the glacial border scarcely 150km northeast of the study area (Figure 1), accelerated freeze-thaw processes during the Pleistocene probably played a significant role in the morphogenesis of the Northern Blue Ridge.

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[1] Fairbridge suggests that it is good policy to describe mixtures of pebbles and boulders in a matrix of fines (other than till) as a diamictite, implying that the origin of the deposit is unclear. Rhodes Fairbridge, The Encyclopedia of Geomorphology (New York: Reinhold Book Corporation, 1968).

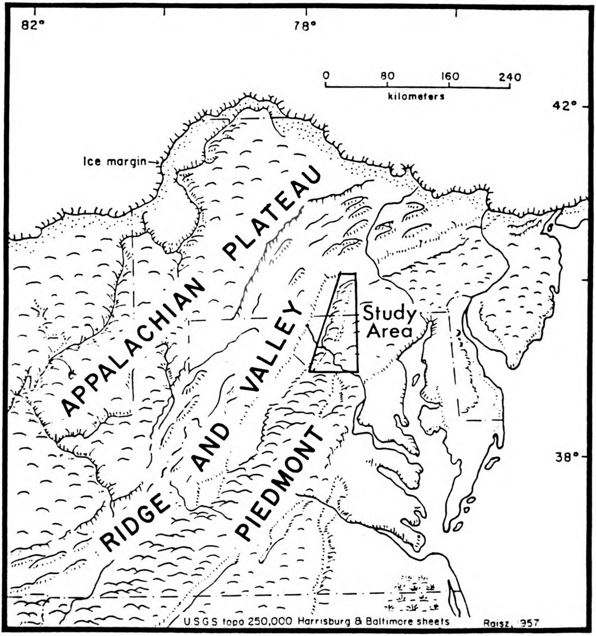

Figure 1. Location of the Northern Blue Ridge Study Area.

Block deposits and material mantling the slopes of the mountain flanks will be the principal focus of this research because they are most widespread. In order to examine the possibility that these features are fossil periglacial landforms, they will be examined in light of the following criteria.

To serve as indicators of former periglacial climatic conditions, block deposits must be presently immobile and in the process of decay (Smith, 1949; Washburn, 1980). Evidence of such stability during the Recent includes: 1) undisturbed forest growth on and adjacent to block deposits, 2) secondary weathering effects on exposed block surfaces, 3) growth of lichens on exposed block faces, 4) soil profile development without interference, and 5) indications that running water has regained its status as the principal erosional process. These characteristics demonstrate that the block landforms are not being produced under present climatic conditions and are, therefore, relict.

Block deposits emplaced by soil flow associated with increased freeze-thaw also exhibit characteristics that indicate specific evidence of transportation (Smith, 1949) including: 1) block material traceable to an upslope source, 2) downslope bending of strata, 3) interruption of the normal soil profile, and 4) a preferred orientation of the long axis of the blocks. Solifluction deposits are typically diamictons composed of angular particles in a fine-grained matrix but some deposits exhibit crude stratification parallel to the slope. They are always characterized by a tendency for the long axis of clasts to be oriented in the downhill direction (Washburn, 1980).

Field data and material from the literature relevant to the former existence of Pleistocene periglacial paleo-climates in the study area will be considered in this investigation. It is the goal of this thesis to: 1) establish that a periglacial paleoclimate is reasonable for the study area, 2) document and describe the characteristics of bouldery landforms and deposits in the Northern Blue Ridge that may be due to erosion out of phase with the present climate, and 3) establish the factors governing the distribution of this regolith in a portion of the Central Appalachians.

Description of the Study Area

The Blue Ridge Province extends about 885km from northeastern Georgia into Pennsylvania. The study area (Figure 1) is situated in the northernmost portion of the Northern Blue Ridge and is bounded on the north by what is known as the Carlisle Prong or South Mountain (Thornbury, 1966; Fauth, 1968) and on the south by the Potomac River. Because the bouldery debris extends into the Great Valley to the west and the Triassic Lowlands to the east, portions of these physiographic regions were also investigated.

The Northern Blue Ridge region was chosen because it exhibits the most distinct and widespread occurrences of what are believed to be periglacial landforms (Smith, 1949, 1953; Godfrey, 1975) of any location in the eastern United States. The Northern Blue Ridge is well south of the glacial border at a comparatively low elevation; nowhere do ridgecrests exceed 700 meters above sea level (m.a.s.l. or m). Farther south, along the Blue Ridge in Virginia, elevations often exceed 1000m yet most of these landforms and deposits are absent or are poorly developed in that area. Bouldery forms in the Northern Blue Ridge appear to be transitional in terms of development between the areas just south of the glacial border in Pennsylvania and those of the Southern Appalachians (Smith, 1949; Hack, 1965; Michalek, 1969; Mills, 1980).

General Structure, Stratigraphy, and Geomorphology

The entire Blue Ridge Province is underlain by Lower Cambrian and Upper Precambrian sedimentary formations and a Precambrian igneous and metamorphic basement complex of variable resistance. Stose (1932, p. 80) described the province as a "great anticlinorium consisting of three or four anticlines and numerous thrust faults" (Figures 2 and 3).

The core of this northeast-southwest trending anticlinorium is composed of Precambrian volcanics and metavolcanics flanked on both sides by Cambrian quartzites except in the northwestern portion of the study area (Fauth, 1968; Shirk, 1978; Figure 3). The Catoctin Formation (Precambrian) and the overlying Chilhowee Group (Lower Cambrian) are of special interest because rock units in

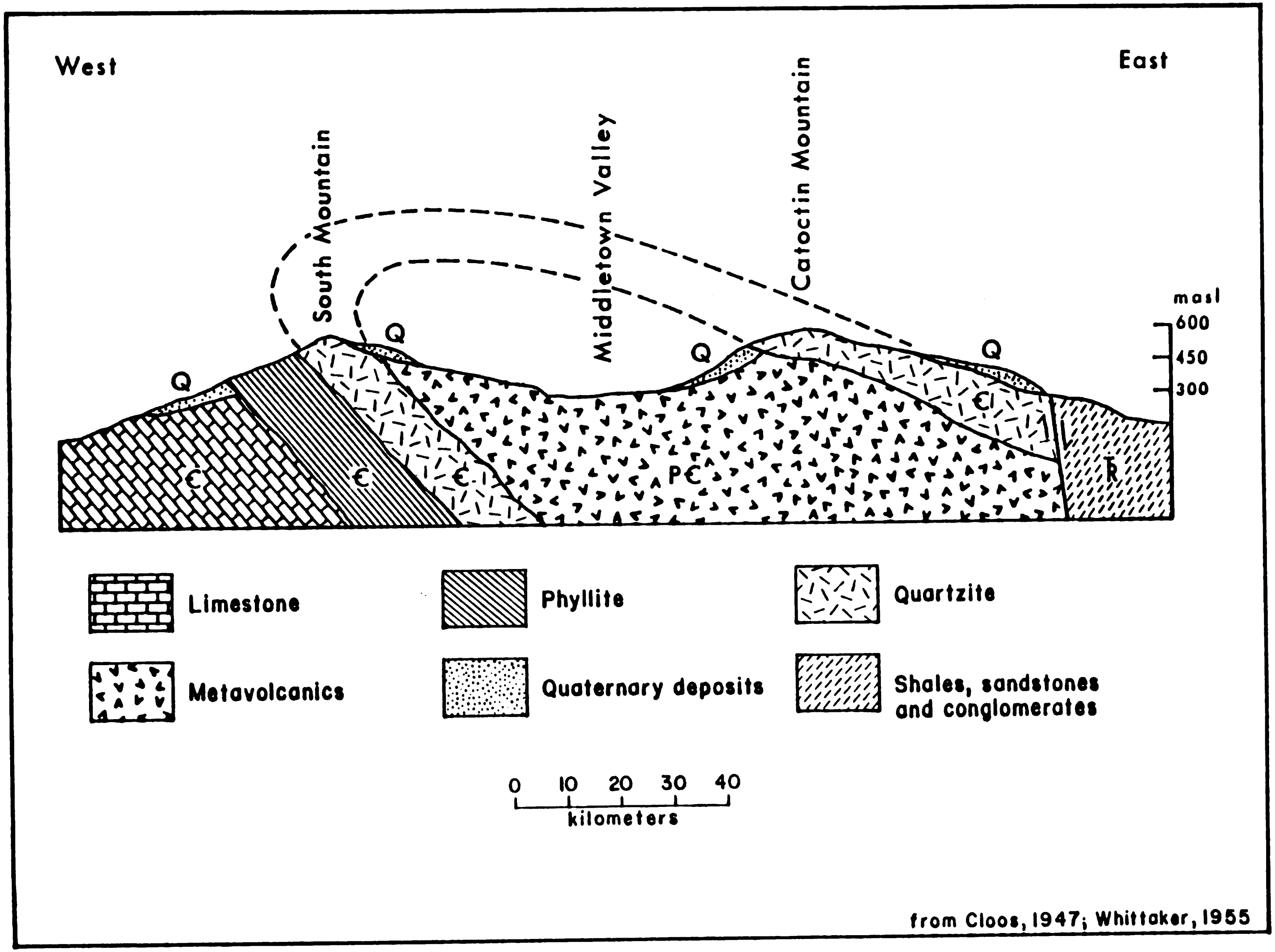

Figure 2. Structure of the Northern Blue Ridge.

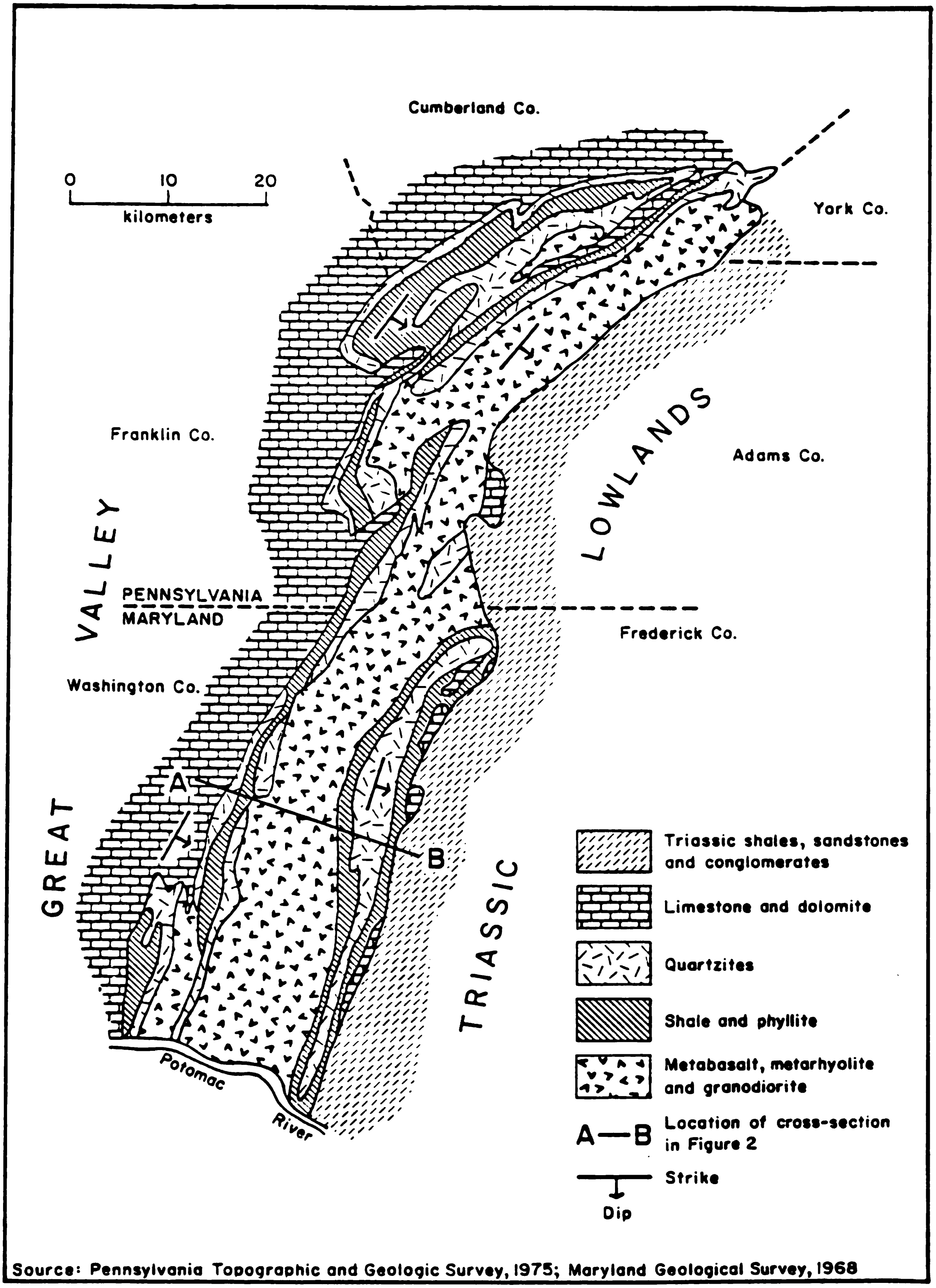

Figure 3. General Geology of the Northern Blue Ridge.

these groups are the principal ridge-formers in the region. The Catoctin Metabasalt is the most important ridge-former in the eastern portion of the study area, whereas the Weverton, Antietam, and Mont Alto quartzites underlie most of the western segments of the upland.

In the southern part of the study area, the Northern Blue Ridge Anticlinorium is breached at its crest, the topographic inversion resulting in two parallel ridges; thus South Mountain on the west and Catoctin Mountain on the east are separated by the Middletown Valley (Figure 4). At the northern end of the study area, the Northern Blue Ridge is a single mountain mass 16 - 19km wide composed of several northeastward trending ridges, each with subordinate ridges and intervening deep, narrow valleys. Elevations in the southern portion range from 225 - 300m while the northern area is higher. Just south of the Maryland-Pennsylvania border the upland reaches 500 - 700m and maintains this elevation to its northern terminus at Carlisle, Pennsylvania.

The gentle eastward dip of the Weverton Quartzite leads to the formation of numerous flat-topped, plateau-like summits. The regional depression of crest heights from north to south is clearly correlated with the structure and thickness of these rock units (Fauth, 1968; Godfrey, 1975). Most of the knolls and summits such as Lambs Knoll, Pine Knob, Quirauk Mountain, Big Flat Ridge, Big Hill, Bear Mountain, and Piney Mountain are the crests of anticlines in

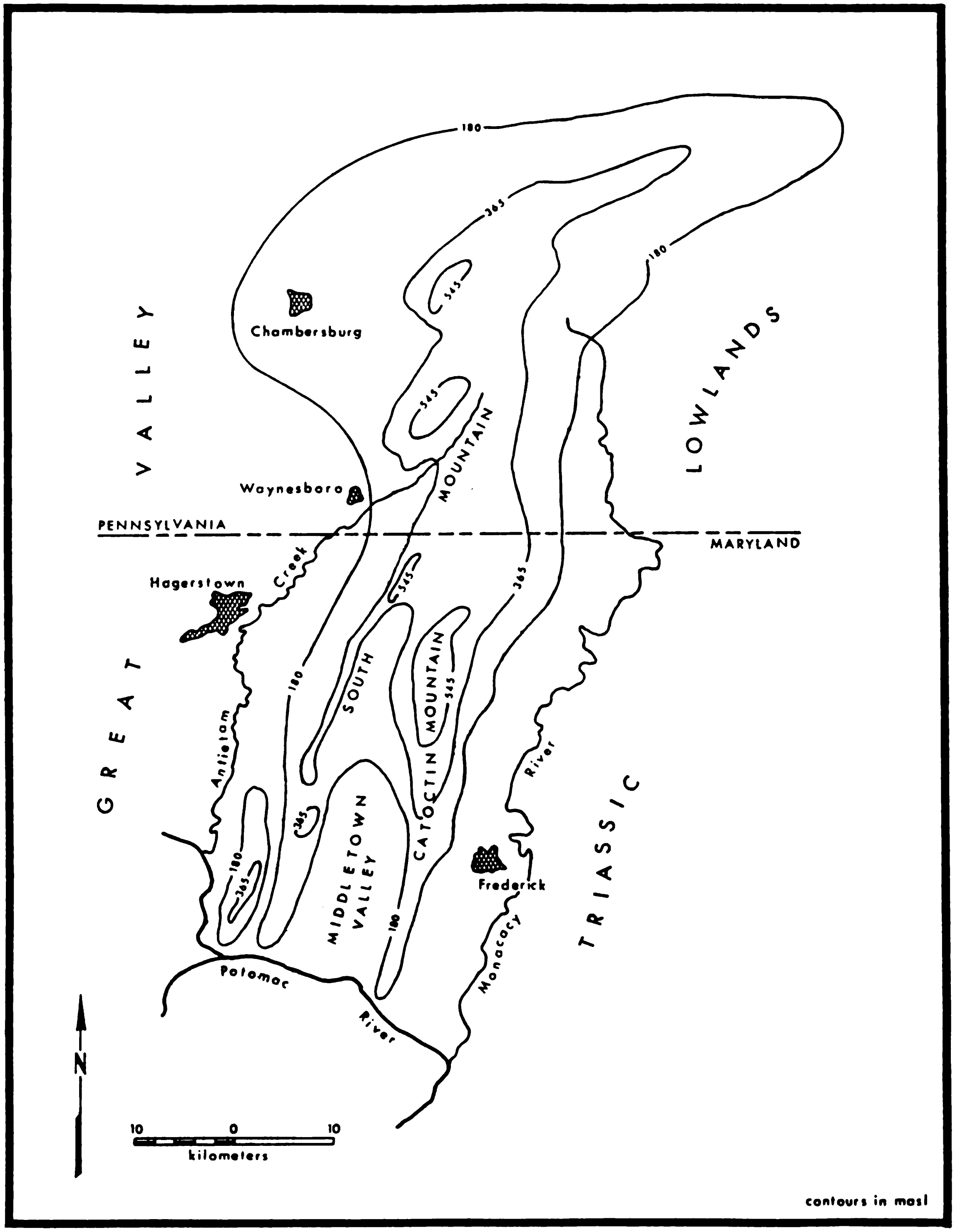

Figure 4. Northern Blue Ridge Study Area.

the Weverton Quartzite (Pierce, 1966; Godfrey, 1975).

Prominent bedrock scarps are developed in the Weverton Quartzite, Antietam Quartzite, and the Catoctin Metabasalt. Most scarps face west in accordance with the eastward regional dip. Smaller scarps range from 2 - 3m high, while larger scarps may exceed 30m. Godfrey (1975) suggested that scarp faces may be obscured in some instances by thick deposits of very coarse, angular to subangular scree.

Boulder deposits of varying character are widely distributed along the entire length of the ridges in the study area, but they are best developed in the central and northern segments. At most locations they occur below massive outcrops of either quartzite or metabasalt. These deposits are composed of very coarse (long-axis diameter varies from .3 - 3m), subrounded to angular boulders and lack a matrix of fines. Typically, these deposits are free of vegetation. Block concentrations on low slopes (3 - 5°) have been described as block fields or block streams, whereas those on very steep slopes (> 30°) are often referred to as talus or scree (Smith, 1949, 1953; Hack, 1965). Extensive areas covered with angular to subrounded boulders embedded in several feet of mineral and organic soil are found downslope from the matrix-free block slopes.

Jonas and Stose (1938), Cloos (1941), Hack (1965), Pierce (1966), and Godfrey (1975) mapped unconsolidated materials in different portions of the Central Appalachians and classified these deposits collectively as alluvium and colluvium, assigning ages ranging from Tertiary to Recent. Their investigations were not concerned with differentiating individual components of this mantle. My field investigations have identified at least two distinctly different sediments that form these deposits: 1) alluvial deposits of various ages composed of subrounded to rounded clasts encased in a matrix of fines, and 2)subangular to angular materials in a matrix of fines.

Alluvial deposits can be subdivided into ancient gravels and modern alluvium. Characterized by rounded clasts set in a silty-clay matrix and a minor amount of sorting at some exposures, the ancient materials are not only locally important, but are widespread regionally as well. Similar deposits have been identified in Soil Conservation Service Survey Reports for the Appalachian region. The old, weathered alluvial deposits were originally laid down in swales or valleys, but many are now in an upland position due to topographic inversion (Hack, 1965). Modern alluvium, exposed in cuts along the banks of the larger streams, is characterized by moderately-sorted to well-sorted mud, sand, and gravels in an unweathered condition and may be matrix supported or clast supported. Recent alluvium and weathered alluvium share several characteristics. First, both contain clay- to boulder-sized fragments that tend to be subangular to rounded (most are well-rounded). Second, both deposit types are composed of coarse particles from the adjacent Blue Ridge upland set in a matrix of fines. The deposits differ in several respects. The recent alluvium displays a higher percentage of coarse particles, is usually moderately to well-sorted, and contains hard, fresh quartzite, sandstone, and volcanic materials. The older alluvium lacks volcanic particles and has cobbles that show distinct evidence of disintegration and weathering rind development (Pierce, 1966).

The best examples of this sediment type are distributed at the base of the westernmost ridges of South Mountain at an altitude of about 250m (Pierce, 1966; Fauth, 1968). The deposits are extensive along the strike axis of the South Mountain Anticlinorium and extend out into the Great Valley to a distance of 2 - 5km. These materials are confined to either the western flank of the Northern Blue Ridge along the Great Valley border, or to the eastern margin of the Catoctin Mountains. Extensive deposits of this type are lacking in the Middletown Valley and in the intermountain axial valleys in Pennsylvania.

Angular rubble encased in a matrix of fine materials veneers many intermediate and lower slopes in the study area. Soil surveys usually map these materials as "stoney land" where rubble covers most of the surface and rock outcrops are commonplace, and Edgemont or Edgemont-Laidig, Dekalb, or Lehew, where the percentage of coarse fragments in the solum is lower (Soil Survey Reports, SCS). These materials are extensive in the study area and elsewhere in the Central Appalachians (Hack, 1965; Pierce, 1966). The rock fragments in these deposits are angular to subangular Antietam Sandstone, Weverton Quartzite, resistant members of the Loudon and Mont Alto formations, or Catoctin Metabasalt. Individual clasts range in size from pebbles to boulders.

Definition of Terms

The principal landform and sediment types central to this research include: 1) summit tors and crest scarps, 2) block-covered areas with a variety of forms, and 3) diamicton. This section defines and clarifies the terminology as it is used in this report.

Summit tors are free-standing, tower-like exposures of rock *in situ* at or near the crests of highlands and are produced by weathering along intersecting joint planes and mass movement of weathered debris (French, 1976; Washburn, 1980). They are best developed in the Weverton Quartzite and to a lesser extent in the Catoctin Metabasalt and Antietam Quartzite. Bedrock scarps, ranging from 2 - 30m high and extending from 100m to 2km in length are best expressed where thick Weverton Quartzite beds crop out with a 15 - 20° eastward dip.

Downslope from the larger scarps, many slopes are mantled with block deposits that vary in form, thickness, and extent. The following terms, adapted from Caine (1968) and Washburn (1980), will be used in this thesis to refer to the various types of block deposits in the Northern Blue Ridge. The term "block" implies an angular to subangular form. Block deposits include all features composed of block material regardless of forest cover, presence of interstitial fine materials, or slope angle. Block stream will be used to refer to those areas on low slope ($\leq$ 10°) with a continuous block cover, lacking fines at or near the surface and devoid of vegetation (except lichens and mosses). Block mantle will be used to describe deposits extensive in a cross-slope direction on steep slopes (> 10°) and free of both vegetation and surficial fines. Block aprons differ from block mantle and block streams, in that forest vegetation and surficial fine materials may be present on these more gently sloping deposits ($\leq$ 10°).

Minor forms with smaller extent and thickness include block tongues with a lobate form that may be present on a variety of slope inclinations without regard to forest cover, and block cascades, which are narrow trains of block material confined to smaller valleys on slopes $\geq$ 10°. Diamicton (Flint, 1971) is a non-sorted sediment containing a wide range of grain sizes. The term is devoid of genetic implications; hence, diamictons may be emplaced by any number of mass-wastage, glacial, fluvial, or subaqueous mechanisms. The term periglacial is used in this thesis to refer to cold climate environments either with or without permafrost (Washburn, 1980). Table 1 summarizes the terminology to be used in this report.

Table 1

Block Deposits

Feature	Block Stream	Block Mantle	Block Apron	Block Tongue	Cascade
Slope Angle	$\leq 10^\circ$	$\geq 10^\circ$	$\leq 10^\circ$	Variable	$\geq 10^\circ$
Vegetation	Absent	Absent	Present	May or may not be present	Present
Form	Extensive down slope	Extensive across slope	Extensive across slope	Lobate	Elongated
Fines at Surface	Absent	Absent	Present	Present	Present

CHAPTER II

REVIEW OF PERTINENT LITERATURE

Geomorphic Indicators of Periglacial Conditions

A substantial number of previous studies have documented several types of cold-climate landforms in the general vicinity of the study area. Collectively, this evidence lends credence to the hypothesis that freeze-thaw processes were major factors in the morphogenesis of the Northern Blue Ridge during the Quaternary. Elsewhere, patterned ground and block accumulations, attributed to periglacial conditions, have been found that have characteristics in common with landforms and deposits in the Northern Blue Ridge (Peltier, 1945; Smith, 1949, 1953; Brunnschweiler, 1962; Rapp, 1967; Clark, 1968; Godfrey, 1975; Hedges, 1975; Cronce and Ciolkosz, 1986; Kite, 1987). The nature of these landforms and their paleoclimatic significance are described in the following sections.

Patterned Ground

Ice-Wedge Casts

Ice-wedge polygons form in areas underlain by permafrost; the presence of their relict casts is, therefore, an excellent indicator of former perennially frozen ground (Embelton and King, 1975; Washburn, 1980). Very low winter temperatures create small tension-cracks in the tundra surface (Price, 1972). During the spring thaw, water will often freeze in these cracks, producing a vertical ice vein that extends down to the permafrost layer. As the upper part of the permafrost warms somewhat during the summer it expands, deforming the host material adjacent to the ice wedge. The crack may reopen during the following winter because the ice vein is a plane of weakness in the permafrost. More ice may be added to the vein in spring. Repeated for centuries, this cycle will create an ice-wedge. With climatic change, the ice-wedge melts out and the void may be filled with material which lies above and adjacent to the wedge or with allocthonus sediments (fluvial or aeolian). The in-fill material, if allocthonus, is likely to be texturally different from that of the host sediment.

Fossil ice-wedge casts may be polygonal, and if so are the best evidence of former permafrost (Washburn, 1980, p. 279). Mean annual air temperatures required for polygonal patterned ground have been found to vary with the sediment in which the cracks form; temperatures from -10° to 0°C have been suggested by various authors (Embelton and King, 1975; Washburn, 1980). According to Péwé (1973), permafrost bordered the ice sheet during the Late Wisconsinan and the -7°C mean annual isotherm was located at least 2000km south of its present position at about 60°N latitude.

Walters (1978) examined polygonal patterned ground in central New Jersey, approximately 45km south of the Wisconsinan drift border (Site 1, Figure 5). Here, the polygons are large and measure from 3 - 30m in horizontal

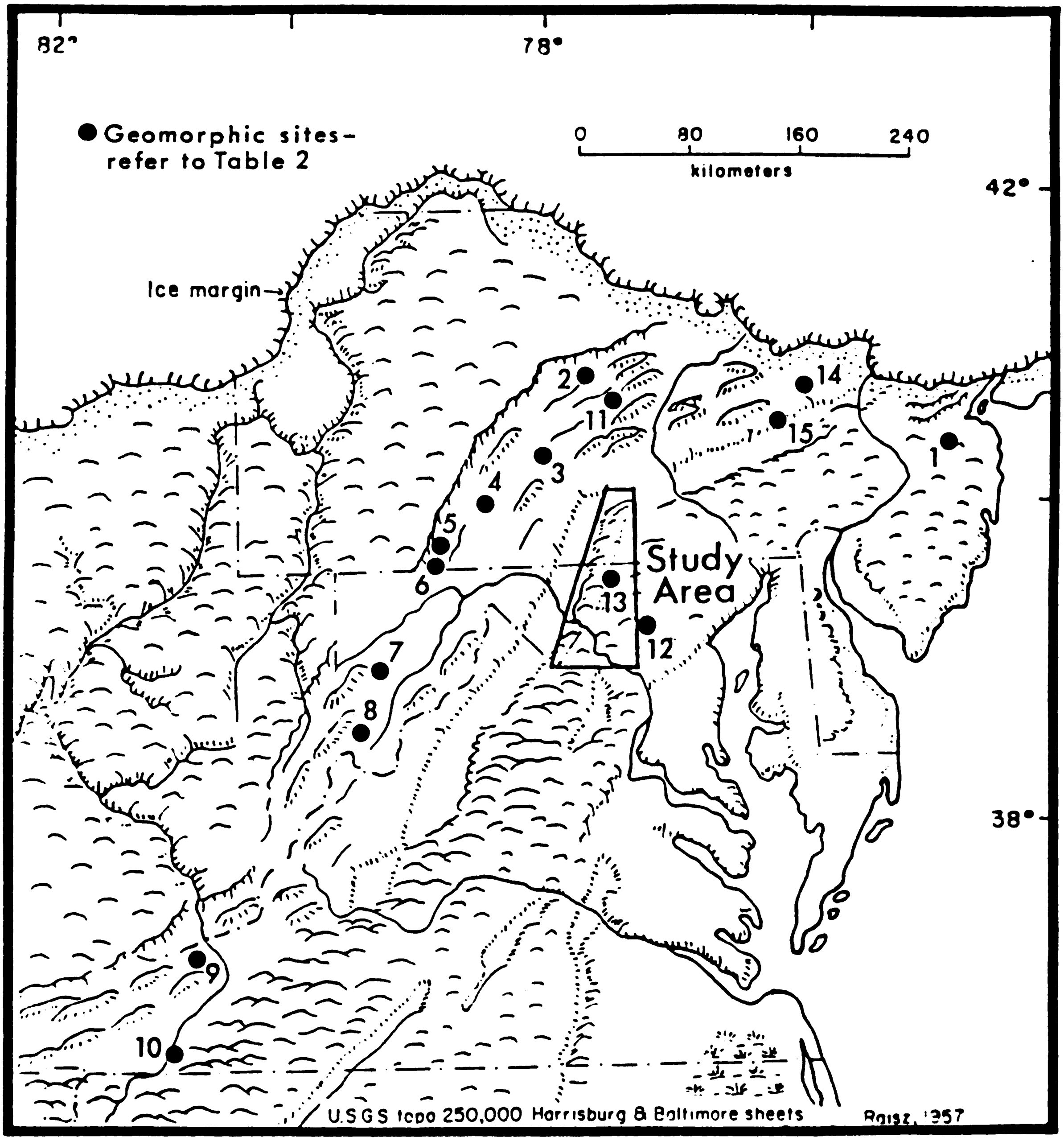

Figure 5. Sites of Geomorphic Evidence of a Wisconsinan-Age Periglacial Paleoclimate, Central Appalachians.

Table 2

Locations of Geomorphic Sites, Central Appalachians, Supporting the Existence of a Wisconsinan-Age Periglacial Paleoclimate

Map Symbol	References	Landform/Structure	Elevation (m)
1	Walters, 1978	Ice-wedged casts	?
2	Cronce and Ciolkosz, 1986	Ice-wedged casts	?
3	Clark, 1968	Patterned ground	707
4	Clark, 1968	Patterned ground	701
5	Clark, 1968	Patterned ground	969
6	Clark, 1968	Patterned ground	975
7	Clark, 1968	Patterned ground	945
8	Clark, 1968	Patterned ground	1219-1478
9	Clark, 1968	Patterned ground	1207
10	Clark, 1968	Patterned ground	1615
11	Rapp, 1967	Patterned ground	600-750
12	Hedges, 1975	Talus and block streams	372
13	Godfrey, 1975	Talus and block streams	500-600
14	Smith, 1953	Blockstream	550-585
15	Potter & Moss, 1968	Blockstream	200-250

mesh diameter. The vertical dimensions of the underlying pseudomorphs extend into the subsurface from 25 to 260cm, and the infilled material is texturally different from that of the host. Walters concluded that the polygonally patterned ground displayed several features typical of ice-wedge casts and postulated that permafrost existed in the periglacial zone distal to the Wisconsinan ice margin. His data also suggest that mean annual air temperatures may have been from 16 - 19°C colder than at present (Walters, 1978 p. 53).

Cronce and Ciolkosz (1986) identified frost-wedge casts in central Pennsylvania developed in limestone residuum and terrace alluvium. Soil profile development within the casts led them to conclude that these frost-wedge casts are of Wisconsinan age (Site 2, Figure 5).

Sorted Circles and Stripes

"Sorted circles are patterned ground whose mesh is dominantly circular and has a sorted appearance due to a border of stones surrounding fine material" (Washburn, 1956, p. 827). Numerous theories have been proposed describing the mechanism that produces this phenomenon but most involve pressure generated by freezing and reduction of pressure upon melting (Embelton and King, 1975, p. 90). These pressure changes can produce sorting of material in which a heterogeneous mix of particles is present. Sorted stripes form on inclined surfaces, characterized by parallel lines of stones separated by intervening zones of finer material.

Stripes and circles are typically best developed in the periglacial zones of high altitude and high latitude under the influence of permafrost (Washburn, 1980, p. 133) and are evidence of mean annual temperatures of 0° to -2°C (Washburn, 1980a, p. 358).

Clark (1968) identified sorted stone stripes and circles in the higher Appalachians of Pennsylvania, Virginia, and West Virginia (Sites 3-10, Figure 5). He found stripes with both linear and sinuous surface patterns. Elongated boulders were on edge and oriented parallel to the stripe border. He also reported stone circles with diameters ranging from 1 to 4m; the largest were identified in Pennsylvania, with diameters decreasing in a southerly direction. Figure 6 shows that their altitudinal distribution varies with latitude. Clark found that the elevation of sorted stone circles at 37°N latitude is twice as high as that of circles found north of 40°N latitude. None of the patterned ground forms reported was found to be actively forming; instead all were overgrown with vegetation and covered with lichens.

Rapp (1967, p. 235) presented evidence of sorted stone stripes and circles near University Park, Pennsylvania, that displayed "all the characteristics of true periglacial stripes." Occurring on slopes < 2° and running transverse to the contour, many of the boulders in the stripes stand on edge. The stripes and circles are presently immobile and in a state of disintegration as evidenced by rounding,

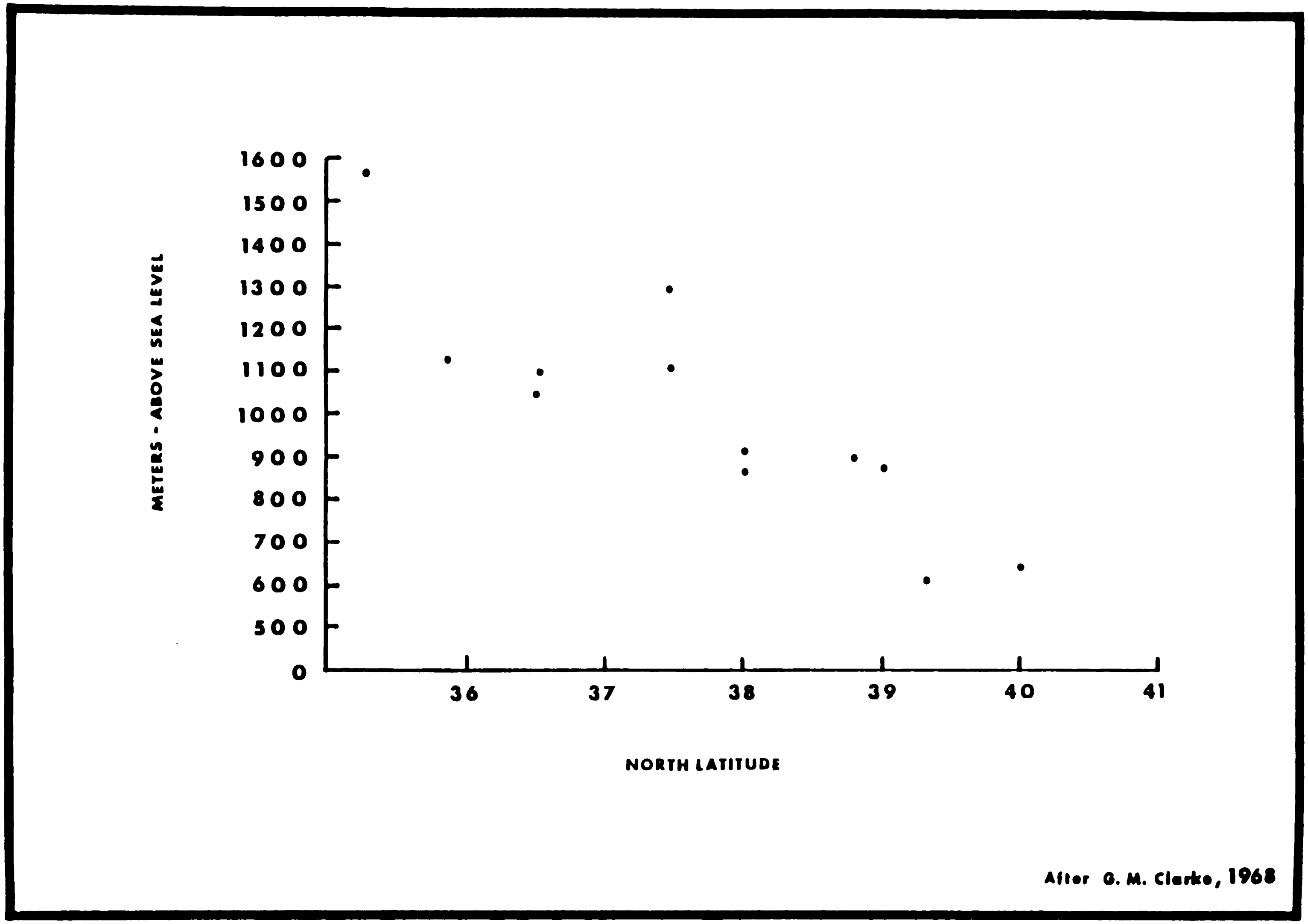

Figure 6. Scattergram: Relationship Between Latitude of Patterned Ground and Altitude.

cracking, solution pitting, and lichen growth on upper block surfaces. Rapp (p. 242) concluded that a cold, treeless, periglacial climate existed in this region during the Pleistocene cold periods, and that neither of the patterned ground forms could have been produced under present climatic conditions (Site 11, Figure 5). Ciolkosz et al. (1986) have recently identified periglacial stripes and circles in other parts of Pennsylvania as well.

Block Accumulations

The size, shape, and arrangement of sedimentary rocks (packing and fabric) are referred to as texture (Pettijohn, 1957). Textural analysis has been the principal method of defining the processes responsible for block field and block stream emplacement (Caine, 1968).

A number of studies in the United States have treated block field texture (Smith, 1953; Potter and Moss, 1968; Psilovikos and Van Houten, 1982), but few detailed studies have appeared in the literature for areas in the Appalachians. Most of the work has been done in Europe (Cailleux, 1947; Lundqvist, 1949; Dahl, 1966; Stromquist, 1973), Tasmania (Caine, 1968, 1983) and in New South Wales (Caine and Jennings, 1968).

The texture or fabric of block streams and block fields is characterized by an orientation of the long axis of individual blocks that is parallel to the direction of slope but usually less steeply inclined (Washburn, 1980). Klatka (In Washburn, 1980) found the fabric to be better developed and the stones to decrease in size with distance downslope. Caine (1968) confirmed these observations but also noted a transverse block orientation near the toe of the deposits. Stromquist (1973) found that block orientation was transverse on steep slopes and that a change to parallel orientation developed on slopes less than 20°. Albjar et al. (1979) found that block accumulations on steep slopes (talus) in periglacial areas are characterized by a preferred orientation of the long axes of coarse particles in the direction of the slope aspect. In non-periglacial areas, the results show no preferred a-axis orientation. See Mills (1981), for a thorough discussion of block orientation.

In addition to the "standard" fabric pattern, where the long axes of the blocks are closely aligned in the slope direction, an on-edge or on-end orientation of clasts is common (Mills, 1981). Washburn (1980) noted, and others have confirmed, the presence of tabular clasts within frost-heaved soil (Vorndrang, 1972, in Mills, 1981; Schunke, 1974, in Mills, 1981). There appears to be no other mechanism that would emplace large, tabular boulders in a vertical to near-vertical position (Mills, 1981).

Block fields, block streams, and talus are significant indicators of increased freeze-thaw conditions (Washburn, 1980). At most mid-latitude locales, block deposits are now stabilized and are being chemically weathered, covered by lichens, and encroached upon by surrounding forests (Flint, 1971, p. 272). Those features for which present day inactivity can be demonstrated may serve as indicators of former periglacial conditions (see methodological discussion of this problem in Smith, 1949, p. 1500; Washburn, 1973, p. 193). Field evidence for such stabilization includes: 1) the growth of lichens on upper block surfaces, 2) secondary weathering effects (splitting, rounding, and formation of weathering rinds) indicating both decomposition in situ and the predominance of chemical weathering over frost shattering, and 3) the growth of undisturbed forest vegetation immediately adjacent to and encroaching upon the deposits.

Beschel (1961) pioneered lichenometry more than three decades ago as a tool to date the exposure of rock surfaces. The science has rapidly evolved although not without controversy over its effectiveness (Jochimsen, 1973; Webber and Andrews, 1973; Hale, 1983). For the most part, lichenometry has been used to date moraine deposition and glacial retreat in high latitude and high altitude locations. Debate centers mostly on the establishment of growth-rate curves for different environments.

Lichens are autonomous organisms with a dual nature. Algae and fungi live symbiotically as a different kind of plant (Hale, 1979). Growth forms include three types, all of which exist in the Northern Blue Ridge. Crustose lichens grow in intimate contact with the substrate. Hair-like fruiticose lichens are shrubby, while foliose lichens are leafy. Crustose lichens increase in diameter more slowly and are most useful in dating rock surfaces although foliose types may also be helpful. Foliose lichens grow 1.0 - 5.0 mm/year in the climate of the Northern Blue Ridge while crustose types increase in size at rates between .9 - 1.0 mm/year (Culberson, 1982).

Lichens occurring in the Central Appalachians are short-lived and grow at faster rates than those of Arctic and Alpine areas. It is impossible to use this technique to date surfaces exposed more than 200 - 300 years ago in the Appalachians (Hale, 1983) but it is useful to confirm or reject the notion of block movement during the past several hundred years. According to Hupp (1983), blocks that have been stable for approximately a century or more in the Northern Blue Ridge area will be nearly completely covered with lichens on their upper surfaces. The sides may also have a lichen cover but it will be less completely developed. Blocks that have been recently overturned (within the last decade) will probably lack surface lichens, but the undersides may have a few remnant patches. Blocks overturned two or three decades ago may exhibit surface lichens, but they will be noticeably smaller than those on undisturbed blocks nearby.

Weathering effects such as the presence of pit-shaped depressions, rounded corners, and rinds can serve as relative age indicators that confirm the stability of block material (Smith, 1949; Cernohouz and Solc, 1966; Colman, 1981.) Weathering pits are well-developed on quartzite blocks in the Northern Blue Ridge as well as elsewhere in the Appalachians (Smith, 1949). Small depressions, originally formed by the intersection of bedding planes and joints, are enlarged by chemical processes associated with water standing in the clefts (Twidale, 1978, p. 203). If pits are present only on the upper surface, block stability is indicated.

Thickness of oxidized weathering rinds has been utilized as a relative dating technique for several decades to establish a chronology for alpine glaciation (Nelson, 1954; Birkeland, 1973; Caroll, 1974; Thorn, 1975; Colman 1981, 1982). As the iron-bearing minerals weather over time, weathering products discolor the edges of the rocks (Nelson, 1954). Caine (1968, pp. 71-72) utilized this technique on Tasmanian block fields and found that 1) mean rind thickness on doleritic (diabase) blocks there averaged 1.7 - 2.7mm; 2) rind thickness was slightly greater on the underside of blocks; 3) rind thickness can vary by up to 100% of the average on the same block, and that rinds encircling the block indicate no further splitting.

Hupp (1983) examined "block fields" at Massanutten Mountain, Virginia (these deposits are actually block mantles following the terminology established for this report). The mantles Hupp studied in an effort to show that they exhibit evidence of current activity were on slopes ranging from 32 - 45°. Using dendrogeochronological techniques, he was able to establish that a significant number of trees on "block fields" bore evidence of recent block movement (scarring and disruption of annual growth patterns). Lichenometry revealed that numerous boulders on the steep slopes showed signs of being overturned in the past century. Block areas with lichens of similar size led him to believe that slope failure in the recent past has modified "block field" form there. He attributed the movement in the bare block areas to the build up of pore pressure within the open block matrix.

Using secondary weathering evidence along with lichen formations, researchers working in the north Central Appalachians have located several examples of stabilized block streams and block slopes. Smith (1953) stated that the Hickory Run Boulder Field in Carbon County, Pennsylvania, represents the best developed deposit of its type in this country. Located just 1.2km south of the Wisconsinan drift border, the 600m x 125m tract was described as a barren expanse of jumbled cobbles and boulders of widely varied size (< 1m - > 8m) and shape (Site 14, Figure 5). Evidence for its fossil nature includes; 1) forest encroachment on the boulder barrens, 2) soil development above and between blocks, 3) rounding of edges on individual blocks and 4) blocks with a strongly developed micro-relief of pits and depressions on their upper surfaces, while the undersides lack signs of chemical weathering.

Smith (1949, 1973) described long, narrow depressions on the surface of the block field. Caine (1968) found similar furrowed features, which he termed grooves, on many Tasmanian block fields; these grooves were roughly dendritic in pattern. Running water was observed at the base of grooves at both locales.

Caine (1968, pp. 32-42) found that the structure of block streams in Tasmania is characterized by three distinct layers. The upper layer, extending from 45cm to 3m, is composed of an open-block matrix with little or no interstitial material except for sand and gravel weathered from the blocks. Below this is a strata in which an organic-rich mud fills the voids. The basal layer contains blocks set in a sandy matrix and extends to an unknown depth. Smith (1953) excavated pits to depths of 1.1 - 2m in the Hickory Run block stream and found a structure very similar to that of the Tasmanian examples; above the water table, there were no interstitial materials; at and below the water table, the interstices were filled with sand.

Smith (1973) suggested that piping, the mechanical removal of clastic materials by underground waters, may be responsible for the absence of surficial interstitial fines and the presence of furrows in the boulder fields of the Appalachians. Removal of fines would lead to settling of the coarse particles left behind. Where stream flow beneath the block matrix was concentrated, settling would be greater, resulting in a furrow on the surface. A reorientation of the blocks would also be likely along the length of the furrow because of the removal of the supporting fines and lowering of the entire mass.

Potter and Moss (1968) studied the Blue Rocks boulder stream in Berks County, Pennsylvania (Site 15, Figure 5). This 800m long deposit of subangular blocks is relict, as shown by lichen growth on the upper block surfaces, encroaching forest, and rounding in situ of the individual blocks.

Using similar kinds of evidence, Godfrey (1975) attributed block deposits of the Blue Ridge in Maryland to increased frost activity during the Wisconsinan (Site 13, Figure 5). He noted that the block deposits exhibited: 1) encroaching forest with no evidence of tilting, scarring, or disturbance of individual trees, 2) lichen cover on upper block surfaces, and 3) pitting and rounding of individual blocks.

Hedges (1975) reported talus aprons and block streams on a quartzite-capped monadnock in the Maryland Piedmont (Site 12, Figure 5). Corners of the individual blocks had been smoothed, forest vegetation was encroaching upon the margins of the deposits, and there was no evidence of material recently added from the ledges above.

Biotic Indicators of Periglacial Conditions

Paleoclimatic conditions can be approximated by comparing past and present ranges of both flora and fauna

(Deevey, 1949; Guilday, 1962; Flint, 1971). This procedure involves the assumptions that climate exercises the primary control over the distribution of the taxa and that the nearest living relatives exhibit the same responses to limiting factors as did the fossil taxa. When dealing with late Pleistocene mammals, one is safe in assuming that the habitat preferences of any given species have remained relatively constant through time. The former geographical range for each taxon (usually at the genus level) in a fossil assemblage is determined, and, if that range lies outside the present distribution, it can be inferred that critical climatic parameters such as mean annual precipitation and mean temperature of the coldest or warmest months have undergone significant change. Although there are various problems associated with paleoclimatic reconstructions, numerous cases show that the interpretation of the fossil biotic record yields results consistent with the inorganic evidence for a postulated climatic change. The following sections briefly review the paleobiotic records of the Central Appalachians, insofar as pertinent research is concerned.

Paleobotanical Evidence

Until recently most paleobotanists and biogeographers agreed that deciduous forest species did not retreat far south of the glacial border in eastern North America during the Pleistocene (Braun, 1951). They envisioned meager, relatively intact zonal displacements of the biota due to shifts in weather patterns (Braun, 1951). It has been suggested that, during glaciation, the diverse habitats of the Southern Appalachians served as a refuge from which recolonization could occur during the interglacials. After years of research, Braun concluded that the environmental changes south of the ice margin were not sufficient to have generated significant biotic displacements and that the full-glacial vegetation patterns were essentially like those of today.

In contrast, Deevey (1949, p. 1374) commented that "glacial chilling in the southeastern states must have been extensive." The near absence of accurately dated microfossils from the maximum of the Wisconsinan glaciation made it almost impossible in 1950 to prove either viewpoint. It is obvious, however, that two divergent positions had emerged: minimal disturbance of plant communities south of the glacial border according to one view, and near total displacement of deciduous forest species from many areas of the southeast, according to the opposite view. The former position is now regarded as untenable by most palynologists and biogeographers because radiocarbon dating and the development of more reliable pollen analytical techniques have confirmed the existence of boreal forest associations well south of the glacial border (Whitehead, 1973; Davis, 1976; Delcourt and Delcourt, 1979; Watts, 1979; Wright, 1981).

The plant communities of the southeastern states during the Wisconsinan bore no resemblance to the modern assemblage in that area. Deciduous trees were generally scarce except for alder, birch, and willows; the forests were dominated by pines (Pinus resinosa and Pinus banksiana) and, to a lesser extent, by spruce (Picea mariana). Fir (Abies sp.) was a minor component of the boreal forest (Maxwell and Davis, 1972).

Sirkin et al. (1977) found a significant change in the late-Wisconsinan flora of the Delmarva Peninsula during the period 30,000 B.P. to about 13,000 B.P. (Site 3, Figure 7). The microfossil evidence in the lower portion of the core sample points toward the existence of pine-birch barrens, with small ponds and swamps--indicators of conditions cooler than now. By 23,000 B.P., this association had been replaced by pine, spruce, and boreal shrubs and herbs. Boreal forest subsequently replaced the forest-tundra ecotone by late-glacial to early post-glacial time (Sirkin et al., 1977, p. 120).

Abundant microfossils of Picea, Abies, Pinus, Betula, and Larix in the basal layers of an undated river terrace deposit in Washington, D.C., indicate boreal conditions (Knox, 1969). The upper portion of the pollen core revealed an amelioration of climate, as evidenced by the presence of Quercus, Fagus, Taxodium, Liquidambar, and Nyssa. Still higher in the core sample, a return to boreal conditions is evident (Site 2, Figure 7).

Pollen spectra from the Hack and Quarles ponds,

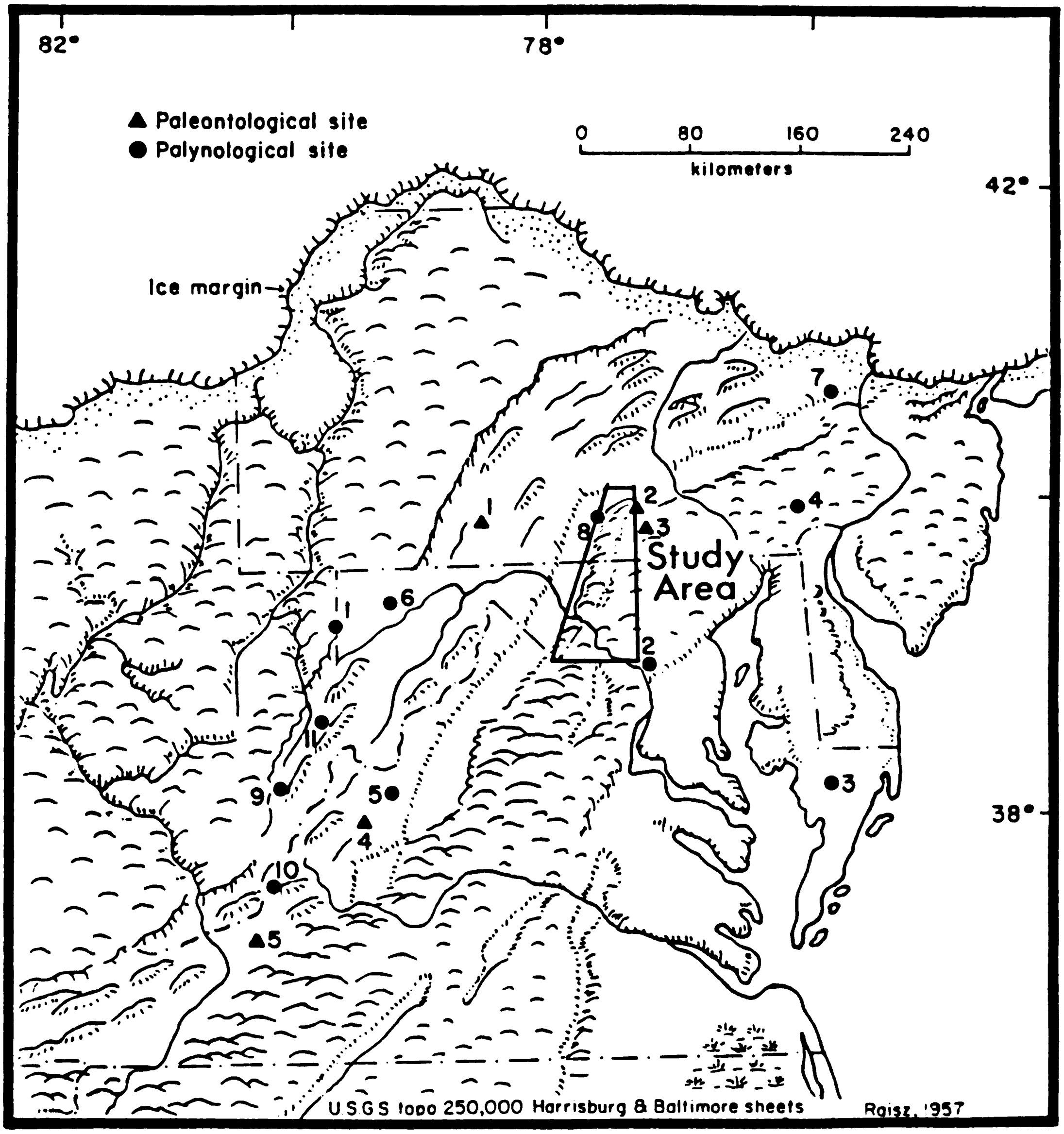

Figure 7. Biotic Indicators of Periglacial Conditions in the Northern Blue Ridge Study Area (see Table 3).

Table 3

Locations of Paleobiological Sites, Central Appalachians

Supporting the Existence of a Periglacial Paleoclimate

Map Symbol	References	Type of Site	Age
1	Cox, 1968	Paleobotanical; microfossils	Late Glacial
2	Knox, 1969	Paleobotanical; microfossils	Undated
3	Sirkin, 1977	Paleobotanical; microfossils	25,000 B.P.
4	Martin, 1958	Paleobotanical; microfossils	13,000 B.P.
5	Craig, 1969	Paleobotanical; microfossils	Late Wisconsinan
6	Maxwell & Davis, 1972	Paleobotanical; microfossils	19,000 B.P.
7	Watts, 1979	Paleobotanical; microfossils	Full Glacial
8	Watts, 1979	Paleobotanical; micro and macrofossils	12,000 B.P.
9	Watts, 1979	Paleobotanical; microfossils	Late Wisconsinan
10	Watts, 1979	Paleobotanical; microfossils	Late Wisconsinan
11	Watts, 1979	Paleobotanical; micro and macrofossils	Late Wisconsinan
1	Guilday, 1967	Paleontological; rodents, caribou	Late Wisconsinan - Post Wisconsinan
2	Guilday, 1964	Paleontological; rodents	Late Wisconsinan - Post Wisconsinan
3	Guilday, et al., 1966	Paleontological, rodents	Late Wisconsinan - Post Wisconsinan
4	Guilday, et al., 1977	Paleontological; rodents in raptor pellets	Late Wisconsinan - Post Wisconsinan
5	Guilday, 1962	Paleontological; rodents and aves	Early Post - Wisconsinan

Shenandoah Valley, Virginia, (Site 5, Figure 7) allowed Craig (1969, p. 294) to divide the sediments into three zones, one dominated by Pinus-Picea, which is late-glacial in age, a Quercus zone of post-glacial age, and a Quercus-Pinus zone determined to be of subrecent age. The lower zone (undated), characterized by 40-60% Pinus pollen, small amounts of Picea, and low percentages of non-arboreal pollen and deciduous tree pollen, indicates the dominance of boreal forest at that site during the Late Wisconsinan.

At Crider's pond, Franklin County, Pennsylvania (Site 8, Figure 7), Watts (1979) identified three vegetative zones on the basis of both microfossils and macrofossils. The basal layer exhibited evidence of pine and spruce (late-glacial in age), the second zone was dominated by spruce (P. rubens, P. glauca, P. mariana) and herbs, while the upper zone displayed a significant increase in diversity. This site lacks positive evidence of tundra, but the sediments are not full-glacial in age.

Martin (1958) recognized four major pollen zones at the Marsh site in the southeastern Pennsylvania Piedmont (Site 4, Figure 7). The basal layer, C^{14} dated at 13,000 B.P., is similar in composition to the horizon above it. Both zones are dominated by non-arboreal pollen (NAP) and contain some Picea, Abies, and Pinus. The high NAP values indicate extensive areas of tundra whereas spruce, fir, and pine suggest taiga. The overlying zone, which is late-glacial in age, shows a significant increase in Pinus and temperate species. Spruce and fir were still present, but NAP was in decline and boreal forest had replaced the forest-tundra ecotone by late-glacial time.

An analysis of the pollen zones at Longswamp Pond, Berks County, Pennsylvania (Site 7, Figure 7), a solution pond sealed by slumped-in clays, revealed a pollen spectrum very much like one that would be obtained from the modern tundra in northern Quebec, Baffin Island, and southern Greenland (Watts, 1979). The full-glacial basal zone, dominated by grasses and dwarf shrubs, is undoubtedly tundra. The middle zone shows a transition to open spruce forest, followed by boreal forest in the upper-most zone. Watts interpreted the full glacial conditions here to be a cold, dry, windy, and treeless tundra.

Most of the palynological evidence cited so far originated from areas of low elevation (generally less than 300m above sea level) in the Coastal Plain, Piedmont, and the Great Valley, but data are also available for the Appalachian Plateau and Ridge and Valley Provinces. At the Cranesville Pine Swamp (Site 1, Figure 7) on the West Virginia-Maryland border (800m), pollen analysis indicated a sub-arctic vegetational association during late-glacial time. The lower zone is dominated by high percentages of NAP, fir, spruce, and pine; the overlying sequence shows the forest-tundra ecotone being replaced by boreal forest and subsequently by advancing boreal-mixed forest ecotone during the post-glacial period (Cox, 1968, p. 142).

Maxwell and Davis (1972) found the Buckles' Bog site on the Appalachian Plateau of Maryland to be unequivocally full-glacial, about 19,000 B.P. (Site 6, Figure 7). Tundra conditions are clearly indicated by very high percentages of NAP and small relative and absolute amounts of tree pollen. In reconstructing the vertical zonation of the forest belts, the authors found the spruce-fir associations may have been confined to areas below 450m in the Ridge and Valley Province (Maxwell and Davis, 1972, p. 522). About 12,700 B.P., a major change in the floristic composition is apparent; tree pollen increased sharply and for the first time during late-Wisconsinan times Abies, Picea, Pinus, and Alnus grew in close proximity to Buckles' Bog. By 10,500 B.P., the spruce-dominated boreal forest was being replaced by mixed coniferous-deciduous forest.

Watts (1979) examined several sites in the Ridge and Valley Province of Virginia and West Virginia (Sites 9 and 10, Figure 7). At Cranberry Glades, West Virginia (1029m), the pollen spectra suggest tundra conditions prior to 12,185 B.P. Watts interpreted a basal layer of fines to be aeolian silt, indicating a cold, dry, and windy periglacial paleoenvironment. Palynological evidence for boreal forest was also found at Potts Mountain Pond, Allegheny County, Virginia. The microfossils at this site, dated at about 11,140 B.P., include spruce, fir, alder, oak, and hemlock.

At the Canaan Valley site (Site 11, Figure 7), Tucker County, West Virginia (792m), forested "block fields" were found above lenses of silt containing plant macrofossils of Picea sp. (Watts, 1979, p. 458). Watts noted that "it is remarkable that the block fields did not overlie herbaceous, tundra-type plants." He explained that the block fields were active until the tundra vegetation departed and boreal forest returned.

Delcourt and Delcourt (1981) mapped the vegetational history of the eastern United States spanning the period 40,000 B.P. to 200 B.P. Figure 8 is their reconstruction of the vegetation for eastern North America at the peak of late-Wisconsinan glacial, approximately 18,000 B.P. A narrow but continuous belt of tundra parallels the ice margin near the study area and discontinuous pockets of tundra are distributed along the higher portions of the Appalachians. Jack pine forest (P. banksiana), spruce (Picea sp.), and fir (Abies sp.) dominate the midslope positions in the Central Appalachians.

Paleontological Evidence

Past animal distributions offer additional biogeographical evidence for the existence of a periglacial paleoclimate during late-Wisconsinan time in the Northern Blue Ridge. Dated fossil specimens are especially valuable because climatic preferences and chronological relationships of the species in the faunal assemblage can often be established.

The significance of the climatic reconstruction is significantly increased when an entire assemblage of species

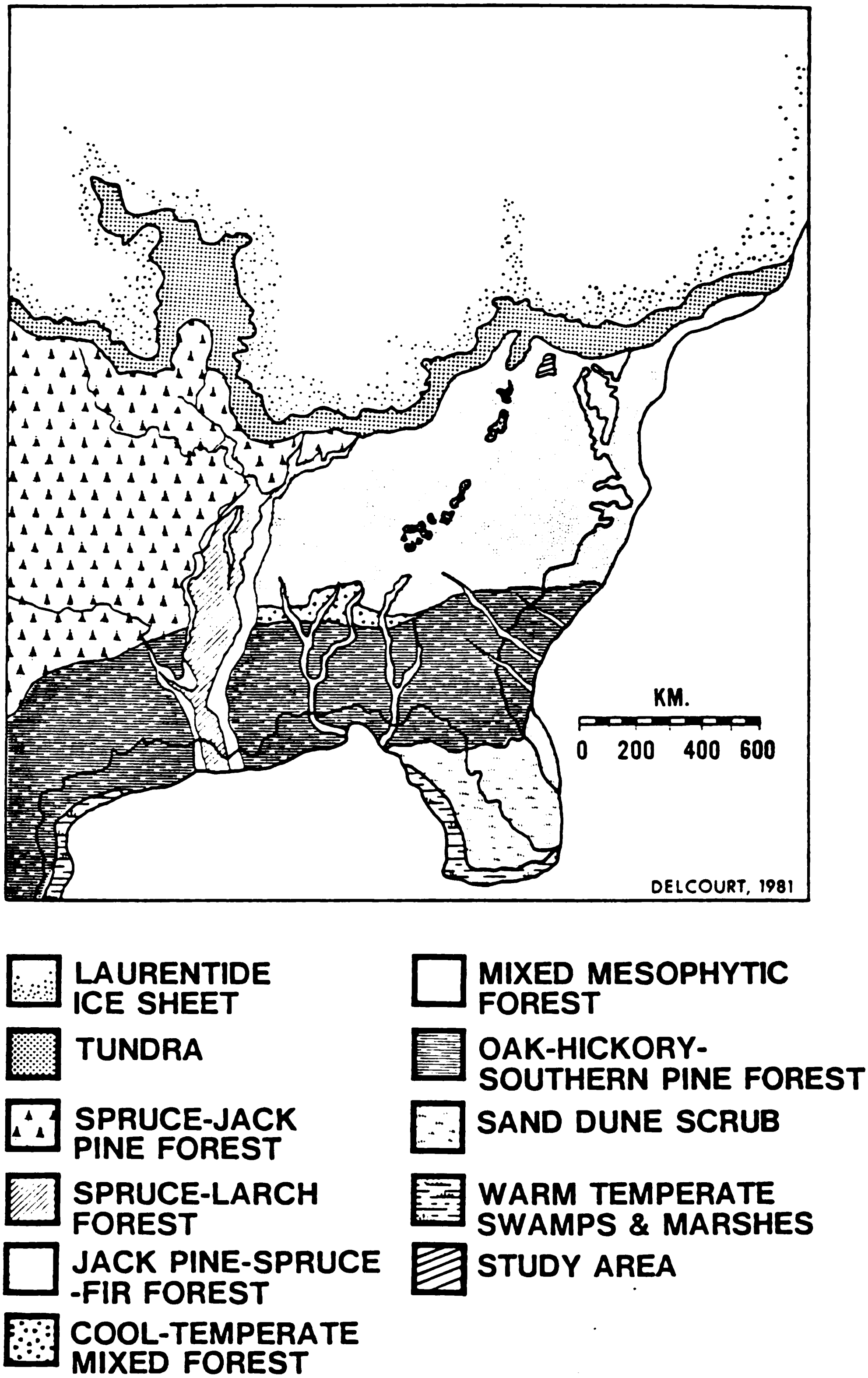

Figure 8. Paleovegetation of Eastern North America, 18,000 B.P.

is found in a deposit with similar habitat requirements or overlapping geographic ranges (Guilday, 1962; Flint, 1971).

Certain mammalian species, known today only from tundra and boreal habitats, were widespread in the Central Appalachians during the Late Wisconsinan as evidenced from fossil accumulations (Guilday et al., 1977; King and Graham, 1986). Many boreal species show up in cave-floor accumulations but two animals are especially sensitive indicators of late-Wisconsinan tundra; the collared lemming and the ptarmigan. The presence of the collared lemming in a fossil assemblage "reflects cold, dry, open environments with sparse vegetational cover and permafrost" (King and Graham, 1986). Ptarmigan are more mobile than rodents and indicate only that open ground was in close proximity (Guilday et al., 1977).

Stratigraphic position, bone condition, and species present in the fossil matrix point to an early post-Wisconsinan age for the Natural Chimneys (Site 5, Figure 7) deposit in the Shenandoah Valley of Virginia (Guilday, 1962). Guilday found remains of distinctly boreal species, such as the snowshoe hare, pine marten, northern flying squirrel, northern bog lemming, spruce vole, yellow-cheeked vole, rock vole, spruce grouse, and gray jay. This assemblage of species implies that the habit included not only boreal forest but also open meadows and swampy grasslands.

The Clark's Cave bone deposit (Site 4, Figure 7) in the

Ridge and Valley Province of west-central Virginia is a late-glacial to very early post-glacial accumulation of raptor pellets in a cave talus matrix (Guilday, et al., 1977). Most raptors prey on rodents that have a very limited range. Therefore the presence in a deposit of great numbers of individuals from a large variety of boreal species strongly suggests that boreal habitats were nearby. Boreal species in the deposit included:

arctic shrew	rock vole
pygmy shrew	northern bog lemming
short-tailed shrew	porcupine
snowshoe hare	ptarmigan
least chipmunk	gray jay
heather vole	sharp-tailed grouse
yellow-cheeked vole	pine marten

Though this assemblage is definitely boreal, most of these species do not favor a tundra habitat, except for the ptarmigan, whose presence suggests at least discontinuous tundra in the vicinity of the site (Guilday et al., 1977).

Bootlegger Sink, in York County, Pennsylvania, is located just east of the study area (Site 3, Figure 7). The fossil remains in the cave-floor breccia are mixed, both chronologically and ecologically. An analysis of the habitat requirements of four members of the fauna (least shrew, cottontail rabbit, yellow-cheeked vole, and arctic shrew) shows that whereas the first two animals prefer a temperate climate, the latter two are boreal (Guilday et al., 1966). Based on the disparate nature of their present-day habitat requirements, it is unlikely that these four species could have been contemporaries. Fluorine analysis of the bones in the deposit revealed that the accumulation occurred over a long period, beginning during late-glacial times. The authors separated the fossil remains into three distinct chrono-climatic intervals, late glacial, hypsithermal, and sub-recent, according to the presence or absence of key species in the cave floor matrix.

A climatic change which can be dated is evident from two distinctly different faunas uncovered at Hosterman's Pit, located in the Ridge and Valley Province of Pennsylvania (Site 1, Figure 7). Deer, pine mouse, and cottontail rabbit remains indicate a relatively recent age and temperate climate conditions while the collared lemming, northern flying squirrel, yellow-cheeked vole, and caribou suggest greater antiquity and a boreal paleoclimate (Guilday, 1967).

Paleoclimatic interpretation depends heavily upon the variation of the relative frequency of indicator species with depth in the deposit. The modern-day habitat for a species found in a deposit is presumed to have been operative in the past; increases or decreases in relative frequency of key species are used to infer warming or cooling trends. For example, raptors, whose diets are composed of small insectivores (voles, lemmings, and shrews), tend to roost in great numbers in caves where their droppings can aggrade for thousands of years. The percentage shifts in species composition of the droppings can be measured and correlated with climatic change (Guilday et al., 1964).

New Paris #4 Sinkhole, York County, Pennsylvania (Site 2, Figure 7), was found to have about 10m of stratified fill. The interpretation of this sequence allowed the authors to infer and date several significant climatic fluctuations (Guilday, et al., 1964). Though the sinkhole accumulation is boreal in its entirety, a warming trend is indicated at about 11,000 B.P. Woodland forms, such as the red-backed vole, increased in frequency toward the surface, indicating a change from tundra to closed boreal forest; at the same time, grassland species favoring a tundra habitat, such as the meadow vole and the yellow-cheeked vole, were in decline.

SUMMARY

Fossil ice-wedge casts are the best indicators of former permafrost and relict, large, sorted stone stripes and circles are evidence of marginal permafrost. The presence of these features in the Central Appalachians allows, by extrapolation, that the Northern Blue Ridge was likely dominated by cold, windy, periglacial Pleistocene paleoclimates. Pollen spectra from numerous sites in Pennsylvania, Maryland, Virginia, and West Virginia indicate that tundra was widespread in the higher portions of the Appalachians.

Vertebrates, ranging in size from diminutive rodents to giant mammoths, have been identified at numerous sites in the Central Appalachians (Guilday et al., 1964; Guilday et al., 1977; King and Graham, 1986). A few of these animals, now associated with a distinctly boreal habitat, offer especially valuable evidence for tundra biomes in the Northern Blue Ridge area during the Quaternary.

During the Wisconsinan Glacial Maximum, climatic, vegetational, and faunal patterns were quite different from that of the Recent in the Central Appalachians. Ocean surface temperatures were significantly reduced at about 18,000 B.P. and the climate on land was likely to have been most severe for the Wisconsinan at that time (Climap, 1976). Sea level was lower than at present, which, I speculate, resulted in increased continentality in the Northern Blue Ridge. The margin of the ice was close to the study area during that interval (about 120km NNE). Although oscillations of the ice front during the period 23,000 - 15,000 B.P. occurred, the massive ice sheet to the north of the study area, despite minor shifts in location, continued to modify climate in the Northern Blue Ridge.

Most of the paleobiological evidence for periglacial conditions in the study area date from the Late Wisconsinan and early post-glacial. It is highly likely that pre-Wisconsinan glacial events also displaced biotic and morphologic regimes. However, fossil evidence of pre-Wisconsinan tundra conditions in the Appalachian region is scarce. Sorted stone circle and stripe development and ice-wedge cast formation in the Appalachians have proven difficult to date; the age of these features is unclear. The Illinoian drift border is within about 70km of portions of the study area and pre-Illinoian deposits are but 50km from the terminus of the Northern Blue Ridge. Pre-Wisconsinan glacials are known to have been of longer duration (Richmond and Fullerton, 1986, p.6) and greater severity. It is likely that sea level was farther depressed during those intervals resulting in a stronger degree of continentality and even colder conditions in the study area. It is fair to suggest that the block deposits and diamictons under consideration in this thesis may have developed during pre-Wisconsinan glacial episodes and were reactivated during Wisconsinan time.

CHAPTER III

METHODS

The nature of the landforms and deposits in the study area has necessitated that this research be confined to the upper layers of the mantles, block streams, and diamictons. Excavation is nearly impossible in most areas without power equipment; therefore, quantifiable data stem mostly from layers at the surface. A variety of techniques was used to document the character of surficial deposits in the study area. The following section describes the approaches used in the collection, analysis, and presentation of morphometric data in this work. Figure 9 shows the location of the data collection sites.

Data Collection Methods and Procedures

The morphometric techniques used in this research to document the nature of the block accumulations follow well-established standard procedures (Caine, 1968; Embelton and King, 1975; Washburn, 1980; Goudie, 1981; Mills, 1981). At the three principal block stream sites, the size, orientation, dip of the long-axis, and angularity of the blocks were measured along systematic, linear traverses. Blocks were sampled at approximately 3m intervals along two transects parallel to the long axis of the feature. Additional perpendicular traverses, approximately 50m apart, were utilized to increase areal coverage. At each sampling

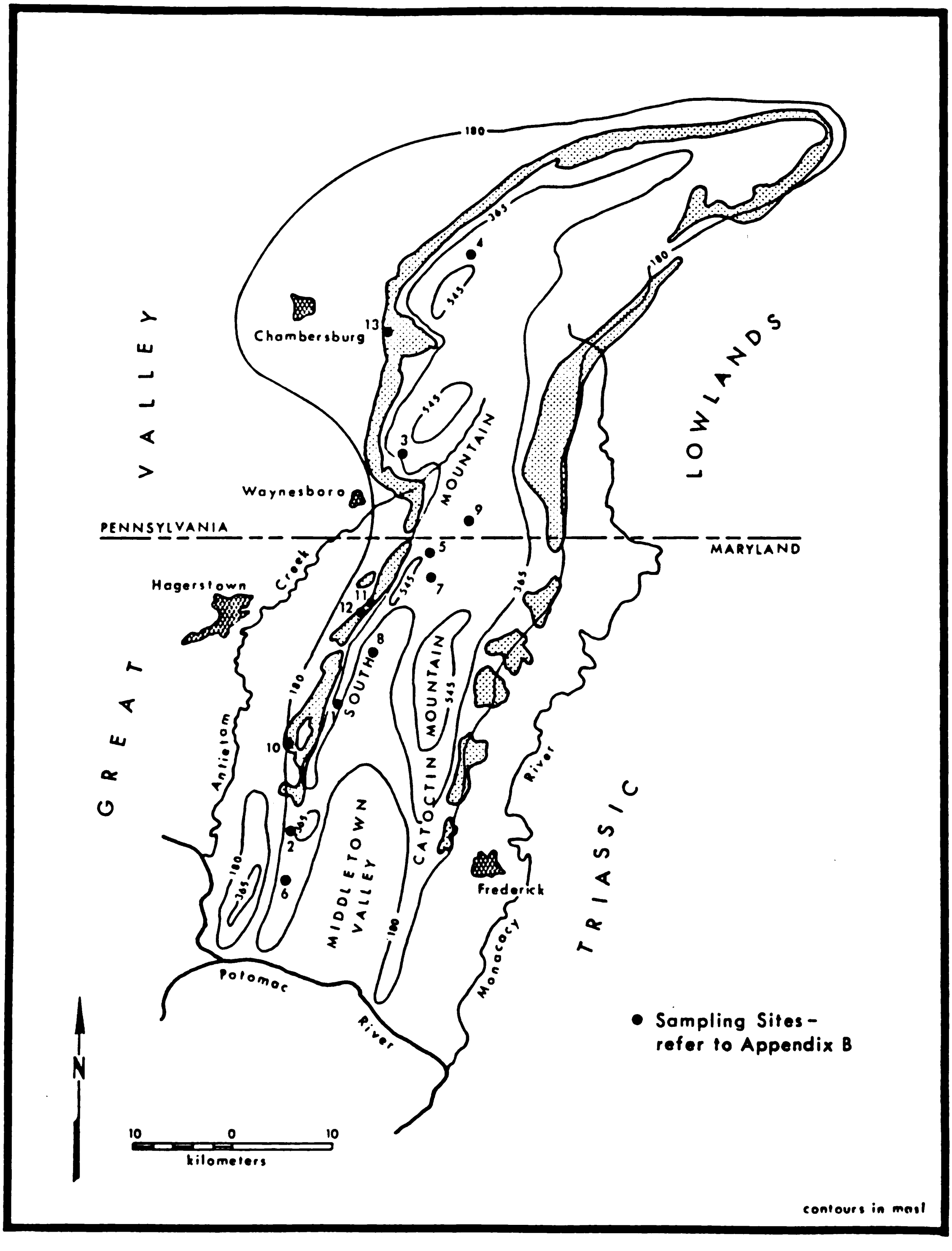

Figure 9. Location of Data Collection Sites.

point along these traverses, the length of the three principal axes of the block was measured with a steel tape; the azimuth of the long ("A") axis was determined with a magnetic compass; and the inclination of the "A" axis was measured with a clinometer. Additionally, the angularity or shape of the block was visually evaluated by comparison to a simplified version of Lee's chart (1964, p. 21). The slope angle of the block stream was measured along the traverse with a clinometer.

At the block mantle sites, traverses perpendicular to the slope were spaced approximately equidistantly along the cross-slope extent of the open block areas. At 10m intervals, the three principal axes of the block were measured with a steel tape, the angularity was visually evaluated by comparison to Lee's chart (1964, p. 21), slope angle was determined with a clinometer, and the orientation determined with a compass.

Excavations to determine the internal structure of the block streams and the variation of block size with depth were limited due to the difficulty of such procedures. But, at the Devil`s Race Course block stream, several pits were excavated and the block stream structure observed. Excavation was laborious, but two of the pits were dug to near the water table level, 1.0 - 1.5m below the block stream surface. At the Wolfe Road site, blocks had been removed by the landowner with power equipment. This 1.5m, near-vertical exposure allowed an excellent view of the internal structure of the block stream. At both sites, the three primary axes of block samples were measured with a steel tape to the nearest centimeter. These samples were drawn from the surface layer and at approximately 30cm intervals to the base of the excavations. No excavations were attempted at block mantle sites.

Black and white panchromatic aerial photographs were employed in the analysis of block stream characteristics in the study area. The 1:20000 scale airphotos available from the Agricultural Stabilization and Conservation Service did not prove useful because of the small size of the block streams and mantles. The open block area of the largest block stream, Devil's Race Course, measures only 60mm x 3mm at 1:20,000; the smaller features are barely recognizable at this scale. The Devil's Race Course block stream was photographed from the air with a hand-held 35mm camera using black and white panchromatic film. The resulting photographs at a scale of 1:2400 are near vertical and were used to provide additional block orientation data.

A transparent grid was placed over each 35mm image and the orientation for one block per grid cell was recorded. Only the largest blocks, (long axis $\geq$ 1.0m) with a 3:2 length-width ratio were measured because of the difficulty associated with measurements of smaller block particles on these photographs.

Weathering rinds are well-developed on the quartzite boulders and cobbles of the Northern Blue Ridge. Five sites, randomly selected, were sampled to establish the character of weathering rind development. Samples were taken from the Devils' Race Course block stream and from four diamicton sites along the flank of South Mountain. Samples were randomly selected at each location.

Samples were taken from at or near the surface. Blocks were split with a maul and their rind thickness measured with a steel rule to the nearest .5mm at three points on each sample.

No attempt has been made in this research to establish an age for each deposit in the Northern Blue Ridge study area; instead, rind thickness was examined to determine if the deposit types are of similar age by comparing rind development. If the deposits are of similar age they may also have a genetic relationship.

Approximately 50 randomly selected blocks at the Wolfe Road, Devil's Race Course, and Black Rock sites were visually assessed to determine whether they exhibited differences in weathering pit development between upper and lower block surfaces. At each site, the extremes of pit diameters and depths were measured to the nearest .5mm with a steel rule.

Dendrogeochronological techniques similar to those used by Hupp (1983) were employed in this study to determine whether block movement could be detected on the slope traverses. Trees were randomly selected and examined for evidence of tilting and scarring. Additionally, the largest lichens growing on block surfaces were selected and measured with a steel rule in an effort to determine a minimum period of stability. Organic mats that have developed on top and between blocks were stripped away and their thickness measured to the nearest .5cm with a steel tape. Measurements were taken at randomly selected points on the Devil's Race Course, Staley Road, and Wolfe Road block streams, and on the Black Rock block mantle site.

Data Analysis, Methods and Procedures

The textural analysis of block streams in this study includes an examination of: 1) block size (long, intermediate, and short axes), 2) orientation of the long axis, 3) dip of the long axis, and 4) angularity of the blocks. Analysis of the block mantles includes only the size, form, orientation and angularity properties.

Two dimensional orientation data have several problems associated with their use and interpretation. A technique employed by Norcliffe and Heidenreich (1974) on Iroquois longhouses in Ontario was adapted for use in this study along with procedures outlined in Till (1974).

The preferred direction (θ), which can be thought of as the mean compass orientation as represented by the azimuth of the mean vector, was calculated for both the field data and the aerial photo data. Then the magnitude of the mean vector was determined for the data sets as a further measure of vector strength (r). Finally, a statistic equivalent to the familiar standard deviation was calculated (s). Block orientations were plotted onto rose diagrams grouped into 30° classes over a range of 180°; because a block orientation has neither a "source" nor a "sink," its orientation angle is unique only over 180° (Norcliffe and Heidenreich, 1974).

Block dip was also plotted onto diagrams that show both the direction and steepness of dip. All three block streams were then compared with respect to dip characteristics.

The major mass-wastage landforms and deposits were classified according to their presence on either the dip slope or the scarp slope of the gently dipping limbs in the South Mountain Anticlinorium. The location of landforms and deposits was plotted onto 1:24,000 United States Geologic Survey topographic quadrangles at selected sites where a continuum of landforms was present. No attempt was made to map all such forms in the Northern Blue Ridge.

Soil samples weighing about 500g were collected from all deposit types including diamicton, block streams, terraces, and block mantle. The texture of each sample was determined using standard sieve and hydrometer techniques.

All statistical procedures used in this study are standard methods of data analysis in the earth sciences (Till, 1974). Data were manipulated using programs from the Statistical Package for the Social Sciences (Nie, et al., 1975).

CHAPTER IV

DESCRIPTION OF THE RELICT MORPHOSEQUENCES

This chapter describes in detail the mass wastage landform assemblage (morphosequence) in the study area. Detailed documentation of the individual sites is important: 1) to allow comparisons with similar features found elsewhere, and 2) because the landforms are suffering from attrition. One block stream was completely removed to provide road bed aggregate (see Thornbury, 1966, p.414) and another is currently being sold by the truckload for landscape stones.

The asymmetrical anticlinal structure of the Northern Blue Ridge (Figure 2) generally results in gently dipping quartzite, metasandstone, and metabasalt limbs that typically produce a distinctive landform continuum. Rather than being randomly distributed throughout the study area, the mass-wastage landforms and deposits adhere to definite patterns, some unique to, or more fully developed on, the scarp slopes, and others best expressed on the dip slopes. Scarp-slope sequences include (from crest to flank) bedrock-defended terraces, summit tors, numerous, well-developed scarps, block mantle, tongues and cascades, aprons, and diamicton (Figure 10). Dip-slope sequences grade downslope from small scarps to block mantle, aprons, tongues and cascades, and block streams in valley bottoms

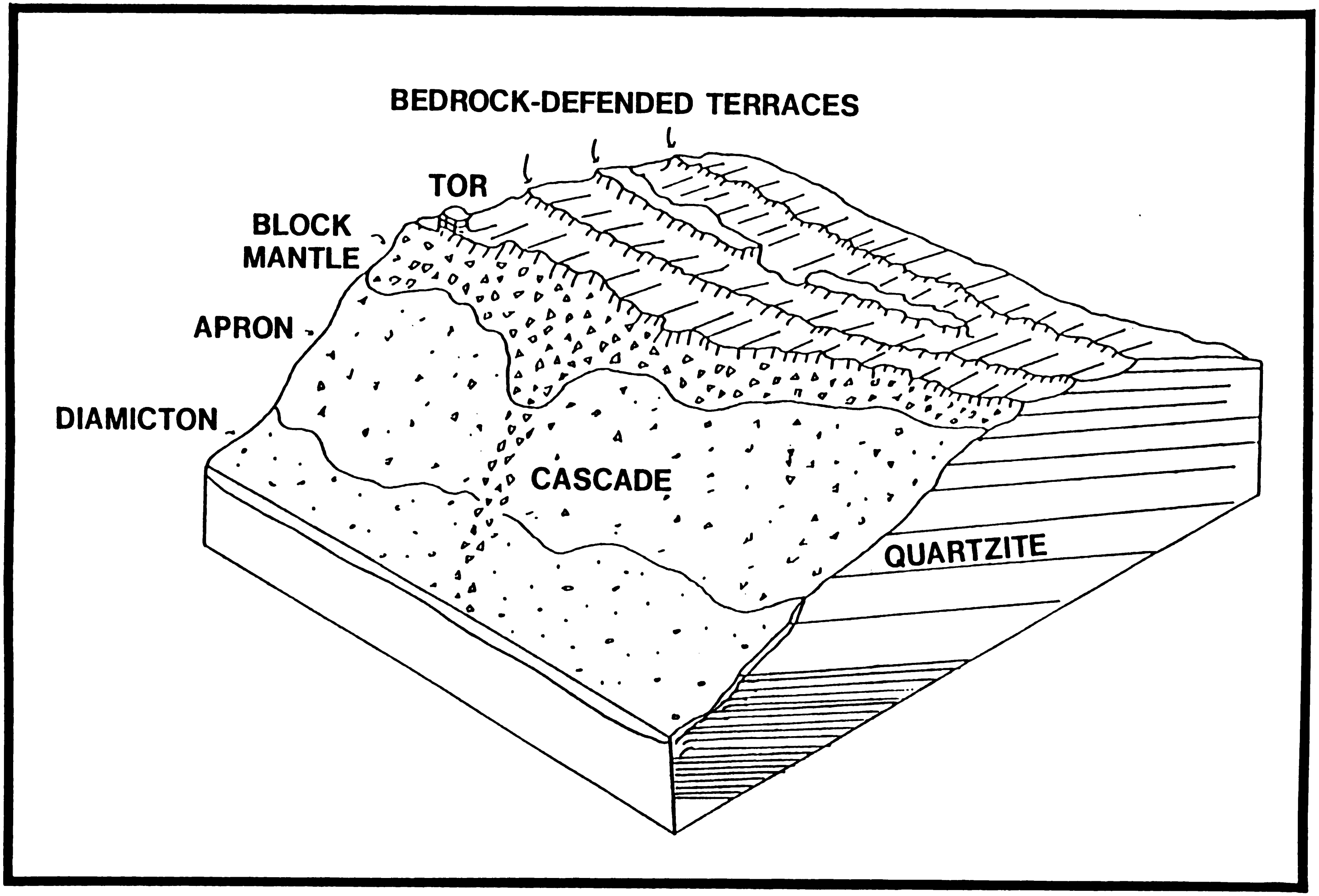

Figure 10. Scarp Slope Morphosequence.

(Figure 11). Well-developed scarps and diamicton are absent on the dip slopes whereas block streams are never associated with scarp slopes.

Structure and lithology control the areal distribution of these deposits and landforms. Boulder deposits, including mantle, aprons, tongues, and cascades, are found wherever the Weverton, Loudon, or Catoctin formations crop out. Block mantle is best developed on the scarp slope where the resistant ridge-maker rock units serve as a line source of boulders that accumulate downslope from steep faces. Block streams develop only on the dip slopes where the ridge-maker units crop out over large areas (Figure 11). The following sections discuss the site characteristics and morphology of typical dip-slope and scarp-slope sequences in the study area.

Deposits Typical of Dip Slopes

Block Streams

All three examples of block streams in the study area lie at the base of the dip slope of ridges composed primarily of heavily jointed Weverton Quartzite. All the block streams examined in this study are extensive bare areas composed primarily of Weverton Quartzite blocks with surface slope ranging from 3 - 6° (Plate 1). No interstitial fines are present at the surface, but silt, sand, and gravel may fill interstices in the sub-surface. Block size was found to be highly variable, ranging from < 0.5 - 6.0m in length. Block shape is generally angular, but individual

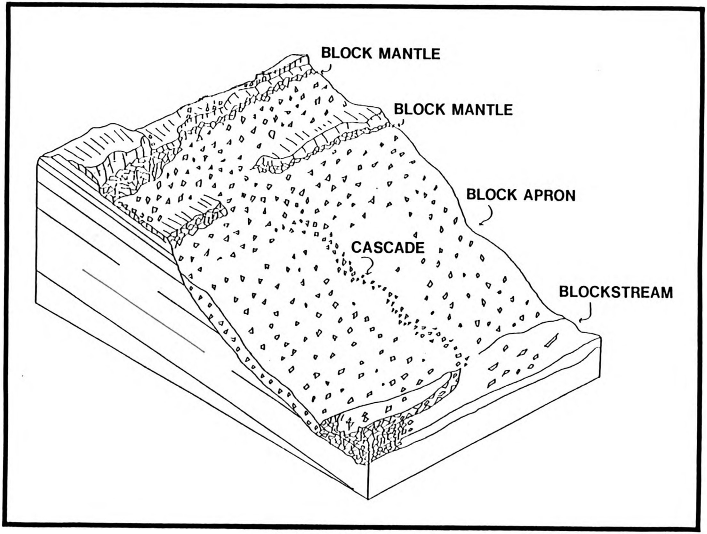

Figure 11. Dip Slope Morphosequence.

Plate 1. Stereo triplet of Devil's Race Course block stream. View is toward vegetated block apron in the background.

blocks exhibit rounded corners and edges (Plate 2). Many boulders exhibit pitting on the exposed upper surfaces to a depth up to 2cm. Block streams exhibit a microtopography generally $\leq$ 1.5m characterized by furrows running nearly parallel to the long-axis orientation of the open block area. Except for irregularly distributed clumps of trees and shrubs growing on organic soil accumulations, and lichens growing on the exposed block surfaces, vegetation is absent on the block streams. Additional characteristics of block streams are summarized in Table 4.

Block Stream Stratigraphy

At the Wolfe Road site the landowner has allowed a portion of the deposit to be excavated as a source of landscape stones (Plate 3). This block stream is 1.5m thick near the toe and rests on weathered quartzite particles set in a matrix of coarse sands.

The cut shows that the block stream stratigraphy and block size varies with depth (Figure 12). An O_1 horizon, from 2 - 4mm thick, covers the surface in some places and is composed primarily of oak leaf-litter. This layer is patchy, however, and is much thicker and more extensive within the vegetated portions of the block deposit. Below the O_1 layer, the organic soil varies in thickness from 2cm to 15cm and is common in the vegetated portion and less common in the open block area. Tree roots extend from this layer down through the open block matrix to about 1.25m below the surface. No fine material is present in most

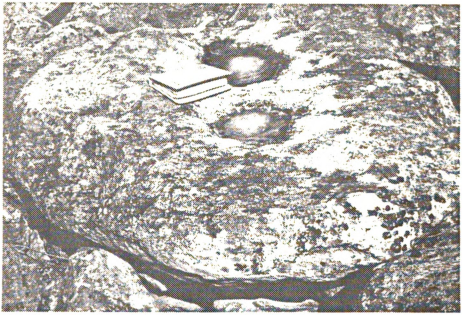

Plate 2. Large, subrounded block with weathering pits at Devil's Race Course block stream. Notebook is 19cm long.

Table 4

<u>Characteristics of Block Stream Sites</u>

Site	Surface Slope	Length (m)	Width (m)	Composition	Orientation	Elevation (m)	Matrix
Devil's Race Course	3-4°	1000	25-100	Weverton Quartzite	N 45°E. to N 20°E.	550	rare near surface
Staley Road	3°	400	25-50	Weverton	S 60°E.	520	uncommon at surface
Wolfe Road	4-6°	200	25-50	Weverton	S 60°E	400	uncommon at surface present at 1.25m

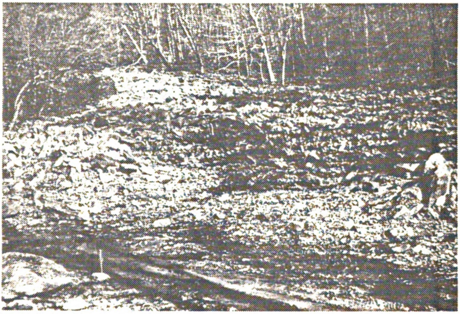

Plate 3. Cross-sectional view across nose of Wolfe Road block stream. Large block in lower left is about 1.5m long.

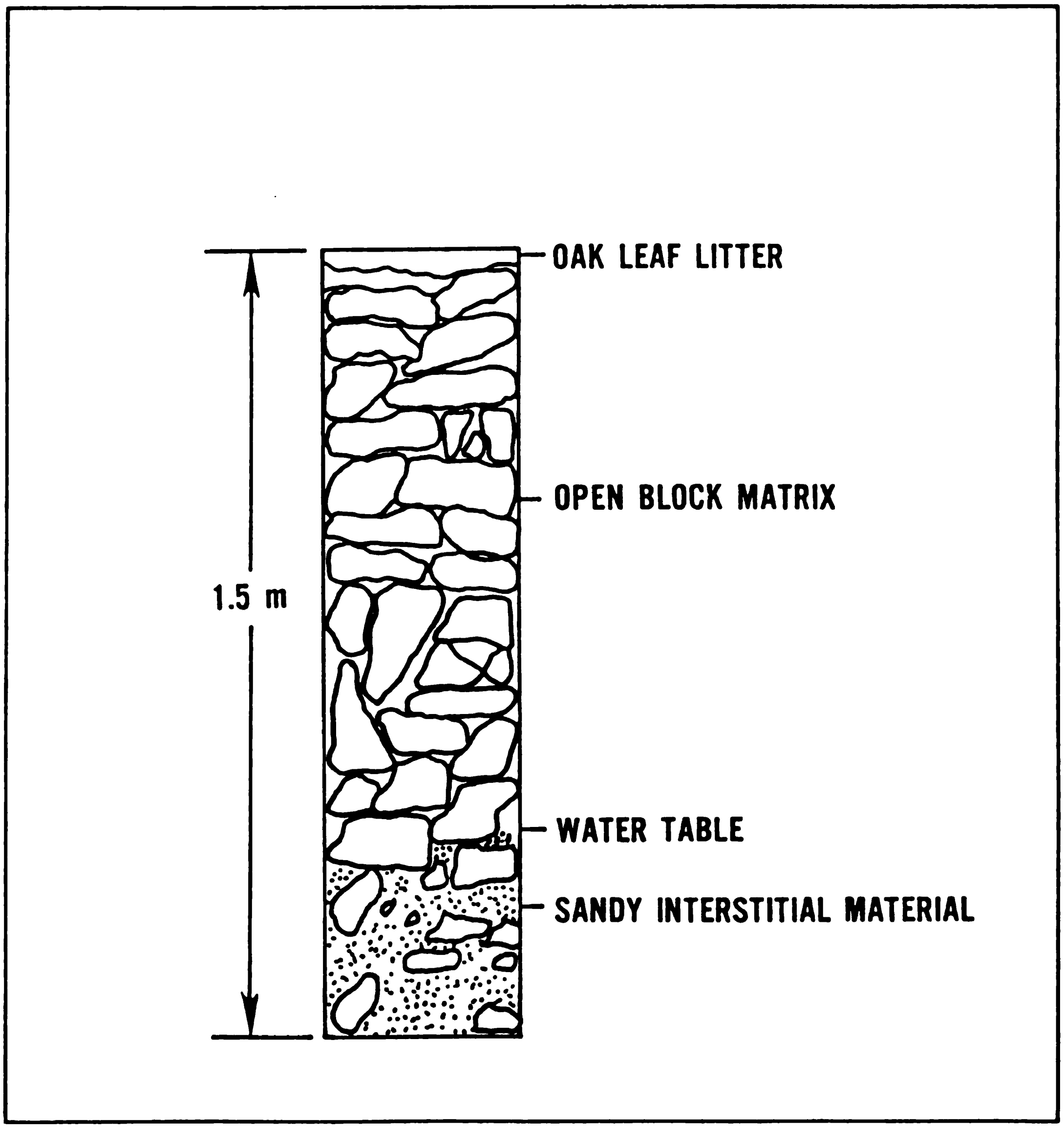

Figure 12. Structure of Wolfe Road Block Stream.

places near the surface but, in areas with concentrations of smaller blocks, coarse sand may fill some of the voids. At depths ranging from about 1.0 - 1.5m, a matrix fills the interstices between the blocks. Numerous pebble- to cobble-sized clasts of quartzite are distributed throughout the sandy loam to sandy-clay loam matrix. The water table is normally present at a depth of about 1.5m.

Data collected within excavations at both the Devil's Race Course and Wolfe Road sites show that block size varies with depth. Table 5 shows that mean surface block size (for the principal axes) is greater than block size at depth (1m). Student's T-Test confirms this observation and Pearson's r reveals a negative relationship existing between the length of the three principal axes and distance from the surface. These data suggest that some crude sorting exists within block streams in the study area.

Table 5

Variation of Principal Axes With Depth, Wolfe Road and Devil's Race Course Sites

	Wolfe Road Site	Devil's Race Course Pit #1	Devil's Race Course Pit #2
Length (cm)			
Surface	43.9	34.1	34.7
1 Meter	32.3	16.2	21.5
Width (cm)			
Surface	17.9	22.6	23.4
1 Meter	16.2	11.9	16.0
Height (cm)			
Surface	12.5	12.5	14.1
1 Meter	10.4	7.9	9.6

Block Stream Microtopography and Texture

Block streams in the study area exhibit a distinctive surface microtopography and texture. The microtopographic and surface textural variables which were examined in this study include elongated furrows, block dip, block orientation, and block size. The following sections consider each of these variables in detail.

Furrows

Linear furrows are distinct microtopographic features on the largest block stream in the study area, the Devil's Race Course site. The other block streams exhibit only limited furrow development. The furrows on the Devil's Race Course block stream are oriented sub-parallel to the long axis of the open block area and overall slope of the feature (Plate 4). Although discontinuous, the furrows may extend uninterrupted for 50 - 100m and are up to 1.5m deep and 2 - 3m wide.

On the Devil's Race Course block stream, the principal furrow has several branches entering it, giving it a dendritic pattern. Closer examination reveals running water approximately 0.5m below the bottom of the furrow. Stream flow is much more pronounced in spring than in late summer and autumn (the sites have been examined several times during the years 1976-1987 in the period March - December). Steeply dipping blocks are common along the length of the furrows, whereas outside of them block dip is much lower (Plate 5).

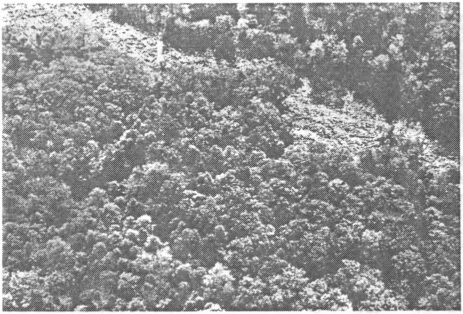

Plate 4. Devil's Race Course aerial view with forested block apron toward bottom of image. Furrows are visible in the larger section of the open block area.

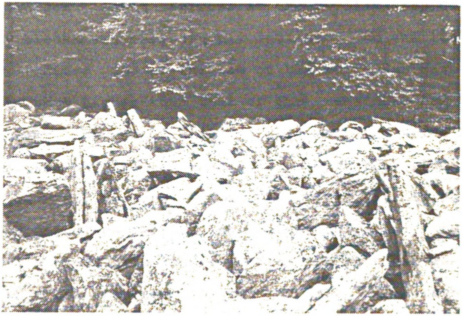

Plate 5. Steeply dipping blocks on a portion of Devil's Race Course block stream.

Block Dip

All three block streams exhibit generally low overall mean block dip angles (Appendix 1). Table 6 shows that the majority of blocks are inclined at an angle $\leq$ 15°, and that 85% of them are imbricated at $\leq$ 30°. But when certain segments of the block streams are isolated, a different pattern emerges. Along furrows at the Devil's Race Course site, many blocks are very steeply inclined. At the toe of the same feature and at the toe of the Wolfe Run site the mean dip is much higher than that of the remainder of the block streams. Figure 13 utilizes data from the Wolfe Road site and shows the steep dips associated with the downslope terminus of the feature. Absolute block dip disregards upslope and downslope imbrication and considers only the dip angle. It is clear from Figure 13 that the mean dip is much higher within the area near the toe of the block stream. Here, the majority of the blocks (66%) are inclined at $\geq$ 45°.

Table 6

Block Dip on Block Streams

(Percent of Blocks Within Groups)

Dip	Staley Road	Devil's Race Course	Wolfe Road
0-15°	70%	57%	71%
0-30°	91%	85%	88%

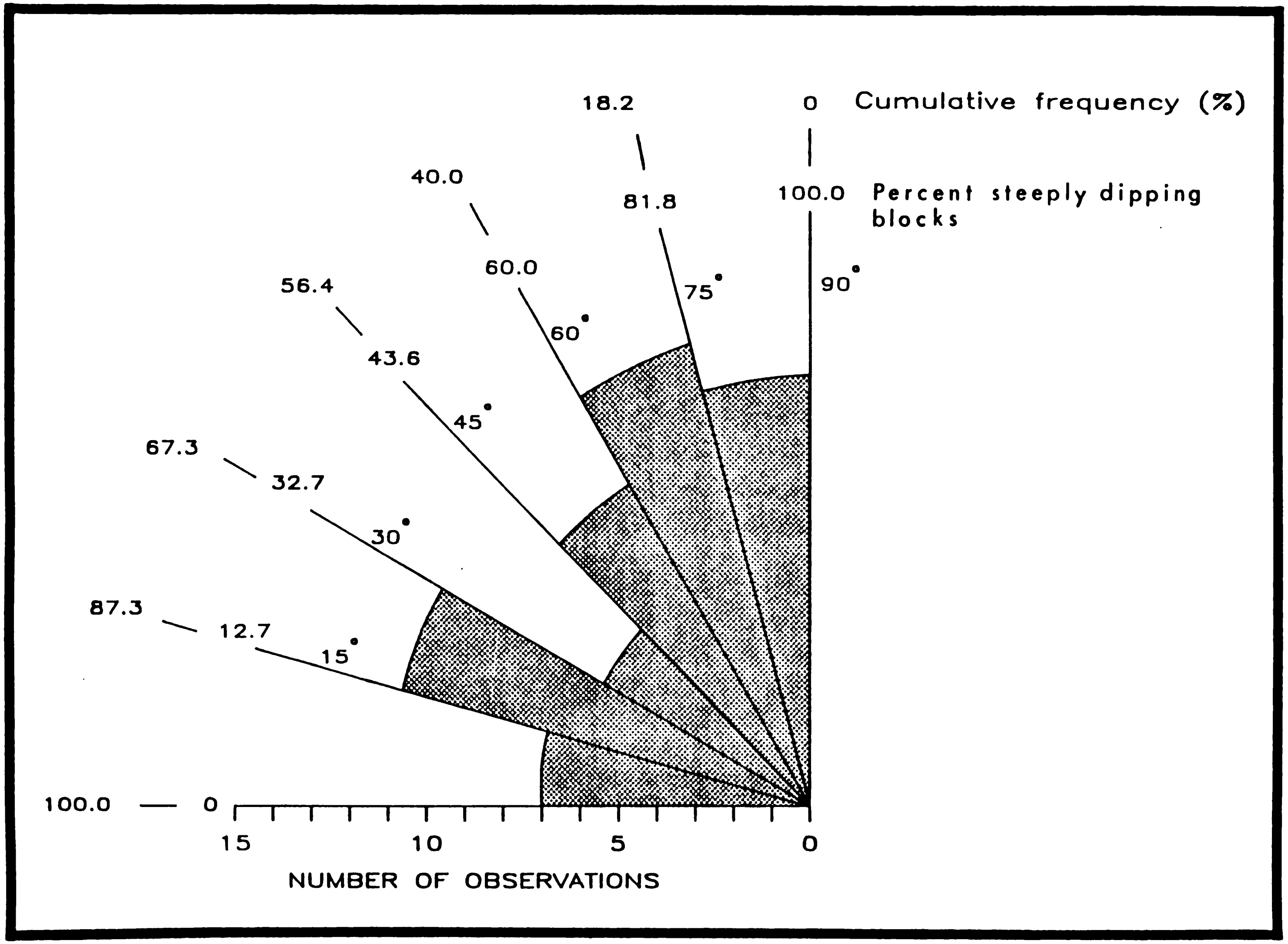

Figure 13. Absolute Block Dip at Wolfe Road Site Near Downslope Terminus.

Block Orientation

Table 7 shows the results of the statistical analysis of the two-dimensional block orientations on block streams. A comparison of the preferred orientation of blocks (Θ) and the slope orientation for both Devil's Race Course data sets (field collected and aerial photography) reveals a very close correspondence. The Staley Road site also exhibits a strong correspondence. The Wolfe Road site, in contrast, does not show a similar relationship. The preferred orientation at this site is nearly at right angles to the slope orientation. Even though the preferred orientation and the slope orientation exhibit close correspondence at two of three sites, the strength of this measure (r) is low and the mean angular deviation is high. Appendix 1 shows diagramatically the block orientation for the block streams examined.

Block Size

Table 8 shows the results of the block size analysis using student's T-test on surface materials within the three sites sampled. Significant size variation within and between block streams is evident. No significant difference exists between the Wolfe Road site and Devil's Race Course, but at the Staley Road site, block components are much smaller than at either of the others.

Table 7

Block Orientation on Block Streams

Site	N	r	s	θ	Slope Orientation
Devil's Race Course (field data)	181	.14	75°	41°	45°
Devil's Race Course (airphoto interpretation)	455	.67	47°	33°	45°
Wolfe Road (field data)	114	.20	73°	32°	300°
Staley Road (field data)	60	.24	71°	293°	292°

N= sample size
r= mean vector magnitude
s= mean angular deviation (similar to standard deviation)
θ= preferred orientation of a-axes
Slope Orientation= the orientation of the block stream

Table 8

Block Size Characteristics on Block Streams (in cm)

Site	Mean Length A-Axis	Range A-Axis	Mean Width B-Axis	Range B-Axis	Mean Height C-Axis	Range C-Axis
Devil's Race Course	83.5	21.3-399.3	46.0	12.2-274.3	20.7	6.1-125.0
Wolfe Road	73.8	21.3-182.9	39.0	9.1-121.9	15.5	6.1- 36.0
Staley Road	41.5	15.2- 91.4	21.6	6.0- 61.0	11.9	3.0- 30.5

Landforms and Deposits Typical of the Scarp Slope Sequence

The scarp slope sequences in the study area include bedrock scarps, bedrock defended terraces, tors, mantle, aprons, cascades and tongues, and diamicton. The following sections discuss the landform assemblage typical of the scarp slopes in the Northern Blue Ridge. Deposits and landforms common to both dip and scarp slopes will be treated in a later section.

Bedrock Scarps

Scarps vary from about 2m to about 30m in height and extend along the west-facing ridges from 100m to several kilometers. Back from the edge of the larger scarps, a plateau-like area of low relief with an increasing thickness of sandy, organic-rich soil extends several hundred meters normal to the scarp line.

Scarp faces exhibit chemical weathering effects. Smoothed and rounded corners and edges and weathering pits up to 10cm in diameter and 2-3cm deep are common on the flat-lying, exposed blocks in the scarp faces. Plates 6 and 8, photographed in 1986, and Plates 7 and 9, photographed before 1907, are of the same outcrops at High Rock and Black Rock (Feldstein, 1984). Little difference can be detected in the joint widths, rounding and smoothness of edges, and overall form. Although the photographs record only a span of about 80 years, the lack of apparent change may be important. It appears that loss of material from scarps is not rapid.

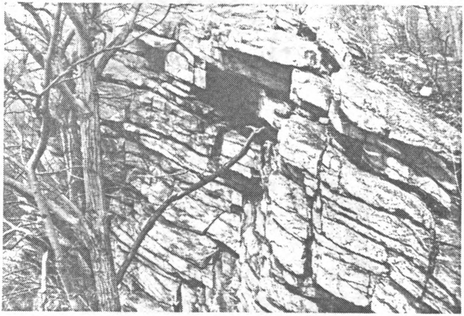

Plate 6. Scarp at summit of High Rock (faces west) composed of heavily jointed Weverton Quartzite.

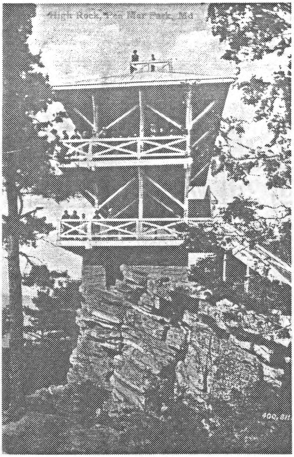

Plate 7. Scarp at summit of High Rock photographed in 1907 from a slightly different aspect as that of Plate 6 (photographed in 1986). Joint patterns show some evidence of chemical weathering over 79 years, but no loss of material is evident.

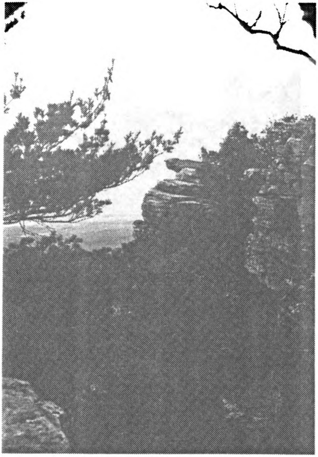

Plate 8. Summit scarp at Black Rock photographed in 1986.
View is toward the north.

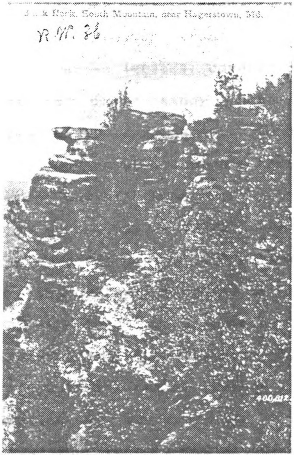

Plate 9. Summit at Black Rock photographed around 1900. Weathering effects exhibit little change over approximately 80 years.

Bedrock Defended Terraces

Stepped terraces, cut into the gently dipping quartzite bedrock, occur along the ridge crests in numerous sections of the study area (Figure 10). Rock outcrops (risers) mantled with blocks ranging from .3 - 1.0m (A-axis direction) bound flat areas (treads) covered with cobble- to boulder-size debris set in a sandy, organic rich, soil matrix. The tread-riser arrangement is repeated up the slope in many areas such as at Crampton's Gap, the Annapolis Rock-Black Rock area, and High Rock.

At Crampton's Gap, the massive, heavily jointed Weverton Quartzite dips gently (30°) eastward and is comparatively thin in outcrop. Terraces are well developed at this site. A west-facing scarp, ranging from 3 - 10m in height, can be traced discontinuously from the gap to the Potomac River, 10km to the south. Coarse lichen-encrusted block material mantles and obscures the scarp. No soil matrix is evident at the crest of the mantle but humus fills many voids near the base of the 12 - 20° slope. At this location the tread of the terrace is approximately 75m wide, though this distance varies considerably along the length of the feature. Downslope from the principal terrace, a more poorly-developed riser and tread continues intermittently for several kilometers along the west-facing ridge.

Outliers of Weverton Quartzite are located on the tread between the scarp of one terrace and the scarp of the next terrace downslope at several locations such as at the summit of South Mountain, and many of the ridges in the northern portion of the study area. These forms attain heights of 3m to 10m and may extend 100m in a long axis direction. The orientation of the outliers is closely aligned with the strike of the ridge.

Tors

These tapering, broadbased, heavily jointed bedrock masses rise 5m or more above the block mantle near the crests of the scarp slope. There are several tors in the Black Rock-Annapolis Rock and High Rock areas, but they are less common elsewhere. Tors are best developed in the Weverton Quartzite and their size is apparently related to the thickness of the outcrop. Quartzite blocks surround the base of all tors examined; the blocks display typical evidence of weathering.

Diamicton

Block aprons along the Northern Blue Ridge flanks often grade downslope into extensive deposits of varying character composed of quartzite, sandstone, phyllite, and metabasalt pebbles, cobbles, and boulders set in a fine-grained matrix. Several characteristics are shared by these sediments. The deposits abruptly cease in the southern sections of the study area where summit elevations in the Blue Ridge upland are less than about 380 - 400m and where the Weverton Formation thins in outcrop. The most extensive examples are associated with the largest modern stream networks. Isolated patches up to 1km from the principal distribution interrupt the continuity of these deposits. Streams flowing out of the Blue Ridge cross-cut the features and have etched out valleys up to 20m deep.

The deposits on either side of the Northern Blue Ridge differ in several respects. The Frederick Valley deposits span the 125 - 150m contours, whereas those of the Great Valley are higher at elevations between 150 - 275m. The form of the diamictons in the Frederick Valley is less linear and less continuous when compared to that of the Great Valley. In contrast, no diamictons have been mapped in the Middletown Valley and little is shown on maps within the intermountain valleys of the Pennsylvania portion of the Northern Blue Ridge.

I was able to identify three different types of sediments that compose these diamictons which previous researchers had classified into a single mapping unit. The following sections describe typical exposures of the three sediment types identified including: 1)recent alluvium, 2)weathered alluvium, and 3)angular materials in a fine-grained matrix.

Recent Alluvium

The largest exposure of recent alluvium is located on Pennsylvania Route 997, 1.4km west of Fayetteville, Franklin County, Pennsylvania, (Scotland, Pennsylvania, 1:24,000 quadrangle). The Mt. Cydonia Sand Company has been exploiting this site for many years as a source of sand and gravel. The Conococheague Creek, whose source is several kilometers to the east in the Blue Ridge upland, flows through this extensive deposit of unknown thickness.

The primary constituents range from sandy clay to boulder-sized materials derived locally from the Antietam, Harpers, Catoctin, and Montalto formations. Sorting, rounding of clasts, a wide range of particle size, iron-cemented layers, and iron and manganese oxide stains (rock varnish) on coarse particles are particularly evident (Plate 10). Examination of the bed of Conococheague Creek reveals a similar lithologic distribution of coarse particles.

Weathered Alluvium

Associated with the recent alluvium are discontinuous deposits, along the flanks of the Blue Ridge, of roundstones in a bright yellow to orange silty-clay matrix. This material shares some characteristics of the modern alluvium but displays several qualities which allow its differentiation, including: 1) lack of sorting, 2) lack of metavolcanics, and 3) greater proportion of fines compared to coarse particles.

A near-vertical exposure north of the Mt. Cydonia Sand Plant #2, along Pennsylvania Route 997, is typical of these deposits (Plate 11). The pebble and cobble-sized fractions of this unsorted deposit are rounded, much like those of the recent alluvium but the proportion of coarse particles is much lower. Coarse fragments were split and found to be sandstone or quartzite with weathering rinds that varied in

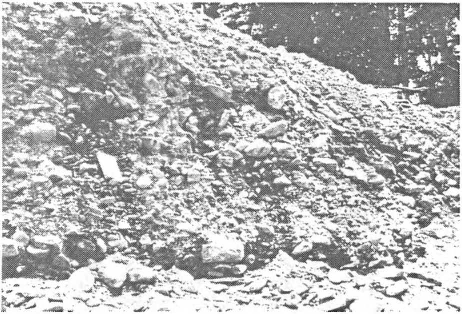

Plate 10. Recent alluvium at Mt. Cydonia Sand Quarry on Pennsylvania Route 997 near Fayetteville, PA.

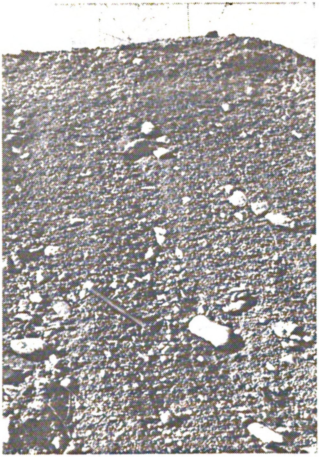

Plate 11. Weathered alluvium about 2.4km NW of Fayetteville, PA.

thickness from 2 - 10mm; no volcanics of the Catoctin Formation were observed.

Angular Materials in Fine-Grained Matrix

An excellent example of angular regolith set in a matrix of fines was exposed in a trench during the construction of a gas transmission pipeline through a portion of the Blue Ridge near Smithburg, MD. Although the phyllitic member of the Harpers Formation dips eastward at about 30° here, the weathered upper layers exposed in the trench are deformed in a westerly, downslope direction (Plate 12). The deformation is abrupt and confined to the area within about 1m of the surface and does not appear to be the result of local folding. The layer above the phyllite varies in thickness from .7 - 1.5m and is composed of angular to subangular quartzite and phyllite pebbles and cobbles in a silty matrix. The boundary between the deformed phyllite and the overburden is distinct, but some mixing of the two is evident. Plate 13 shows a quartzite boulder (.5m in long axis dimension) surrounded by platy phyllitic cobbles in a matrix of fines. The elongated quartzite boulder appears to have set up a disturbance in a flow regime. The plates of phyllite are clearly oriented with their long axes aligned with the slope.

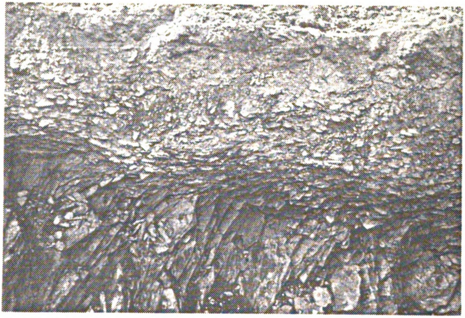

Plate 12. Deformed, overridden Harper's Phyllite exposed in a gas pipeline cut near Smithsburg, Maryland. Downslope is toward the right.

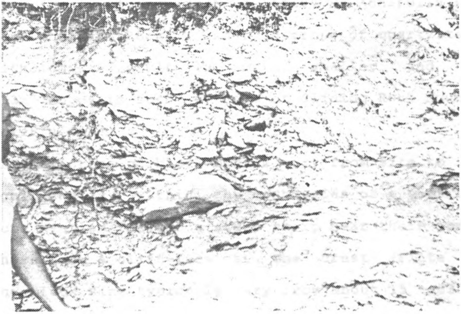

Plate 13. Quartzite boulder set in a matrix of fines with accompanying pebbles and cobbles. Exposure is a gas pipeline excavation. Downslope is to the left.

Block Deposits Common to Both Dip and Scarp Slopes

Steep Block Mantle

Block accumulations are normally found downslope from thick outcrops of Weverton Quartzite and produce extensive slope deposits (up to 1 - 2km in length and 100 - 350m in downslope direction). Mantles are typically composed of relatively large blocks such as those at Annapolis Rock, Black Rock, and High Rock. Thinner outcrops of quartzite and other lithologies result in much smaller and less spectacular deposits such as those at Sliding Rock Mountain and Bisecker's Gap.

Characteristics of block mantle vary from site to site and, significantly, within the boundaries of a particular site. Some mantles include a steep scarp near their summits while others lack a cliff-face at the crest (Plate 14). Slope and block size typically vary from about 15 - 33° and from 30cm (in long axis diameter) to 6m, respectively. Block shape is angular to sub-angular. Some block-mantled slopes are completely devoid of vegetation (except for lichens). Downslope from the open block area, at lower slope angles, deciduous forest grows on an organic soil mat developed over the block surface. Further downslope, a mineral soil has developed between the blocks (block apron). There are no exposures that show mantle in contact with bedrock in the study area. However, rock outcrops alongside and within some of the sites and evidence from other sites in the Central Appalachians indicate a shallow thickness of

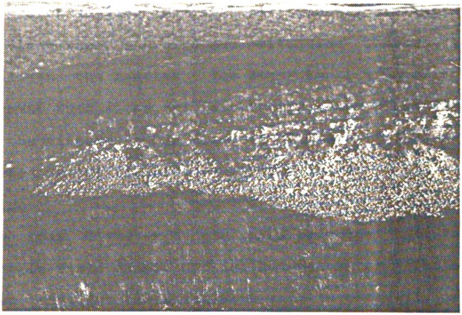

Plate 14. Aerial view of a portion of the Black Rock - Annapolis Rock complex. Stepped summit scarps and block mantle are clearly visible while block apron is obscured by forest vegetation in the foreground. This view is east toward the Middletown Valley.

approximately 5m.

Block mantle sites share certain characteristics but differ in other respects. Table 9 summarizes the important characteristics of the block mantles examined in this study. Elevation, slope angles, aspect (except the southeast facing slope at Bisecker's Gap), lack of vegetation, block form, and absence of surface interstitial fines are similar at all sites. Block size, and site and situation characteristics vary between the mantles. The Black Rock, Annapolis Rock, and Monument Knob sites are west-facing scarp slope deposits whereas the Bisecker's Gap site is located in a narrow, steep-sided valley oriented at about N 45° E.

Block Size

The mean diameter of the three principal axes for the block mantle field samples varies between sites (Table 9). The mean size for the Black Rock site is generally greater than any of the other sites sampled. Block size exhibits change over distance at all four sites. At Sliding Rock Mountain and within 100m of the scarp at Black Rock, block size increases slightly with increasing distance from the boulder source ($r = .46$ and $r = .26$, respectively). Both of these sites are characterized by a scarp face at their summit. At Washington Monument, Bisecker's Gap, and the lower slope segment of Black Rock, block size decreases slightly with increasing distance from the crest ($r = -.24$, $-.29$, and $-.26$, respectively).

Table 9

Characteristics of Block Mantle Sites

Site Name and Location	Elevation at Summit (m)	Slope Angle	Cross-Slope Extent (m)	Down-Slope Extent (m)	Aspect	Block Size (cm) A-Axis	Block Size (cm) B-Axis	Block Size (cm) C-Axis	Range of A-Axis (cm)	Block Size With Distance	Scarp at Crest	Interstitial Fines
Monument Knob Washington Monument State Park, MD. (Keedysville, MD. 1:24,000 Quadrangle)	425	15° near crest; 28° at mid-slope; 12-14° at toe	250	100	N 60°W	78	41	23	18.3-243.8	r=-.24	Absent	Absent
Black Rock-Annapolis Rock (Myersville, MD.) 1:24,000 Quadrangle)	550	30° below scarp; 28° at mid-slope; 13° at toe	150-350	100-150	N 70°W	78	44	22	18.3-265.2	r= .26 / r=-.26	Present	Absent
Sliding Rock Mountain (Walnut Bottom, PA. 1:24,000 Quadrangle)	490	25°	100	50		34	20	10	6.1-97.5	r= .46	Present	Absent
Biesecker Gap Road (Waynesboro, PA. 1:24,000 Quadrangle)	450	30°	200	150	S 50°E and N 40°W	29	15	9	9.1-67.1	r=-.29	Absent	Absent

Block Orientation

Table 10 shows the results of the statistical analysis of the two-dimensional block orientations on the block mantles at Black Rock and Washington Monument. The upper and lower segments of the mantles were examined independently to see whether a strong difference in slope angle (25 vs 12°) would influence block orientation.

Block orientation on the lower segments of the mantles (at lower slope angle and within the transition area to apron) differs from that on the steep mantle. At both Black Rock and Washington Monument, the r values are stronger (although still not high) and the s values are lower (indicating tighter clustering around the mean and less scattering) within the lower mantle. Correspondence between the preferred orientation and the slope orientation is strong at both the Black Rock and Washington Monument sites.

Table 10

Block Orientation on Mantles

Site	N	r	s	θ	Slope Orientation
Black Rock (upslope)	319	.18	73°	290°	280°
Black Rock (downslope)	194	.36	65°	277°	280°
Washington Monument (upslope)	440	.24	71°	290°	320°
Washington Monument (downslope)	172	.31	67°	263°	320°

N= sample size
r= mean vector magnitude
s= mean angular deviation (Similar to standard deviation)
θ= preferred orientation of a-axes
Slope Orientation= the orientation of the mantle

Block Aprons

Steep block mantle normally grades downslope into block aprons at lower slope inclinations. Aprons may continue downslope 200 - 400m. Although blocks cover much of the surface of an apron, the interstices are filled with mineral soil material capable of supporting forest vegetation. The percentage of the surface covered with blocks is much lower than in the block mantle (block mantles are characterized by 100% of their surfaces covered by blocks).

Block size continues to decrease downslope within the aprons. Few blocks with long axis diameters > 1m are present in aprons. Excavations within aprons at the Washington Monument and Black Rock sites revealed a mineral soil between quartzite pebbles, cobbles, and small boulders. The percentage of coarse particles composing the deposit decreases with distance downslope. Mechanical analysis of soil samples from the Black Rock and Washington Monument sites shows that the texture of the soil varies with distance from the crest (Table 11).

Table 11

Soil Texture Change Within Aprons

Distance from the Crest (m)	% Sand	% Silt	% Clay
200	75	20	5
300	38	42	20
350	22	54	24

Tongues and Cascades

Cascades and block tongues are irregularly but widely distributed within the block aprons and are found all along the scarp slopes in the study area. Tongues are lobate in form and consist of matrix-free, coarse blocks that appear to "spill out" of the block mantle immediately upslope. Cascades form in small intermittent stream valleys and can extend downslope 100m. They are narrow, usually 1.5 - 4.0m wide, thin, and consist of blocks that concentrate in these tiny valleys.

Chapter Summary

A distinct morphosequence is evident in the study area as a result of mechanical weathering of the resistant sandstones, quartzites, and metabasalts of the asymmetrical South Mountain Anticline. From the crests of steep, west-facing scarp slopes, morphosequences grade from bedrock defended terraces, tors, and scarps to steep mantle immediately downslope. At the base of the mantle, less steeply inclined block aprons drape the lower slopes. A diamicton has developed on the flanks of the ridges and is, in some instances, in contact with the apron immediately upslope. Dip slopes, on the other hand, are characterized by steep mantles near the crest that grade downslope into aprons and blockstreams in low-order stream valleys

Tors, scarps, and terraces result from the weathering of the gently dipping limbs of the overturned structures of South Mountain. Unvegetated block mantles are developed extensively in a cross-slope direction on inclinations ranging from 14 - 35°. Block aprons are similar in character to mantles except that slope angles are lower and forest vegetation is present. Cascades and tongues of blocks are numerous on the lower segments of scarp slopes. Diamictons in the study area are of three basic types. The recent alluvium is readily distinguishable because it is fairly well-sorted, contains a greater proportion of coarse particles compared to fines, and includes cobbles of metavolcanics, quartzites, and sandstones. In contrast, the weathered alluvium lacks sorting, contains a much higher percentage of fines, and lacks metavolcanics. The third type of diamicton is very different from the alluvium and is typified by angular clasts set in a matrix of fines.

Dip slopes share some deposits and landforms with scarp slopes. Mantles and aprons are less common on dip slopes and, where present, are poorly developed. Cascades and tongues are present near the bases of aprons. Dip slopes lack diamictons but produce block streams characterized by low slope angles, a general lack of forest vegetation, variable block size, a furrowed microtopography, decreasing block size with depth, and a thickness of 1.0 - 1.5m.

CHAPTER V

RESULTS, DISCUSSION, AND ANALYSIS

This chapter is divided into two principal sections. The first section: 1) establishes the stability and relict nature of the scarp and dip slope sequences, 2) summarizes the support for the hypothesis offered by the field evidence, and 3) examines the degree of morphoclimatic change during the Late Pleistocene. The second section: 1) analyzes the distribution of the block deposits and diamictons, 2) proposes mechanisms for their development, and 3) examines the chronologic and genetic relationships between the block deposits and diamictons.

Establishing the Stability and Relict Nature Of Scarp and Dip Slope Sequences

Lichen growth, forest encroachment, organic soil development, and weathering features such as rinds, pits, and the rounding of block edges and corners attest to the stability of the landforms and deposits under the present climatic regime. The results of this part of the investigation are discussed in the sections that follow.

Botanical Evidence of Stability

Several species of both crustose and foliose lichens were identified, photographed, and measured (Plate 15). Table 12 lists those and gives the maximum diameters for lichens measured in this study and growth rates for each

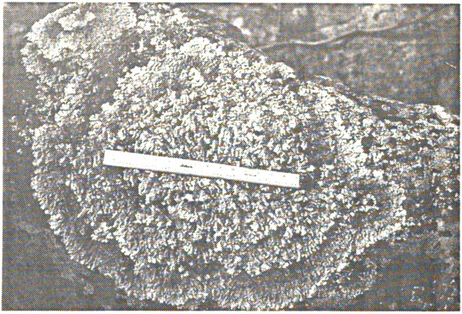

Plate 15. Lichens on block at Wolfe Road block stream. Scale is 15cm long.

species (Hale, 1979; Culberson, 1982).

Table 12

Lichen Size and Growth Rates

in the Study Area for Selected Species

Foliose Lichens	Maximum Diameter (mm)	Annual Growth Rate (mm)	Age (yrs)
Lasallia papulosa	25	1.0 - 2.0	12.5 - 25
Umbilicaria mammulata	150	2.0 - 3.0	50 - 75
Parmelia conspersa	350	2.0 - 5.0	70 - 175
Crustose Lichens			
Dimelanea oreina	40	0.5	80

Based on the size and abundance of lichens present on upper surfaces and their absence on the undersides of blocks, there appears to have been little block movement in the past 50 - 175 years at most mantle and block stream sites. Some blocks have obviously been disturbed, particularly at sites near human access points. But where exposures are difficult to reach, the boulder materials generally exhibit a nearly homogeneous lichen coverage. An exception to this is the Black Rock site where areas high on the steep block mantle exhibit a lower density of lichen cover; this is especially evident immediately below the scarp face.

Forest encroachment upon the block deposits of the study area is a further indication of stability. The block aprons (Plate 16) immediately adjacent to both block mantle

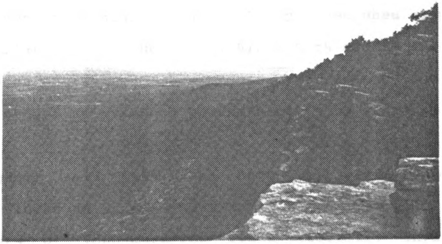

Plate 16. Summit scarp, steep block mantle, and forested apron (right to left) at Black Rock. View is toward the north.

and block streams are heavily forested with mixed hardwoods. Additionally, block streams and some steep block mantles may have small, irregularly distributed clumps of forest vegetation growing at their margins and within their open block areas.

Block mantle, aprons, and block streams were observed in order to determine the extent of tree disturbance by block movement. Tree clumps on block mantles exhibit a very limited amount of scarring and tilting, even when slopes are steep (Plate 17). But, the Black Rock mantle site lacks tree copses entirely. Trees growing on aprons and block streams showed no evidence of disturbance by recently moving blocks.

Organic soil mats that have accumulated above and between blocks on aprons and block streams are also useful indicators of long-duration block stability. Invasion of the open block areas by forest, and reestablishment after fires, is probably relatively slow due to the lack of soil, severe drought stress, and high summer daytime heat accumulation and retention. Biomass production is likely to be stunted under such stressful conditions and the associated accumulation rates of organic debris beneath the forest is probably correspondingly low.

Organic soil mats, covered with oak-leaf litter, have accumulated in patches between and on top of blocks at many of the sites to depths of about 1 - 50cm. Near the downslope margins of the block mantles, where the slope

Plate 17. Block mantle at Washington Monument site showing red maple in midst of open block area. Lack of tilt and scarring on trunk suggest little block movement on mantle.

becomes more gentle ($\leq$20°), thin organic soils have accumulated above and between the smaller blocks. Steep block mantle does not usually support organic accumulations. Block streams, which are on very low slope (4 - 6°), have the thickest mats in the study area. Mat thickness varies from about 1 - 47cm at the Devil's Race Course site. Thickness at other block stream sites varies similarly.

Data concerning organic accumulation rates are scant. Crocker and Major (1955) found that organics accumulate beneath alder in Alaska at the rate of 12 - 14cm/100 years and McDowell et al. (1969) reported the same figure for Everglades peat. Nichols (1969) documented the accumulation of peat in Manitoba and Northwest Territories at 1.6cm/100 years and 2.3cm/100 years, respectively. Using the most rapid accumulation rate of 12 - 14cm/100 years (Crocker and Major, 1955) yields a minimum block stream stability of about 335 - 390 years for sites in the Northern Blue Ridge. Using the slowest accumulation rate of 2.0cm/100 years yields a maximum stability duration of about 2350 years.

Weathering Features as Stability Indicators

Table 13 shows weathering rind data for the Devil's Race Course block stream site and four diamicton sites. All samples collected were drawn within 1m of the surface (above water table). Rind thickness varies only slightly between the Devil's Race Course site and the first three diamicton locations. Student's T-Test confirms that there is no significant difference in rind thickness between the block stream and the diamictons. However, the Fayetteville, PA site is significantly different from the others at the .01 level.

Table 13

Weathering Rind Thickness - Devil's Race Course

Block Stream and Diamicton Sites

Site	Mean Thickness (mm)	Std. Dev.	Range	Min	Max<
Devil's Race Course	.89	.91	4.93	0.07	5.00
Boonesboro High School	1.33	.89	4.33	0.00	4.33
Smithsburg, MD	.87	.88	3.50	0.00	3.50
Raven Rock Hollow Road	.94	.90	2.67	0.00	2.67
Fayetteville, PA	2.59	.89	3.67	1.17	4.83

Boulders and cobbles at the Wolfe Road, Devil's Race Course, and the Fayetteville sites were also examined for an encircling rind. An abruptly discontinuous rind suggests that the particle must have been split after rind development ensued. All samples exhibited a continuous, but variable, rind.

Rind thickness similarity exhibited by the Devil's Race Course site and the first three diamicton sites (Table 13) points toward a similar age for these features. The Fayetteville, PA site may be considerably older because the mean rind thickness is up to three times that of the other sites. The continuity of rinds around the particles suggests that the mechanism that split them has ceased or markedly slowed.

Weathering pits exhibit variable characteristics on blocks in the Northern Blue Ridge (Plate 2). Some blocks have multiple pits which are often linked by gutters. Typically, the base of a pit is covered by a dark, organic stain and may contain sandy material weathered from the quartzite. The deeper pits can hold water for several days after a precipitation event.

Pit depths range from less than 1cm to nearly 3cm, whereas diameters vary from approximately 5cm to 15cm. Although many blocks exhibit a very rough and irregular surface, individual, well-defined pits are absent on many blocks. The deepest and largest pits appear to be associated with the intersection of minor fractures in the Weverton Quartzite where chemical weathering has been accelerated along these zones of weakness.

No pits were found on unexposed faces. The undersides of the blocks appeared fresh, light gray to pink in color, unpitted, and largely free from chemical weathering effects (Plates 18 and 19). This is an important indication of block stability because the Weverton Quartzite and many of the other ridgemakers in the study area are considered to be highly resistant to chemical attack. A long period of block stability would, therefore, be required to weather only the exposed surfaces.

With time, weathering processes will blunt the edges of angular boulder material fractured from a nearby bedrock source and eventually round the particle. Table 14 shows

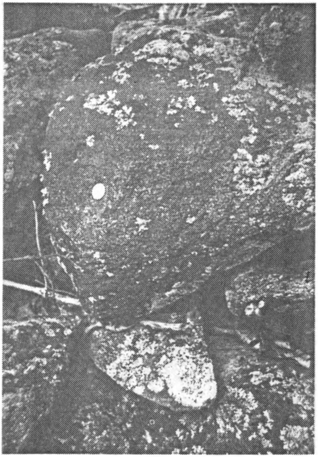

Plate 18. Block of Weverton Quartzite photographed at Devil's Race Course site showing extensive lichen cover and small weathering pits on exposed surface (quarter for scale).

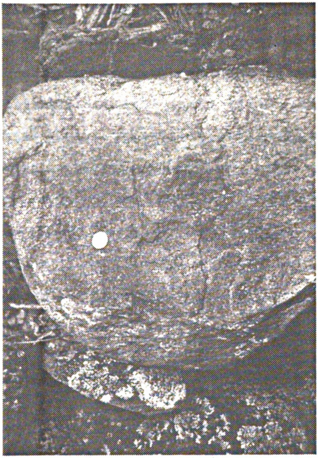

Plate 19. Underside of quartzite block shown in Plate 18. Undisturbed blocks typically exhibit fresh, unweathered faces free from lichens (quarter for scale).

the results of the visual shape assessment for all of the block deposits sampled. All sites sampled show similar mean angularity values ranging from about 6.0 - 7.0 (i.e., within the angular range). Even though the blocks exhibit an overall angular appearance, distinct rounding and blunting of the edges and corners has occurred at most sites. The Black Rock site, with a steep scarp face upslope, is an exception. Immediately below the scarp face, blocks were observed to be distinctly more angular than those on low slope near the toe of the mantle. Blocks in the Sliding Rock Mountain deposit were also observed to be highly angular. Elsewhere, in aprons, lower mantles, and in blockstreams, edges and corners are rounded.

Table 14

Angularity of Blocks at Selected Sites

Site	Mean Angularity	Range
Devil's Race Course	5.97	4.0- 9.0
Wolfe Road	6.35	4.0- 9.0
Staley Road	6.29	5.0-10.0
Washington Monument	7.01	5.0-10.0
Devil's Race Course Traverse, Block Stream to Mantle	6.61	5.0- 9.0

These data are important indicators of stability because if block parting were currently active, all of the deposits should exhibit blocks with sharp edges and corners. Because only those areas with a bedrock source immediately upslope contain large numbers of blocks with sharp edges and corners, most of the deposits must be regarded as currently inactive.

The similarity of mean angularity values also sheds some light on the relative age of these deposits. Assuming that climatic factors do not vary significantly across the study area, and that various block lithologies have near-equal resistance to weathering, the angularity may be so similar because all of the sites are of approximately the same age. By the same reasoning, the segments of the Black Rock site and the Sliding Rock Mountain site, with less-weathered, more angular blocks, might be younger than their downslope extentions, the other mantles that lack an upslope scarp, block aprons, and block streams.

Review Of Field Evidence Supporting The Hypothesis

Although fossil ice-wedge casts were not found in the Northern Blue Ridge study area, other reasonable indicators of a Pleistocene periglacial climate have been identified in this study. Additionally, field evidence has been presented showing that solifluction has ceased and frost action is much less important than formerly. The following sections summarize the evidence for Pleistocene solifluction and recent stability.

Evidence for Solifluction

Deposits emplaced by soil flow associated with periglacial conditions exhibit characteristics of transport such as 1) debris traceable to an upslope source, 2) deformed, overridden beds with drag effects on the substrata, 3) an interruption of soil profile development,

4) crude stratification parallel to the slope, 5) contortions in the basal zones of the deposits, 6) present immobility, and, most importantly, 7) a preferred orientation of the long axis of coarse particles. The following section examines evidence from block stream, diamicton, and block mantle and apron sites that suggest such an origin for these deposits.

Block Stream Sites

The block material at all block stream sites is clearly traceable to scarp faces. These outcrops probably served as the source of the transported debris since the lithologies and joint patterns are similar.

The strength of the preferred orientation of blocks (r) at two block stream sites is not strong, but does exhibit a very close association with the slope orientation. However, at the Wolfe Road site, the preferred orientation of blocks is transverse to the slope. Both of these conditions have been reported in the literature. The relatively low mean vector magnitude values for the sites examined in this study can possibly be explained on the basis of the low slope of the block streams. Since all are inclined at less than 6°, a relatively low vector magnitude may not be unusual.

The other characteristics of deposits emplaced by soil flow were not encountered at any of the block stream sites. Evidence of deformed beds, and interrupted soil profiles were not observed at any of the block stream sites.

Further support for Pleistocene periglacial conditions in the study area comes from the on-edge or on-end orientation of some of the boulders in the blockstreams. It is well-documented in the literature that frost heave, frost pull, and frost push can move very large particles toward the surface, even when they are in close contact with other large particles. Both the Wolfe Road and Devil`s Race Course sites bear evidence of the upfreezing of stones. Irregularly distributed clusters of boulders at both sites exhibit on-edge and on-end orientations. At the Wolfe Road site, two-thirds of the blocks near the toe of the feature display dips > 45°. A similar area was noted at the toe of the Devil's Race Course site. Such frost action effects demand the presence of a filled matrix; upfreezing of large blocks is otherwise impossible.

Block stream stratigraphy adds further support to the notion of the presence of a periglacial paleoclimate in the study area during the Pleistocene. Northern Blue Ridge block streams are essentially similar, in terms of structure, to those from other areas which have been described in the literature as having formed under periglacial conditions. Block size is significantly greater at the surface than that at depth. One mechanism to account for the variation in block size with depth is sorting due to down slope motion of the block mass. Smaller blocks tend to work their way downward, deeper into the block matrix, filling the great gaps between the larger blocks during transport of the block mass.

Diamicton Sites

Orientation of clasts in the slope direction was clearly observed at a pipeline excavation on the eastern flank of South Mountain near Smithsburg, Maryland (Plate 12). The pipeline excavation there also serves as the best example of deformed beds and drag effects produced by material from upslope, probably as a result of increased frost creep. The "hooks" in Plate 12 (similar to those described by Jahn, 1978) are obscured by .75-1.25m of overburden. It is difficult to explain the hooks and the overburden in terms of present-day, ongoing processes. Soil development in the regolith above the hooks indicates the relative stability of this overburden in the present environment.

Block Mantle and Apron Sites

There is little question that the debris at apron and mantle sites is traceable to a source upslope based on : 1) lithologic similarities between blocks and the in situ bedrock, and 2) the close correspondence between the size of joint-bounded blocks exposed in outcrops and the blocks of the mantles and aprons. Coarse particles exhibit a preferred orientation at both sites where orientation data were gathered, though the strength of this measure is not particularly high. The mean orientation of blocks is consistent with the slope aspect at both mantle sites sampled. These results indicate a solifluction origin for these deposits since studies of block-covered slopes of non-periglacial origin have been shown to exhibit no preferred orientation of coarse particles (Albjar et al., 1979).

Differences in the strength of the mean vectors (r) within block mantles appear important. High on the slope at Black Rock the strength is (r=.18) less than that of areas lower on the slope (r=.36). This substantial vector-strength difference might be related to origin and age of the mantles. First, the lower r-vector magnitudes from areas high on the mantles could stem from additions of block material by fall, tumble, and slide during the Recent. Material added in this way would possess no preferred orientation, but would serve to "dilute" any preferred orientation possessed by blocks emplaced earlier and moved downslope in a matrix of fines associated with solifluction. Only those areas on the mantle near the upslope block source would receive such additions. The lower mantle and aprons would not receive material in this way. Most blocks cascading from the scarp would be intercepted by the coarse, open network of the high mantle. The higher r-vector values associated with the lower mantle support this notion. Therefore, the surface layer of steep block mantle might be younger than the block mantles lower on the slope. Recently added surface debris on steep block mantles might mask older debris beneath.

The view in Plate 20 is from the scarp summit at Black

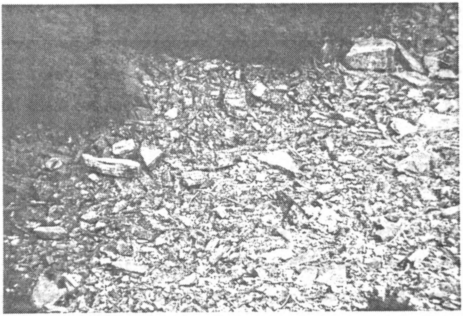

Plate 20. View is downslope toward forested apron at Black Rock site. Light-toned blocks in foreground exhibit a different degree of lichen coverage from the darker blocks in the farground.

Rock toward the mantle below. There is a distinct tonal contrast between those blocks lower on the slope (darker, toward the upper left section of the photograph) and the blocks closer to the source (lighter, toward the lower right). This tonal contrast stems from lower lichen density on the blocks of the upper mantle as compared to the lower mantle. The light-toned Weverton Quartzite, with a sparse lichen cover, appears brighter than the blocks on lower slope that are masked by foliose lichens. Because lichens require decades to cover a block, many of the surface blocks of the upper mantle probably have been added within the past few hundred years. Those lower on the slope exhibit a longer, but unknown, period of stability.

The Washington Monument mantle site, which lacks a summit scarp, does not exhibit strong contrast in r-vector magnitude between steep block mantle and mantle on low slope (.24 on steep mantle, .31 on lower mantle). The lichen cover there is more uniform. Both conditions can probably be attributed to the lack of a bedrock scarp at Washington Monument to act as a source for falling and cascading blocks.

Evidence of Stability Under the Present Climate

The following sections review the field data supporting the notion that the scarps, mantles, aprons, block streams and other related deposits in the study area are relatively stable, are for the most part in a state of decay, and are, therefore, relict. Evidence of such stability centers around: 1) undisturbed forest growth on and adjacent to block deposits, 2) secondary weathering of blocks, 3) lichen growth on exposed block surfaces, 4) soil development within deposits and 5) the return of running water as the principal erosional agent.

There is little observational evidence for growth disturbance to clumps of forest on steep block mantle, forest on aprons, and copses on block streams. Trees grow with little disturbance even on the steep slopes within large block mantles.

The rarity of disturbances to trees on mantles and the lack thereof on aprons and block streams indicate that falling, rolling, and cascading blocks must be relatively uncommon in comparison to the lifespan of trees. If blocks were actively being added, more disturbance to trees would be observable.

However, the complete absence of copses at Black Rock might also suggest that falling blocks occur with sufficient frequency there to prevent establishment of trees on the steep mantle. This notion is supported by the lichen growth patterns and block angularity at that site.

Lichens have been shown in this study to have limited utility as indicators of block stability in the Central Appalachians. Even though colonies of several lichen species cover blocks at most sites, the maximum period of stability that can be inferred from these data is approximately a century because lichens tend to grow relatively rapidly under the temperate conditions in the Northern Blue Ridge. Very large lichens in excess of 200mm may represent only 50 - 250 years of growth. Evidence for stability within this time frame is clear, however, because no blocks with lichens present on unexposed surfaces were located at block stream sites, and only those mantles with summit scarps exhibit lichen-free blocks.

The Devil's Race Course block stream has been carefully observed over the past ten years and little forest extension has occurred. Therefore, accumulation rates for the organic mats within and adjacent to open block areas are probably extremely slow. The accumulation rates from various portions of North America may be more rapid than are those of the study area.

No block material has been observed in a position above organic mats on any block stream, mantle, or apron; therefore, little material has been added recently to these deposits from upslope. Based on the accumulation rates from other portions of North America and the thickness of the organics in the Northern Blue Ridge, the maximum period of stability that can be inferred is about 2000 years. This, however, may be a conservative estimate since the breakdown of this material may proceed more rapidly in the study area than in the areas cited in the literature.

Secondary weathering effects were used in this study in an effort to demonstrate the immobility of the blocks in the Recent. Weathering rinds are well-developed and encircle the coarse particles sampled at blockstream sites, on lower mantles and diamictons. Rinds that encircle the edge indicate that the block has not been further split since rind development ensued. If a block were to have been split after a rind was established, one side would lack a rind. Since no blocks with discontinuous rinds were observed, it is safe to conclude that splitting occurs at a slow rate and that frost riving is now of less importance than formerly.

Blocks at most sites exhibit a surface microtopography produced by the differential weathering of minerals. The undersides of the blocks retain a fresh, relatively unweathered appearance. These weathering effects suggest that the blocks are now in a state of chemical decay. If there was a high degree of mobility, blocks would not likely remain in place for a sufficient duration to produce such well developed weathering effects; both the exposed and unexposed surfaces would display a microtopography if block mobility was significant.

Mineral soil development downslope from steep block mantle and within aprons lends further support to the notion of their stability. If blocks were continually being added, soil profile development would exhibit evidence of interruptions.

Proposed Degree of Morphoclimatic Change During the Wisconsinan

Palynological, paleontological, and geomorphic data from the literature allowed for the reconstruction of a late-Wisconsinan mean annual air temperature and tree line for the study area. Habitats in the Central Appalachians must have varied considerably both spatially and temporally between 30,000 B.P. and 11,000 B.P. and included a mix of boreal forest, taiga, and tundra during the maximum of the Wisconsinan between about 26,000 B.P. and about 15,000 B.P. It is probable that these three habitats were, at times, coexistent in the Northern Blue Ridge due to: 1) relief differences that range between about 200m and 600m, 2) variable aspects provided by long, linear ranges, and 3) cold air drainage into deep valleys. Tundra conditions probably persisted in the Northern Blue Ridge area for less than about 10,000-12,000 years.

Tree Line Reconstruction

Figure 14 shows the correlation between elevation of sites with strong indications of former tundra and minimum distance to the glacial limit. Indicators of former tundra include the presence of patterned ground, which is assumed to be of Wisconsinan age (Rapp, 1967; Clark, 1968), bog sites with pollen from tundra plants (Maxwell and Davis, 1972; Watts, 1979; Delcourt, 1983), and the fossil location of <u>Dicrostonyx hudsonius</u>, the collared lemming (Guilday <u>et al</u>., 1977). Paleoecological and geomorphological studies in the Central Appalachians have been used to extrapolate the elevational limits of tree line (Delcourt, 1983). The line of best fit, $y = a + bx$, was used to estimate or predict the elevation of tree line at a particular latitude.

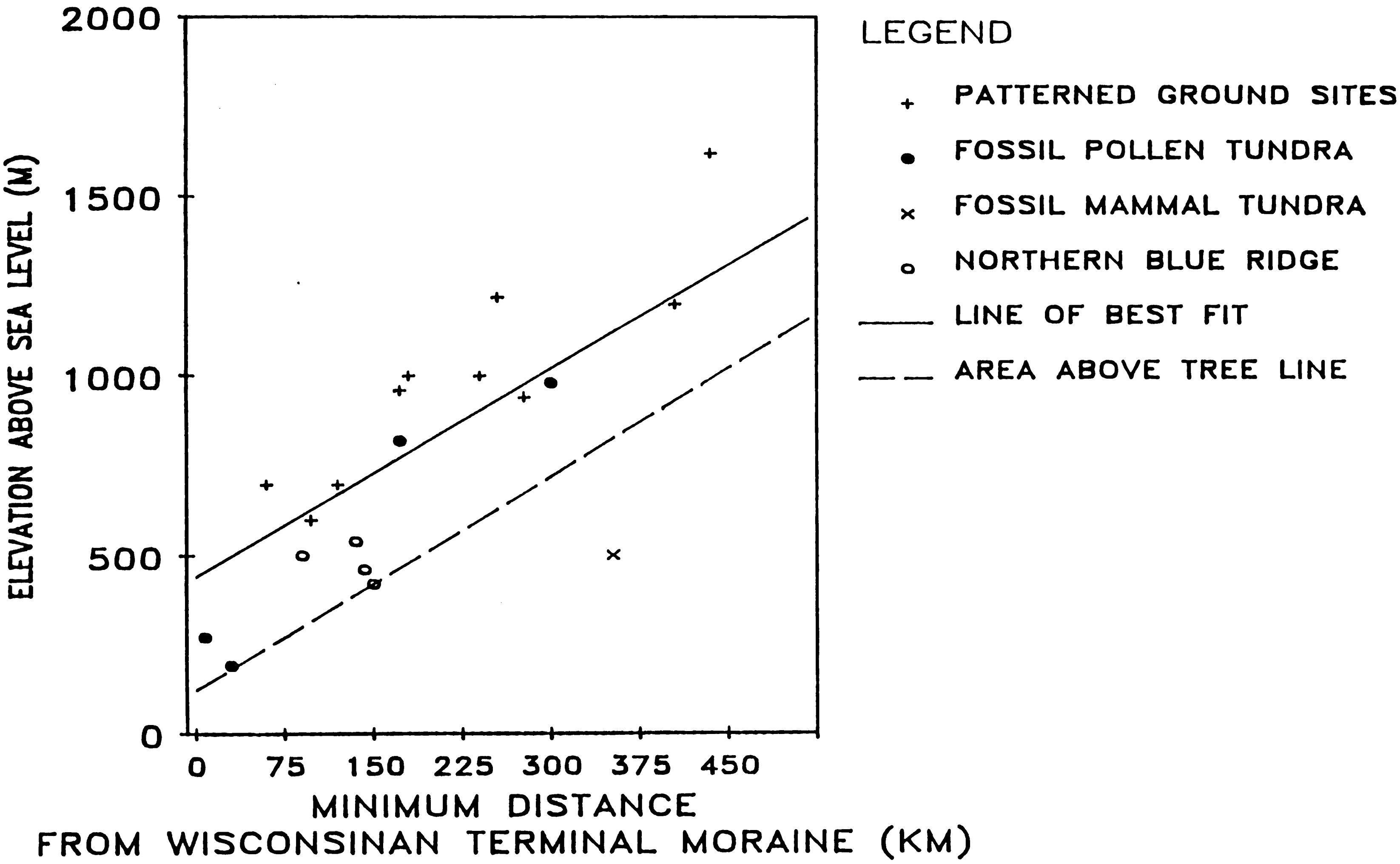

Figure 14. Pleistocene Tree Line in the Central Appalachians.

The latitudinal extent of the Northern Blue Ridge ranges from about 39° 05' to 40° 08'. Elevations vary from about 350m in the south, near the Potomac River, to over 600m near the Maryland-Pennsylvania border. The principal block sites in the study area are shown in Figure 14 along with the locations of the various tundra indicators. The dashed line shows the probable location of the tree line in the study area (at the 95% level of confidence) during the Wisconsinan maximum. The northern end of the study area, where elevations exceed 600m, was probably above tree line. Near the Potomac River, tree line was likely higher than the summits of South and Catoctin mountains.

Late Wisconsinan Paleotemperature Reconstruction

Table 15 shows: 1) the modern mean annual air temperature (MAAT) for stations within the Northern Blue Ridge between 300m and 670m, 2) the MAAT at the Wisconsinan maximum employing a conservative 10° C temperature depression, and 3) the MAAT at the Wisconsinan maximum employing a 15° C temperature depression. No long-term temperature data are available for sites in the Northern Blue Ridge upland, but MAAT were calculated from the average of eight stations in the adjacent Frederick Valley and Great Valley and adjusted for elevational differences employing a 6.5° C/1000m lapse rate. The temperatures inferred in this way were verified by comparing them to Leffler's (1981)

Table 15

<u>Paleotemperature Reconstruction, Northern Blue Ridge</u>

Elevation (m)	MAAT Today C°	Wisconsinan MAAT Utilizing a 10°C Depression C°	Wisconsinan MAAT Utilizing a 15°C Depression C°
300	11.0	1.0	-4.0
365	10.6	0.6	-4.4
425	10.2	0.2	-4.8
485	9.8	-0.2	-5.2
550	9.4	-0.6	-5.6
610	9.1	-0.9	-5.9
670	8.7	-1.3	-6.3

MAAT for sites in the Blue Ridge Upland were calculated using a lapse rate of 6.5°C/1000m.

method of temperature estimation for sites lacking data. Excellent correspondence resulted from the comparison.

The modern MAAT for stations in the Great Valley and the Frederick Valley is 11.8° C at a mean elevation of 175m. The modern MAAT at elevations in excess of 500m is about 9.0° - 9.5° C. Utilizing a 10° C temperature depression for the maximum of the Wisconsinan, most areas in the Great Valley would have experienced a paleo MAAT of about 1° to 2° C; at elevations around 500m, in the Northern Blue Ridge upland, the Wisconsinan MAAT would probably have been around 0° C. If Wisconsinan paleotemperatures were depressed as much as 15° C, the MAAT in the Great Valley would have been around -3° C, at elevations of around 500m, about -5° C, and near the summits of the highest peaks the MAAT would have been about -6° C.

No sorted patterned ground was observed in the study area, although numerous examples have been noted in the Appalachian Plateau of Pennsylvania, and the Ridge and Valley of Pennsylvania, Virginia, and West Virginia. The presence of large (greater than 2m in diameter) patterned ground indicates marginal permafrost and a MAAT of 0° to -2° C. The lack of these landforms in the study area allows a more precise paleotemperature reconstruction. The temperature depression in areas near the Northern Blue Ridge, according to palynological, paleontological, and geomorphic indicators, amounts to about 10° C at the peak of the Wisconsinan. The Great Valley probably experienced MAAT of about 2° C whereas the uplands likely experienced temperatures around 0° C.

The rigor of the cold phases of the Pleistocene induced a significant morphoclimatic change that reduced extensive areas of in situ bedrock to rubble in the study area. Mantles and block streams are relatively rare in the Northern Blue Ridge, but aprons and rocky soils on terraces and summit flats are ubiquitous. Soil maps reveal that nearly all of South Mountain and the Catoctin Uplands are covered with soils described as "stoney land" or soil series with high coarse-fraction content. The Pleistocene climate must have been rigorous in order to have shattered so much material.

Analysis

Various lines of evidence have been drawn together in this study to support the view that a variety of erosional and depositional surface features in the Northern Blue Ridge are presently in a state of decay, are out of equilibrium with the present climate, and are primarily the result of a Pleistocene periglacial regime. The following sections 1) discuss the factors that govern their distribution, 2) propose mechanisms to explain their development, 3) examine their genetic and chronologic relationships, and 4) summarize the most important findings.

Distribution of the Block Deposits and Diamictons

I sought to resolve several problems regarding the nature of the spatial patterns of the block deposits and diamictons in the Northern Blue Ridge. The following sections suggest possible solutions to questions of the distribution of the major regolith types in the study area.

Block Deposits

I have isolated two important questions regarding the principal variables governing the location of block mantles, aprons and block streams. Did microclimatic variables of slope aspect, elevation, and latitude influence the distribution of these deposits? To what degree does structure and lithology control the location of these forms?

Slope aspect was thought to be important because north-facing slopes are typically moister and cooler than south-facing slopes. North-facing slopes have a more abundant moisture supply, later lying snow fields, and an active freeze-thaw period extending into late spring and early summer. South-facing slopes tend to be warmer and drier, but might have a greater frequency of freeze-thaw cycles. These microclimatic parameters could, in certain environments, influence the block size and thickness of the deposits.

The mantle site at Bisecker's Gap is the best example of its type in the study area with both north and south aspects. No significant difference in block size or form was detected between north-west and south-east facing slopes there. Additionally, the mantle extends up and down slope to the same approximate elevations on both slope aspects. The thickness of both deposits was found to be similar.

Differences in aspect at the Bisecker's Gap site did not significantly influence block size, block form, or mantle thickness.

I thought that elevation might play a microclimatic role and influence the distribution of the block deposits, too. I found that the extent and level of development of mantle, aprons, and block streams is related to elevation. The best examples of mantle and block streams are located at elevations exceeding 500-600m. Areas with elevations less than about 400m have poorly developed block deposits. I consider about 400m to be a critical lower elevation with respect to block stream and mantle distribution. No deposits of either type were observed at elevations below this threshold. Mantles and scarps were observed at and near summits, suggesting that there is no critical upper elevational limit in the study area.

Superficially, it appears that elevation exerted a microclimatic control of sufficient strength to sort out block deposit development in the Northern Blue Ridge. However, thickness of the ridge-forming rock units is reflected in the elevation and ruggedness of the topography. Where the gently-dipping Weverton, Antietam, and Mont Alto quartzites and the Catoctin Metabasalt are thickest, elevations are highest. Where elevations are highest, the block deposits are best developed. But the best examples of mantles, scarps, aprons, and block streams are also associated with thick outcrops of ridge-makers. Elevation and block feature development both vary with the thickness of the resistant rock units.

The microclimatic role of elevation on block mantle, apron, and block stream distribution is both difficult to assess and difficult to separate from the structural influence of ridge-maker thickness. Since relief does not exceed a few hundred meters within the study area, I do not believe that a strong vertical temperature gradient was produced that could have exerted important control over the development of the block deposits.

Latitude varies by less than one degree within the study area. Even though the best developed block deposits occur toward the northern end of the study area, and toward the southern margin they are poorly developed to absent, I do not believe that latitude played an important role in their distribution. Ridge-maker thickness probably exerts a much stronger control than such a small change in latitude. Over the extent of the Southern and Central Appalachians the effect of latitude is strong, however, and has been noted in the literature and observed by the author.

Generally, lithology and structure appear to be the dominant influences on the distribution of the block mantles, aprons, and block streams in the study area. Where the Weverton, Mont Alto, Loudon and Antietam formations are thick and gently-dipping to near-horizontal, especially within the limbs of overturned anticlines, the block deposits are best developed.

There are other problems regarding the distribution of block streams and mantle/aprons that require resolution, however. Why do blockstreams occur only on the dip slope, and why are mantles and aprons best developed on the scarp slopes in the study area? The following summarizes the principal topographic, lithologic, and structural variables that I believe most affect the distribution of scarps, mantles, aprons, and block streams.

1. Very resistant lithologies favor the development of rugged terrain that may be sustained throughout long episodes of weathering. Bedrock types that are resistant in the study area include the: a) Weverton Quartzite, b) Catoctin Metabasalt, c) Mont Alto Quartzite, and d) Antietam Quartzite. The block deposits are mostly confined to the above bedrock types.

2. Gently-dipping limbs of various resistant lithologies produce nearly flat-topped summits, sharp scarp faces, and long, often stepped, dip slopes. Such structure provides steep topography, that can be maintained through time, on the scarp slope. Steep rock faces that resist downwasting are associated with summit scarps, block mantle, and block apron landform sequences.

3. Thickness of the ridge-makers is linked to the development of the block deposits. Where thick beds of resistant lithology crop out, block landform suites are best developed. Where the ridge-makers thin in outcrop, block deposit development is either absent or retarded.

4. Massive, thickly bedded bedrock with joints in a moderately spaced net produces large blocks that weather slowly. Where joint spacing is tighter and bedding planes are thinner, smaller blocks result. Block survival into the Recent favors the former set of conditions.

5. Gently dipping layers of resistant lithology, like the Weverton Quartzite, often overlie a less resistant formation, like the Harpers Phyllite. Differential weathering on those lithologies of contrasting resistance produce steep slopes (like those at High Rock and Black Rock). The upper layer, often the Weverton, provides a line-source of blocks that, upon weathering, free-fall downslope and accumulate at the base of the slope and mantle the underlying, less-resistant rock. The massive, jointed Weverton is able to maintain steep scarps due to near parallel slope retreat. Mantle and apron sequences depend on maintenance of steep scarps; without scarps, mantles would eventually disappear. Without a less-resistant rock layer underlying a more resistant unit, scarp development would be retarded.

6. Block streams in the study area are always associated with thick outcrops of the Weverton Quartzite that dip downslope toward a stream valley that parallels the ridge strike. Dip slopes of resistant lithology produce areal sources of blocks. That is, where the Weverton Quartzite is thick and gently inclined, long dip slopes may be composed entirely of this single rock unit. Massive,

jointed, resistant lithologies can supply copious amounts of block debris capable of downslope movement on low inclinations over the gliding plane of the dip slope.

7. If regional dip of the resistant rock unit is steep, a line source of blocks and steep slope would likely result on either side of a ridge crest. Such a structure would produce steep block mantle on both flanks.

Diamictons

Three important questions have emerged during the course of this study regarding the distribution of diamictons in the study area. What factors are responsible for the presence of diamictons on both the east and west flanks of the Northern Blue Ridge and their absence in the Middletown Valley? Why does the form, size, and continuity of these deposits vary between the Great Valley and the Frederick Valley? Why do the diamictons abruptly pinch-out toward the south on both flanks of the Blue Ridge? The answers to these questions may be interrelated.

Diamictons on the flanks of the Northern Blue Ridge are associated with thick outcrops of the Weverton Quartzite. Diamictons are present wherever streams from the mountain mass debouch onto softer rocks. The largest diamictons are associated with streams from the high relief mountain mass with the largest drainage basins.

The absence of diamictons in the southern portion of the study area is probably tied to the geomorphology, structure, lithology, and hydrology. The Weverton Formation thins in outcrop toward the Potomac River, resulting in a pair of very narrow ridges there (South Mountain and Catoctin Mountain are only about .7 - 1.0km wide). Streams debouching from these ridges are of very low order because of their very small drainage basins. Such small streams may not have been able to deposit sufficient quantities of material to create thick and extensive diamictons like those toward the central and northern portions of the study area (where the mountain mass and drainage areas are much larger). Perhaps these small streams were able only to deposit thin veneers which have been subsequently eroded.

The Great Valley diamictons are smaller, less continuous, and more linear than their Frederick Valley counterparts. Differences in their extent, form, and continuity are probably also related to the same variables that account for their absence in the southern portion of the study area.

The Catoctin upland is more extensive than that of South Mountain and has correspondingly larger watershed areas, streams with higher discharges, and large gaps that face the Frederick Valley. These larger watersheds can transport and deposit more load. The largest fan-shaped diamicton deposits are associated with the largest streams debouching onto the Frederick Valley. The Great Valley (south of the Pennsylvania border) has no streams comparable in size to the Hunting Creek and Fishing Creek watersheds, and consequently diamictons there are smaller in areal extent. Where the headwaters of Antietam Creek flow out onto the limestones of the Great Valley near Fayetteville, PA., the diamictons are extensive but so is the drainage area within the mountain mass.

Why are diamictons absent in the Middletown Valley? Two possible reasons might explain their absence. They may never have been deposited or they may have once existed but failed to persist into the Recent.

If the diamictons were never deposited in the Middletown Valley it could stem from a lack of clast supply. An adequate supply of clasts is obviously required for the deposition of diamictons of the type described here. There is no scarcity of quartzite, the major coarse fraction diamicton component, in either the South Mountain or Catoctin Mountain area, as boulder-covered slopes face the Middletown Valley on both its flanks. I do not believe that lack of supply plays a role in the absence of diamictons in the Middletown Valley.

Another explanation might account for the lack of diamictons in the Middletown Valley. This hypothesis is closely related to the factors that might also account for the contrast in form, extent, and continuity between Great Valley and Frederick Valley diamictons. Streams heading on the east side of South Mountain, on the west side of Catoctin Mountain, that flow toward the Middletown Valley are short, of low order, with small drainage basins, steep gradients, and low discharges. Perhaps these streams are insufficiently competent to have deposited large volumes of debris.

The Middletown Valley may once have had diamictons but they could have been subsequently removed by erosion. Middle Creek and its principal tributary, Catoctin Creek, may have been able to more rapidly downwaste the Middletown Valley when compared to the downwasting ability of streams that cross the flanks of the Blue Ridge (Fishing Creek, Little Antietam Creek). This may explain the persistence of diamictons on the Blue Ridge flanks and their absence in the Middletown Valley. The granodiorites of the Middletown Valley are softer and would likely erode more quickly than the resistant lithologies of the Blue Ridge. Any diamictons deposited may have been removed as the entire landscape was lowered. The Middle Creek-Catoctin Creek watershed is large with a moderate gradient resulting in a high discharge that could move large amounts of material.

Proposed Mechanisms for the Development of the Major Landforms and Deposits

The following sections review the principal geomorphic processes that I feel have influenced the major landforms and deposits examined in this study.

Mantles, Aprons, and Block Streams

Landforms described in this study as block mantle, block aprons, and block streams appear to be related both temporally and genetically. These deposits probably evolved generally through: 1) the production of the block material by frost weathering along joint planes, 2) frost fall-sorting, 3) movement by solifluction, and 4) removal of the interstitial fines.

Mantles

Frost-fall sorting of blocks normally occurs on mantles where the cliff face is high; the larger blocks accumulate near the toe. On mantles lacking a cliff face or with low cliff faces, the coarsest particles remain near the top (reversed fall sorting). The block mantles probably moved downslope enmasse during the cold phases of the Pleistocene through various processes or combinations of processes including frost creep, solifluction, and the build-up of ice between blocks. Interstitial fines may have been produced by mechanical and chemical weathering processes and facilitated movement of the block mass by keeping moisture available between the blocks. Gliding planes on ice and the reduction of friction by flowage in a matrix of fines would have encouraged block movement. When the climate ameliorated in the late Pleistocene, rainfall throughflow could have easily sluiced away the fine-grained matrix and deposited it downslope in the apron areas.

My results from the Northern Blue Ridge support such an origin for the block mantles there. The materials constituting the steep block mantle were weathered, at most locations, from the well-jointed Weverton Quartzite. This is evidenced by the: 1) lithologic homogeneity among the blocks and their upslope source, 2) similarity of joint spacing among the blocks and the in situ bedrock, and 3) similarity of weathering effects between the blocks in the mantle and their presumed source in outcrop upslope.

Data indicate that both types of frost fall-sorting have occurred in the study area: fall sorting and reversed fall sorting. At the Black Rock site, where the cliff face is high, block size increases downslope to a position near the point where slope angle decreases abruptly and forest vegetation begins (fall sorting). At Bisecker's Gap and Washington Monument, block size decreases with distance downslope (reversed fall sorting).

Two subtypes of mantles have developed in the study area: 1) mantles having formed below a cliff face, and 2) mantles lacking a cliff face upslope. These mantle subtypes differ in several respects. Where a high cliff face is present, block size increases with distance from the crest to a point on the slope where the slope angle decreases sharply. From that point on, block size decreases with distance. On the steep mantle with scarps upslope, the strength of the preferred orientation is lower than that of the blocks on the lower portion of the slope. Where no cliff face is present block size decreases from the summit and the strength of the preferred orientation changes little between the lower and upper slope segments.

I interpret these data in the following manner. The upper portions of mantles with a cliff face upslope have continued to receive materials from the scarp during the

Recent. The more recently added blocks have not acquired a preferred orientation on the steep upper mantle. The lower segment of the mantle, characterized by blocks with a stronger orientation, may be related to the solifluction periods of the Pleistocene, and could continue beneath the layer of recently added block material.

Aprons

Block aprons are similar to block mantle and are their counterparts on low slope; the most significant differences between the two deposits are slope angle, presence or absence of vegetation, presence or lack of interstitial fines, and strength of preferred orientation. Block mantles are much steeper and usually unvegetated. Block aprons may have been vegetated more easily than mantles for two reasons. First, the coarsest particles within mantles are much larger creating large voids. Smaller clast size results in smaller, more numerous interstices which can trap fines, effectively providing lower drought stress for the growth of plants. Second, block additions in the Recent have been rare on the aprons, hence an extremely low degree of forest disturbance has prevailed there.

Block Streams

Block streams appear to be the downslope extent of aprons that have moved into preexisting stream valleys. The block movement may have been facilitated by interstitial fines. When the block mass began to stabilize, piping could have removed the fine-grained material. The open-block network of the block streams is probably maintained today by the piping process. No blockstream was observed without a stream flowing below the open-block area. The irregular margins of the open-block areas are also associated with upstream extensions of tributaries to the main water courses.

It is difficult to unequivocally prove that fine-grained materials were abundant as a matrix in the block-covered portions of the study area. But their existence in irregularly distributed areas today shows that such a presence was possible. A fine-grained matrix may facilitate block movement. Without a matrix, movement of the block masses is very difficult to explain. The presence of oriented blocks suggests that block streams were deposited by solifluction, a situation that would be impossible without the presence of fines given the size of materials in these deposits. Vertical blocks would also be difficult to explain in the absence of fines.

Figure 15 reviews the probable development of block mantles, aprons, tongues and cascades, and block streams. The model has been divided into three stages: 1) an early stage, 2) middle stage, and 3) early post-glacial. Since absolute dates are lacking for either the initiation or cessation of block deposition in the Central Appalachians, it is possible that the following series of events was repeated during early, middle, and late-Wisconsinan time and during pre-Wisconsinan episodes as well.

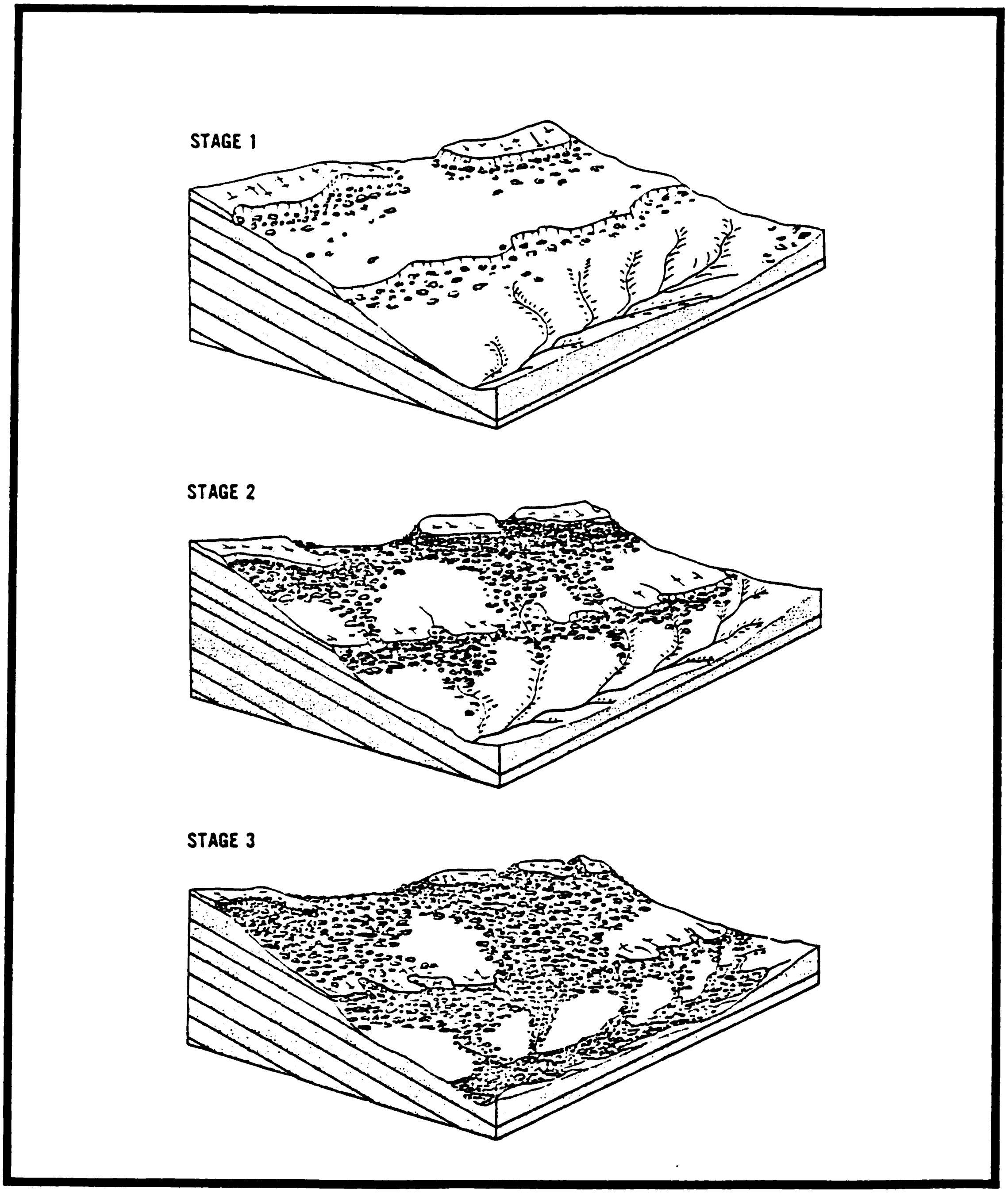

Figure 15. Probable Development of Mantle, Aprons, Block Streams, and Tongues.

During the first stage, as the ice front advanced out of New England and freeze-thaw cycles increased in number, the well-jointed Weverton Quartzite became heavily fractured as joint partings widened. A mantle began to accumulate downslope from the line-sources provided by the nearly flat-lying to gently-dipping limbs of the South Mountain Anticline. Weathering of the quartzite blocks may have created a matrix for the block debris.

After reaching a critical mass during a long cold phase, the block accumulations may have begun to sag. Downslope movement could have been facilitated by lubrication stemming from moisture trapped in the mass of blocks and fines, ice lenses within the matrix, and freeze-thaw of the block mass. Block movement into preexisting stream valleys would have been favored while encased in matrices of fines. Bedrock scarps and outliers were consumed by the high rate of block production during the extended cold phases, resulting in the near ubiquitous rubble.

In the third stage, which was probably post glacial, frost wedging declined and block production slowed. Solifluction ceased as the climate rapidly ameliorated. Rainfall throughflow may have removed the matrix, concentrating the blocks within the mantles, aprons, cascades and tongues, and block streams. Furrows on the block streams probably began to develop and continue to the present. Creep processes operating in the Recent continue to move block material downslope, but at a much slower rate than during the cold phases of the Pleistocene. Blocks continue to aggregate in small valleys along the flanks of the slopes where fluvial processes tend to concentrate the coarse particles giving rise to tongues on gentle slopes and cascades on steeper ones.

Figure 16 reviews the probable mechanism for furrows, the concentration of blocks, and the vertical dips displayed by blocks along the horizontal extent of the furrows. The model has been divided into three stages.

I speculate that stage 1 probably began during the period in which the ice margin retreated into New England at the close of the Wisconsinan. As the climate ameliorated, frost-wedging of the outcropping Weverton Quartzite must have slowed, while block movement of the mantle came to a halt stemming from the decreased frequency of freeze-thaw cycles and the melting of ice in the matrix. Since palynological evidence (Watts, 1979) suggests that the climate changed rapidly around 12,400 B.P. in the areas marginal to the retreating ice front, this phase may have begun then. The piping process may have ensued at this time to remove the fine-grained matrix from between the blocks.

Stage 2 was characterized by continued piping of the fines present in the block matrix and the continued sluicing of the contemporary weathering products from the blocks. At this stage, while piping removed the fines, the block mass on the slopes and in the valley floor began to concentrate.

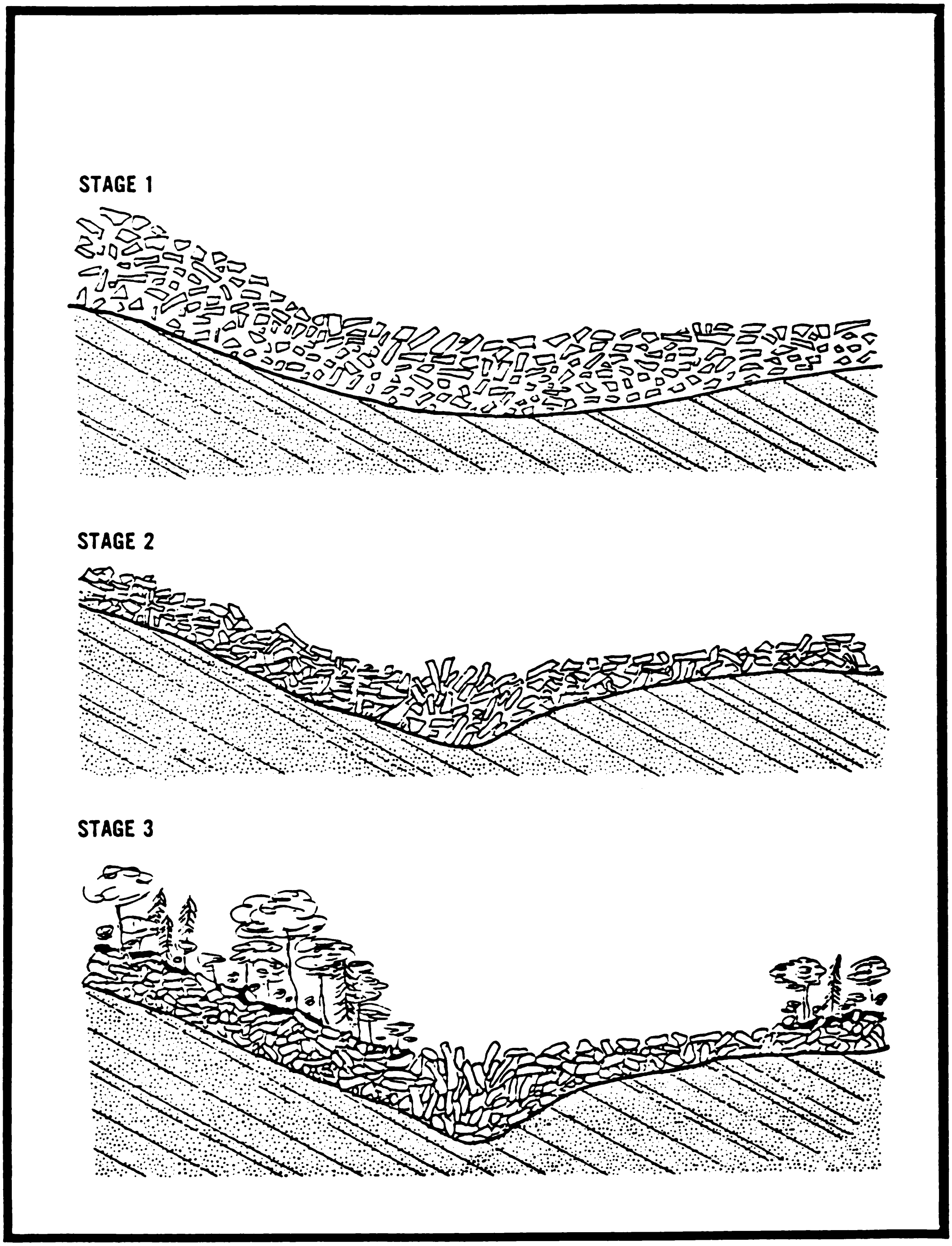

Figure 16. Probable Development of Block Stream Furrows.

Furrows in the block stream began to develop as the channels beneath the blocks extended headwardly and incised themselves into the material below. The removal of the matrix which supported the block mass, and stream incision would have led to the development of the furrows in the block stream; as support was removed the blocks were lowered, on-end, into the valley created by the stream.

Stage 3 may have begun sometime in the early portion of the Holocene and represents a set of ongoing processes. The stream flowing beneath the blocks 1) continued to pipe away material as it was weathered from the blocks, and 2) further incised itself into the bedrock below. I do not see any reasonable alternative to the initial presence and later removal of the fines. During this period, due to stabilization of the mantles and aprons, forest invaded the bare block areas by establishing a thin organic layer from leaf fall, windthrow, and windsnap at the edge of the forest cover. Shade at the edge of the forest mitigated droughtiness and heat accumulation and allowed lichens, grasses, herbs, and shrubs to become established. As the organic layer thickened, seedlings of various tree species were able to gain a foothold.

Subsurface stream flow continues to pipe away both organics and weathering products from the blocks today. In areas away from concentrated stream flow, organics can become established and fines preserved between the blocks. Where streamflow is well-developed near the center of the block mass, piping continues. The open block areas on the block streams are probably maintained today by piping.

Tors and Bedrock-Defended Terraces

Tors and bedrock-defended terraces result wherever the massive Weverton Quartzite, Antietam Quartzite or Catoctin Metabasalt are thick in outcrop and nearly horizontal in orientation. Although these landforms have historically received a great deal of attention in the periglacial literature, no concrete evidence emerged from this study that can be used to support a periglacial origin. Instead, their distribution seems to be strongly related to lithologic and structural control.

Diamictons

The three primary diamicton types identified in this study include recent alluvium, weathered alluvium, and angular regolith in a matrix of fines. Several characteristics facilitate their differentiation. The recent alluvium: 1) lacks distinctive weathering effects, 2) contains rounded pebbles, cobbles, and boulders in a sorted condition within a matrix of fines, 3) includes coarse particles of sandstone, quartzite, and metabasalt, and 4) has a greater proportion of coarse particles compared to fines. These factors indicate a relatively recent age and a fluvial origin for these materials. The weathered alluvium differs from the recent variety in that: 1) the proportion of fines is greater than that of coarse particles, 2) sorting is absent, and 3) the metavolcanics are absent. The angular regolith in a fine-grained matrix lacks sorting and exhibits no evidence of clast rounding. Clearly, three different types of materials previously classified in the literature as diamictons are distributed throughout the study area.

Chronologic and Genetic Relationships of the Block Deposits and Diamictons

Direct evidence for the absolute age of the various deposits in the Northern Blue Ridge is lacking. No materials suitable for radiocarbon dating were located during the field seasons. Other dating techniques such as weathering rind development, rubification of soils, fresh- to weathered-block ratios, angularity, and size of weathering pans and pits are useful only to assess the relative age of deposits unless their development can be tied to absolute age (i.e. radiocarbon). Lichenometry has been used successfully, but only in alpine and arctic environments on very young deposits. Previous researchers working in the Central Appalachians have suggested dates, based on indirect evidence, for surficial deposits that range from Cretaceous to Recent. It is likely that the deposits in the study area extend over a wide spectrum of the Cenozoic Era as well.

Weathering effects are evident on all of the deposits examined and include pits and pans on upper block surfaces, rounded edges, blunted corners, weathering rinds and microtopography stemming from differential mineral decomposition. In most instances, blocks on aprons, mantles, and block streams retain an overall angular form. Blocks on block streams and aprons appear most weathered, blocks on lower mantles are somewhat less weathered, whereas those immediately downslope from scarps are least weathered. This relationship implies that these deposits might be of differing age. Blocks on lower mantles and aprons are smaller than those higher on mantles. This may be related to age differences between aprons and steep block mantle. Blocks emplaced earlier would have been subject to a greater number of freeze-thaw cycles and would reduce to smaller size than those deposited later.

I interpret these data in the following manner. Blocks have continued to be wedged from scarp faces during the Recent and have accumulated immediately below scarp faces. Their relatively fresh appearance, lower lichen densities, and larger size attest to the relative youth of steep block mantles. Lower mantles and aprons must be older as evidenced by more advanced weathering characteristics, smaller block size, dense lichen cover, and, in aprons, interstitial soil development. Steep mantles remain relatively active in the Present while lower mantles, aprons, and block streams are stable.

Steep block mantle below scarps will, with time, stabilize as the scarp position retreats. Material that is now apron was previously mantle.

Some of the diamictons in the study area exhibit characteristics that indicate considerable antiquity: 1) incision of streams through the deposits, 2) reversal of topography, 3) extensive weathering of rounded cobbles, as indicated by "ghosts" in outcrops, and 4) high concentrations of clays and silts that are stratigraphically associated with rounded pebbles, cobbles, and boulders.

Stream incision in excess of 10m requires a considerable but unknown duration of erosion. Rounded clasts that are clearly of fluvial origin cap knobs near the mountain flanks. Topographic reversals of this magnitude probably require a considerable amount of time. The absence of metavolcanic clasts in these deposits indicates a long exposure to weathering. If these deposits were young, metavolcanics would be present because they form a major component of the bed load in modern stream courses within the study area. Clays, silts, and sands dominate the older diamictons while pebbles, cobbles and boulders are secondary. The lack of sorting, close association of the large clasts and fines, and a low percentage of metavolcanics argues for a long period of weathering.

Other diamictons are quite different from the ancient alluvium. Recent alluvium is confined to valley bottoms, and there is no evidence of topographic reversal. The deposits are clast-supported, coarse particles are rounded, and volcanics are present in some exposures indicating a considerably shorter time available for weathering. Most deposits preserve a higher degree of sorting than the weathered alluvium, indicating a much more recent origin.

The recent alluvium probably bears little relation to the block mantles, aprons, and block fields, except to the extent that some clasts in the deposits may have originated as block material wedged from bedrock outcrops during the cold phases of the Pleistocene. Since these deposits are fresh in comparison to the weathered alluvium, they are probably much younger.

Therefore, the only diamictons that might be related to the block deposits are the angular materials set in a fine-grained matrix. Several characteristics of these deposits, reviewed earlier, suggest that they were emplaced by soil flow influenced by active freeze-thaw.

The maximum of the Wisconsinan lasted about 10,000-12,000 years. The Northern Blue Ridge was about 150-175km south of the ice margin at about 18,000 B.P. Climate was certainly rigorous then as demonstrated in previous sections of this thesis. But, could such massive amounts of fragmented debris now found in aprons, mantles, block streams, and diamictons, have been deposited in the relativley short period of about 10,000 years? The ridge-makers in the study area are highly resistant to weathering. The ubiquity of the rubble in the study area suggests that more time was required for deposition than that available during the Late Wisconsinan.

Illinoian and pre-Illinoian deposits in Pennsylvania have been identified within about 50km of the study area.

Because these glacial episodes are known to have been both longer and colder than the Wisconsinan, it follows that the periglacial deposits in the study area might date from pre-Wisconsinan glacials as well.

Although no absolute dates exist for any of the deposits in the Northern Blue Ridge, Watts' (1979) study of Crider's Pond can be used in an indirect manner to infer the date of the cessation of periglacial landform morphogenesis. Pollen deposition probably began at Crider's Pond about 15,000 B.P. Therefore, solifluction slowed at that time creating conditions of sufficient stability to allow pollen deposition to begin.

Chapter Summary

The relict nature of these block deposits is evident from several indicators. The blocks associated with these features appear weathered with rounded corners and edges, and lichens and weathering pits on their upper block surfaces. The undersides of the blocks appear fresh and totally lack lichen growth. Organic soil mats are well-developed in several places on the block streams. No block material could have been added at these locations for a considerable duration based on organic accumulation data. Soil profile development in aprons exhibits no interruptions due to additions of blocks. Forests are encroaching upon all of the open block areas indicating recent stability. Periglacial deposits may date from Wisconsinan to Illinoian time.

Portions of the study area exceeding about 500m in elevation were probably above tree line during the Wisconsinan maximum as evidenced by fossil pollen and fossil mammal indicators of tundra conditions. Temperatures during this time frame were probably depressed by about 10° C in and around the study area.

CHAPTER VI

SUMMARY OF CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Various bouldery deposits and diamictons in the Northern Blue Ridge, thought to be related both in process and time, have been examined for the first time in this regional study as a suite, or continuum, of landforms. Other researchers have investigated similar landforms in the Appalachians as examples of increased frost activity during the Pleistocene, treating the features as isolated cases. But none of these previous studies has considered these landforms together as a landscape profoundly affected by frost action of the Pleistocene.

The objective of this research was to discover the degree to which frost processes effected landscape change in the Northern Blue Ridge during the Pleistocene. More specifically, an attempt was made to: 1) document the character of the bouldery deposits and diamictons, 2) establish the factors that affected their distribution, 3) determine the genetic and chronologic relationships between the boulder deposits and diamictons, and 4) propose mechanisms to explain their development in a periglacial morphoclimatic regime.

Data that support the existence of a Pleistocene periglacial paleoclimate in the study area have been gathered and synthesized from the paleobiological and geomorphic literatures and coupled with field data. I first attempted to establish from the literature that such a paleoclimate is completely reasonable for the study area. I demonstrated that both floral and faunal populations underwent drastic changes during the waning phase of the Late Wisconsinan, from isolated pockets of tundra to boreal conditions, and finally, to a temperate climate. Other areas in the Central Appalachians were shown to exhibit landforms characteristic of former periglacial landscape modification.

I thought that I could demonstrate the widespread effects of a rigorous Pleistocene climate by showing that: 1) the landform continuum in the study area is now largely degenerative and out of phase with the present climate, and that 2) many of the deposits are a product of solifluction heavily influenced by freeze-thaw processes.

Field procedures were designed to gauge the degree of stability associated with the landforms in order to show current decay. Weathering features, lichen growth, forest encroachment, and organic soil accumulations were assessed to detect any current motion. Other field and laboratory procedures were designed to show that aprons, mantle, and block streams were emplaced by solifluction processes that are no longer important morphoclimatic agents in the study area. Solifluction deposits are characterized by coarse particle orientation in a downslope direction, and disrupted, overridden beds. Orientation studies, both in the field and from large-scale aerial photographs, were employed to measure particle alignment strength. Finally, standard field and laboratory techniques were employed to document the character and distribution of the various landforms and deposits.

Major Findings

The major findings of this research include (and are summarized in the sections that follow): the nature of the morphosequence on typical scarp and dip slopes; characteristics of block deposits and diamictons; the chronologic and genetic relationship between block deposits and diamictons; the current stability and decay of the major landforms and deposits; and the degree of morphoclimatic change between the late Pleistocene and the Recent.

Figure 17 shows the typical structural, lithologic, topographic, and areal relationships of the major landforms and deposits in the Northern Blue Ridge. The sequence most often found associated with scarp slopes includes, near the crests, bedrock-defended, stepped terraces, tors, and scarps. Downslope from the scarps, steep, unvegetated block mantle has accumulated. A break in slope occurs near the base of the mantle where the declivity decreases sharply and the mantle grades into the more gently inclined and forested block apron. Depending on the slope angle, tongues and cascades pour out of the block aprons that supply them. Several types of diamictons are often in contact with aprons, tongues, and cascades at the base of scarp slopes.

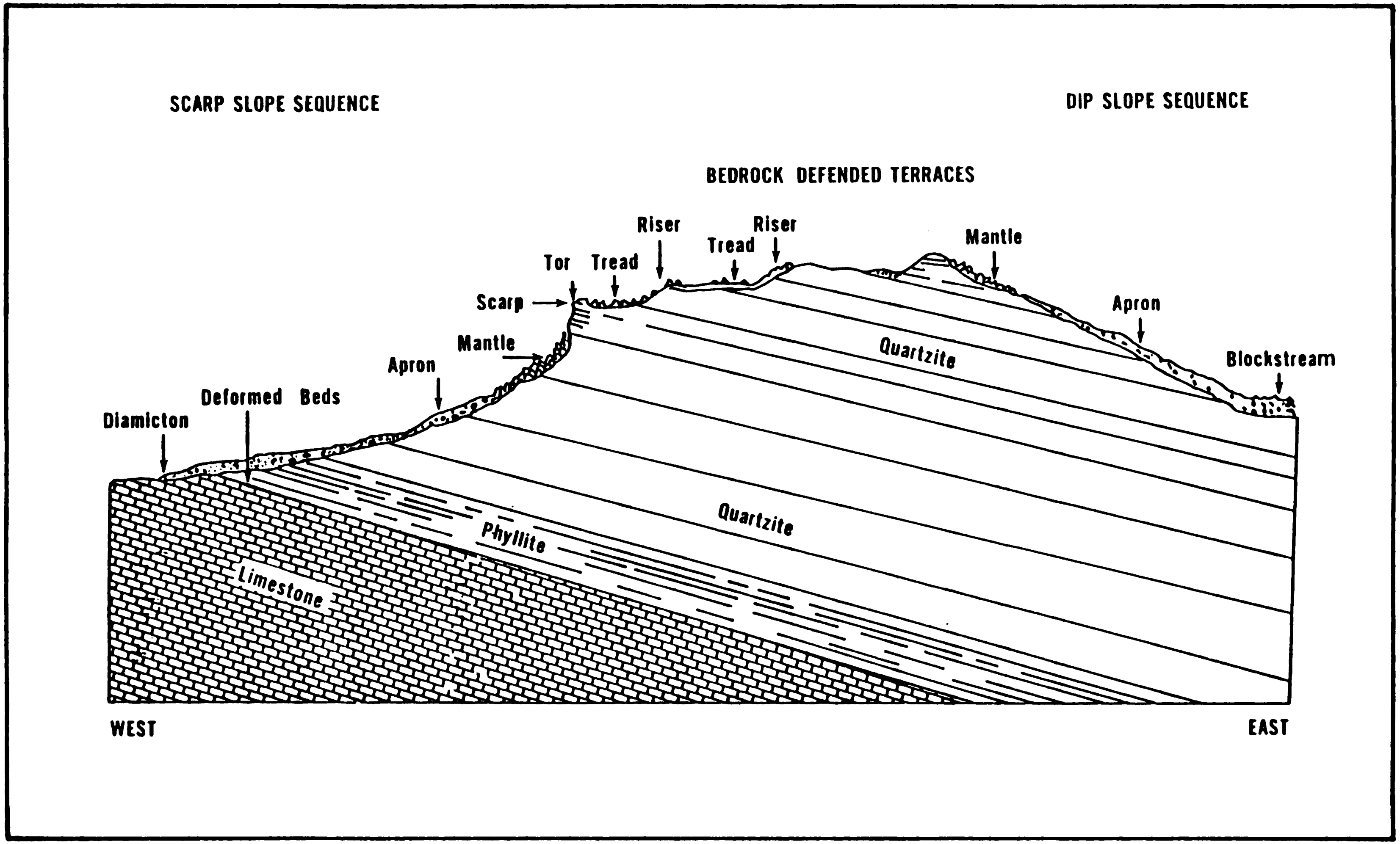

Figure 17. Principal Periglacial Morphosequences in the Northern Blue Ridge.

Dip slope sequences commonly include more poorly developed scarps at summit crests, below which steep block mantle has accumulated. Mantles on dip slopes also grade into forested block aprons on the lower, gentler slopes. Cascades and tongues spill out of block aprons; block streams on low slope at the base of the dip slopes complete the sequence there.

No scarp slope landform sequences were found to include block streams. No dip slopes were found to have diamictons except for terrace deposits related to modern streams.

Diamictons observed within the study area were judged to be of three types: 1) modern alluvium, 2) ancient, weathered alluvium, and 3) angular materials (colluvium). The first two types are probably unrelated to increased frost action of the Pleistocene while the third type exhibits evidence of deposition promoted by increased freeze-thaw and solifluction.

No absolute age for any of the deposits and landforms in the study area was established in this study. But, based on indirect evidence, I conclude that the landforms and deposits in the Northern Blue Ridge were probably initially emplaced during pre-Wisconsinan times and weathered during the Sangamon Interglacial. The return of cold conditions during the Late Wisconsinan resulted in additional deposition and modification of previously deposited materials. It seems improbable that such widespread blocky materials could have been deposited during the relatively short Late Wisconsinan and then blunted, rounded and pitted from post glacial time to now.

Evidence points to a genetic relationship between all of the deposits and landforms that I examined in this study, except the two types of diamictons termed modern alluvium and weathered alluvium. The block deposits are products of previously enhanced frost weathering that has now largely ceased and has been supplanted by chemical weathering in the Recent. The modern and weathered alluvium are clearly fluvial deposits.

The major landforms and deposits are judged to be relict and stable. Several factors indicate a decrease of material supplied from upslope during the Recent. Lichen growth on exposed block surfaces and their lack on undersides suggests immobility at most sites. Measurement of maximum lichen diameters prove immobility of blocks for up to 175 years. Forest disturbance on block mantles, aprons, and block streams is minimal as evidenced by lack of damage to trees. The absence of scarring and tilting suggests that damage caused by rolling and tumbling blocks must be rare when compared to the life span of tree species. Organic soil accumulations on the surface of aprons and block streams indicates stability up to 2350 years. Weathering effects, such as pits, rinds, rounded corners and edges, and micro-relief on exposed block surfaces and their lack on unexposed surfaces indicate relative stability of considerable but unknown duration.

Several lines of evidence allowed the reconstruction of the late-Wisconsinan MAAT and tree line. Lack of positive evidence for widespread, continuous permafrost (ice-wedge casts) suggests that MAAT were above a range of -10° C to -4° C. The lack of large-scale patterned ground suggests that MAATs were generally above -2° C to 0° C. Using a conservative temperature depression of 10° C for the study area during the Wisconsinan maximum indicates a MAAT of around 0° C to 2° C. Tree line, reconstructed from various geomorphic, palynologic, and paleontologic evidence, passed through the areas above about 500m during the Wisconsinan maximum.

Bare block mantles of large extent and block streams are uncommon in the study area while vegetated aprons, tongues, cascades, and stoney land are widespread. The enormity of these deposits in the study area indicates that Pleistocene morphoclimates were indeed rigorous in the Northern Blue Ridge in order to have emplaced such large volumes of debris over extensive areas.

Suggestions for Further Research

At least one page in the story of the Pleistocene for the Northern Blue Ridge remains virtually unturned, that relating to absolute chronology. The lack of a time frame is most disturbing and I think that this problem should be addressed in any future study. Two techniques that have gained considerable attention in recent years might shed significant light on the age of these deposits; they include thermoluminescence dating and rock varnish dating.

Exposure to sunlight during weathering effectively erases light emitted from minerals. After deposition, sediments again will acquire thermoluminescence (Bradley, 1985). Though still in its infancy, this technique might prove valuable in assessing the age of matrix materials in diamictons and block deposits.

Dark stains coat the coarse particles of diamictons of fluvial origin and block deposits in the study area. Rock varnishes are accumulations of iron and manganese oxides and organic matter. Several authors have noted the presence of these stains on deposits in the Northern Blue Ridge and I have observed and noted them in the course of this research. Rock varnish has been used recently to date the onset of varnish formation and to approximate the age of deposits. Potentially, paleoenvironmental and paleoecological information may be extracted from the organic matter tied up in these accumulations (Dorn, 1983, 1985). Both of these techniques might substantially augment understanding of the Quaternary chronology in the Central Appalachians.

Other research possibilities center around the further utilization of the degree of weathering rind development to detect age differences between steep block mantle, mantle on low slope, and aprons. Distinctly different weathering rind thickness on mantles and aprons could add substance to the notion that aprons are older than, and continue beneath, steep block mantles.

APPENDICES

APPENDIX A

Chapter IV treats the characteristics of the major landforms and structures in detail, but additional material pertaining to block streams is shown here as Figures A1-A4.

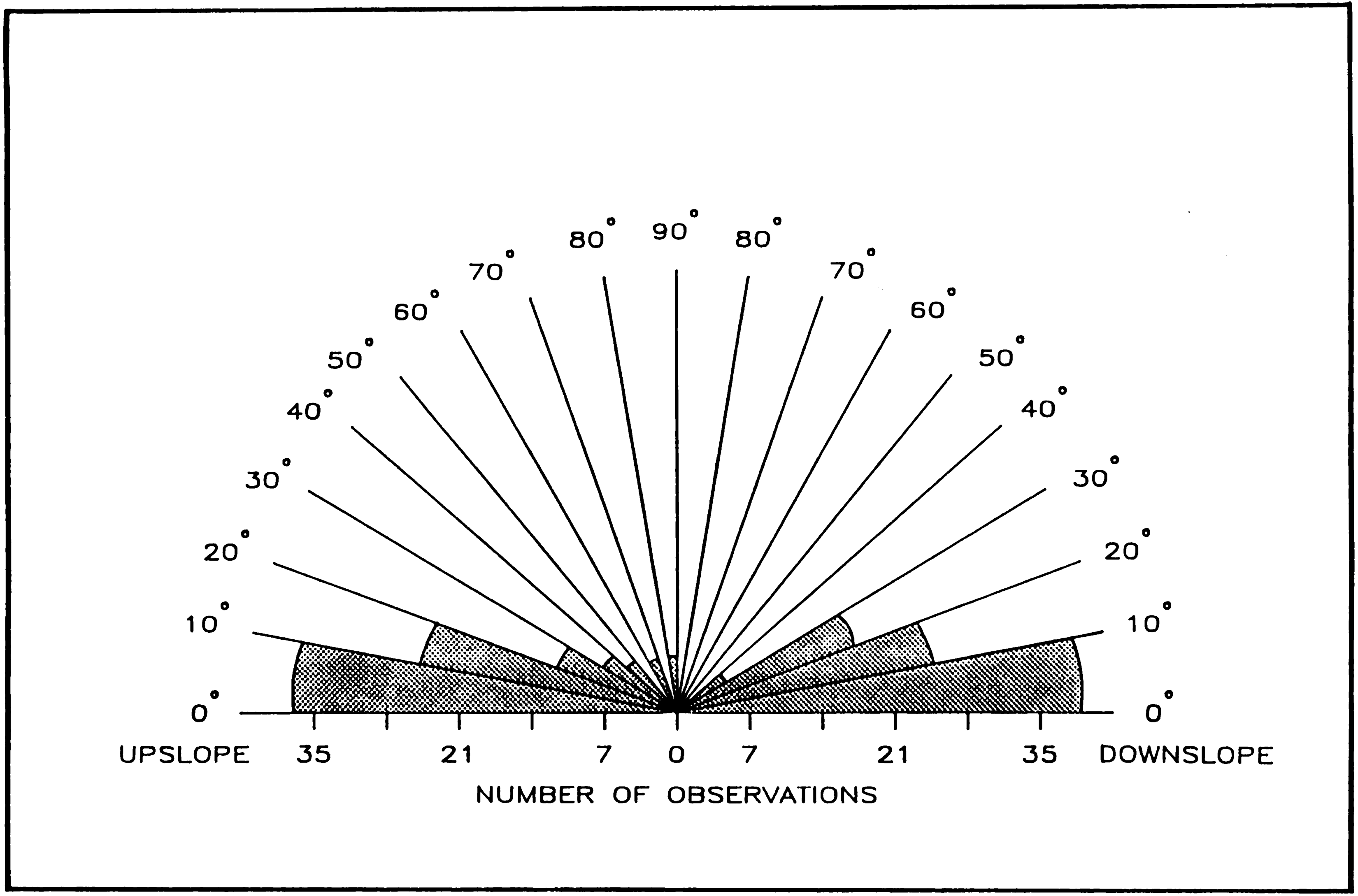

Figure A1. Block Dip at Devil's Race Course Block Stream.

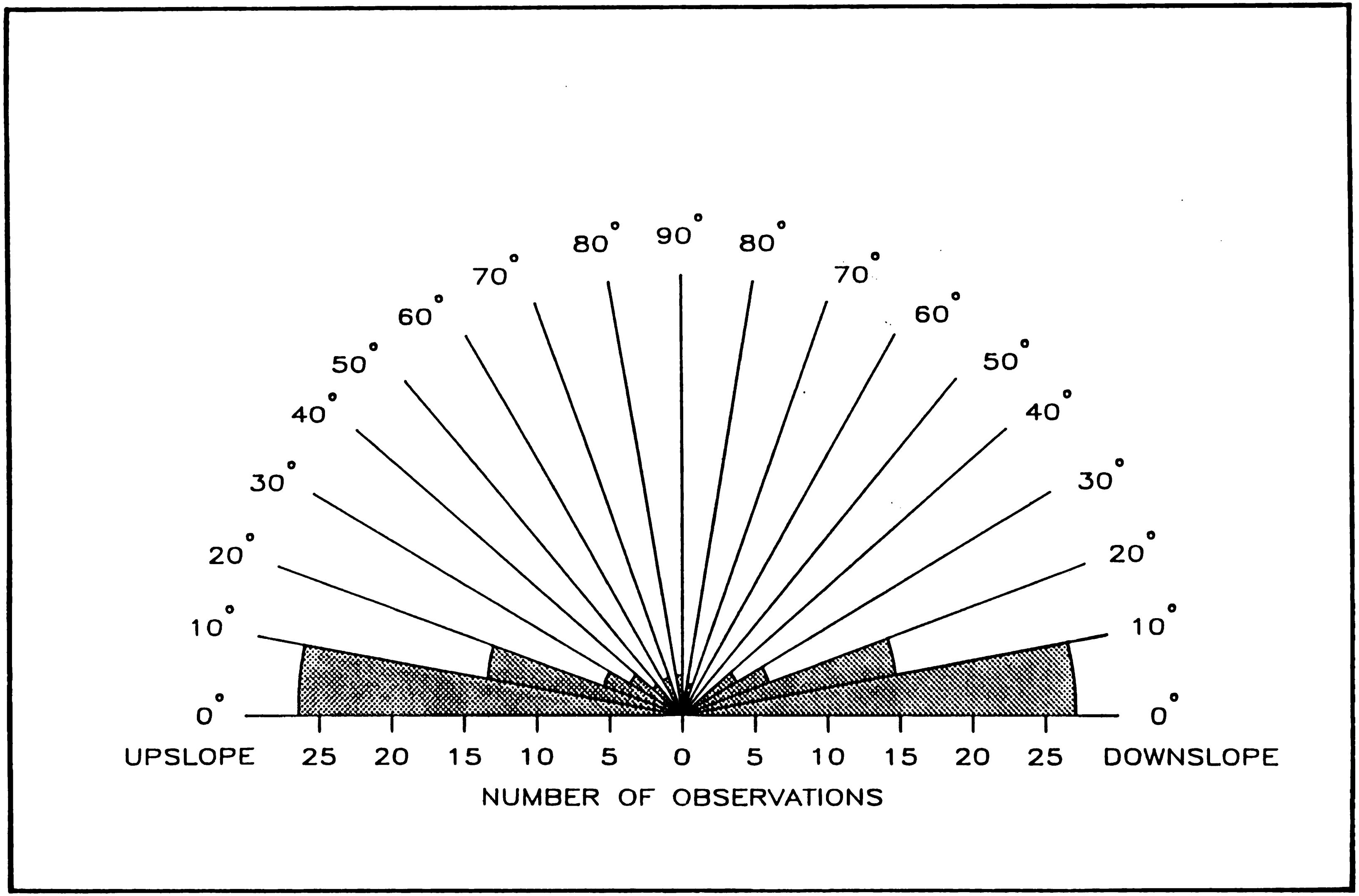

Figure A2. Block Dip at Wolfe Road Block Stream.

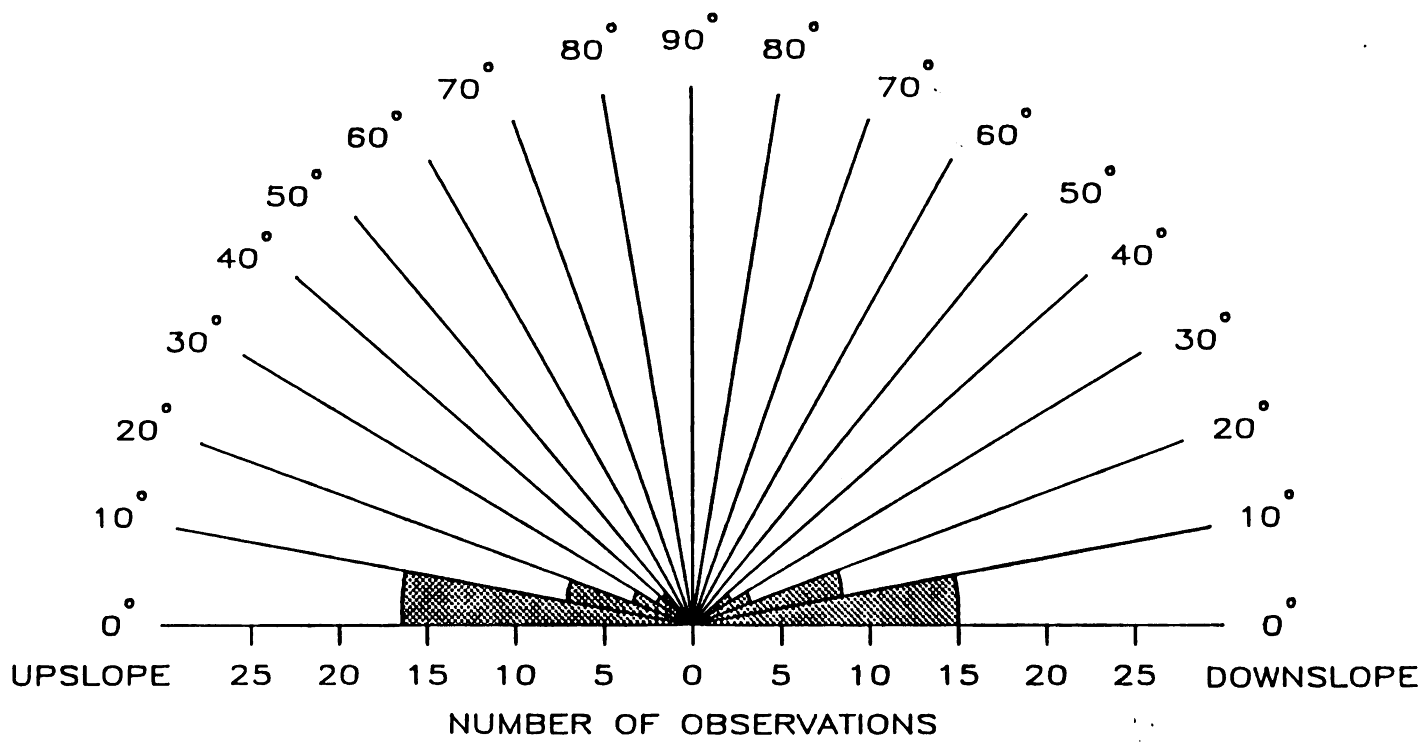

Figure A3. Block Dip at Staley Road Block Stream.

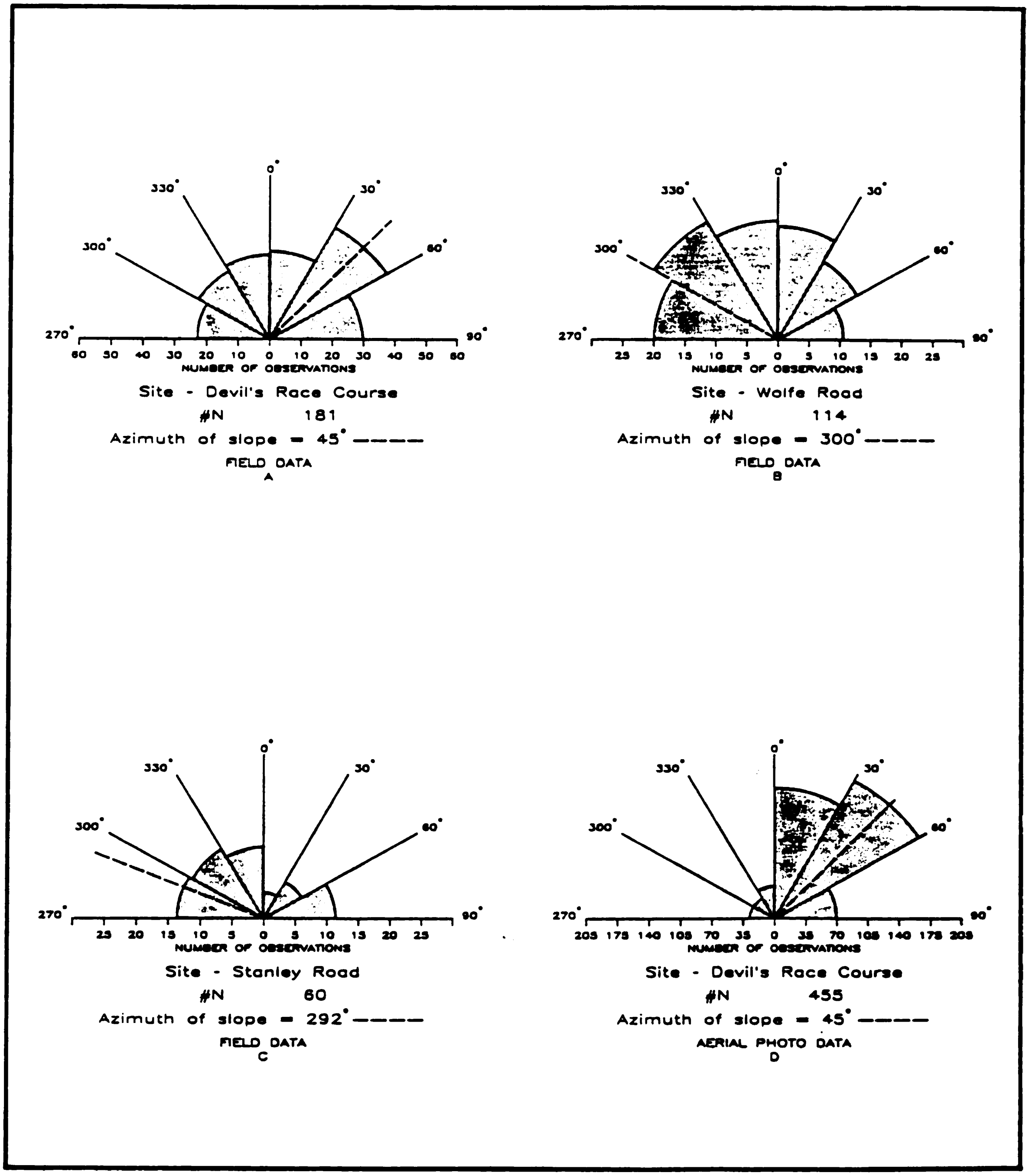

Figure A4. Block Orientation.

APPENDIX B

SITE	U.S.G.S. 1:24,000 TOPOGRAPHIC MAP	LATITUDE AND LONGITUDE	COMMENT
<u>Mantles</u>			
1. Black Rock-Annapolis Rock	Myersville, MD	39°34'N 77°35'W	Accessible from Appalachian Trail
2. Washington Monument	Myersville, MD	39°30'N 77°37'W	Accessible from Washington Monument State Park and Appalachian Trail
3. Bisecker's Gap	Waynesboro, PA	39°38'N 77°32'W	Accessible from Bisecker's Gap Road
4. Sliding Rock Mountain	Walnut Bottom, PA	40°02'N 77°23'W	Accessible from Village of Brookside
5. High Rock	Smithsburg, MD-PA	39°41'N 77°31'W	On Appalachian Trail near Pen Mar, PA
6. Crampton's Gap	Keedysville, MD-WV	39°24'N 77°38'W	Accessible from Maryland Rt. 67 at Gathland State Park
<u>Block Streams</u>			
7. Devil's Race Course	Smithsburg, MD-PA	39°40'N 77°31'W	Accessible from Ritchie Road, off of Maryland Rt. 491
8. Wolfe Road	Myersville, MD	39°36'N 77°34'W	Accessible from Black Rock Road
9. Staley Road	Waynesboro, PA	39°48'N 77°30'W	Accessible from Staley Road along Trucker Run
<u>Diamictons</u>			
10. Boonesboro High School	Funkstown, MD	39°31'N 77°39'W	Off Maryland Rt. 66 at Boonsboro, MD
11. Smithsburg, MD Maryland	Smithsburg, MD-PA	39°40'N 77°32'W	1.6km NE of Smithsburg, MD on Maryland Rt. 92
12. Raven Rock Hollow	Smithsburg, MD-PA	39°40'N 77°32'W	2.3km NE of Smithsburg, MD on Maryland Rt. 92
13. Fayetteville, PA	Scotland, PA	39°55'N 77°32'W	Accessible from Pennsylvania Rt. 997

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