SOUTH MOUNTAIN GEOMORPHOLOGY

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INTRODUCTION

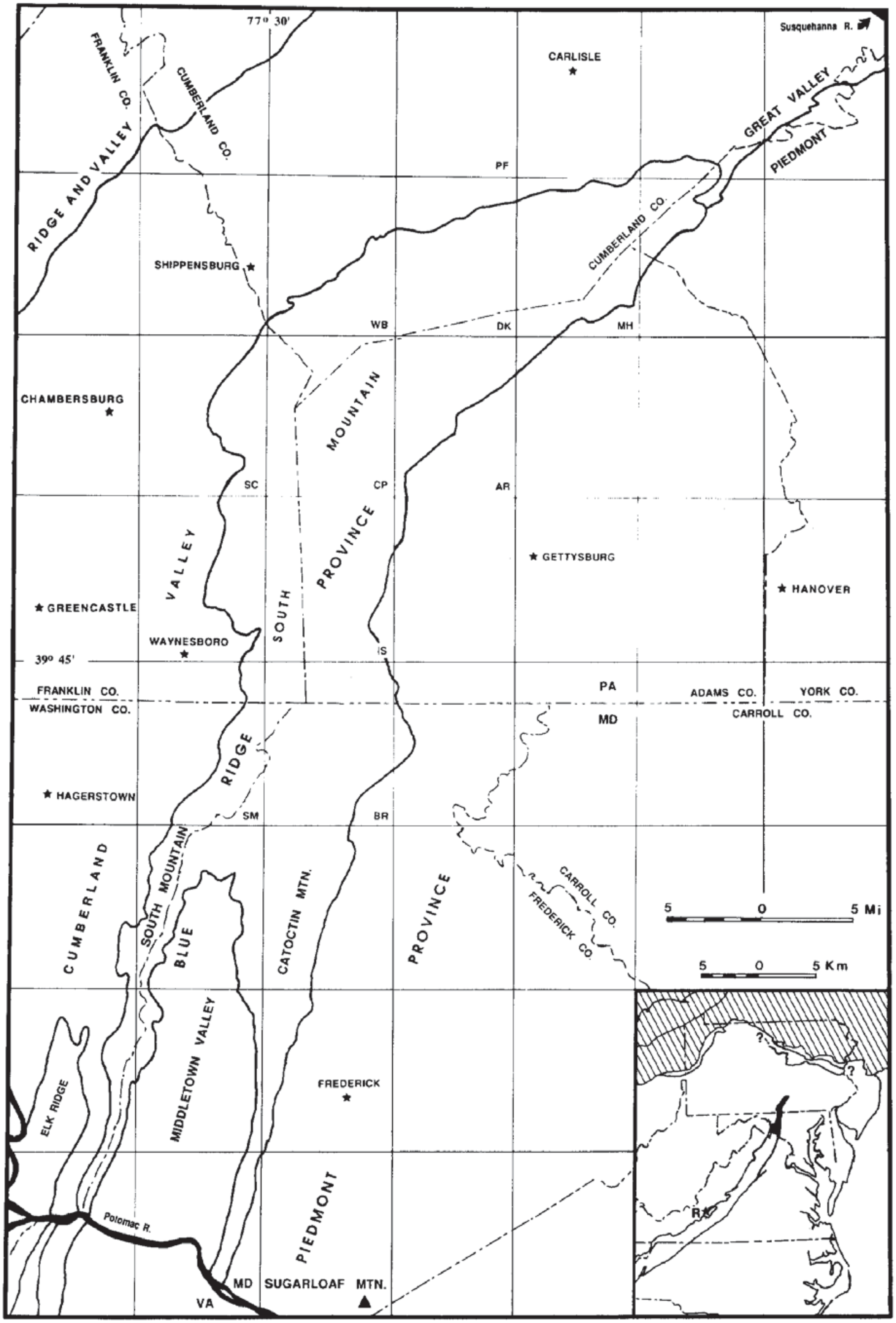
South Mountain is geographically near the midpoint of northeast-southwest Central Appalachian structural trends and comprises the northeastern terminus of the northern section of the Blue Ridge geomorphic province which extends south to the latitude of Roanoke, Virginia (Figure 11). Several modern overviews provide background for the present state of geomorphic research in this part of the Appalachians south of the glacial borders. Mills and others (1987) summarized studies of Appalachian geomorphic research and noted some pressing landscape origin problems in the region. Gardner and Sevon (1989) brought together papers on geomorphic evolution of the Appalachians that focused attention on fundamental questions about the geomorphic history of this mountain system. Mills and Delcourt (in press) describe several aspects of the nonglacial Quaternary geology of the Appalachians, including hillslope, fluvial, and periglacial features. South and Catoctin Mountains are at once both unique geomorphic entities and microcosms of Appalachian mountain geomorphology; they have individualistic landforms and materials, plus they illustrate subsets of problems in mountain geomorphology that are representative of many other parts of the Central Appalachians.

The origins of topography and drainage remain at the core of classical American geomorphology. Among the many unsolved geomorphic problems on South and Catoctin Mountains are the existence of accordant ridge tops that locally truncate lithology and structure in the upland areas, and the origin and evolution of the fluvial drainage from and around this massif. Early workers explained the summit "levels" as remnants of a once-continuous peneplain; subsequent arguments simply were about the number of partial peneplains that existed and about their correlation with surfaces elsewhere in the Appalachians. Fenneman (1938), for example, cited as distinctive the summit level at 366-396 m elevation on South Mountain that extends 8-10 km north of Potomac River and then is abruptly replaced by higher elevations to the north. With respect to the genesis of Central Appalachian rivers, this mountain range does not figure prominently in published drainage evolution schemes that mainly targeted the origin and evolution of transverse drainage. This omission is due, at least in part, to the fact that this upland is not bisected by transverse drainage north of the Potomac River.

As the father of the geographical cycle of erosion concept, Davis (1889) illustrated his notions about the peneplain as an ideal end state of fluvial erosion using the nearby Ridge and Valley province in Pennsylvania. The highest ridge crest levels were interpreted by Davis (1889) as remnants of a once-continuous peneplain, and the transverse paths of master rivers were used as supporting evidence. Davis' promulgation of the geographical cycle of erosion was so effective that for decades many workers concentrated on definition, description, and correlation of numerous summit level accordances, and the most common hypothesis used to explain Appalachian upland surfaces and transverse drainage was the peneplain concept (Sevon and others, 1983). Since the peneplain concept fell from favor (e.g., Flemal, 1971), a common practice has been to deny, ignore, or explain away the fact that ridge top relationships do exist. The ascendance in importance of process geomorphology in the United States might have discouraged researchers from investigation of field relationships that smacked of regional denudational chronology. Mills and others (1987) remarked on the overall shortage of geomorphologists working in the Appalachians, and noted many pressing applied geomorphic problems in the region that require significant input of human resources. These trends in American geomorphology, and perhaps other factors, have resulted in a nearly-complete stasis of geomorphic research on upland surfaces in the region as a whole and in the Northern Blue Ridge section in particular. Whatever the reasons, there is little modern geomorphic research on South and Catoctin Mountains to synthesize, although there are several excellent individual studies of selected features and areas (e.g., Godfrey, 1975; Middlekauff, 1987).

Geomorphic research today is concerned with aspects of process geomorphology, applied geomorphology, and Quaternary geology and geomorphology that are based upon sound theoretical and operational concepts, and that draw from related sciences in an interdisciplinary format. Examples of research that would be highly appropriate to further our understanding of South and Catoctin Mountain geomorphology could include: geomorphic studies of hillslope and fluvial processes; measurement of weathering, erosion, and denudation rates for selected catchments; dating the numerical ages of exposure and erosional histories of geomorphic surfaces using new cosmogenic methods; and surface and subsurface geomorphic and geophysical investigation of the complex diamicton deposits.

Figure 11. Opposite page. Index map of South Mountain-Catoctin Mountain area. Inset map shows northern section of the Blue Ridge geomorphic province, which extends from latitude of Roanoke, Virginia (= R) to northeastern end of South Mountain, Pennsylvania. Lined area = extent of Late Wisconsinan ice at 18 Ka; solid lines beyond 18 Ka border = extent of Pre-Wisconsinan ice; data from northeastern Pennsylvania courtesy of D.D. Braun. Main Map: Rectangular gridding shows location of 7.5-minute quadrangles; AR = Arendtsville; BR = Blue Ridge Summit; CP = Caledonia Park; DK = Dickinson; IS = Iron Springs; MH = Mount Holly Springs; PF = Plainfield; SC = Scotland; SM = Smithsburg; WB = Walnut Bottom. Base map from U.S.Geological Survey, 1:250,000 sheets, Harrisburg and Baltimore sheets.


77° 30'
Susquehanna R.
FRANKLIN CO.
CUMBERLAND CO.
CARLISLE
RIDGE AND VALLEY
GREAT VALLEY
PIEDMONT
PF
CUMBERLAND CO.
SHIPPENSBURG
WB
DK
MH
CHAMBERSBURG
SOUTH MOUNTAIN PROVINCE
SC
CP
AR
VALLEY
GETTYSBURG
GREENCASTLE
HANOVER
WAYNESBORO
IS
39° 45'
FRANKLIN CO.
WASHINGTON CO.
PA
MD
ADAMS CO.
YORK CO.
CARROLL CO.
RIDGE
HAGERSTOWN
SM
BR
CUMBERLAND
SOUTH MOUNTAIN
BLUE
CATOCTIN MTN.
PROVINCE
CARROLL CO.
FREDERICK CO.
5 0 5 Mi
5 0 5 Km
ELK RIDGE
MIDDLETOWN VALLEY
FREDERICK
PIEDMONT
Potomac R.
MD
VA
SUGARLOAF MTN.
?
?
R

REGIONAL GEOMORPHOLOGY

The concept that there are discrete natural regions that can be defined and circumscribed was richly developed by German and French geographers who identified and described areal entities they named Landschaften and pays, respectively. The traditional method of classification has been that of subdivision, with the construction of a descending hierarchy of successively finer subdivisions. The weakness in this approach, of course, is that it assumes we have some understanding of the causes of similarity and variation within and between landscape categories. Nonetheless, the regional concept was eagerly adopted by botanists, climatologists, foresters, geographers, physiographers, and soil scientists in western countries. In the United States the classical criteria for recognition of geomorphic provinces have been similarities or differences in: geologic structure, lithology, topography, and geologic history (Thornbury, 1965). Today in areas where landmasses can be identified as collages of microplates, this tectonic attribute can often be used effectively as a regional geomorphic criterion. Landscapes also bear the stamps of the various formative climatic environments under which they have evolved, although this factor has largely been ignored in American regional geomorphology. Finally, the operation of similar geomorphic process groups should logically be expected to result in similar erosional and depositional landforms, so that landform genesis would also seem to be a highly desirable criterion. Many process geomorphologists, however, would no doubt argue that to implement such a scheme successfully would require data and genetic understanding far in excess of those available at present.

The striking geologic and physiographic similarities within and differences between geographically large land units in the Appalachian Highlands lend themselves well to this type of landscape analysis. Fenneman (1938) and Thornbury (1965) agreed that the best rationale for dividing a landmass into provinces is the one that allows the greatest number of general statements about each subdivision before qualifications and exceptions become necessity. In most areas of the Appalachians, however, subdivision has not progressed much beyond subdividing provinces into sections. One hindrance to the advancement of regional geomorphology has been its lack of a quantitative basis. Godfrey and Cleaves (1991) specifically targeted the quantification of areal magnitude as a topic requiring numerical treatment if effective systems of landscape classification are to evolve, and constructed a ranking of landscape units based upon areal extent. The Godfrey and Cleaves (1991) hierarchy lends itself well to classification of landscape units in the Central Appalachians, and has been modified for use in the South Mountain area (Table 4).

An informal application of landscape classification to the South Mountain-Catoctin Mountain massif is illustrated in Table 5; some of the units are mapped onto Figure 12. Refinement of sectional-level landscape units into subsections, districts, and subdistricts is possible using existing geologic and topographic maps, and these subdivisions can be observed in the field. In

Table 4. Ranking of landscape units used in description of South and Catoctin Mountain landforms and landscapes. Modified from Godfrey and Cleaves (1991).

Rank/Areal Magnitude (km^2)		Basis (Dominant Entity)	Examples
Realm	10^7	Largest plate-tectonic units	North American Plate
Major Division	10^6	Sub-continental entities	Appalachian Highlands
Province	10^5	Regional similarity	Ridge and Valley; Blue Ridge
Section	10^4	One tectonic-landscape style	Northern Blue Ridge
Subsection	10^3	Structure-landform similarity	South Mountain; Catoctin Mountain
District	10^2	Form-material relationships	Middletown Valley
Subdistrict	10^1	Direct material-form linkage	Ridge Road Upland
Zone	10^0	Few form-relief parameters	Diamicton apron
Locale	10^{-1}	Individual landforms	Stream terrace remnant
Compartment	10^{-2}	Single form/relief units	Lobe or terrace slope break
Feature	10^{-3}	Specific microform	Opferkessel; expanded fracture
Fracture			

Table 5. Informal subdivision of landscape lnits in the South Mountain-Catoctin Mountain area.

Province	Piedmont	Blue Ridge	Ridge and Valley
Province	Piedmont	Northern Blue Ridge	Middle Section
Section	Mesozoic extensional basins	South Mountain-Catoctin Mountain	Appalachian Great Valley
Subsection	Gettysburg Basin	Strong belt of NE-SW trending linear ridges	Cumberland Valley
District	The border fault zone complex	Ridge upland	Shale uplands
Subdistrict	Diabase dike ridge (major individual)	Diamicton footslopes	Carbonate lowlands

general, landscape units follow structural trends and the map patterns of lithologic units, as might be expected in a deeply-eroded old fold-belt mountain system. One striking difference, however, can be seen by contrasting the appearance of the west and northwest sides of South Mountain and the north half of the east side of Catoctin Mountain as shown on Figures 11 and 12. Northwest and west of South Mountain are extensive constructional lobelike aprons and sheets of diamicton deposits that extend out from the mountain fronts from one to several kilometers, achieve known thicknesses ranging up to 137 m, and thus are largely responsible for creating topographic form in these areas. The form and relief of this landscape is further complicated by the destructional effects of subsurface solution of the underlying carbonate bedrock, so that an unknown amount of land surface subsidence has occurred as well. Landscape classification, therefore, need not be restricted to the practical classification of land for planning and management; it can also have theoretical value in delimiting morphogenetic units. European and Canadian physical geographers, for example, have refined the techniques of geomorphological mapping in an attempt to provide a cartographic explanation of all of the mappable relief elements in an area.

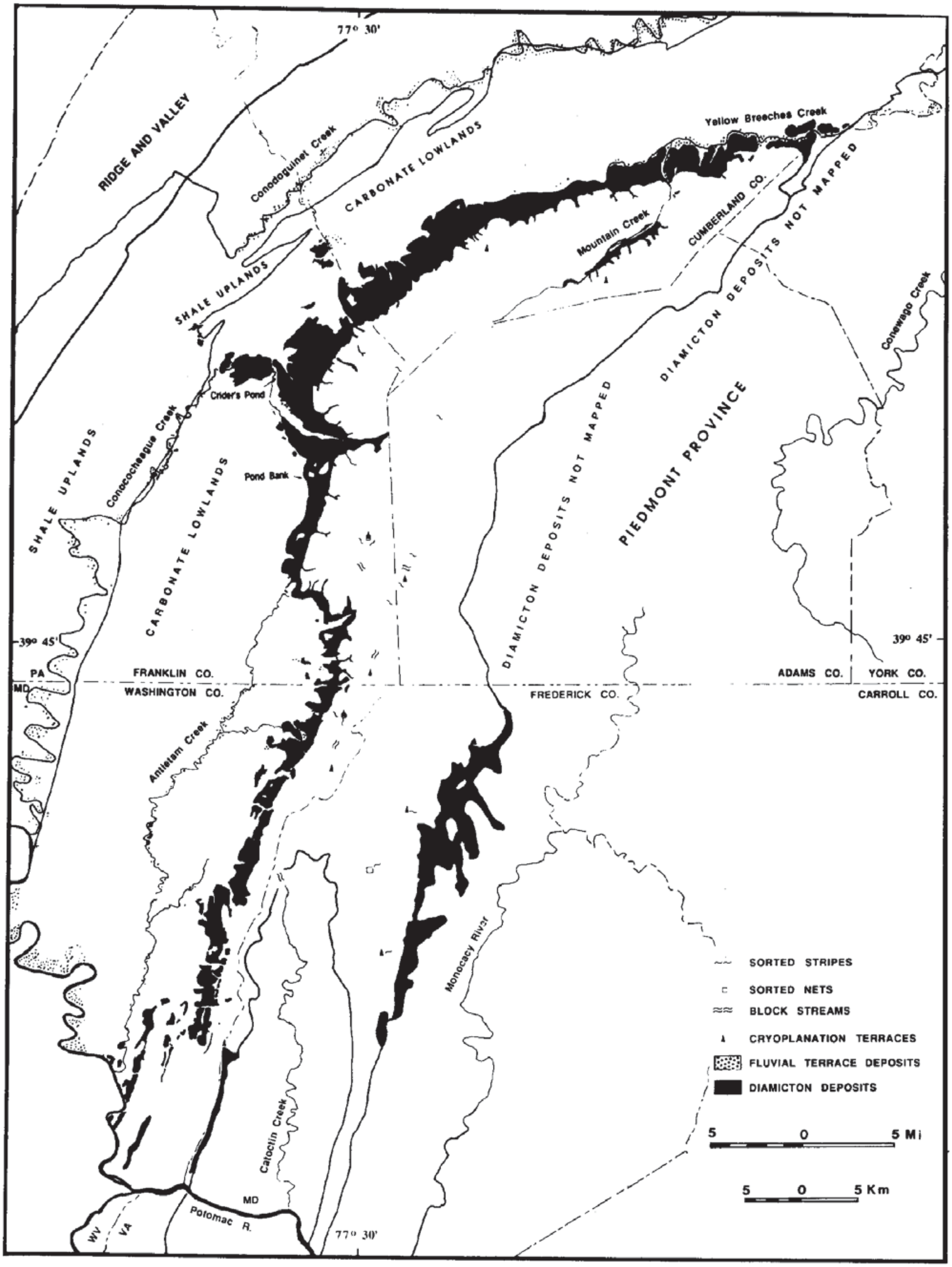
TOPOGRAPHY

The South and Catoctin Mountain massif extends 107 km from about 20 km WSW of the Susquehanna River to the Potomac River; first S45°W, then abruptly S25°W into Maryland, and finally, S10°-20°W to Potomac River (Figure 11). The sharp change in structural and topographic grain of South Mountain is at the latitude of Caledonia Park, and occurs across the Carbaugh-Marsh Creek fault zone that separates different folding intensities. Fauth (1968) reported that folds north of the Carbaugh-Marsh Creek fault zone are more numerous and more intensely developed than those south of the fault zone. In Pennsylvania and northern Maryland, South Mountain varies relatively little in width, averaging about 15 km. In Maryland, about 15 km south of the Mason-Dixon line, the Middletown Valley opens to the south separating South Mountain from Catoctin Mountain, both of which trend S10° to 20°W to Potomac River. South of the opening of Middletown Valley both South and Catoctin Mountains narrow toward the Potomac River, ranging in width from 1-3 km.

In the central part of the range in Pennsylvania and northern Maryland, the gently rounded to flat-crested upland summits reach 525-640 m; their slope angles vary from nearly horizontal to about 15°, except near and in the narrow V-shaped first- to third-order valleys where sideslopes of 20°-30° are common. On the outer mountain flanks away from exiting valleys, slopes increase and then decrease valleyward in a generally upward convexo-concavo form through a wide range of slope angles. Away from stream valleys that exit the mountain, the steeper crest slopes range from about 17°-23°. The lower midslopes range from about 6°-12° with an average around 9°. Footslopes on diamicton sheets and aprons are in the 1°-2° range in undissected areas. Maximum mountain relief is about 375 m and average local relief is approximately 130-200 m.

Where split by the Middletown Valley in Maryland, South and Catoctin Mountains have form differing from the topography in South Mountain to the north, and from each other.

Figure 12. Opposite page. Map showing locations of selected periglacial features, and locations of large fluvial terrace and diamicton deposits. Diamicton deposits in Cumberland, Franklin and Washington Counties generalized from 1:24,000-scale mapping completed from county soil surveys by N. Potter. Mapped diamicton deposits include bouldery, cobbly, and sandy deposits; some small areas of high alluvial terrace gravels, residual sand from weathering of the Antietam Formation, and other materials may be included at this scale. Areal distribution of diamicton deposits in Frederick County highly generalized from county soil map, and may include areas of fluvially reworked and retransported material, especially bordering streams and in distal areas. Mapped terrace deposits are old alluvium above modern flood levels, except for lowest terrace levels which may be flooded during extreme events. Base map from U.S. Geological Survey, 1:250,000 series, Harrisburg and Baltimore sheets.


77° 30'
RIDGE AND VALLEY
Conodoguinet Creek
CARBONATE LOWLANDS
SHALE UPLANDS
Yellow Breeches Creek
Mountain Creek
CUMBERLAND CO.
DIAMICTON DEPOSITS NOT MAPPED
Conewago Creek
Crider's Pond
Pond Bank
Conococheague Creek
SHALE UPLANDS
CARBONATE LOWLANDS
DIAMICTON DEPOSITS NOT MAPPED
PIEDMONT PROVINCE
DIAMICTON DEPOSITS NOT MAPPED
39° 45'
39° 45'
PA
MD
FRANKLIN CO.
WASHINGTON CO.
FREDERICK CO.
ADAMS CO.
YORK CO.
CARROLL CO.
Antietam Creek
Monocacy River
Catoctin Creek
WV
VA
MD
Potomac R.
77° 30'
SORTED STRIPES
SORTED NETS
BLOCK STREAMS
CRYOPLANATION TERRACES
FLUVIAL TERRACE DEPOSITS
DIAMICTON DEPOSITS
5 0 5 Mi
5 0 5 Km

South Mountain represents the overturned western limb of the Blue Ridge Anticlinorium, with the topographic crest predominantly underlain by the Middle, or Ledgemaker Member of the Weverton Formation. To the east, Catoctin Mountain in the north is underlain by wide outcrop widths of the Weverton Formation that narrows southward, and in the south by a continuous strip of the Loudon Formation and by increasing outcrop widths of the Catoctin Formation.

DRAINAGE

No throughgoing fluvial system bisects the Blue Ridge north of the Potomac River, and surface runoff from South and Catoctin Mountains is therefore longitudinal either to the Potomac or the Susquehanna (Figures 11 and 12). The northern end of South Mountain is drained by Yellow Breeches Creek, tributary to Susquehanna River. Northwest of South Mountain the central and master streams draining Cumberland Valley are Conodoguinet Creek northeast to Susquehanna River, and Conococheague Creek south to the Potomac River. The longitudinal surface divide of contest is about 1.5 km south of the Shippensburg-Scotland 7.5-minute quadrangle boundary. South from the northern part of the Waynesboro quadrangle, however, Antietam Creek drains the mountain front southward to Potomac River. Southeast of South Mountain the main streams receiving flow from South Mountain are Conewago Creek draining northeast to the Susquehanna River, and, southwestward, for South and Catoctin Mountains, the Monocacy River which flows south to the Potomac River.

Within South Mountain map patterns in the low order drainage basins tend to be trellis-shaped on clastic rock units and dendritic on the Catoctin Formation. First-, second-, and third-order streams as delimited on 1:24,000 topographic maps have steep gradients about 55-75 m/km to their exits from the mountain fronts, where gradients drop to an average of 30 m/km on proximal diamicton aprons and decrease rapidly toward distal areas. On many such deposits, especially over carbonate bedrock units, the smaller streams are not perennial, and only the larger streams maintain surface drainage to the major longitudinal valley drainageways.

There is some evidence for structural control for the siting of certain stream reaches and individual "straight" stream segments. On South Mountain, several larger streams tend to parallel the position of mapped faults. For example, the fault trace of the transverse Carbaugh-Marsh Creek Fault is remarkedly parallel to the course of Conococheague Creek over most of its alluvial valley within the Scotland quadrangle (Fauth, 1968, Plate 1). This part of the valley is floored with alluvium, however, so that bedrock is obscured. A segment of the headwater area of Conococheague Creek northeast of the Chambersburg Reservoir is also paralleled with a mapped longitudinal fault (Fauth, 1968, Plate 1). Mountain Creek exits South Mountain in a water gap along a mapped transverse fault (Freedman, 1967). Of course there are many straight stream segments and water gaps on South Mountain that do not coincide with mapped faults or other known bedrock structures. Faults are not easily identified on South Mountain because of: the large thickness of mappable rock units, lithologic similarity in different parts of the stratigraphic section, gradational rock unit contacts, lack of stratigraphic control, and almost continuous soil cover. Moreover, streams may follow shattered and unhealed bedrock along structures that lack offsets such as lineaments, fracture traces, and major joints. Thus, the very limited bedrock exposures on South Mountain preclude any rigorous tests of structural control on stream location.

West of South Mountain in the Hagerstown Valley, Maryland, Nutter (1973) was able to locate sufficient exposures in carbonate bedrock units to map joint patterns. He compared rose diagrams of straight stream reaches with rose diagrams of joint strikes in an area north of the junction of Antietam and Beaver Creeks and concluded that the drainage pattern of Antietam Creek is strongly controlled by strike and cross joints, and that the map pattern of Beaver Creek also showed some, but lesser, joint control.

In the mountains only the larger creeks have floodplains that are continuously developed for appreciable lengths along their courses, and that have widths mappable at a 1:24,000 scale. Examples on South Mountain are Mountain Creek, Antietam Creek, and Conococheague Creek. In the Middletown Valley, Maryland, Catoctin Creek is tributary to Potomac River, and has developed a floodplain on Precambrian crystalline rocks in the core of the South Mountain Anticlinorium.

WEATHERING AND SOIL GEOMORPHOLOGY

Modern research throws increasing doubt on the simple dichotomy of physical versus chemical weathering; much weathering is turning out to be biochemical. Nonetheless, an elementary distinction can be made between clastic rocks that appear, on the outcrop level, to fragment mechanically (Figure 13), and those where loss by solution is evident. The only quantitative study of the effects of weathering in land denudation in the South and Catoctin Mountain area is by Godfrey (1975) who concluded that terranes with different lithologies would undergo differential lowering over time. An apparent paradox in the South Mountain upland is represented by extremes of rock decomposition. For example, there are exposures of firm bedrock, such as Hammond's Rocks (Stop 8), and sites where deeply-weathered, in-place, thoroughly rotted rock, or saprolite, occur such as Mt. Cydonia (Stop 5). Some, but certainly not all, of these weathering extremes can be understood by recourse to the composition and texture of matrix and cement in these rocks. In the case of resistant members within the Weverton Formation that can give rise to expossures of firm rock, the grains and rock fragments in the sandstone and conglomerate beds are held tightly by a dense matrix largely composed of sericite and quartz (Fauth, 1968). In weathered exposures of quartzites in the Antietam Formation, there is little to no primary matrix or cement remaining for study; this rock apparently had sufficient original permeability

Figure 13. Slump block separation from shattered outcrop near summit area of Salamander Rock. Notebook case 23 x 30 cm.

and a soluble matrix and/or cement to allow for removal of these materials. Field relationships at Mt. Cydonia suggest that what is observed there is the lower portion of the iron and clay accumulation zone. If this is so, then by analogy with full weathering profiles in subtropical and tropical regions that have similar iron and clay zones, the weathering profile has probably undergone deep truncation.

Soil maps have been prepared for the six-county area that includes the South Mountain-Catoctin mountain massif. Modern soil maps are valuable for a number of geologic purposes in addition to their obvious primary agricultural and silvicultural uses. In addition to many applied geomorphic uses, detailed soil maps depict soils developed from residual and transported geologic parent materials. On South and Catoctin Mountains many soils are developed on a wide variety of transported, or colluvial, parent materials. Bordering the major mountain creeks (Mountain Creek, Conococheague Creek, Antietam Creek) some soils have also developed on alluvial parent materials on the present floodplains. Soils developed from carbonate rock parent material in

Cumberland Valley also reflect their parent rock material. Soils developed from impure carbonate rock units tend to have a solum with silt loam texture; soils formed from material weathered from relatively pure limestone tend to have a solum with a silty clay or silty clay loam texture. In the Cumberland Valley and on the Piedmont, there are also modern soils developing on the floodplains, and on a number of alluvial terrace levels. Study of the terraces and the soils developed in them would help to unravel the Quaternary fluvial geomorphic history of the area.

The mineral and rock composition, texture, and structure of parent material have profound influence on two very important areas of soil science, and these are well illustrated in the South and Catoctin Mountain area. First, parent material exercises strong controls on the nature and properties of soil that develops in it. Both physical and chemical properties of soils bear stamps of original parent material; these properties are evident both in the field and in the results of laboratory soil characterization analyses. Second, a prime interest area of soil morphogenesis is to understand the genetic pathways along which soils progress as they develop over time. For example, two nearby soils with the same climatic, vegetational, and topographic environments but with significantly differing parent materials will evolve along quite different genetic pathways as the final major control on soil development, time, runs its course.

Soil survey information was used by Noel Potter to map both diamicton deposits and alluvial terrace remnants (Figure 12) on the north and west flanks of South Mountain in counties that have modern soil surveys. An interesting aspect of an exposure in these deposits at the Mainsville quarry (Stop 6) is the soil development at the top of the exposure (E. J. Ciolkosz, personal communication). A red paleosol is developed in the upper part of the diamicton, is truncated, and is overlain by colluvium in which the modern brown soil development is occurring. These soil geomorphic relationships indicate that the Mainsville diamicton deposit beneath the truncated red soil is relatively old, and probably predates Wisconsinan cold-phase events. If extensive mobilization of regolith on South Mountain did occur in Late Wisconsinan time, these sediments: (1) never reached downslope to the site of the present Mainsville operation; (2) bypassed the older deposits (in channels?); or (3) were present in at least some areas but were removed by one or more Latest Wisconsinan erosional event(s). Thus, soil geomorphology reveals glimpses of the complicated Late Cenozoic history of the diamicton deposits, and identifies problems that need study. Unfortunately, South Mountain has not received the detailed soil geomorphic research that has been conducted in colluvium in the Ridge and Valley province to the north (Ciolkosz and others, 1990). Soil geomorphic study of nearby high-level gravels and alluvial terrace remnants in the Cumberland Valley would provide new information about the origin and age of these clastic sediments that overlie carbonate bedrock units, and might also reveal information about their relationships with the mountain footslope and toeslope diamicton deposits.

PALAEOCLIMATOLOGY, WEATHERING, AND EROSION

Several closely-spaced glacial margins separate the Appalachian Quaternary realm into two divisions: regions known to have been glaciated by Laurentide Ice Sheets during Late Cenozoic glacial ages when ice was there, and areas beyond the glacial borders such as South Mountain in Pennsylvania (e.g., Braun 1989a). Present interpretation of the glacial and interglacial history of these unglaciated mountain landscapes is difficult because of the lack of datable geomorphic surfaces and deposits and the dearth of modern research.

Palaeobotanical research, particularly of pond, bog, or marsh sites is one approach that can provide information on vegetational history, and, by extension, information about former climates. Two such deposits in the South Mountain area are the Pond Bank and Crider's Pond sites (Figure 12). Both of these deposits are preserved in depressions on diamicton deposits on the western slopes of South Mountain.

Samples of organic-rich sandy clay from the spoil pile of the Pond Bank deposit discussed by Pierce (1965) were examined for plant fossils by Tschudy (1965) who assigned the deposit a Mid-Late Cretaceous age. Although no paleoclimatic interpretation of the vegetational assemblage was made, it may be assumed that the climate was sufficiently warm and wet to support lush vegetation and that weathering and erosion were at a maximum (Cecil, 1990). Unfortunately, no samples are known of the more than 20 feet (> 6.1 m) of lignite containing seeds and pieces of wood that is reported to occur at depth in the deposit (Pierce, 1965).

New information on vegetational history is quite likely forthcoming from Professor Alfred Traverse (personal communication, August, 1991) from a sample found at the Mainsville site in May, 1991. A clast of unconsolidated sediment containing organic material including vegetation macrofossil fragments was discovered on one of the cut benches in the Mainsville quarry, collected, and submitted for sample preparation and identification.

Crider's Pond, 3.2 km east of Scotland, Pennsylvania is at an elevation of 289 m. Watts (1979) studied the pollen and macrofossil remains from an 8 m organic core from Crider's Pond. From base to top the core was composed of: silt with black bands, banded silt, organic silt, peat, and organic silt. Several ^{14}C age dates were obtained: a near-basal date of 15,210 yr BP, a date in the banded silt of 13,260 yr BP, and a date in the peat of 11,650 yr BP. Watts also identified five pollen zones as follows: Zone Cr-1 (base), dominantly pine and spruce overlain by a small peak of birch dated to about 15,000 yr BP; Zone Cr-2, dominantly spruce with pollen of tall wet-meadow herbs; base of Zone Cr-3, abrupt and large increases in pollen diversity of both aquatic and woodland species, an assemblage similar to that found in the southern part of the present-day Boreal Forest; Top of zone Cr-3 red spruce followed by white pine; Zones Cr-4 and Cr-5, Holocene vegetational assemblages of predominantly pine and oak The significance of the Crider's Pond fossil record is that it does document vegetational changes in the South Mountain area during the past 15,000 years. The record does not indicate tundra vegetation such as occurs in the Longswamp sequence studied by Watts (1979) in Berks County, but rather a forest tundra dominated by spruce. Longswamp was within 60 km of the Late Wisconsinan ice border while Crider's Pond was 125 km from the ice and a half a degree farther south. This presumably accounts for the differences if the 14C dates are correct.

Watts (1979) suggests that discontinuous permafrost may have existed in the South Mountain area during and for some time following the Late Wisconsinan glacial maximum (18 Ka). He also suggests that the climate was cold, dry, and windy. It would have been these climatic conditions that controlled weathering and erosion during the period 25-15 Ka at comparable elevations and exposures. What conditions were like in the much higher and much more exposed mountain slope and crestal areas is not known, but they probably were much more severe. The probable products of this weathering and erosion are the subjects of much of this chapter.

An interesting aspect of the core stratigraphy at Crider's Pond is the presence of numerous scattered small rock fragments in zone Cr-3 suspended in the massive (visually unbedded) sediment. Watts (1979) considered solifluction and storm activity as possible agents of delivery for the rock fragments in the center of the pond.

Sparsity of dateable, uninterrupted, long-term terrestrial stratigraphic sequences in the Appalachians has driven researchers to the marine record. Using the marine 18O record as a proxy, Braun (1989b) concluded that, in addition to a major glaciation at about 2.4 Ma, eight out of ten major cold-phase events in the last 0.85 Ma, including the three for which there is stratigraphic evidence in northeastern Pennsylvania, would have brought severe cold-phase environments to the unglaciated Appalachians. An important geomorphic effect of these cold-phase events would have been enhanced erosion. Braun (1989) was able to find several localities where geomorphic effectiveness of mass wasting processes in generating colluvium could be assessed. These localities in east-central Pennsylvania, north-central West Virginia, and northwestern South Carolina bracket the South Mountain area both in latitude and in elevation. Calculated cold-climate hillslope erosion rates are 3-13 times greater than present-day fluvial erosion rates for eastern United States. Repeated for the number of major cold-climate events interpreted from the marine record, Braun (1989b) estimated that tens of meters of material has been stripped from ridge crests and transported valleyward during the last 0.85 Ma alone. Applying these data to South and Catoctin Mountains raises some interesting possibilities with respect to origins of the upland surfaces and diamicton deposits. These considerations will be discussed in subsequent sections.

Thus there are two end members of palaeoclimate for the South Mountain area: the Late Cretaceous which was warm and wet and the Late Pleistocene which was cold and dry. What happened during the 65 million intervening years? Until recently there was not much evidence which could be used for guidance. However, some diverse research is beginning to show a consistent pattern for Cenozoic palaeoclimate in the eastern continental area of North America.

Poag and Sevon (1989) reported on sedimentary deposits of the U.S. Middle Atlantic continental margin and showed a consistent pattern of decreasing siliciclastic deposition and increasing chemical sedimentation from the Late Cretaceous to the Middle Miocene. This indicates a decreasing amount of physical erosion and an increasing amount of chemical denudation in the Appalachian source area which includes South Mountain. This pattern changed significantly in the Middle Miocene when large quantities of sediment were transported to the offshore. What caused the marked change in nature and quantity of transported material in the Middle Miocene? Climate is one possibility.

Barron (1989) indicates that the Appalachians would have been an area of focused precipitation throughout the Cenozoic, but with gradually decreasing rates. Frakes (1979) discusses at length the complexity of the Cenozoic climate changes and their problems. Cenozoic climates in eastern North America apparently varied considerably during the first half of the era, but followed a major trend of increasing warmth and rainfall accompanied by a lack of pronounced seasonality. Frakes indicates that a major change in climate starts in the Middle Miocene with a trend of cooling and rainfall change which culminates in the Pleistocene. Tiffney (1985) discusses the vegetational changes that occurred in northeastern North America during the Cenozoic and notes that the warm temperate to subtropical vegetation which gradually developed to cover much of North America during most of the Eocene was gradually replaced as the climate began world-wide cooling and attained increased seasonality. A similar story is reported by Wolfe (1985).

A speculative scenario which can be created from the above is that during the first part of the Cenozoic (to the Middle Miocene) the climate was sufficiently wet and warm to support a cover of abundant vegetation which inhibited physical erosion but enhanced chemical erosion. These conditions caused deep weathering of rock, but allowed only a minimal amount of this weathered rock to be eroded in clastic form. As both climate and and associated vegetation changed significantly, a critical threshold was reached in the Middle Miocene and large amounts of clastic sediment were eroded in the Appalachians and transported to the Middle Atlantic offshore basin. Erosion slowed during the Pliocene, but was renewed in the Pleistocene.

It is suggested later (Stop 5) that saprolite developed in metaquartzite of the Antietam Formation, along with its associated iron cementation and kaolinite, are the result of the deep Cenozoic weathering. It is further suggested that the major erosion which gave the landscape of today its basic form commenced in the Middle Miocene. The final sculpting of the landscape was accomplished during the Pleistocene, and this is the subject of most of the remainder of this paper. Thus the landscape we see in South Mountain today is polygenetic in origin and owes little of its present form to weathering and erosion under the present climate.

PRESENT CLIMATE, WEATHERING, AND EROSION

South Mountain is within the area of humid continental warm summer climate. This climate occurs in the area of conflict between polar and tropical air masses. During the winter, polar continental air masses dominate with much colder weather interrupted occasionally by surges of tropical maritime air. During the summer, maritime and continental air masses bring higher temperatures and increased rainfall. The climate has a large annual range of temperature, high summer humidity, and about 150 frost-free days. Because of the influence of the nearby Atlantic Ocean, rainfall is distributed fairly uniformly throughout the year. Table 6 presents a summary of climatic data compiled from four stations near South Mountain.
The stations used for compilation of Table 6, Carlisle, Chambersburg, Gettysburg, and Shippensburg occur in low-relief, broad valley positions at elevations of 142,195, 152, and 207 m respectively. South Mountain is characterized by narrow ridges and

Table 6. Summary of climatic data compiled for Carlisle, Chambersburg, Gettysburg, and Shippensburg, Pennsylvania. Data from

Month	Monthly Prec.[1] Mean	Monthly Prec. Mean High	Monthly Prec. Mean Low	Daily[2] Prec. Mean Max.	Snowfall[3] Mean	Annual Mean Temp.[4]	Annual Mean Max. Temp.	Annual Mean Min. Temp.	Record High Mean Temp.	Record Low Mean Temp.	Days Temp.[1] Crosses Freeze Line
Jan	3.02	6.66	1.03	1.95	8.9	29.9	38.3	22.0	72.4	-12.5	18
Feb	2.64	4.88	0.52	2.07	8.7	31.5	40.6	22.6	73.9	-11.3	17
Mar	3.56	6.28	0.86	2.7	7.0	40.3	51.0	30.4	84.7	0.7	18
Apr	3.54	7.42	0.94	2.03	1.9	51.6	63.4	39.9	93.3	17.7	6
May	3.79	7.92	0.96	2.37	0	61.9	74.2	49.8	95.4	28.2	0
Jun	3.87	10.73	1.13	5.18	0	70.6	82.4	58.9	100.6	37.3	0
Jul	3.63	8.02	1.19	3.58	0	74.8	86.6	63.1	103.9	45.0	0
Aug	3.80	9.94	0.91	3.62	0	73.0	84.6	61.5	102.4	41.7	0
Sep	3.50	9.87	0.47	4.49	0	66.2	78.1	54.6	100.7	29.8	0
Oct	3.14	9.34	0.50	3.56	0	54.4	66.3	43.1	93.8	20.5	4
Nov	3.11	7.31	0.61	2.53	1.7	43.2	52.9	34.1	81.2	7.1	13
Dec	3.11	6.02	0.70	1.78	6.2	33.0	41.0	25.1	70.0	-10.0	19
Annual	40.63				33.2	52.5					95

1 - in inches; 2 - 1951-1980 data only; 3 - 1931-1980 data only; 4 - in degrees Farenheit.

	Years of record	Continuous since
Carlisle	99	1916
Chambersburg	94	1921
Gettysburg	112	1904
Shippensburg	54	1933

Records

Highest annual prec.: Shippensburg, 1937, 59.13
Lowest annual prec.: Chambersburg, 1930, 19.60
Highest monthly prec.: Carlisle, 6/1972, 18.51
Lowest monthly prec.: Carlisle, 12/1877, 0.05
Highest temperature: Chambersburg, July, 107
Lowest temperature: Gettysburg, January, -20

valleys, generally with local relief of 130 m or more. Low elevations of 152 m at the change from adjacent broad valley to mountain slope at the northeast end near Dillsburg rise to around 275 m near Shippensburg and then decline to about 245 m at Waynesboro. Maximum elevations range up to almost 640 m in the Big Flat area and are frequently greater than 450 m. These topographic conditions produce considerable variations in South Mountain climate from the surrounding recording stations. Unfortunately there are no year-around recording stations within the area of South Mountain to provide even generalities about the differences in microclimate.

When thinking about potential microclimate differences, the following should be kept in mind. The ridge crests will receive more and higher velocity winds than the valleys. During the day the valley bottoms may be cold sinks while the warmest temperatures are occurring on the shoulders of the slope. Slope orientation is very important on clear sunny days when the difference of light between the North and South facing slopes amounts to 46 units (say in g cal/cm2 hr-1). In diffuse light all slopes receive the same amount.

Amounts, types, and rates of weathering in the present humid continental climate of Pennsylvania have received very little attention. Sevon (1984) calculated an in situ atmospheric weathering rate of 0.26 m/Ma for a resistant sandstone in northeastern Pennsylvania. Pavich (1989) indicates that weathering in the Piedmont of Virginia produces upland regolith at rates between 4 and 20 m/Ma. Godfrey (1975) has done the most comprehensive work directly related to South Mountain and its rocks. His work in the Fishing Creek basin of Maryland involved rocks from the Harpers Formation and the Weverton Formation. Godfrey indicates (Godfrey, 1975, Table 4, p. 30) that the rate of soil formation decreases with increasing percent of matrix and varies from 18.3 m/Ma for 10 percent matrix to 3.66 /Ma for 50 percent matrix. These rates are in excellent agreement with those of Pavich (1989) and thus may provide a good indication of the rate of weathering in South Mountain under the present climate.

Erosion rates in the Appalachians under the present climate have been determined by many people and are reviewed by Sevon (1989). The various erosion rate determinations show great variability and a close relationship to disturbance of the surface by human activity. For the South Mountain area Godfrey (1975) determined a rate of land surface lowering of 2.5 m/Ma in a forested and undisturbed watershed.

PERIGLACIAL GEOMORPHOLOGY

Introduction

There is evidence for a strong periglacial influence in the development of landforms and materials on South and Catoctin Mountains (Clark and Ciolkosz, 1988). By the term "periglacial" (Lozinski, 1909) is understood cold climatic environments, with or without permafrost, and their landscape units (Godfrey and Cleaves, 1991) produced directly and indirectly through the process effects of strong frost action, intensive mass wasting, and aeolian activity operating on land that is seasonally snow free (Black, 1966, p. 329; Washburn, 1980, p. 2). Fluvial processes and fluvial landscape units are also of great importance, and differ from their humid temperate region counterparts in both form and process especially as they have been affected by ground ice and surface ice and snow (Clark, 1988; French, 1976; Worsley, 1984). Within a framework of cyclic-time and cold climate denudation, Troll (1948) enumerated six general periglacial process groups. These were: congelifraction, cryoturbation, solifluction, river gravel deposition, gelideflation, and cryoplanation. These periglacial process groups operate on different temporal and spatial scales. There are many specific processes, earth materials, and landforms produced due in part to the almost endless variety of space-time combinations, coupled of course with variations in local geologic materials, and surface and subsurface conditions. The treatment below will be limited to landforms, materials, and inferred processes of development that are relevant to the South Mountain-Catoctin Mountain area.

Some periglacial processes such as snow and slush avalanches operate quickly and produce "instant" landforms and deposits. Snow avalanches, and their stream-channel counterparts, slush avalanches, are important depositional agents, which produce or help to produce landforms such as cones, lobes, and avalanche road-bank tongues. Alpine mudflow events are another example of rapid periglacial processes that are important in presently-active mountain periglacial environments.

Small patterned ground features (less than about 40 cm) produced during diurnal freeze-thaw cycles are an example of periglacial features that can form over short time spans as days to weeks. Other periglacial processes require longer time intervals. The growth of ice wedges is an example of a periglacial process group that requires many years of growth (Mackay, 1990). Processes that operate to produce cryoplanation terraces are an example of even slower process rates. Priesnitz (1988) estimated that even under favorable conditions, cryoplanation terraces require on the order of 10,000 yr to reach full morphological development.

The size scale of periglacial features is important because forms of different sizes may have different origins and chronologies. Karte (1982) found that periglacial features can be grouped into three empirical categories: microforms, mesoforms, and macroforms. Periglacial microforms exist at the feature or compartment scales (Table 4), and thus there can be another size hierarchy nested within this category. Microforms include: both sorted and nonsorted patterned ground, gelifluction lobes, small frost mounds, and tors of periglacial origin (Washburn, 1980). Periglacial mesoforms are on the zone or locale scale of landforms (Table 4); examples are: block fields, block slopes, block streams, Felsenmeer, individual cryoplanation terraces, and snow avalanche tongues. Periglacial mesoforms grade upward in size into periglacial macroforms on the subdistrict scale level (Table 4). Examples of periglacial macroforms are: some types of large diamicton sheets and lobes, dells, certain asymmetric valleys, and the various domal, smooth convexo-concavo debris-mantled slopes, steplike, and planar features that collectively make up periglacial landscapes. Excellent overviews of how various scales of features interact and overlap to produce periglacial landscapes are in French (1976) and Clark (1988). There also may be subsurface periglacial features that do not fit into a surface classification, such as: bedded and oriented rock chip deposits, involutions, and rock and soil wedges.

Terminology is the bane of periglacial geomorphology. Usage problems remain, despite efforts in English language works, as those by French (1976) and Washburn (1980), who have attempted standardization and the separation of descriptive terms from terminology with genetic connotations. The terminology used here is descriptive and objective wherever appropriate and widely accepted standardized geometric nomenclature exists in the literature.

Periglacial Features

Introduction

To date (1991), features of probable periglacial origin reported on South and Catoctin Mountains include: tors, topographic terraces and risers, block streams, sorted stone stripes, and sorted circles and nets. Some of the forms are transitional with each other. Almost all of the forms and materials discovered on South and Catoctin Mountains to date are along or very near access routes as roads, trails, and power lines where both reconnaissance efficiency and visibility can be good. This bias in the inventory needs to be borne in mind. The reported paucity of large-scale sorted stone nets, for example, may be due to the lack of roads and trails over many of the high, nearly flat areas where these forms occur.

Block streams

Block streams are elongate swaths of contiguous blocks that have their long axis generally perpendicular to topographic contour (White, 1976). Smith and Smith (1945) reported the presence of block streams in the northern section of the Blue Ridge province. South and Catoctin Mountain block streams may occur in several different topographic situations, as in ravine heads, on sideslopes, or in valley bottoms. There are both forested and treeless block streams on South and Catoctin Mountains. Tree-covered sites dominate the inventory. Excellent examples of forested ravine-head block stream occurrences are along the access road between High Rock and the crest of Quirauk Mountain in the Smithsburg quadrangle, and below North View, Cat Rock in the Catoctin Furnace quadrangle. For example, one block stream below North View derived from talus breakdown, averaged 23 m in width, had an average gradient of 13.5^{o}, and extended downslope 132 m. Outstanding examples of tree-covered valley bottom block streams are in the Fishing Creek drainage basin, Catoctin Furnace quadrangle, and were studied by Godfrey (1975). The several forest-free block streams are, however, visually the most spectacular, and they permit the study of block fabrics, microtopography, and other features unimpeded by vegetation mats. The following description of individual block streams will be limited to the treeless occurrences; some data for these forest-free block streams are in Table 7.

Table 7. Treeless South Mountain block streams.

Name Quadrangle	Latitude Longitude	Elevation (m)	Gradient (degrees)	Trend	Condition
Green Ridge North Iron Springs	39°49'50" 77°26'40"	415-501	--	--	
Green Ridge Central Iron Springs	39°49'15" 77°26'44"	381-512	5.1-11	S72-87°W	Disturbed (logging)
Green Ridge South Iron Springs	39°48'32" 77°27'15"	347-460	--	--	
T(r)ucker Run Waynesboro	39°48'54" 77°30'01"	463-488	2	S45°E	Excellent
Devils Racecourse Blue Ridge Summit	39°44'55" 77°27'13"	305-335	--	SSW	Treeless area removed
Raven Rock Hollow Smithsburg	39°40'20" 77°31'20"	421-482	3.5-5	S20-50°W	Disturbed in local areas
Black Rock Road Myersville	39°36'12" 77°34'11"	402-421	4-7	S10-65°E	Toeslope removed

Green Ridge Block Streams. The largest of these three block streams was studied in 1969 by students of Noel Potter, Jr., Dickinson College, as a research project. The students identified a main block stream with six tributary block streams and two subsidiary single block streams, one north and one south of the main feature (Table 7). A segment of Green Ridge about 1 km long and underlain by the Weverton Formation served as the source area for the blocks. The middle block stream varies in width from 9-46 m and extended downslope from the ridge crest for a minimum of 1675 m; the lowermost visible portion ends at water level in the Waynesboro reservoir. This block stream lacked trees and surface fine materials for most of its length. Three distinct linear segments of this main block stream were defined. A headward "source" section was characterized in the downslope direction first by a continuous block slope with two topographic terraces having treads inclined 15-20° and about 45 and 85 m wide separated by risers of 35°. These features had angular blocks up to 6 m in a-axis length and occupied the upper 180-215 m of this 610 m long segment. Downslope, the remaining portion of this upper section trended S72°W with a mean slope of 5.5°. The middle "central" segment was also about 610 m long, had a mean gradient of 5.1°, exhibited good edge definition and vertical orientation of tabular blocks, and was fed by a number of tributary block streams entering from the sides. Topographic depressions, elongate in the upslope-downslope direction, are common in the middle section; dimensions range from 0.9 x 2.4 m and 0.6 m deep to 2.4

x 9 m and 1.2 m deep. The lower or "bottom" segment trended downslope S87°W, had a mean gradient of 11°, and varied in width between 30-60 m.

Block fabric analyses showed several statistically-significant correlations. All block axes' lengths decrease with increased distance from the ridge crest in the headward source segment. Correlation coefficients for block size were weaker in the central and bottom segments. Block shape factors were more pronounced in the source and bottom segments, and block shape was more irregular in the central section. Block shape factors, when related to block axis dip, and their relationships with slope direction and slope angle showed weak to not significant correlation coefficients.

The multiple-tributary block stream investigated by Potter's students, and the two bordering single block streams would have been ideal features for additional research, Unfortunately, much of the Green Ridge block stream area has been subjected to logging by heavy mechanized equipment subsequent to this study, and many of the features have been disrupted or destroyed.

Tucker Run or Trucker Run. Earlier topographic maps named the fluvial drainage in this hollow Tucker Run, but the name has been changed to Trucker Run on later map editions. There are several discrete treeless areas along the upslope-downslope trend of this block stream separated by wooded areas. This is the only known treeless block stream on South Mountain that is in undisturbed condition (Figure 14), and it displays a number of pristine features. There is complex microtopography consisting of elongate to nearly circular cone shaped pits and some low mounds. Visual size sorting of large blocks from small boulders has produced sorted nets with the smaller stones in the center. Vertical orientation of tabular blocks is evident in several areas, with the ab-planes trending parallel to the gradient of the field.

Devils Racecourse or Devil's Racecourse. Thornbury (1954, Figure 16.14, p. 414; 1969, Figure 21.1, p. 511) reported this block stream west of Gladhill, Pennsylvania as an example of a palaeo-periglacial, or relict, landform. Source rock for this feature was apparently greenstone metabasalt derived from the Catoctin Formation. Some time prior to 1968, however, all of the treeless area had been removed for use in the manufacture of roofing material (G. M. Clark, field notes, 15 August 1968).

Raven Rock Hollow Block Stream. With a forest-free length of about 1 km, the Raven Rock Hollow block stream is the longest known treeless block stream in the South and Catoctin Mountain areas. This block stream shows several features typical of deposits formed by periglacial movement and is also exceptional because of its accessibility. The features include: obvious upslope source in Weverton Formation outcrops; downslope reduction in block size; some late-stage block orientation; patterned ground (circles) formed after the block field was emplaced; and recent development of Opferkessel. These features are discussed in detail at the description for Stop 1.

Black Rock Road Block Stream. This feature is located on the east flank of South Mountain west of Black Rock Road. An unknown volume of the toeslope of this block stream has been removed, but

Figure 14. View upslope of Tucker (or Trucker) Run block stream. Geopick on top of large on-edge block is 32 cm long.

much remains for study, including the potential for subsurface investigation in the excavated area. Upslope portions of this complex block stream display a number of features, including several feeder streams and highly complex microtopography. Slope gradient changes rapidly over short horizontal distances; slopes of 4 to 6 degrees are common as are small essentially horizontal areas. Microtopography is pronounced, and one feeder stream has a V-shaped depression oriented along gradient. The Black Rock Block Stream is an excellent example of longslope transport of surface blocks. Much of the surface blocks and boulders is derived from the Weverton and the Loudon Formations, although the lower 0.3 km of the features overlies the Catoctin Formation (Fauth, 1981).

Interpretation. Although relationships with mapped bedrock geology at several localities require minimum longslope transport of at least several hundred meters over very low gradients, there is no surface evidence of block stream migration today. Large blocks are weathering and breaking up in place without separation of the constituent fragments (See Stop 1). Neither the forested block streams nor the forested margins of the treeless examples show any disturbance of arboreal vegetation. Organic matter from lichens, mosses, leaves, and woody stem material slowly accumulates on and around blocks and boulders. Eventually, a vegetation mat develops that is capable of supporting rooted plant life. Trails and logging traces shown on maps over half a century old show no disruption in the field. Features within the block streams such as cone-shaped topographic depressions and sorted stone circles are nearly equant in plan view, and most logically formed after significant down-gradient motion ceased. An inactive, or more likely truly fossil, nature is the most rational conclusion that can be drawn from present evidence. Why some block streams are forested and why several are treeless is of interest. Observed relationships at the edge of the treeless features are most easily understood if a scenario of gradual forest encroachment is envisioned (e.g., Sevon, 1987; 1990).

Sorted stripes can be traced downslope into the headward areas of several block streams, and their downslope fringes may terminate as sorted stripes. Sorted circles and rarely sorted stripes as defined by concentrations of finer and more rounded boulders and cobbles are found within the treeless areas of several block streams. Physical continuity, therefore, is one line of evidence that links the origin of the block streams with that of sorted patterned ground, and a probable periglacial origin. Both visual and measured fabrics in South Mountain block streams are similar to those found in active periglacial environments. Thus there seems little doubt that South Mountain block streams are partly to wholly periglacial features.

Sorted Patterned Ground

Introduction. Both large scale (> 2 m dimension in plan view) sorted stone stripes and nets (Washburn, 1980) occur in the South and Catoctin Mountain areas (Tables 8 and 9). Most occurrences are either in areas underlain by the Weverton Formation and/or the blocks and boulders in their stone borders have been derived from this rock unit. Almost all of the finds to date (1991) have been on gently-sloping upland areas. Finds of sorted nets are relatively rare, the observed nets tend to occupy nearly horizontal upland flats and to become transitional to stripes in the slightly higher gradient areas downslope.

Table 8. Large-scale sorted nets on South and Catoctin Mountains.

Quadrangle Location	Latitude Longitude	Elevation (m)	Gradient (degrees)	Trend	Average width of stone border (m)	Mesh (stone-free center) dimensions (across slope x down slope, in m)
Iron Springs Snowy Mountain	39°50'02" 77°29'30"	622	0-3.5	N10°E	1-3	5.5 x 7.3
Smithsburg Quirauk Mountain	39°41'44" 77°30'49"	649	3.5-4	S40°W	3.6	2.5 x 5.0
Catoctin Furnace Salamander Rock	39°34'38" 77°29'19"	555-561	1.5-2.5	S15-30°E	2	4.6 x 6.5

Table 9. Large-scale sorted stripes on South and Catoctin Mountains.

Quadrangle Location	Latitude Longitude	Elevation (m)	Gradient (degrees)	Trend	Average width of stone border (m)	Remarks
Caledonia Park Headwater Valley Long Pine Run	39°57'53" 77°27'45"	530-533	3	N52°W	5.3	SE side of road
Caledonia Park Big Flat Ridge	39°58'02" 77°27'17"	590	1.5	S18°E	2.4	SE side of road
Caledonia Park Piney Mountain	39°55'42" 77°25'19"	558-570	3	N42-72°W	4.1	Both sides of road
Caledonia Park Piney Mountain	39°56'03" 77°24'56"	559	8	N52°W	6.9	SE side of road
Iron Springs Monument Rock	39°48'44" 77°29'02"	436	3-8	N85°E	8.0	N side of road
Iron Springs Snowy Mountain	39°50'02" 77°29'30"	622	2-3.5	N0°E	5.2	On tread surface
Iron Springs Currans Road	39°49'58" 77°29'52"	619	2.5-9	S20°E	5.7	SSE side of road
Iron Springs Three Springs Road	39°49'25" 77°26'27"	509	2-10.5	S80°W	6.5	W side of road
Iron Springs Three Springs Road	39°47'50" 77°27'23"	518	2-4	S50°E	5.9	NW side of road
Iron Springs Three Springs Road	39°47'07" 77°28'02"	436	7-10	N80°W	8.6	W side of road
Iron Springs Three Springs Road	39°46'55" 77°28'20"	415	10.5-12.5	N50°W	5.7	SE side of road
Iron Springs Currans Road	39°49'41" 77°29'21"	543-549	6-8	S50°W	8.1	W side of road
Iron Springs Currans Road	39°49'51" 77°29'17"	573-579	3-8	S40°W	7.7	W side of road
Waynesboro Snowy Mountain	39°49'31" 77°30'16"	594-600	4-7	N70°W	5	S side of road
Smithsburg Quirauk Mountain	39°41'44" 77°30'49"	649	4	S02°E	3.6	On tread surface
Smithsburg Mt. access road	39°41'49" 77°30'52"	646	4-10	N60°W	3	W side of road
Smithsburg Mt. access road	39°41'48" 77°31'12"	543-555	13	N75°W	6	WNW side of road
Smithsburg Mt. access road	39°41'44" 77°31'17"	549-556	15	N60°W	11	Both sides of road
Catoctin Furnace Power line	39°37'02" 77°26'41"	408-421	11-15	N32°E	6.6	Between towers RCM 113 & 115
Catoctin Furnace Salamander Rock	39°34'38" 77°29'18"	555-561	1.5-6	S15-30°E	5.9	N, NE, & E of tower
Catoctin Furnace Hamburg Tower	39°30'36" 77°28'27"	469-488	4-6	N70°E	9	ENE of tower

Only several occurrences of well-developed and well-preserved sorted stone nets are known (Table 8), but more probably occur on isolated high flat areas that lack road or trail access. The nets occur either immediately downslope from talus breakdown only a few meters below summit levels or on high flats without surface evidence of former outcrop. Downslope the nets are transitional to sorted stripes on slightly steeper land surfaces. Many of the sorted nets may have once been well-formed sorted polygons, as suggested by slightly angular corners in the stone meshes.

Sorted stone stripes, by contrast, are much more common on South and Catoctin Mountains and tend to occur on land with slightly higher slope gradients (Table 9). Individual sorted stripe length may vary from < 10 m to about 100 m. Sorted stone stripes occur as solitary forms, and also in conjunction with sorted stone nets on gently-sloping upland surfaces (Figure 15), block slopes, and block streams. It is common to find sorted stripes merging either downslope into block streams or having an apparent surface source upslope from block slopes or block streams. Some to much of the block and boulder material, however, may have come from subsurface bedrock sources.

Interpretation. As noted above some sorted stripes are physically continuous with block streams; stripes enter some block streams from upslope directions, apparently as feeders, and emerge at the distal termini of some block streams, apparently as disseminators. Sorted circles, defined as nests of smaller and more rounded cobbles and boulders, are present in block streams. Thus there is a physical, if not genetic, linkage between the origins of at least some block streams and some sorted patterned ground.

Most but not all large-scale (> 2 m mesh or stone border diameter/width) sorted patterned ground is of cold-climate, or periglacial origin (Washburn, 1980; Williams and Smith, 1989). The requisite conditions for other types of origins for these large features are lacking on South and Catoctin Mountains. Neither are there soils with large percentages of expanding clay minerals (Vertisols), nor are there soils that contain large amounts of salts (certain Aridisols). Goldthwait (1976) interpreted sorted polygons and nets over 2 m in diameter as features requiring permafrost for development, but Washburn (1980) urges caution. Regardless of the ground thermal state that accompanied their development, the above authors agree that the development of large-scale patterns over broad areas occurs only above treeline. The only known exceptions are local azonal conditions, as for example small sites with high water tables and areas where forest cover has been removed by human activity.

If these sorted patterned ground features are old, how have they survived tree growth and tree throw? The answer may lie in the subsurface, as these features are of the deep "rooted" variety, with tabular blocks tending to be oriented with their ab planes vertical and anchored firmly in the subsoil. There are few places where the maximum depth of stone concentrations can be seen on South and Catoctin Mountains, but for the larger stripes observed the approximate depth to base of contiguous stones ranges from about 1 m to a maximum of 1.7 to 1.8 meters. If permafrost was present during sorted stripe development, this stone depth might represent the thickness of the active layer. On the other hand, depth to base of contiguous blocks may simply

Figure 15. Sorted stripe trending from lower right to photograph center, then splitting into sorted net area upslope, Snowy Mountain. Tor, composed of shattered rock derived from the Weverton Formation, is on left skyline. Length, with handle, of 50-m tape resting against survey monument is 33 cm.

represent the effective depth of highly-disruptive seasonal frost activity. As negative evidence, surface periglacial features that lack a blocky armor are not conspicuous in the South Mountain-Catoctin Mountain area. If well-developed surface features such as nonsorted patterned ground, solifluction lobes, and small nivation hollows once formed here during Pleistocene cold phases, they may have been obliterated by the subsequent 10 Ka of tree-root activity in the Holocene. A few vague forms that may represent old solifluction lobes and nivation hollows may be seen in some places. For example, northwest of the topographic profile across High Rock Road (called Three Springs Road on the Iron Springs 7.5-minute quadrangle, but High Rock Road on the Michaux State Forest road map and sign posted as such) (Figure 16C) are very subtle lobe- and hollow-like microtopographies that might easily be overlooked, but that are visible to the believer.

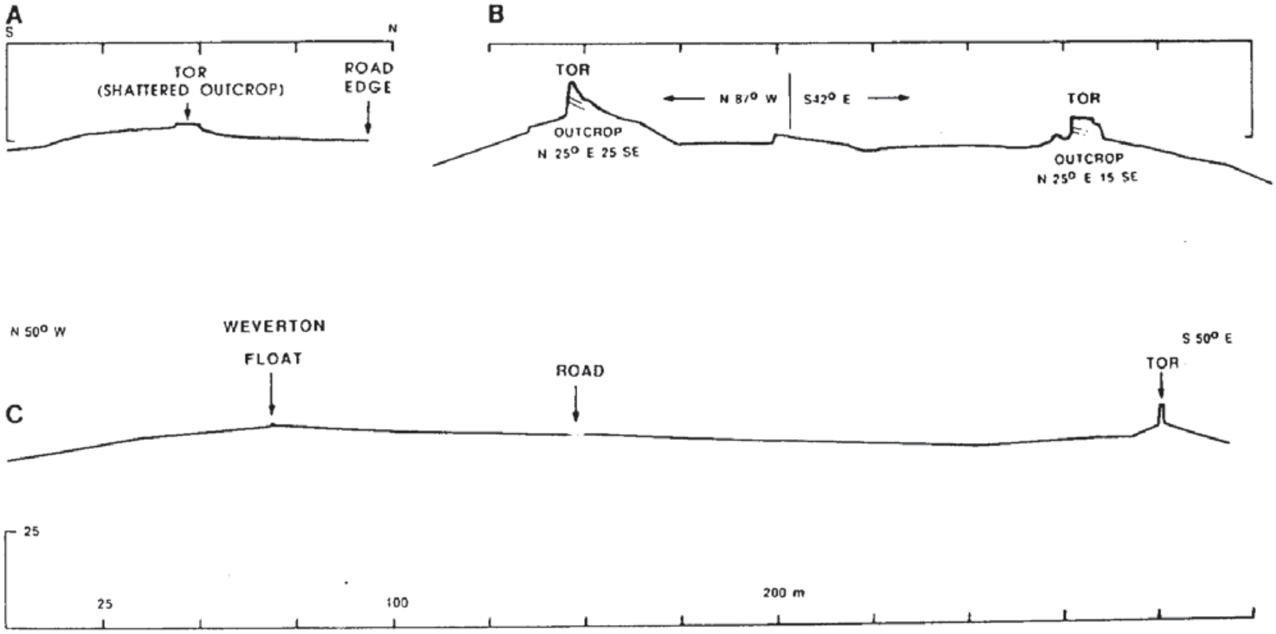


Figure 16. Topographic profiles across edge of upland surfaces, risers, and treads; no vertical exaggeration: A. Snowy Mountain site, profile line is due South (left)--North (road); B. Cat Rock, note bend in line of section. Attitude of bedding in the Middle, or Ledgemaker Member, of the Weverton Formation varies away from lines of profile (Fauth, 1977); C. High Rock Road site; profile line is N50°W-S50°E.

Tors, Summits, and Upland Terraces

Introduction. One of the most striking and most scenic attributes of South Mountain is the gentle upland subdistrict, as typified by the Ridge Road Upland Area. The Ridge Road has been described as the Skyline Drive of Pennsylvania, albeit at a degree and a half higher latitude and about 500 m lower elevation than otherwise comparable topography in Virginia. High flats along parts of the Skyline Drive, as in the vicinity of Stony Man, Hawksbill, and Big Meadows, Virginia are examples. As these features occur on the zonal, subdistrict, and even district topographic scale units, they form important aspects of South and Catoctin Mountain landscapes, and will be treated in some detail. Some of the flats in South Mountain have been named, such as Big Pine Flat Ridge, Big Flat Ridge, and East Big Flat Ridge on the Caledonia Park quadrangle and Big Flat on the Walnut Bottom quadrangle.

Despite the work of Monmonier (1967; 1968; 1971) and Hack (1975; 1989) on the major relationships between rock type and structure, which indicates that peneplanation is not a viable explanation of Appalachian uplands, the problem of the origin of flat upland surfaces still remains. Both South and Catoctin Mountains display outstanding upland "flats". In areas where bedrock is exposed, it can be shown that this gentle topography truncates lithologic differences and structural trends. Closer inspection of the "flats" in many areas reveals that this general appearance is a collage of smaller tread- and riser-like features that, in the aggregate, give the visual appearance of flatness. For example, Godfrey (1975), Middlekauff (1987), and Olson (1989) have all referred to the steplike nature of zone-, locale-, and compartment-sized landscape units on uplands on South and Catoctin Mountains.

Methodology. Areas on South and Catoctin Mountains in Pennsylvania and Maryland were chosen for investigation to see if field relationships at significant distances (about 200 km) from Late Cenozoic continental ice margins (Figure 11) have experienced major topographic modification. This is because general agreement exists today that periglacial effects near the glacial border were severe and that extremely harsh environmental conditions also extended to low elevations (Clark and Ciolkosz, 1988; Watts, 1979). For example, Watts (1979) reported clear evidence of tundra vegetation in association with colluvium in areas within 35 km of the Late Wisconsinan border at the Longswamp, Berks County, Pennsylvania site (40o 29' N; 75o 40' W) at an elevation of only 192 m. Marsh (1991, written commentary) remarked on the great number of flat uplands in the Ridge and Valley province in central Pennsylvania, and noted that contour maps from digital elevation tapes display flat, abrupt-edged uplands better than standard 7.5-minute quadrangle maps, even with the same contour interval. As one example noted by Marsh, part of a digital elevation map covering the Hartleton, Pennsylvania, 7.5' quadrangle shows excellent examples of these highest flats that Marsh reports break abruptly into blocky slopes.

Topographic maps covering South and Catoctin Mountains at 1:24:000 scale (Figure 11) were examined to identify local broad upland sites on the zonal scale (Table 4). Many of the identified uplands display prominent topographic benches and some show chimney-like summit protuberances. Localities for field study were chosen where comparable-scale geologic maps were available, or where it was known from other sources that bedrock exposures were present. Topographic profiles were constructed from traverses run at right angles to topographic slopes. Slope profiles and surficial materials were described utilizing standard geomorphological procedures (Gardiner and Dackombe, 1983). Although most locations have road access corridors, several sites do not, including locations along the Appalachian Trail or near power transmission lines. Locations in the following section on description of sites refer to Figure 12 and Tables 10 and 11.

Description of Sites. On and around Hammond's Rocks, Freedman (1967, Figure 21 and Plate 1) mapped structural elements that detail the trend of the Hammond's Rocks anticline. Dips of bedding, jointing, and cleavage are discordant to the topography, but are also nearly perpendicular to the overall topographic trend of tor-like features on the upland (See Stop 8, Day 2). Structural details mapped by Potter and others show a striking discordance between structure and topography on and around Hammond's Rocks (See Stop 8). Farther northeast, along the Hammond's Rocks Ridge Road, flat upland surfaces exist that are underlain by the Montalto Member of the Harpers Formation as mapped by

Table 10. Locations of selected South and Catoctin Mountain local broad upland sites.

Site No. (Table 11)	Quadrangle Locality name	Latitude Longitude	Elevation (ft) Elevation (m)	Feature name Aspect
1	Mount Holly Springs, PA	40°04'05-20"	1405-1520	Summit with tors
	Hammond's Rocks area	77°14'30-55"	428-463	Crestal area
2	Dickinson, PA	40°03'35"	1460-1470	Southerly sloping area
	High Mountain Road	77°22'15"	442-463	Southerly sloping area
3	Iron Springs, PA	39°50'03"	2020-2040	Summit with tor remnant
	Snowy Mountain	77°29'30"	616-622	Crestal area
4	Iron Springs, PA	39°48'02"	1760-1800	Summit with tor
	Three Springs Road	77°27'08"	536-549	Longitudinal divide
5	Blue Ridge Summit, MD-PA	39°43'44"	1680-1694	Summit area
	Mount Dunlop	77°29'23"	512-516	Crest
6	Smithsburg, MD-PA	39°41'44"	2120-2140	Riser, terrace
	Quirauk Mountain	77°30'48"	646-652	S10°W
7	Smithsburg, MD-PA	39°39'38"	1560-1580	Summit tor
	Buzzard Knob	77°32'20"	475-481	Crest
8	Catoctin Furnace, MD	39°36'58"	1520-1560	Tors, subsummit flat
	Cat Rock	77°26'54"	463-476	N86°W-S41°E
9	Catoctin Furnace, MD	39°30'36"	1600-1620	Tor, risers
	Hamburg Lookout Tower	77°28'31"	488-494	Crest
10	Keedsville, MD	39°25'00-52"	1320-1400	Risers, terraces
	South Mountain	77°38'19-27"	402-433	N62-82°W

Table 11. Form and material attributes of South and Catoctin Mountain upland sites. Numerical values given are for representative specific features measured.

Site No. (Table 10)	Width (down slope) Length (along slope) (m)	Tread gradient Riser gradient (degrees)	Tread material Riser material	Tread features Riser height (m)
1	30-40	4°	Soil with blocks, 1-8 m a-axis	Sparse stones
	65	20-38°	Outcrop, loose blocks	4-12
2	80	4°	Blocky soil	Sparse stones
	200	15-25°	Outcrop, block rubble	15
3	43-105	2-4°	15-25 % blocks	Sorted stripes
	170	8.5-15°	Outcrop, shattered outcrop	2-3
4	230	1-2.5°	Relatively stone-free soil	Smooth slopes
	300	20-90°	Tor, loose block rubble	1
5	40	0-11°	Outcrop, stony soil	Shallow
	150	summit	Summit	N/A
6	190	3.5-6°	Stony soil	Sorted stripes
	190	>10°	Blocks	5, disturbed
7	50	2-4°	5-35% blocks	Float
	62	27-30°	Outcrop above scree apron	15
8	120	1.5-16.5°	0-30% blocks	Shallow
	215	52.5-113°	Bedrock	4.5-5.8
9	330	1-5°	Outcrop, stony soil	Two treads
	275	30-85°	Outcrop, shattered outcrop	1-4
10	40-115	2-10°	< 5% stones	Few blocks
	235-445	44-53°	Blocks, outcrop	3-11

Freedman (1967). There are few outcrops on the upland surface, however, and structural, lithologic, and topographic relationships are obscure.

Snowy Mountain, also on South Mountain, provides an example of a summit tor landform rising above bordering treads that constitute the local broad upland surface at this site (Figures 15 and 16A). Bedrock exposures in the area comprise thick-bedded, coarse-grained sandstone of the Weverton Formation (Fauth, 1978). Dip of rock cleavage and bedding are strongly discordant to the local tread topography. Large-scale, sorted patterned ground on the tread can be traced upslope toward talus breakdown below the outcrop.

Across the High Rock Road, there is upland topography between a bedrock tor developed in quartz-vein rich Weverton Formation, a bordering area of loose blocks derived from this outcrop, and gently-sloping upland surface northwest of these features. A topographic profile (Figure 16C) shows these gentle slopes, risers on both sides of the tor, and the topographic expression of the tor.

On Mount Dunlop, the summit topography is characterized by gentle slopes over distances of hundreds of meters. The Weverton Formation bedrock (Fauth, 1978, Plate 1), dips from 10° northwest to 75° overturned to the southeast. Outcrop-level structures display even more spectacular discordances between topography and bedrock attitudes. Farlekas (1961) mapped folds in a thin but locally continuous "quartz" unit over a portion of the summit area, and showed the striking discordance between the bedrock and summit topography.

Along South Mountain in Washington County, Maryland, bedrock attitudes in the Weverton Formation (Edwards, 1978) are discordant to the trend and slope of local upland topographic surfaces. Summit topography on Quirauk Mountain, Maryland, follows in general the major structures and outcrop belt in the Weverton Formation as do most of the summits and knolls on South Mountain (Godfrey, 1975, p. 5). At the outcrop level, however, there are discordances between topography and the sense of bedding in shattered outcrops. An excellent example of cross-cutting relationships occurs south of the U. S. Army Information Systems Command Site C installation where most of the riser and tread topography is still preserved. Large-scale sorted stripes on the tread can be traced up slope gradient to contiguous blocks that comprise the riser. Also present are funnel-shaped depressions and microhollows visually similar to features that Demek (1969, Photo 15 and 16) termed respectively "solifluction forms" and "nivation funnels". Farther south on South Mountain at the Buzzard Knob site, tor microtopography and a bordering terrace, both discordant to structure, are well displayed. At the South Mountain site, Hedges (1975) noted excellent riser and terrace development that crosscut bedding in the Weverton Formation along the Appalachian Trail between the Townsend Memorial and Lambs Knoll.

Similar antipathy between bedrock attitudes and local summit topography also obtain at Cat Rock (Figure 16B) and east of Hamburg Lookout Tower on Catoctin Mountain. Whitaker (1955b) mapped and drew cross-sections of an area east of Hamburg Fire Tower in detail (Figure 5, p. 454) and showed the contrast between asymmetrically overturned shear folds in two members of the Weverton Formation and the plateau-like bench and scree summit topography. Mapping by Fauth (1977) also illustrates discordance between structure and topography at these two locations. Taken together, the Maryland Blue Ridge sites demonstrate that local summit topography is discordant to the dip of bedding structure and lithology on both limbs of the South Mountain Anticlinorium where a variety of structural attitudes exist. Nor are distinctive treads and risers confined to the clastic rocks. Excellent tread and scarp topography is developed in the Catoctin Formation along the Foxville Fire Tower road near the boundary between the Catoctin Furnace and Myersville Quadrangles, and also in the Cunningham Falls vicinity in the Blue Ridge Summit Quadrangle.

In conclusion, rock weathering and surface soil horizon characteristics at all of the sites provide qualitative evidence of relatively prolonged slope stability. When broken open, both bedrock ledges and float blocks show differential weathering effects on top *versus* bottom areas. Large blocks are weathered and broken up in place, with little separation of the constituted fragments. Gently-inclined surfaces of some large quartzite blocks show well-developed Opferkessel (weathering pits in quartzite) that show no morphological evidence of block disturbance during the time they have developed. Hedges (1969) assembled convincing evidence that Opferkessel are contemporary features that develop slowly under modern environmental conditions, although the rates of formation are unknown.

Visual evidence of active surficial processes on local broad uplands is largely confined to weathering, and the estimated rates of denudation are low. Ciolkosz and others (1990) reviewed estimates of modern rates of soil formation from sandstones on ridge crests that range between 0.026 and 1 cm/ka. Godfrey (1975) calculated chemical erosion rates for metaquartzites of 1.8 m/Ma for a drainage basin; ridge top rates might be lower or higher. Unless estimates of current rates of weathering and denudation on resistant rocks that underlie these uplands are radically in error, topographic development during Holocene time has been negligible, requiring that summit landscape development occurred in Pleistocene or earlier time.

Proposed Hypothesis: Palaeoperiglaciation. It is therefore hypothesized that the individually-small (zone or locale; Table 4) forms and materials developed on South and Catoctin Mountains are relict cryoplanation features that formed under rigorous periglacial environments (with or without permafrost) that are no longer operative. One suggestion that would explain the evenness of skyline impression is that the aggregate visual effect of these features, developed to common elevational ranges in local areas, is that of a much larger single summit "plain" when seen from a distance. This interpretation argues that large areas of Northern Blue Ridge local broad uplands can be viewed as relic incipient-to-essentially-complete assemblages of much smaller individual surfaces of cryoplanation (*cf.* Figure 17), as opposed to remnant fragments of peneplanation. A further conjecture is that in the aggregate the visual "evenness of skyline" effect

Figure 17. Clearcut area showing terrace wraparound of outcrop area, South Mountain, Pennsylvania. (Dickinson, PA 7.5-minute quadrangle; High Mountain Road; elevation 442-463 m.).

that these summit and bordering summit landforms have on our visual perception is that very impression which led early workers to adopt the peneplain remnant hypothesis. This hypothesis is presented as an alternative to the peneplain hypothesis which long fascinated geologists both here and abroad (*cf*. Thornbury, 1965; Adams, 1975; Sevon and others, 1983; Fulton, 1989) but does not disprove the peneplain hypothesis. Nor does it disprove the possible production of planation surfaces by the etchplain mechanism argues by Budel (1982), or through a process of topographic reversal that has been demonstrated to work on steeper lower slopes (Mills, 1981). These other hypotheses are not reviewed in detail here; see Clark and Hedges (in press).

The term "cryoplanation" (Bryan, 1946) is understood to mean cold climate land reduction with concomitant development of conspicuous upland flats, risers, terraces, and other features (e.g., Demek, 1969: p. 5-8; Washburn, 1980: p. 237). Although periglacial environments have also been considered as regions of extremely active valley incision and destruction of plains (e.g., Budel, 1982), modern workers increasingly recognize the presence of planar upland landforms that presumably have been produced under periglacial environmental conditions (e.g., Priesnitz, 1988). Extensive documentation exists on cryoplanation forms from a wide variety of localities (e.g., Demek, 1969). Given suitable bedrock structure, lithology and, climate, one overall impact of periglacial environment on summit- and near-summit level landforms is the production of upland flats, risers, and treads, although all of the responsible processes and required ground frost environments have yet to be elucidated (Washburn, 1985).

Mention of cryoplanation in the Central Appalachians is not new. Peltier (1949, p. 30, 67-69) invoked cryoplanation as a process to explain the form and relief of mountain tops in the Susquehanna River Valley. North of the glacial border Berg (1975, p. 32) indicated that surface morphology of Wisconsinan-age till has been modified by periglacial cryoplanation. Godfrey (1975, p. 7) noted that areas with "flat outcrops" along South Mountain, Maryland closely resemble the "cryoplanation terraces with frostriven scarps" of Demek (1972). Middlekauff (1987) and Olson (1989) also noted the presence of steplike landforms in the Blue Ridge Province in Maryland. Péwé (1983, Figure 9-11, p. 169 and Table 9-7, p. 177) reported an unpublished observation of cryoplanation for Mt. Davis, Pennsylvania.

That periglacial processes might be responsible for major modification of summit topographic forms over wide areas to the extent that they could be mistaken for surfaces of other origins is, however, a more sweeping proposal. Russell (1933) studied geomorphic form in western United States and stated this concept clearly:

> "Herein lies the explanation of numerous forms, ranging in size from minute, steplike benches to slopes covering whole mountain sides and broad surfaces across highlands which may readily be mistaken for parts of peneplains." (1933: 939).

There are few references to cryoplanation summits and terraces as major elements of Appalachian ridge tops over wide or disparate areas. Hedges (1975) proposed that cryoplanation had produced the truncation of bedrock structure and lithology on Sugarloaf Mountain on the Maryland Piedmont, and also noted well-developed terraces at the South Mountain, Maryland, site. Clark (1989a) offered the option that Central Appalachian ridge crests might be incipient cryoplanation features rather than remnants of peneplains, but did not publish site data in support of this speculation.

The morphological features reported in this study are similar or identical to forms described as cryoplanation features by previous workers. Tors on the local broad upland summits resemble tors that have been interpreted as periglacial in origin. For example, Ehlen (1990) studied topographically-similar summit landforms developed on granites in Dartmoor. She found that the summit tors are composed of rocks that are highly resistant to erosion, and are parted by highly-spaced vertical joints and medium-spaced horizontal secondary joints. Ehlen (1990, personal communication) indicated that there is a consensus among researchers that the Dartmoor tors are of periglacial origin. In the Appalachians, Braun and Inners (1990) and Braun (1990, personal communication) interpreted tors morphologically identical to those reported in this paper as periglacial in origin and not as relict Tertiary features.

Cryoplanation summit flats described by Demek (1969, p. 7) and those illustrated by Péwé (1970) (see Figure 18) resemble those of the uplands, and can be quite extensive, as in the Ridge Road Upland Area. On the outcrop level, trend and dip of bedding is discordant to local upland surfaces at the localities studied, although of course over broad areas (as major folds) there is a general positive relationship between major bedrock structures, lithologies, and mountain summit topography.

The form, relief, and materials of risers described (cf. Table 11) conform remarkedly well with descriptions of cryoplanation risers reported in the literature (cf. Table 12). Features composed of firm bedrock, shattered bedrock, and slumped to jumbled blocks singly and in various combinations are present in the study sample.

Table 12. Geomorphic form and material attributes of reported cryoplanation terraces compiled from Demek, 1969; Priesnitz, 1988; Péwé, 1975; Reger and Péwé, 1976).

Characteristic	Reported data		
Slope and slope position			
Summits	Summit cryoplains, with or without tors		
Slopes	Interrupt middle and upper slopes; generally several levels		
Width (along contour)	30 m (low)	400 m (common)	> 10 km (high)
Length (normal to contour)	5 m (low)	100 m (common)	> 1 km (high)
Riser or scarp height	1 m (low)	6 m (common)	> 50 km (high)
Gradient			
Tread or flat	1^{o} (low)	6^{o} (common)	14^{o} (high)
Riser or scarp	9^{o} (low)	30^{o} (common)	90^{o} (high)
Tread material	< 1-3 m debris depth, rarely more; sorted patterned ground		
Riser material	Bedrock, shattered bedrock, block rubble 1-3 m thick		
Rock type	Resistant lithologies that produce coarse debris favorable		
Lithologic control	Commonly initiate at or near breaks in lithologic reistance		

The sizes, shapes, surficial geomorphic materials, and site factors of treads are also similar to features of cryoplanation terraces described in the literature (cf. Tables 12 and 13). For example, Demek (1969, p. 55-56) noted that, although cryoplanation terraces are rare to absent on steep slopes, their development is not excessively dependent on leveled surfaces. The same topographic situations are present at the study sites. One shortcoming of this study is that detailed subsurface data that would permit mapping of the bedrock-soil interface are lacking. Many investigators consider cryoplanation terraces as transport slopes, with 3 m or less of debris mantling the bedrock. On the other hand, Demek (1969: p. 6-8) also recognized less common cryoplanation terraces with external parts composed of loose material. He termed these complex features compound cryoplanation terraces.

Important problems remain, moreover, and some new ones are raised. The volume of debris remaining on terraces cannot be computed until the soil-bedrock interface is mapped with tomographic geophysical techniques. Rates of removal cannot be computed and the geomorphic effectiveness cannot be assessed until

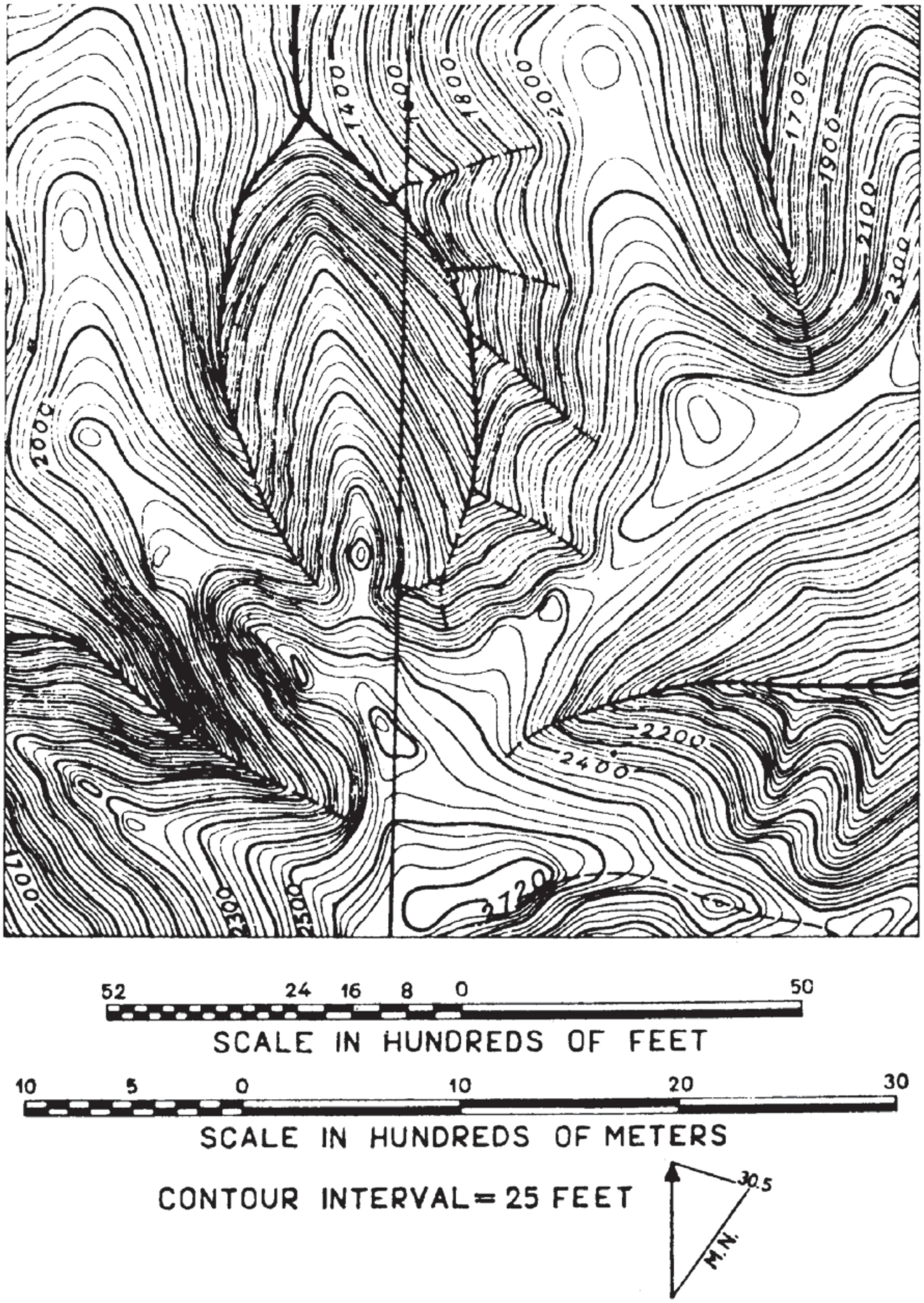


Figure 18. Topographic map of ridge at head of Kokomo Creek, 33 km NE of Fairbanks, Alaska showing cryoplanation terraces cut on Birch Creek Schist at elevations of 610-825 m (2,000-2,700 feet). Contour interval 25 feet. (From Péwé, 1970, Figure 2D. p. 361).

Table 13. Environmental (site) associations on cryoplanation terraces (compiled from Priesnitz, 1988; Péwé, 1975; Reger and Péwé, 1976).

Influencing factor	Favorable conditions	Unfavorable conditions
Wind effects on snow drifting	High	Low
Exposure to prevailing winds	Lee slopes	Windward slopes
Proportion of snow in total precipitation	High proportion	Low proportion
Sublimation rates	Low	High
Relation to local snowline	300-500 m below to very little above snowline	Rarely down to 1000 m below snowline
Summer temperatures	Cold	Warm
Freezing index	> 1000 degree days (°C)	---
Permafrost required		
Continental areas	Yes	---
Maritime areas	No	---
Formation time (estimated)	ca. 10,000 years	> 10,000 years

age(s) of the terrace deposits and the downslope diamictons into which they grade are determined. Numerical ages will, in most cases, have to be measured with new methods of dating of geomorphic surfaces and materials. The time span required for cryoplanation terrace development has only been estimated (Table 13). Further complication is indicated by evidence that individual terraces may record more than one episode of development (e.g., Lauriol, 1990).

A hypothesis has been presented that relates the origin of local broad uplands on South and Catoctin Mountains to cryoplanation during cold phases of Late Cenozoic time, and, in speculation, that the accordance of their summit levels may be due to the effects of periglacial processes that worked to produce a common elevation range. Rather, it is hoped that this hypothesis will stimulate detailed geomorphic research on upland rocks, soils, and landforms which can be tested with newly-developing field and laboratory techniques. These techniques will also be useful to search for and evaluate evidence for or against deep weathering stripping (Büdel, 1982) as a process group that could also help to explain the formation of local broad uplands and perhaps summit accordance as well. The same methodologies should also help unravel geometries and depositional histories of the complex diamicton deposits that border these Blue Ridge upland surfaces.

It is of course premature to make palaeoclimatic interpretations until definitive studies of both the Appalachian features and comparable active analogs have been completed. Some notions, though, of the potential of cryoplanation terraces for providing palaeoenvironmental information are in order (cf. Table 13). Karte (1982) noted that, in addition to forms found in treeless, cold continental permafrost environments (e.g., Reger and Péwé, 1976), cryoplanation terraces are forming above the forest limit in maritime "Icelandic type" areas without permafrost where mean annual air temperatures are between -1° to -2° C. When definitive work on active forms becomes available, moreover, terraces may provide opportunity for other types of palaeoenvironmental inferences in a region where such data are difficult to obtain. In Alaska, for example, the altitudes of cryoplanation terraces plot about 100-300 m below the Wisconsinan snow line (Péwé, 1975, Figure 8, p. 22). The proportion of rain to snow in total precipitation is another possible palaeointerpretation. Péwé (1975, Figure 8, p. 22) showed that the elevation of cryoplanation terraces in central Alaska is lower in areas where the proportion of snow to rain is higher. Palaeowind interpretations and other aspect inferences may also be possible in the future (Table 10).

The genesis of accordance in elevation or "evenness of skyline" remains unaddressed. Tarr (1898) suggested that rock above tree line undergoes more rapid weathering and erosion than in areas below the forest limit. Daly (1905, p. 120-123) discussed the accordance of summit elevations above the forest limit in mountains and argued for the effectiveness of alpine processes in both rock disintegration and removal of rock waste. On South and Catoctin Mountains, much work must be done in order to define montane palaeoclimatic altitudinal zones, the landscape-forming processes that operated there, and their geomorphic effectiveness.

Diamicton Deposits

Introduction. Another problem at least spatially related to the ridge uplands is the presence of complex, thick, and extensive diamicton deposits along many mountain flanks that border the upland surfaces especially in the Ridge and Valley and Blue Ridge provinces (e.g., King, 1950; Pierce, 1966; Godfrey, 1975, Moss, 1976; Clark and Ciolkosz, 1988; Clark and others, 1989; Braun, 1989b; Ciolkosz and others, 1990). Previous workers have referred to these sediments as: "mountain wash", "alluvial mountain wash", and "alluvial cones of mountain wash". On South and Catoctin Mountains, what were the specific source areas for the debris, what were the mechanisms of entrainment, transport, and deposition of the sediments, and when and under what conditions did these events occur? Except in several areas in the Appalachians, (e.g., Braun, 1989b), little is known about the geometry and chronology of diamicton emplacement, so that questions of erosion magnitude and rates, geomorphic effectiveness of the responsible process groups, and Quaternary landscape history have been difficult to address in a quantitative manner.

Methodology. Potter (unpublished data) used the Cumberland, Franklin, and Washington County soil survey reports to map diamicton deposits on the north and west flanks of South Mountain. Data were compiled at a map scale of 1:24,000. These data have been generalized and are shown in Figure 12. The older county soil surveys are not as useful in identifying and mapping diamicton parent material in detail. Thickness to bedrock of these unconsolidated deposits is known only at a few localities. Becher and Root (1981) mapped diamicton thickness from well logs on the northwest flank of South Mountain in part of Cumberland Valley. This mapping indicates that thickness is highly irregular but in general decreases away from the mountain front. A maximum depth to bedrock is 137 m, although within 1-2 km of the mountain front well depths to bedrock of about 60 m are more common. Nutter (1973) studied the hydrogeology of these sediments in the Frederick and Hagerstown Valleys, and mapped their thickness using well log information along the foot of South Mountain on the east side of the Hagerstown Valley. Maximum reported depths to bedrock were 390 feet (119 m) and 400+ feet (> 122 m) 2.5 miles (4 km) and 7 miles (11.3 km) SSW, respectively, of Smithsburg, Maryland. Overall, Nutter found that the diamicton deposits decrease in thickness away from the contact between the Antietam and Tomstown Formations. A few seismic refraction lines have been run in several areas and generally corroborate the well log data. It would be helpful to know the form of the soil-bedrock interface as well, but sufficient detail to do this is lacking.

The Mainsville quarry (Stop 6) provides a temporary opportunity to study some of the diamicton material in plan and section, and the main aspects of that site are discussed later. Despite the information presently available from the Mainsville site, there are no absolute answers on when and under what palaeoclimatic, vegetational, and soil conditions the deposit formed, although Early through Middle Pleistocene time constitutes a reasonable temporal interval.

Interpretation. If development of the several types of block accumulations, sorted stone stripes, cryoplanation landforms, and other periglacial features involved deep erosion and transport of bedrock, periglacial processes may indeed be responsible for removal of much material from the mountain uplands (see Liestl, 1961 for a modern-day example), but how were the volumes of coarse to fine clastic sediment transported and deposited? Are the present-day channels strictly features formed in Holocene time, are they only the sites of former channels that are now being further deepened, or have they shifted laterally, perhaps by some mechanism of gully gravure? Until recently, few references were made to sources or transport mechanisms for these great volumes of sediment. Carter and Ciolkosz (1986) conducted a systematic study of bedrock depth on a ridge crest in the Ridge and Valley province, and found that the soil is 3 to 4 m deep. Based on seismic and rock fragment orientation data and the presence of sorted and stratified material in the upper 1 to 2 m of the profiles, they concluded that the upper 1 to 2 m of the soil is colluvium and the underlying material is residuum. Braun (1989b, p. 249) calculated that 8 to 10 periglacial episodes of the last 850,000 yr have been capable of tens of meters of ridgetop reduction. Ciolkosz and others (1990) showed that the upper parts of ridge-crest residual soils in the Ridge and Valley province of central Pennsylvania were truncated during Late Wisconsinan time and then either buried with local colluvium or cryoturbated. These nearly in situ parent materials have been stable since Late Wisconsinan time as evidenced by the nature and properties of soils developed in them. It is not known how applicable the studies in the nearby areas of the Ridge and Valley province are to South Mountain, but they can certainly serve as a guide for discussion and future research.

Could erosional magnitudes sufficient to form the features interpreted as periglacial landforms and deposits described on South and Catoctin Mountains have accounted for at least some of the thick diamict deposits that underlie simple side slope and complex lobe-shaped landforms in this part of the Blue Ridge province? The development of periglacial features described above would have produced large volumes of debris that would have been transported valleyward, although the rates of many periglacial processes are not well known (Washburn, 1980). In speculation, if widespread and deep periglacial weathering, erosion, transport, and deposition accompanied a number of cold-climate phases, the cumulative production of debris may have been sufficient to account for the materials both at the base of the Blue Ridge and those spread out into the bordering geomorphic provvinces (Figure 12). Suggested processes include, but are not limited to: snow and slush avalanches, alpine debris flows and mudflows, and catastrophic high-flow fluvial transport. Much better knowledge of the origin and age of these diamicton deposits will be required to evaluate these scenarios, however.

SYNTHESIS

Present climates in the Northern Blue Ridge are humid continental. Soil temperature regimes in the Central Appalachian mountains are mesic on the lower ridge crests and frigid at the higher elevations (Carter and Ciolkosz, 1980). Cryic soils are unknown and frost pockets are unlikely in topographically well-drained areas. Under natural forest conditions with snow cover, Central Appalachian mountain soils are frozen in winter to depths of less than 25 cm (Carter and Ciolkosz, 1980). Leffler (1981), moreover, demonstrated that Appalachian summit temperatures can be estimated reliably; his method has been refined further by Schmidlin (1982). These summit-level temperature estimates are characteristic of middle-latitude forested mountains. The predominant natural summit area vegetation on South and Catoctin Mountains is deciduous forest cover (Braun, 1950).

Set against the modern climatic environment are reports refining the Pleistocene glaciation sequence in Pennsylvania (e.g., Braun, 1989a), and on palaeoclimatic and palaeovegetation data beyond the ice sheets in eastern North America as a whole (Delcourt and Delcourt, 1981; 1984), including the last deglaciation (Jacobson and others, 1987). There is palaeobotanical evidence that the South Mountain-Catoctin Mountain area experienced severe cold-climates during Late Wisconsinan time as the work by Watts (1979) illustrated. Sediment influxes present in core samples suggest that the cold climates were accompanied by landscape disturbance on the district to lower landform scales (Table 4) on the lower slopes of the South Mountain area surrounding Crider's Pond (Watts, 1979). Physiographic location of sample sites is important for interpreting the palaeoenvironmental record. Mountainous areas such as the higher parts of South Mountain probably lacked arboreal vegetation and effective ground cover, had more severe palaeoclimates, and experienced greater landscape disturbance than lower-lying areas because of several reasons.

Important contributing topographic factors are: temperature decrease with increasing elevations (adiabatic lapse rates), greater and more varied exposure to atmospheric precipitation and wind, redistribution of snowfall, cloud cover, and steeper slopes with greater potential energy of gravitation. Thus, the envisioned reconstructed upper mountain climatic-vegetational environments would have been favorable for severe landscape disturbances that are interpreted to have had profound effects on Appalachian Highland landscapes (see Braun, 1989b).

It is not yet possible to construct an altitudinal zonation of periglacial features on South and Catoctin Mountains. In other parts of the world, when azonal features produced by unusual local conditions are excluded from the inventory, a common sequence of zones (1 to 7) from lower to higher altitude is as follows: (1) ploughing and braking blocks (Wanderbl_cke); (2) terrace-like garlands; (3) earthflows; (4) miniature patterned ground; (5) sorted or stony lobate forms; (6) large-scale sorted patterned ground; and, given resistant lithology, (7) a mantle of riven rock (Felsenmeer). These zones overlap in space in present-day periglacial environments, and it is important to realize that what is seen in palaeoperiglacial zonation is a collage of features resulting from waxing and waning environments as altitudinal climatic belts moved up and down environmental gradients. All of the above situations are further complicated by exposure and ground conditions. Thus, the interpretation of altitudinal zonation is extremely difficult, and leads to a subset of questions, not the least of which is whether palaeoperiglacial features can be used to answer them. Where were treelines? Did permafrost exist and above what elevations? Can mean annual soil or air temperatures and their probable ranges be deduced?

Although modern basic geomorphology as practiced in the United States is highly process driven, still there is interest in geomorphic form. On South and Catoctin Mountains two overall kinds of landscapes on the district to subdistrict scale levels (Tables 4 and 5) can be seen in the field and on large-scale, small-contour-interval topographic maps. These are: smooth convexo-concavo debris-mantled slopes, and gently-inclined summit and near summit planar features. The convexo-concavo landscapes are magnificently developed on the outer sides to lower slopes of South and Catoctin Mountains and can be seen from many vantage points in the Piedmont and Ridge and Valley provinces. These debris-mantled slopes merge down gradient into the complex lobe-like to sheetlike topographies that overlie the complicated and often thick diamicton deposits. On the crests and in the interior of the mountains and away from incised fluvial landscapes are the gently inclined summit surfaces with or without tors, that may be flanked by subtle risers and subjacent topographic terraces that have been interpreted by Clark and Hedges (in press) as cryoplanation features. Karrasch (1974) studied alpine landscapes in Europe and in the United States and described both landscapes with smooth rounded forms (Glatthänge) and landscapes with stepped flat-and-riser slopes (Treppenhänge). He attributed the development of Glatthänge landscapes to development conditioned by high-relief mountain environments and the formation of

Treppenhänge landscapes to environments with lower relief that are underlain by structural-lithologic irregularities (Karrasch, 1974). Albeit with less relief, the same general topographic and substrate conditions are met on South and Catoctin mountains with the same topographic results.

Assessment of the quantitative effects of long-term erosional activity on overall relief between mountain summits and bordering valleys is beyond the scope of this presentation. Godfrey (1975) measured and compared present chemical and physical rates of erosion in the South Mountain area, Maryland. He speculated that cold-climate processes would have reduced overall relief between ridge crests and the intervening Middletown Valley, whereas temperate climatic weathering and erosional processes would tend to increase relief. During times of temperate climate Godfrey (1975) estimated that the Catoctin Metabasalt beneath the valley would be eroded at a rate three to four times faster than the Loudon and Weverton Formations on the ridge crests. Under Pleistocene cold-phase conditions he concluded that the ridge crests would have been lowered faster than the valley, causing an overall reduction in landscape relief. Braun (1989b) hypothesized that Pleistocene periglacial erosion should be the dominant Pleistocene erosional process in the Appalachian Highlands, and that present processes are shaping the landscape to provide slope forms necessary to transport the periglacial debris. To address the hypotheses and speculations presented by Godfrey (1975) and Braun (1989b), the form, volumes, stratigraphy, and ages of summit erosional landforms and diamicton deposits will need to be determined. New methods for the numerical age dating of geomorphic surfaces hold great promise, as do evolving geophysical tomographic techniques that image subsurface soil and rock conditions. Only then can we begin to address concepts of landscape equilibrium and disequilibrium in a quantitative fashion in areas where surficial evidence indicates that effects of Late-Cenozoic environmental change have been severe.

Caution in making conclusions about specific palaeoenvironments must still be urged for several reasons. Washburn (1980) documented the dearth of information about formative environmental conditions of features active in present day periglacial environments, and he noted little improvement five years later (Washburn, 1985). To further complicate reconstruction of palaeoperiglacial environments, the degree of similarity between Central Appalachian conditions their modern day analogs, is not clear. These analogs occur either at much higher elevations in other mountain chains (for similar latitude and sun angle) or at much higher latitudes (for similar elevations). Also, the lack of subsurface information and numerical age dates restricts our ability to use analogs in present-day periglacial environments and to compute process rates and make correlations. For example, Büdel (1982, p. 78-80) interprets certain bedrock erosional surfaces as pre-Quaternary features that have only been overprinted by Pleistocene cold phase palaeoperiglacial processes.