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CENTRAL APPALACHIAN PERIGLACIAL GEOMORPHOLOGY

A Field Excursion Guidebook

under the auspices of:

27th INTERNATIONAL GEOGRAPHICAL CONGRESS
COMMISSION ON FROST ACTION ENVIRONMENTS

INTERNATIONAL PERMAFROST ASSOCIATION
WORKING GROUP ON MOUNTAIN PERMAFROST
WORKING GROUP ON PERIGLACIAL ENVIRONMENTS

INTERNATIONAL GEOLOGICAL CORRELATION PROGRAMME
IGCP #297
GEOCRYOLOGY OF THE AMERICAS

Leaders:
G. Michael Clark, Organizer
Robert E. Behling
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Central Appalachian Periglacial Geomorphology

Postcongress Field Excursion C. 20c.

Sponsored by:
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INTRODUCTION

The existence of a number of features in the Appalachians—now generally regarded as forms that had a periglacial origin—has been known for over a century (Clark and Ciolkosz, 1988). Some of these landforms, especially large treeless block accumulations on gently sloping land surfaces, attracted the attention and speculation of early immigrants from certain areas in western Europe (Geyer, 1979). A number of early reports, not referenced herein, tended to regard such features more as scientific curiosities than as objects for serious research. In particular, in Pennsylvania, some of these localities also later became renowned as exceptional geological attractions (Geyer and Bolles, 1979, 1987). One such feature, the Hickory Run Boulder Field or Block Stream, Carbon County, Pennsylvania, has achieved widespread recognition as a prime example of a relict periglacial feature (Sevon, 1987).

Despite the publication of a number of papers on periglacial features and deposits, a number of factors have combined to inhibit the progress of periglacial research in the Central Appalachians. These hindrances include: the lack of a regional stratigraphic framework for terrestrial sequences of Late Cenozoic age (*cf.* Ridge, *et al.*, 1992), the presence of a dense forest cover, the lack of road or trail access in many mountainous locations, the absence of visible surface expressions of some features that can therefore only be studied in excavations, and, until recently, the lack of a "critical mass" of interested researchers. Clark and Ciolkosz (1988) provided a brief history of periglacial studies in the Appalachians south of the glacial border and listed some of the extant problems and prospects for future work.

The identification and correct interpretation of periglacial forms and materials is important for many reasons. There is increasing recognition that palaeoperiglacial activity has played a role in the geomorphic history of the region (*cf.* Braun, 1989b; Clark and Ciolkosz, 1988; Sevon, 1992a). Rates of erosion during times of maximum glacial and periglacial activity were high (Braun, 1989b) especially when contrasted with those of today (*cf.* Judson and Ritter, 1964; Sevon 1989a). Some fossil features are—or in the future may become—valuable indicators of former environmental conditions during the time(s) of their development. One traditional goal of periglacial geomorphology has been to determine whether or not permafrost was present (*cf.* Brown and Péwé, 1973), and, if possible, some quantitative estimate of mean annual air or soil temperature. However, additional interpretations may be possible as well. For example, some features may indicate nature and direction of prevailing winds, proportion of snow to total precipitation, sublimation rates, relation to the local and regional palaeosnowlines, and minimum time required for form and material development.

From a soil genesis standpoint, many parent materials in the Central Appalachians are partly to wholly products of one or more periglacial episodes of development; by hillslope, fluvial, or aeolian processes. Among the soil-forming factors, the nature and properties of the parent material exert very strong controls on subsequent pedogenesis. Accordingly, the importance of parent material in soil genesis will be stressed during the excursion. Considering next the time factor in soil development, it is very important to try to ascertain the age(s) of origin and emplacement of parent materials in order to establish minimum ages of topography and soil development.

There are also many important practical reasons for recognition of periglacial materials. The increasing requirements for sound bases for decisions on land use and development have created strong demands for quantitative information on the physical and chemical properties of parent materials, many of which may be partly to wholly of relict periglacial origin. Visually spectacular periglacial features are excellent tourist attractions, whether accessible by road (*cf.* Sevon, 1987) or by trail (*cf.* Wilshusen, 1983). Finally, there is the overwhelming need for us to understand more about global climate and environmental change with respect to processes, interactions, and their effects. Many periglacial environments worldwide will—to judge from already documented changes—undoubtedly become heavily impacted if and when formative conditions change. Such situations can therefore become very sensitive indicators, although the nature and magnitude of potential change is difficult to predict. One of the important parameters lacking in many global models is the time dimension. Unfortunately, relatively little is now known about Appalachian palaeoperiglacial domains, and therefore much can be gained by concentrated efforts at understanding the legacy of past terrestrial environments in a region that is so rich in periglacial landforms and materials.

This excursion is the first intensive field effort to focus solely on the periglacial geomorphology of the Central Appalachians in the vicinity of, and south of, the glacial borders (Figure 1). A number of previous field trips in upland areas, however, have included valuable information on selected periglacial forms and materials in their guidebooks. Examples of such works that called attention to the wealth of periglacial landforms and earth materials in this part of the Appalachians include, but certainly are not limited to: Sevon (1969), Ciolkosz, *et al.* (1971), Sevon, *et al.* (1975), Clark, *et al.* (1989), Sevon and Potter (1991), and Sevon (1992b).

The central focus of this excursion is to gain some initial appreciation of the nature and magnitude of the geomorphic responses of earth materials and landforms to cold-climate environmental changes that have occurred in the field trip corridor. Localities have been chosen to show different aspects of this theme. Some sites, for example, showcase several of the classic and best-developed features that have received previous study, such as the Hickory Run Boulder Field or Block Stream. Other localities permit examination of poorly-understood or recently-discovered forms and materials, such as the topographic welts in Union County, Pennsylvania.

There are always differences and misunderstandings in the use of scientific terminology where research crosses disciplinary lines and international boundaries. Use and misuse of the term "regolith" is a case in point (Gale, 1992). It has been known for some time that the terminology in periglacial geomorphology is particularly difficult and complex (*cf.* Bryan, 1946). Today, for example, the terms "colluvium" and "grèzes litées" have different usages and have been applied to different earth materials in Europe and the United States. In this guidebook, names for features and materials follow—wherever possible—established (U. S.) usages, such as designations for rock and soil colors. We have endeavoured to adhere to usages of descriptive and nongenetic terms such as those proposed by Flint, *et al.* (1960a, 1960b) and, more importantly, to quantification as refined by Washburn, *et al.* (1963). We have also tried to avoid terminology that presupposes genetic understanding. In this respect, we have tried to follow the lead of Washburn (1956), who set a standard for patterned ground terminology that is based on objective geometric considerations. On the other hand, some "new" forms, especially those recently discovered in the region, temporarily defy our efforts at standardization.

More importantly, many of the difficulties encountered in the study of relict or truly fossil periglacial phenomena in the Appalachians are fundamental ones and are but a microcosm of the situation in palaeoperiglacial regions worldwide. Several different kinds of these basic research problems exist; a few of the most perplexing and commonly-occurring difficulties are described below. One pervasive problem is that, even with exacting description and proper identification of particular palaeoperiglacial (Karte, 1982) features with their present-day active analogs, there is often a lack of understanding of the environment and genesis of the actuoperiglacial (Karte, 1982) phenomena. Both field and laboratory data on active features that would be necessary to constrain genetic hypotheses and to reconstruct environments of formation are often lacking. The complexity of actuoperiglacial environments is in itself often daunting, because of interactions that produce second- to nth-order effects. One excellent example comprises the effects of thermal and moisture changes caused by snow drifting. Redistribution of snow cover can strongly affect the development and evolution of periglacial materials and landforms, for example by the redistribution of moisture (Nyberg, 1991). Another problem area is that, in some cases, there are no known clear examples of truly analogous active features that could be used for guidance in understanding the fossil landforms and materials. A further situation can arise when analogs from two or more distinctively different areas have given rise to visually-similar landforms and materials under apparently completely different environmental conditions. In this last case it is unknown what, if any, of the supposed analogs would be appropriate to the morphologically and sedimentologically similar features found in the Appalachians. Such occurrences are prime examples of the equifinality (or convergence) principle.

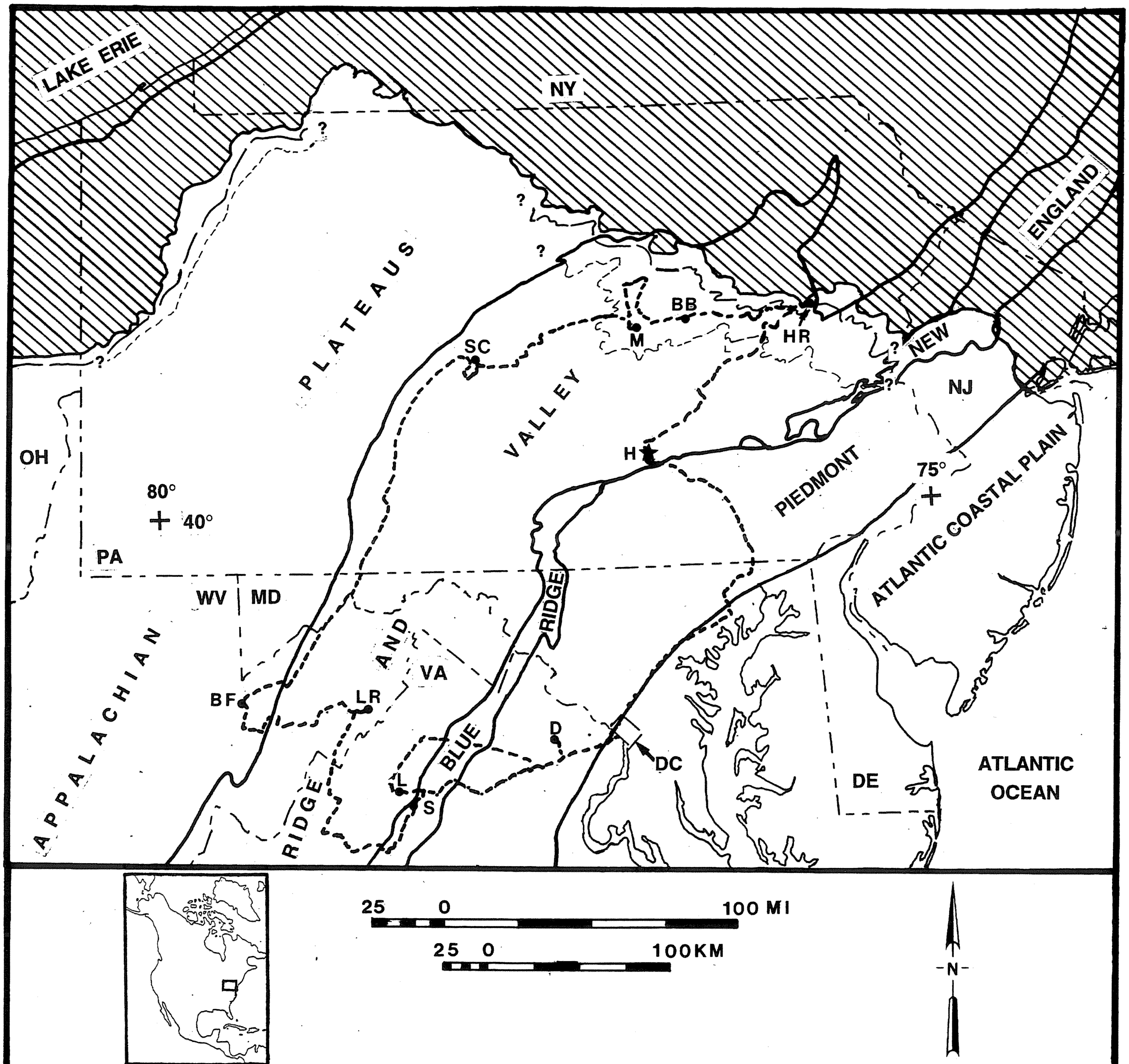

Figure 1. Area of the Central Appalachians traversed by IGU Postcongress field excursion C.20c., 14-18 August 1992. Diagonally-lined area indicates maximum coverage of Late-Wisconsinan ice at about 18 Ka; light long dashed line with question marks indicates glacial border of Late-Illinoian (?) age; light short dashed line with question marks shows an even older glacial border. Excursion route described in the road logs section is shown by short heavy dashed lines. Glacial border location information from Braun (1989a) and D. D. Braun (unpublished data). In eastern West Virginia and in Virginia, alternate tour routes are shown above and are given in the road logs. Actual routes by two field parties during the excursion on these optional pathways are: LR-D-DC and LR-L-S-D-DC. BB = Bloomsburg, BF = Blackwater Falls, D = Dulles International Airport, DC = District of Columbia, H = Harrisburg, HR = Hickory Run, L = Luray, LR = Lost River, M = Montandon, S = Skyland, SC = State College.

With respect to specific landforms and their environments of development, Washburn (1985) focused on a number of periglacial processes and features in need of directed research. A number of such features occur in the Central Appalachians. These are: patterned ground, involutions, minerogenic fossil frost mound remnants, frost creep and gelifluction deposits, block fields, block slopes and block streams, hollows and benches, cryoplanation terraces, and stratified slope deposits. Washburn (1985) also noted uncertainties that arise when such features are used as palaeoclimatic indicators in environmental reconstructions. French (1987a, b) described completed and ongoing laboratory and field studies on cryogenic weathering, frost heave and ice segregation, ground ice, ice wedges, ice-cored terrain, thermokarst, active layer processes, mass wasting, and patterned ground. The results of such process-oriented research are, and will continue to be, critical to our efforts in interpreting features in the Appalachians. In particular, research cited by French (1987a, b) that deals with the origins and environments of weathering pits and tors, ice wedges, mass wasting, and patterned ground are apropos to obvious interpretative problems in the Appalachians, and many of the other studies cited by him may also prove to be so.

The difficulties noted above, however, could be attacked and at least partially resolved by the completion and publication of additional process-oriented laboratory and field research. In some cases, there is subsequent research progress to report (*cf.* Boardman, 1991; Dixon and Abrahams, 1992), or research is either already underway or is planned for the future. There are also rapid advances being made in areas of technology. For example, new direct and remote sensing devices, monitoring equipment, and computer-guided processing and modeling software and hardware can be used, as tools, in both actuoperiglacial and palaeoperiglacial studies. We view the above drawbacks as only temporary barriers to the advancement of knowledge.

On balance, therefore, the periglacial geomorphology of the Central Appalachians presents many challenging and positive opportunities. The correct identification of landforms and materials as truly periglacial in origin must be established. Demonstration of their truly fossil nature must be made in the case of features that have the alleged capibility of forming in the region under certain modern environmental conditions. Landforms and materials must be quantitatively described and put into correct parent material and stratigraphic perspectives, so that they can be adduced to support hypotheses about mechanisms and environments. Numerical age dates must be obtained for materials in proper stratigraphic context. Problems of scale must be addressed. Interpretations of process-response mechanisms need to be constrained, and the inferred geomorphic-climatic environments of development must be tested and evaluated. The actual distribution of representative phenomena must be determined, as opposed to the present mapping, which consists of plotting chance finds. Finally, some species of synthesis must be effected that will not only tie together the offshore marine record with what is known of the terrestrial periglacial record, but that will also, in turn, be capable of international levels of correlation (IGCP). By so doing, it should be possible to apply the knowledge gained to understand the geomorphic responses to environmental change (GERTEC) that characterized specific parts of the Central Appalachians during specific time spans and then use these data to evaluate parts of global change models that deal with conditions beyond ice sheets. It is, therefore, our hope that the research efforts stimulated during and after this excursion will lead to further productivity and an increased understanding of the origin of periglacial forms and materials and their palaeoenvironments of development in the Central Appalachians.

This guidebook has been structured to facilitate future use by others who may wish to visit localities in the field excursion corridor. Figures and tables are presented sequentially and separately in the text and in the road log, so that these parts of the guidebook may be used independently. The dates of publication of county soil surveys are given in Appendix A, along with selected other references on areal geology and geomorphology. Names of topographic quadrangles that contain the locations for many features that can be observed on or near the excursion route are given in Appendix B. Selected soil characterization laboratory data that bear on aspects of soil development that are of interest from a periglacial standpoint are in Appendix

C. Except where otherwise noted, quadrangle names of maps refer to the 7.5-minute topographic series of the U. S. Geological Survey.

BEDROCK GEOLOGIC HISTORY

INTRODUCTION

The portion of the Central Appalachians traversed in this trip is between the northwestern structural front of the Grenville tectonic province and the Atlantic Coastal Plain. Depending upon their age and location, the terranes in the Appalachian Highlands major geomorphic division have experienced the effects of from one to several major orogenies. Whereas the sedimentary rocks of the Appalachian Plateaus and Ridge and Valley provinces commonly have a fairly straightforward terrane history of deposition on relatively stable cratonic platforms and shelves, rocks of the Blue Ridge and Piedmont provinces have had a much more intricate origin that involved both terrane accumulation and continent-continent collision. Thus, the Blue Ridge, and especially the Piedmont, are composed of juxtaposed belts and blocks of often-composite terranes assembled by strike-slip faulting, transpressive collision, and compressive collision (Hatcher, *et al.*, 1989; Rast, 1989), and their bedrock geology is highly complex. Most of these rocks owe their lithologies and structures to several magmatic, metamorphic, and tectonic events superimposed by successive orogenies. The resultant continental crust of the Appalachians records two essentially complete Wilson Cycles during Proterozoic and Phanerozoic time, comprised of Grenvillian orogeny, Late Proterozoic rifting, Late Paleozoic collision, and Early Mesozoic rifting. A comprehensive explanation of Central Appalachian topographic and drainage evolution would need to encompass rocks and structures produced during both Wilson Cycles, because this region has both varying erosional levels and tectonic throughprinting of structures from lower tiers, including the Grenville basement. For brevity, a compromise is effected here, in which emphasis is placed on events and rocks that figure importantly in the production of periglacial materials and the landforms that overlie them. Some of the effects on rocks of both cycles can be observed in the Piedmont and Blue Ridge provinces along the field trip corridor (Figure 2).

Why stress bedrock geology in a periglacial presentation? Research findings to date suggest that bedrock nature is extremely important in conditioning the kind and amount of weathering and soil parent materials produced (Washburn, 1980; Lautridou, 1988; Hall and Lautridou, 1991). A specific example, from Douglas, *et al.* (1991), illustrates this principle. These authors collected rock fragments below a cliff that was composed of basalt flows of varying geotechnical and mineralogical properties. Laboratory data were collected on three groups of rock properties: discontinuities, especially microfractures; void-dependent properties; and amounts and types of mineral alteration. The clearest positive relationship was found to be between microfracture density and the yield of rock fragments. Although Douglas, *et al.* (1991) stressed that reconciliation of field and laboratory data is difficult, and that "single cause" approaches are too simplistic, this study demonstrated close connections between measurable rock properties and present-day debris fall activity.

The rocks and their structures have provided the geologic materials which periglacial (and other) processes have weathered, sculpted, eroded, transported, and deposited to form the parent materials and soils we see today. For example, large-scale sedimentary clastic wedges are not only important in palaeogeographic and palaeotectonic reconstructions, but also provided resistant sandstone and conglomerate rock units which were sources for the blocks and boulders in many periglacial deposits. Unfortunately, however, there are few detailed studies of the petrography, petrology, and geotechnical properties of such resistant rock units in the Central Appalachians, so that details of how such rocks might be expected to weather are obscure. There are a few studies, however, that provide basic mineralogic and lithologic data (*cf.* Horowitz, 1965; Sevon, 1969; Stancel, 1980). Geotechnical data that could bear on rock resistance to breakdown, however, are generally lacking. Another example of the importance of bedrock geology is the effect of large-scale, differential fracturing of brittle rock units in the production of parent materials. Canich and Gold (1985) and Parizek and White (1985) studied the effects of fracture traces and lineaments expressed on remote sensing imagery on other rock structures and on the location of linear topographic lows in the topography in central Pennsylvania. An example of such a feature is the McAlevy's Fort-Port Matilda Lineament (FIGURE R.4.1). Some of these linears can be related to areas where more extensive development of certain periglacial features occurs, as for example various types of areally-large sandstone block deposits. Could such controls have influenced, for example, the development and distribution of scree deposits in the Central Appalachians? A final example is the great importance that the parent material factor in soil formation exerts in soil development in the region (Ciolkosz, *et al.*, 1989; Ciolkosz, *et al.*, 1990).

BEDROCK GEOLOGIC HISTORY

Introduction

The basement rocks that are exposed in this part of the Appalachians consist of plutonic and metasedimentary lithologic units which were deformed and recrystallized into gneissic rocks between 950 and 1100 Ma. Although exposed only on the Piedmont and in the core of the Blue Ridge in the excursion area, these rocks underlie the other terranes that comprise the sources for parent materials at the surface. Then, initial rifting, and drifting, of Grenville basement rocks occurred between *ca*. 680-760 Ma (Rast, 1989) and comprised an especially important series of events in the early development of Blue Ridge geology. Large volumes of lavas, ranging from basaltic to rhyolitic in composition, were extruded onto land and into water bodies during this extensional series of events. Their metamorphosed equivalents can be seen in a number of exposures in the Blue Ridge province. For example, there are excellent exposures of metabasalt along the Skyline Drive in northern Virginia. Such resistant rocks are parent materials for the blocks and boulders that comprise a number of features such as block slopes, block streams, and boulder fields, and, also for many thick deposits of stony colluvium in the Blue Ridge province.

Tectonism and Sedimentation

The Taconic Orogeny lasted from Late Ordovician (Late Caradocian, 420-440 Ma) to Late Silurian time. In the Central Appalachians, the widespread deposition of carbonate rock units that occurred during long time spans in the Cambrian and Ordovician Periods was halted by the influx of clastic wedge sediments from the present northeast. Examples of rock units that belong to the Taconic clastic wedge include the Martinsburg (locally Reedsville), Oswego (locally Bald Eagle), and Juniata Formations of Ordovician age, and the Tuscarora and Bloomsburg Formations of Silurian age. Both the Oswego Formation and, especially, the Tuscarora Formation are noted not only as ridge-forming rock units but, also, as prolific producers of scree and stony colluvium. The Juniata Formation has also produced large volumes of grayish-red colluvium that cover large areas on many mountain slopes. Non-resistant rocks in the Taconic clastic wedge have also played a part as producers of parent materials for some periglacial deposits. The Martinsburg Formation and a western partial equivalent, the Reedsville Shale, are parent rocks for large volumes of shale-chip deposits on lower slopes.

The Acadian Orogeny produced a major clastic wedge sequence that accumulated from Middle Devonian through Early Carboniferous time. A prime example of sedimentation during this time was the Catskill marine and nonmarine clastic wedge that prograded westward onto the continental shelf during Middle and Upper Devonian time (Faill, 1985). The overall clastic wedge sequence continued through deposition of the Pocono Formation in Early Mississippian time (Sevon, 1969), an excellent "ridge-forming" rock unit that is also a prolific producer of large sandstone clasts. During Devonian time, deposition of fine-grained clastic materials resulted in the production of a number of shale rock units that produced parent materials for stratified slope deposits.

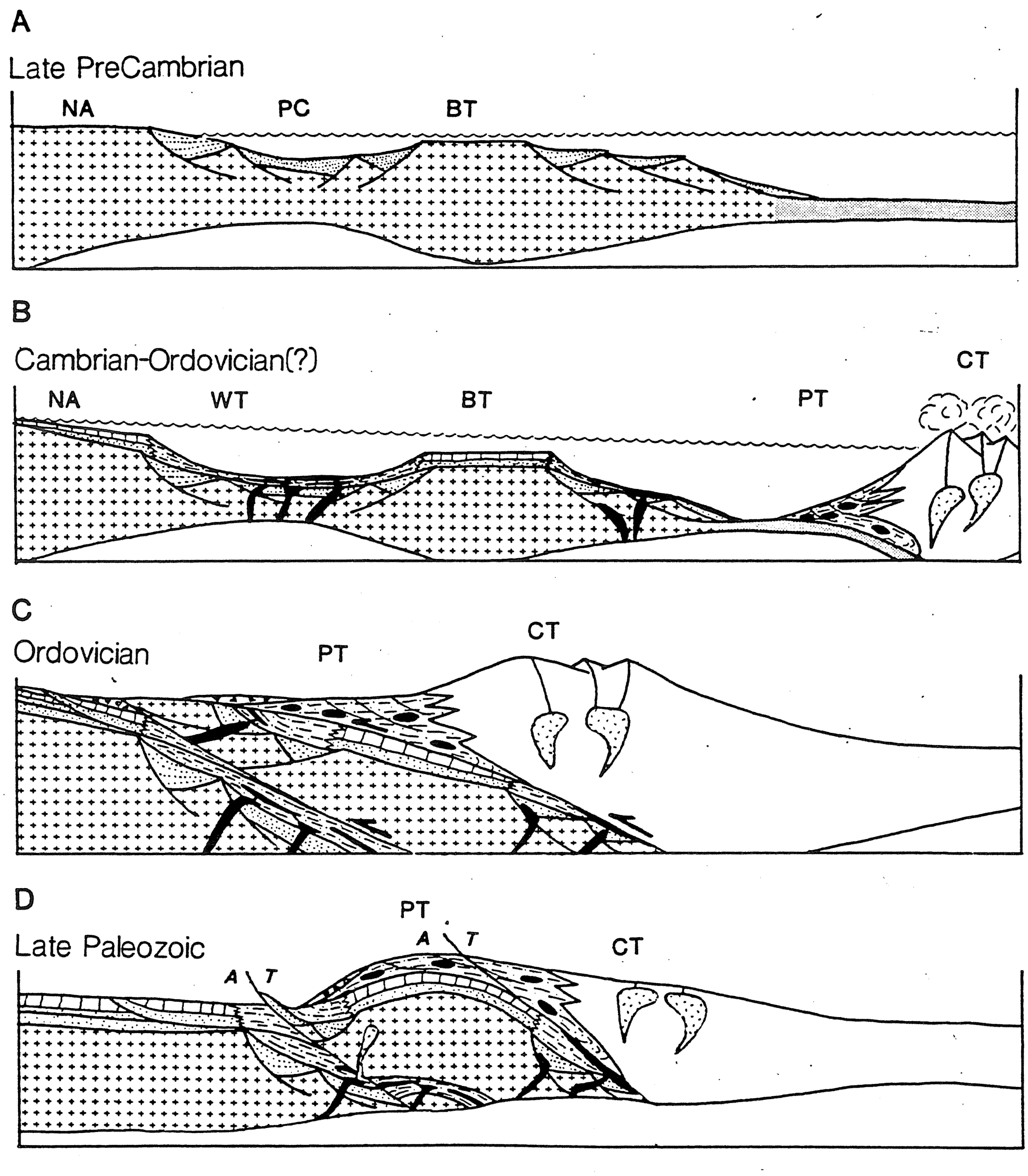

Figure 2. Cross-sectional diagrams (A-D) illustrating development of the rocks in the Piedmont province of northern Maryland and adjacent areas in Pennsylvania. NA = North America, PC = Peters Creek Basin, BT = Baltimore Terrane, WT = Westminster Terrane, PT = Potomac Terrane, CT = Chopawamsic Terrane, A = away from viewer, T = Toward viewer. (From Gates, *et al.*, 1991). Reproduced with permission of Virginia Museum of Natural History.

The last major compressive event, The Alleghenian Orogeny, was also the most pervasive orogeny to affect the area of the Central Appalachians in Phanerozoic time. Bedrock exposures provide evidence of a number of discrete to overlapping episodes of deformation that collectively comprise the effects of the Alleghenian Orogeny in these regions. For example, Geiser and Engelder (1983) and Dean, *et al.* (1988) documented superimposed Earlier and Later Alleghenian events in Pennsylvania and West Virginia, respectively. Deformation may have been initiated in the Early Carboniferous and could have lasted through the Early Permian (Geiser and Engelder, 1983), but was generally an Early Permian event. The Alleghenian orogenic clastic wedge was shed onto the Appalachian platform from Late Mississippian (*ca.* 320 Ma) to Permian (*ca.* 286-266 Ma) time and may even have lasted into Late Permian time (*ca.* 245 Ma). Of particular interest to periglacial geomorphology, a number of stratigraphic sequences in this wedge contain medium- and thick-bedded quartz-rich sandstones and conglomerates that are noteworthy for their ability to form tors, constitute the meshes in sorted patterned ground, and to provide large quantities of other types of stony regolith.

Deformational History and Resultant Structures

On the regional scale, the classic Central Appalachian surface first-order fold and blind thrust style of deformation that is seen at the surface in Pennsylvania, Maryland, West Virginia, and northern Virginia (Figure 3) and its topographic expression (Figure 4) is a function of a number of factors. The stratigraphic sequence, composed of sedimentary packages that have alternating major differences in their response to deformation, conditioned the initiation and propagation of the major thrust systems and their related structures. The requisite major tectonic compressive stress fields during successive orogenies permitted long-term, but changing, deformational patterns to develop. The subsequent uplift and erosional history has allowed a depth of erosion into these blind thrust systems that exposes not only the structures but also has allowed the magnificent development of topography on rocks of contrasting resistance to erosion in the Middle section of the Ridge and Valley province. (In the Southern Appalachian Valley and Ridge section, by contrast, much of the Paleozoic sedimentary package was thin, apparently lacked a thick sequence of highly resistant sandstone rock units, and has been eroded to much lower stratigraphic levels).

The resultant major structures had strong influences on both the evolution of topography and drainage and the juxtaposition of belts of resistant rocks against belts of weak and soluble rocks. This superimposition of structural effects on lithological differences "preconditioned" the Central Appalachian terranes for the development of overlying terrains that developed as the result of prolonged differential weathering and erosion. These processes of weathering and erosion were highly complex and underwent many changes in both nature and intensity, as will be suggested later in this guidebook.

One of the striking megageomorphic features of the Central Appalachians that developed before the Mesozoic Era is the physiographic expression of salients and recesses (Figure 4) that had formed in the inter-regional structure by the end of Alleghenian deformation. Thomas (1977) explained the evolution of these Appalachian oroclinal features as regional bends that have evolved from promontories and reentrants in the early Continental Margin. In a study of distinct joint sets around the Pennsylvania Salient, Orkan and Voight (1985) showed a possible 5- or 6-fold clockwise sequencing from WNW in the southwest to nearly N in the northeast. This study suggests that oroclinal development may have been progressive in time and space, although many questions remain about continuous *versus* incremental development of structures, their overprinting, and the relative contributions of different orogenic events to the end product.

Mesozoic deformational history began in the Late Triassic (Carnian). In two parts of the field trip area, such activity was characterized by faulting, rift basin development and sedimentation, and the igneous intrusion of dikes, sills, and other structural forms composed of hypabyssal doleritic rocks (Manspeizer, *et al.*, 1989). The timing of the igneous activity is currently bracketed by radiometric dates ranging from 175-210 Ma, although a major 190-200 Ma igneous event is known (Manspeizer, *et al.*, 1989). Kunk, *et al.* (1992) obtained results that indicate an emplacement age of 200 Ma for sheets and dikes in the Culpeper Basin area. These sedimentary and igneous rocks now underlie the Gettysburg-Newark Lowland geomorphic section in the part of the excursion in Pennsylvania on the Piedmont, and the Culpeper Basin geomorphic section in the Piedmont in Northern Virginia. The sedimentary red beds underlie lowlands proper, and the dolerite dikes and sills commonly underlie low, often linear, ridges that in places display corestones on their surfaces.

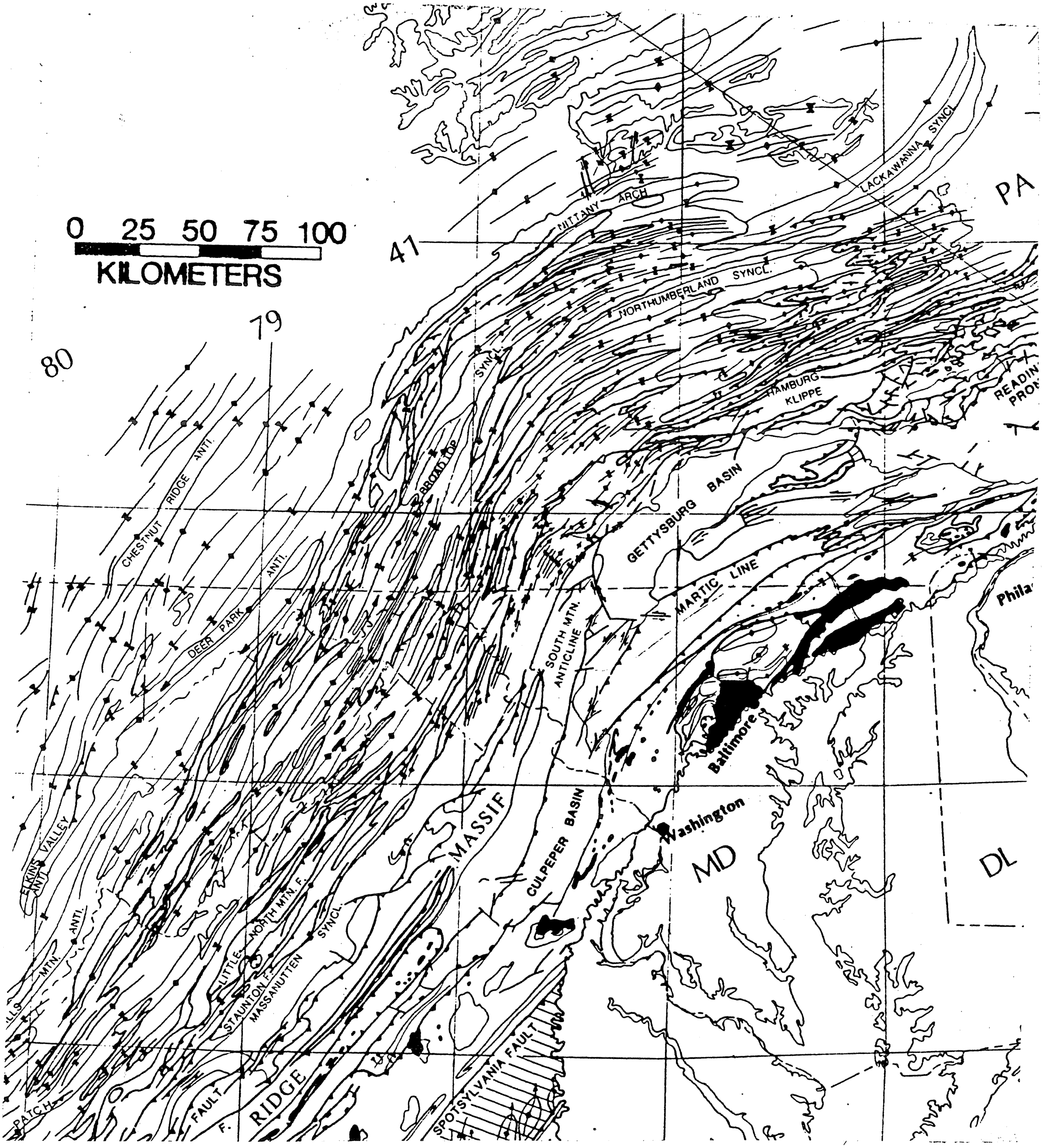

Figure 3. Part of the Tectonic Map of the Appalachians, showing some major tectonic elements in the area of the Central Appalachian discussed in this paper. Folds and faults are indicated by conventional structural symbols. Solid black areas represent areas of ultramafic rocks (including mafic-ultramafic complexes). (From Hatcher, *et al.*, 1988). Compare with Figure 4.

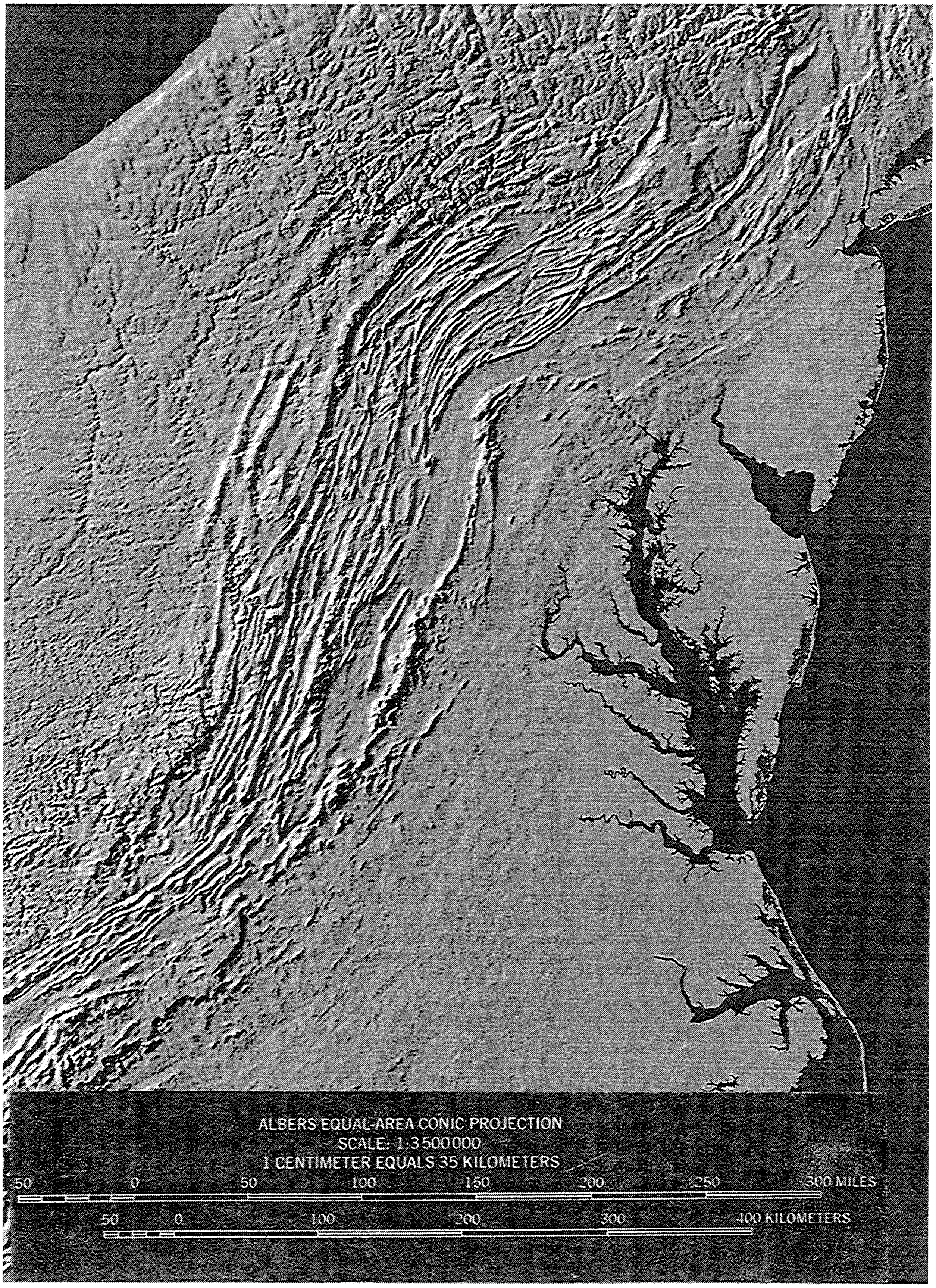

Figure 4. Portion of composite digital image map that depicts some major topographic characteristics in the area of the Central Appalachians discussed in this paper (from Thelin and Pike, 1991). Compare with Figure 3.

After the cessation of the extensional tectonic, igneous, and sedimentational activity in the Appalachian Highlands that marked the opening of the present North Atlantic, diastrophism shifted from orogenic activity to epeirogenic types of deformation. Thus, in the Cretaceous Period and during the Cenozoic Era, the effects of diastrophism have been more subtle, but nevertheless have probably had a profound influence on landscape development in many areas. For example, Hack (1982) noted topographic and drainage characteristics in the Piedmont and Blue Ridge provinces that suggest these areas owe at least some of their topographic and relief characteristics to epeirogenic activity. Gardner (1989) summarized evidence about recent epeirogenic activity in the Appalachians, including data on, and differing conclusions about, the present stress field. He concluded that the present-day stress field has a northeast-southwest oriented maximum horizontal compression related to far-field plate tectonic sources. There is debate about the existence of a northwest-southeast oriented maximum horizontal compression in the Atlantic Passive Continental Margin east of the Appalachian Front (Gardner, 1989). More recently, Pazzaglia and Gardner (1992) present preliminary information about the Late Cenozoic geology and geomorphology of the Piedmont and Coastal Plain in the Central Appalachians. They propose that the Late Cenozoic tectonic regime of the U. S. Atlantic Margin is dominated by isostatic processes. They suggest that these processes were originally driven by the thermal structure of the lithosphere, and later by the distribution of surficial mass after the opening of the North Atlantic Ocean in the Late Jurassic. Research on fluvial terraces, upland gravels, Coastal Plain sediments, and their relationships with dated marine lithologic units will be used to construct a well-constrained model of the Late Cenozoic history of this region (Pazzaglia and Gardner, 1992).

EROSION

LONG-TERM LATE PALEOZOIC, MESOZOIC, AND EARLY CENOZOIC EROSION

As a world-class example of an old fold- and thrust-belt mountain system, the Appalachian Highlands predominantly owe their form and relief to the results of the struggle between the resistive framework, for example composed of lithology and binding vegetation, and the driving (process) framework of uplift, weathering, and erosion. Hack (1980) made strong cases that there are overall agreements among lithology, tectonism, and major aspects of topography in the Appalachian Highlands. The need for additional study, however, becomes apparent when one either attempts to reconstruct the geomorphic history of a much smaller area in detail or tries to understand the genesis of specific landforms and geomorphic materials in the field.

How did the major aspects of topography and drainage evolve? Woodward (1985) drew balanced structural cross sections of the Ridge and Valley province that included the Central Appalachians north to Pennsylvania. These constructions indicate that most major Appalachian Ridge and Valley thrust faults in the Central Appalachians are blind thrust systems with coeval cover deformation (Dunne and Ferrill, 1988). The form, relief, and structural weaknesses (for example see Billman, *et al.*, 1989) developed in these roof sequences are of interest because they could have been exploited by early drainage development, if they had not been buried by the major sediment cover postulated by Beaumont, *et al.* (1988). Levine (1983, 1986) concluded that maximum deformation and burial in the Anthracite Region in Pennsylvania were confined to 285-270 Ma, and that much of the 6-9 km of overburden was emplaced tectonically. Levine inferred that extreme lithotectonic controls existed in the area and probably also shaped early drainage trends inferred from lithologic criteria. Hawman (1980) used the Scranton, Pennsylvania gravity high as evidence for a high-density mafic intrusion that may have loaded the crust to produce atypical flexural downwarp (*cf.* Haworth, *et al.*, 1980).

Evidence that could be used to support a late-Alleghenian break-back sequence (northwest to southeast) was summarized briefly by Perry (1978) for the Central Appalachians. The related back thrusts, when breached by erosion, could have been exploited by early drainage on the thrust sheets. Palaeotopographic effects of the break-back sequence may also have been important in this late stage of deformation, but of course it is not known what landscape forms these may have had. On the other hand, Beaumont, *et al.* (1987, 1988) indicate an Alleghenian orogeny-derived Permian cover more than 4000 m thick throughout the Central and Southern Appalachians which may have masked much of the folding and faulting and allowed drainage initiation from an alluvial plain surface. Sevon (1989b) constructed a model of the Central Appalachian landscape during the Alleghenian Orogeny. Mountains as high as 10 km or more occupied the area of the present Piedmont province; the area to the northwest was the site of deposition for alluvial sediments of Permian age that thinned from more than 7 km in Pennsylvania to 2 km or less in Ohio and West Virginia. These deposits established a northwest-directed drainage pattern and would have permitted superposition of it on the underlying folded and faulted rock units of older Paleozoic age. Extensional tectonics in Late Triassic time initiated drainage reversal and headward erosion from the southeast. For example, Faill (1973) gave sedimentological evidence for a subaerial deltaic fan of Mesozoic age in the Newark-Gettysburg Basin. The present course of the Schuylkill River trends across the mapped ENE portion of this fan (Faill, 1973, Figure 3, p. 728). Poag (1992) shows similar patterns. Such evidence suggests that an overall southeast-flowing drainage system was already in existence at that time, although its full areal extent and degree of integration are unknown. Similar evidence indicates that the Susquehanna River was established at a somewhat later time, but still in the Late Triassic. Sevon (1989b) concluded that the present Atlantic Ocean-Gulf of Mexico divide has shifted northwestward by subsequent Mesozoic and Cenozoic headward erosion and subsequent piecemeal capture by the shorter and higher gradient rivers of the Atlantic slope. Stream capture by lateral cross-divide piracy has probably also played a role in drainage evolution, if relatively recent examples can be used as a guide (Outerbridge, 1987).

The above vignettes could suggest an ancient drainage pattern that might well have influenced subsequent drainage pattern evolution, but the specific pathways followed by the early drainage while evolving into the present drainage are not known at this time. Classical analysis might assume that later drainage evolved vertically in place from former drainage lines, but this need not be so in such an old fold-belt mountain system. Continued unroofing of weak covermasses and underlying resistant lithologies might have exposed different structural complexities to downcutting rivers, and changing spatial patterns of epeirogenic warping could have influenced drainage evolution. On the other hand, in 1973, Gold, *et al.* (discussed in Parizek and White, 1985) proposed the hypothesis of the "permanency of master streams" (major transverse drainages). In this concept, planar-like, vertical zones of structural weaknesses allowed the master streams to be superimposed across rock units of differing relative resistance to erosion over relatively long spans of geomorphological time, presumably measured in terms of millions to tens of millions of years. The vertical let-down would continue until the essentially-vertical zones played out with depth, or until the master stream was pirated, or until major episodes of tectonism or climatic change intervened. In such a case, one might expect that present-day drainage lines that developed on such essentially-vertical disturbed zones would be inherited from ancestors that had been above their modern locations.

Some guidance about processes that may have been involved in Central Appalachian drainage evolution is available from several sources, however. Oberlander (1985) applied his knowledge of the Zagros Streams in Iran to explain how transverse drainage in the Appalachians might have evolved. He concluded that local superposition from weak covermass rocks can replace a requirement for regional superposition, and he mapped a sequence of hypothesized drainage development for a part of the Central Appalachians. Whether or not Oberlander's work can be applied directly to this part of the Appalachians is, of course, open to debate. Ciciarelli (1971, 1984) studied the breaching of resistant rock in anticlines in Pennsylvania and hypothesized a sequence of drainage development as streams dismember these structures. A similar scenario, in diagram form, was prepared for Nittany Valley, central Pennsylvania, by Parizek and White (1985, Figure 19, p. 100). These studies illustrate how progressive unroofing of large anticlinal structures could give rise to some major elements of the present landscapes on the District and Subdistrict levels (Table 2). The stage is now set for the Late Cenozoic players responsible for the development of the present-day landforms and landscapes that are seen on the excursion. As will be suggested later, the agents of landscape development that operated in Late Cenozoic time may have been influenced more by the exogenous forces that create landscapes than they have been by the endogenous geomorphic agents.

LATE-CENOZOIC EROSION

If reasonable rates for uplift and erosion of the Central Appalachians are assumed, the general major landscape patterns of uplands, lowlands, and master river courses in this part of the Appalachians were well established when major episodes of rapid and increasingly severe climatic deterioration began to appear during Late Cenozoic time. How were the Quaternary paraglacial, periglacial, and interglacial processes affected by the forms and materials brought from the deep subsurface into the realm of geomorphic processes by uplift and erosion?

Accelerated rates of physical weathering and erosion during cold phases (Braun, 1989b) should have been enhanced even more along and down zones of structural weaknesses in rocks where atmosphere, water, ice, and biota could have penetrated and worked. An interesting test of this idea could be completed by relating maps of lineament-related structures to the distribution and thicknesses of colluvium in areas where subsurface data are already available (construction sites, wells, geophysical data) or could easily be obtained. Parizek and White (1985), for example, demonstrated the presence of deeper residual soils developed at a fracture trace intersection on the campus of The Pennsylvania State University. The same general type of relationship might be demonstrable for colluvium in upland areas, along and downslope from the positions of lineament-related structures that could be mapped from remote sensing imagery. Even local so-called "anomalies" in the coming-and-going of features such as scree aprons below the crests of ridges underlain by resistant rock units might be a demonstrable result of differential fracturing along the trends of such rock units, if adequate subsurface data were available.

REGIONAL GEOMORPHOLOGY

INTRODUCTION

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 was that of subdivision, with the construction of a descending hierarchy of successively smaller compartments. The regional concept soon was eagerly adopted in western countries by botanists, climatologists, foresters, geographers, geologists, physiographers, and soil scientists.

A major weakness in this approach is that it assumes we have some understanding of the causes of similarity and variation within and between the various landscape categories. There are many other difficulties; disputes continue between proponents of genetic *versus* generic schemes (Beckinsale and Chorley, 1991), scale problems persist (Godfrey and Cleaves, 1991), and objections continue to surface about the priority of studying breaks between areas rather than links. Indeed, the field of regional geomorphology, despite its considerable history (Beckinsale and Chorley, 1991), seems hardly to have come of age. One problem may be the lack of a sound and modern theoretical basis. In discussing the multiplicity of trends in geomorphology today, for example, Thorn (1988, p. 31) stated:

> "Meanwhile, there has been little or no theoretical growth in regional or mesoscale geomorphology."

A number of different strategies have been used to classify landscapes, including encyclopedic, subdivisional, accretional, drainage basin analysis, practical, and complex or combinatorial (Beckinsale and Chorley, 1991). 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). In terranes where landmasses can be identified as collages of microplates, tectonic attributes can often be used effectively as regional geomorphic criteria. Landscapes also bear some stamps of the various formative climatic environments under which they have evolved, although until recently the climatic factor has largely been disregarded in American geomorphology (*cf.* Sevon, 1985, who called climate "the ignored factor" in the development of landscapes in Pennsylvania). Finally, the operation of similar geomorphic process groups working on similar earth materials 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.

Early overall treatises on the Central and Southern Appalachians dealt largely with physiographic description and the fluvial and erosional surface history (*cf.* Hayes and Campbell, 1894; Fenneman, 1928; Fenneman, 1938). Topographic depictions that include the excursion region include the land surface-form map by Hammond (1963) and the report by Redington (1978). But other than to name several new sectional subdivisions, primarily in the Appalachian Plateaus province, little work has been done with regional geomorphology since Thornbury (1965). The geomorphic subdivision terminology used in this guidebook is shown in Table 1.

Table 1. Provisional geomorphic subdivisions used for the Appalachians and the bordering Atlantic Coastal Plain of eastern United States. Terms in quotation marks are informal (paraphrased, undefined or poorly-defined in pre-existing literature) working subdivisions used for lack of defined geomorphic units in the literature.

HIERARCHY (modified from Thornbury, 1965)	NOTATIONS
"Atlantic Continental Margin" major division	
Atlantic Coastal Plain province	
Cape Cod–Cape Hatteras section	
Lowland subsection	*cf.* Berg, *et al.* (1989)
Intermediate Upland subsection	*cf.* Berg, *et al.* (1989)
Cape Hatteras–Florida section	
Appalachian Highlands major division	
New England province	
Reading Prong section	Berg, *et al.* (1989)
Piedmont province	
Northeastern Highlands subprovince	Hack (1982)
Piedmont Lowland section	Berg, *et al.* (1989)
Conestoga Valley district	
Lancaster Valley district	
Piedmont Upland section	Berg, *et al.* (1989)
Gettysburg–Newark Lowland section	Berg, *et al.* (1989)
Foothill Zone subprovince	Hack (1982)
Culpeper Basin section	Hack (1982)
Blue Ridge province	
Northern Blue Ridge section	north of Roanoke River
South Mountain district	located mostly in Pennsylvania
Catoctin Mountain district	located mostly in Maryland
Middletown Valley district	located in Maryland
"Harpers Ferry district"	
"Northern Virginia district"	
Southern Blue Ridge section	south of Roanoke River
Ridge and Valley province	
Middle section = "Ridge and Valley"	Delaware River to near James River[1]
Appalachian Great Valley subsection	*cf.* Berg, *et al.* (1989)
Lehigh Valley district	
Lebanon Valley district	
Cumberland Valley district	
"Shenandoah Valley" district	
"Massanutten Mountain" district	
"Page Valley" district	
Appalachian Mountain subsection	*cf.* Berg, *et al.* (1989)
"Alternating Ridges and Valleys district"	
"Breached Carbonate Valley district"	
"Broad Top district"	
"Bedford Synclinorium district"	
"Western Anticlines district"	

Southern section = "Valley and Ridge"	south of James River area[1]
"Valley and Ridge of Virginia" district	
"Roanoke Valley" district	
"Great Valley of Virginia" district	
"Valley of East Tennessee" district	
"Bays Mountain" district	
"Georgia–Alabama" district	
"Coosa Deformed belt" subdistrict	Bearce (1978)
"Eastern Coosa Valley" subdistrict	Bearce (1978)
"Weisner Ridges" subdistrict	
Appalachian Plateaus province	
Mohawk section	Fenneman and Johnson (1946)
Catskill Mountains section	Fenneman and Johnson (1946)
Glaciated Low Plateau section	Berg, *et al.* (1989)
Glaciated Pocono Plateau section	Berg, *et al.* (1989)
Glaciated Pittsburgh Plateau section	Berg, *et al.* (1989)
High Plateau section[2]	Berg, *et al.* (1989)
Mountainous High Plateau section[3]	Berg, *et al.* (1989)
Pittsburgh Low Plateau section[4]	Berg, *et al.* (1989)
Allegheny Mountain section	Berg, *et al.* (1989)
Parkersburg Plateau section	Outerbridge (1987, Plate 1)
Ohio Plateau section	Outerbridge (1987, Plate 1)
Logan Plateau section	Outerbridge (1987, Plate 1)
Cumberland Mountains section	Fenneman and Johnson (1946)
Cumberland Plateau section	Fenneman and Johnson (1946)

[1] Fenneman (1938), however, placed the Middle–Southern sectional boundary at the New–Tennessee River divide. From a tectonic basis, though, there are several reasons for placing the transition at the bend in the Roanoke (or Virginia) Orocline. For details about differences in structural deformational styles between the Southern and Central Appalachians, see Lowry, *et al.* (1971). For three-dimensional quantitative structural data on the noncoaxial deformation across the junction, including the transition zone, see Couzens (1992). From a structural-geomorphic perspective, then, this sectional boundary could be placed at Buchanan about 37 km NE of Roanoke, and would then pass NW along the James River Valley to the Iron Gate, next up the Jackson River Valley to the Covington area, and finally generally west to the border of the Ridge and Valley province with that of the Appalachian Plateaus province.

[2] Fenneman and Johnson (1946) placed the glaciated portion of the High Plateau section in their Southern New York section, and placed the unglaciated portion of the High Plateau section in their Kanawha section.

[3] Fenneman and Johnson (1946) placed the glaciated portion of the Mountainous High Plateau section in their Southern New York section, and placed the unglaciated portion of the Mountainous High Plateau section in their Kanawha section.

[4] Fenneman and Johnson (1946) included the Pittsburgh Low Plateau section in their Kanawha section.

The striking geologic and physiographic similarities within and differences between geographically large land units in the Appalachian Highlands provide opportunities for and challenges to landscape analysis. Fenneman (1938) and Thornbury (1965) specified 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 necessary. 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 this part of the Appalachians (Table 2).

Table 2. Ranking of landscape units used in description of landforms and landscapes in the part of the Central Appalachians traversed by field trip C.20c. Modified from Godfrey and Cleaves (1991).

Rank	Area (km^2)	Basis (Dominant Entity)	Example(s)
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	Appalachian Great Valley
District	10^2	Form-Material Relationships	Massanutten Mountain
Subdistrict	10^1	Direct Material-Form Linkage	Egg Hill; Georges Valley
Zone	10^0	Few Form-Relief Parameters	Upland Flat; 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 Joint

Another long-standing obstacle in the path of regional geomorphology has been the lack of declassified imagery with high-resolution capabilities for civilian terrain analysis at appropriate scale levels. Thelin and Pike (1991), however, have prepared a 1:2,500,000-scale shaded relief map of the United States from digital elevations that shows major landscape subdivisions clearly (see Figure 4). They also calculated statistics of central tendency and dispersion for elevation, slope angle, texture, and slope azimuth for each major physiographic land unit. In the Central Appalachians, refinement of sectional-level landscape units into subsections, districts, and subdistricts would be possible using these techniques and existing imagery and geologic and topographic maps. The visual geomorphic character of some such potential subdivisions can be observed and discussed in the field during this excursion. In general, these possible landscape subdivisions follow structural trends and the map patterns of lithologic units, as might be expected in a deeply-eroded old fold-belt mountain system. There are some most interesting exceptions, however. In some areas, there are both positive (armoring, for example) and negative (underground solution, for example) topographic expressions of deep weathering of soil and rock. In other areas, thick colluvial and alluvial fills have created positive topographic expressions, for example as diamicton lobes, aprons, and sheets and as terrace deposits and valley fills.

The discussion on regional subdivisions that follows is highly general, and it neither differentiates below the province and section levels of the provisional subdivisions given in Table 1, nor does it rank landscape units according to Table 2. There are reasons for this abbreviated treatment. One reason is that, although there is much qualitative evidence that the subdivisions in Table 1 exist in nature, we lack published numerical data to quantify these "visual perceptions." A second reason is that the results of map and imagery analyses require subsequent expensive and time-consuming field research in order to relate imagery properties to forms and materials on a one-to-one basis so that they can be interpreted. A third reason is that increasing demands on shrinking resources requires both agencies and individual researchers to prioritize their efforts. Such a major undertaking would, therefore, require major justification. Thus, we have no Appalachian-specific, quantitative, applications of the classification by Godfrey and Cleaves (1991) that would allow meaningful back-generalizations at lower that the regional and sectional levels. Sadly, we still remain at the subdivisional levels of the classical masters of regional geomorphology.

REGIONAL SUBDIVISIONS

Piedmont province

Extending from Alabama to New Jersey, the Piedmont province is mostly underlain by multideformed igneous and metamorphic rocks. Rift basins filled by Mesozoic sedimentary rocks and intruded by Mesozoic plutons occupy certain areas, such as the Culpeper Basin and the Gettysburg-Newark Lowland. Bedrock is characteristically mantled by saprolite (Cleaves, 1988, 1992; Pavich, 1986) ranging from 0 to 100 m in thickness, except in areas where fluvial erosion or deposition predominate. In many piedmont hillslope areas, saprolite is capped by colluvium, on which the modern soils are developed. Upland surface elevations rise from about 100 to 600 m from the Coastal Plain to the Blue Ridge, with isolated hills (or "monadnocks") common on the Piedmont near the Blue Ridge province. Hack (1982) has produced a subdivision of the Piedmont Province based on objective topographic, fluvial, and bedrock characteristics on the subprovince and section levels (Table 1). The work of Hack (1982) shows how meaningful subdivisons could be constructed in other areas of the Appalachians.

Pazzaglia and Gardner (1992) studied fluvial terraces, upland gravels, and their associated landforms in Maryland and southeastern Pennsylvania. They describe the relationships among terrace levels, tectonic geomorphology, and Late Cenozoic bedrock geology at a number of sites in the Lower Susquehanna River Valley in Maryland and Pennsylvania that are in or near the field excursion corridor. Although the objectives of Pazzaglia's research do not include regional geomorphic subdivision, his findings should prove valuable to any subsequent research efforts that attempt to map landforms and geomorphic materials in a regional context.

Blue Ridge province

Introduction

Extending from Georgia northeastward to Pennsylvania, the Blue Ridge province is a geomorphic region that exhibits striking bedrock and topographic differences between its Southern and Northern sections. Structural relations in the Southern Blue Ridge are highly complex. Fensters in several areas demonstrate long-distance tectonic transport of thrust sheets which themselves contain highly-deformed rocks of low to high metamorphic grades. The Southern section widens southwestward from Roanoke, Virginia, attaining a maximum width of about 120 km at the North Carolina-Tennessee state line. Much of this section is bordered on the southeast by the high Blue Ridge escarpment and on the northwest by a foothills belt that is separated from the Valley and Ridge by the Blue Ridge tectonic front. In much of Tennessee, the foothills belt is backed by a much higher range, the "Unaka Mountains" of some writers. Between the Unaka Mountains and the Blue Ridge escarpment to the southeast are a series of irregular, ladderlike transverse ranges separated in some areas by irregularly-shaped basins (Hammond, 1963). Many of these intermediate ranges are quite high in elevation; the various Balsams and, of course, the Blacks with Mt. Mitchell are examples. The highest elevations in the United States east of the Mississippi River are attained in the Southern Blue Ridge (2038 m). The expected coincidences of relatively resistant rocks, high elevations, and exposure to extremes of weather and climate result in a large number of landforms and deposits of probable periglacial origins in the Southern Blue Ridge section. Many of these features differ from those found to date in the Central Appalachians, however, and will not be treated here.

Northern Section of the Blue Ridge province

Exposed structural and lithologic relationships in the Northern section appear somewhat less complex than those in the Southern section. Much of this mountain range is underlain by a pervasively-faulted anticlinorium that is strongly asymmetrical to overturned to the northwest, and bounded there by the Blue Ridge tectonic front. The core area of the Northern Blue Ridge is underlain by igneous and metamorphic rocks of Precambrian age, many of which were formed during Grenville events. These rock types include gneisses, charnokites, granites, metabasalts, and metarhyolites. On the northwest, these basement rocks are unconformably overlain by metasedimentary siliciclastic rocks of Latest Precambrian to Cambrian age. Near the end of the excursion, road traverses in Shenandoah National Park, Virginia, show rock and landscape features typical of much of the Northern section in Virginia (Gathright, 1976). North of Potomac River in Maryland, however, the northern Blue Ridge is composed of an eastern mountain range, Catoctin Mountain, and a western range, South Mountain, separated by the Middletown Valley. These ranges unite to form a single, but complex, upland near the Pennsylvania border that extends into Franklin, Cumberland, and Adams counties, Pennsylvania, as the South Mountain district.

Sevon (1992a), and Sevon and Potter (1991) describe a number of aspects of the bedrock geology and geomorphology of the South Mountain district. This range is underlain by Late Precambrian igneous and metamorphic rocks and Lower Paleozoic sedimentary and metasedimentary rocks that have been deformed into a complexly folded and faulted anticlinorium. Many upland areas on South Mountain contain periglacial landforms and deposits including sorted patterned ground, tors, cryoplanation terraces, block streams, and complex diamicton deposits (Clark, 1991).

Ridge and Valley province

Introduction

The Ridge and Valley province extends northeast from north-central Alabama 1930 km to the St. Lawrence lowland. As wide as 100 km in parts of Pennsylvania, and as narrow as 23 km near the New York-New Jersey line, the province ranges in width from approximately 50 to 100 km in the latitudes transected by this field trip. This region is exemplified by northeast-southwest-trending ridges and valleys in its northwestern portion—the Appalachian Mountain subsection—and a 3 to 80 km wide valley—the Appalachian Great Valley subsection—to the southeast.

Appalachian Great Valley Subsection

The Shenandoah Valley in northern Virginia and easternmost West Virginia, and the Lebanon Valley in Pennsylvania, are underlain by thick sequences of carbonate rocks of Cambro-Ordovician age that are tightly folded and pervasively faulted and otherwise fractured in many areas. In Virginia, The Massanutten Mountain Synclinorium contains downfolded clastic rocks of Ordovician, Silurian, and Devonian age. Here, the ridge crests are capped by the Massanutten Sandstone, partially equivalent to the Tuscarora Sandstone farther west (Rader, 1982).

Overall, the Appalachian Great Valley drainage is trellis with transverse linkage streams (see Hack, 1973). In detail, there are many stream pattern complexities that are probably related to the underlying structures and rock types. Other drainage network map patterns may be relateable to recent stream capture events and to effects produced by climatically driven events. A number of streams exhibit striking meander belts, such as those of the North Fork of the Shenandoah River (Hack and Young, 1959).

Appalachian Mountain Subsection

The Appalachian Mountain subsection is characterized by longitudinal, northeast-southwest trending, fold-belt mountain ridges. These ranges progressively occupy larger areal portions of certain parts of the province northwest of the Appalachian Great Valley as one goes northeastward along trend. Major surface thrust faults become less common to the northeast along strike, and subsurface or blind thrust systems with coeval cover deformation become the dominant tectonic style (Dunne and Ferrill, 1988). Erosional levels are stratigraphically higher in the Appalachian Mountain subsection, and rocks of Ordovician age are commonly the oldest rocks exposed, although there are exceptions, as in parts of Nittany Valley, Pennsylvania. North of New River, in Virginia, the Tuscarora Sandstone (Clinch Formation equivalent) is the prime ridge maker. From east-central West Virginia northeastward, the underlying clastic Oswego and Juniata Formations of Upper Ordovician age become important secondary ridge-forming rock units. Additional, but lesser, ridge-forming rock units in this part of the Appalachians include sandstones within the Rose Hill Formation (such as the "Cacapon"), and sandstones in the Clifton Forge and Eagle Rock-Williamsport "Keefer" rock units, all of Silurian age. The Ridgeley (or Oriskany) Sandstone of Devonian age is another rock unit that upholds secondary ridges in this part of the region. In eastern West Virginia, and extending through Maryland into Pennsylvania, large synclinoria, such as the Bedford Synclinorium, bring down extensive sequences of fine-grained clastic rocks of Devonian age into broad hilly valleys. The southern extension of one such fold is an example that will be skirted during the field trip in the Petersburg area, West Virginia. The narrow to wide breached anticlinal valleys that are more typical of the western part of the Middle section are underlain by shales, siltstones, and carbonate rock units of Lower Paleozoic age.

Master drainage in the western Ridge and Valley is classic trellis, with longitudinal tributary streams in strike valleys, and transverse drainage—often in spectacular water gaps—as linkages. North Fork Gap and Brocks Gap are excellent examples that will be traversed during the excursion in West Virginia and Virginia, respectively. "Wind" gaps are another striking feature in this part of the province. The gap through the eastern end of Bald Eagle Mountain, (see Montoursville South, Pennsylvania quadrangle) is an outstanding example. Another spectacular example is Dolls Gap (quoted by Davis, 1889, p. 245), which is also very close to the excursion transect (see Antioch, West Virginia quadrangle).

Appalachian Plateaus Province

The Appalachian Plateaus province extends from the Coastal Plain in northwestern Alabama to northwestern New York. On this excursion, it is visited only in eastern West Virginia, where the excursion route ascends the Allegheny Front, crosses several major folds that have strong topographic expression, passes through the Dolly Sods area, and then descends the Allegheny Front. The highest portion of the unglaciated Allegheny Plateau section reaches 1482 m on Spruce Knob, 33 km south-southwest of the excursion route through the Dolly Sods area. In this part of West Virginia, the Allegheny Front is both the topographic and structural boundary between the Plateau on the west-northwest and the Ridge and Valley on the east-northeast. Allegheny Front is underlain primarily by clastic sedimentary rocks of Devonian and Mississippian age that are capped at the crest by Pennsylvanian-age sandstones and conglomerates of the Pottsville Group. These rocks have been raised and laterally transported northwestward above the subsurface tectonic discontinuity produced by the Waynesboro Sheet upramping to the Martinsburg Sheet (McKoy, 1988).

West of Allegheny Front, the Allegheny Plateau in the field trip area is underlain by sedimentary rocks of Mid- to Late-Paleozoic age that have been folded into large, broad, doubly-plunging anticlines and synclines. In this part of West Virginia, these folds have been breached by erosion so that canoe-shaped anticlinal valleys and broad synclinal uplands dominate the topography. Examples of anticlinal valleys are Canaan Valley and Tygart Valley; an example of a synclinal upland is the Cabin Mountain-Stony River area.

Major drainage lines follow fold and lithologic trends and, perhaps, fracture zones in transverse gorges. Deep gorges with rapids and waterfalls are common in this part of the Plateau. Headwater reaches often exhibit dendritic patterns, and, their wellspring areas are often poorly drained. In the area of the Plateau visited by this trip, drainage is tributary to the Cheat River system that flows *via* the Monongahela River north to the Ohio River at Pittsburgh, Pennsylvania.

CLIMATOLOGY

PALAEOCLIMATOLOGY

Paleozoic Era

A time scenario of Central Appalachian palaeoclimates—and one germane to the excursion route—could begin with the Late Paleozoic, just before and during the Alleghenian Orogeny, when global palaeogeography, diastrophism, and astrophysical climatic forcing functions combined to close out the Paleozoic Era, with dramatic changes in depositional, deformational, and surficial environments. During the Pennsylvanian Period, certain basins of deposition had conditions conducive to the accumulation and burial of vast areas and great thicknesses of plant materials and clastic sediments that accumulated under a variety of environments. The "coal swamps" and their related depositional environments eventually gave way to environments characterized by increasing aridity that were accompanied by pronounced oxidizing terrestrial conditions during the Permian Period. Likely scenarios during appropriate parts of this time window have been aptly played out by Beaumont (1978, 1979) for relationships between stratigraphy and isostasy, and by Sevon (1989b) for probable palaeogeomorphological conditions.

Triassic and Jurassic Periods of the Mesozoic Era

Hallam (1985) reviewed the overall climatic history of the Mesozoic Era. During the Triassic Period, the results of extensional tectonics and continued aridity are recorded in the sediments of the extensional Gettysburg-Newark and Culpeper basins that are traversed by this excursion. Schlee, *et al.* (1988) suggest that Triassic-Liassic environments may have been savanna-like over much of the region, with drier conditions in northern basins of deposition than in southern basins.

Early and Middle Jurassic landscapes were probably characterized by alternating elongate rift lakes separated by flood basalt terranes; arid conditions are indicated by salt and anhydrite deposits (Schlee, *et al.*, 1988). Chandler, *et al.* (1992) ran the three-dimensional GISS Global Circulation Model (GCM) to simulate Early Jurassic climates. Using data for the boundary conditions required by this model, Chandler, *et al.* (1992) concluded that Early Jurassic climates in Pangaea were warm, probably arid, and could have experienced pronounced annual temperature ranges. Scholle (1980) reported that the log of the COST No. B-3 offshore well records sediments of Jurassic age, including numerous coal seams. Thickness of the Jurassic sequence in the COST No. B-3 well area is approximately 9 km, according to seismic data. These data suggest significant erosion from ancient uplands produced by the direct and indirect effects of orogenic activity. From a palaeoclimatic standpoint, it is of interest to note that at least coastal environments were capable of supporting coal swamps in areas representative by the COST No. B-3 well.

Cretaceous Period of the Mesozoic Era

Scholle (1977) reported that the COST No. B-2 well penetrated about 914 m of sediments of Upper Cretaceous age and about 8000 feet (2438 m) of sediment of probable Early Cretaceous age. This well record indicates a major decrease in clastic sediment yield from the Central

Appalachians during Early Cretaceous time. A decrease in sediment yield could have been related to decreasing relief in the source area and/or to the development of a continuous vegetative cover over the source area. From other lines of evidence, Cretaceous climates in the Central Appalachians can be interpreted as having become increasingly humid (Pierce, 1965).

A major marine transgression that began during the Early Late Cretaceous was accompanied by the deposition of sediments suggesting warm shallow marine conditions off the eastern United States (Schlee, *et al.*, 1988). Onshore, warm and more humid climates would have favored abundant vegetation growth. Such conditions in the Central Appalachians could have enhanced deep chemical and biochemical rock weathering, and the accumulation of residual weathering products essentially *in situ* beneath a dense and essentially continuous forest cover.

Cenozoic Era

Introduction

Because most calculations of rates of uplift and erosion suggest that modern landscapes produced in conjunction with tectonic events probably are no older than Tertiary, it is productive to concentrate on the last 65 million years of climatic history. Even within this narrower time slice, there was, until recently, not much evidence which could be used for guidance. The Atlantic Coastal Plain province, however, contains a wealth of stratigraphic information about Cenozoic events in the Appalachian Highlands. Offshore, the depositional record in the Atlantic Continental Margin contains a very valuable and often much less discontinuous long-term record of former conditions in the bordering Appalachian Highlands (Poag, 1992). Frakes (1979) discussed at length the complexity of the Cenozoic climate changes and major unresolved research 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 (1979) indicates that a major change in climate started in the Middle Miocene with a trend of cooling and rainfall change which culminated in the Pleistocene.

Tertiary Period

Poag and Sevon (1989) reported in detail 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 the field trip region. This pattern changed significantly in the Middle Miocene, when large quantities of sediment were transported offshore. Barron (1989) indicated that the Appalachians would have been an area of focused precipitation throughout the Cenozoic, but with gradually decreasing rates.

Tiffney (1985) discussed the vegetational changes that occurred in northeastern North America during the Cenozoic. He noted that the warm-temperate to subtropical vegetation which gradually developed over much of North America during the Eocene was gradually replaced as the climate began world-wide cooling and increased seasonality. Land-based records for the Cenozoic in the Central Appalachians provide very few—but extremely valuable—scraps of evidence about palaeoenvironmental conditions in the highlands. Many such sites are mountain footslope environments underlain by soluble carbonate bedrock that produces residuum and karst topography upon weathering. Near the mountain fronts, ancient solutional terrains were partially stripped of their deep residual soils and then buried by complex sharpstone and roundstone diamicton deposits shed from the mountains. Evidence indicates, however, that the deeply buried carbonate bedrock is still undergoing active groundwater flow and solution (Sevon and Potter, 1991). The regolith continues to undergo differential lowering that maintains and shifts the karst topography. Hack (1965) argued that solution of carbonate bedrock and the production of residual ore deposits in the Shenandoah Valley, Virginia exemplify a landscape in dynamic equilibrium. Regardless of the timing, continuity, and environments of development, a number of the sinkholes have trapped sediments that contain plant remains. Pierce (1965) described such a site in Pennsylvania. Tschudy (1965) made palaeobotanical identifications of plant remains collected at this site, documented a rich assemblage, but published no palaeoclimatic interpretation. The most reasonable general interpretation, however, is that the climate was sufficiently warm and wet to support a dense and continuous forest cover.

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 and biochemical 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 associated vegetation changed, a critical threshold was reached in the Middle Miocene. Large amounts of clastic sediment were then eroded from the Appalachians and transported to the Middle Atlantic offshore basin. Erosion slowed during the Pliocene, but was renewed in the Pleistocene, especially during cold intervals which fostered vigorous glacial and periglacial erosion (Braun, 1989b).

Quaternary Period

A wealth of information about climatic history is contained in terrestrial sediments of Quaternary age in the Central Appalachians. These data indicate that glacial episodes were interspersed with interglacial ocurrences of palaeoclimates that were warmer than now. This land record, however, is often weathered, fragmented, and lacks continuous sequences containing easily dateable materials. The marine record must still be referred to for a long-term and nearly continuous record of events on land (see Ridge, *et al.*, 1992). Using the marine record as a guide, the last major glaciation of Pre-Wisconsinan age (> 130 Ka) is inferred to be correlative with the Late Illinoian glaciation of midwestern United States. In like manner, the succeeding warm interval (*ca.* 130-75 Ka) is inferred to be correlative with the midwestern Sangamon interglacial. The last major glaciation in the Appalachians is divided into a long, but not severely cold Early and Middle Wisconsinan interval (*ca.* 75-25 Ka) (see Eyles and Westgate, 1987) and a shorter (*ca.* 25-10 Ka) Late Wisconsinan that had extremely cold conditions in its earlier phases. The later phases were less cold, for example, the Late Wisconsinan, Late Glacial interval (*ca.* 16.5-12.5 Ka) (*cf.* Ridge, *et al.*, 1992). An excellent overall summary for North America on the Late Wisconsinan glacial and deglacial history of the Laurentide Ice Sheet is in Andrews (1987).

At the Pleistocene-Holocene boundary, dramatic changes in climate, vegetation, and geomorphic process-response mechanisms occurred. Environments, processes, and their effects rapidly approached essentially modern aspects in Early Holocene time. The Middle Holocene time interval—termed the Altithermal or the Hypsithermal—had elevated temperatures and decreased effectiveness of precipitation, as compared to the present. The Late Holocene time interval began with climatic conditions similar to those of today. It was followed by the Neoglacial geologic-climatic time unit (Porter and Denton, 1967), an episode of minor climatic deterioration that terminated with the end of The Little Ice Age (Grove, 1991). Subsequent climates in the excursion area have approximated those shown in historical records.

One geomorphically important effect of the Early and Late Holocene climates during spring, summer, and fall seasons was the increased availability of moisture-laden air masses from the Atlantic Ocean and the Gulf of Mexico (Delcourt and Delcourt, 1981). Such moisture supplies, coupled with the increased moisture capacity of warmer air columns, provided conditions permitting increased likelihood of catastrophic precipitation events that could modify landscapes rapidly (Jacobson, *et al.*, 1989a, b). Newson (1980) distinguished two types of floods, based upon their different kinds of geomorphic effectiveness: "slope floods" that produce severe hillslope and toeslope modification, and "channel floods" that mainly impact floodplain areas. Both types of storms can be observed in the same geographical area during a short span of time under the same overall climate. For example, in the field trip corridor area in West Virginia, the storm of 17-18 June 1949 was accompanied by cataclysmic debris slide/debris flow events (as well as by local flooding, see Clark, 1987a, 1987b), but the storm of 3-5 November 1985 was characterized mainly by extreme channel modifications in small and intermediate-sized river basins (Clark, *et al.*, 1987). McKoy (1990), Miller (1990), and Miller and Parkinson (in press) have documented varying severity of geomorphic effectiveness of the 1985 "channel flood" in different reaches of Potomac River drainage in eastern West Virginia.

There is stratigraphic evidence that "slope floods" have occurred in prehistory. For example, Kite (1987) reported that the stratigraphy of debris fan deposits he studied contains a complex record of older debris slide/debris flow events in the region. The work of Hack and Goodlett (1960) strongly suggests that such fans can be largely products of record storm events.

Stratigraphic evidence also shows that "channel floods" floods have occurred in prehistory as well. Wall (written communication, 13 July 1992) found flood scours, and resultant fluvial insets, filled with sediments interpreted as flood deposits in archeological excavations between West Virginia Route 28 and the South Branch of the Potomac River on the east side of Petersburg, West Virginia. Jacobson, *et al.* (1989a) reported such aggradational sequences in the South Branch of the Potomac River valley, West Virginia that were radiocarbon dated between 2170±180 yr BP and 7060±230 yr BP.

The hillslope and channel flood effects discussed above need to be borne in mind when discussing the survivability of supposed relict geomorphic deposits and landforms, especially those as old as Pleistocene. For example, there may be few to no relict features on certain steep hillslope areas and on affected floodplains. On the other hand, Jacobson, *et al.* (1989b) concluded that the effects of cataclysmic geomorphic events have had a relatively small role in the overall evolution of topography in the Central Appalachians.

During Neoglacial time, environments at the higher elevations in the Appalachians were severe enough to produce minor remobilization of regolith that had apparently been stabilized throughout earlier Holocene time. On floodplains, accumulation of sediments suggest that one or more episodes of intensified aggradation may have occurred in the Neoglacial. Some of these events may predate the effects of European settlement. For example, Foss (1973) found evidence of enhanced colluviation during this time interval at the Thunderbird Archeological Site along the South Fork of the Shenandoah River in Warren County, Virginia. It is thus necessary for researchers to apply rigorous field and laboratory criteria to the study of forms and materials that could have developed under marginal periglacial conditions such as those that occurred during Neoglacial time.

PALAEOCLIMATIC SUMMARY

Research to date therefore defines a number of "intermediate-member and end-member extremes" of palaeoclimates for the Central Appalachians. The Late Triassic was warm and arid, the Early Jurassic was hot and dry, the Late Cretaceous was warm and wet, and Palaeogene climates were subdued replicas of the Late Cretaceous. Climatic deterioration began in the Neogene and culminated with the rapidly alternating Pleistocene palaeoenvironments, which fluctuated between cold-and-dry and warm-and-humid in the glacial and interglacial phases, respectively. Calculated effects of climatic change on erosion rates are given in the Conclusions section of this text, before the daily road logs.

PRESENT-DAY CLIMATE

The field trip region is within the belt of humid continental warm summer climate. This climate occurs in the middle-latitude zone of conflict between polar and tropical air masses. During the winter, continental polar air masses dominate, especially in the interior and at high elevations. The much colder winter weather is interrupted less frequently on the Appalachian Plateaus and much more commonly on the Piedmont by surges of maritime tropical air. Because of the influence of the nearby Atlantic Ocean, rainfall is distributed fairly uniformly throughout the year. During the summer, however, maritime and continental air masses bring higher temperatures and somewhat increased rainfall. The overall climate therefore has a large annual range of temperature, high summer humidity, and a wide range in the number of frost-free days. The average time period between the last spring frost and the first fall frost, or "growing season" can range from about 230 days in the Piedmont to much shorter than 150 days at the highest elevations on the Appalachian Plateaus and in cold air drainage sites. Mean annual air temperatures range from about 6.6 to about 13.5°C. Mean annual precipitation varies widely. Rain shadow areas in the Ridge and Valley province of eastern West Virginia and in the Shenandoah Valley of Virginia may routinely receive less than 900 mm annually. Windward high elevation sites in the high Appalachian Plateau of West Virginia may receive 1500-2000 mm per year. Such great variety in detail is a result of complex interactions among: differences in elevation, exposure, latitude, distance from water bodies, and other factors.

The factors listed above produce considerable local variations in climate, especially in the mountains. When dealing with potential microclimate differences, the following factors should be borne in mind. The ridge crests, especially on their windward edges, will receive more and higher velocity winds than the valleys. Second-order, air-density- and topographic-driven winds may be channeled downslope, particularly in hollows and ravines. Especially during the earlier parts of the day, the valleys may be cold sinks, with the warmest temperatures occurring on the shoulders of the slope. At any elevation where there are local topographic depressions, "frost pockets" may occur. Slope orientation (aspect) is very important on clear sunny days, when the difference of light between north- and south-facing slopes amounts to 46 units (say, in g cal/cm^2 hr^{-1}). In diffuse light, all slopes should receive the same amount.

Unfortunately, there are insufficient meteorological stations in the mountainous areas in this part of the Central Appalachians to provide data on average summit temperatures or to calculate probable altitudes of treelines (Leffler, 1981a, b). Because of the shortage of mountain weather data and the high interest in climatic conditions on Appalachian summits (Leffler, 1981a), methods of approximation have been used. Leffler (1981b) analyzed temperature records from eight summit-level stations (topographic crests at least 300 m above surrounding land) from New Hampshire to South Carolina at elevations from 524 to 2022 m. He calculated lapse rates for summits in New England and developed inter-regional linear equations for computing 30-year average monthly and average daily maximum and minimum summit temperatures as functions of elevation and latitude. Schmidlin (1982) evaluated Leffler's equations in an area where they had not previously been tested and found that the estimated average monthly temperatures were within 0.6°C of the averaged long-term weather records.

Especially in rural and mountainous areas, weather data for much of the field trip corridor vary greatly in their years of record and in their continuity. Some station locations have been changed, and a few have even been destroyed during catastrophic flooding events. The relatively short time span of observation is complicated by the location of many reporting stations in developed areas that are increasingly affected by human activity. Thus, except for those stations with good long-term records, the data do not lend themselves well to treatment in tabular form. Some examples averaged on a county basis, however, can help illustrate present-day climates in the field trip corridor, although they may not be representative of a particular geomorphic region as a whole. Other examples are drawn for individual weather stations to illustrate either good records or climatic extremes that are of interest for soil and geomorphic purposes. The years of record vary widely, but most figures given are valid for the general time frame of 1931 through the 1970s.

On the Piedmont in northern Virginia, mean annual air temperatures average 13.5°C and the growing season ranges from 165 to 231 days. Precipitation averages 1064 mm for this six-county area, although droughts—which may last several years—are common. On the Piedmont in southeastern Pennsylvania, as typified by records in the Lancaster County area, mean annual air temperature is 11.3°C, the growing season ranges from 163 to 210 days, and yearly precipitation averages 1096 mm.

In the Shenandoah Valley, Virginia, there are rain shadows in Rockingham, Shenandoah, and Warren Counties where the average precipitation is only about 877 mm and drought years are common. For example, Woodstock, Shenandoah County recorded only 490 mm of precipitation in one year. Mean annual air temperatures in this part of the Shenandoah Valley average about 12°C. The growing season in this northern part of the Valley of Virginia is reported to be between 131 and 187 days. In the central part of the Appalachian Great Valley in Pennsylvania (the Lebanon Valley), mean annual air temperature is about 12°C, the reported growing season ranges widely from 142 to 239 days, and mean annual precipitation is 1016 mm.

In the Ridge and Valley province, almost all weather stations are in the valleys. This situation should be borne in mind when evaluating weather records in this region. In the Anthracite Basins in Pennsylvania, as typified by records in Schuylkill, Luzerne, and Carbon Counties, mean annual air temperature is 9.6°C, the growing season ranges between 120 and 200 days, and average valley precipitation is 1170 mm. West of the Anthracite Region, in Montour, Northumberland, and Union Counties, mean annual air temperature is 9.6°C, the growing season ranges between 118 and 221 days, and the mean annual precipitation averages 1019 mm.

Excellent records of climate in the western anticlinal valley floors in central Pennsylvania are available in Centre County. At University Park, mean annual air temperature is 9.86°C, the growing season ranges between 116 and 198 days, and yearly precipitation averages 934 mm. In one year in ten, the expected range of precipitation is from 770 to 1105 mm. To the southwest, in Blair County, mean annual temperature is 9.9°C, the growing season ranges from 139 to 199 days, and mean annual precipitation averages 920 mm. In Allegany County, Maryland, mean annual temperature averages 11.6°C, the growing season range is 157 to 168 days, and mean annual precipitation is 927 mm.

In the Ridge and Valley province in West Virginia, there are climatic extremes related to the strong effects of topography. Rain shadow effects east of the high Allegheny Front produce dramatic examples. Data for valley locations in Mineral County indicate a mean annual air temperature of 11.4°C, a growing season range of 106 to 164 days, and average annual precipitation of 830 mm. Wardensville, Grant County records a mean annual air temperature of 10.8°C, a growing season range of 123 to 171 days, and average annual precipitation of 877 mm. Upper Tract, Pendleton County, West Virginia, is even drier; the mean annual precipitation between 1898 and 1930 was 732 mm. Platt (1951, Figure 9, p. 278) graphs a single year within this interval when a record low of only 241 mm was recorded! For those years between 1931 and 1952 when records were kept, the station at Upper Tract that was located at 442 m elevation averaged only 787 mm of precipitation.

The eastern part of the Appalachian Plateau in West Virginia reaches extreme elevations and experiences severe weather. Spruce Knob, Pendleton County, 33 km south-southwest of the field trip route through Dolly Sods, is the highest elevation on the Appalachian Plateau (1482 m) but has no weather station. The station by that name is west of Spruce Knob at 1387 m, has a mean annual temperature of 8.7°C and mean annual precipitation of 1125 mm (including 1836 mm of snowfall). On the field trip route, a station in Canaan Valley at 991 m recorded a mean annual air temperature of 8.4°C, and precipitation of 1349 mm (including 2327 mm of snowfall) for the years between 1931 and 1952, when records were kept. Another example, Bayard, in western Grant County, has a mean annual air temperature of 8.3°C, a growing season range of only 83 to 140 days, and average annual precipitation of 1207 mm.

At the high elevations of the Blue Ridge, along the Skyline Drive in Virginia, mean annual air temperatures are about 8.3°C, and the growing season is shorter and less predictable than on the Piedmont to the east or in the Shenandoah Valley to the west. Precipitation on this part of the Blue Ridge is high and averages 1292 mm. There have been extremely wet years, and high individual precipitation events, such as the storm of 3-5 November 1985 (Clark, *et al.*, 1987) when the station at Montebello 2NE recorded 24.33" (615 mm) of rainfall.

In several mountainous areas in the Central Appalachians, there is actually more generally-valid information about mountain soil temperatures than about air temperatures. Carter and Ciolkosz (1980) found that soil temperature regimes are mesic on the lower ridge crests and frigid at the higher elevations. Cryic soils are not known in the field trip corridor, although frost pockets do occur in areas with excessive internal drainage of cold winter air. Under natural forest conditions with snow cover, however, representative Central Appalachian mountain soils are frozen in winter to depths of less than 25 cm (Carter and Ciolkosz, 1980).

Beyond the standard climatic data collected at most weather stations, there are also large variations in other factors of interest to geomorphologists and soil scientists. These include: rainfall intensity, extent and magnitude of severe storms that cause landslides and floods, humidity, cloud cover, length and severity of droughts and wet periods, and microclimatic variations. Few to no such data are available at the present time for the field trip corridor area.

MORPHOCLIMATIC REGIONS

One aspect of this excursion on which it would be interesting to speculate is whether or not middle latitude ice-age climates ever had the requisite combination of strength and duration to complete a periglacial "cycle of erosion" as envisioned by Peltier (1950). The preserved record suggests that, indeed, the periglacial overprint has been strong. However, the inheritance of overall, larger scale (Godfrey and Cleaves, 1991) mountain and valley form and relief must be acknowledged, if resistive framework versus driving framework mechanisms operated in process and magnitude as we conceive them today. Also, different forms and weathering materials inherited from interglacial phases, for example, must also be accounted for. Beckinsale and Chorley (1991) reviewed the development and evolution of climatic geomorphology from its inception until the widespread acceptance of global plate-tectonic theory. The realization that lithospheric plates have drifted through global climatic belts during worldwide climatic change has had a sobering effect upon the development of master theories about morphogenetic landscapes that would require long time intervals for completion.

Periglacial environments, however, are widely regarded as having high rates of weathering, erosion, transportation, and deposition, so that geologically long time intervals presumably would not be required for distinctive landscapes to equilibrate under truly severe climatic conditions. There remains, though, a great lack of specific, process-based knowledge about how weathering, hillslope, and fluvial processes operating on different terranes respond to the same climatic changes, although it is known that they have responded differently (Ridge, *et al.*, 1992). In our present state of ignorance, therefore, it is probably better to speculate that the Central Appalachians represent a polyclimatic morphogenetic region where the landscape effects of glacial, paraglacial, proglacial, and periglacial environments have strongly overprinted—but not destroyed—the Pre-Quaternary landscapes. Whether or not the periglacial "stamp" has been severe enough to warrant classification of this area as a "*palaeoperiglacial region*" (Williams and Smith, 1989) must await the results of much future research that is needed to quantify the areal and volumetric importances of the processes that have produced geomorphic materials and shaped landforms.

VEGETATION

QUATERNARY VEGETATIONAL HISTORY

Introduction

The reconstruction of vegetational history has important ramifications for many related fields of earth science. The composition and distribution of plant communities exert powerful controls on fauna, landscape stability, and soil genesis. Influential workers in the Appalachians included Braun (1950, 1951), who wrote that Pleistocene vegetational assemblages and their distributions beyond the ice sheets in Eastern North America were probably not much different than those of today. Those researchers lacked the technology to obtain deep, continuous cores from long-term pond, bog, or marsh accumulations, and they did not have access to high-precision numerical age dating techniques and other methods of analysis. Therefore, it must have been difficult for the early workers to envision successive scenarios of dynamic, forcing-function driven, vegetational pattern migrations on a sub-continental-scale level.

By contrast, modern research on vegetational history has provided a wealth of information on fossil plant assemblages and, by extension, palaeoclimatic history. Although not on the field trip route, a number of important localities are either close to it or are circumscribed by it. Several specific examples from a latitudinal range bracketing that of the excursion are available to illustrate the impact of such studies on our concepts of Quaternary palaeoenvironmental history.

Selected Site Studies

Watts (1979) studied pollen and macrofossil remains from an 8 m organic core from Crider's Pond, 3.2 km east of Scotland, Pennsylvania. This deposit is at an elevation of 289 m at the western foot of South Mountain, which forms the northern terminus of the Blue Ridge province. This site is less than 100 km southwest of the Late Wisconsinan terminal ice position. 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. An interesting aspect of the core stratigraphy 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.

The significance of the Crider's Pond fossil record is that it does document vegetational changes in the northernmost Blue Ridge (South Mountain)-Appalachian Great Valley area during the past 15,000 years. The record does not indicate tundra vegetation, but rather a forest tundra dominated by spruce. Watts (1979) suggests that discontinuous permafrost may have existed in the South Mountain-Appalachian Great Valley 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.

Another site of interest to palaeoperiglacial geomorphic reconstructions that was also studied by Watts (1979) is the Longswamp site in Berks County, Pennsylvania. At an elevation of only 192 m, this site provides clear evidence from both pollen and macrofossils for tundra vegetation 60 km south of the Late Wisconsinan glacial margin. Watts distinguished four zones. The lowest zone is a basal banded silt with pollen and macrofossils that indicate a grass-dwarf shrub tundra. The second, overlying, two-part zone is mainly composed of organic silt with plant fragments. The basal subzone is characterized by fossils of dwarf birch, and is overlain by a subzone characterized by a rise in *Picea* pollen to 50% of the pollen rain as spruce forest replaced the tundra. The third zone is characterized by a drop in spruce pollen to 10% of the total and the influx of fossils of pine and fir, as well as the appearance of pollen and macrofossils of deciduous species. The upper, fourth zone is oak dominated, with chestnut in the upper part. Unfortunately, the ^{14}C dates from Longswamp appear to be much too young, probably from contamination. Watts estimated that the basal date at Longswamp should be 15,000 BP or older.

On the Appalachian Plateau, West Virginia, Larabee (1986) extracted a 2.3 m core from Big Run Bog, West Virginia (39° 07' N; 79° 35' W; 980 m), about 25 km WNW of the Bear Rocks area on Allegheny Front. He found that, between 17,040 and 13,860 yr BP, plant communities surrounding the site were a mosaic of alpine tundra dominated by sedges and grasses. By 13,860 yr BP, spruce and fir had invaded the area. Wet meadow and disturbed ground conditions were prevalent until 11,760 yr BP, indicating the dominance of colluvial activity in the drainage basin.

South of the field trip route in the southern Shenandoah Valley, Virginia, Craig (1969) prepared pollen diagrams from cores in Hack Pond (37° 59' 05" N; 78° 59' 50" W; 469 m) and Quarles Pond (37° 59' 45" N; 79° 04' 20" W; 500 m), at the base of the Blue Ridge. He found a basal *Pinus-Picea* zone that had abundant conifer pollen with relatively large amounts of herb pollen. He distinguished two subzones; a *Sanguisorba-Isoetes* subzone at Hack Pond with a ^{14}C date at its top of 12,720 ±200 BP and a *Quercus-Corylus* subzone with less herb and more deciduous-tree pollen. Above the basal zone, Craig identified a middle *Quercus* zone that began shortly after 9520±200 yr, with a lower *Tsuga* subzone and an upper *Carya-Cephalanthus* subzone. A third upper *Quercus-Pinus* zone contained much oak and pine pollen and also substantial amounts of deciduous tree pollen in addition to that of oak.

SUMMARY

Excellent summaries of the responses of vegetation to changing palaeoenvironmental conditions during Late Quaternary time are in Delcourt and Delcourt (1984) and Jacobson, *et al.* (1987). For a number of sites in the Central Appalachians during the last 40 Ka, Delcourt and Delcourt (1981) prepared vegetation maps that enclose the field trip region. They later detailed tree population dynamics for eastern North America during the last 20 Ka to provide patterns for: vegetational stability during late-glacial cold-phase maximum conditions; late-glacial conditions of disequilibrium, instability and migrations and invasions of species; and a return to equilibrium vegetational assemblage conditions in Holocene time (Delcourt and Delcourt, 1987). For the time interval of the last glacial cold-phase maximum (23 to 16.5 Ka), tundra and boreal forest vegetational assemblages occupied the field trip area. For the Late Wisconsinan, Late Glacial Interval (16.5 to 12.5 Ka), spruce-rich forests invaded tundra ecosystems. During Holocene time (12.5 to 0 Ka), deciduous vegetation proliferated throughout the region, except on drier sites, in areas where soils lacked necessary plant nutrients, at extreme elevations, and/or exposures. At high elevations on the Appalachian Plateaus, and at a few sites on high ridge crests in the Ridge and Valley province, spruce forests have persisted during Holocene time (Delcourt and Delcourt, 1986). Today, even the highest summits are well below estimated climatic timberlines. For example, Leffler (1981a) infers that Spruce Knob, West Virginia is 2000 to 3000 feet (610 to 914 m) below the climatically determined forest limit.

PRESENT-DAY VEGETATION

Hardwood forest cover was the predominant vegetation on the Piedmont in northern Virginia before European settlement. The dominant stands were oak-hickory, with scattered areas on drier exposures of red cedar, and scrub, shortleaf, white and Virginia pine. Today, less than about a third of a typical Piedmont county in northern Virginia is covered by forest, and most of this coverage is at least in second growth. Many areas have been cut and/or burned a number of times. The successional forest may be hardwood, mixed hardwood and pine, or pine stands, in the case of abandoned fields. In the Piedmont in Pennsylvania, the pre-settlement forest was also dominantly composed of hardwoods. Chestnut, locust, walnut, maple, white oak, and hickory were the most important tree types. Conifers were limited to drier slopes, or to very shaded sites, in the case of hemlock.

In the Ridge and Valley and Blue Ridge provinces in Pennsylvania, Maryland, West Virginia, and northern Virginia, the oak-chestnut association was the dominant forest type in many locations. Additional common hardwoods included black walnut, hickory, red maple, and locust. Conifers were not an important component of vegetation, with the exception of hemlock stands in deep valleys and other shaded sites that have low light levels. In the Appalachian Great Valley, there were extensive areas of white oak forest. Braun (1950) called this overall vegetational region the Oak-Chestnut Forest region.

At lower elevations on the unglaciated Allegheny Plateaus section, the pre-European settlement forest dominance was shared by a wide variety of arboreal species. Chestnut, red oak, white oak, chestnut oak, sugar maple, tuliptree, beech, basswood, buckeye, walnut, shagbark hickory, sour gum and black cherry were typical components. Braun (1950) called this highly diverse forest region the Mixed Mesophytic Forest region. At the higher elevations on and near the eastern edge of the Appalachian Plateau in West Virginia, red spruce was very abundant before the logging era. It either grew in pure stands or was mixed with yellow birch, beech, mountain ash, or balsam fir, and was common at elevations above 3200 feet (975 m) and sometimes down to as low as 2500 feet (762 m). The largest and best developed original spruce stands in West Virginia were in Canaan Valley and in nearby areas in Tucker County (Core, 1966). Beneath the spruce areas, but above the Mixed Mesophytic Forests, there is a belt of higher-elevation deciduous forest with beech, maple, and birch as common dominants.

WEATHERING AND PRODUCTION OF PARENT MATERIAL

INTRODUCTION

The periglacial morphoclimatic zone (Beckinsale and Chorley, 1991) has long been considered as one in which physical weathering and erosion rates are extremely high, indicating that there is substantial production of debris. For example Jansson (1988) collected sediment-yield data from drainage basins of size range 350-100,000 km^2. In most instances in her study, however, rivers were not classified according to topography, and no allowances were made for unique geomorphological conditions (extensive loess deposits, presence of active glaciers, etc.). Another *caveat* is that allowance must be made for cases in which rivers drain paraglacial areas (Church and Ryder, 1972) where extensive mantles of glacial and proglacial debris are being stripped without concomitant replacement by present-day processes. Even so, Jansson (1988) found that the sediment yield data for a number of rivers in boreal and tundra climates were high, although their yields were exceeded by many basins in tropical and temperate rain-forest climatic environments.

OPFERKESSEL

Enclosed depressions in exposed silicate bedrock and rock blocks are termed Opferkessel, literally meaning offering cups or kettles. Although Opferkessel are not considered to be periglacial weathering features *per se*, they are valuable indicators of rock stability and exposure, and will be considered here in these regards. Their morphology (closed depression with flat floor and undercut rim) is similar to that of tinijitas found on outcrops of carbonate rocks in arid regions; the name difference mainly reflects the compositional difference in host rock.

There is an extensive literature on Opferkessel outside North America. The relatively limited North American literature up to about 1965 was summarized by Hedges (1969). Despite the potential value of Opferkessel in establishing and dating rock stability, or the lack of it (see below), little subsequent interest in these features has developed in the North American literature.

It seems likely that Opferkessel are modern, not relict, features. Their morphology is sharply defined and fresh. The absence of debris in most of them indicate that silica, as well as feldspar and other minerals (when present in the host rock) is removed by solutional, colloidal, and other processes especially when heavy rains cause the basins to overflow.

The conditions prerequisite for the development of Opferkessel include a homogeneous silica-rich rock, with a level, soil-free exposure. Precipitation falling on such a site, particularly one in a humid temperate climate, gathers in slight depressions. There the growth of moss, lichens, and other life is enhanced. Chemical and biochemical compounds, such as acids produced by organic growth and decay, increase the ability of atmospheric water to dissolve the underlying rock, leading to a gradual widening and deepening of the initial depressions. As fresh water from each subsequent precipitation event mixes with the old water and drives it out, material from the interiors of the developing basins is carried away in solutional, colloidal, and suspensional forms. In cold weather, the developing basins are also ideal traps for snowfall and for snow drifting over the surface of the exposed rock. During intervals of below-freezing temperature, ice forms and freezes to the bases and sides of the developing basins. The effects of cold weather on Opferkessel development are not known to the authors at this time.

At the lowest point in each basin rim, a spillway develops, a shallow channel whose elevation is preserved almost indefinitely by the inability of mechanical, subaerial agencies as rapidly to reduce its floor as the stagnant, highly-aggressive water retained in the basin cuts away the basin floor. Concomitantly, and for the same reason, those parts of the walls which lie below the level of the spillway are cut back more rapidly than are those parts which lie above it, leaving a pronounced undercut, a water-level plane, at the level of the spillway.

A density/saturation gradient established in the water overlying the basin floor and a thin layer of solution-retarding residuum accumulated on its lowest part combine to ensure that the highest areas of the floor are preferentially degraded; the floor tends to become level and horizontal, irrespective of the shape of the initial depression from which the basin grew or the angle at which the adjacent rock surface slopes.

Growth of the Opferkessel continues until its expanding walls are breached by their having intersected a rock face or an open joint or other fissure, until the basin is broken by some other means, or until changed environmental conditions cause the basin to become filled with detritus. Several closely adjacent Opferkessel may expand to unite one with another, or the partial breaking of a basin may cause the development of a composite form including several basins nested one inside another. But, as long as the Opferkessel remains capable of holding water and is free from debris, it will continue to enlarge its domain.

In the Appalachians, Opferkessel are well developed on Old Rag Mountain, Shenandoah National Park, on the crests and flatter slopes of Stone Mountain, Georgia, in the mountains of western North Carolina, on the summit of Bear Mountain, south of Newburgh, New York, on granite in the area of Table Rock on the Piedmont, South Carolina, (Howard Wilkerson, personal communication, 1976), on metaquartzite bedrock in many places in the Blue Ridge province, and on orthoquartzite bedrock in many localities in the Ridge and Valley and Appalachian Plateaus provinces (Figure 5). They are also developed on diabase in several places in Pennsylvania, but these occurrences are not documented in the literature except by occasional photographs (W. D. Sevon, personal communication, 1992).

Opferkessel are valuable indicators of rock stability, or the lack of it. Until the advent of cosmogenic dating techniques that can date the exposure ages and erosion rates of exposed bedrock and rock blocks, there seemed little hope of using Opferkessel to quantitatively date stability and age.

SUMMARY

Older discussions on periglacial weathering and erosion rates often emphasized the importance of mechanical weathering. Rapp (1960), however, showed that, when quantitative measurements are made, mineral and rock removal rates by chemical weathering processes are found to be very rapid. Lautridou (1988), Lautridou and Ozouf (1982), and Hall and Lautridou (1991) have summarized the results of research on cryogenic weathering. These authors note that several weathering processes other than freeze-thaw are now known to be significant under cold-climate environments. These agents include: interaction of freezing with salt weathering, wetting and drying, thermal fatigue, chemical weathering, and biological weathering. Much weathering which visually suggests production by physical processes actually is caused by microscopic plant and animal activity. Research on types of weathering in the Appalachians that are probably due to palaeoperiglacial processes is still in its infancy. There are, however, some striking effects of weathering observed in the Central Appalachians that hold promise for further study.

Figure 5. Opferkessel on the crest of Stack Rock, a prominent tor on the Allegheny Front, Grant County, West Virginia (Blackbird Knob quadrangle). Bedrock is orthoquartzite conglomeratic sandstone of the Pottsville Group. Depressions are partially filled with ice that is frozen to sides and bases. Notebook case is 23 x 30 cm.

SOILS

SOIL CLASSIFICATION

Soil Taxonomy (Soil Survey Staff, 1975, 1990) has been the official soil classification system of the United States since 1965. It has six hierarchical levels (Table 3), and a soil can be discussed or mapped at any of the levels. At the order level the soil name is made up of a specific formative element joined to the suffix-sol (Latin-solum, soil), e.g., Incepti-sol, Alfi-sol, and Ulti-sol. At the suborder through subgroup levels, other formative elements are added to the order formative element to give these categories distinctive names (Table 3). Each of these formative elements provides a significant amount of information about a particular soil. For example, the Hagerstown soil is an Alfisol; it has a subsurface horizon of clay accumulation, with a high base (Ca + Mg + K + Na) saturation (of the cation exchange capacity) status; it is a Udalf, an Alfisol in a humid climate; it is a Hapludalf, a Udalf with only a moderate degree of development; and it is a Typic Hapludalf, it has a typical set of horizons for a Hapludalf. At the family level additional connotative terms are added: clayey, mixed, mesic which means the texture of the soil is clay with the possible exception of the surface horizon; it has a mixture of various kinds of clay minerals, and it is in the mesic soil temperature regime (temperate region). Additional formative element information for common Appalachian soils is given in Table 4. It should be noted that some of the suborder formative elements can also be used at the great group level. Additional information is found in the following references: Soil Survey Staff (1975, 1990), Buol, *et al.* (1989), Fanning and Fanning (1989), and Birkeland (1984).

Table 3. Soil Taxonomy Classification of Five Soils of the Southern and Central Appalachians.

Hierarchy	Example 1	Example 2	Example 3	Example 4	Example 5
1. Order:	Spodosol	Inceptisol	Alfisol	Ultisol	Ultisol
2. Suborder:	Orthod	Ochrept	Udalf	Udult	Udult
3. Great Group:	Haplorthod	Dystrochrept	Hapludalf	Hapludult	Fragiudult
4. Subgroup:	Entic Haplorthod	Typic Dystrochrept	Typic Hapludalf	Typic Hapludult	Aquic Fragiudult
5. Family:	sandy-skeletal*, siliceous, mesic (frigid!)	loamy-skeletal*, mixed, mesic	clayey, mixed, mesic	clayey, mixed, mesic	Fine-loamy Mixed Mesic
6. Series:	Leetonia	Dekalb	Hagerstown	Allenwood	Buchanan

*Skeletal means soil material has >35 percent rock fragments.

Table 4. Orders, Formative Elements, and a Brief Description of the Meaning of the Formative Element of Common Southern and Central Appalachian Soils.

Formative Element	Description
Order	
Ent (Entisol)	Weakly developed (young) soil without a B horizon, A/C profile or if very sandy a weakly developed color B horizon
Ept (Inceptisol)	Weak to moderately well developed (relatively young) soil with a color and/or structural B horizon (cambic) or a fragipan B horizon
Alf (Alfisol)	Moderately well developed soil with a B horizon of illuvial clay accumulation (argillic horizon) and relatively high subsoil base (Ca + Mg + Na + K) saturation status (>35 percent of the cation exchange capacity)
Ult (Ultisol)	Moderately well to very well developed soil with a B horizon of illuvial clay accumulation (argillic horizon) and low subsoil base saturation (<35 percent of the cation exchange capacity)
Od (Spodosol)	Weak to moderately well developed, sandy soil with a spodic B horizon (subsurface horizon of humus, Fe and Al accumulation)
Ist (Histosol)	Soil composed of organic materials (peats and mucks)
Suborder	
Aqu	Wet - aquic moisture regime (somewhat poorly and poorly drained)
Fluv	Composed of recent alluvium (on floodplain)
Hum	High organic matter content in the A horizon
Ochr	Thin, light colored, A horizon
Orth	Most common type of profile
Psamm	Sand or loamy sand texture
Ud	Humid climate
Umbr	Thick, acid dark colored A horizon
Great Group	
Dystr	Low base saturation status soil
Eutr	High base saturation status soil
Frag	Fragipan - dense impermeable subsurface B horizon
Hapl	Moderately developed, simple set of horizons
Pale	Well developed thick profile
Rhod	Dark red color
Subgroup	
Aeric	Better aerated (drained) than typical (Typic)
Aquic	Wetter than typical (Typic)
Entic	Has some Entisol properties
Lithic	Bedrock within 50 cm of surface
Typic	Typical development of that Great Group
Ultic	Lower base saturation status than typical (Typic)

SOIL GEOMORPHOLOGY

Introduction

Soils of the Appalachian Highlands have developed under a wide variety of changing climates, vegetational assemblages, evolving topographies, diverse parent materials, soil biota, and differing intervals of time and human manipulation. Many soils bear the imprints of two or more discrete environments of formation, and many more may have subtle and as yet unrecognized impressions of the milieu under which they developed. Many fascinating morphogenetic problems exist, including the development of argillic horizons and fragipans (see Table 4), and Spodosol and Ultisol morphogenesis. These subjects will be illustrated and discussed during the excursion. With respect to known regional distribution of fragipans, for example, several relationships are evident from Table 5: (1) The amount of colluvial soils decreases with increasing distance from the Wisconsinan glacial border in counties 1 through 8. (2) Farther south, the amount of colluvium increases with increasing elevations. (3) The presence of stacked colluvial soils with fragipans indicates that geomorphic processes covered existing soils with younger sheets of the relatively thin colluvium that is apparently necessary for fragipan development. (4) The high proportion of colluvial soils with fragipans is closely associated with either nearness to the glacial border or with higher elevations. These affiliations suggest that geomorphic processes associated with periglacial activity probably produced the widespread sheets of thin colluvium and perhaps the other conditions required for the formation of genetic fragipans. In the Northeastern United States, the present soil temperature regimes are thermic in the Piedmont province south of Maryland. In the remaining areas, it is mesic, or, at high elevations, frigid (Buol, 1973; Carter and Ciolkosz, 1980; Ciolkosz, *et al.*, 1989; Springer and Elder, 1980; Lietzke and McGuire, 1987). The field trip area displays many varieties in the orders of Entisols, Inceptisols, Alfisols, Ultisols, Spodosols, and Histosols (Ciolkosz, *et al.*, 1989). Of these Orders, Inceptisols and Ultisols comprise the largest surface areas of any two Orders. Despite the great variety of soils present, some regional generalizations can be made, especially with respect to freely-drained soils developed on relatively-stable landform assemblages.

Table 5. Percent Colluvial Soils and Percent of Colluvial Soils that have a Fragipan in selected mapped Central and Southern Appalachian counties in Ridge and Valley Province, unless otherwise noted.

County	State	% Colluvial Soils	% With Fragipans
1. Centre	PA	22	91
2. Blair	PA	35	92
3. Huntingdon	PA	23	96
4. Fulton	PA	25	95
5. Randolph**	WV	18	100
6. Tucker**	WV	19	100
7. Rockingham	VA	14	59
8. Warren	VA	11	23
9. Augusta	VA	6	31
10. Greene***	VA	13	3
11. Madison***	VA	18	1
12. Albemarle***	VA	5	3
13. Campbell***	VA	1	0
14. Summers**	WV	12	92
15. Mercer**	WV	12	66
16. Giles	VA	26	*
17. Montgomery	VA	10	*
18. Bland	VA	15	9
19. Tazewell	VA	13	10
20. Smythe	VA	10	19
21. Lee	VA	9	6

* Due to mapping and correlation, it was not possible to determine percentage of colluvial soils with fragipans.
**In Appalachian Plateaus province.
***In Blue Ridge and/or Piedmont provinces.
NOTE: Because of mapping concepts used to map forest soils, the acreage of colluvial soils in mountainous counties is considerably underestimated.

Parent material effects on Appalachian soils

Most of the soils of the Appalachians are relatively young. Thus, parent material has been one of the more important soil forming factors determining the properties of these soils. A complete evaluation of this topic will not be attempted here, but two aspects pertinent to soils seen on the excursion will be discussed. They are the disaggregation or weathering of Lower and Middle Paleozoic red and grayish-brown siltstones and shales and the development of Ultisols.

Regardless of the geologic age of these siltstones and shales, the red rocks (usually reddish brown 2.5YR4/4) disaggregate or weather more rapidly than the grayish-brown rocks. This difference is manifested in the soils found on Appalachian landscapes. Soils developed from red-rock parent material tend to be deep, nonskeletal, with argillic horizons (Hapludults), while the grayish-brown rock soils tend to be shallow to moderately deep, skeletal, and without argillic horizons (Dystrochrepts). Soils data (Table 6) from soils frequently encountered in the field excursion region are available from four counties in Pennsylvania and support this conclusion.

Table 6. Relative percentage of shallow (<50 cm) moderately deep (50 to 100 cm) and deep (>100cm) to bedrock soils on red and grayish brown siltstones and shales in four Pennsylvania counties that encompass the Allegheny Front. The data are from Steputis, *et al.* (1966), Braker (1981), Merkel (1981), and Kohler (1986).

County	Red Rock Soils			Grayish-Brown Rock Soils		
	Shallow	Mod. Deep	Deep	Shallow	Mod. Deep	Deep
Lycoming	23*	0	87	66*	34*	0
Clinton	5*	0	95	8*	89*	3
Centre	0	16*	84	25*	74*	1
Blair	0	0	100	37*	63*	0

*These soils are also skeletal (have >35 percent rock fragments)

The reason for these differences is undoubtedly a reflection of the cement and/or matrix holding the clastic rock fragments together, because the soils are found in juxtaposition on the same landscape. The best example of this type of soil-landscape is the Allegheny Front. In addition to forming deeper soils with fewer rock fragments, the red rock parent material also weathers to clay size material rapidly. Some of this clay has moved from the A into the B horizon forming an argillic horizon in the same time that only cambic horizons have formed in the soils developed from grayish-brown rock materials.

The older concept of the Red-Yellow Podzolic and Reddish-Brown Lateritic soils of the 1938 USDA Soil Classification System as presented by Thorp and Smith (1949) was developed in the southeastern United States. These soils have well developed morphology (thick sola) and show advanced chemical and mineralogical weathering (McCaleb, 1959). In the development of Soil Taxonomy (Soil Survey Staff, 1975), the Red-Yellow Podzolic and Reddish-Brown Lateritic soils were used as the central concept for the development of the criteria for the Ultisol soil order (Soil Survey Staff, 1960). The class limits of the Ultisols were defined to include soils with argillic horizons and low subsoil base saturation. These features separate Ultisols from Inceptisols and Alfisols. The application of the Ultisol criteria has resulted in the classification of large areas of soil in the Central Appalachians of Pennsylvania, Ohio and West Virginia as Ultisols. In Pennsylvania alone, there are 9 million acres of Ultisols (31% of the state) of which over half (5 million acres) are found on the unglaciated Appalachian Plateaus (Day, *et al.*, 1988), and the 5 million acres represent 50% of that region. The bulk of these Ultisols resemble ones illustrated by the Gilpin data (Table 7) and were not classified as Red-Yellow Podzolics or Reddish-Brown Lateritic Soils in the 1938 system. Although Soil Taxonomy was developed as a tool for making and interpreting soil surveys, the criteria used at the order level were selected to indicate the major genetic pathway of soil development (Smith, 1983). Thus, there is a genetic pathway anomaly in the classification of Ultisols in the Appalachians. The Gilpin soil, which is classified as a Typic Hapludult, illustrates this anomaly. The Gilpin is a relatively weakly developed soil that is only moderately deep, has a high rock fragment content, and a thin B horizon. These features indicate that it is not a genetic Ultisol, and it is better called a parent material Ultisol. Therefore, we have two types of Ultisols, the parent material Ultisols of the Central Appalachian Mountains and the genetic Ultisols of the southeastern United States.

Table 7. Characterization data for Gilpin soil pedon S65 PA 2-8(1-6). Data from Cunningham, *et al.* (1972).

Horizon	Depth	Color	pH	Percent				
				Rock Fragments*	Sand	Silt	Clay	Base Sat.
	cm							
Ap	0-18	10 YR 4/3	4.4	16	21.6	64.8	13.6	10
Bt1	18-25	10 YR 5/4	4.8	31	23.4	56.6	20.0	18
Bt2	25-53	10 YR 5/5	5.1	15	34.4	42.7	22.9	24
BC	53-69	10 YR 5/4	5.3	61	46.5	36.5	17.0	26
C	69-74	10 YR 5/5	5.3	66	52.1	31.7	16.2	19
R	74-90	10 YR 4/3 and 5/3 shale						

*On a weight basis

Regional Soil Geomorphology

Piedmont Province

Soils of the Piedmont are dominantly Ultisols, mainly Hapludults developed on saprolite and Paleudults formed on old alluvial and colluvial parent materials (Cunningham and Ciolkosz, 1984; Ciolkosz, *et al.*, 1989). Entisols and Inceptisols are present on younger parent materials, especially on floodplain sediments of Holocene age.

Blue Ridge Province

In the Northern Blue Ridge section, as illustrated on the excursion in Shenandoah National Park, soils are strongly related to topography and parent material. Hapludalfs, Eutrochrepts, and Hapludults are typical upland soils that form in parent materials derived from the Catoctin Formation along the Skyline Drive.

Ridge and Valley Province

Strong differences between soils developed on siliciclastic rock parent materials on ridges, and soils formed on carbonate-rich rock units in many valleys are a hallmark of this province. Inceptisols, especially Dystrochrepts, are common soils of low to high ridges underlain by shale, siltstone, and sandstone parent rock materials. Ultisols, chiefly Hapludults and Paleudults, are common soils in valleys underlain by carbonate sedimentary rock units (*cf.* Ciolkosz, *et al.*, 1986a). Alfisols are the only other major soil Order in the Ridge and Valley field trip area (Ciolkosz, *et al.*, 1989; Cunningham and Ciolkosz, 1984). Limited areas of Entisols are present along flood-prone reaches of the major rivers and on debris fans produced by Late Holocene mass movement events. Mollisols of very minor extent occur on low river terraces that have been affected by cultivation activities of Amerind cultures as early as the Middle Woodland period (*cf.* Cridlebaugh, 1984), and on high-carbonate content limestones. The presence of Mollisols in the eastern United States is probably related to the invasion of tall grass prairies into this area during the warmer and dryer Hypsithermal time interval (3,000-5,000 B.P.).

Appalachian Plateaus Province

Plateau soils are mainly either Ultisols (Hapludults, Fragiudults, and Ochraquults) or Inceptisols (mostly Typic Dystrochrepts, but also Umbric Dystrochrepts and Umbrepts). Entisols are common soils on actively-forming floodplains, reworked lowermost terraces, and newly-formed debris fans. At the higher elevations, on stable upland surfaces, limited areas of Spodosols have developed, especially over orthoquartzite parent materials that support coniferous forest covers.

PERIGLACIAL GEOMORPHOLOGY

INTRODUCTION

What do we mean by periglacial? For example, specially with field excursion sites so close to the Late Wisconsinan glacial border and within older borders, the possibilities of paraglacial effects (Church and Ryder, 1972) must be borne in mind. Therefore to circumscribe our field of endeavour, we must define our term. The original definition by Lozinski (1909) included both a geographical connotation (proximity to sub-polar ice sheets) and a process-product requirement (the mechanical production of debris, or rubble, by the action of freezing). French (1976; 1987a, b) focused on two criteria which identify periglacial places; the intense daily or seasonal freezing and thawing of the ground, and the development and maintenance of permafrost. Clark and Ciolkosz (1988) followed Black (1966) and Washburn (1980) by interpreting the term periglacial to mean cold climatic environments (with or without permafrost) and their landform elements, landforms, and landscapes produced indirectly and directly through the effects of strong frost action, intensive mass wasting, and fluvial and aeolian processes that operate on land that is seasonally snow free. Williams and Smith (1989, p. 2) characterized about 35% of the land surface of the earth as having effects from freezing, and freezing and thawing, such as to radically affect the nature of the land surface; they referred to these areas as the "*periglacial regions*," a notion that Peltier (1950) had set into climatically-defined parameters. Thorn (1992, p. 1 and p. 24) provided a tentative operational definition of periglacial geomorphology as follows:

> "Periglacial geomorphology is that part of geomorphology which has as its primary object physically based explanations of the past, present, and future impacts of diurnal, seasonal, and perennial ground ice on landform and landscape initiation and development. Additional components of the subdiscipline include similar investigations of the geomorphic roles of snowpacks (but not glaciers) and fluvial, lacustrine, and marine ice."

The above definition by Thorn (1992) serves well to focus attention on the central importance of ground and surface ice on the development of periglacial landforms and landscapes. From a Central Appalachian palaeoperiglacial perspective, one might add and emphasize certain embellishments to Thorn's definition. These include: the generation and subsequent preservation of certain earth materials of demonstrable cold-climate origin that underlie and uphold periglacial landforms and landscapes, and the direct and indirect importances of cold-climate aeolian activity on landforms and materials.

It will also be productive at the present time, when Central Appalachian periglacial geomorphology is in a nascent state, to focus on objectives. Here, Thorn (1992) lists five primary objectives, as follows: (1) identification of the chemistry, physics and/or mechanics of processes; (2) identification of periglacial landforms; (3) identification of permafrost and its distribution; (4)

investigation of the nature and behaviour of permafrost and active layers and their processes; and (5) reconstruction of palaeoperiglacial geomorphological realms.

In the Central Appalachians, periglacial research has not progressed sufficiently to establish the specific process mechanisms responsible for many features. This objective is often extremely difficult to reach even in the study of active features in actuoperiglacial realms, and it is even more daunting in palaeoperiglacial regions where the processes no longer operate. Nonetheless, it is a highly desirable goal if we are to become able to reconstruct past cold-climate environments. A number of landforms of probable periglacial origin have been identified in the region, based upon their morphology and the nature of the underlying earth materials. Only several types of features, however, are generally believed to be diagnostic indicators of permafrost, and quantification of the specific conditions of development for these features remains under debate. Reconstruction of the former nature and behaviour of permafrost, active layers, and their processes must await a much fuller understanding than that available at present. Finally, the reconstruction of palaeoperiglacial realms in the Central Appalachians will require much additional reconnaissance as well as detailed studies. Beginnings have been made in a few geographical areas. Other parts of the region, however, have received little to no study. Especially in areas where distinctive landforms either are not present or have been modified, destroyed, or obscured, diagnostic evidence of former periglacial processes and environments may have to come from subsurface evidence. This may be the case in certain areas of the Central Appalachians. For example, finds to date of wedge-shaped casts in Pennsylvania have only been made in excavations, because the features are blanketed from surface visual observation by homogeneous soil horizons.

It is, of course, obvious that rigorous attention to definitions (Thorn, 1988, Chapter 4) and research objectives are necessary but not sufficient conditions for the development and promulgation of optimum research strategies. An adequate theoretical basis must also exist. Thorn (1988) demonstrated that a sound basis in theory is necessary in every area of geomorphology in order for science to advance. How we actually *do* proceed, however, will be a measure of how thoroughly our theoretical periglacial and, in the case of our site-specific palaeoperiglacial Appalachian studies, constructs are prepared and followed.

As indicated by French (1987a, b), periglacial geomorphology in Europe developed mainly as a branch of Pleistocene and Quaternary studies, while North American periglacial geomorphology evolved as a rigorous offshoot of process geomorphology. In contrast with periglacial studies in Europe, where, for more than a century, many reports have identified and described landforms and materials attributed to former cold climatic conditions (Washburn, 1980), there were few periglacial studies in the U. S. Appalachians prior to the decade of the 1960s. Clark and Ciolkosz (1988) grouped publications into two categories: historical reports and publications that describe results of modern research. The historical reports they reviewed were of two types; studies of particular kinds of periglacial features such as block streams and rock cities, and areal reports that described the deposits and landforms in a particular geographical area. These early studies are important, because they kept interest alive in the subject of palaeoperiglacial geomorphology in the Appalachians despite skepticism by a number of other writers. Those skeptics either did not believe in the existence of former periglacial environments or doubted that relict features could have survived throughout the Holocene. The modern studies that Clark and Ciolkosz (1988) summarized cover a wider variety of forms and materials and deal with site-specific studies of features that most workers agree are indicative of former periglacial activity.

The descriptions and discussions in the following sections are organized along objective and nongenetic criteria to the extent thought possible at this early stage of periglacial research in the region. We hope that this organizational scheme can be replaced by much more meaningful classification schemes in the future.

SURFACE PERIGLACIAL LANDFORMS AND DEPOSITS

Ploughing Blocks and Braking Blocks

Blocks in this class of palaeoperiglacial features moved downslope on or shallowly within the parent material. These blocks, therefore, are not necessarily rooted in the subsoil. Ploughing blocks or Wanderblöcke constitute a special type of frost creep and/or gelifluction form consisting of isolated block- or boulder-size rocks that form a low "push ridge" downslope and leave a linear depression upslope (Washburn, 1980).

Although ploughing blocks can be identified for some time after motion has been arrested, there are few reports of them in the Central Appalachians. Large ploughing blocks and braking blocks may be inactive in the present-day environment and could, thus, record a former cold-climate environment, as suggested by Sevon (1992b). By contrast, braking blocks impede gelifluction, and an accumulation of colluvial and surface wash debris develops behind the upslope side of the block (Washburn, 1980). Sevon (1992b) describes large braking blocks in the Rimrock Overlook area and in Dixon Gully, both located in Warren County, Pennsylvania. Additional field investigations would probably reveal many more such features in areas where large surface blocks are present on colluvial hillslopes.

Sorted Patterned Ground

Introduction

Examples of most categories of sorted patterned ground described by Washburn (1956, 1980) occur in the Central Appalachians. These features exist at several size scales. Small-scale forms (up to about 40 cm in diameter) can be found on previously-disturbed ground that lacks vegetative cover and can be active in the present climate. Intermediate-scale forms (about 50 cm to 2 m in diameter) appear to be inactive today and may be features that formed during prior disturbances in historic times (logging, fires) and/or during colder times, such as The Little Ice Age. Large-scale forms (greater than 2 m in diameter) are completely inactive or truly fossil, and both weathering features and soil geomorphic criteria indicate that such features are relict forms many thousands of years old (Rapp, 1967; Clark and Ciolkosz, 1988; Clark and Ciolkosz, unpublished data; and this guidebook). Only the large-scale features will be discussed below.

General Site Characteristics

Large scale (> 2 m diameter in plan view) sorted stripes and nets occur in the Central Appalachians. Most occurrences either are in areas underlain by resistant rock units and/or the blocks and boulders in their stone borders have been derived from upslope subcrops or outcrops of these rocks. Almost all of the finds to date (1992) have been on gently-sloping upland areas. Finds of well-developed and well-preserved sorted nets are less common; the observed nets tend to occupy nearly horizontal upland flats. Of course, many more sorted net localities probably occur on isolated high flat areas that lack road or trail access. The nets occur either immediately downslope from rock breakdown only a few meters below summit levels or on high flats without surface evidence of former outcrop. Downslope, some of the sorted nets are transitional to sorted stripes on slightly steeper slopes. Many of the sorted nets once may have been well-shaped sorted polygons, as suggested by slightly angular corners in the stone mesh intersections.

Site-Specific Studies

Several site-specific studies are available that provide some basic data on the characteristics of sorted patterned ground in the Central Appalachians. For instance, Clark and Ciolkosz (1988) summarized the work of Hodgson (1967) on several geometries of sorted patterned ground in

Centre County, Pennsylvania and that of Troutt (1971) on nonsorted nets in Huntingdon County, Pennsylvania.

Ciolkosz, *et al.* (1971) and Clark and Ciolkosz (1988) have presented some data on sorted nets in several localities. These sites are on Mt. Davis, Pennsylvania (Markleton, PA, quadrangle), and on Canaan Mountain, West Virginia, (Blackwater Falls, WV, quadrangle). The site on Canaan Mountain was visited during a Geological Society of America field trip in 1971 (Ciolkosz, *et al.*, 1971) and is a site that was chosen for periglacial soil geomorphology research. The soils associated with this sorted net site at Red Run (Figure 6) vary significantly from under the contiguous stones in the mesh to the net centers. The upper meter of the rock fragment accumulation is fragmental (little, if any, fine earth fills the voids between the stones). At about one meter below the stone surface, the first horizon of a very poorly drained Fragiaquept soil is encountered. The horizon sequence is as follows:

Oa, 0-20 cm (22% organic carbon); A, 20-31 cm (9% organic carbon); Bxg, 31-61 cm; Cg, 61-84 cm.

Within the interior of the net a very different soil is found; it is a moderately well drained Fragiorthod. It has the following horizon sequence, which starts at about the same level as the top of the stone mesh accumulation:

A, 0-5 cm; E, 5-18 cm; Bh, 18-28 cm; Bs, 28-38 cm; Bw, 38-48 cm; Bx, 48-114 cm; Bxg, 114-150 cm; Cg, 150-180 cm. Samples from the Fragiorthod were included in the Spodosol study of Stanley and Ciolkosz (1981). This study indicates that this is a well developed Spodosol and that the better drained (well and moderately well drained) Spodosols of the Appalachians are associated with frigid soil temperature regimes. The mean annual soil temperature (MAST) at this site is 7.9°C. Frigid soils have MAST's of <8.0°C. The presence of the fragipan and the Spodosol soil indicate that little movement has taken place in this pattern for at least the last 8,000 to 10,000 yrs.

Sorted stone stripes, by contrast, are much more common in the Central Appalachians and tend to occur on land with slightly higher slopes. Individual sorted stripe lengths may vary from less than 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, block slopes, and block streams. It is common to find sorted stripes either merging 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.

Ciolkosz, *et al.* (1971) and Clark, *et al.* (1989) have reported some data on a sorted stripe complex in West Virginia. This site (Figure 7) is located on Cabin Mountain (Blackwater Falls, WV, quadrangle), was visited during the Geological Society of America field trip in 1971 (Ciolkosz, *et al.*, 1971), and has also been chosen for intensive periglacial soil geomorphology research. The soils associated with the stripe site vary significantly from under the contiguous rock fragments in the pattern to the relatively rock-free adjacent area. The upper meter of the stone accumulation is fragmental (no fine earth fills the voids between the rock clasts). At about one meter below the rock-fragment surface, the first horizon of a poorly drained Haplaquept is encountered. The horizon sequence is as follows:

A, 0-5 cm; Bw, 5-20 cm; Bwg1, 20-30 cm; Bwg2, 30-53 cm; 2Bw1, 53-64 cm; 2Bw2, 64-86 cm; 3Bt1b, 86-100 cm; 3Bt2b, 100-112 cm; 3Cb, 112-140 cm. Adjacent to the stripe on both sides very different soils are found.

The following somewhat poorly drained Aeric Fragiaquept horizon sequence was described about 2 meters west of the center of the stripe: A, 0-2 cm; E, 2-28 cm; Bw1, 28-43 cm; 2Bw2, 43-61 cm; 2Bw3, 61-74 cm; 2Bx1, 74-109 cm; 2Bx2, 109-137 cm; 3Bt1b, 137-147 cm; 3Bt2b, 147-175 cm; 3Cb, 175-196 cm. At this site, there was apparently a residual soil that became truncated, and two layers of colluvium were deposited either before or contemporaneous with the development of the sorted stripe. The presence of the fragipan and the moderate degree of development of the soils indicates that this site has been stable for at least 8,000 to 10,000 years; it possibly dates to the Woodfordian glacial stage.

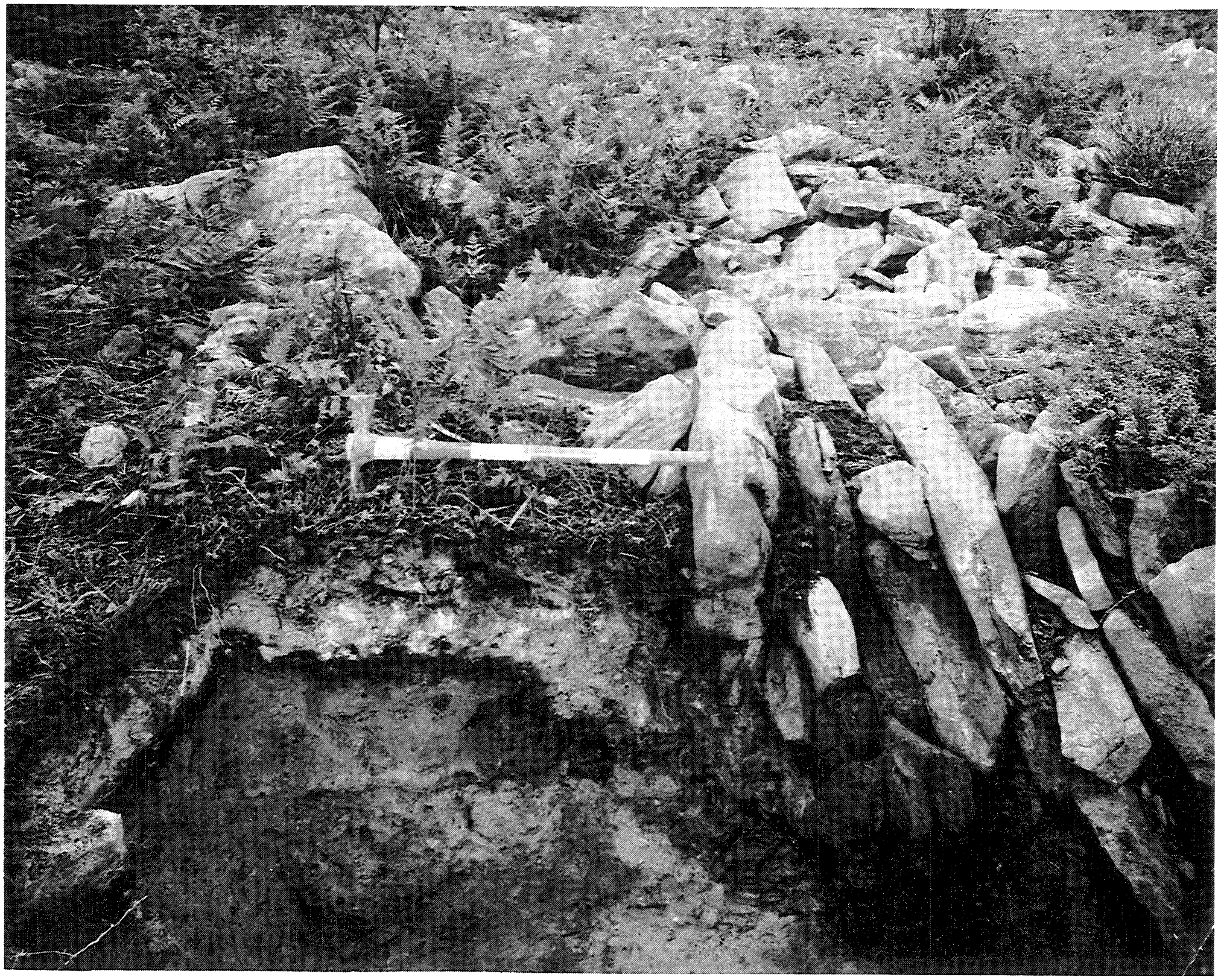

Figure 6. Sorted net site on Canaan Mountain, Blackwater Falls, WV, quadrangle. Divisions on mattock handle are 6 cm. Reproduced with permission of Elsevier Science Publishers B. V.

Figure 7. Sorted stripe complex on Cabin Mountain, Blackwater Falls, WV, quadrangle. Meter stick on fallen block, lower left of center, for scale. From Clark, *et al.* (1989, Figure 44, p. T150: 68). Reproduced by permission of American Geophysical Union.

Discussion

Clark and Ciolkosz (unpublished data) have located more than 50 sites where large-scale sorted nets occur, and more than 150 locations where large-scale sorted stripes are present. These finds, however, should not be regarded as providing a true picture of sorted patterned ground distribution. For example, there are as yet few finds of sorted patterned ground on the Appalachian Plateau. In part, this may be because many areas on the Plateau lack exposures of suitable resistant lithologies. On the other hand, there has been no systematic reconnaissance effort made to locate patterns in this area, although there are several finds. The report of sorted stripes 10 to 15 feet wide and many tens of feet long on the slopes of Montgomery Creek in the southern half of the Penfield quadrangle (Edmunds and Berg, 1971, p. 61) is a case in point. Figure 8 shows the distribution of quadrangles in the field trip area beyond the Late Wisconsinan glacial border that contain finds to date (1992) of large-scale sorted patterned ground.

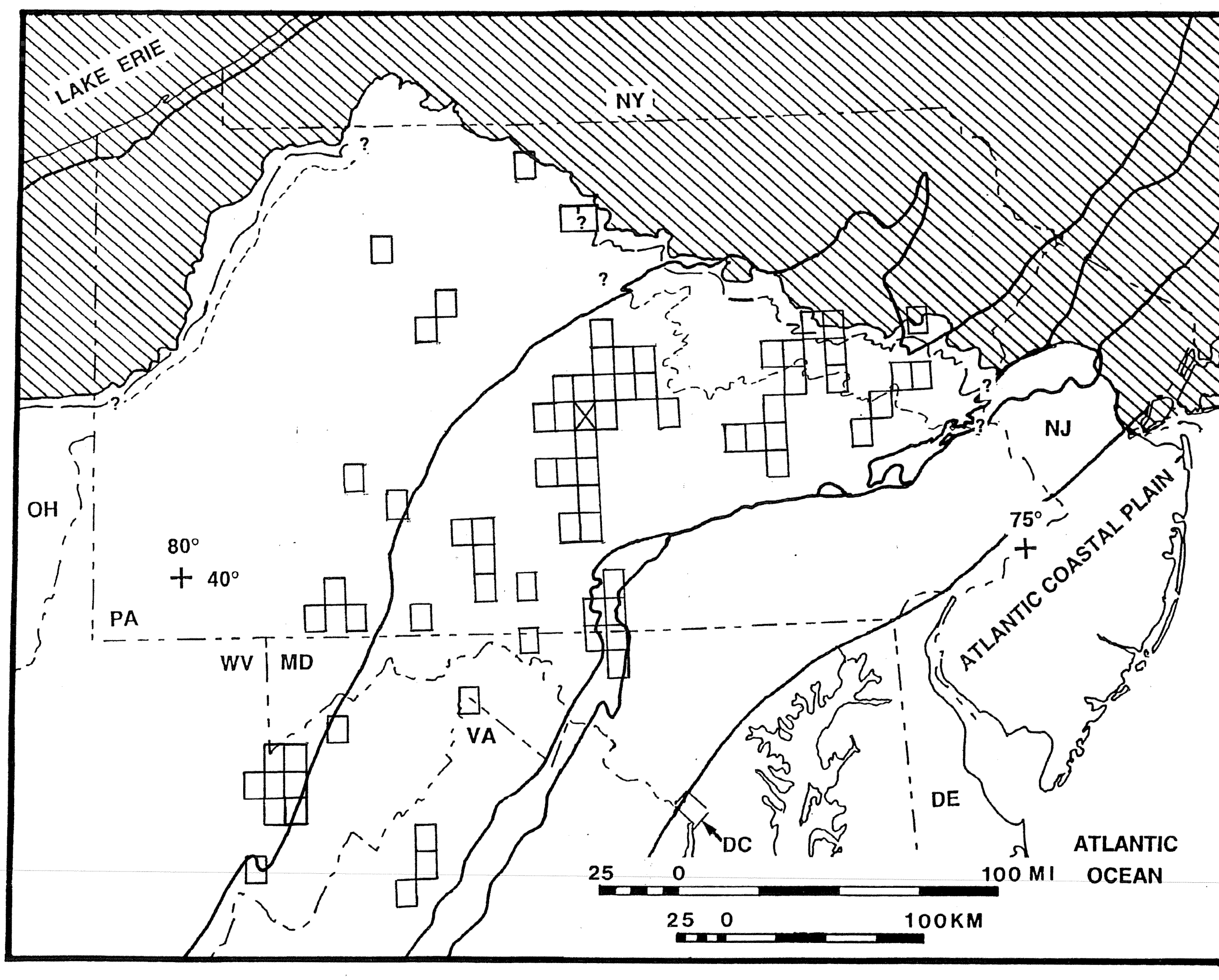

Figure 8. Distribution of quadrangles (open rectangles) that contain finds of large-scale sorted patterned ground in the field excursion area beyond the Late Wisconsinan glacial border. Geomorphic provinces as keyed in Figure 1. Data are from Ciolkosz, *et al.*, (1986b), Clark and Ciolkosz (1988), Clark and Ciolkosz (unpublished data), and Denny (1956).

Some sorted stripes are physically continuous with block streams; stripes enter some block streams from upslope directions, apparently as feeders, and others 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 necessarily genetic, linkage between the origins of at least some sorted patterned ground and some parts of some block streams.

Coutard, *et al.* (1988) conducted an experimental study of frost heave and frost creep in an insulated tank. The materials consisted of loam, sandy loam, and a poorly sorted sediment mixture that included gravel. The experimental slope had a 12° inclination and was designed to include subsurface water flow. They found that processes changed downslope and intensified in loam where water supply was greater. The largest movements occurred just after thawing fronts passed through the materials. They demonstrated that frost creep was able to deform sorted polygons into sorted stripes and that such activity took place with the progressive disappearance of gravel-rich wedges transverse to the slope direction.

Most, but not all, large-scale (> 2 m mesh or stone border diameter) 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 today in the Central Appalachians. Neither are there soils with large percentages of expanding clay minerals (Vertisols), nor are there soils that contain large amounts of salts (certain Aridisols). Some authors, such as Goldthwait (1976), interpret sorted polygons and nets over 2 m in diameter as features requiring permafrost for development. 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 for any type of sorted patterned ground are much smaller sized patterns in 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 date from one or more Quaternary cold-phase events and are thus so old, how have they survived tree growth and tree throw? The answer may lie in the subsurface, as these features that can be seen in excavations are of the "deep rooted" variety, with tabular blocks tending to be oriented with their ab planes (maximum projection area) vertical and anchored firmly in the subsoil. There are few places, such as road cuts, where the maximum depth of stone concentrations can be seen without backhoe excavation, but for the larger stripes observed, the approximate depth to base of contiguous stones ranges from about 1 m to a maximum of about 1.7 to 1.8 meters. If permafrost existed during sorted stripe development, this stone depth might have some relationship with the thickness of the active layer. On the other hand, depth to base of contiguous blocks may simply be a measure of the effective depth of highly-disruptive seasonal frost activity that was capable of segregating, orienting, and transporting large blocks.

Block Fields, Block Slopes, and Block Streams

Introduction

Areally large surface accumulations of gently-sloping, contiguous block or boulder deposits—especially those that lack present-day arboreal vegetation—have long held the fascination of workers in the Appalachians. Treeless portions of gently-inclined contiguous blocks were probably among the first scenic geological features described by early European immigrants to the Central Appalachians. Geyer and Bolles (1979, 1987) describe a number of spectacular examples of such deposits in Pennsylvania. In this treatment, we exclude the steeply-sloping taluses, also termed scree slopes (Washburn, 1980), and their underlying block materials, which are called scree or sliderock by many workers. Such forms and materials, with or without present-day arboreal vegetation cover, are almost ubiquitous features below cliffs and cliff remnants along ridge crests in the Appalachians, as well as on the steep slopes in water gaps. As detailed later, there is also evidence of recent activity on such steeply-inclined deposits (*cf.* Hack, 1965; Hupp, 1983), so that at least part of their form and material is due to contemporary processes.

Terminology has been a major problem for workers who have described block deposits in the literature. Some species of scientific nomenclature is a necessary condition for geomorphologists to be able to communicate on a regular and standardized basis (Thorn, 1988, Chapter 4). Ideally, the terminology should be objective, at least semi-quantitative, and nongenetic, because the origins of active block accumulations in actuoperiglacial environments is poorly understood, and that of their fossil analogs is even more tenuous. For example, Caine (1968), following the work of Fezer (1953), provided standardized definitions of terms for block accumulations that he studied in Tasmania at elevations above about 1200 m. Both slope and slope position are important criteria for the classification of block and boulder deposits. For instance, features that occur on upland flats, or that straddle divide areas with gently-sloping floors traditionally have been termed block fields. The term block field (or blockfield), however, has been used for many different features in the Appalachians (*cf.* Hupp, 1983; Kochel, 1976; Peltier, 1945; Potter and Moss, 1968; Walters, 1984). Map-view geometry also enters into the definition and distinction of the different types of contiguous block deposits. Both block fields and block slopes are sheet-like accumulations of large angular rock clasts (White, 1976) that are not elongate in an upslope-downslope direction. Block streams, on the other hand, extend farther in a downslope direction than parallel to the slope (White, 1976). Usage still varies between researchers, however. For example, most workers refer to the deposit at Hickory Run as the Hickory Run Boulder Field, but White (1976) used the term block stream. On the other hand, the Hickory Run block accumulation is a very complex feature. For example, large clasts in the mid and lower parts of the feature are well rounded, but in the upper part of the main field and in the southeastern arm area, the rocks are very angular. Middlekauff (1991) named contiguous block accumulations in the Northern Blue Ridge "block mantles" where matrix-free, and "block aprons" where the cobble-and boulder-size debris is set in organic-rich soil and is forest covered. Elongate, vegetation- and matrix-free block accumulations on slopes of 3 to 6°, however, were termed block streams (Middlekauff, 1991, p. 26-28).

From a practical standpoint, however, as in cases where mapping criteria must be applied, such accumulations of large clasts must be differentiated from other deposits that also contain large particles. What criteria could be applied to effect such differentiation? Sevon (1975a, 1975b) used the following criteria to distinguish boulder fields from boulder colluvium: Boulder fields are thick deposits of accumulated boulders that have no interstitial material at the surface; fitted and polished surfaces between boulders exist; boulders at depth even when surrounded by interstitial material are still in point contact; boulder fields are barren of vegetation except along margins; and boulder fields generally occur on gentler slope classes that boulder colluvium.

In this paper, we use a standardized scheme, shown in Table 8, simply for the purposes of clarity and consistency. The classification is nongenetic and has been designed so that it reflects features found in the Central Appalachians south of the Late Wisconsinan glacial border.

The classification scheme shown in Table 8 can, of course, be modified to precisely describe a wide range of features found in the field. For instance, Rapp (1967) divided block fields he found in central Pennsylvania into a "ridge-side type" and a "valley-bottom type." Other examples could be "forested valley-bottom block stream" and "block slope with interstitial fines below 50 cm." Special-purpose investigations can also require modification of terminology. For example, in a survey that involved use of topographic maps to identify such deposits, Fritz and Meierding (1989) used operational definitions as follows: "blockfield" 10° slope or less; "blockslope" 10-24° slope; "steep blockslopes" > 24°; and "blocksheets," which were a category of steep accumulations that apparently encompass some of the foregoing deposits and which lack visible source ledges at their headward areas. In a final example, Middlekauff (1991) used a morphosequence approach, and divided landforms and deposits into either scarp slope deposits or dip slope deposits. He then traced the progressive changes from one type of block deposit to another from ridge crests to the bordering valleys (see Middlekauff, 1991, Figure 3, p. 23).

Table 8. Terminology used for accumulations of contiguous blocks in the Central Appalachians south of the Late Wisconsinan glacial border (modified from Fezer, 1953; Caine, 1968; Washburn, 1980; and White, 1976).

TERM	DEFINITION
Block	A coarse angular detrital rock fragment with a-axis dimension > 10 cm.
Block Deposit or Block Accumulation	A general term for the entire size-shape range of contiguous large angular and subangular blocks generally lacking arboreal vegetative cover and lacking a surface matrix of fine-grained sediments.
Block Field	A block deposit of low slope angle, generally < 10°.
Block Slope, or, if aprons, Block Glacis	A block deposit that is areally most extensive normal to the slope. This term is equally applicable to the low-angle sheet of blocks below a talus slope or to an elongate deposit where a talus slope is absent.
Block Stream	A block deposit which is most extensive in an upslope-downslope direction. Depending upon topographic position, several subspecies of block streams can be identified as being common in the Central Appalachians, such as Sideslope Block Stream, Valley-Axis Block Stream, and Valley Bottom Block Stream.
Block Field Saddle	Block deposits which occupy narrow to broad divide areas and that spill at least marginally outward in both side saddle slope directions.
Felsenmeer	A flat or gently sloping upland area veneered with a block deposit which is presumed to have been derived either *in situ* by intensive frost action or involving some lateral transport.
Boulder	A rounded detrital rock fragment with a-axis dimension > 10 cm.
Boulder Field	A deposit of contiguous boulders with no arboreal vegetative cover, lacking a surface matrix of finer-grained sediments, and having a low slope angle, generally < 10°.

Block Fields

Block fields (White, 1976) comprise the lowest slope category of features composed of angular contiguous blocks at the surface. If the clasts are rounded, the term "boulder field" is more appropriate. A number of block and boulder fields are reported in Pennsylvania (Ciolkosz, *et al.*, 1986b) and in the Appalachians south of the Late Wisconsinan glacial border (Clark and Ciolkosz, 1988), and some have received detailed study. The Hickory Run Boulder Field (or Block Stream) (Figure 9) is renowned for its great size (unforested area of 500 m long and 125 m wide), development on a low gradient (about 1°), surface topographic features, sedimentological features, and the geologic relationships in the surrounding area, and is on the excursion route. The Hickory Run Boulder Field or Block Stream was studied by Adler (unpublished data), and later described by Sevon (1969, 1987). Adler (unpublished data) identified, set up mapping criteria, and mapped kinds of microtopography based on size, shape, and elevation within the forest-free part of this feature. He also used boulder composition, size-shape, color, orientation, packing, and microtopography to create 12 mapping units, which were then mapped. Adler then produced a tentative relative age sequence of emplacement of these elongate, stream-shaped, mapping units, based upon interference patterns and cross-cutting relationships. From a visual standpoint, these mapping units can most readily be seen on low-level, color, aerial photographs, but can also be identified in the field, as can be demonstrated on the excursion.

Another interesting occurrence of a block accumulation in the field trip corridor is a topographic-position variation of a block field known as a block field saddle. The Devils Turnip Patch is in a col only about 3 km north of the field excursion route. US Route 15 traverses the blockfield saddle in a spectacular wind gap through Bald Eagle Mountain (Geyer and Bolles, 1987). In map view, The Devils Turnip Patch appears as an elongate, elliptical deposit that occupies the floor of the wind gap. Geyer and Bolles map this block field saddle as having widths up to about 425 m and a length of about 1350 m. The block field saddle contains many tabular blocks with sub-vertical ab planes. The thickness of the deposit ranges from about 2 to about 15 m (Geyer and Bolles, 1987). Despite its length, The Devils Turnip Patch is included in the discussion of block fields, because its position in a topographic saddle is an over-riding criterion and because no width-length criteria have yet been applied to block fields in topographic saddles. Blocks derived from the Tuscarora Formation have moved down gradient both north and south of the topographic divide. Geyer and Bolles (1987) note that the Devils Turnip Patch is one of the finest examples of its type in Pennsylvania.

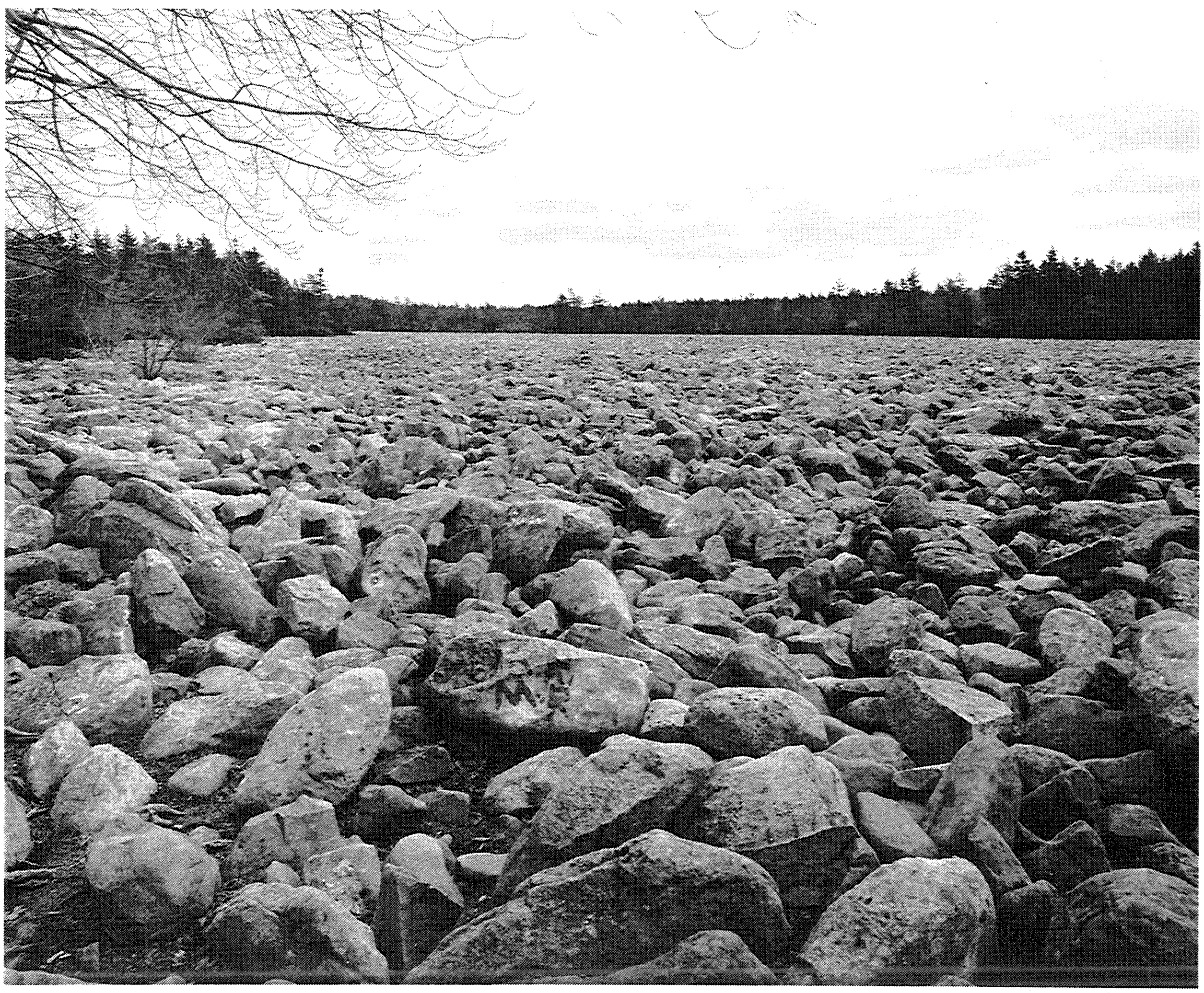

Figure 9. The Hickory Run Boulder Field (or Block Stream), Carbon County, Pennsylvania (Hickory Run quadrangle). View is upslope from near the parking area. The average slope gradient on the field is about 1°.

Block Streams

Block streams are elongate swaths of contiguous blocks that have their long axes generally perpendicular to topographic contour (White, 1976). Perhaps because of their spectacular appearance—when free of arboreal vegetation—these features have attracted much popular attention, and some scientific study, in the Central Appalachians (Clark and Ciolkosz, 1988). Most early reports were of sites near the glacial borders, but Smith and Smith (1945) extended the range of reported features by noting the presence of block streams in the northern section of the Blue Ridge province in Pennsylvania and in Maryland. The South Mountain features did not receive modern study, however, until work by Godfrey (1975), Middlekauff (1991), and Clark (1991). 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 in the Central Appalachians; tree-covered sites dominate the inventory, but forest-free sites dominate the literature. Of course, this is because, in the heavily-forested mountain regions, treeless block streams are visually spectacular (Figure 10). Sites that are free from rooted plant life also permit the unimpeded study of block fabrics, microtopography, and other features. Such studies have been completed in several areas in the Central Appalachians. These sites include: the Bowmanstown, Pennsylvania Boulder Field (Sevon, 1967); the Blue Rocks Block Stream (Potter and Moss, 1968); the "Devil's Racecourse" of Martin (1971)—(same feature as Devils Race Course of Geyer and Bolles, 1987); and the previously-cited studies in the Northern Blue Ridge.

After periods of high precipitation or rapid snowmelt, loud sounds of subsurface running water can be heard in and near the central part of many block streams. These waters emerge downslope as surface streams, and could have provided a mechanism for the removal, over time, of any interstitial clastic matrix that may have existed between the blocks (Smith, 1953a). On the other hand, the very presence of running water below the surface would have also provided an abundant source of water to form interstitial ice that might have acted both as a matrix and aided mechanisms of block transport.

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. 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 some are treeless is of interest. Observed relationships at the edges of the treeless features are most easily understood if a scenario of gradual forest encroachment is envisioned.

Sorted stripes can be traced downslope into the headward areas of several block streams, and the downslope fringes of the block streams 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 Central Appalachian mountain block streams are similar to those found in block streams in active periglacial environments. Thus, there seems little doubt that at least the most extensive and best-developed Central Appalachian block streams are largely to wholly periglacial features.

Caine and Jennings (1968) studied block streams in New South Wales (36+°S; 1680-1780 m) developed from basalt. The block streams range in length from about 150 to over 300 m and in width up to about 70 m (in single occurrences) or 85 m (when merged). Slopes on the west side of the Toolong Range vary from 4.5 to 12° in their midsection areas and average about 9°. Some of the long profiles have transverse inclined steps or berms and may contain irregularly distributed topographic hollows about 1 m deep that are free of interstitial fine materials. One block stream has some longitudinal V-shaped grooves up to 2 m deep separating rounded ridges. The main bodies of the block streams have a somewhat concave cross-profile, but with slightly higher edges than the bordering soil. Some of the westernmost block streams have distal ends that are gently convex in cross-section and relatively steep, bulging toes with upslope flats. The toes may be more than 2 m higher than the soil surface immediately downslope.

Caine and Jennings (1968) interpreted the origin of the block streams as products of mass movements that originated under periglacial environmental conditions. Soil and vegetational evidence demonstrate that there is no present-day movement. Postulated mechanisms of movement could have included some solifluction or congelifluction that occurred when the block streams were filled with finer-grained materials, or movement may have occurred when the interstices were filled with ice that may have formed as a result of Balch ventilation. Subsequent removal of fines by piping after block stream emplacement would have been required in the former case. In the latter case, these authors reported several lines of evidence that seem to have required interstitial ice. These are that substantial portions of some block streams are composed only of basalt columns, with no source area for fines; the irregular map pattern of the surface pits; and the toe morphology. Timing of block stream emplacement, controlled by ^{14}C dates, was between 35,200 and 15,000-20,000 yr BP. For interstitial ice to have been an effective geomorphic agent, Caine and Jennings postulated a MAAT below 0° C during development and suggested that effective precipitation had been reduced in order to minimize the likelihood of insulating effects of thick and long-lasting snow cover.

Certain block streams in the Central Appalachians have many surface features in common with the block streams in the Toolong Range studied by Caine and Jennings (1968). Appalachian occurrences have similar: map dimensions; gradients; lack of interstitial fine-grained sediments at and near the surface; and microtopography, including hollows and longitudinal grooves.

Block Slopes

Block slopes (White, 1976) represent the steepest slope class of this trio of landforms composed of contiguous blocks. Block slopes are elongate normal to mountain slope directions, and are distinguished from talus slopes by their lack of a cliff, or free face, at their upslope termini. Block slopes may be forested or unforested, may lack interstitial fines at depth or may contain them. Block slopes are almost ubiquitous features in many parts of the Ridge and Valley and Blue Ridge provinces and in upper valley locations in the Appalachian Plateaus province but almost no research seems to have been done on them. One exception is Allamong (1991), who studied the "Black Rocks" block deposit on the western flank of New Creek Mountain in the New Creek River Valley, Grant County, West Virginia. "Black Rocks" is a feature that is transitional between a talus slope and a block slope; there are some cliff remnants in the ridge crest area. This feature has both forest-free and forested areas and occupies about 0.8 km^2. The sandstone blocks fill a contiguous series of hemi-amphitheatre-shaped depressions separated by steep ridges. The scree slopes average about 35° in slope angle and lack interstitial matrix at observable depths. Nearly all of the blocks are angular in shape; the average a-b-c axis lengths are 0.89 x 0.66 x 0.44 m, with the largest block measured being 2.93 x 2.07 x 1.37 m. Downslope from the block slope, the western footslope of New Creek Mountain is underlain by a colluvial apron with a coalescing, fan-like morphology. Two exposures in the colluvial apron revealed 3.5 and 6 m of sand-matrix supported cobbles and boulders, and bedrock was not exposed. Allamong attributed the presence of the "Black Rocks" block deposit to structural and lithologic controls, although he indicated that periglacial conditions may have influenced the rate of weathering. It is unfortunate that block slopes have not received the study they deserve, especially when their interrelationships with other block and block-rich deposits, and the large areas of mountain slopes covered by them are considered.

Caine and Jennings (1968) described block slopes on the eastern side of the Toolong Range, New South Wales. On the eastern side of the mountain range, block slopes have slope angles of 15° and occasionally more than 25°, although they are significantly less steep than talus slopes in the area (Caine and Jennings, 1968).

Figure 11 shows the locations of a number of block fields and block streams in the field trip region. A few of these features have been studied, but many have not.

Figure 10. Lock Haven, Pennsylvania block stream on northwest slope of Bald Eagle Mountain. Elevation range of forest-free area is about 980 to 1900 ft (299 to 579 m). This block stream was studied by Kirkby (1965). Lock Haven quadrangle.

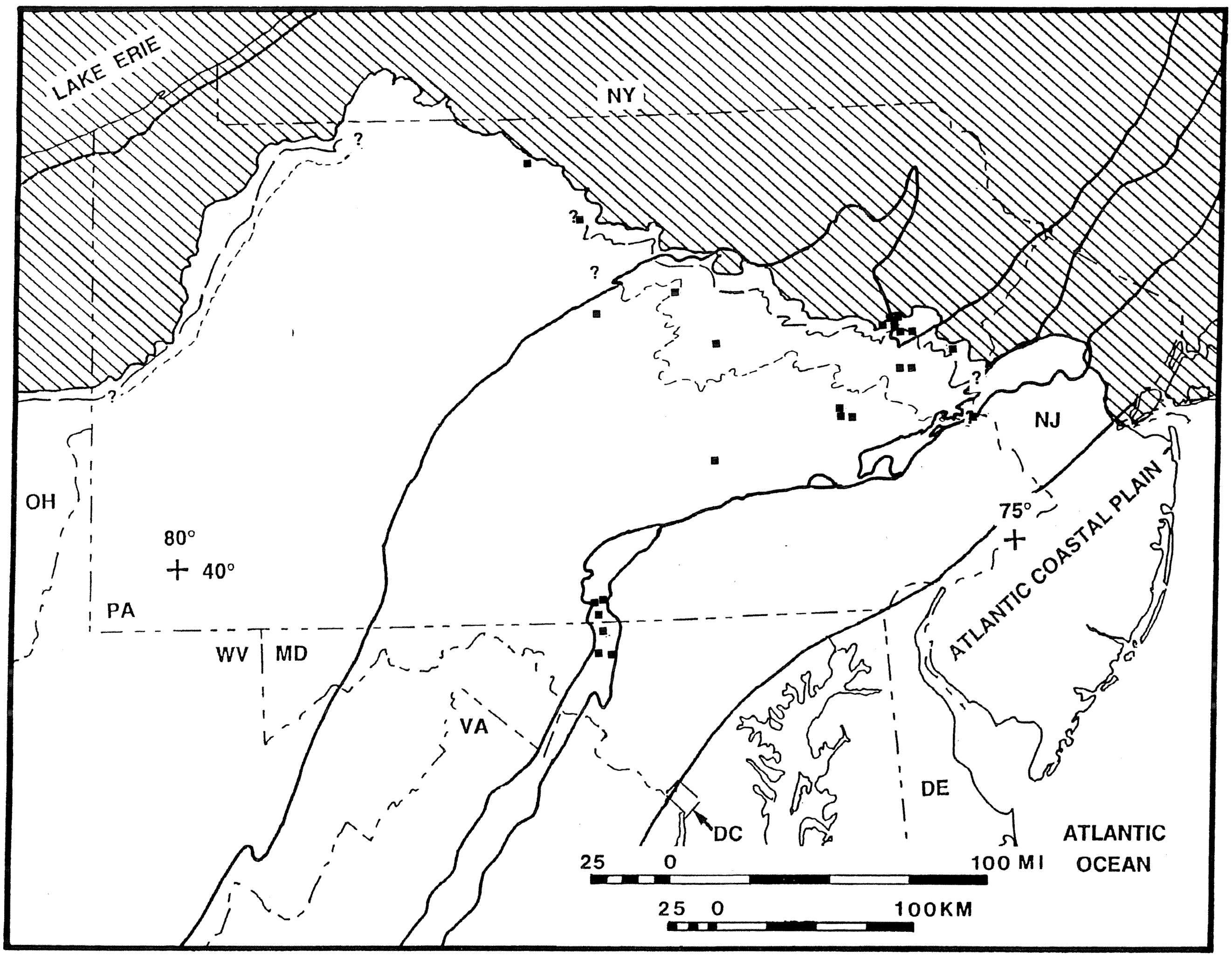

Figure 11. Selected block fields and block streams (shown by small squares) in the field trip area beyond the Late Wisconsinan glacial border. In areas of dense concentration, such as Carbon County, Pennsylvania (Sevon, 1969), only prominent features are shown. Geomorphic subdivisions and glacial borders are as keyed in Figure 1. Data are from Ciolkosz, *et al.* (1986b); Denny, 1956; Geyer and Bolles, 1979, 1987); Godfrey (1975); Middlekauff (1991); Martin (1971); Sevon (1969); and unpublished data of the present authors.

Discussion

Hack (1960) applied the concept of equilibrium to landscape development and indicated that the downwasting rates of adjacent areas underlain by differentially resistant rocks should be in dynamic equilibrium when slopes are adjusted to the work to be done. He later applied the dynamic equilibrium concept to the origin of topography and ore deposits in the Shenandoah Valley, Virginia, (Hack, 1965), including areas with steeply-sloping screes. There, he found strong evidence of present-day movement of scree in the St. Marys River Valley on slopes of about 36° and in the Madison Run and Paine Run areas on slopes of 19° to 20° and about 35°, respectively. However, Hack (1965) also concluded that many large areas of scree are probably preserved from the Pleistocene. Hupp (1983) has also presented convincing evidence for contemporary scree movement on steep slopes at relatively low elevations in Virginia. Fluvial erosion at the base of such slopes may be a contributing factor. On the other hand, Rapp (1967) noted that some talus slopes can be at least partly of an inactive or fossil nature, and termed them "stabilized talus slopes." Rapp (1967) also clearly recognized that such forms are less reliable indicators of a palaeoperiglacial environment, and this is the main reason why these features are not treated herein.

Some confusion therefore exists as to what landforms in the region are evolving dynamically versus features that may be inactive or fossil. At least some of this uncertainty about the state of activity may be due to the lack of standardization on terminology (White, 1976) with respect to the critical limiting slope-angle classes. For example, when describing Holocene activity on steeply-sloping screes, some authors have used the term "block field" (Hupp, 1983) or the term "rock streams" for block deposits in Arkansas (Lookingbill, *et al.*, 1987). Acceptance of a steady state concept is not difficult for steeply sloping landforms with underlying soil and rock materials that can equilibrate rapidly to changing environmental conditions, especially in areas where streams are flowing at or near the bases of hillslopes. In contrast, the block fields and block streams described herein are on gentle slopes without surface streams at their bases, and display weathering features that suggest long-term stability. An interpretation of inactive or fossil state is not unreasonable considering the low slope gradients, blocky armor, resistant lithologies, and relatively long distances from active stream channels that characterize these features.

In a study that included the easternmost range of mountains in the Ridge and Valley province in Pennsylvania, Maryland, West Virginia, and Virginia and in Shenandoah National Park in the Northern Blue Ridge province, Fritz and Meierding (1989) mapped treeless areas from 1:24,000-scale U. S. Geological Survey topographic maps with green forest cover overprint. The operational definitions used were: "blockfield" 10° slope or less, "blockslope" 10-24° slope, "steep blockslopes" > 24°, and "blocksheets" which were a category of steep accumulations that apparently encompass some of the foregoing deposits and which lack visible source ledges at their headward areas. Elevations of finds on the maps were plotted against latitudes of the localities. From a comparison of modern lapse rates, Fritz and Meierding (1989) concluded that development of these block accumulations required Quaternary cold phase mean annual temperatures of 13°C below the present MAT in this part of the Appalachians.

Middlekauff (1991) used both biologic and geomorphic evidence to assess the stability of deposits and landforms he studied in the northern Blue Ridge. Indicators of stability were: undisturbed forest growth on and adjacent to block deposits, secondary differential weathering of blocks, lichen growth on exposed block surfaces, and accumulation of organic-rich soil on and between blocks. Middlekauff (1991) concluded that the landform continuum in the area of the Northern Blue Ridge he studied is now largely relict and constitutes a disequilibrium situation with the present-day climate there.

There is need for more detailed study of all types of block accumulations in the Central Appalachians. Research on block fields and block streams that contain distinctive features such as microtopography, geometric arrangements of rock patterns, and stone sortings by size and shape could yield much information that would help in understanding their mechanisms, environments of evolution, and ages of development. Study of the almost ubiquitous and areally extensive block slopes would assist in understanding diamicton development and transport and would provide a much fuller understanding of the effectiveness of periglacial processes and environments in producing the present mountain landscapes. The largely unpublished work by A. A. Adler on the Hickory Run Boulder Field, however, still remains the most comprehensive study of block accumulations in the Central Appalachians. His definition and mapping of "flow" units is a major advance in our knowledge of the compositional, textural, and fabric elements of the Hickory Run deposit, and may have applications elsewhere. For example, Psilovikos and Van Houten (1982) indicate that the Ringing Rocks barren block field (see Peltier in Willard, *et al.*, 1959) may contain several debris flows. Much of the difficulty in getting data from block deposits seems to be mechanical, in that subsurface information is difficult and expensive to obtain. Relatively new seismic tomographic techniques, coupled with limited direct subsurface sampling—such as diamond drilling—may provide tools useful for future work.

Frost Mounds and Ground Ice Scars

Introduction

The general category of frost mounds includes a diverse assemblage of features such as palsas, pingos, and other topograpically-related features. The rapidly-expanding literature on actuoperiglacial geomorphology demonstrates that these varied forms and their underlying materials can have a multitude of environments and mechanisms of origin. When dealing with probable fossils of such features, the problem is even more daunting. For example, the difficulties in interpreting the genesis of probable ground ice scars are well known (see Carpenter and Bryant, 1987).

Marsh (1987) reported the presence of two sites in Pennsylvania where fossil frost mound remnant features interpreted as pingos or minerogenic palsas are located. These forms and materials are located in the Halfway Run and Penns Creek areas, Union and Snyder counties, Pennsylvania, respectively. The landforms are elliptical basins that average 20 by 50 m in plan view and 4 m in depth. Descriptions of the features at the Halfway Run site are in the road log itinerary for this excursion.

Palsas and Related Landforms

Following Washburn (1983a, b) and Seppälä (1988a, b), palsas are defined as peaty permafrost mounds in the height range of about 0.5-10 m, and having an average diameter of at least 2 m. Washburn (1983b) noted that palsas comprise both aggradation forms produced by permafrost aggradation at an active-layer/permafrost interface zone, and similar-appearing degradation forms produced by disintegration of an areally-extensive peaty sediment. Seppälä (1988b) does not favor use of the term "mineral palsas" because it would require recognition of the existence of peat bogs without peat. When dealing with frost mounds, one reflection of the terminology problem is the introduction of a term that could be used in a nongenetic sense when referring to frost mounds of hybrid earth material composition. S. A. Harris (in review, Sixth International Conference on Permafrost, Beijing, 1993) has proposed the term "*lithalsa*" for forms and materials that neither conform to the widely accepted definition of palsas nor are purely minerogenic mounds of frost origin. Fossil forms of frost mounds of palsa scale have great potential in palaeoenvironmental research (Nelson, *et al.*, 1992).

Palsas may represent local spots of active permafrost aggradation, or they may be residuals left from permafrost degradation in a thawing peat bog. Active palsas and related forms develop in both the zone of continuous permafrost, and in the zone of discontinuous permafrost (Washburn, 1983a). The equatorward limit of true classic Fennoscandian palsas has been shown to coincide with the equatorward margins of discontinuous permafrost (see discussions in White, *et al.*, 1969 and in Seppälä, 1988b). The internal composition of a palsa may be ice-rich peat or ice-rich silt; but ice crystals and lenses comprise about 80-90% of the volume of the mound.

Allard, *et al.* (1987) studied both palsas and minerogenic permafrost mounds in northern Québec. They found that palsas occur predominantly in areas of forest tundra. By contrast, mineral permafrost mounds are found mainly in shrub tundra areas that have somewhat colder environmental conditions.

Seppälä (1988a) found three different types of peat mounds with permafrost cores in northern Ungava, where continuous permafrost is overlain by shallow active layers only 30 to 50 cm thick in mire areas. In this study, even in areas where peat accumulations reached 2 m, no true palsas were found. The features that do occur are erosional peat mounds, thermokarst mounds found in association with ice-wedge polygons, and "frost blisters."

The erosional peat mounds resulted from fluvial erosion in a stream valley. Presumably, they are frost-cored remnants of once more continuous masses that have been dissected by running water.

The thermokarst mounds developed in the centers of nonsorted polygons 10 to 20 m in diameter that were underlain by thawing ice wedges. These peat mounds developed as raised-center nonsorted polygons, and Seppälä preferred to classify them as high-centre nonsorted polygons instead of incipient palsas.

The third type of peat mound had been upraised by a massive body of ice at least 60 cm thick located below the peat and above coarse gravel on the side of a large stream valley. An upslope gully had provided suprapermafrost water, which froze during active layer freezing. Seppälä interpreted this type of feature as a temporary "frost blister" that might persist for several years and then melt and/or reform in similar very local environments. Seppälä (1988a) likened the near-surface ice development in the "frost blisters" to their related surface hydrological developments—Aufeis or naled—that form from seeps, springs, or running water. Muller (1947, p. 76-82) described the forms that such icings can take as sheets, fields, mounds, or irregular encrustations. The surface of icings is usually very irregular. The effect of snow thickness on the development of such icings is very great; with no or thin snow cover (roughly less than 0.5 m), icings can form in early winter. Early heavy snowfalls either retard the development of icings until spring snowmelt or prevent their development altogether.

What specific types of conditions are necessary for such mounds to form in a periglacial environment? In discussing palsas and related forms, Seppälä (1988b) notes the infrequency of occurrences in unglaciated areas of Alaska and the Yukon, suggesting that some sort of glacial or glaciofluvial substrate is favorable for their development. For formation of true palsas and palsa-like features, low precipitation (about < 400 mm/yr) is required; low values of both summer rainfall and winter snowfall are critical. Low air temperatures are also a necessity; MAAT less than about -1°C are usually required, and an extreme upper MAAT limit of 0°C seems to hold true (Seppälä, 1988b).

Deterioration of palsas occurs in response to a number of factors. Major warm phases of climatic change—as during the Pleistocene-Holocene transition—would obviously cause melting and palsa destruction. Warmer air temperatures could be aided by influx of warmer water in spring and summer months due to widespread thawing of surface and ground ice and loss of the insulating surface peat cover by any of a number of means (White, *et al.*, 1969). Concomitant collapse of the ice-rich core could leave a depression caused by the thinner remnant peat from the former crest of the mound, due to lower formation rates and/or erosion. Mechanisms for the production of a rampart, however, are somewhat problematical.

Pingos and Pingo Scars

Pingos are permafrost mounds that grow from the crystallization of pressurized underground water (Pissart, 1988). Contrasted with palsas, pingos are typically larger. A massive ice core composed of segregation or injection ice is a characteristic, but not required, internal feature of pingos. Some pingos have cores with multiple ice lenses, rather than one discrete ice core. Pingos may form in the thick continuous permafrost zone (closed-system pingos) or in the discontinuous permafrost zone. Closed-system pingos characteristically form where the mean annual air temperature is about -5°C or lower. Open-system pingos may develop in continuous permafrost or in discontinuous permafrost. Those in discontinuous permafrost may form in areas where the mean annual air temperature is as high as -2° or -1° C (Washburn, 1980).

With respect to fossil features, the identification of pingo scars is addressed by de Gans (1988). He lists several tentative diagnostic criteria as follows: (1) a central depression with a minimum depth of 1.5 m and a minimum diameter of 25 m; (2) the bottom of the central depression is below the level of the surrounding land and is composed of permeable material; (3) at least part of a rampart is present, and is composed of slope material derived from the depression; (4) the scars may lie on horizontal land or on slopes up to 5°; and (5) the pingo remnants are accompanied by other permafrost features.

Summary

Are the ground ice scars found in the Halfway Run and Penns Creek areas in Pennsylvania fossil forms of palsas, or of minerogenic mounds, or of "*lithalsas*?" With our present incipient understanding, the origin of these features can only clearly be understood if permafrost formerly existed, but was the permafrost continuous or discontinuous during the active stages of feature growth, and what range(s) of mean annual air (or soil) temperatures might be reasonable?

Could the ground ice scars be remnants of pingos? Pingos also form under a wide range of permafrost conditions, and the range of composition of the core materials, including the type and distribution of ground ice in the permafrost, can be quite great. Considering the topographic position of the features in the Halfway Run and Penns Creek areas, some kind of open-system pingo is a reasonable, but probably a simplified model. On the other hand, perhaps these features are hybrid forms that partook of the properties of two or more kinds of end-member forms that exist in actuoperiglacial environments and that are described in the literature. Perhaps they have no modern described analogs.

Aeolian Sediments

Introduction

A number of authorities do not include aeolian processes and their effects in defining and delimiting periglacial processes and regions. This is understandable from both the standpoint that aeolian activity and deposits are widespread in many climatic and geomorphic regions worldwide and from the perspective that some periglacial areas lack obvious aeolian feature or deposits. Nonetheless, the end results of past aeolian processes are treated here because there is mounting evidence that wind action had strong direct and indirect effects in the Central Appalachians during more than one Quaternary cold phase. The direct evidence includes: the presence of fossil sand sheets and sand dunes, loess sheets and the anomalously high silt content of certain soil horizons, and the presence of large quantities of extremely fine-grained sediments often referred to as "aerosolic dusts" (or "desert dusts," because of their probable origin) in certain soils. For example, Cronce (1988, p. 159) calculated that soils at the Bellefonte, Centre County, Pennsylvania, site he studied contain between 2.8 and 5.1 cm of aerosolic dust that represent 28,000 to 51,000 yr of aeolian deposition. Indirect evidence rests on the presence of landforms that, from the literature, seem to require strong wind action in order for them to develop or that, with our present inadequate state of knowledge, appear to require strong and persistent wind activity in the past. In the former case, such features include cryoplanation features in Pennsylvania, Maryland, and West Virginia; in the latter instance, an example would be the "wind-oriented welts" in Union County, Pennsylvania.

Loess and Loess Sheets

Although detailed mapping (*cf.* Inners, 1981) demonstrates that there are mappable areas of loess in the field trip area at, for example, 1:24:000 scale, the map "Pleistocene eolian deposits of the United States" (Thorp and Smith, 1952) is the only known published work on the overall areal distribution of loess in the field trip region. Thorp and Smith (1952) mapped loess less than 4 feet (1.22 m) thick covering 33% to 67% of the land surface in large areas of Bucks and

Montgomery counties, Pennsylvania. Along the Susquehanna River in Pennsylvania, Thorp and Smith (1952) mapped large areas with less than 4 feet (1.22 m) of loess covering less than 33% of the land surface in Bradford, Wyoming, Luzerne, Columbia, Montour, Union, Northumberland, Snyder, Juniata, Dauphin, Perry, Cumberland, York, and Lancaster counties. The works of Carey, *et al.* (1976), Carey (1978), and Petersen, *et al.* (1972) along the Delaware River and those of Inners (1981), Millette and Higbee (1958), and Peltier (1949) along the Susquehanna River, however, provide the only detailed information about the characteristics of loess in eastern Pennsylvania. Wolfe (1977, p. 271) cited two reports of loess deposits in different areas in the Piedmont province of New Jersey and Pennsylvania, but noted that no detailed information on the areal distribution of loess in New Jersey was available at that time. Figure 12 shows the distribution of Pleistocene aeolian deposits in the Central Appalachian area, as mapped by Thorp and Smith (1952).

There is a particular dearth of modern information about loess in western Pennsylvania. Field observations indicate that loess occurs in many areas of western Pennsylvania, but there is little documentation of its distribution or character. In a north-south belt along the Allegheny, Beaver, and Monongahela rivers, Thorp and Smith (1952) mapped loess less than 4 feet (1.22 m) thick and covering less than 33% of the land surface in Cattaraugas and Chatauqua counties, New York; in Warren, Crawford, Forest, Venango, Mercer, Clarion, Butler, Lawrence, Beaver, Armstrong, Allegheny, Westmoreland, Washington, Greene, and Fayette counties, Pennsylvania; and in Monongahela and Marion counties, West Virginia. Still, we can find no published research results on the characteristics, origin, or ages of loess sheets in western Pennsylvania or in northern West Virginia. Many of these areas are not far west of the excursion route in southern Pennsylvania, western Maryland, and on the Appalachian Plateau in West Virginia and would be expected to give some guidance about the likelihood of the presence and thicknesses of aeolian sediments in soil parent materials in the field trip corridor.

Conant, *et al.* (1976) reported the presence of a surface layer of gray clayey silt that overlies the "upland" gravels in Cecil County, Maryland, at an elevation of about 125 m. The main filling of the sediment-filled pots in this area that will be discussed later appears to have been derived from the silt cap. Conant, *et al.* (1976) could not ascertain the genesis of the relict silty layer, but noted that deposition as a loess sheet during Pleistocene time was a possibility.

Periglacial Sand Dunes

The dearth of information about aeolian sand deposits of probable palaeoperiglacial origin in the Central Appalachians is likewise notable. Two old (Pre-Wisconsinan?) sand dune deposits are known in the Susquehanna River Valley, Pennsylvania (Figure 12). Peltier (1949) referenced some localities in Pennsylvania where aeolian sand deposits occur, including the Montandon dune field. Chase (1977) provides a published description of the transverse and parabolic sand dune field south of Montandon, Pennsylvania. This site is on the excursion route, and data on this deposit are given in the road log. Some features may remain to be discovered. For instance, Denny (1974) reported sand dunes of Late Wisconsinan age on the Delmarva peninsula at lower elevations and latitudes than most of the features reported here.

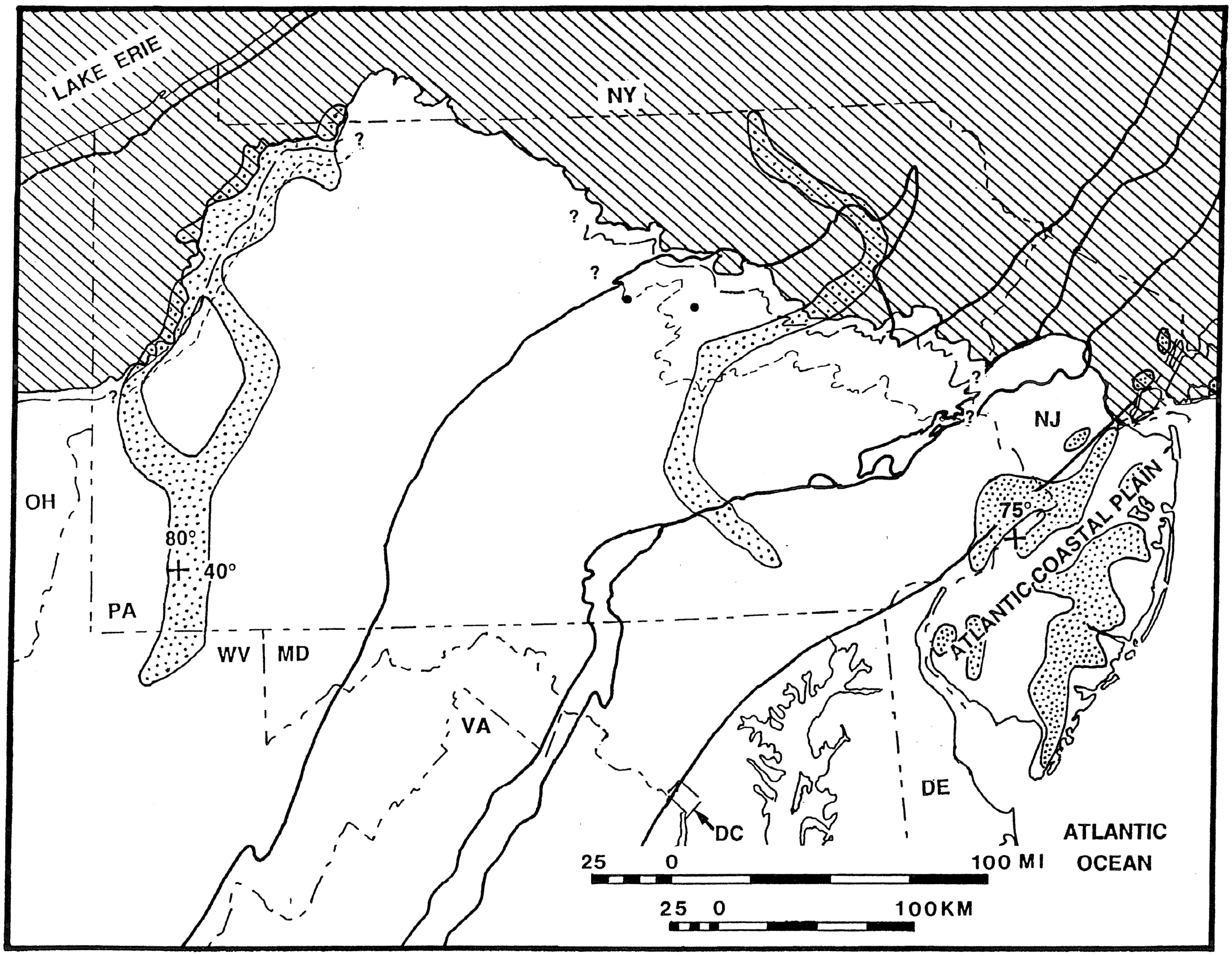

Figure 12. Pleistocene aeolian deposits in the Central Appalachian area, as mapped by Thorp and Smith (1952). Geomorphic subdivisions and glacial borders are as keyed in Figure 1. Loess less than 4 feet (1.22 m) occupying less than 33% of land area shown by open-stipple pattern; loess less than 4 feet (1.22 m) occupying between 33% and 67% of land area shown by close-stipple pattern. Two known areas of sand dunes of Pre-Wisconsinan (?) age are shown by round dots. (Soil characterization analyses for soils at these two sites of older sand dunes were performed at the Soil Characterization Laboratory, The Pennsylvania State University, University Park, PA.)

Tors

Tors are free-standing, essentially-in-place, tower-like masses of residual rock that are as yet unconsumed by erosional episodes. Ehlen (1990, 1992) presented a semiquantitative classification of tors on Dartmoor. She differentiated summit tors, valleyside tors, and spur tors on the bases of variations in relief, joint spacing, and composition, texture, and structure of the bedrock. Tors have been extensively studied in Australasia, Europe, and Africa, but have received little attention in North America. Exceptions include Cunningham (1969), Bailey (1983), Inners (1988a), and Braun and Inners (1990). Tors surmount topographic crests and upper slope breaks on ridges in locations where knowledge of their history would be useful in both glacial and periglacial studies. Until recently, however, there have been few detailed investigations about the structural and lithologic properties of tors; Ehlen (1990, 1992) is an exception. Quantitative geophysical and geochemical methodologies have only recently become available for attacking problems of tor origin and evolution, and for establishing erosional histories and ages of exposure of these features.

Prominent tors near roads or trails in the Central Appalachians have been identified as scenic geological features, and some of them display outstanding lithologic and structural features. A spectacular example in the Piedmont Upland section in Pennsylvania is Chimney Rock in York County, it rises almost 10 m above the ridge crest (Geyer and Bolles, 1979).

There are also excellent examples of tors in the Northern Blue Ridge section in Pennsylvania. Chimney Rocks and Hammonds Rocks, Cumberland County, and Monument Rock, Eagle Rock, and White Rocks, Franklin County, are examples of tors that are known as scenic geological examples (Geyer and Bolles, 1979). On the other hand, at least some spectacular examples in the Blue Ridge and other provinces probably remain to be publicized as outstanding scenic geological features. The High Rock Road Tor, east of Three Springs Road in Adams County is an example that remained unreported until 1991, when it was noticed by N. Potter, Jr. and W. D. Sevon (Sevon and Potter, 1991).

In the Appalachian Mountain subsection in Pennsylvania, Wolf Rocks, Monroe County, and Devils Pulpit, Carbon County, are examples of scenic tors (Geyer and Bolles, 1987). Prominent tors in the Anthracite Region have been studied by Inners (1988a) and by Braun and Inners (1990). These tors include examples in the Freeland (STOP 2.3) and Hazleton quadrangles (STOP 2.4A). Braun and Inners concluded that these features are of Quaternary age and have a periglacial origin; they are not relict features of Tertiary age.

There are excellent examples of tors in the Appalachian Plateaus province. In the High Plateau section in Pennsylvania, Castle Rock, Sullivan County, rises about 12 m above the surrounding area (Geyer and Bolles, 1987). The Allegheny Front in eastern West Virginia also displays well-defined tors (Clark and Hedges, 1992). The Bear Rocks area (STOP 5.2) contains a number of tors that display a wide variety of features produced by prolonged differential weathering. North of the Bear Rocks area, Stack Rock (Figure 13) is a large, high, and topographically isolated well-known landmark on the eastern edge of the plateau.

At least five separate hypotheses have been proposed to explain the origin of tors. Tors in some areas may have been subject to significant environmental change and thus may be polygenetic in origin. When considering the following hypotheses of origin, it would be well to remember that authors who subscribe to backwasting as a primary process group generally agree that the production of deep chemical alteration need not be involved in tor production in summit areas, but might well occur on gentle upper valley sides. In areas where tor evolution is active, such lower surfaces might eventually encroach upon and consume the summit areas (King, 1966).

Tors may be end products of a two-cycle development. The first stage requires hot, humid tropical conditions, with production of a deep, differentially-weathered regolith. The second stage mandates the removal of surrounding weathered fine clastic sediment to exhume the firm rock towers. Driving processes may include climatic change (Linton, 1955), tectonic or epeirogenic rejuvenation (Falconer, 1912), or internally-driven subsurface weathering and removal processes that do not require climatic or tectonic input (Thomas, 1965). Under the two-cycle hypothesis, tors in areas without present-day tropical climates would be interpreted as palimpsests that may have had their originally-rounded morphology altered or destroyed by subsequent processes.

Tors could originate and evolve under humid tropical climatic environments and be subaerial features throughout their existence (Macar, 1957). In this scenario, tors found in non-tropical environments today would be interpreted as subaerial survivors of subsequent processes that may be acting to modify or destroy them.

Tors that are of periglacial origin are the last remnants left by erosional processes involved in the production of cryoplanation terraces in upland areas above the forest limit under extreme periglacial environments (Fitzpatrick, 1958). Cryoplanation terraces (Demek, 1969) may develop in extremely cold, relatively dry, continental environments (Reger and Péwé, 1976) and in wet maritime areas, such as Iceland, where mean annual air temperatures are near 0° C (Priesnitz, 1988). Tors existing in areas that are now below the forest limit would be interpreted as fossil forms that are being modified by subsequent environmental conditions (Palmer and Radley, 1961).

Figure 13. Stack Rock, a prominent tor on Allegheny Front, Grant County, West Virginia (Blackbird Knob, WV, quadrangle). Bedrock is conglomeratic orthoquartzite sandstone of the Pottsville Group. Pack frame, resting on large boulder at base of tor is 80 cm high.

Finally, the genesis of some tors may not have occurred under one environment, but may be the complex product of a number of rapidly alternating morphogenetic systems during Late Cenozoic time. These features could be called tors of compound multigenesis.

Research on the origins and ages of tors in the Central Appalachians is just beginning. With relatively new geochemical and geophysical research tools, it should be possible to determine the erosional histories, ages, and the nature of the subsurface conditions immediately surrounding selected tors.

Cryoplanation Features

Introduction

The term "cryoplanation" (Priesnitz, 1988) encompasses a broad spectrum of periglacial landforms, materials, and interpreted climatic environments and processes of formation. Washburn (1985) concluded that this entire topical area of periglacial geomorphology will require critical reexamination. For example, there is evidence that such features may be products of more than one cold-phase event (Lauriol, 1990). The work of Nelson (1989), however, provides incentives for further study of even fossil cryoplanation features, because of the close altitudinal frequency distribution of these features with that of cirques and snowlines in central and western Alaska. Inferences about palaeoenvironmental conditions may be possible in the future when environmental conditions of formation for different kinds of cryoplanation terraces become better known. Inferences will be especially valuable if the times of formation of relict features can be dated.

The relative "evenness of skyline" of linear ridges and the flat-topped summits of local broad uplands and their mutual visual sense of accordance in elevation in many parts of the Central Appalachians have attracted attention since the time of Davis (1889). Bryan, *et al.* (1932/33) underscored the importance of summit topography as one of the three cornerstones of the "Appalachian problem" (*i.e.* the origin of topography and drainage in an old fold-belt mountain range). Péwé (1970) noted that, in the Fairbanks area, Alaska the highest flat areas (about 650 to 900 m in elevation) were related to peneplanation surfaces by early workers. Péwé also indicated that, in many low-elevation areas, the terraces are masked by surficial deposits and dense vegetation. In the Central Appalachians today, dense vegetation may exist even at the highest elevations.

Appalachian Planar Upland Features

Monmonier (1967, 1968, 1971) employed trend surface analysis to study ridge crest ("strike ridge") and local broad upland (wide and "flat" summit areas) topography and elevation in an objective manner and to determine quantitatively whether or not accordance exists. Data were derived from large-scale (1:62,500) topographic maps that cover the Ridge and Valley province within Pennsylvania. Monmonier divided ridge samples into a population from the narrow ridge crests ("strike ridges") and a population of local broad uplands (wide and visually "flat" summit areas). In effect, this subdivision separates summits controlled by different aspects of structure and rock character. Monmonier found that much local variation in elevation is explained by the presence of only one formation underlying local broad uplands. Monmonier demonstrated conclusively that flat upland surfaces—which he termed local broad uplands—exist, and that consistency in the elevations of summits (summit accordance, *cf.* Daly, 1905) in some areas does indeed occur.

Fossil Cryoplanation Surfaces in Appalachia?

Features that could be interpreted as cryoplanation landforms have been reported from many disparate regions in the conterminous United States that are now or that were in the past under periglacial environments. For example, Russell (1933) noted the high frequency of occurrence of steplike and planar landforms in alpine regions of western United States. The field trip corridor in the Central Appalachians spans a large part of one such region. Peltier (1949, p. 30, 67-69) concluded that mountain tops in the Susquehanna River Valley, Pennsylvania owed their form and relief to cryoplanation. Hedges (1975) studied the topography and surficial sediments on Sugarloaf Mountain, Maryland and found that summit-area form and relief do not follow structure and lithology, but cut across them. Hedges concluded that these discordances are due to the effects of multiple episodes of cryoplanation that operated during cold phases of Pleistocene time. In Pennsylvania, Berg (1975, p. 32) concluded that the morphology developed on till of Wisconsinan age has been modified by cryoplanation. Along the summit areas of South Mountain, Maryland, Godfrey (1975, p. 7) noted that areas with "flat outcrops" closely resemble features described as cryoplanation terrace(s) with frost-riven cliff and frost-riven scarp morphology by Demek (1972, Fig. 24, p.166 and p. 171). Also in the Maryland Blue Ridge area, Olson (1989) reported the presence of steplike landforms. Péwé (1983, Figure 9-11, p. 169 and Table 9-7, p. 177) recorded an unpublished observation of cryoplanation morphology for Mt. Davis on the Appalachian Plateau in southern Pennsylvania.

Clark and Hedges (1985, 1992) studied such local broad upland sites in Pennsylvania, Maryland, and West Virginia, where relatively flat uplands locally truncate lithology and structure, and break abruptly at their edges into blocky slopes. Short horizontal and vertical distances downslope from these risers are one or more terraces (Figure 14). At other localities, where a major local broad upland is absent and a linear (strike) ridge occurs, the topographic crestal area may contain elongate scarps cut in bedrock that are flanked by terrace topography (*cf.* Figure 15). Figure 16 shows the locations of local broad uplands in Pennsylvania and of sites that have received field study to date by Clark and Hedges.

Weathering and soil horizon characteristics at all 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 surfaces. Large blocks are weathered and broken up in place, with little separation of the constituent fragments. Gently-inclined surfaces of some large quartzite blocks and bedrock tors show well-developed Opferkessel that usually show no morphological evidence of block disturbance during the time over which they have developed. Two terrace localities in West Virginia reported by Clark and Hedges (1992) are on the excursion route in West Virginia.

Clark and Hedges (1985, 1992) conclude that the upland forms and materials they studied are fossil end products of complex processes that worked to produce cryoplanation terraces (treads), and frost-riven cliffs and frost-riven scarps (risers). In their interpretation, the merging of cryoplanation terraces on opposite upland slopes created summit cryoplains above which remnants of former topographical surfaces may rise as tors. Demek (1972, p. 171) states:

"The cryoplain can theoretically develop as cryoplanation summit flats coalesce."

When viewed from a long distance from another upland surface, these summit plains and their bordering vertically-closely-spaced terraces produce the aggregate visual effect of accordant level crests and even altitudes described so clearly by Davis (1889) and reiterated by many subsequent workers until the decline in popularity of Davisian concepts in the United States (*cf.* Flemal, 1971). In the interpretation of Clark and Hedges, however, these local broad uplands and flat linear ridge crests in the study region are incipient surfaces of cryoplanation as opposed to remnant surfaces of peneplanation. The accordance in elevation of these topographic flats in certain areas can be explained by the propensity for cryoplanation terraces to develop in narrow altitudinal belts from just above to short vertical distances below regional snowlines (Péwé, 1975; Nelson, 1989), although the specific formative mechanisms are poorly known.

If the interpretations and conclusions of Clark and Hedges (1985, 1992) are correct, then the level character of strike ridge crests and the flatness of the local broad uplands are truly fossil features. Given a periglacial scenario, whatever the pre-Quaternary landscapes in the highlands were like, their topographic forms have been destroyed by multiple episodes of erosion during cold phases of the Quaternary (Braun, 1989b).

On the other hand, there are some reports of materials in the subsurface which indicate that, at least in a few localities, stripping of earlier, non-periglacial materials was not complete (*cf.* Berg, *et al.*, 1981; Sears; 1957). These materials include saprolite, deeply weathered diamictons, and lignite. Such remnants suggest that conditions which predated the overlying glacial or periglacial sediments were much warmer and had effective moisture regimes. The existence of an ancient low-relief upland surface of some time can not be discounted. Thus, a demonstrated periglacial origin for the uplands we see today cannot disprove that a former planation surface of one type or another (*cf.* Baulig, 1952) existed, but it certainly renders it unnecessary.

Figure 14. Cryoplanation summit, bedrock riser, and terrace (from right to left). Bedrock dips 18° to the right below the left one of two figures shown in the photograph. The terrace, covered with large blocks of orthoquartzite sandstone and conglomerate, slopes 1 to 7° to the left (Hopeville, WV quadrangle). Reproduced with permission of John Wiley & Sons, Chichester, and Elsevier Science Publishers, B. V.

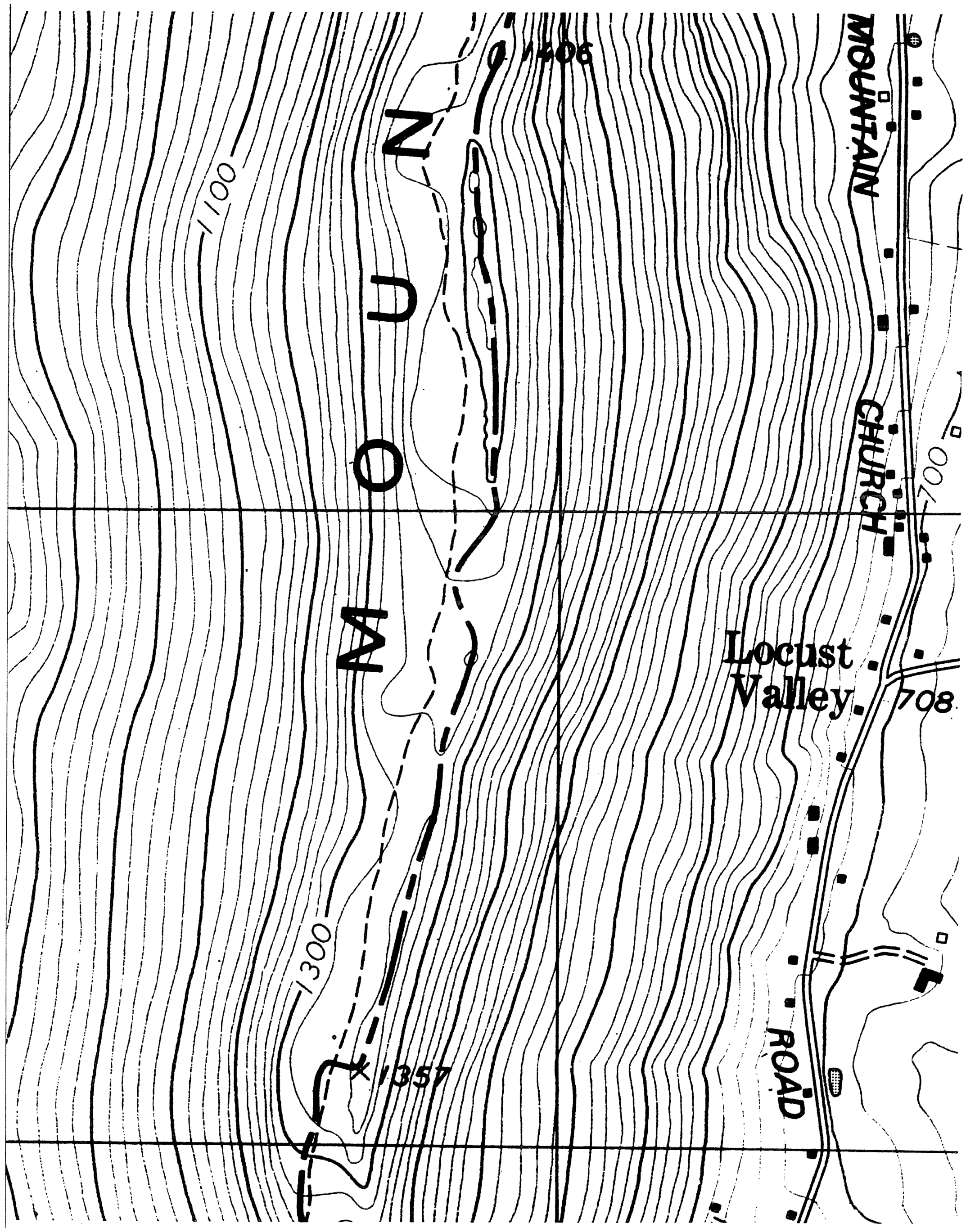

Figure 15. Topographic map expression of cryoplanation terraces on South Mountain, a linear "strike ridge" (as opposed to a local broad upland). Note terraces that have formed west of scarps developed in the Weverton Formation at the ridge crest along the Appalachian Trail (light dashed line) between the Townsend Memorial and Lambs Knoll. This type of contour pattern is typical of landforms developed on single ridge crests where lithology, structure, and initial relief were favorable, and can only be seen on large-scale topographic maps of high quality (Keedysville, MD quadrangle, 1978 edition, produced from aerial photographs taken in 1974). An earlier map edition (1953, produced from aerial photographs taken in 1943) shows these landforms very poorly. Heavy long-dashed and short-dashed line along topographic crest between spot elevations 1357 and 1406 feet is Washington County (to west) Frederick County (to east) line.

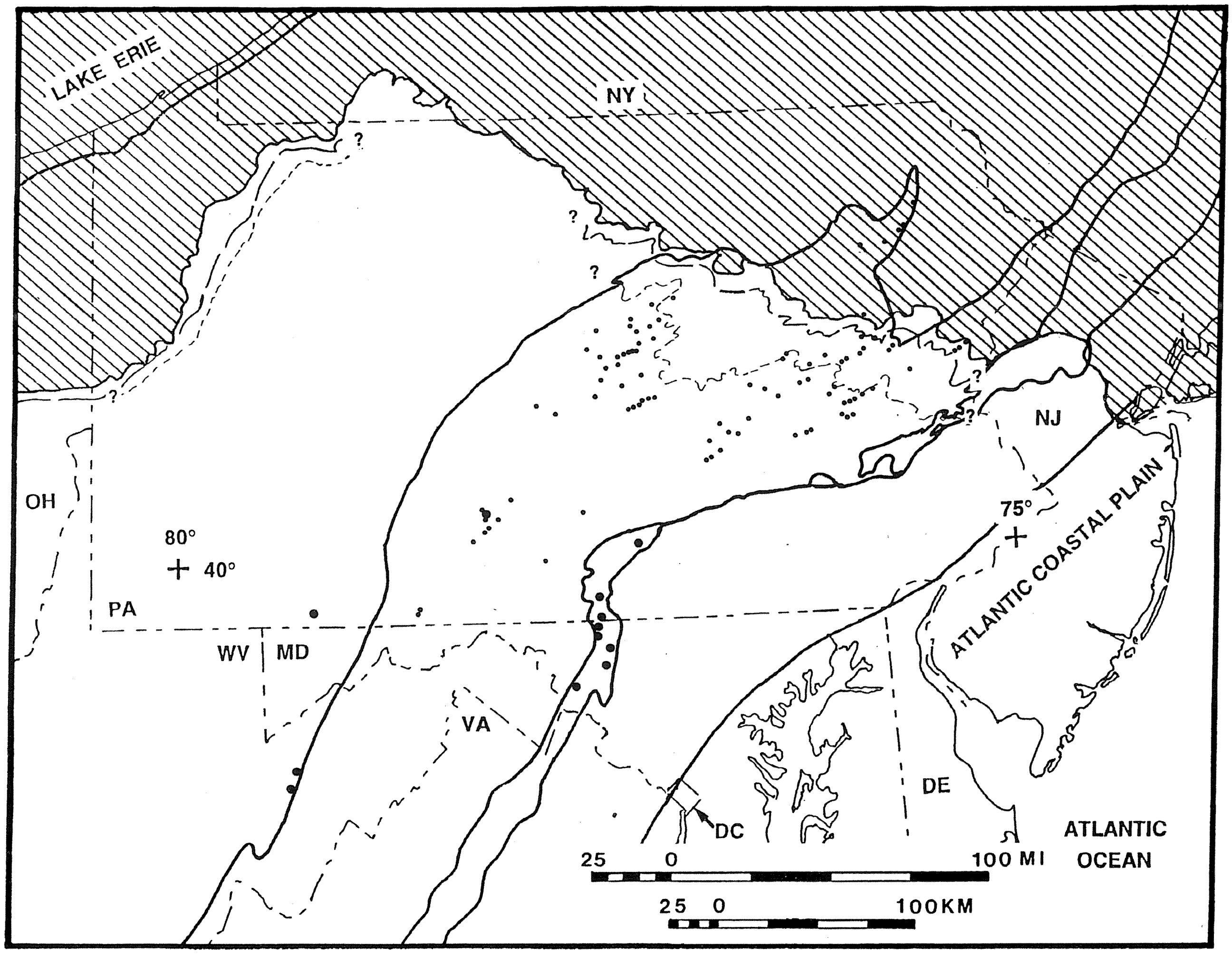

Figure 16. Locations of local broad uplands (small dots), as mapped by Monmonier (1967). Large dots show locations of twelve local broad uplands studied by Clark and Hedges (1992) that have been investigated for features typical of cryoplanation summits, risers, and terraces. Geomorphic subdivisions and glacial borders are as keyed in Figure 1. Data from Clark and Hedges (1992), Clark and Hedges (unpublished data), and Monmonier (1967).

Rock Cities

Smith (1953b) described large, rectilinear, high-standing blocks of massive conglomerate that have been separated by passageways developed predominantly by horizontal expansion of essentially vertical joints. Block lengths extend up to about 23 m. The "passageways" range up to about 1 m in width and 3 or more m in height. Smith described the walls as comparatively straight, approximately parallel, and as having a rectilinear to angular pattern in map view. Detached blocks adjacent to the parent bedrock outcrops exhibit only movements of horizontal translation. Dislocation of blocks increases with increasing distances from their source, and they grade into deposits that Smith termed "landslide masses." The blocks appear to be undergoing in-place disintegration. Smith ascribed the origin of the expanded joints to periglacial frost wedging, he stated that would have been optimal during Wisconsinan time.

Smith (1953b) gave the overall term of "rock cities" (Ashley, 1933) to these features and proposed them as a new kind of periglacial phenomenon in the Appalachians. The type areas are near Olean and Salamanca, New York, in the High Plateau section south of the Late Wisconsinan glacial border. The proper noun Rock City, however, also refers to one occurrence that is a tourist attraction in the Southern Appalachians near Chattanooga, Tennessee (Wilson, 1983).

Another excellent example of an inactive or fossil rock city in New York is Panama Rocks west of Jamestown, New York, which is located within the Late Wisconsinan glacial border (D. D. Braun, personal communication, 1992). Block movement at this locality may have occurred under paraglacial instead of, or as well as, periglacial environmental conditions. The Panama Rocks site would also suggest that rock cities may develop during relatively short time intervals if the palaeoperiglacial environment in the paraglacial zone was indeed short lived. No numerical age dates are known, however, that could be used to bracket and test this interesting occurrence.

In the High Plateau section in Pennsylvania, examples of rock cities are Baker Rocks, Brooks Rocks, Jakes Rocks, Lottsville Rock City, Nuttles Rocks, Pikes Rocks, Sams Rocks at Rimrock Overlook, and The Pass, all in Warren County. Examples in the Mountainous High Plateau section are Midway Crevasse, Luzerne County; Labyrinth, Sullivan County; and Bigler Rocks and Panther Rocks, Clearfield County. In the Allegheny Mountain section are Bear Rocks, Westmoreland County; and Baughman Rocks and Vought Rocks, Somerset County. At the latter two sites, the expanded joint openings are about 0.3 m or less wide and the blocks are up to about 6 m high. An example in the Pittsburgh Low Plateau section is Beartown Rocks in Jefferson County. These sites are described by Geyer and Bolles (1979, 1987).

Rock cities also occur in other areas of the Central Appalachians. On the Appalachian Plateau in West Virginia are Bear Rocks, Beartown State Park, Droop quadrangle, and Rock City, Coopers Rock State Park, Lake Lynn quadrangle (J. S. Kite, unpublished data). Another location on the Appalachian Plateaus province with a small but well-developed rock city is the Olson Lookout Tower area, Backbone Mountain, Mozark Mountain quadrangle, West Virginia (G. M. Clark, unpublished data). In the Ridge and Valley province, there is a well-developed rock city upslope from the outlet of Mountain Lake, Giles County, Virginia (G. M. Clark, unpublished data). No systematic study of the distribution or properties, however, of such far-flung rock cities has been made.

Requisite bedrock conditions for the development of rock cities in sedimentary rocks in the Appalachians appear to be massive, relatively resistant sandstones and conglomerates and very gently dipping to horizontal bedding planes. Such site factors occur together much more frequently in the Appalachian Plateaus province than elsewhere. Sevon (1992b) notes that block separation may take three forms: blocks may remain upright, they may topple forward, or their bases may rotate outward, (as in a Toreva block). All three geometric forms of block displacement are present in the Central Appalachians, although essentially horizontal displacement has produced some of the largest and most spectacular occurrences. The mechanics required to initiate movement of such great masses over such low declivities demand extremely high levels of force. The force requirements could be reduced if the resistant blocks are underlain by rock types that enhance susceptibility to lateral movement, if between-bed water pressures became high, or if such intervals became loci for ice growth. Confining mechanisms to accomplish such work seem lacking, however. Smith (1962) favored the effects of frost or ice wedges in order to explain the horizontal displacement. Hedges (1972) favored ice wedging as the mechanism adequate to expand joints, but noted the necessities of the presence of sliding surfaces and valley incision through the bluff-forming rock and into the underlying weak rock. The timing of block movements remains a problem. Most areas have blocks which display surface evidence of prolonged differential weathering, and some sites show block breakup in place with little or no separation of the fragments. A scenario of development under periglacial conditions during Late Wisconsinan time and subsequent slope stability during Holocene time is reasonable, but no numerical age dates are available to test this speculative chronology.

Mountain Sideslope and Toeslope Topographic Form

The rounded, gentle concavo-convex, nature of many mountain slopes in areas away from active drainage lines is a striking feature in many areas of Pennsylvania, and is quite pronounced near the glacial borders. The upper mountain slopes are gently rounded, are convex upward, and grade almost imperceptibly downslope in the middle segments. Exposures of the middle and lower mountain slopes, often in road cuts, suggests that much of the middle and lower mountain slopes is mantled by colluvium, usually of unknown thickness and nature. Topography in an area typical of such mountain slopes is shown in Figure 17.

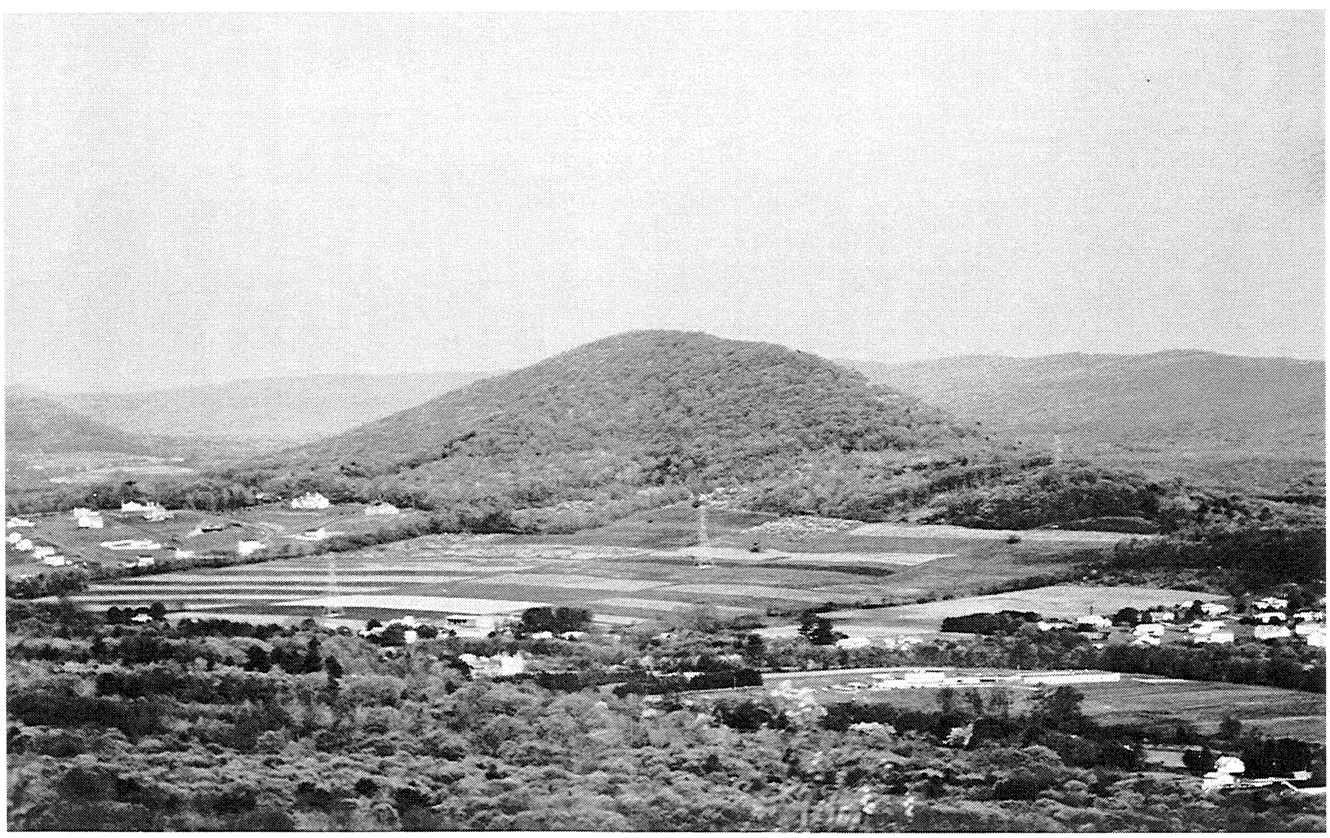

Figure 17. Sugarloaf Mtn. (514 m), a well-known isolated mountain illustrating topographic form of slopes in the vicinity of the glacial borders. (Conyngham, PA, quadrangle). The underlying bedrock is composed of clastic sedimentary rocks assigned to the Mauch Chunk Formation.

The timing and rates of such mountain slope development are not known. Caine and Jennings (1968) were able to estimate scarp retreat of the basalt cap in the Toolong Range, New South Wales from ^{14}C dates and volumetric computations of the basaltic debris block streams they studied. Up to 33 m of basalt cap retreat has occurred since 35,000 yr BP. In the field trip area, however, there are no definitive numerical age dates that could be used to assign the age of landform development.

Fans, Lobes, and Fanlike Features

The mouths of small water gaps that do not contain transverse drainage often display fan or fanlike deposits that are usually of unknown thickness or origin. These features occur both within and without glaciated areas. Where adequate exposures occur, such features are underlain by diamicton deposits of complex nature, such as those described by Denny (1956). Rapp (1967) termed these features "fossil alluvial fans." A fossil nature is suggested because, even during record historical "channel flood" events, the present-day streams appear to do little geomorphic work on these features. The associated stream is generally incised several meters into the fan and, if the fan is near a larger stream which runs normal to the fan axis, the distal part of the apron may be significantly truncated. An example of the surface morphology typical of such features in central Pennsylvania is shown in Figure 18.

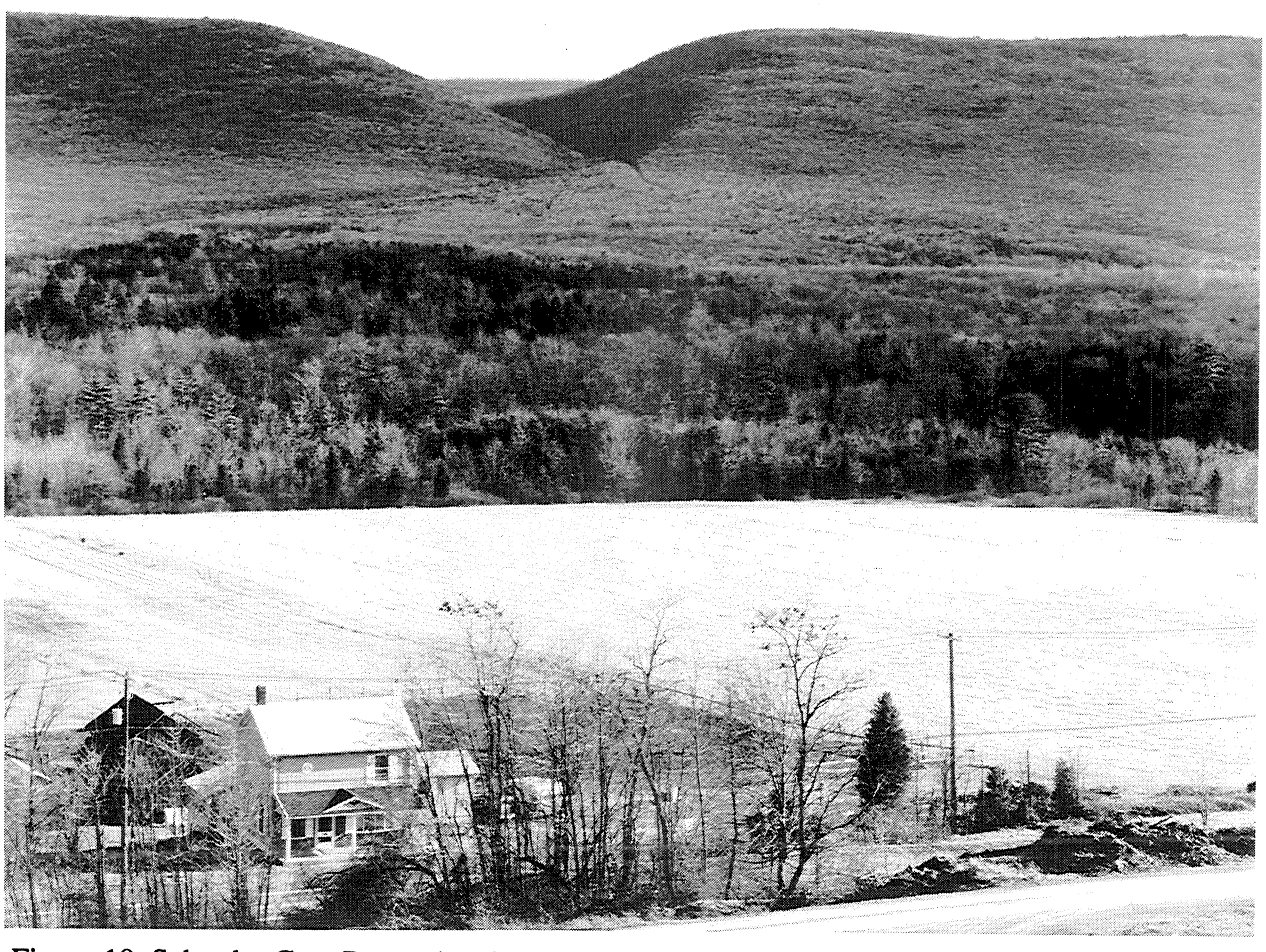

Figure 18. Schrader Gap, Pennsylvania. (Beavertown, PA, quadrangle).

Fluvial Terraces

Introduction

In large areas of maritime western Europe and Great Britain, evidence suggests that the development of extensive fluvial terraces was almost entirely associated with the occurrence of cool climatic conditions (Green and McGregor, 1987). Such cool conditions would be associated with climatic deterioration from interglacial conditions to glacial or periglacial conditions or with other environmental changes during the Quaternary. Especially in the Ridge and Valley province, many Central Appalachian river floodplains are bordered by one to many fluvial terraces and terrace remnants (Mills, *et al.*, 1987). Considering their number and distribution, there have been relatively few studies of these landforms and sediments in most parts of the field excursion corridor. Several works are available, however, to indicate the nature of at least some Central Appalachian fluvial terraces.

Related Studies

King (1950) identified and mapped three sets of gravel units in the Elkton area, Virginia. He termed these the "older gravel unit," the "intermediate gravel unit," and the "younger gravel unit." As a morphostratigraphic unit, the older gravel unit is highest in altitude and forms a series of remnant benches along the entire length of the foothills of the Blue Ridge in the Elkton area. There are also remnants of this unit on gravel-capped knobs out in the Shenandoah Valley. Near the Blue Ridge, the older gravel unit rests on erosion surfaces on residuum of the Tomstown and Waynesboro Formations; on the Massanutten Mountain side, this gravel unit rests on the Martinsburg Formation. Although King (1950, p. 58-59) recognized fanlike morphologies in the older gravel unit, he did not map these units separately. The older gravel unit of King consists of pebbles, cobbles, boulders, and angular blocks as large as about 1 m in diameter in sandy clay matrices. It may reach thicknesses of 80 m, although thicknesses of 15 to 50 m may be more representative. Bell (1986) noted that such high terrace materials are intermixed with colluvium.

The intermediate gravel unit of King (1950) covers larger areas than the other gravel mapping units, is generally composed of similar materials, and exhibits extensive surface sinkhole development.

Deposits of the younger gravel unit of King (1950) are usually less than 7 or 8 m thick and they rest on benches 15 to 23 m above modern river level (AMRL).

Bell (1986) identified and mapped fluvial terraces and terrace remnants on both sides of the South Fork of Shenandoah River in Rockingham County, Virginia. She found it possible to distinguish alluvial terraces and their remnants of the South Fork from fanlike deposits of its tributaries.

Kite, *et al.* (1986) provided a progress report on three studies on floodplain, fluvial terrace, and fanlike deposits in the upper Potomac River drainage basin, Virginia and West Virginia; one of these studies was Bell's. The other studies were in the Lower Shenandoah Valley area, Virginia, and in the New Creek Valley, Mineral and Grant Counties, West Virginia. At least two pedologically distinct terrace units in the Lower Shenandoah Valley area are at 5-20 m and more than 20 and up to 65 m AMRL. The New Creek Valley, which is on the excursion route, has many complex alluvial remnants, including a terrace 7 to 10 m above modern stream level (AMSL), shale straths at about 6 to 12 m and 15 to 20 m above the present floodplain, and higher terraces and strath remnants at heights such as 40 and 60-65 AMSL, as well as tributary terraces (Kite, *et al.*, 1986; Allamong, 1991).

Kochel and Simmons (1986) described two distinct types of thick (20-150 m) gravel fan deposits on the western flanks of the Blue Ridge in central Virginia. The surface fans have well-developed soils and presumably are at least several thousands of years old. At several meters depth is a well-developed paleosol that is developed in gravels with a red matrix and rotted metaquartzite clasts. Kochel and Simmons suggest that there have been at least two episodes of fan development during Quaternary time, separated by a long interval of inactivity and soil formation.

Kaktins (1986) identified five terrace levels in the Juniata River Valley, central Pennsylvania, and studied the soils developed in their parent materials, which are roundstone diamictons up to 10 m in thickness. The diamictons were interpreted as post-depositional products of bioturbation, clast dissolution and disintegration, cryoturbation, and mass wasting. The soils constitute a chronosequence that represents increasing soil age with increasing elevation AMRL. Kaktins concluded that the terraces have developed as a result of lateral migration during major cold phase intervals when periglacial environments were present, and that incision occurred during interglacial time intervals. The higher three terraces were estimated to be pre-Wisconsinan in age, and some even higher diamictons, 101 to 131 m AMRL, may thus be pre-Quaternary in age. The lower two terraces were thought to be Wisconsinan in age, and the establishment of the Juniata River floodplain was dated at 12,000 BP (Kaktins, 1986).

Summary

Stream and river terraces are produced by events of aggradation or lateral erosion, followed by vertical incision (Green and McGregor, 1987). These authors present a set of examples of changes in factors that influence terrace formation that show the relative probabilities of aggradation, lateral erosion, and vertical erosion for several hypothetical threshold conditions. Time intervals of dynamic response to threshold-crossing are separated by time intervals of relative geomorphological quiescence in the sense of landform- and material-production. If Green and McGregor (1987) are correct in their interpretation of the evidence in Great Britain and in many areas of maritime climate in western Europe, suggesting that areally extensive terraces as morphostratigraphic units are almost completely correlative in time with cool climatic conditions, then such features and sediments are inextricably linked with glacial and periglacial environments. They consider that these conditions are necessary to force fluvial systems across geomorphic thresholds that produce terrace development. Such process-response linkage mechanisms may also have operated in the Central Appalachians, but whether these conditions obtained on a precise one-to-one basis with Quaternary cold phases remains, of course, to be demonstrated.

SUBSURFACE PERIGLACIAL FORMS AND MATERIALS

Introduction

A major research problem in the Central Appalachians is the lack of visually evident indications that could be used in prospecting for subsurface features. As negative evidence, most surface periglacial features that lack a blocky armor are not very conspicuous in the field excursion area, the vast majority of which was under forest cover throughout almost all of Holocene time. A few vague forms that may represent old solifluction lobes and nivation hollows may be seen in some places. In such sites, there are often very subtle lobe- and hollow-like microtopographies that might easily be overlooked, but that are visible to the true believer. If well-developed surface features such as nonsorted patterned ground, solifluction lobes, and small nivation hollows also formed here during Pleistocene cold phases, they (or their obvious surface expressions) may have been partly to wholly obliterated by the subsequent 10 Ka of vegetation activity, mass wasting effects, and by other processes during the Holocene. Regardless of the reasons why some features are not visually apparent at the surface, several of them hold promise for palaeoperiglacial research and are discussed below.

Colluvium

Many reports attest to the areal extent and volume of colluvium in many parts of Pennsylvania and New York south of the glacial borders (*cf.* Carter and Ciolkosz, 1986; Moss, 1976; Potter, 1985; Snyder and Bryant, 1992; Waltman, 1985; Werner and Moss, 1969). Other studies have investigated colluvial deposits of probable periglacial origin at greater distances from the glacial borders derived from many different parent materials and located in a number of topographic positions. The compositions and textures of these diamictons are highly variable, as would be expected from the wide variety of parent materials available. Although little fundamental research has been done on the genesis of these diamicton deposits, brief summaries of several reports from localities in geomorphic provinces traversed by the excursion can give some idea of the range of forms and materials encountered to date.

Pazzaglia and Gardner (1992, p. 99-100) noted that multiple colluviation events at a Piedmont locality in Maryland have produced a number of diamictons with an up-section increase in clast size of the deposits. These surficial sediments likely represent "unroofing" of weathering profiles that were produced by saprolitization of bedrock during former times when rates of saprolite production equaled or exceeded the rates of erosional stripping. Pazzaglia and Gardner (1992) hypothesize that much of the colluviation was produced during episodes of periglacial activity that occurred during cold phases of Pleistocene time.

D. D. Braun has mapped large areas underlain by colluvium in the Bel Air, Maryland-Pennsylvania, quadrangle (unpublished data and FIGURE R.1.2). Particularly in areas where relatively resistant rock types occur, as in localities with massive crystalline rocks, Braun has mapped area sideslopes with colluvium that ranges from less than one to about two meters in thickness. Hollows in the quadrangle area may be underlain by colluvial mantles up to 5 meters thick (FIGURE R.1.2).

As previously noted, one important geomorphic characteristic of the tectonically deformed terranes in the Blue Ridge and Ridge and Valley provinces is the structural juxtaposition—by folding and faulting—of thick-bedded to massive resistant rocks against less resistant fine-grained-clastic and carbonate rocks. Subsequent long-term differential erosion has produced topographic settings in which mountain crests and fronts underlain by resistant rocks stand hundreds of meters above valleys underlain by the more easily eroded rocks. Mountain sideslopes and toeslopes in these areas characteristically have a variably thick mantle of regolith that extends and thins valleyward and that contains high amounts of blocks, boulders, and finer-grained sediments derived from the ridges.

Extensive areas of the northern section of the Blue Ridge province are mantled by colluvial deposits, but few of them have received close study. In his report on the geology of the Elkton area, Virginia, King (1950, p. 62-63) described blocky deposits he termed "talus" and "talus fields." Many such deposits are composed of large clasts derived from the Antietam Formation, but some are derived from the Weverton Formation, and a few come from Precambrian rock units. Many of the deposits formed from the Antietam Formation have metaquartzite ledges at their head, but some do not. Outcrops are lacking in localities associated with the Weverton Formation. King reported that the accumulations on steeper slopes contain angular fragments of "all sizes." On gentler slopes, individual rock fragments are 0.15 to 0.6 m in diameter, and the surfaces of the deposits are irregular with many ridges and hollows. The deposits lack a fine-grained matrix at the surface and form treeless to sparsely vegetated areas on the steeper mountain flanks, where slopes are usually greater than 25°. In other topographic positions, such as low-gradient hollows with slopes of 10° or less, the diamictons contain a finer-grained matrix and support dense arboreal cover (King, 1950).

On South and Catoctin Mountains in Pennsylvania and northern Maryland, Clark (1991) described diamicton aprons and sheets mapped by Noel Potter, Jr. from county soil survey reports. The diamictons extend valleyward from the mountain flanks for one to several km. The thicknesses of the diamicton deposits are known only in several areas, but are generally greatest near the mountain fronts and become less valleyward. Well data indicate thicknesses as great as

400 feet (122 m), but more representative thicknesses obtained from well data within about 1 to 2 km of the mountain fronts are in the range of about 60 m and become less valleyward (Clark, 1991).

Crestal areas in the Ridge and Valley province have lithologies which produce blocky and bouldery colluvial deposits containing clasts of sandstone and conglomerate. The finer-grained matrix material could have been produced by disintegration of shale- and siltstone-rich strata, and, also, from disintegration of some material from the resistant units, and from aeolian components. In the Ridge and Valley province in Pennsylvania, as noted in the section on soil geomorphology, Ciolkosz, *et al.* (1986b) estimated that about 27% of the land in a typical county is covered by colluvium. If most of the colluvium is of periglacial origin, this material constitutes by far the most areally and volumetrically extensive type of periglacial deposit in Pennsylvania.

In Mineral and Grant Counties, West Virginia, Allamong (1991) located numerous deposits of colluvial and probable colluvial origin in the New Creek Valley. Allamong's study is notable for the great variety of diamicton compositions, textures, and structures he found; their varied stratigraphic relationships with bordering, overlying, and underlying materials, and the fact that such variations occur within one stream basin. Although Allamong (1991) did not ascribe a periglacial genesis to the diamicton deposits and the landforms they underlie that he studied, his thesis is an excellent example of why the recommendation by Poser (1977) to conduct complete inventories of periglacial features in selected areas should be taken seriously.

Another relatively recent finding is that, in many areas, the brown colluvium that mantles many mountain sideslopes, toeslopes, footslopes, and hollows in the Ridge and Valley province is underlain by red colluvium usually of unknown thickness and lateral distribution beneath the slope. A common practice is to suggest that the red colluvium may be a product of intense interglacial (Sangamon?) weathering that preceded intense periglacial activity of Wisconsinan age, but as yet no numerical age dating has been obtained to fix the chronology of the red colluvium (Ciolkosz, *et al.*, 1990).

Colluvial deposits are also widespread on the Appalachian Plateaus, especialy near the Late Wisconsinan glacial border (Denny, 1956; Denny and Lyford, 1963). Kocsis-Szücs (1971) used geophysical techniques to determine the thicknesses of colluvium in an area about 8 km southeast of the Late Wisconsinan glacial border in Butler County, northwestern Pennsylvania. He found that the colluvium is between 20 and 30 feet (6-9 m) deep over bedrock and underlies slopes that average 7-8°. Slope asymmetry is present, and north- and east-facing slopes are 2° gentler than southwest-facing slopes. Kocsis-Szücs (1971) interpreted the colluvium as a periglacial solifluction mantle, based on studies of regolith in soil trenches. Colluvium also mantles extensive areas in Warren County, Pennsylvania, in the vicinity of the glacial borders (Sevon, 1992b). Pomeroy (1983) reported large relict debris flows that occupy drainageways in the unglaciated Appalachian Plateau in Cameron, Elk, Forest, McKean, Potter, and Warren counties, Pennsylvania. The most common occurrences are on forested concave slopes of 20 to 50 percent that have a relief of about 150 m. These diamicton deposits contain blocks and boulders up to about 3 m in their a-axis length in a clayey sand to silty matrix. Pomeroy reported that most of the debris flows are probably less than 10 m thick, but locally can be 30 m thick. They are typically about 0.6-0.9 km long and 0.2-0.5 km wide, although larger deposits are known. These debris flows are prehistoric, and Pomeroy (1983) attributed their genesis to colluvium generation and subsequent mass movements under periglacial environments that probably continued into early Holocene time. Aguilar and Arnold (1985) attributed the development of asymmetrical valleys in the plateau to solifluction that differentially truncated south-facing slopes moreso than north-facing slopes.

Large areas of old colluvium also exist on the unglaciated Appalachian Plateau at some distance from the ice margins. Pomeroy (1986) mapped extensive areas of old colluvium in Greene County, southwestern Pennsylvania. Gray, *et al.* (1979) concluded that ancient landslides on the Appalachian Plateau occurred under former periglacial conditions. There are few numerical age dates, however, to constrain movement times. D'Appolonia, *et al.* (1967) reported that ^{14}C dating of slide surfaces at Weirton, West Virginia yielded minimum ages of > 40 Ka.

Philbrick (1962) obtained ^{14}C dates of 9,750±200 and 8,940±350 yr on slide surfaces north of Wheeling and southwest of Morgantown, West Virginia, respectively.

Ridge, *et al.* (1992) studied colluvium developed from sandstone, slate, gneiss, and carbonate rock terranes in the Delaware Valley, New Jersey and Pennsylvania. In areas beyond the Late Wisconsinan glacial border, they reported areas that have extensive colluvial deposits derived from a variety of parent rocks and regoliths on all of the four terranes.

Sediment-Filled Pots

Conant, *et al.* (1976) reported rounded, pot-shaped depressions filled with sandy clay in "Upland" gravels of probable Miocene age in Cecil and Harford Counties, northeastern Maryland, and in Fairfax County, Virginia, near Washington, DC. The thicknesses of the gravels range from about a meter to more than 15 m, but the pots are present only at or near the present land surface. Elevations of the sites range from about 125 to 150 m. The pots range in width from 1 to 8 m, but none are significantly deeper than 2 m. Most of the pots have vertical or nearly vertical sides, but rounded V-shapes and overhanging walls are also present. Most pots have rounded bases, but some are nearly flat.

The pots are mostly filled with clayey silt that contains a few percent to about 40 percent of sand and gravel. The uppermost 30 cm is commonly more gravelly. Most of the silt is medium gray in color and largely structureless, but it may have faint to distinct stratification parallel with the pot margins. Some pots have flat pebbles aligned with the sides.

The host gravels are reddish brown in color and are distinctly stratified, except for about the upper 1 to 2 m, which is visually structureless. Stratification next to the pots commonly bends downward, and the beds under many pots appear slightly depressed. In some places the surrounding gravel beds are warped upward on the sides of the pots, and plate-shaped pebbles are commonly oriented parallel with the pot margins.

Conant, *et al.* (1976) suggested that the pots developed as a result of some seasonal frost process, when such freezing penetrated the land surface to about a depth of 1 m. These authors also considered an alternative hypothesis, in which permafrost provided an impermeable base in the soil that trapped moisture in the active layer. This hypothesis was considered as an unlikely alternative, however, because the thickness of the active layer would have had to reach 2.5 m or greater, and the host gravels below about 1 m depth are not disturbed. The ages of the pots were not determined, but both Illinoian and Wisconsinan time were considered by the authors as possible.

Involutions, Periglacial Involutions, and Cryoturbations

Involutions (Denny, 1936, p. 338) are visually aimless, mechanical, soil deformations, redistributions, and interpenetrations that occur below the land surface and that show no surface topographic manifestations. Involutions characteristically display structures with rounded and/or laminated layers and borders that suggest some species of plastic deformation. Vandenberghe (1988) considers the term involutions to be a purely descriptive term, although Denny used the term to refer to features that he concluded were of periglacial origin. The term periglacial involutions (Sharp, 1942, p. 115), however, is genetic and leaves no doubt as to the inferred origin of such features. Periglacial involutions therefore, are those varieties of involutions which can be assigned to a genesis in cold-climatic environments. Edelman, *et al.* (1936) considered the term cryoturbations to embrace all sediment movements affected by cold, a definition that needs to be narrowed to include only nonsorted types of deposits (Vandenberghe, 1988).

Involutions are known from a number of locations in Pennsylvania (Ciolkosz, *et al.*, 1986b; Pollack, 1992). There are probably many more to be found. For instance, some reports of features in the literature suggest that the authors might be describing involutions, but the descriptions are not definitive. Involutions have also been reported at low elevations in the coastal plain of southern New Jersey at low elevations (Newell, *et al.*, 1988), so that it is reasonable to expect their presence in susceptible sites in the Appalachian Highlands. Figure 19 shows the distribution of some reported finds of involutions in Pennsylvania.

Vandenberghe (1988) presents a morphological classification of involutions according to symmetry, amplitude-wavelength ratio, and pattern of occurrence. Six types of deformations are recognized. Vandenberghe evaluates the genesis of these deformations with respect to processes involved in loading, cryohydrostatic pressure, and cryostatic pressure and heaving. He then considers the conditions prerequisite for the development of the deformations, stressing climate and lithology. The significances of these deformations are: soil behavior, palaeoclimatic reconstructions, palaeoenvironmental reconstructions, and use in correlation of stratigraphic sequences (Vandenberghe, 1988).

Unfortunately, in the field trip corridor, there are to date, no known quantitative descriptions of involutions that could be used to interpret past conditions of development in the Central Appalachians. Future study of involutions, therefore, offers many opportunities for advancing our knowledge about palaeoperiglacial geomorphology in this region.

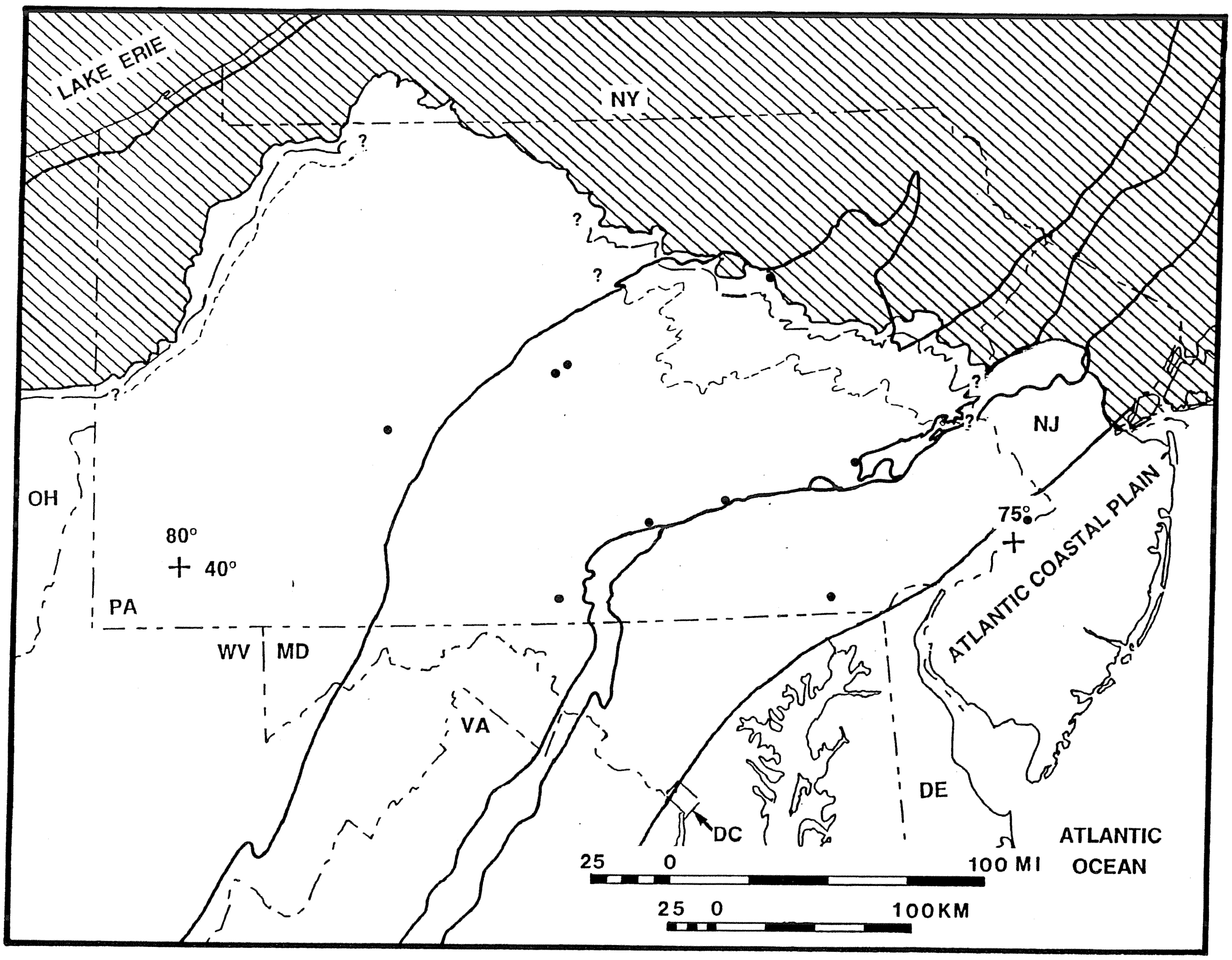

Figure 19. Distribution of some reported finds of involutions in Pennsylvania south of the Late Wisconsinan glacial border. Geomorphic subdivisions and glacial borders are as keyed in Figure 1. Data are from many sources, including Ciolkosz, *et al.* (1986b), Denny (1951), Pollack (1992), and Willard, *et al.* (1959).

Stratified Slope Deposits

DeWolf (1988) used the term "stratified slope deposits" to encompass a wide range of hillslopes sediments composed of more-or-less regularly alternating beds of coarse and fine sediments derived from the upslope substrate. Much confusion reigns concerning the terminology of the various types of stratified slope deposits, however. Guillen (1951) applied the term "grèzes litées" to deposits composed of frost-derived granules, sand, and finer clastic sediments arranged into superimposed bedded deposits of variable thicknesses and homogeneities. Grèzes litées are derived from a rocky surface or substrate, occasionally from cliffs, and exhibit well-developed, mature sorting and stratification. Stratification in grèzes litées is fine, highly developed, gently sloping, and inclined at dips that characteristically are slightly greater than the overlying land surface, which can be as low as 3° (de Wolf, 1988). The classic type areas of true grèzes litées are in southern France (Guillen, 1951; van Steijn, *et al.*, 1984; de Wolf, 1988). The term "groizes litées" refers to granulometrically heterogeneous detrital sediments that are coarser-grained than grézes litées, implying lesser maturity of the deposit (deWolf, 1988). Stratified "talus" or stratified sliderock deposits (éboulis ordonnés), which underlie scree slopes, were mistakenly equated with grèzes litées by Callieux (1948) who regarded the two terms as having equivalency.

In western Europe, the recognition of stratified slope deposits as fossil sediments of palaeoperiglacial origin predates that recognition of the deposits found in the Appalachians. In Pennsylvania, at lower mountain-slope elevations where suitable shale bedrock parent materials are available, there are oriented and stratified shale-chip-rubble deposits (Peltier, 1949; Rapp 1967; Jobling 1969; Sevon and Berg, 1979; Clark and Ciolkosz, 1988; Gardner, *et al.*, 1991). Jobling (1969) located and studied a number of such stratified slope deposits in the southern half of Centre County, Pennsylvania. He proposed that solifluction was responsible for the emplacement of the shale-chip deposits he studied. Gardner, *et al.* (1991) located ten sites in central and south-central Pennsylvania and studied the Benfer, Pennsylvania, deposit in detail. Exposures permitting, a number of excellent examples of such stratified slope deposits can be seen along the excursion corridor in Pennsylvania.

The distribution of selected prominent finds is shown in Figure 20, although most or all of the stratified slope deposits have since been removed from some of these localities. Most of these deposits consist of brown or gray relatively unweathered platy to elongate shale fragments, but in a few localities one or more of these deposits overlies a truncated and older, deeply weathered, red shale chip deposit. These shale chip deposits suggest that conditions for mechanical fragmentation of shale bedrock were optimum at the times when these deposits accumulated. Unfortunately, there are no known numerical age dates for the emplacement of these sediments, so that the age of the mechanical weathering cannot be related either to other periglacial activity or to glacial events in the region.

Detailed sedimentological experiments were performed by van Steijn (1987); he concluded that two transport mechanisms were required to produce an alternation of matrix-supported rock fragments with openwork-structured layers. Next, van Steijn (1988) investigated the role of debris flows as a possible process group responsible for the deposition of coarse-grained stratified slope deposits, which differ from grèzes litées. The coarse-grained stratified slope deposits he studied have irregular stratification, in which differing kinds of lenslike structures dominate. The textural range of the sediments is much greater than in grèezes litées, and the dips of individual strata are much steeeper, from ±18° to 35°. From the results of field investigation and laboratory research, van Steijn (1988) concluded that debris flows are the main transport mechanisms responsible for the stratified slope deposits he studied.

Francou (1988) studied stratified slope deposits in the High Andes of central Peru that may provide clues to the origin of some of the sorting and stratification in stratified slope deposits. He reported a "tracked-vehicle type" of forward motion, in which upslope lobes of debris over-ride older strata downslope. Francou (1990) reports that bedding is produced by solifluction sheets which move at the rate of only a few centimeters per year. The solifluction involves needle ice, frost creep, and gelifluction within surface thicknesses of less that 20 cm.

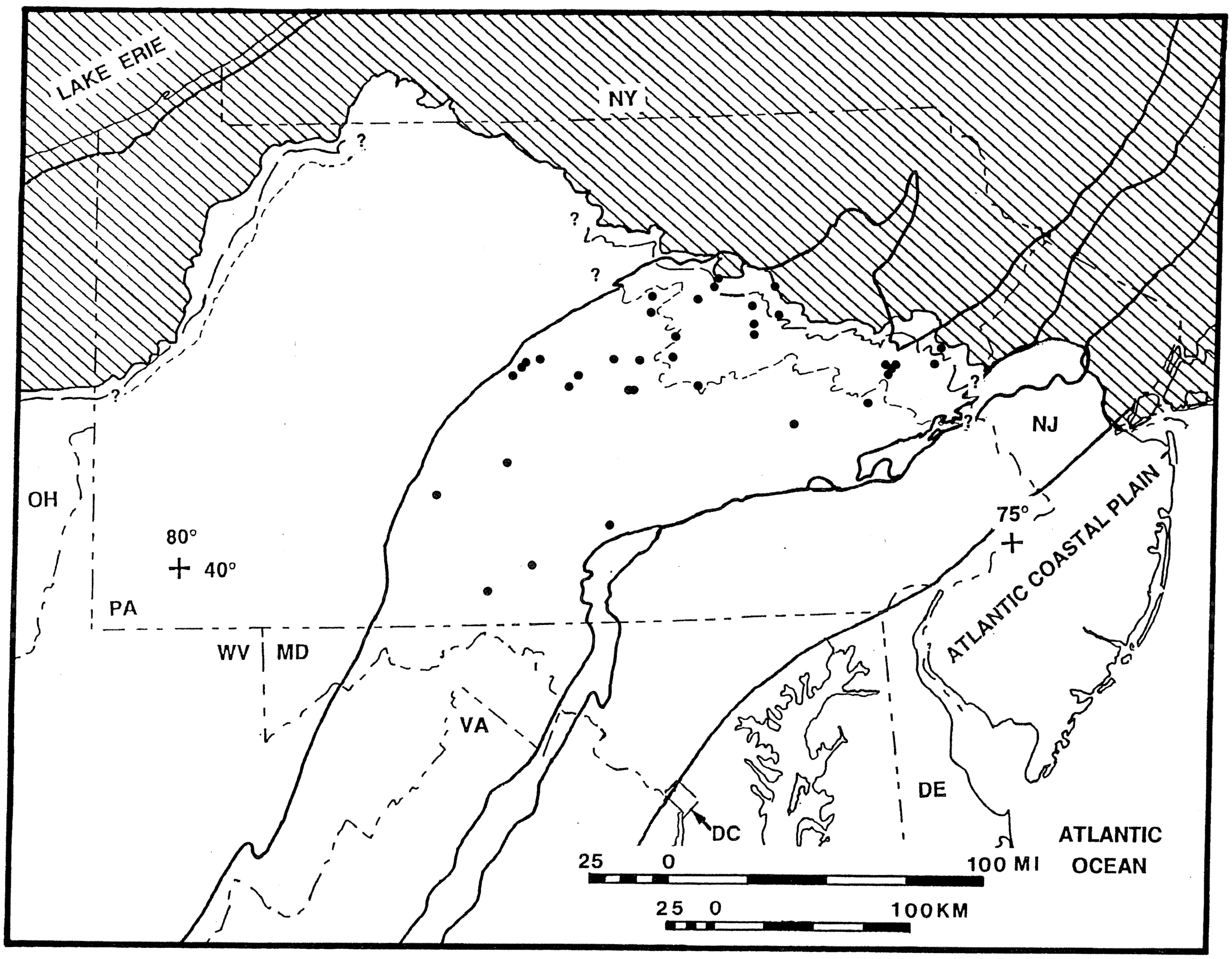

Figure 20. Location of selected reported stratified slope deposits in Pennsylvania south of the Late Wisconsinan glacial border. Geomorphic subdivisions and glacial borders are as keyed in Figure 1. Data from Ciolkosz, *et al.* (1986b); Gardner, *et al.* (1991); Jobling (1969), and other sources.

Rock and Soil Wedges

Introduction

Despite their importance in palaeoclimatic reconstructions, the search for, and location of, rock and soil wedges in the Central Appalachians is still in its infancy. Part of the problem in this region is the difficulty in finding suitable features for study. In many areas where wedge-shaped forms have been found, their tops are blanketed by homogeneous soil horizons, and there is no visible surface evidence of their occurrence. Therefore, almost all finds of rock and soil wedges (Figure 21) have been confined to excavations.

Central Appalachian Occurrences

Walters (1978) studied features in the low-relief Triassic Lowland area of north-central New Jersey within about 45 km of the Wisconsinan glacial border. He found that, unlike in areas in Pennsylvania studied to date, nonsorted polygons could be identified from aerial view and their patterns mapped. Polygon diameters vary from about 3 to over 30 m and have an average diameter of about 20 m. Both orthogonal and nonorthogonal geometric patterns exist. Walters investigated nonorthogonal forms and found that the borders are underlain by wedges of infilled sediment 10 to 240 cm wide, averaging 50 cm, extending in depth from 25 to 260 cm, averaging 125 cm.

Cronce (1988) studied the morphology and soil profile development of soil wedges developed in limestone residuum and rock wedges produced in shale bedrock in Centre County, Pennsylvania, 80 to 120 km from the Late Wisconsinan glacial border. The research sites were located on gently convex valley uplands between 300 and 400 m in elevation and had southeast to southwest aspects. Research sites overlying limestone residuum had slopes of less than 5%; those sites overlying shale bedrock had slopes of less than 10%. Field observations and measurements were made on 13 wedge-shaped forms in limestone residuum at 5 sites and on 16 wedge-shaped forms in shale bedrock at 5 sites. Four sites in limestone residuum and three sites in shale bedrock were described in detail and sampled for laboratory analyses.

Cronce found that the soil wedges in limestone residuum are downward-narrowing in cross section, have rock fragments that are oriented within the wedges, and have upturned and downturned orientations in the host materials. Wedge-shaped casts in shale bedrock (Figure 22) are narrower, have coarser textures, and contain less well developed pedons than wedges developed in residuum. Maximum width of the wedge-shaped casts in limestone residuum was 137±43 cm and of the casts in shale bedrock 53±24 cm. Forms in limestone residuum had average lower depths of 176±27 cm and in shale bedrock were 139±31 cm deep. The width/depth ratio in residuum was 0.8±0.2 and in bedrock was 0.4±0.2 m. Cronce was able to demonstrate that the wedge casts were linear at several sites, but not whether they were part of a polygonal network in plan view.

Cronce (1988) considered independent supporting evidence for permafrost in central Pennsylvania, the likelihood that the host materials had abundant moisture and lacked significant snow cover during development, and the evidence of pressure effects and slumped fabrics. He interpreted the forms in both host materials as ice wedge casts and estimated their age as Wisconsinan (based on degree of soil development).

Most of what is known about the location of rock and soil wedges in the Central Appalachians comes from the work of Walters (1978), Cronce (1988), and Pollack (1992). The other localities are largely chance finds known to the present authors and other researchers. The distribution of such finds of large, well-defined rock and soil wedges in Pennsylvania is shown in Figure 21.

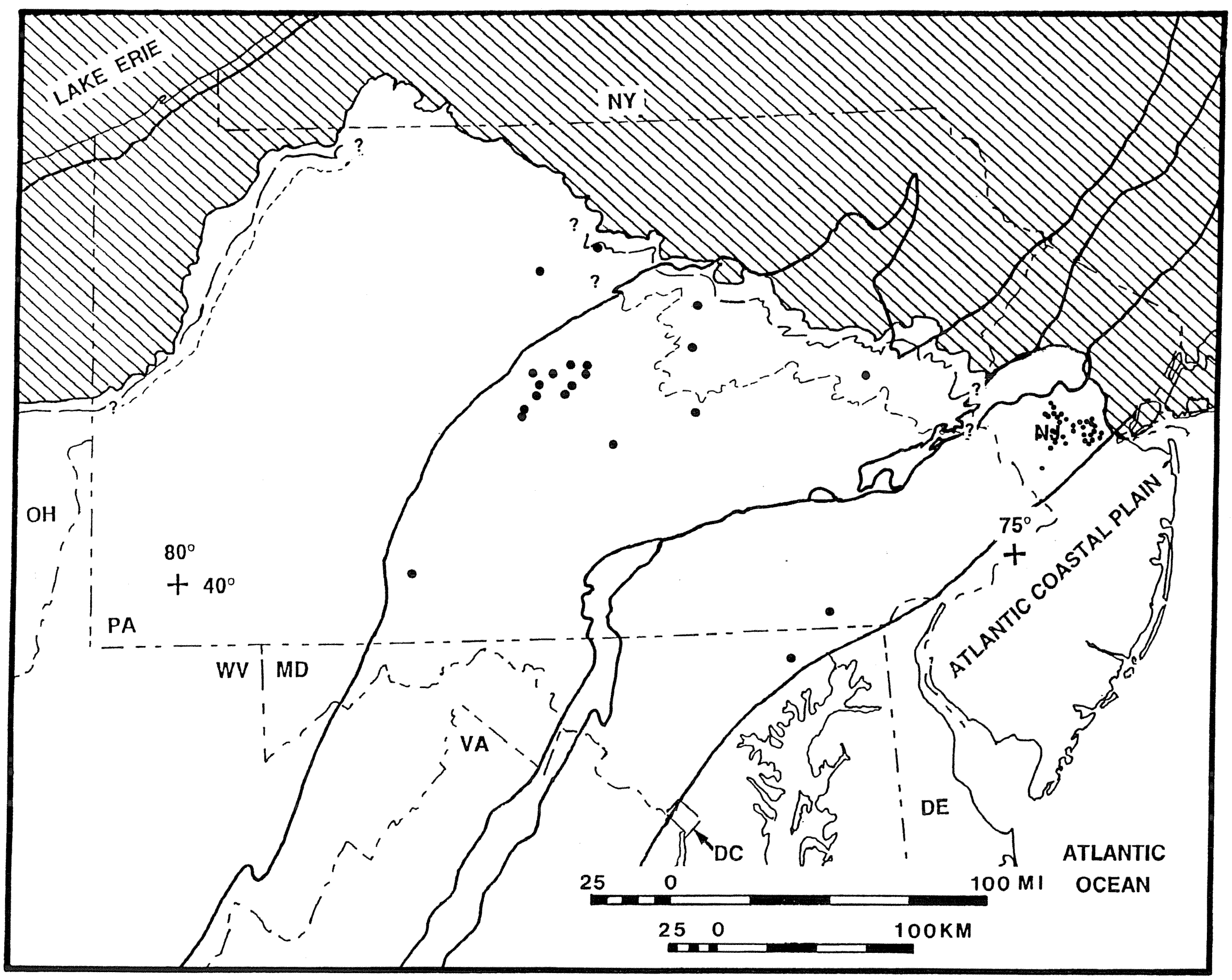

Figure 21. Distribution of selected reported wedge-shaped casts in bedrock and soil in the field trip area beyond the Late Wisconsinan glacial border. Geomorphic subdivisions and glacial borders are as keyed in Figure 1. Locations from Cronce (1988), Ciolkosz, *et al.* (1986b), and Pollack (1992) shown by large dots. Locations of both polygonal patterns and wedge casts (undifferentiated) from Walters (1978) shown by small dots.

Figure 22. Soil wedge developed in shale bedrock in the Tom Swank Shale Pit, Centre County, Pennsylvania (Centre Hall quadrangle). Geologic hammer for scale is 32 cm long. (Potters Mills site of Cronce, 1988).

Discussion

Despite the dangers inherent in possible misinterpretation of wedge-shaped features as ice-wedge casts (Black, 1976a), the correct recognition of ice-wedge casts has great palaeoclimatic significance (Black, 1976b). In order for wedge-shaped casts in soil or in bedrock to be considered pseudomorphs after ice wedges, a number of criteria must be met. These include: (1) independent supporting evidence of permafrost; (2) existence of multiple wedges that intersect to form a large (10-40 m) polygonal network in map view; (3) pressure effects on adjacent soil or rock; and (4) slump fabrics with arcuate downward stratification across the wedge filling (Black, 1976a; Washburn, 1980). When demonstrated, however, the existence of ground ice pseudomorphs provides clear evidence of palaeoclimatic conditions sufficiently severe to have had permafrost (Harry, 1988). Little doubt now exists in our minds that many features such as those described above can be fossils of ice wedges. Correct identification of these wedge-shaped casts as ice-wedge casts would demonstrate the former existence of permafrost and, therefore, permits assumption of an extremely rigorous palaeoperiglacial environment (Péwé, 1983). Knowledge of the actual distribution and nature of wedge-shaped casts in the Appalachian Highlands would help delimit a number of important aspects of palaeoperiglacial geomorphology in the Central Appalachians (Cronce and Ciolkosz, 1986). Such aspects would include estimates of mean annual air temperature ranges and some information about surface and subsurface site conditions at the times when the ice wedges developed.

The work of Cronce (1988) demonstrates the potential for detailed work on such features in other areas of the Appalachians. The size and excellent development of these features, their distance from the ice margins, and the relatively low elevation of the finds all suggest that future research of this type would reveal many additional features. For instance, Newell, *et al.* (1988) reported wedge shaped casts at a number of localities on the Coastal Plain of southern New Jersey at elevations and latitudes significantly lower than those in central Pennsylvania.

CONCLUSIONS

SUMMARY

Much of Central Appalachian periglacial geomorphology is still in the discovery and reporting stage. Almost every field season results in new finds of landforms and materials—some of these are first reports in the region of features that may prove helpful in palaeoenvironmental reconstructions.

The distribution of known forms and materials shown in this guidebook of course reflects, in part, the field areas where interested researchers have had opportunity to work (*cf.* Figures 8, 11, 12, 16, 19, 20, and 21). Vast areas remain virtually unexplored for periglacial features. In particular, there are geographically large areas in Virginia, West Virginia, Maryland, New Jersey, New York, Ohio, and in northern, northwestern, western, and southwestern Pennsylvania that lack reported finds of many features. The apparent absence of periglacial features is at least partly due to the lack of periglacial research in these areas. This can be demonstrated for several areas in western and northwestern Pennsylvania, where single publications often have identified and described periglacial features in places that are surrounded by large geographical areas without such finds (see, for examples, Edmunds and Berg, 1971; Denny, 1951, 1956; Kocsis-Szücs, 1971; Sevon, 1992b). Additional field work in the Central Appalachians will be needed before we know even the approximate spatial distributions of important features such as ice wedge casts and cryoturbations. Still more research will be required before we can begin to establish periglacial zones (*cf.* Karte, 1987) where, for example, permafrost might have occurred (*cf.* Rapp, 1983). Such data, plus, of course, increased understanding of genesis from studies of actual phenomena, will be necessary to formulate criteria for the eventual definition and delimitation of Central Appalachian *palaeoperiglacial regions.*

THE PLIO-PLEISTOCENE AGE OF THE PRESENT LANDSCAPE

Long-term landform and landscape development (Thomas and Summerfield, 1987) has been a central theme in Appalachian geomorphology for over a century (see Gardner and Sevon, 1989). Since the publication of the majestic synthesis of Davis (1889), what have been needed are quantitative data to constrain overarching theories about the origin and evolution of the present landscapes in the Central Appalachians. Chief among these needs are accurate estimates of the source areas, volumes, and inclusive ages of sediment eroded from the Central Appalachians. Some data now exist, and more can be made available. The data include, but are not limited to: computer modeling exercises to constrain hypotheses; numerical age dates from new and/or improved methods of dating; abilities to image, study, and compute the volumes of thick diamicton deposits; and new techniques for and results from offshore research.

From the results of offshore research, (Poag and Sevon, 1989; Poag, 1991) it is clearly indicated that, since about 16 Ma (post Middle Miocene time), a tremendous volume of siliclastic sediment has been eroded from the Central Appalachians. These sediment volumes, if combined with reasonable rate ranges for chemical erosion, would produce an estimate of post Middle Miocene erosion of 1.1 km for this part of the Appalachians inland of the Coastal Plain province (Braun, 1989b). Such an estimated average erosion depth for just the Quaternary Period would yield a value of 120-150 m (Table 9).

Due to the amount of post Middle Miocene erosion, there is little likelihood that the higher elevations in the present landscapes we observe in the field trip area contain any vestiges of older, low relief, erosion surfaces (*cf* "Kittatinny" or "Schooley"). The approximate summit accordances, and the local broad uplands developed on many of them, might (through inheritance) reflect the former existence of a deeply weathered low relief erosion surface of Middle Tertiary age, but those summits have been lowered many tens, perhaps even hundreds, of meters since then.

In the valley areas, the remnants of deeply-weathered materials under some parts of these landscapes (*cf* "Chambersburg" or "Harrisburg" surface) cannot represent in-place material of Middle Tertiary age, because this time scenario would only permit post Middle Tertiary incision of the present lowland valleys. That amount of erosion could only account for a small fraction of the time-equivalent sediment on the Atlantic Margin.

As argued by Hack (1965), it is more likely that these deeply weathered materials have accumulated, where temporarily stored in sinkholes or protected by superincumbent lag deposits, as they were created during downwasting. Both Hack (1965) and Pavich (1989) argued that present day geochemical processes are capable of forming much, if not all, of such weathered material. These arguments assume that effects on critical surface and subsurface weathering environments—such as fluvial incision and ground-water systems—have not changed radically throughout the geologic time intervals involved.

On the other hand, the available evidence does not preclude a scenario for the valley surface(s) that would involve one or more discrete time intervals of intense weathering, oxide mineral deposit accumulation, and surface development, interspersed with interval(s) of quiescence or even some erosion. High-resolution stratigraphic studies and numerical age dating of the deposits and their bounding surfaces will be needed to address the relative importances of "steady state" *versus* climato-tectonic "dynamic disequilibrium" models of landscape development for these valley surfaces.

Table 9. Calculation of Appalachian erosion depths necessary to account for the volume of Atlantic Margin sediment. Explanatory notes on each numbered column are given below the table (Revised from Sevon (1989c), using the data of Poag (1992).

1 GEOLOGIC AGE	2 DURATION (Myr)	3 AREA OF COASTAL PLAIN ($10^4 Km^2$)	4 AREA OF SHELF ($10^4 Km^2$)	5 SED. VOL. ($10^4 Km^3$)	6 ERODED ROCK VOL. ($10^4 Km^3$)	7 EROSION INLAND OF FALL ZONE (Km)
Quaternary	1.6	7.84	4.23	2.6600	2.394	0.094
Pliocene	3.7	6.19	4.71	5.6749	5.107	0.200
U.Miocene	5.9	3.81	0.96	5.4061	4.865	0.191
M.Miocene	5.4	2.14	1.44	14.077	12.669	0.497
TOTAL				27.818	25.036	0.982

1 GEOLOGIC AGE	8 EROSION FALL ZONE & 1/3 CP (Km)	9 EROSION FALL ZONE & 1/3 CP & 1/10 SH (Km)	10 EROSION FALL ZONE & 1/3 CP & 1/10 SH +10M/Myr CHEM EROS (Km)	11 EROSION FALL ZONE & 1/3 CP & 1/10 SH +20M/Myr CHEM EROS (Km)	12 PHYSICAL EROSION RATE (M/Myr) FALL ZONE & CP & SH
Quaternary	0.085	0.084	0.100	0.116	52
Pliocene	0.185	0.182	0.219	0.256	49
U. Miocene	0.182	0.181	0.240	0.299	31
M. Miocene	0.483	0.481	0.535	0.589	89
TOTAL	0.936	0.928	1.094	1.260	

Table 9 column explanatory notes:

1. From Poag (1992).
2. From Poag (1992).
3. For these calculations, the Central Appalachian drainage area is measured from the Fall Zone to the Atlantic drainage divide.
3. Coastal Plain areas are from Poag and Sevon (1989) and from Poag (1992).
   Areas are taken between the Fall Zone line and the present coastline, or to the zero deposition line where it is inland of the present coast.
4. Shelf areas are from Poag and Sevon (1989) and from Poag (1992).
   Areas are taken between the present coastline, or the zero deposition line where it is inland of the present coast and the zero deposition line is on the shelf.
5. From Poag (1992).
6. Sediment volumes are corrected for porosity to obtain eroded bedrock volumes.
   Continental margin sediment porosity values from COST B-2 well data ((Rhodehamel, 1977). Continental rock porosity of 10% has been subtracted from the continental margin sediment porosity to correct for the initial porosity of the source land rocks.
7. Corrected sediment volume (Column 6) divided by the area between the Fall Zone and the Atlantic drainage divide (Column 1) yields the average depth of erosion inland of the Fall Zone.

8. Maximum local relief on the Coastal Plain is 1/3 to 1/10 of that on the area inland of the Fall Zone.
   Assume that Coastal Plain erosion is 1/3 of that inland of the Fall Zone. Dividing bedrock volume (Column 7) by the area between the Fall Zone and the Atlantic drainage divide, (Column 1) plus 1/3 of the Coastal Plain (Column 2), yields the average depth of erosion inland of the seaward edge of the Coastal Plain.
9. Continental Shelf relief is 1/10 or less that of the area inland of the Fall Zone.
   Assumed continental shelf erosion is 1/10 of that inland of the Fall Zone. Dividing bedrock volume (Column 7) by the area between the Fall Zone and the Atlantic drainage divide, (Column 1) plus 1/3 the area of the Coastal Plain (Column 2), plus 1/10 of the Continental Shelf, yields the average depth of erosion inland of the zero deposition line.
10. Erosion depth for the area inland of the zero deposition line (Column 10), plus the erosion depth calculated from the 10m/Myr chemical denudation rate (Column 11) (Median of values from Sevon, 1989a), yields a total physical and chemical denudation depth.
11. Erosion depth for the area inland of the zero deposition line (Column 10), plus the erosion depth calculated from the 20m/Myr chemical denudation rate (1/2 of median of Sevon, 1989a), yields a total physical and chemical erosion depth.
12. Erosion depth for the area inland of the zero deposition line (Column 10), divided by the time duration of the geologic time unit in question (Column 1), yields the erosion rate for the area inland of the zero deposition line for the appropriate geologic time unit.

A speculative scenario of Central Appalachian landscape development might start with a deeply-weathered erosion surface of Middle Tertiary (Middle Eocene to Early Miocene) age that was about one kilometer above the present surface (see final section of text). The Middle Tertiary landscape may have been a low relief fluvial erosion surface, perhaps like the Schooley Peneplain of Davis (1889). Another alternative is that the Middle Tertiary landscape may have been a "double planation" etchplain surface (Büdel, 1977; Sevon, 1985) that had a rolling lowland and strike ridge relief somewhat like that of the present day, but one lacking an incised drainage network. In either case, due to the depth of post Middle Miocene erosion, the form of the Middle Tertiary erosion surface cannot be determined strictly from the present erosion surface, because no part of the Middle Tertiary surface is preserved on the present surface (Braun, 1989b).

By about 2.5-2.4 Ma, global cooling triggered threshold process events which resulted in dramatic changes in middle latitude temperature, precipitation, seasonality, vegetation, and geomorphic process-response activity. There followed the now well known interspersals of glacial and interglacial episodes, with their concomitant dramatic effects on erosion, transportation, and deposition of sediment, and the rapid destruction of old earth materials, their overlying landforms and landscapes, and the production of newer geomorphologies. Effects were profound not only in glaciated areas and their paraglacial extremities, but beyond the glacial borders, where intense periglacial activity during cold phases alternated with interglacial phases when climates were warmer than now.

The dramatic changes in climate, vegetation, and geomorphic process-response mechanisms that ushered in the Holocene produced postglacial environments that had essentially modern aspects during Early Holocene time. The subsequent Altithermal or Hypsithermal Middle Holocene time interval in the Appalachians was characterized by conditions that were warmer and effectively drier than those of the present day. Except for cooling during Neoglacial (including the terminal Little Ice Age) time, the Late Holocene time interval has experienced environmental conditions similar to those of the present day.

The problem of effects on Appalachian topography and drainage by cataclysmic landscape-making events during Holocene time must be addressed if we are to consider so many landforms as relicts of Pleistocene cold phases. Two end-member types of storm events (hillslope events and floodplain events) have been identified as having had major effects in certain areas in the Appalachians (Miller, 1990). Jacobson, *et al.* (1989b) evaluated the effectiveness of catastrophic geomorphic events in the Central Appalachians, and concluded that the effects of catastrophic precipitation events have been minimal in shaping landforms and landscapes. Although to strict adherents of the concept of dynamic equilibrium, preservation of so many relict landforms and materials over such wide geographic areas may seem anathema, it can be readily understood in light of the great thicknesses, resistance to erosion of blocky armor, low slope gradients, and distance from major fluvial courses that characterize many landforms and regoliths described herein.

Except for the Holocene events responsible for weathering, erosion, and soil formation, the present geomorphic materials and their upper bounding physical limits—the major landforms and landscapes—are, therefore, essentially of Late Miocene-Pleistocene age. These landscapes have been carved from whatever deeply-weathered series of paleosurfaces existed in Middle Tertiary time.

Of course, the questions of scale (Table 2) and of geographic location, resistance to weathering and erosion of the underlying lithology, and whether topography or drainage is being discussed, are important when one essays on the "age" of a particular present-day landscape. For example, at least some of the major rivers may have been in their present map locations since about the Late Triassic, although, of course, neither the form and relief of their valleys at such ancient times are known, nor are their distances above the present surface. The conclusions reached above are, therefore, intended to apply to landscape scales of about the subsection level (Table 2). Fortunately, these scale levels comprise those of concern to us in both pure and applied research efforts, and indeed are the features that are commonly depicted on imagery and maps of the various practical scales in use today.

Thus, in summary, the overall present-day landscape could be generally explained simply as the result of continuous, post-Middle Miocene erosion that had, albeit, major variations in processes and rates. A hypothesized, long-term, general model (Braun, 1989b), would be far closer to the continuous, dynamic equilibrium idea of Hack (1960) than it would be to the cyclic uplift-standstill-erosion theory of Davis (1889) or to the periglacial notion of Troll (1948).

Such general, long-time interval, models, however, leave the observer without any explanations for the myriad of individual topographic features and their underlying geomorphic materials that actually comprise the landforms, landscapes, soils, parent materials, and related rocks of the Central Appalachian region. Perhaps, development and refinement of a hierarchical, region-specific, model like that prepared for the Delaware Valley in New Jersey and Pennsylvania by Ridge, *et al.* (1992)—and one constrained by the detailed stratigraphy, morphometry, volume, and direct dating of these terrestrial materials—would help answer focused questions about the genesis and environment of formation of palaeoperiglacial (and other) landforms and geomorphic materials in the Central Appalachians.

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ROAD LOGS

WASHINGTON, D.C. AREA THROUGH BALTIMORE, MARYLAND AREA TO HARRISBURG, PENNSYLVANIA, AREA *VIA* FALL ZONE AND PIEDMONT OF NORTHERN MARYLAND, AND PIEDMONT AND GREAT VALLEY IN PENNSYLVANIA:

Total	Interval	Description
0.0	0.0	Start mileage at Washington Beltway (I-495) exit for I-95 North to Baltimore. Between Washington, D.C. and Baltimore, this interstate highway (I-95) runs along the Fall Zone and perpendicular to the regional northwest-to southeast-drainage. The interfluves are capped by unconsolidated sediments of the Potomac Group of Cretaceous age. This dominantly sandy unit with subordinate silt and clay is a fluvial deposit with locally abundant terrestrial plant fossils. Earlier interpretation of this unit as a marine sediment was used as evidence by Douglas Johnson (1931) to propose a sedimentary cover of Cretaceous age over the Appalachians that permitted superposition of the present drainage across this part of the Appalachians. The valleys are cut into crystalline rock units of the Piedmont province, here predominately the Baltimore Gabbro complex with some gneiss. The generalized bedrock stratigraphy across the part of the field trip in Maryland and southeastern Pennsylvania is given in TABLE R.1.1. The generalized bedrock geology for this part of the field trip route is shown in FIGURE R.1.1.
22.8	22.8	Enter the city of Baltimore. In a few miles, the Baltimore harbor area will be crossed. The higher portions of the landscape are underlain by the Potomac Group of Cretaceous age, and the lower elevations near the harbor are underlain by a complex sequence of fluvial and marine sediments of Late Cenozoic age.
31.4	8.6	Leave Baltimore and continue along the Fall Zone. The valleys are here cut in gneiss and in the Bel Air gabbro complex. Some interfluves are capped by gravels of Late Cenozoic age, and others are capped by both the Potomac Group and gravels of Late Cenozoic age.
47.1	15.7	Exit 77B. **BEAR RIGHT** onto MD Route 24 North to Bel Air. In the next few miles, the Fall Zone will be ascended aand the route will cross onto the Piedmont province at Bel Air.
52.7	5.6	Cross US Route 1 (Business Route) in the town of Bel Air.
54.2	1.5	Merge onto US Route 1 North.
56.0	1.8	**TURN LEFT** and continue on US Route 1.
57.2	1.2	Continue on US Route 1 across MD 543. From here to Stop 1, the route follows a broad interfluve, underlain by the Bel Air Gabbro complex. This interfluve divides streams draining south to the Chesapeake Bay from streams draining east to the Susquehanna River. The crest of the drainage divide is underlain by residuum and saprolite; the sideslopes are underlain by colluvium and saprolite with bedrock pinnacles. Wooded hollows are mantled with boulder colluvium. A few miles ahead is STOP 1.
59.7	2.5	**BEAR RIGHT** onto Forge Hill Road. In a few tenths of a mile, enter the area of the surficial deposit map.
60.9	1.2	Outcrops of metagabbro occur during descent into the Deer Creek Valley.
61.3	0.4	Cross Deer Creek on bridge.

TABLE R.1.1. Generalized bedrock stratigraphy for the part of the Piedmont province in northeastern Maryland and southeastern Pennsylvania. From Pazzaglia and Gardner (1992, Figure 3, p. 11).

NORTH OF THE MARTIC LINE

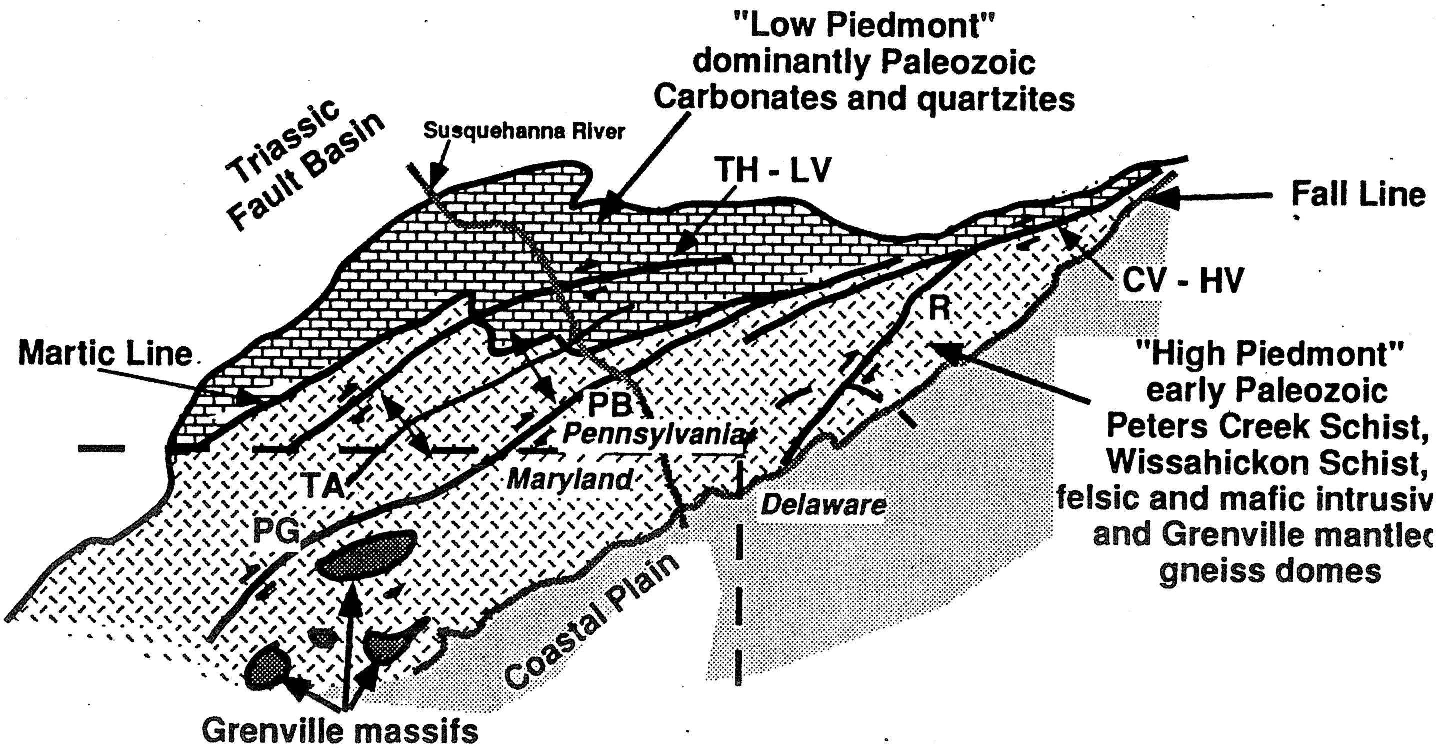
CAMBRIAN	**Conococheague Group**	Conostoga Formation (Ꞓ and O)
	Zooks Corner Formation	
	Ledger Dolomite	
	Kinzers Formation	
	Longs Park (upper) Member	
	Thomasville (middle) Member	
	Emigsville (lower) Member	
	Vintage Dolomite	Chillhowee Group
	Antietam Quartzite	Chillhowee Group
	Harpers Phyllite	Chillhowee Group
	Chickies Quartzite	Chillhowee Group
	Hellam Conglomerate Member	
PRE-Ꞓ	**Metavolcanics**	
	metarhyolite and greenstones	

(Unconformity between Hellam Conglomerate Member and Metavolcanics)

SOUTH OF THE MARTIC LINE

EARLY PALEOZOIC	**Peach Bottom Slate**		
	Cardiff Metaconglomerate		
	James Run Metavolcanics	/ Felsic Intrusives	
	Port Deposit Gneiss	/ Felsic Intrusives	
	Peters Creek Quartzite	"Wissahickon Formation"	Glen Arm Series
	Deer Creek Metagreywacke	"Wissahickon Formation"	Glen Arm Series
	Wissahickon Schist	"Wissahickon Formation"	Glen Arm Series
	Cockeysville Marble		Glen Arm Series
	Setters Quartzite		Glen Arm Series
PRE-Ꞓ	**Baltimore Gneiss**		
	(Grenville basement)		

(Unconformities between Cardiff Metaconglomerate and James Run Metavolcanics, and between Setters Quartzite and Baltimore Gneiss)



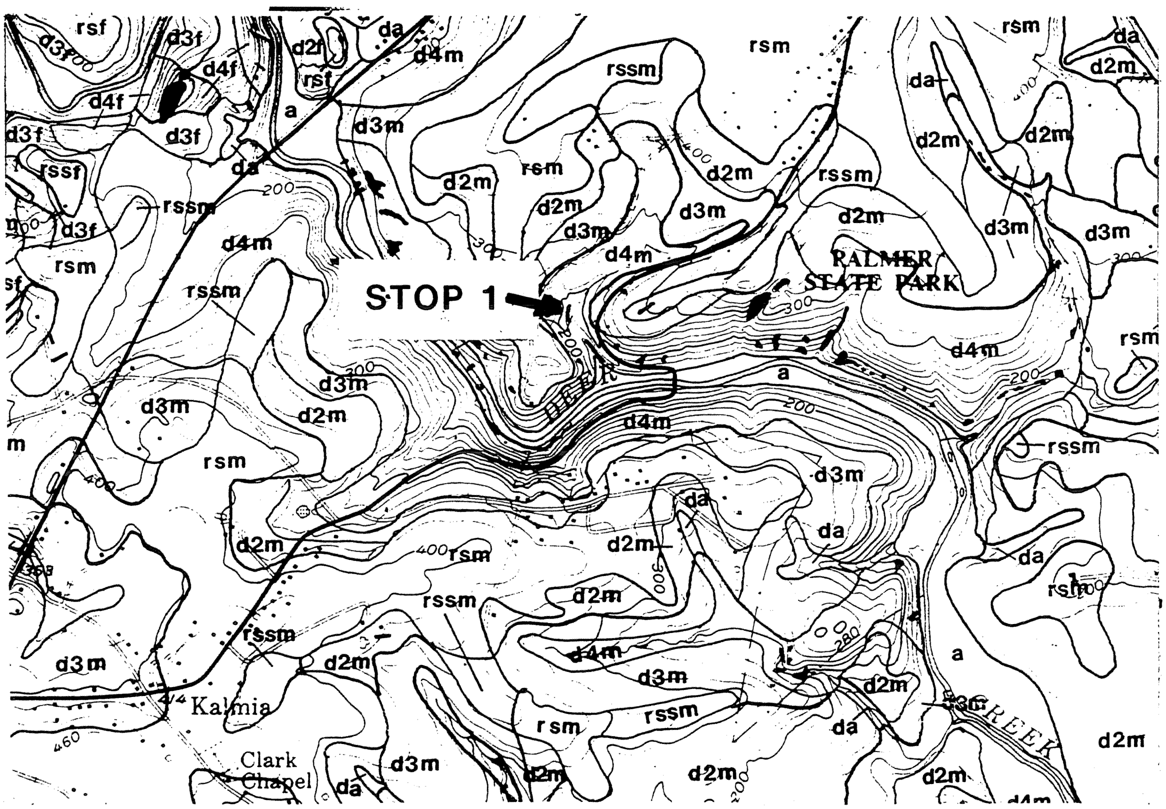
CV - HV = Cream Valley, Huntington Valley faults
PB = Peach Bottom shear zone
PG = Pleasant Grove fault
TA = Tucquan Antiform
TH - LV = Turkey Hill fault; Lancaster Valley tectonite zone
R = Rosemont fault

FIGURE R.1.1. Generalized map of geology of the part of the Piedmont province in northeastern Maryland and southeastern Pennsylvania. From Pazzaglia and Gardner (1992, Figure 4, p. 12).

61.6 0.3 **STOP 1.1**. Park on road shoulder at a concrete culvert. Disembark, cross the road, and walk downslope to STOP 1.1.

STOP 1.1: BOULDER COLLUVIUM IN A PIEDMONT HOLLOW

This stop (see FIGURE R.1.2) exemplifies the boulder mantle that covers the floors of first order tributary hollows cut in metagabbro on the Piedmont upland of northern Maryland. Under the boulder mantle is a matrix supported diamict with pockets of clast-supported diamict that is in turn underlain by saprolite. These boulder surfaces in the past have been interpreted to represent lags of corestones left by fluvial incision of a deeply weathered landscape. The concentration of the largest clasts at the surface of the material, clast size exceeding the size that could possibly be transported by the first order stream, and the "on edge" orientation of many boulders are strongly indicative of a periglacial origin for the boulder surfaces. Fluvial incision during Holocene time has cut a channel along one side of the boulder stream at the contact between the valley wall and the valley floor.



Map Legend for FIGURE R.1.2.

a	Stratified sand and gravel alluvium
da	Non-stony colluvium and alluvium
rsm	Red non-stony residuum on mafic rock
rssm	Red stony residuum on mafic rock
rsf	Yellow-red non-stony residuum on felsic rock
rssf	Yellow-red stony residuum on felsic rock
d2m	Red non-stony colluvium on mafic rock
d3m	Red stony colluvium on mafic rock
d4m	Red boulder surface colluvium on mafic rock
d2f	Yellow-red non-stony colluvium on felsic rock
d3f	Yellow-red stony colluvium on felsic rock
d4f	Yellow-red boulder surface colluvium on felsic rock

FIGURE R.1.2 Surficial deposit map of the area around STOP 1.1. The hilltops are underlain by less than 1 m of residuum that is in turn underlain by 3 m or more of saprolite. The sideslopes are underlain by 0.5 to 2 m of colluvium that is in turn underlain in most places by more than 2 m of saprolite. Hollows on the metagabbro have a one stone thick boulder mantle. Area was mapped at a scale of 1:24,000 onto topographic map of the Bel Air quadrangle by D. D. Braun.

Upon leaving STOP 1.1, continue ahead (uphill) on Forge Hill Road. Stop at topographic crest of hill and turn right into open field.

STOP 1.2: BACKHOE PIT IN FIELD EXPOSING WEDGE-SHAPED CAST ON BOTH SIDES OF PIT

This temporary exposure (see FIGURE R.1.3) showed a large, wedge-shaped cast which was present on both sides of the backhoe pit.

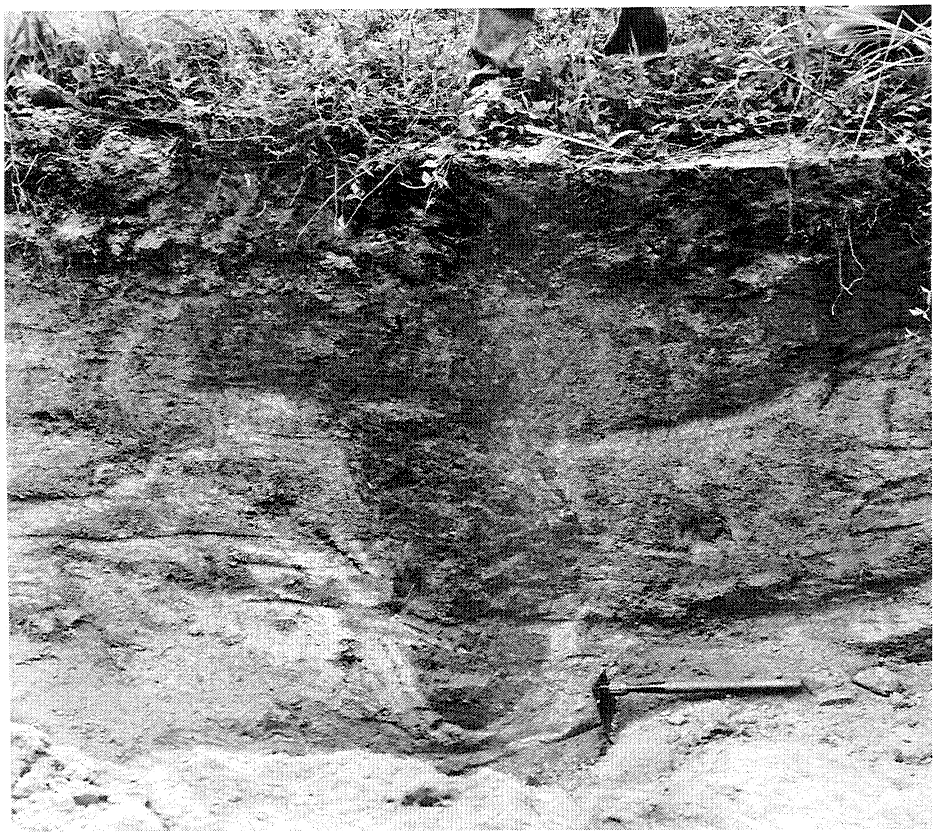


FIGURE R.1.3. Exposure of wedge-shaped cast in backhoe pit in field at STOP R.1.2. Length of shovel handle is 55 cm. Bel Air, MD quadrangle.

62.9	1.3	**BEAR RIGHT** onto US Route 1 east. For the remainder of the trip in Maryland, the road log area will be underlain by metagabbro.
67.8	4.9	Begin the descent into the gorge of the Susquehanna River, then cross the river on the crest of Conewingo Dam. On the right are the rapids that mark the beginning of the Fall Zone on the Susquehanna River. The rapids extend upstream all the way through the Piedmont in a gorge that reaches a depth of 800 feet (244 m) in the middle of the Piedmont belt.
69.6	1.8	Start the ascent back up onto the Piedmont upland.
70.5	0.9	**TURN LEFT** onto US 222. Continue the ascent of the Piedmont upland..
70.9	0.4	Reach top of the Piedmont upland.
73.4	2.5	Ahead and to the left, is an an overview of the gently rolling surface of the Piedmont upland.
74.1	0.7	Enter Lancaster County, Pennsylvania. For the next few miles, the area is underlain by ultramafic crystalline rocks and serpentinite. Then for the remainder of the way across the Piedmont upland, the area will be underlain by the schists of the Peters Creek and Wissahickon Formations. There is little

		apparent difference in topographic expression of these diverse crystalline rocks in this part of the Piedmont upland.
78.4	4.3	**BEAR LEFT** onto 272.
87.0	8.6	Descend from the Piedmont upland onto the Conestoga Valley district. The lowland is underlain by the Conestoga Limestone.
91.8	4.8	Start one way travel in Willow Grove.
93.6	1.8	**TURN LEFT** onto 741-West at stop light where US 222 rejoins 272.
93.8	0.2	Cross 272-South, continuing on 741-West.
95.2	1.4	**TURN RIGHT** onto 324, continuing on 741-West.
95.7	0.5	Straight ahead at stop light, continuing on 741-West. (324 goes right.)
98.5	2.8	Cross 999, continuing on 741-West.
100.5	2.0	Cross 462, continuing on 741-West.
101.5	1.0	Cross 23, continuing on 741-West.
102.0	0.5	Cross US 30, continuing on 741-West.
103.5	0.9	**TURN LEFT**, just before four lane I-283, continuing on 741-West.
103.9	0.4	Go under four lane I-283 and then immediately **TURN LEFT** onto entrance ramp to I-283-West.
105.5	1.6	At about the 722 exit, enter a lowland area underlain by a sequence of carbonate and shale bedrock units of Cambro-Ordovician age.
115.5	10.0	At about the exit for Rheems, enter the Gettysburg-Newark Lowland section. This landscape unit is predominantly underlain by red mudstone and sandstone.
118.5	3.0	At the 743 exit, cross a wooded ridge underlain by a diabase sill. In places the ridge sides are veneered with corestones.
120.2	1.7	Cross another wooded ridge underlain by diabase.
123.1	2.9	At the Toll House Road exit, cross yet another wooded upland underlain by diabase.
127.0	3.9	Starting at the 441 exit, and for the next few miles, I-283 runs essentially on top of the boundary fault for this sedimentary basin of Mesozoic age. To the left (south) are the red beds of Mesozoic age and to the right (north) are the carbonate and shale rock units of Ordovician age that underlie the Great Valley subsection of the Ridge and Valley province. The fault here has essentially no topographic expression, due to the juxtaposition of rock types of similar resistance to erosion.
129.8	2.8	Continue straight ahead on the four lane road as I-283 turns right.
130.3	0.5	"T" intersection at Eisenhower Boulevard. **TURN RIGHT** onto Eisenhower Boulevard and then in 0.3 mile turn into the Congress Inn parking lot.

HARRISBURG, PENNSYLVANIA AREA TO BLOOMSBURG, PENNSYLVANIA, *VIA* GREAT VALLEY AND APPALACHIAN MOUNTAIN SUBSECTIONS OF THE MIDDLE SECTION OF THE RIDGE AND VALLEY PROVINCE:

Total	Interval	Description
0.0	0.0	Leave Congress Inn, **TURN LEFT** onto Eisenhower Boulevard, and then immediately **TURN LEFT** onto 283.
0.2	0.2	**TURN RIGHT** onto entrance ramp for I-283 North.
3.0	2.8	Continue straight ahead, merging with I-83 North.
6.9	4.1	**BEAR RIGHT** onto I-81 East. This road runs down the length of the Great Valley subsection of the middle section of the Ridge and Valley province. Here, the bedrock is shale assigned to the Martinsburg Formation of Ordovician age. The accordant hilltops in this area have been interpreted to represent the Chambersburg (or Harrisburg) Peneplain by early physical geographers and geologists. The wooded ridge to the left, called Blue Mountain, is the first ridge of the Appalachian Mountain subsection of the middle section of the Ridge and Valley province. The crest of this mountain is underlain by resistant orthoquartzite sandstones assigned to the Tuscarora Formation of Lower Silurian age. The crest of the ridge, and others like it, would, in the Davisian geographical cycle of erosion scheme, be interpreted to represent remnants of the once-continuous Schooley Peneplain. The ridge is mantled by scree from crest to toeslope. A generalized description of bedrock units in the Appalachian Mountain subsection ahead is given in TABLE R.2.1.
25.2	18.3	Bear left, continuing on I-81 East.
29.0	3.8	Swatara water gap through Blue Mountain. Water gaps also played a pivotal role in the geographical cycle of erosion concept. Their presence, and alignment, directly across succeeding ridges underlain by resistant rocks led early workers to search for mechanisms of regional river superposition. The Appalachian National Scenic Trail, which extends from Maine to Georgia, is crossed here. Wilshusen (1983) describes a number of features of periglacial origin along the part of the Appalachian Trail in Pennsylvania.
30.2	1.2	I-81 is now running along strike on the shales and sandstones assigned to the Mahantango, Trimmers Rock, and Catskill Formations of Devonian age.
39.9	9.7	Water gap through Second Mountain. The ridge is underlain by quartz sandstone and conglomerate assigned to the Pocono Formation of Mississippian age. Large joint- and bedding-bounded blocks mantle the mountain slopes.
40.6	0.7	At the Ravine exit, cross a valley underlain by the red mudstone and sandstone of the Mauch Chunk Formation of Mississippian age.
41.1	0.4	Climb ridge, crossing conglomerates assigned to the Pottsville Formation of Lower Pennsylvanian age. Next are sandstones, shales, and coals of the overlying Llewellyn Formation.
43.7	2.6	Cross the synclinal axial trace of the Southern Anthracite Coal Basin. This is the southernmost of the four anthracite basins in Pennsylvania (Southern, Eastern Middle, Western Middle, and Northern).
45.7	2.0	I-81 now runs along the crest of Broad Mountain, a homoclinal ridge on the south-dipping Pottsville Formation. This ridge marks the north limb of the Southern Anthracite Coal Basin. The ridge crest has numerous tors, some areas of upland flats (local broad uplands of Monmonier, 1967), and extensive areas of boulder colluvium. To the left is a homoclinal valley underlain by the Mauch Chunk Formation.

59.5	13.8	At about the Frackville exit, Broad Mountain becomes an anticlinal ridge separating the Southern and Western Middle Anthracite Coal Basins. Smaller scale folds on the flanks of the major folds complicate the attitudes of bedding observed in the road cuts.
65.0	5.5	Approaching the Mahanoy City exit, Broad Mountain becomes a homoclinal ridge separating the synclinal valley to the left, the Western Middle Anthracite Coal Basin, from the anticlinal lowland to the right, underlain by the Mauch Chunk Formation.
69.0	4.0	The Delano exit. Start crossing the synclinal axial trace of the Western Middle Anthracite Coal Basin. Also, the route is crossing into the area that was covered by pre-Illinoian ice. Tors on either side are composed of conglomerate assigned to the Pottsville Formation of Lower Pennsylvanian age.
70.2	0.3	**PICTURE STOP 2.1: BEAR RIGHT** into scenic area for a short picture stop of the anticlinal lowland and the nose of a plunging anticlinal ridge.
		CONTINUE AHEAD on I-81 North.
71.3	1.1	Cross wooded ridge underlain by conglomerates of the Pottsville Formation.
72.6	1.3	Road cut exposing red beds of the Mauch Chunk Formation.
73.7	1.1	Just after the McAdoo (309) exit, a large road cut exposes a syncline developed in conglomerate beds of the Pottsville Formation cut by a thrust fault.
74.0	0.3	Enter Eastern Middle Anthracite Coal Basin. For the next 7 miles, the route crosses a series of anticlinal ridges underlain by the Pottsville and Mauch Chunk Formations and synclinal valleys underlain by the Llewellyn Formation. The ridges have many tors and upland flats, while the valleys are covered by colluvium as thick as 20 m that is, in turn, underlain by glacial deposits of pre-Illinoian age that are as thick as 50 m.
80.7	6.7	Outcrop of Pottsville Formation conglomerate. The land surface is characterized by boulder colluvium and isolated tors.
81.0	0.3	At 93 exit, start descending into broad homoclinal valley underlain by red beds of the Mauch Chunk Formation. The ridge across the valley to the left is underlain by sandstones of the Pocono Formation. At this point the route crosses into the ice margin position of Late Illinoian(?) glaciation.
85.6	4.6	**BEAR RIGHT** onto I-80 East. Here, the route crosses into the ice margin of Late Wisconsinan age.
89.5	3.9	After passing the 309 exit, tors on the ridgeline to the right will constitute STOP 2.3 later in the day. Ice of Late Wisconsinan age extended part way up the mountain side, and ice of Late Illinoian(?) age covered the ridgetop.
95.7	6.2	**BEAR RIGHT** into rest area for short rest stop.
98.7	3.0	Cross the Lehigh River gorge and start climbing onto the Pocono Plateau.
99.5	0.8	**BEAR RIGHT** onto the Hickory Run exit and then turn right onto 534 East.
101.6	2.1	**TURN LEFT** at "T" junction, staying on 534 East.
104.9	3.3	Pass headquarters area for Hickory Run State Park.
105.4	0.5	**TURN LEFT** onto park road to Sandy Run and the Hickory Run Boulder Field or Block Stream.
105.6	0.2	Morainic topography developed on glacial deposits of Late Wisconsinan age.
105.9	0.3	**TURN LEFT** onto road to the Boulder Field or Block Stream.
106.5	0.6	**BEAR RIGHT** onto gravel road to the Boulder Field or Block Stream.
107.2	0.7	Leave morainic area and enter wooded part of Boulder Field or Block Stream.
107.9	0.7	Cross under Pennsylvania Turnpike.
109.3	1.4	Arrive at parking lot. Disembark for STOP 2.2.

TABLE R.2.1. Generalized bedrock description of bedrock units for part of the Anthracite Region, Pennsylvania. (From Inners, 1988b, Table 1, p. 2).

System	Geologic unit	Thickness (feet)	Dominant lithologies
Pennsylvanian	Llewellyn Formation	1,500	Interbedded conglomerate, sandstone, shale, claystone and coal
	Pottsville Formation		
	Sharp Mtn. Member	100-150	Quartzitic conglomerate and sandstone; minor shale, claystone and coal
	Schuylkill Member	100	
	Tumbling Run Member	0-125	
Mississippian	Mauch Chunk Formation		
	Upper member	500-600	Gray conglomerate and red mudstone
	Middle member	2,000	Red sandstone and mudstone
	Lower member	500	Gray sandstone and red mudstone
	Pocono Formation	600-650	Quartzitic sandstone
Mississippian-Devonian	Spechty Kopf Formation	0-500	Quartzitic sandstone
Devonian	Catskill Formation		
	Duncannon Member	1,100	Interbedded red and gray sandstone, shale, and siltstone
	Sherman Creek Member	2,500	
	Irish Valley Member	1,800-2,000	
	Trimmers Rock Formation	2,500	Siltstone, shale, and sandstone
	Harrell Formation	100	Grayish-black shale
	Mahantango Formation		
	Tully Member	50-60	Argillaceous limestone and shale
	Lower member	1,100-1,200	Shale, locally fossiliferous
	Marcellus Formation	300	Grayish-black shale
	Onondaga Formation	50-175	Shale and limestone
	Old Port Formation	150	Limestone, shale and chert
Devonian-Silurian	Keyser Formation	125	Limestone, nodular and fossiliferous in part
Silurian	Tonoloway Formation	200	Laminated limestone
	Wills Creek Formation	600-700	Calcareous shale and limestone
	Bloomsburg Formation	500	Red mudstone and siltstone
	Mifflintown Formation	200	Limestone and shale
	Keefer Formation	40	Quartzitic sandstone
	Rose Hill Formation		
	Upper member	120	Shale, limestone, and sandstone; locally hematitic
	Centre Member	60	
	Lower member	720	
	Tuscarora Formation	350	Quartzitic sandstone

STOP 2.2: THE HICKORY RUN BOULDER FIELD OR BLOCK STREAM

The Hickory Run Boulder Field (or Block Stream), Figure R.2.1, was studied in detail by Alan A. Adler (unpublished data). Sevon (1969) described some of the sedimentological aspects of this deposit and also noted the presence and great diversity in compositions, textures, and structures of other block accumulations in Carbon County, Pennsylvania. Sevon (1987) brought attention to Hickory Run as a spectacular example of a palaeoperiglacial legacy of cold-climatic environmental conditions that originated in close proximity to the Late Wisconsinan glacial border.

Adler approached the origin and evolution of the Hickory Run feature using the method of multiple working hypotheses (Chamberlin, 1897). Adler considered hypotheses that proposed both in-place methods of block accumulation genesis and hypotheses that stipulated longslope transport of blocks. In order to test hypotheses, Adler set up objective mapping criteria for both microtopographic features and lithologic mapping units. TABLE R.2.2 lists the microtopographic elements on the compartment and feature levels of scale (Table 2) that Adler defined.

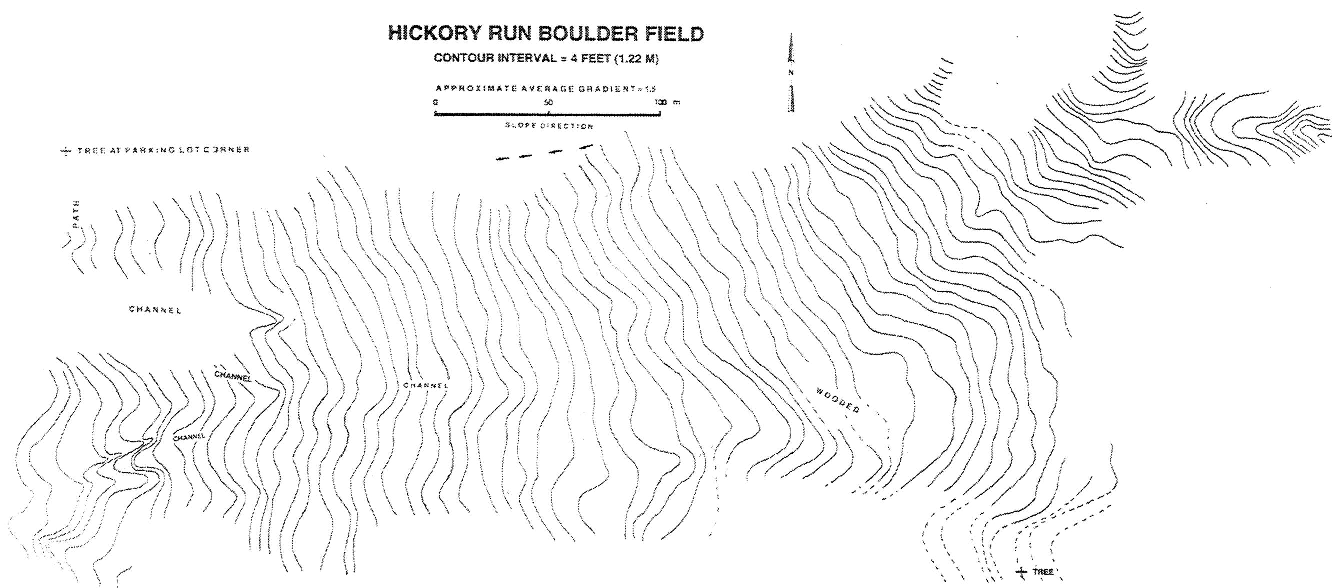


FIGURE R.2.1. Topographic map of the Hickory Run Boulder Field or Block Stream. Contour interval is 4 feet (about 1.3 m). Prepared with plane table and alidade by A. A. Adler.

TABLE R.2.2. Microtopographic features (also associated with lithology and/or sorting) that have been identified, described, and defined on the Hickory Run Boulder Field or Block Stream (*cf.* Figure 9; FIGURE R.2.2). Some of these features are shown on FIGURE R.2.2; others are not.

NAME	SYMBOL	DESCRIPTION
Low Mound	LM	A low mound exists, but the surrounding topography is not well developed into a ring-like form, and the segregation of boulders by size and their tendency for up-ended attitude are not well pronounced.
Vague Low Mound	VLM	Vague mound area but with poor topographic expression and poor boulder segregation, so that little if any suggestion of a ring or net is present.
Elongate Low Mound	ELM	Same features as Low Mound, but elongate with a long axis-short axis aspect ratio of 1.5 or greater. Overall map pattern suggestive of garlands or stripes.
Vague Elongate Low Mound	VELM	Same features as Vague Low Mound but with 1.5 or greater long axis-short axis aspect ratio.
Irregular High	IH	Irregular topographically high area, but with form and boundary conditions. Boulders usually irregularly arranged and not well segregated by size.
Ring	R	A well-rounded mound or high area surrounded by channels or pits, and forming a topographic ring. Boulders are well segregated into smaller ones concentrated in the mound and larger, up-ended ones found in the surrounding pits and channels.
Poorly-developed ring	PR	Topography and boulder segregation not as well developed as in rings. The ring may only be partially surrounded with channels or pits, or have an excellent topographic ring development but only has poor to fair boulder segregation and up-ending of boulders.
Channel		Linear depression, often "V" shaped.
High-Angle Lobe	HAL	Topographically high-standing concentration of larger boulders in a semicircular fashion.
Low-Angle Lobe	LAL	Concentration of larger boulders in a semicircular fashion bur exhibiting low to no microrelief .
Tree border		Edge of contiguous arboreal cover.

TABLE R.2.3. Mapping unit descriptions.

MAP SYMBOL	DESCRIPTION
I	Boulders with maximum a-axis lengths of 2 m; all composed of sandstone (5Y 5/2)
II	Boulders with > 2 m a-axis length, ~30% cgl + cgl ss; well-rounded light "purplish" (5R 4/2) weathering
III	<< 1 m boulder a-axis length; dirty grayish (N7); well-rounded < 30% down to <20% cgl & cgl ss, poor surface morphology
IV	Extremely large boulders (3.0-4.6m common), max average ~2 m; 50-70% cgl or cgl ss; white to grayish weathering crust; poor topographic expression except where incised by channels; high degree of jumbling
W.IV	Nearly 2 m boulder a-axis average; 50% cgl or cgl ss with grayish (N7) weathering crusts; blocks highly jumbled; poor topographic expression
V	Very small, well-segregated, well rounded, boulders; many of the larger boulders concentrated in pits and channels; 5% or less cgl; grayish weathering crust (N7)
VI	Large, well-rounded, boulders, some with surface "polish"; up to 2 m a-axis length; well rounded; cgl content 30-60%; light gray weathering crust (~N7)
VIIa	Small, well-rounded boulders, but strongly elongate to platy; very coarse-grained ss; 10-20% cgl (5Y 5/2)
VIIb	As above, but larger, equant to elongated ss boulders w/trellis weathering pattern on surfaces
VIIc	Platy, angular boulders from scarp and rotten float
VIId	Large slabs, coming from white zone
VIII	60-90% vfg ss; low (0-10%) cgl (N7); partial weathering crust
IX	Traceable by distinctive boulder trains, only.
X	Traceable by distinctive boulder trains only
XI	Traceable by distinctive cgl boulder trains only
XII	Boulders with 1-2 m a-axis lengths; 30-60% cgl (5R 4/2)

Adler identified a number of linear-like areas of similar lithologic composition, texture, structure, and weathering characteristics. These criteria were used to set up a number of mapping units. TABLE R.2.3 describes the twelve mapping units that Adler used to map lithologic features in the down-gradient portion of the Hickory Run boulder deposit.

A map of the microtopographic features in a small area of the forest-free area is shown in FIGURE R.2.2 (also shown in Sevon, 1969). Adler set up criteria by which the relative ages of emplacement of mapping units in the deposit could be interpreted. TABLE R.2.4 shows the criteria of relative age used to interpret the depositional sequence of the mapping units. FIGURE R.2.3 shows a portion of Alder's map as presented in Sevon (1969).

TABLE R.2.4. Age sequence of latest preserved major downfield movement in Hickory Run Boulder Accumulation.

RELATIVE AGE	CRITERIA
Younger than	Block Size: larger than Block Angularity: more angular than (blocky, slabby, equant) Block Orientation: in-place to jumbled Block Weathering Crust: still largely preserved Local Field Topographic Relief: high and irregular X-C Relationships: cross-cut by (or "trapped" by) older mapping units
Older than	Block Size: smaller than Block Angularity: more rounded than Block Orientation: few jumbled intact blocks; some flat-lying boulders Block Surface and Weathering Crust: almost completely gone, color changes and/or "second-cycle" of pitting in remaining surface crust; high-degree of vegetation and/or lichen cover Local Field Topographic Relief: flat or smooth X-C Relationships: penetrated by; cut-off; "pushed by"; incorporated into; distortion of boulder "flow" streaks In-Place Development: ring patterns; sorted rings; stripe patterns

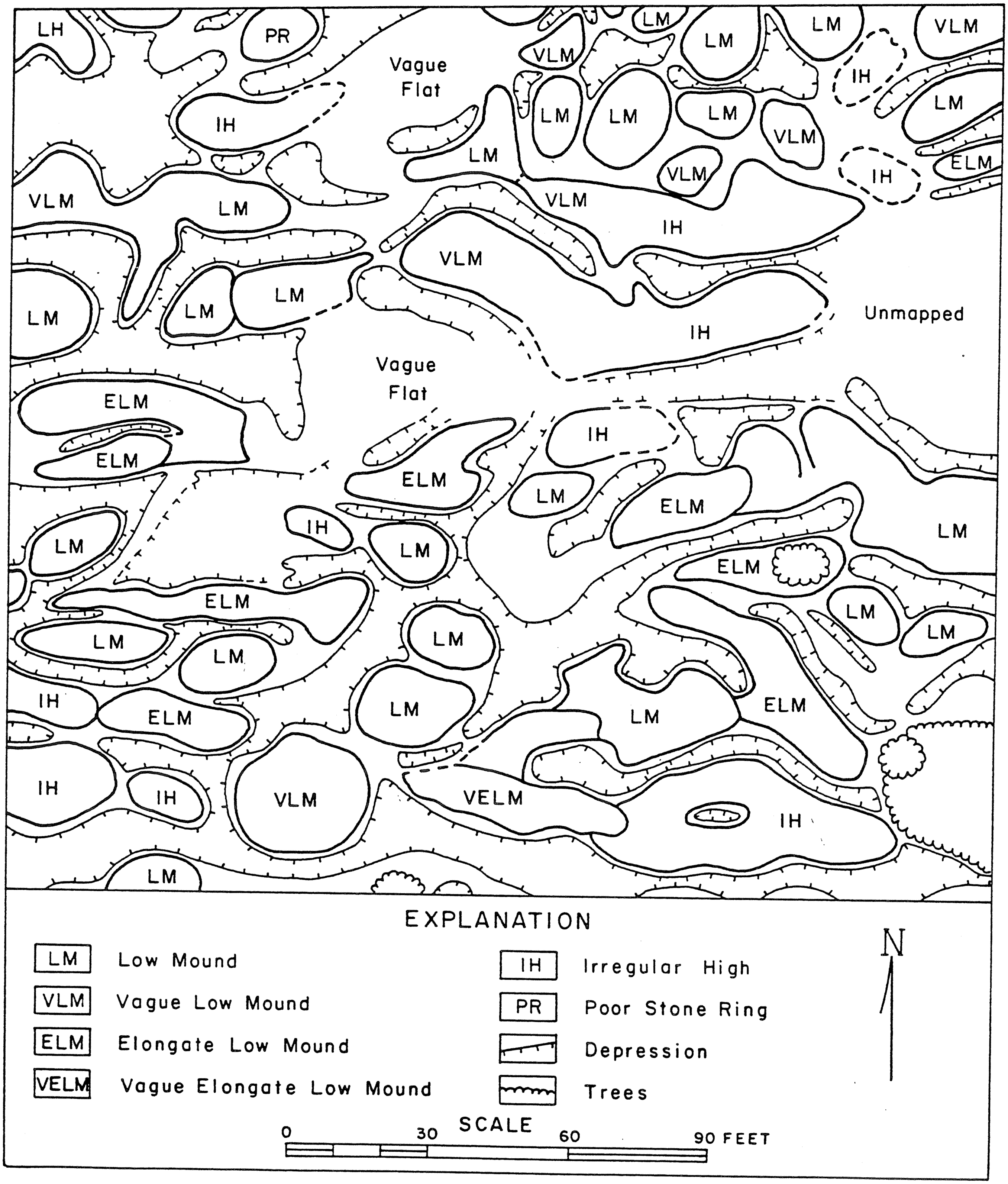
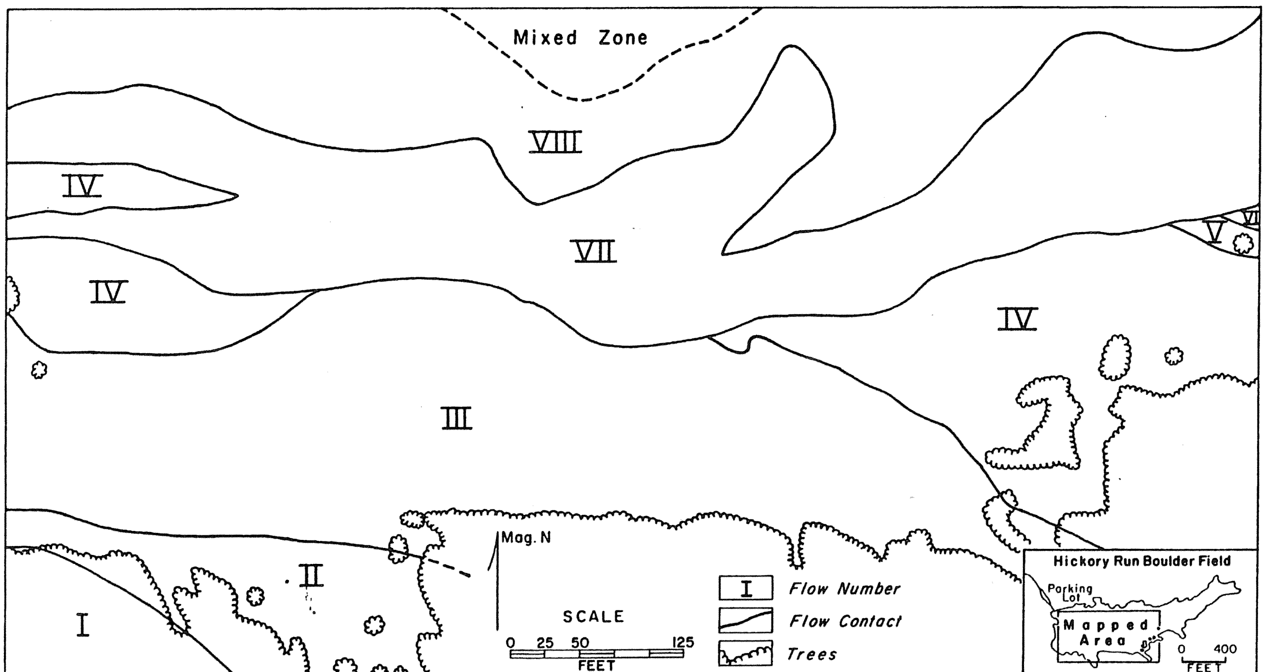


FIGURE R.2.2. Map of microtopography in a small part of the Hickory Run Boulder Field or Block Stream (From Sevon, 1969, Figure 10, p. 224). A. A. Adler mapped the entire forest-free area in this detail. For description of topographic microfeatures see TABLE R.2.2.



DESCRIPTIONS OF FLOWS

I: 100% Ss., 5-6' max. average boulder
II: 30% Cgl.+ Cgl.Ss., rounded purplish boulders
III: < 30% Cgl.+ Cgl.Ss., small red + gray Ss. boulders
IV: 50% ± Cgl. + Cgl. Ss., poor surface morphology
V: 5% ± Cgl., small rounded boulders, good morphology
VI: 30-60% Cgl., large rounded boulders
VII: 0-20% vcg. Ss., small rounded tabular boulders
VIII: 60-90% vcg. Ss., some Cgl.

FIGURE R.2.3. Map of "flows" of distinctively different lithologies in the Hickory Run Boulder Field or Block Stream. This map (From Sevon, 1969, Figure 11, P. 226) represents a part of the entire forest-free area mapped in this detail by A. A. Adler. Note apparent truncating nature of some contacts, indicating relative ages of depositional events. For description of mapping units see TABLE R.2.3. For criteria of relative age used by Adler see TABLE R.2.4.

Adler cites the following lines of evidence of emplacement of individual mapping units by some form of "flowage" as opposed to a non-viscous or non-plastic type of emplacement:

(1) Zones of boulder orientation were found and mapped that suggest that the individual units displaying these zones were emplaced by some sort of viscous flowage.

(2) Some mapping units display boulder units with lobe forms that have corresponding boulder imbrications on the frontal lobe ends.

(3). "Flow Streaks" which are aligned with the orientation of the elongate mapping units up- and down-gradient can be seen on some of the oblique aerial color photographs, and in some cases on the ground. The streaks are deflected at almost the same point where the major boulder streams are deflected, and tend to swerve and bend where the major mapping unit bends.

(4) "Feeder" sorted stripes from upslope source areas merge into boulder streams and enter the main field in certain upslope parts of the deposit. Orientations of boulders can be seen in some of these sorted stripes.

(5) There is a decrease in size, increase in rounding, increase in segregation and sorting, change in color of weathering crusts, and increase in pitting and etching of such crusts in the downfield direction in almost all of the boulder streams.

(6) "Exit" sorted stripes are present in the lower portions of the field. Orientations of boulders can be seen in some of these sorted stripes.

(7) Orientation of boulders can be seen in some of the topographic channels.

(8) Along the borders between the elongate mapping units, smearing out of boulders can be observed.

(9) Penetration of one mapping unit into another can be mapped.

(10) Individual boulders of "foreign" lithology are incorporated into adjacent mapping units and are almost completely to completely encircled by the adjacent unit.

(11) The microrelief features that correspond to the individual elongate mapping units are deflected and oriented to parallel the borders of the individual mapping units. In areas where boulder mixing is mapped, and where it appears that the individual mapping units were competing for space, the microrelief features tend to be more equant, or tend to parallel the trend of penetration.

(12) Where mapping units are penetrated or deflected, they "thin out" and sometimes are cut off from the parent elongate unit up-gradient.

Adler used the following criteria to indicate that the Hickory Run deposit is stable under the present climatic and geomorphological environment:

(1). A study of forest vegetation, conducted with the use of aerial photographs taken from 1939 to 1959, indicates that vegetation has encroached onto the field in this time interval.

(2) An extensive lichen covering of boulders is present around the margins of the field.

(3) Mineral stainings and coatings of boulders show no evidence of recent scratching or scraping.

		TURN AROUND and return to two-way gravel road.
110.2	0.9	**TURN LEFT** onto one-way gravel road.
111.7	1.5	Cross under Pennsylvania Turnpike.
113.1	1.4	**TURN RIGHT** at "T" junction with paved road.

114.2	1.1	**TURN RIGHT** onto 534.
118.0	3.8	Continue straight ahead along the Lehigh River Valley as 534 turns right.
119.8	1.8	**TURN LEFT** onto 940 West and cross the Lehigh River to enter downtown White Haven.
120.0	0.2	**TURN LEFT** at the first street beyond the bridge and immediately park on the right by the restaurant.

LUNCH STOP

After lunch, **TURN AROUND** and **TAKE A LEFT TURN** onto 940 West.

120.3	0.3	**TURN LEFT**, continuing on 940 West.
120.6	0.3	Cross over I-80, continuing on 940 West.
123.9	3.3	Climb a hill and pass outside the Late Wisconsinan glacial limit.
127.0	3.1	**TURN RIGHT** onto Crescent Road.
127.4	0.4	**BEAR RIGHT** onto Maple Street.
127.8	0.4	**TURN LEFT** and then immediately **RIGHT** onto Birkbeck Street.
128.1	0.3	Start across a valley. Thick drift deposits of Late Illinoian(?) age are exposed in strip mines to the right.
129.3	1.2	Just before the road turns sharply to the left where a NO OUTLET road continues straight ahead, park on the left and disembark. Walk up the NO OUTLET road that continues straight ahead between some houses and then follow trail through woods.

STOP 2.3: TORS ON GREEN MOUNTAIN THAT ARE YOUNGER THAN LATE-ILLINOIAN(?) IN AGE

SITE OVERVIEW:

The valley downslope (north) shows a strike valley carved in bedrock assigned to the Mauch Chunk Formation composed of clastic red beds of Devonian age. This valley also contains a part of Interstate-80 that was traveled this morning on the way to the Hickory Run area. The next ridge is underlain by the Pocono Formation of Mississippian age which is here a resistant siliciclastic sandstone and conglomerate. If the skyline is visible, the ridge there is underlain by the Pottsville Formation of basal Pennsylvanian age, here a resistant siliclastic sandstone and conglomerate marking the south limb of the Northern Anthracite Coal Field. Ice of Late Wisconsinan age buried the near ridge and stopped 100 to 150 m below the tors on the slope immediately below. In the strict geographic sense of the original definition of the term "periglacial" (Lozinski, 1909) these tors were then indeed truly periglacial!

The view across the mountain (south) shows a shallow synclinal valley and then a smoothly rounded anticlinal ridge on which the town of Freeland lies. Strip mines in the shallow valley expose 50 m of glacial deposits, including, multiple till tongues that wedge out against the anticlinal ridge to the south. The Late Illinoian(?) glacial limit lies along the crest of the anticlinal ridge at Freeland.

SITE DISCUSSION:

The Green Mountain tor site (FIGURE R.2.4) was covered by Late Illinoian(?) ice. Thus, tor development postdates the Late Illinoian(?) recession (if we assume wet-based ice conditions during advance). If geographic proximity is an important control on severity of periglacial activity, this site had an extremely severe periglacial environment during Late Wisconsinan glaciation, since it was just outside the Late Wisconsinan glacial limit.

A boulder colluvium mantle covers the shallow valley to the south and overlies the glacial deposits assigned a Late Illinoian age. Boulder colluvium covers the steep slope of Green Mountain to the north and extends onto the Late Wisconsinan terminal moraine in places. The production of such a colluvial mantle immediately adjacent to the Late Wisconsinan terminus is expectable. As the sole remaining residuals of upland bedrock at this site, tors (FIGURE R.2.5) may represent the most resistant parts of the bedrock structure and stratigraphy here. What is interesting is that there is significant weathering pan development (0.5 m long, 0.2 m deep) in the relatively pure quartzite bedrock on top of the tors. The presence of these Opferkessel implies a relatively rapid weathering rate, considering what is known about solution rates of quartz, since (presumably) the land surface at the end of the Sangamon interglacial was stripped off the ridge to provide the parent material for the downslope colluvium. Summary statistics of bedrock properties at two localities in this area are given in TABLE R.2.5.

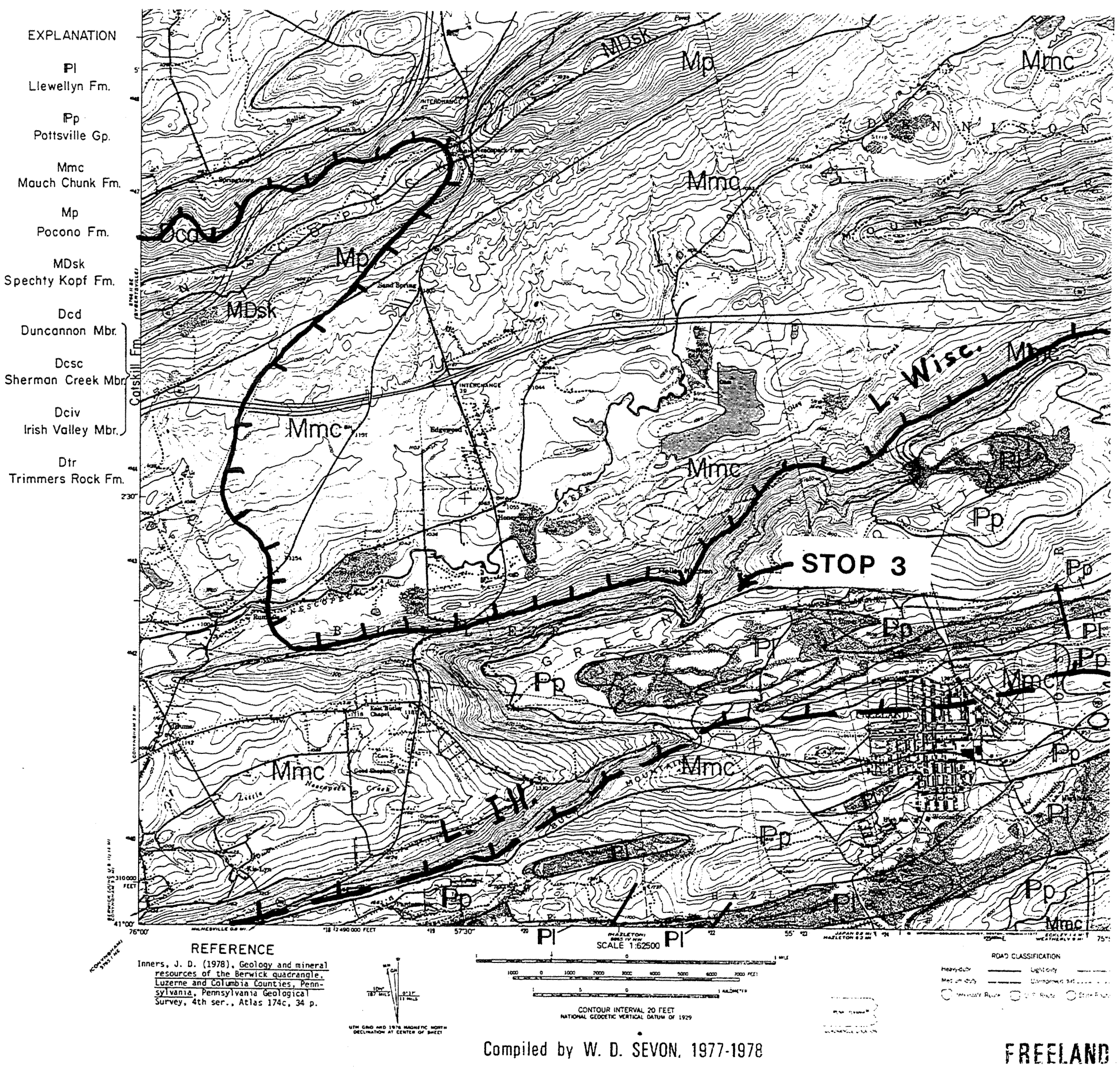


FIGURE R.2.4. Map of tor area near Hells Kitchen, in the Freeland, PA quadrangle.

STOP 2.4A: TORS THAT ARE YOUNGER THAN PRE-ILLINOIAN

SITE OVERVIEW:

The view downslope toward the city of Hazleton (north) shows a series of shallow valleys and rounded ridges running west to east (FIGURE R.2.6). Each ridge marks an anticline crest that exposes either tor-producing conglomerate and sandstone of the Pottsville Formation or non-tor producing mudstone and sandstone of the Mauch Chunk Formation. Each synclinal valley contains anthracite coal overlain by glacial deposits assigned a Pre-Illinoian age that are in turn overlain by colluvium derived from the adjacent ridge crests. The wooded ridge beyond Hazleton marks the last ridge underlain by Pottsville Formation on the northern edge of the Eastern Middle Coal Field, and it also marks the Illinoian glacial limit. The ridge beyond, on the skyline, is underlain by the Pocono Formation. The intervening valley underlain by the Mauch Chunk Formation was traversed earlier in the day to reach Hickory Run.

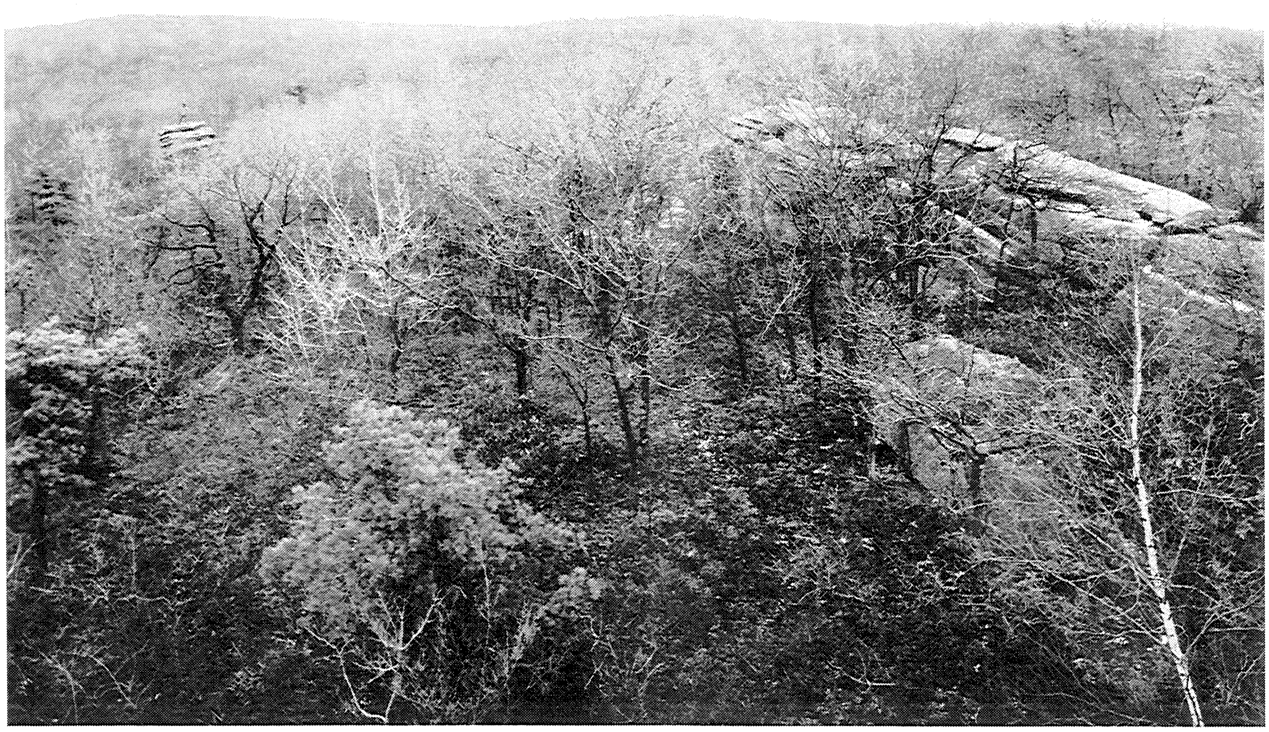


FIGURE R.2.5. Tors in the Hells Kitchen area of the Freeland, PA, quadrangle.

TABLE R.2.5. Tor characteristics at two selected sites in the Anthracite Region (D. D. Braun, unpublished data).

ROCK CHARACTERISTIC	STOP 2.3: GREEN MT. TORS	STOP 2.4A HAZLETON TORS
Bedrock lithology	Quartz-pebble conglomerate and coarse-grained qtz ss	Quartz-pebble conglomerate
Bedding Characteristics	Planar-bedded to x-bedded, beds 0.25 to 1.0 m thick	Planar to x-bedded, Beds 0.5 to 2.0 m thick
Bedrock strike	N 75° to 80° E	N 75° E
Bedrock dip	10° to 20° SE	Horizontal to 5° NW
Structure setting	Crest of homoclinal ridge	Crest of anticlinal ridge
Dominant joint orientation	N 40°-50° W (dip joints) N 50°-60° E (strike joints)	N 35°-40° W (dip joints) N 55°-65° E (strike joints)
Joint spacing	1.0 to 7.0 m (dip joints) 2.0 to 8.0 m (strike joints)	2.0 to 5.5 m(dip joints 2.0 to 6.5 m (strike joints)
Tor dimensions:		
Height	2.0 to 5.0 m	2.0 to 6.5 m
Length	3.0 to 17.0 m (along strike)	3.0 to 20.0 m (along strike)
Width	2.0 to 8.0 m (across strike)	2.0 to 6.0 m (across strike)

Leave parking spot and **IMMEDIATELY BEAR LEFT** on the main road.

130.6	0.7	**TURN LEFT** onto a three-lane road.
131.0	0.4	**TURN RIGHT** where the third lane ends and cross outside the Late Illinoian(?) ice limit.
132.0	1.0	**TURN RIGHT** onto 940 West.
134.2	2.2	**TURN LEFT** onto SR 3019. An active strip mine is ahead.
134.7	0.5	Stop briefly at the strip mine in this synclinal valley to view the largest dragline in the anthracite coal fields and possibly to observe exposures of glacial material.
135.5	0.9	Cross anticlinal ridge underlain by the Mauch Chunk Formation. The red bed material readily breaks up and does not produce boulder colluvium on the slopes.
136.1	0.6	Continue straight through the intersection and across a synclinal valley with more strip mines.
136.7	0.6	Start up next anticlinal ridge. This ridge is underlain by conglomerates of the Pottsville Formation.
137.2	0.5	Crest of the anticlinal ridge underlain by conglomerates of the Pottsville Formation.
138.3	1.1	**TURN RIGHT** onto 93 North.
139.0	0.7	**TURN LEFT** onto road to 309.
140.1	1.1	Park on the right side at a wide paved spot on the road shoulder that is across from an access road to a water tank on the left. Walk up road to the water tank area, then go right into the woods.

The view past the water tank (south) shows a single synclinal valley and then a homoclinal ridge marking the south edge of the Eastern Middle Coal Field. Tors composed of orthoquartzite conglomerate of the Pottsville Formation are visible in the clearing under the electrical power line near the ridge crest (FIGURE R.2.7). The culm bank (coal waste mound) west of the site marks the location of one of the large "coal breakers."

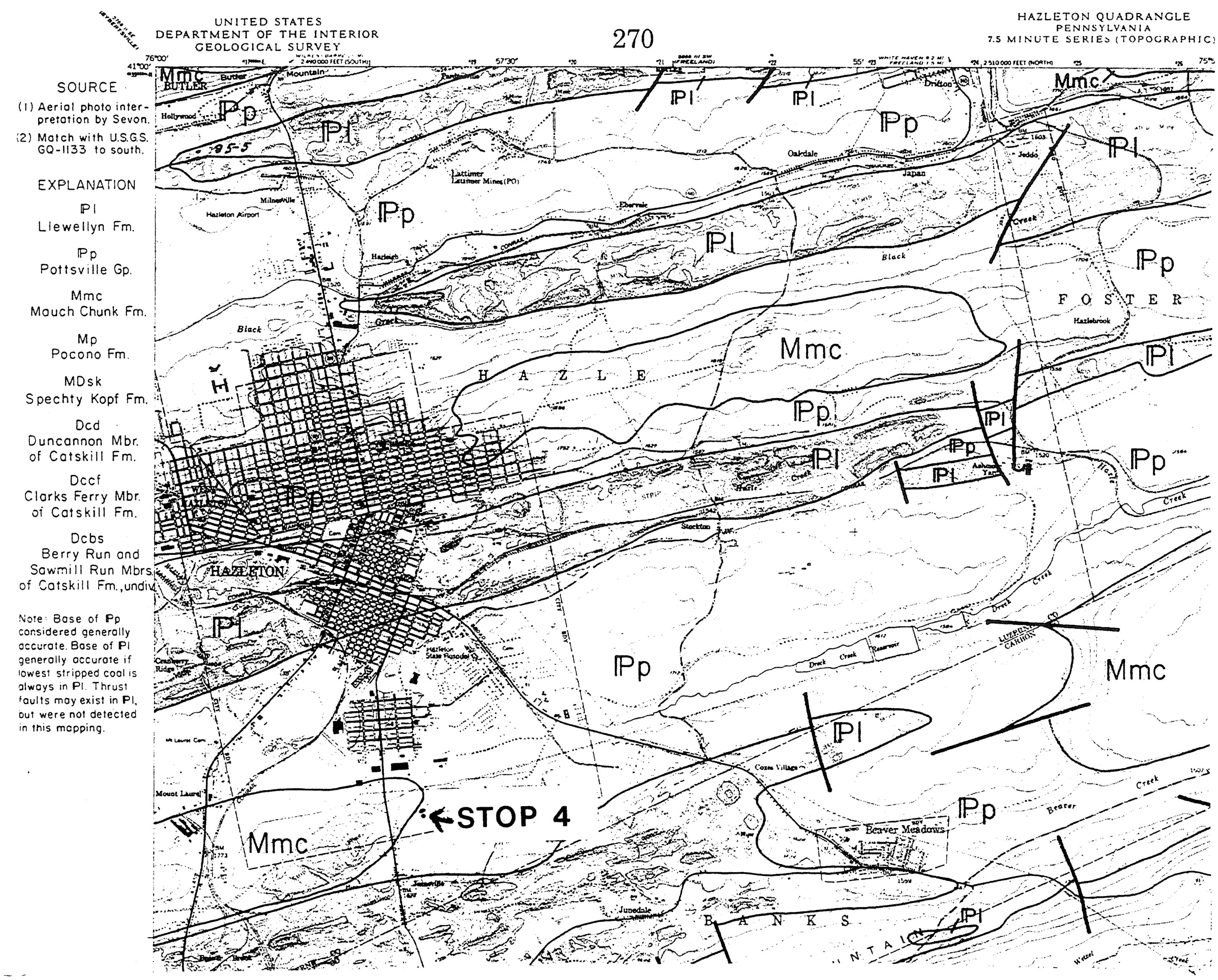


FIGURE R.2.6. Location map for STOP 2.4A and STOP 2.4B, in the Hazleton, PA quadrangle.

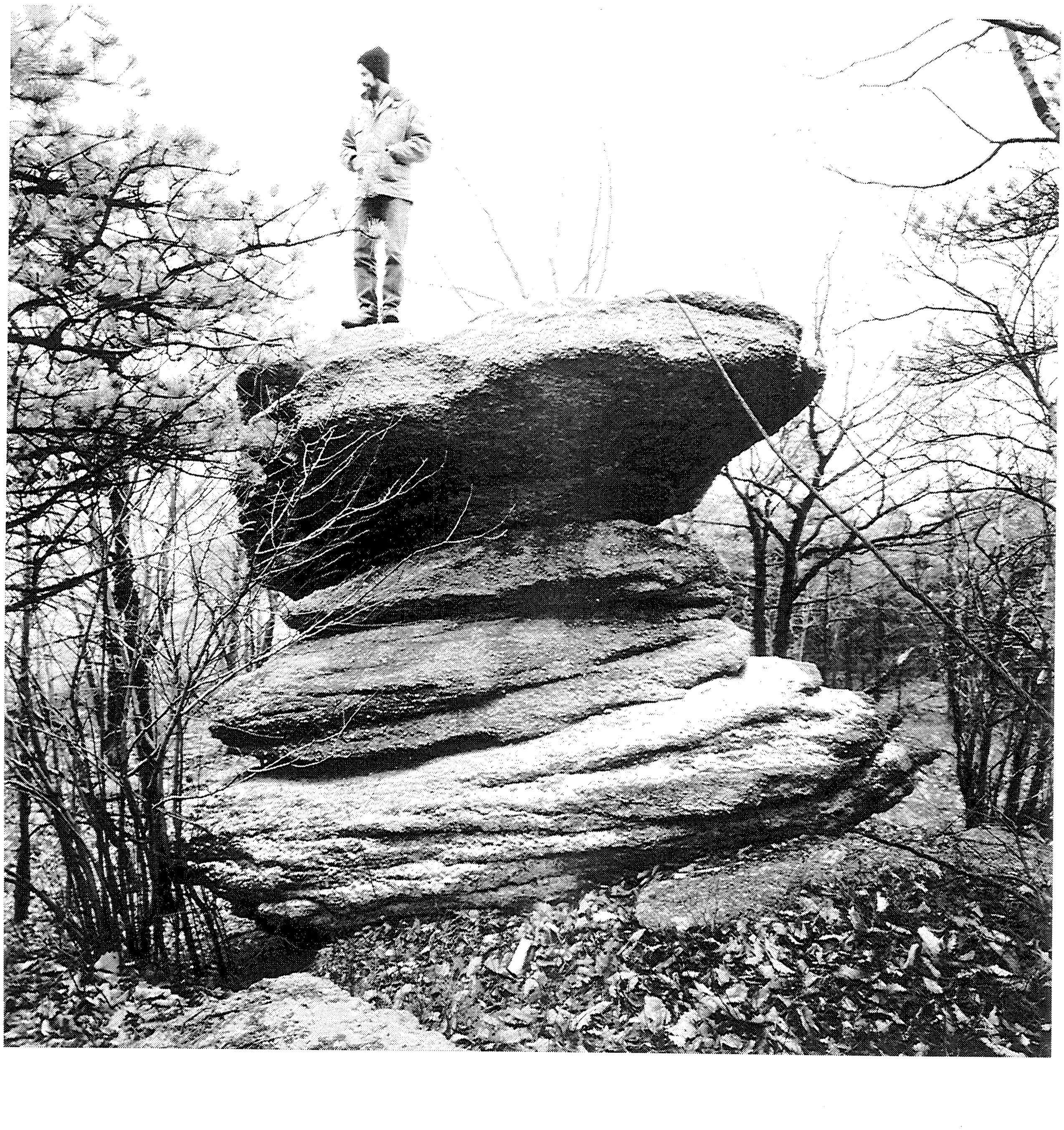


FIGURE R.2.7. Isolated tor in the STOP 2.4A area, Hazleton, PA quadrangle.

SITE DISCUSSION:

This site is on the crest of a broad anticlinal ridge underlain at the surface by orthoquartzite conglomerate of the Pottsville Formation. The tors are erosional remnants of a former outcrop of conglomerate of the Pottsville Formation. The dip of intact bedrock should be nearly horizontal, but strata in the individual tors have dips of 20° to 25° south into the topographic slope. These tors are elongate along strike at the very crest of the hill. Then, progressively downslope, the tors become more disrupted until their remains form a bouldery mantle that extends downslope to the valley floor. This volume of boulder colluvium indicates that at least 10 m, and more probably 30 m, of material has been eroded off the ridge crest since the Pre-Illinoian ice covered this site.

The top surfaces of the tors show a variety of weathering pits, pans, and runnels. These weathering features are somewhat more prevalent that those at the Green Mountain tor site (STOP 2.3). Still, all such features are tentatively interpreted as having developed during Mid- to Late-Pleistocene time since this area became free of wet- (or warm)-based Pre-Illinoian ice (possibly O^{18} stage 12). These tors also represent a surface 10 or more m below the original glaciated surface and, thereby, probably represent only Post-Late-Illinoian(?) weathering, a good topic for discussion.

STOP 2.4B: EXCAVATION 150 M DOWNSLOPE OF STOP 2.4A

Here, deposits of diamictons from weathering and transport of parent material derived from Pottsville rocks can be seen in an excavation.

		Upon leaving, **CONTINUE STRAIGHT AHEAD.**
140.4	0.3	**TURN RIGHT** onto South Popular Street and enter the city of Hazleton.
141.6	1.2	**TURN LEFT** onto 93 North and go through downtown Hazleton.
143.0	1.4	**BEAR RIGHT**, continuing on 93 North.
145.9	2.9	Cross I-81, continuing on 93 North and descending for the second time into the lowland underlain by the Mauch Chunk Formation, and into the area of Late Illinoian(?) glaciation.
150.2	4.3	Get into the left lane as I-80 is approached.
150.4	0.2	Cross under I-80, then **TURN LEFT** onto Old Berwick Road beyond the exit ramp for I-80 East.
150.6	0.2	**BEAR SHARPLY RIGHT** and continue uphill.
150.9	0.3	**TURN RIGHT** into the telephone company parking lot. Disembark and walk around to the right side of the fenced enclosure.

STOP 2.5: STONY COLLUVIUM, INTERPRETED AS BEING OF ILLINOIAN AGE, OVERLAIN BY BOULDER-RICH COLLUVIUM, INTERPRETED AS BEING OF WISCONSINAN AGE.

This site was covered by ice of Late-Illinoian(?) age and is only about 10 km outside the Late-Wisconsinan glacial limit. This site is in a toeslope on the dipslope of Nescopeck Mountain, a ridge underlain by sandstones and conglomerates of the Pocono Formation. The location map for this stop is shown in FIGURE R.2.8. The land surface here is covered by a one-stone-thick cobble and boulder mantle that is vaguely sorted into areas of stone-rich and stone-poor soil that trend normal to contour lines.

The upper one-half meter or so of material has a brown color that is generally associated with glacial drift and colluvium of Late Wisconsinan age in the region. The thinness of the material of probable Late Wisconsinan age suggests that this location represents a transport zone of colluvium toward a depositional zone further downslope. It is possible that the deposition of at least several meters of Post-Late-Illinoian(?) recession-aged colluvium produced a transportational surface uniquely shaped for the entrainment of colluvium of Late Wisconsinan age.

The upper colluvium is underlain by reddish-brown material that may be reworked or colluviated drift of Late-Illinoian(?) age that once mantled the upper slopes of Nescopeck Mountain. The well-developed upslope-downslope fabric in clasts indicates that this material has been completely remobilized and moved downslope since glaciation. Glacial flow here is parallel to bedrock strike and along the slope trend, so that the fabric cannot be glacial in origin.

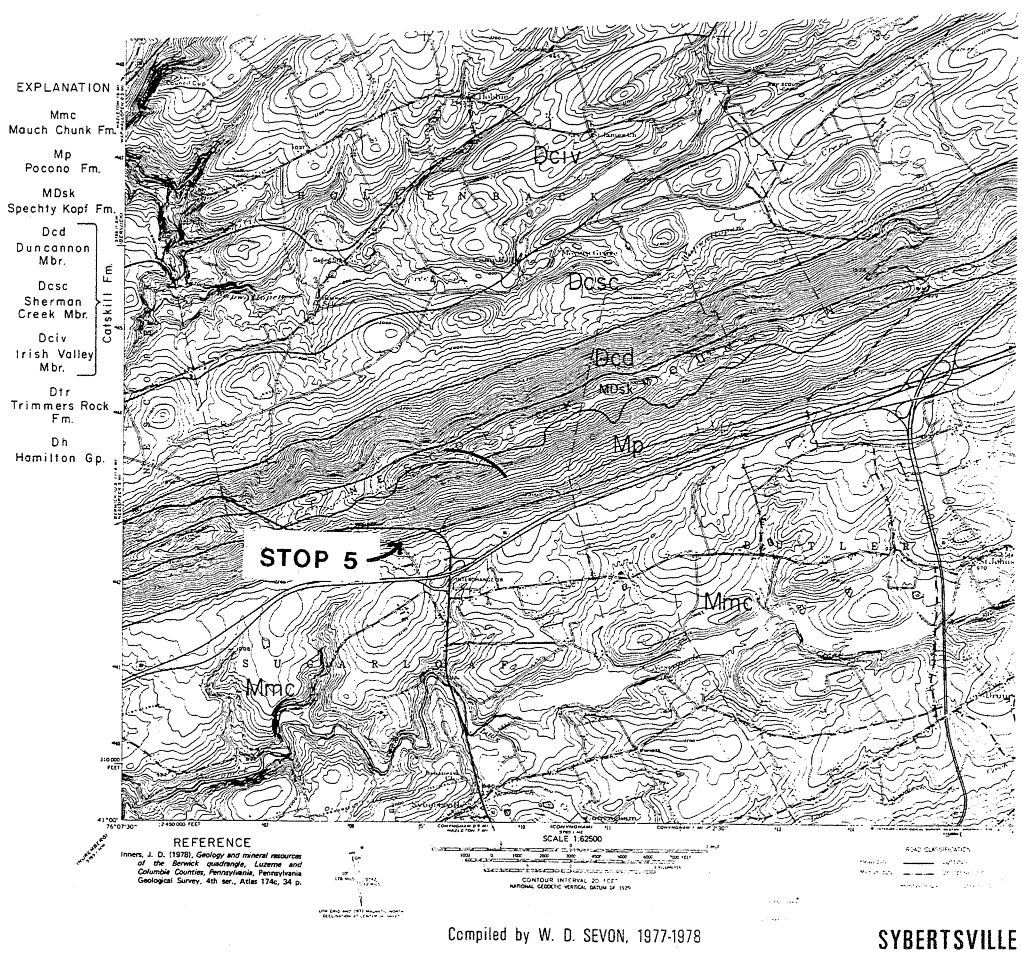


FIGURE R.2.8. Location map for STOP 2.5 in the Sybertsville, PA quadrangle.

RETRACE ROUTE to 93.

151.4	0.5	**TURN RIGHT** onto 93 and then immediately **TURN RIGHT** again onto entrance ramp for I-80 West.
155.3	4.1	Outcrops of red beds of Mauch Chunk Formation.
156.5	1.2	Water gap through Nescopeck Mountain, underlain by the Pocono Formation.
157.4	0.9	Outcrops of red beds of the Catskill Formation.
164.3	6.9	Cross the underfit valley of Ten Mile Run, an abandoned valley of the North Branch of the Susquehanna River, diverted by deposits of Late Illinoian(?) age.
165.0	0.7	Late Wisconsinan outwash terraces on the right.
165.5	0.5	Cross the North Branch of the Susquehanna River.
166.5	1.0	Ascend from the valley onto an anticlinal structure here composed of non-resistant red mudstone of the Bloomsburg Formation.
170.7	4.2	Crossing the buried valley of Fishing Creek, the valley to the right that is "aimed" right at I-80. In pre-Illinoian time, the creek flowed from right to left across the present position of I-80. The valley was filled by the frontal kame deposits of the Late Illinoian(?) terminus.
171.1	0.4	At the exit for Bloomsburg University, the I-80 roadcut is in the 50 m thick frontal kame deposits of the Late Illinoian(?) terminus.
174.3	3.2	**BEAR RIGHT** onto the Buckhorn Exit (Exchange 42) and continue to bear right, staying in the right lane.
174.8	0.5	**TURN RIGHT** into the Columbia Mall entrance and then immediately turn right again.
175.0	0.2	**TURN RIGHT** into the Econo Lodge Motel.

Overnight stop.

BLOOMSBURG, PENNSYLVANIA, TO STATE COLLEGE, PENNSYLVANIA *VIA* APPALACHIAN MOUNTAIN SUBSECTION OF THE MIDDLE SECTION OF THE RIDGE AND VALLEY PROVINCE:

Total	Interval	Description
0.0	0.0	Depart Econo Lodge, Buckhorn exit, Bloomsburg, PA, and **TURN LEFT** on PA Route 42, north toward I-81.
0.5	0.5	**RIGHT TURN** onto ramp for I-81 West; enter I-81 west.
21.0	20.5	**EXIT** from I-81 west onto Route 180 north
33.5	12.5	**EXIT RIGHT** off Route 180 toward PA Route 405
33.7	0.2	**LEFT TURN** onto PA Route 405 west into Muncy; **CONTINUE STRAIGHT AHEAD** through Muncy.
35.5	1.8	Begin crossing West Branch Susquehanna River.
37.0	1.5	Cross drainage of Turkey Run and **IMMEDIATELY TURN RIGHT** on State Home Road.
37.8	0.8	**STOP 3.1: MUNCY LOESS-MANTLED TERRACE**

The Duncannon soil at this site is developed in loess over pre-Wisconsinan till or terrace material. The soil has a weakly developed argillic horizon (see pedon data 041-023) and is classified as a Typic Hapludult. This pedon has a lower base-saturation in the lower B horizon than is usually found in the Duncannon soil. When this soil was sampled, in 1974, it appeared to have ice wedge casts in the underlying pre-Wisconsinan material that were filled and mantled with loess. The terrace surface on which the Duncannon soil is located is the fourth level above the floodplain of the Susquehanna River. Soils were sampled on each of these 4 levels, as well as on the floodplain. Loess was identified on terrace levels 2, 3, and 4, but not on level 1, which has an elevation that is only slightly above the flood level of the last major flood in this area (Hurricane Agnes, 1972). Since sampling, no follow-up work has been done on these terraces or the soils on them.

With the possible exception of "Pre-Nescopeck Loess" (Inners, 1981), all of the loess known to date (1992) in Pennsylvania appears to be of late Wisconsinan (Woodfordian) Age. The placement of the loess as Woodfordian is based on similar soil development in loess in unglaciated areas (Bucks and Lycoming counties) and in glaciated areas (Bradford County). In the glaciated area, the loess is found on top of Woodfordian till. Pre-Wisconsinan loess must have been deposited, but no unequivocal loess of this age has been reported. Such deposits presumably exist and may be identified in future studies.

In Pennsylvania, loess occurs adjacent to the Susquehanna, Delaware, and Allegheny Rivers. On gentle slopes, the loess varies in thickness from less than 30 to 150 cm. Greater accumulations are found locally and in footslope areas (Millette and Higbee, 1958). Loess less than 25 cm thick is very difficult to identify in soil profiles, and it is likely that more loess is present in Pennsylvania than has been reported. Loess does not extend laterally away from the major river valleys for any appreciable distance, particularly where the slopes are steep. The loess apparently was eroded—either contemporaneously with or subsequent to its deposition. This is well illustrated in Bucks County adjacent to the Delaware River. In the central part of the county, soils on slopes of less than 8% are developed in brown loess. Soils on the steeper slopes in the same area are developed in red Triassic sandstone and shale material that underlies the loess (Carey, 1978). The brown and red soils contrast strongly and are easy to identify on these landscapes.

37.8	0.0	Leave soil pit on Muncy State Prison Grounds, and **CONTINUE WEST** on State Home Road.
38.6	0.8	**CONTINUE STRAIGHT** at stop sign at Brick Church Road.
39.5	0.9	**TURN RIGHT** on Brouse Road.
40.6	1.1	**TURN RIGHT** on PA Route 54.
42.2	1.6	**TURN LEFT** onto US Route 15. Route 15 to the right (north) is climbing into a classic wind gap, the presumed ancient course of the Susquehanna River across Bald Eagle Mountain before stream piracy brought it to its present course around the eastern end of the mountain (Faill, 1979, p. 3). Route 15 passes through an impressive low-gradient block field, the Devils Turnip Patch (Geyer and Bolles, 1987), that occupies the floor of this gap.
46.3	4.1	Proposed site for hazardous waste incinerator is on the left, sited on Pre-Wisconsinan till (rocky orange soil visible in road cuts) that is slowly being lowered into dissolving limestone.
56.9	10.6	**TURN RIGHT** on Loan Road (just before the Weis Market, at the third traffic light entering Lewisburg from the north).
57.2	0.3	**TURN RIGHT** on JPM Road, then make an **IMMEDIATE LEFT** into Lewisburg Medical Park. Park in Dr. Bruce's lot; the features are in the open space to the west.

STOP 3.2: LEWISBURG MEDICAL PARK: NONSORTED PATTERNED GROUND AT AN ELEVATION OF 160 METERS

Here, a polygonal network of filled joints in shale is interpreted as ice wedge casts.

Soil was removed from a several hectare site in 1987, preparatory to its development as a medical park. The cold, dry winter of 1987-1988 caused preferential needle ice growth in the weathered axes of these wedge-shaped casts. This made them visible—and mappable—in plan as a net of orange welts. They are somewhat visible in summer, as stripes of weathered beige soil within the black shale bedrock.

The elevation here is 160 m. The bedrock is highly friable Marcellus Shale of Devonian age. Bedrock dip and topographic slope are both within a few degrees of horizontal. It is probable that over 0.5 m of soil was removed during excavation. All soil horizons are gone. Soil wedges tend to be about 1 m to as much as 1.5 m deep in this valley; the remaining parts of the wedges here (after excavation) are less than 0.3 m deep.

Wedge casts are often visible near here in foundation excavations into flat uplands made of shale bedrock, like this site. They show deformation of adjacent bedding and well-weathered, vertically oriented, exogenuous clasts at their axes. To date, (1992) more of the finds are in bedrock of the Bloomsburg Formation than in bedrock of the Marcellus Formation, but this may be biased toward trends in development and construction in the area.

When mapped (FIGURE R.3.1), this net of wedges is sub-rectangular, with preferred orientations of 60° and 140°. These are highly plausible orientations for jointing in this rock; it is presumed that the wedging happened along joints. The length of side of the polygons is a very regular 7 m. FIGURE R.3.2 shows details in an excavation into one wedge filling at this site.

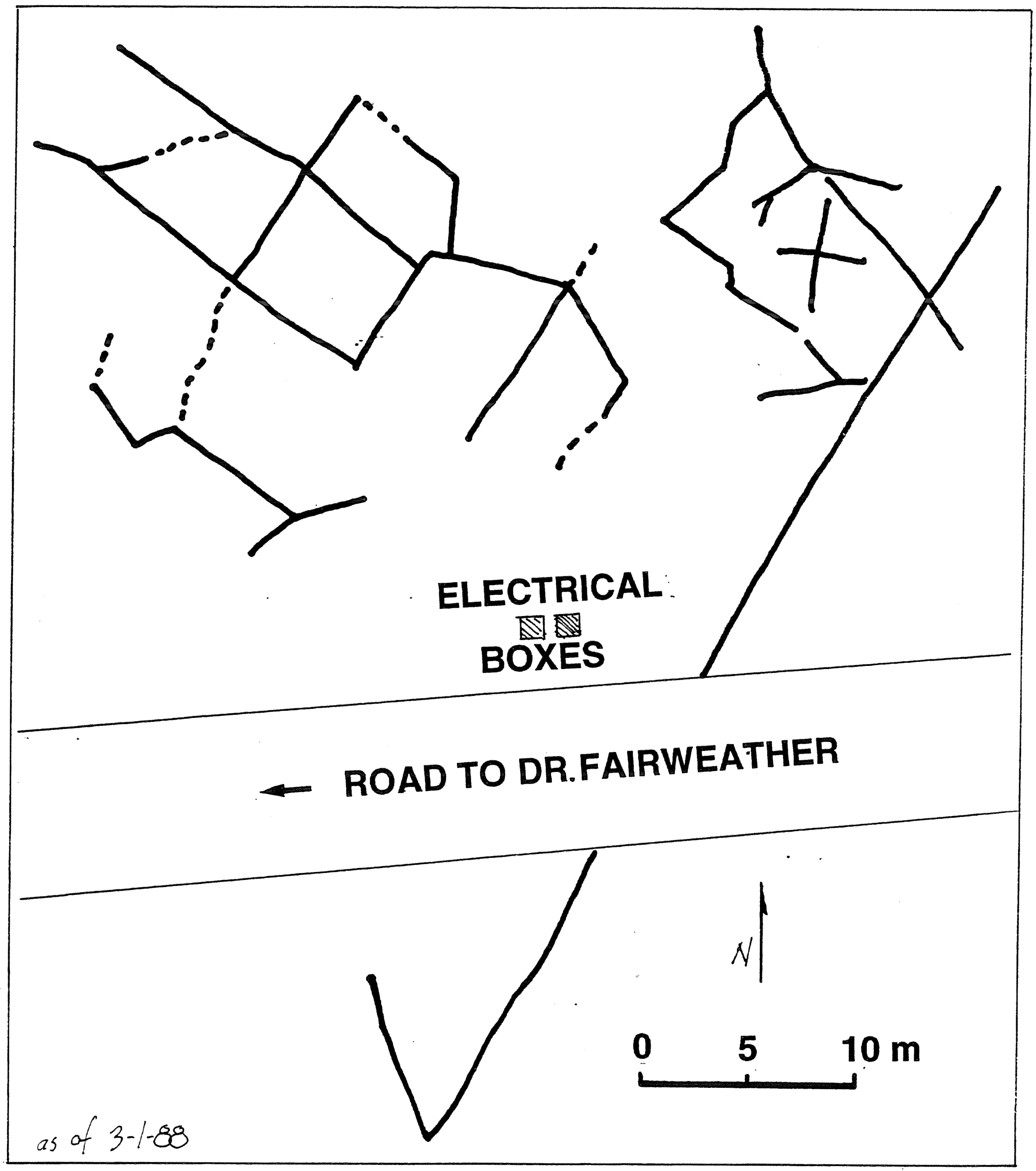


FIGURE R.3.1. Map view of net of wedge-shaped casts visible at the surface as low ridges of weathered shale, 01 March 1988. The northeast quarter of the site has since been developed into a doctor's office. Lewisburg, PA, quadrangle.

FIGURE R.3.2. Photograph (16 August 1992) of trench into shale bedrock across wedge filling in shale. Previous horizontally-directed excavation had stripped the soil and some of the immediately underlying shale bedrock from the land surface at this exposure. Note deformation of shale bedrock on both sides of wedge filling.

57.3	0.1	Return to JPM Road, **TURN LEFT**.
57.5	0.2	**TURN RIGHT** at the stop sign on Hospital Road.
57.8	0.3	Go straight at the light, crossing U S Route 15 onto River Road.
58.5	0.7	**TAKE THE FIRST LEFT** after the bridge, onto North Water Street.
58.8	0.3	**TURN LEFT** onto Market Street, PA Route 45, at stop sign.
60.2	1.4	**TURN RIGHT** at flashing amber light in Montandon, onto Houser Run Road.
60.5	0.3	Park safely at Richard Brown's farm, just before the greenhouses.

STOP 3.3: MONTANDON SAND DUNE FIELD

For the Central Appalachians, this area is an unusual occurrence of palaeoperiglacial aeolian landforms and materials. A field of parabolic dunes and an aeolian mantle were developed at the edge of the preserved Wisconsinan terrace of the Susquehanna River.

About 5 square kilometers of aeolian sand surround the town of Montandon (FIGURE R.3.3). The central part of this feature was described by Chase (1977). The body of sediment starts at the edge of the Wisconsinan floodplain of the river and extends eastward. Three morphologies are recognizable:

- There are over 100 parabolic dune forms, oriented to a wind from 287°, concentrated at the edge of the terrace and extending to 2.5 km east.
- There are massive dune-sand bodies, up to 200 m x 1000 m x 6 m high, oriented parallel to the river. Chase (1977) refers to these as longitudinal dunes. They are all on the floodplain, and they have been streamlined by river flow.
- There is an amorphous sand mantle 2 km wide, grading into a loess soil cap which extends up to 4 km inland. The sand mantle at Montandon exhibits little relief, but it probably is many meters deep in some places, such as at the Montandon cemetery, just NE of the central intersection. Loess is deep, but spotty, west of the river. On the Bucknell University Campus, 1.5 km due west, bedded, well-sorted silt is up to 3 m deep on lower slopes.

The physical association of this deposit with the exceptionally wide Pleistocene terrace is obviously important, as that was the source of the sand. The terrace here is 1 km wide. Perhaps ponding at the Shamokin Mountain-Montour Ridge narrows just downstream created the wide alluvial plain here. Its surface is 10 m above bedrock; the present channel of the Susquehanna River has cut back down to that pre-glacial level, flowing less than a meter above weathered limestone bedrock at the Lewisburg bridge. The surface of the terrace is marked with the bars and swales of the heavily loaded river which carried meltwater from Wisconsinan ice about 40 km upstream.

Chase (1977) correlates the formation of the dune field with down-cutting by the post-glacial Susquehanna River, arguing that this was when the water table dropped enough to liberate sediments to the wind. She also suggests that an arid period might have been necessary to mobilize sediment.

An alternative explanation is that the desiccated and abandoned winter channel of the broad melt-water stream would have provided abundant aeolian sediment year-after-year. This could have happened during deglaciation, but also during the glacial cold-phase maximum. The streamlining of the longitudinal dunes suggests that they formed when the river was far higher than it is today. The presence of parabolic dunes implies that the climate was humid enough to support the vegetation which anchored the windward end of the dunes, at the same time that abundant sand was being provided.

This site is a soil pit into a dune at the farm of Richard Brown. The site is within 10 m of the Wisconsinan Susquehanna River alluvial surface; it was likely washed by the stream periodically during deglaciation. The nearby topography is a low-relief sand mantle.

FIGURE R.3.3. Air photo of Montandon dune field; USGS image AQO-4W-114, 7-3-59. The image is 4.5 km wide. The West Branch of the Susquehanna River is on the left edge; the town of Montandon is in the lower middle; the three-part greenhouse at which STOP 3.3 is located is visible 200 m above the bottom of the image, immediately west of the fiducial mark. Arcuate dune sections are visible in a belt running north from that point, and extending a kilometer and more to the east. The region between the dune field and the river (including the wooded areas) is the Pleistocene terrace noted above. Northumberland, PA quadrangle.

The Lakin soil at this site is developed in aeolian sands. Data from a Lakin pedon (049-013) sampled 1.8 km south of this site indicates that it is a Udipsamment, although it does have a color B horizon. Soil Taxonomy does not allow soils with color B horizons to be classified as Inceptisols if they have very sandy B horizon texture. The age of this soil is uncertain, but because it has a color B horizon, it is probably of Woodfordian Age. Lamellae (thin layers of clay and iron oxide accumulation) are common in the lower parts of these soil pedons (profiles).

Two small areas of old dunes are located upriver between this site and Jersey Shore. These sites are approximately 50 meters above the present river level. The age of the old dunes is not known. The best estimate of their age comes from the soils developed in them, which indicates a pre-Wisconsinan Age.

60.5	0.0	Return to Houser Road, **TURN LEFT**.
60.8	0.3	Straight at flashing red light in Montandon.
63.0	2.2	**RIGHT** at stop sign onto PA Route 405.
64.2	1.2	Keep on Route 405 when road divides just past railroad underpass.
64.5	0.3	**TURN LEFT** onto PA Route 642 (Mahoning Street) at first traffic light in Milton; straight at next two traffic lights, go across the river (leave Northumberland County and enter Union County) and under US Route 15.
69.0	4.5	**TURN RIGHT** on Sunrise Road (first road past Fort Titzell Road in the village of Kelly Crossroads).
70.6	1.6	**STOP** in front of Sunrise Church, at Miller Bottom Road.

STOP 3.4: SUNRISE CHURCH PICTURE STOP AND DISCUSSION.

Regional overview: A general view of the processes that operated during Cenozoic time to create the overall mountain landscape and the processes that operated during Pleistocene time that molded its surface (FIGURE R.3.4).

Sunrise Church overlooks the east end of the Nittany Anticlinorium, within which the rest of the day will be spent. Great anticlinal folds that involve the Tuscarora Formation, a medium- to thick-bedded orthoquartzite sandstone of Silurian age, plunge all around us. STOP 3.6 is atop Buffalo Mountain (= Sand Mountain) directly to our west, from where the pattern will be clearer.

This area was weakly glaciated during Pre-Wisconsinan time. It is presumed that ice extended short distances into these synclinal valleys, but uplands no bigger than the one we are on were above the ice. Clear ice margin features—a moraine and proglacial drainage—are visible in Laurelton, 30 km WSW.

The profile of the characteristic concave lower hillslope—a broad, low-angle apron—is seen on the north flank of Buffalo Mountain. STOP 3.5 is on the equivalent hillslope on the opposite side of the valley. The convex upper hillslope is also visible here, although its appearance is exaggerated by the curving bedrock of the anticline.

FIGURE R.3.4. View west from Sunrise Church area. The prominent ridge is Buffalo Mountain, underlain by the Tuscarora Formation in the nose of an anticline that plunges toward the viewer. To the left (south) of Buffalo Mountain are other anticlinal ridges also plunging easterly. The southern half of the valley of Spruce Run is shown on the right side of this view. View is from within the Allenwood, PA quadrangle looking west into areas in the Williamsport SE and Mifflinburg quadrangles.

The heads of two sizeable creeks lie within 200 m of each other, just west of this stop: Spruce Run flows to the south, and Little Buffalo Creek flows north. The pattern of two streams heading in, and draining, one mountain valley suggests that drainage here is inherited from a large fan deposit which covered most of the surrounding lowlands. Such a fan is well defined at Buffalo Gap, north of Hartleton, 25 km WSW. That fan seems to have been created by debris flows which came out of the gap. The edges of the fan have been degraded by headward erosion. Debris may still be being added to the head of fans during Holocene time, but only during catastrophic events that have a long recurrence interval. Fresh-looking debris flow deposits abound in the mountain valleys around here.

The floodplain of Spruce Run (in the valley due west) is clearly the product of an agent other than the stream that now flows on it. Just beyond the Pennsylvania State Forest boundary on Spruce Run Road (ahead), the graded valley bottom is 500 m wide, bouldery, and possesses multiple sub-parallel channels. Either debris flows or large and very heavily loaded stream flow aggraded this valley. The de-icing of a permafrost landscape is a likely timing for this event, but there is no direct dating.

70.6	0.0	Continue west on Sunrise Road.
71.9	1.3	Go straight on Spruce Run Road at 3-way-stop.
74.3	2.4	The small dirt road to the right is at the foot of the feature mapped in FIGURE R.3.6.
75.7	1.4	Park at the shale pit on right, 200 m past Running Gap Road.

STOP 3.5A: RUNNING GAP: MEGA-CREEP IN BEDROCK

Mega-creep: Fractured bedrock is smoothly deformed through 110° from true structural dip, and for 15 m downslope.

The site is in the south-facing lower slope of Nittany Mountain, 50 m west of Running Gap Run, where it flows onto a debris fan above Spruce Run. A Pennsylvania State Forest borrow pit enters the Rose Hill Formation, a shale unit of Silurian age, dipping off the Nittany Mountain anticline at about 80° south. The local dip is parallel to the land surface and overturned; it is approximately 10° south. This is a result of the creeping of the layers as a continuous mass. The amount of movement is apparently 15 m at the surface, 5 m at 2 m depth, and 0 m at about 5 m depth.

A soil zone of dark mineral accumulation about 1.5 m below the surface in the east wall suggests an impermeable layer at that level, perhaps associated with a Pleistocene frost table. A wedge-shaped cast, here interpreted as an ice wedge cast, extending to approximately the same depth, is visible at the center of the north wall. A 5 m by 1 m mass of silty, bouldery sediment on top of the shale on the west side of the north wall is material from one of the welts mentioned below.

STOP 3.5B: RUNNING GAP: WIND-ORIENTED TOPOGRAPHIC WELTS.

Wind-oriented welts: Welt-shaped or tread-and-riser slope features are oriented across Pleistocene wind direction.

A 1 m high welt intersects Spruce Run Road 20 m west of the shale pit. It begins 60 m above the road, and continues 260 m down the 14% slope, before apparently being truncated by Spruce Run at the foot of the slope. Its bearing is 18° above the road and 23° below it. To the east, which is down the trend of local hillslope, the edge of the feature seems to be a bouldery topographic scarp. A similar welt lies 20 m west of this one. The two are separated by a swale of 3 m maximum depth. At 160 m south of the road, the swale "spoons" into a semicircular blocky barrier across the depression.

This feature resembles hundreds of similar welts or treads-and-risers in this region. The features occur on the lower hill-slopes of sandstone ridges, hill-slopes which are underlain by colluvium rich in fine-grained material. The slopes range between 10° N and 22° SSE, averaging about 6° SSE. Features on flat or on west- or north-facing slopes tend to be welts like this feature, about 20 m wide and about 3 m above the regional slope (see FIGURE R.3.5.).

Features on south-facing slopes tend to be straight treads-and-risers (see FIGURE R.3.6). These features are up to 1400 m in length and up to 8 m in height. A slight valley, often occupied by a small stream, is common just up-slope from the top of the riser. The top of the riser appears to be a welt, like the feature described at this site.

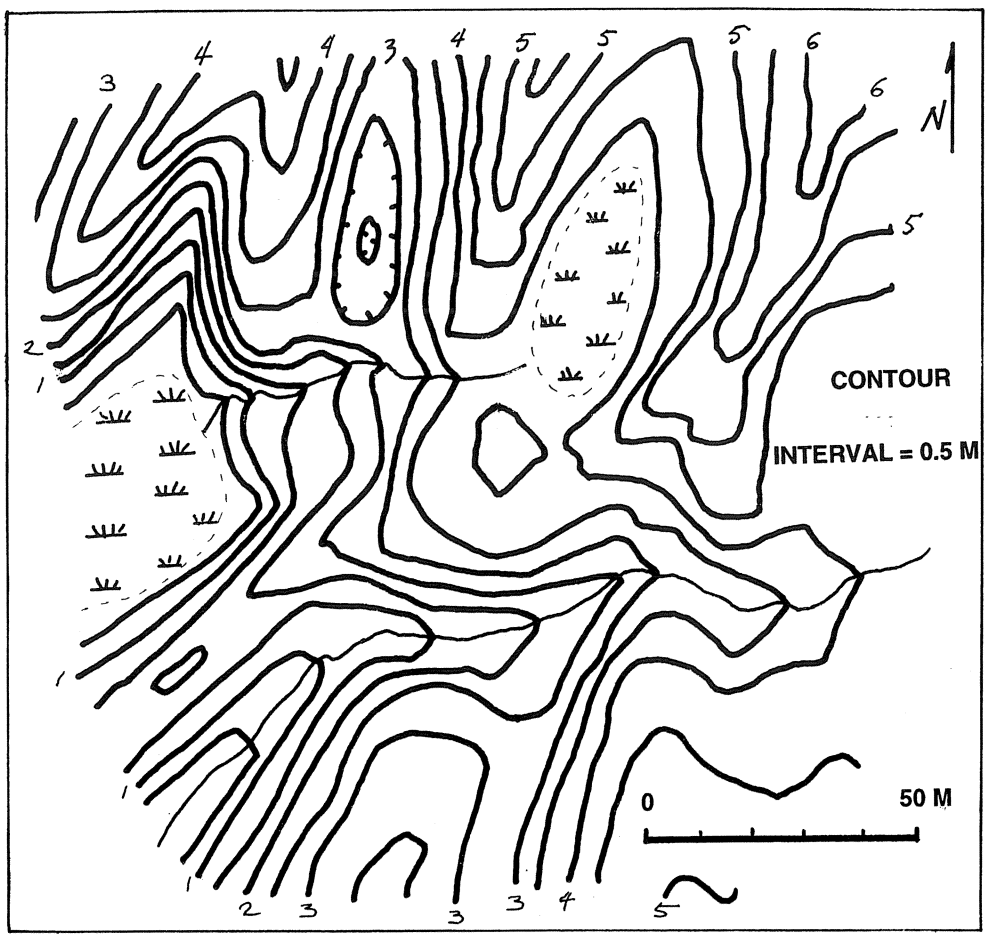


FIGURE R.3.5. Wind-oriented welts on gentle west-facing slope in Halfway Run Valley, 700 m WSW from the intersections of Sand Mountain and Boyer Gap Roads (see FIGURE R.3.9). Note rounded section, 20 m width, and ponding on east side of welts. Williamsport SE quadrangle.

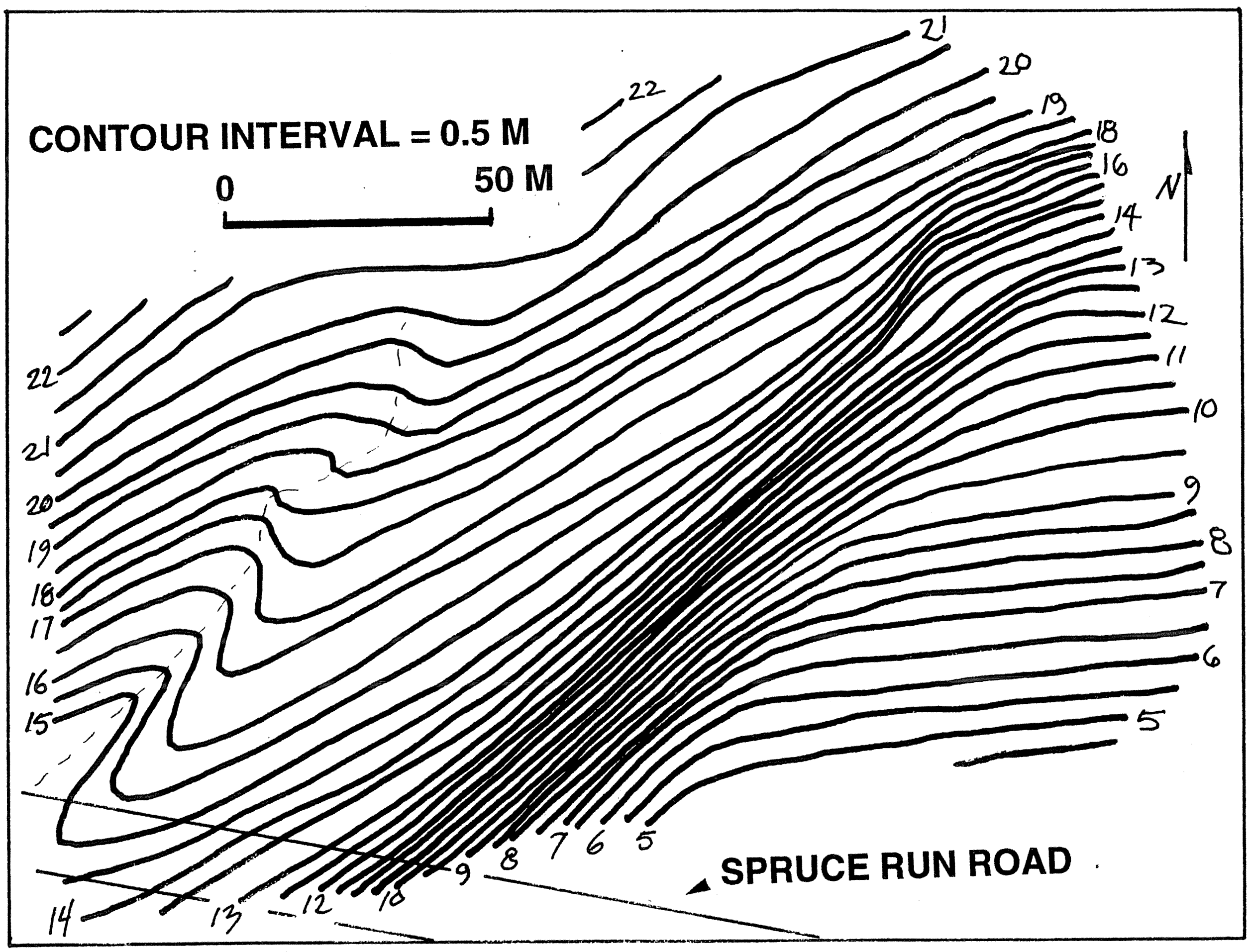


FIGURE R.3.6. Wind-oriented step-and-riser on south-facing slope on Spruce Run Road, 2.4 miles west of intersection with Sunrise Road. Note significant scarp on downslope side, small welt form on edge of tread. Williamsport SE quadrangle.

These linear features are preferentially oriented across the direction of the dominant winds during Wisconsinan time, as reconstructed from the parabolic dunes at Montandon, 12 km east (see FIGURE R.3.7.). The direction normal to the mean orientation of slope features, based on a sample of 179 features identified on aerial photographs, is 292°, compared to the paleowind direction of 287° reported at STOP 3.3. This one is normal to 293°.

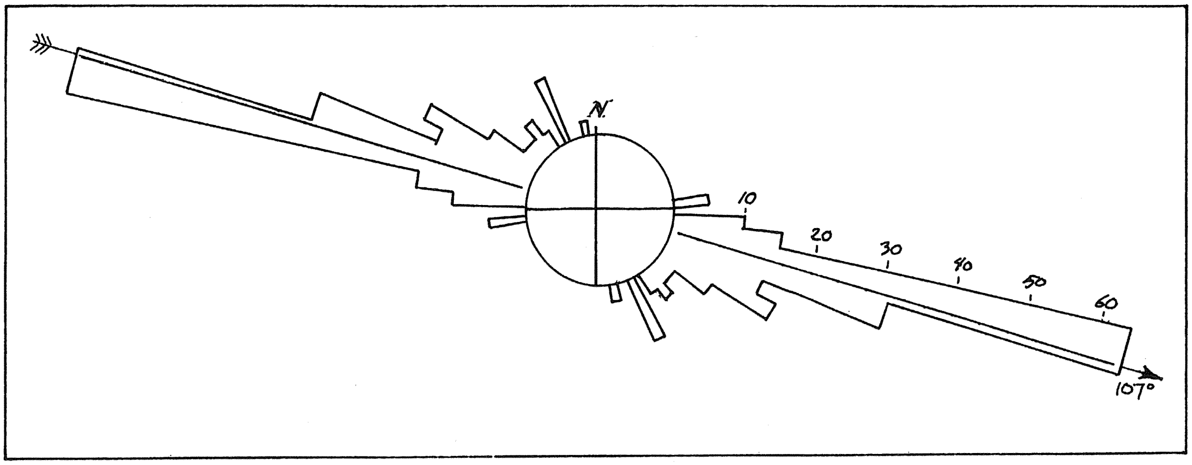


FIGURE R.3.7. Rose diagram of directions normal to the orientations of 179 welts and steps, measured on aerial photographs. Arrow indicates presumed Pleistocene wind direction, from Chase (1977).

A second-order regression of feature orientation against hill-slope accounts for 60% of the variance in orientation and predicts a cross-feature orientation of 284° on a flat surface. The best-fit surface shows that the greater the slope is (at an angle different from the wind direction), the more the orientation of the features differs from wind direction. This suggests that the features tend strongly to line up across the prevailing winds, and that they tend weakly to be oriented across slopes.

No bedrock controls match the average orientation. Strike of the bedrock averages 80°, and jointing is at many angles. In any case, the features are not found on undisturbed bedrock or on residual soils.

The features are clearly associated with other periglacial features, indicating a Pleistocene age and a periglacial origin. Features such as these are continuous with the scars of former frost mound features dated to 12.8 Ka at STOP 3.7. The upper ends of the ramparts of those features are equivalent to these oriented welts.

Sorted stone stripes are found between, and occasionally diagonally across, these features. Spacing of the stripes is 13 m to 18 m; they have very nearly the same bearing as the lobes.

I (B. Marsh) suggest here that snow accumulation in the lee of irregularities affected the thermodynamics of slope movement and ground patterning. Snow accumulations insulated the down-wind sides of solifluction features, decreasing depth-of-freezing and directing slope movement; the topography is colluvial. The differences between the simple welts on north- and west-facing slopes, and the risers on east-facing slopes reflect the difference between whether snow accumulated upslope of the welt, preserving a basin, or downslope of it, accelerating the steepening of a slope. This explanation is also consonant with the association with sorted stripes, which are also influenced by heat flow at the surface. Apparent patterned ground in limestone lowlands to the east is also preferentially oriented across wind direction.

Snow accumulation may have accelerated nivational processes in these spots; the topography is partly erosional. The surface of the lows between adjacent welts is very blocky and relatively flat, suggesting a channel lag. Results of refraction seismic analysis (FIGURE R.3.8) suggest that the welts are constructed out of relatively loose material and lie atop a level (but creeped?) bedrock surface.

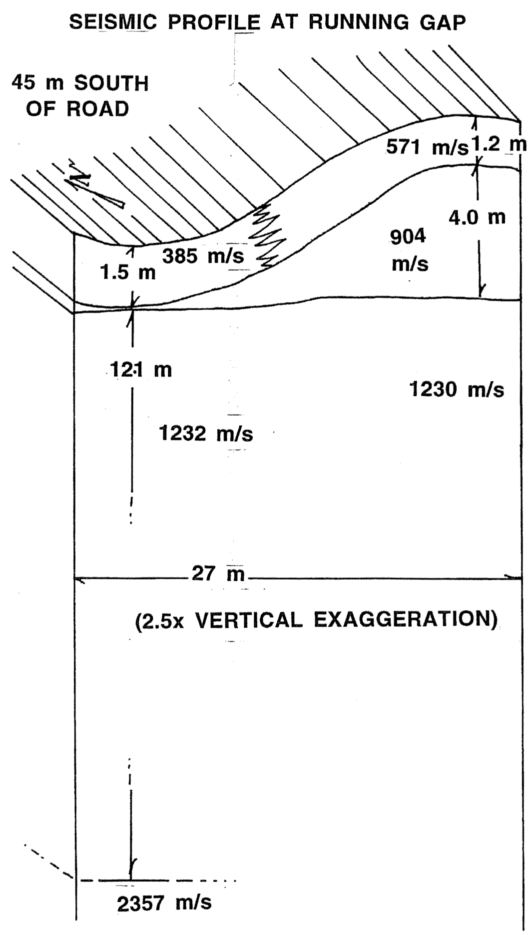


FIGURE R.3.8. Perspective view which diagrammatically shows results of seismic refraction over topographic welt. The results suggest that the welts are constructed out of relatively loose material and lie atop a level (but creeped?) bedrock surface.

Neither of these explanations accounts for the form of the welt-fragment at the shale pit across the road. The material of that welt seems to be draped across the creeped bedrock. It seems to show neither deformational penetration nor erosion into the slope material. But we may be looking at material moved off the welt, and not the welt itself.

75.7	0.0	**CONTINUE WEST** on Spruce Run Road.
79.1	3.4	**MERGE** (turn left) onto Cooper Mill Road.
80.3	1.2	**TURN RIGHT** onto Sand Mountain Road.
81.4	1.1	**PARK** opposite the yellow gate on top of mountain and walk to fire tower.

STOP 3.6: SAND MOUNTAIN FIRE TOWER

Regional overview; asymmetrical valleys: This stop features a mountain-top view of the central part of the middle section of the Ridge and Valley province, with a preview of the situation at STOP R.3.7.

The site is a Pennsylvania State Forest fire lookout tower atop a plunging anticlinal nose. The regular topography reflects the highly systematic bedrock geology of the area. A family of anticlines plunges toward the east, like porpoises at Sea World. Two ridge-forming sandstone bedrock mapping units produce high areas in the local topography: the Oswego (or Bald Eagle) Formation of Ordovician age, underlying this site, and the Tuscarora Formation of Silurian age, which underlies the ridge encircling this stop to the south, east, and north. Each of these formations supports ridges which can be followed back-and-forth across the landscape as far as one can see to the northeast and the southwest along this front of mountains. Accordance of ridge summits—whatever genesis one chooses to believe in—is convincing from this flat upland. See FIGURE R.3.9.

Across the lowlands underlain by shales and limestones of Silurian and Devonian ages which the route just crossed, two doubly-plunging anticlines underlain by the Tuscarora Formation are visible to the southeast. Between them, 50 km away, is the synclinal nose underlain by the Pocono Formation of Mississippian age surrounding the Western Middle Anthracite Field near Shamokin. Some distance to the west is the lowland of Brush Valley (eventually connecting to Nittany Valley), underlain by various limestone and dolostone rock units of Ordovician age.

Immediately to the west is Halfway Run valley, site of the fossil frost mound field of STOP 3.7. The area of these ground ice scars is indicated by the darker-colored hemlock forest on the valley floor. The anticlinal valley is bounded by ridges underlain by the Oswego (or Bald Eagle) Formation and floored by the Reedsville Shale. The asymmetry of this valley is apparent from this vantage, with the south-facing slope flatter than the north (see FIGURE R.3.9). Presumably, the south-facing slope underwent more freeze-thaw cycles during the Pleistocene when the slopes were most active. In this valley, as in most similar anticlinal valleys (where slopes are free of structural control), the more active south-facing slope has forced the stream to the south side of the valley, and the road is built on the more open north side.

These narrow shale valleys were very heavily colluviated in the Pleistocene. Aggressive, headward erosion into this colluvium is ongoing now in Cranberry Flats, the next anticlinal valley to the southwest (underlain by the Reedsville Shale), with rapid piping and chaotic drainage. The clearest ground ice scars in the mountainous area occur in these valleys which have high-water tables, impermeable bedrock, low relief, low stream energy, and abundant fine-grained sediment.

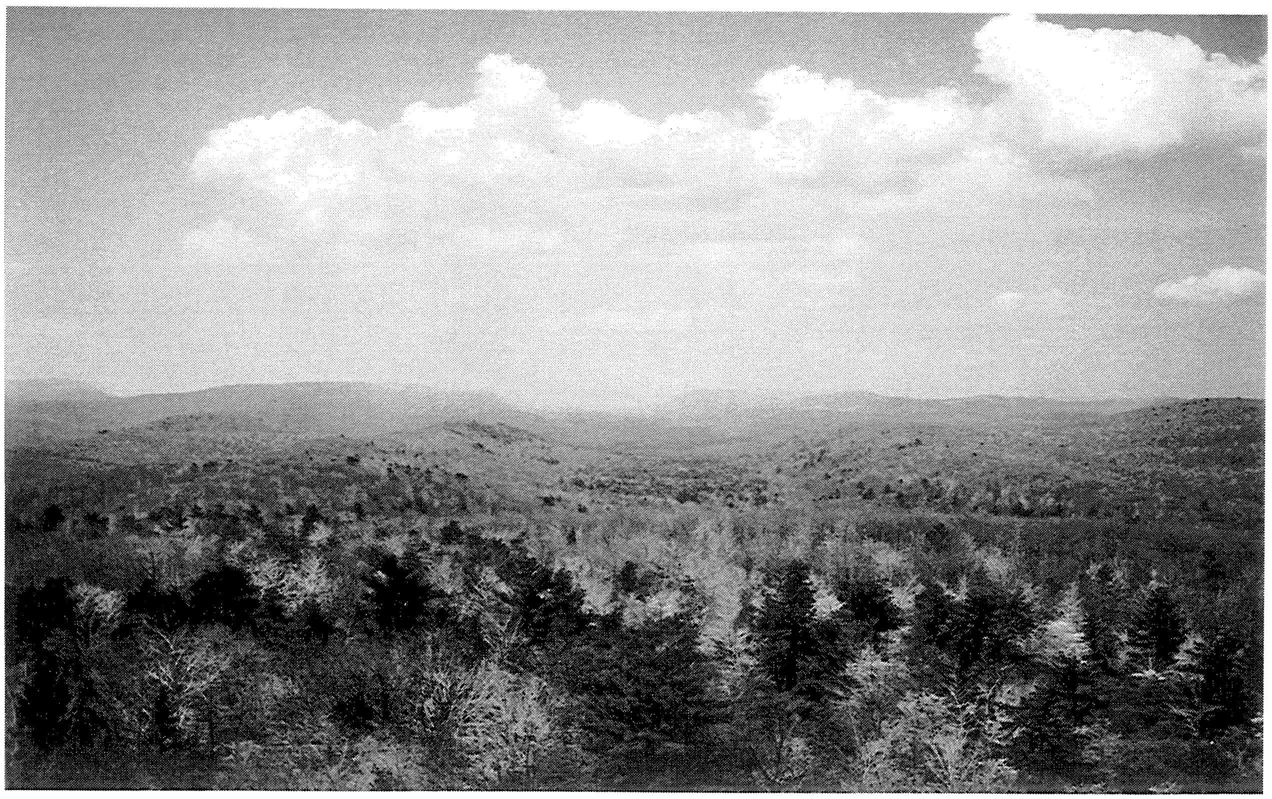


FIGURE R.3.9. View westward into area of the Hartleton quadrangle from Sand Mountain Lookout Tower located in the Carroll quadrangle.

81.4 0.0 Continue west on Sand Mountain Road.
82.2 0.8 Bear right at the junction with Boyer Gap Road.
83.3 1.1 The faint dirt road turning steeply to the left is the entrance to the fossil frost mound field (see FIGURE R.3.10).

STOP 3.7: HALFWAY RUN:

Ground-ice scars: Scars of fossil frost mounds developed in saturated colluvial lower slopes.

Dozens of elliptical basins—identified as ground-ice scars—occur along Halfway Run, in the relatively flat colluvial floor of the valley (Marsh, 1987). Basins are elongated down-slope and are bounded by parabolic, 1 to 3 m high ramparts which merge into the hillslope at their upper ends (see FIGURE R.3.10). Ramparts and basin-linings are blocky, sandy colluvium from the surrounding ridges. The basins are 2 to 9 m deep from the rampart top. They usually contain watery peat and silt. Modal size of the bogs within the basins is about 20 by 50 m, with maximum dimensions up to 150 m. Nearly every basin in this area has a seep or spring at its head.

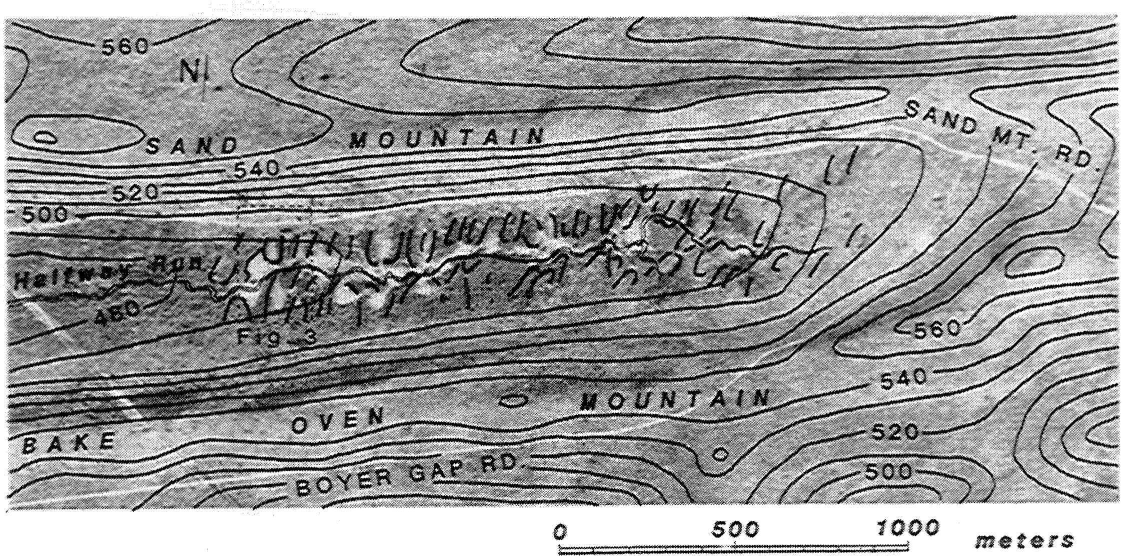


FIGURE R.3.10. Aerial photograph-topographic map composite of Halfway Run area in the Hartleton, PA quadrangle. Locations of individual low ridges—ramparts and oriented welts—are indicated near the stream. From Marsh (1987).

The bottom of the basin visited by this field trip, called Cattail Bog, is 6 m below the rampart top, at its maximum (see FIGURE R.3.11). Its area is about 100 by 40 m, and it is filled by a bog to half those dimensions. A sample of wood collected from 2 m depth at its northern end dated to 12.8 Ka.

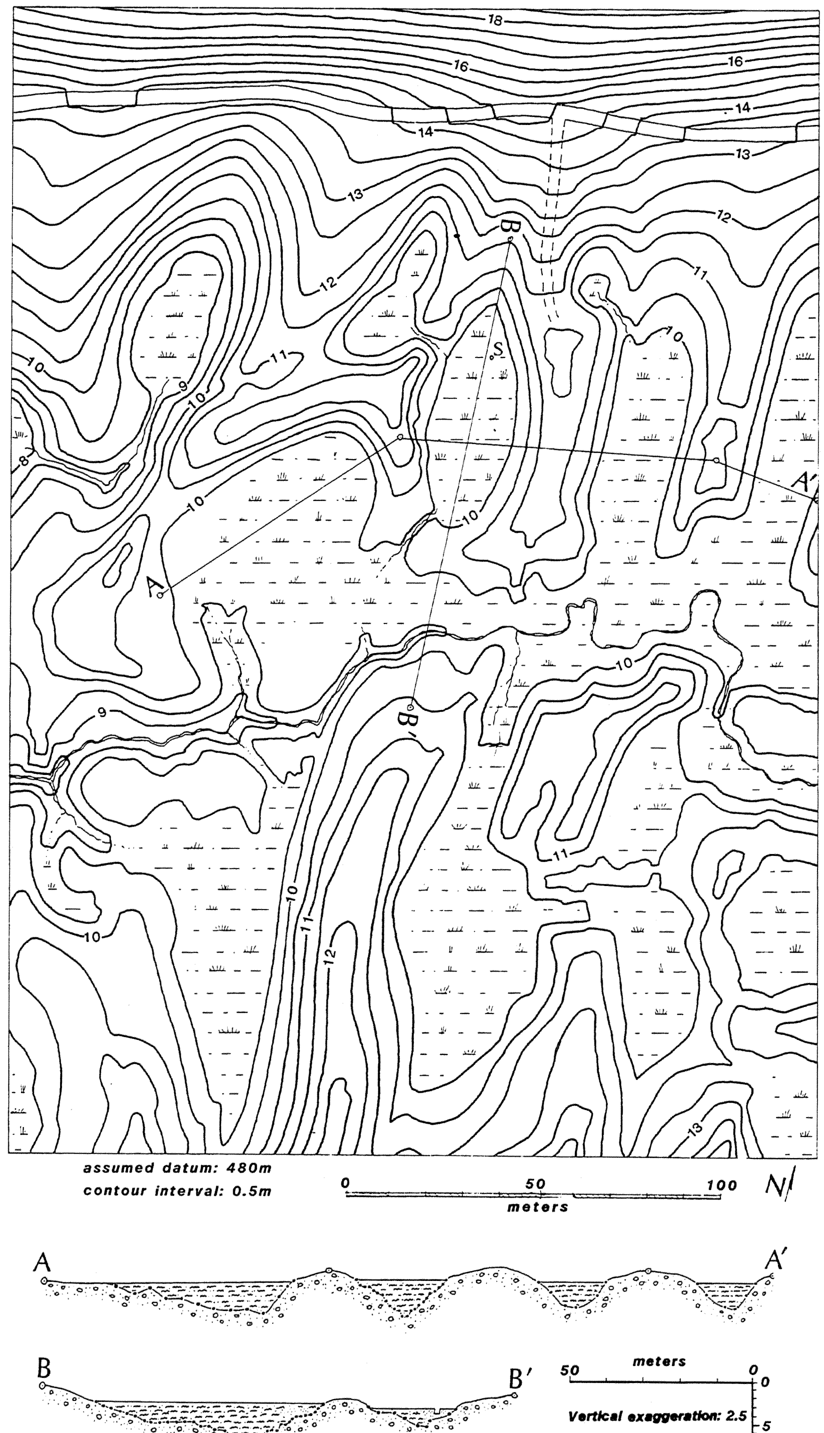


FIGURE R.3.11. Topographic map of part of the valley of Halfway Run, showing multiple ramparts and basins. Area of map is indicated as "Fig. 3" in FIGURE R.3.10 of this publication. The field trip will stop at the jeep trail branching off of Sand Mountain Road. Radiocarbon date in text is from material collected at point marked S (upper center). Cross-sections show mixed unconsolidated fill in basins lined with blocky colluvium. Dots on contact indicate depths-to-refusal for individual probings. (From Marsh, 1987). Hartleton, PA quadrangle.

The features are identified as ground ice scars on the basis of their depth below grade and their Pleistocene age. The association with seeps and springs suggests a genesis like that of an open-system pingo (Washburn, 1980), with ice forming within the ground from pressurized groundwater supplied from the rocky, sunny south-facing slope to the north.

An identification of these features as classic open-system pingo scars would probably be too simple. It is difficult to model a process which will produce stable growth of an elongate ice body from artesian pressure; surely, one end or the other would rise faster. A process like the growth of "mineralogical palsas" (Pissart, 1983) may be more plausible. The essential difference is that palsas grow by drawing water out of saturated ground by freezing it onto a growing ice body.

Similar fields of aligned, small, elliptical basins are common throughout the region. An extensive field of ramparts and bogs occurs in a patch of Pre-Wisconsinan glacial drift on the floor of a broad valley near the town of Penns Creek in Snyder County, about 25 km south of here. These are much longer than the basins at Halfway Run and are "beaded," as Pissart (1983) would suggest for minerogenic palsas. The features in this field are very consistently aligned across the paleo-wind direction, as Allard, *et al.* (1987) found in palsa fields in northern Quebec.

The ramparts of these ground-ice features *are* wind-oriented welts. They have morphology, topographic situations, component material, and orientations which are indistinguishable from those of the features described at STOP 3.5. On slopes facing into the wind, such as at the Penns Creek field or the east end of the Halfway Run field, the welts appear to have developed across the slope and have interrupted drainage. In these places, the ground-ice features appear to be a deepening of the basins created by those welts. In contrast, the putative pingo scars here at Halfway Run seem to be located where welts extended downslope onto saturated material. Whether the welts (or associated ice-wedges and patterned ground) localized the growth of ground ice between, or whether ground-ice bodies guided the growth of the slope features, is not known. In any case, the thermodynamic impact of accumulation of snow would have affected the development both of the welts and of the palsas.

83.3	0.0	**CONTINUE WEST** on Sand Mountain Road.
83.9	0.6	Cross power line; enter Raymond B. Winter State Park.
84.4	0.5	Continue straight ahead at intersecting paved road within Park.
85.1	0.7	End up heading west on the big paved road, at complex intersection of Sand Mountain Road, McCall Dam Road, and PA Route 192. Continue west on PA Route 192.
85.2	0.1	Leave Union County, enter Centre County. Route 192 ascends the strike valley of Rapid Run to the surface drainage divide, that is about on the Hartleton-Woodward quadrangle join. The route now descends into drainage of Elk Creek and, at Livonia, enters the cleared area in Brush Valley. Continue ahead on PA Route 192 through Wolfs Store, Rebersburg, and Rockville.
101.1	15.9	**LEFT TURN** at the Junction of PA Route 192 with PA Route 445. The direction of travel is now toward Spring Bank and the Millheim Narrows, a spectacular water gap of Elk Creek through Brush Mountain (FIGURE R.3.12).
101.9	0.8	Stop at the Stoltzfus farm.

FIGURE R.3.12. Millheim Narrows, a transverse water gap through which flows Elk Creek from one elongate strike valley to another. Millheim, PA quadrangle. A number of small (non-transverse) water gaps in Shriner Mountain (the ridge on the left) drain either side of Shriner Mountain and visually appear to be equally-spaced along the trend of Shriner Mountain on both sides of the ridge.

STOP 3.8: STOLTZFUS SOIL PIT.

At this pit, there is a good example of brown colluvium over red colluvium over shale bedrock. The red colluvium is about 6 meters thick, while the brown material at the surface is about 1 3/4 meters thick. The soil developed in the brown colluvium is best called a Buchanan (Aquic Fragiudult), although it does not appear to have a fragipan.

The major ridges in the Ridge and Valley area have the lower one-half to three-fourths of their slopes mantled with colluvium. The colluvium ranges from less than 30 cm to more than 30 m in thickness, and it forms simple side slope as well as more complex fan deposits. The simple, side-slope deposits extend on the average one-half mile (0.8 km) from the ridge crests, while the fan deposits (adjacent to gaps in the ridges) commonly extend one-quarter to one-half mile (0.4 to 0.8 km) beyond the simple slope deposits. The colluvial material extends downslope until the slope becomes very gentle or until a secondary ridge or stream is encountered.

The genesis of the soils developed in the brown colluvial deposits is discussed by Ciolkosz, *et al.* (1979). These authors indicate that these soils may have textural changes with depth. The textural changes are a reflection of both textural variation in the parent material and of argillic horizon development. The authors also indicate that these soils have fragipans in them, if they are not too clayey or if they do not have much limestone influence (Murrill soils) in the parent material. The authors concluded, from an evaluation of the properties of these soils and from the degree of weathering of their clay minerals, that they show only a moderate degree of soil development. The colluvial material on these slopes does not appear to be moving downslope today. Little, if any, deformation of tree trunks can be seen, if this deformation is a reliable indicator of soil and/or rock creep. Over a longer relative time span, the undeformed argillic horizons and fragipans in these soils indicate landscape stability since the time(s) of their development.

Thus, if these slopes are currently stable, when did the colluviation take place? Early workers attributed the movement and deposition to periglacial activity associated with glaciation during the Wisconsinan (Denny, 1956; Peltier, 1949). The only published numerical-age-dated evidence of visually-similar brown colluvium comes from radiocarbon dates in West Virginia (Jordon, *et al.*, 1987; Behling, *et al.*, 1991), which give a Late Wisconsinan age. Also pointing to colluviation and permafrost during Late Wisconsinan time are lines of evidence summarized by Clark and Ciolkosz (1988). Under a rigorous periglacial climate, mass movement of material downslope and the accumulation of it on the lower side slopes could occur. The similarity in soil development between the (brown) soils of these colluvial deposits and those soils developed in glacial till deposits of Late Wisconsinan age also indicates that periglacial movement and deposition occurred during Late Wisconsinan time (Marchand, *et al* ., 1978).

Of course, the chronology of deposition of the colluvium here is not known absolutely. The West Virginia radiocarbon dates indicate late Wisconsinan deposition of similar colluvium. The brown colluvium throughout Pennsylvania seems to be of a similar age. This is indicated by similar soil development in the same kind (same lithology) of colluvium throughout the state. The soils developed in the colluvium are similar in some aspects to late Wisconsinan (Woodfordian) Age soils developed in glacial till in that they have fragipans, but in addition to fragipans, they have argillic horizons. This probably indicates that the colluvium was more weathered than the till, and that it had more fine clay which could be moved to form an argillic horizon.

Recent work by Hoover (1983) and by Hoover and Ciolkosz (1988) indicates that the stratigraphy of the colluvial deposit is more complex than previously reported. These studies indicate that the slopes in the Ridge and Valley area in Pennsylvania have red colluvium buried by the brown colluvium. This site (Stoltzfus Pit, Millheim, PA quadrangle) is a good example of this association. Limited published and unpublished data indicate that the red colluvium is thicker than the brown material. The red color of the buried colluvium is due to oxidation associated with soil formation when the red colluvium was at or near the surface. Thus, the red material is a buried, but truncated, paleosol. The age of this buried paleosol is not known, although it is conventionally thought to be correlative with similar weathering products assigned to the Sangamon Interglacial in classical localities in the American midwest. Where the brown Wisconsinan colluvium is thin, present soil forming processes extend into the older material, welding the present surface soil to the buried paleosol.

101.9	0.0	**CONTINUE SOUTH** on PA Route 445 through the Millheim Narrows.
104.4	2.5	Junction, at traffic light, of PA Route 445 with PA Route 45 in downtown Millheim. The route is now in Penns Valley. **RIGHT TURN** onto PA Route 45 west. Continue on PA Route 45 west past Penns Valley High School on the right (north) and through the village of Penn Hall.
109.9	5.5	Spring Mills. **LEFT TURN** off PA Route 45 into the town of Spring Mills.
110.0	0.1	Then **TAKE ANOTHER LEFT TURN** through Spring Mills.
110.1	0.1	**CONTINUE LEFT** at "Y" intersection.
110.3	0.2	Cross Penns Creek, then **TAKE AN IMMEDIATE LEFT TURN**, following the main paved road around the ENE end of Egg Hill. Egg Hill is mainly composed of Reedsville Shale, but with a cap rock of the overlying Oswego Sandstone, all preserved in the trough of the Egg Hill syncline.
110.7	0.4	Inactive shale pit on right.
111.0	0.3	**RIGHT TURN** onto paved road that parallels the SE side of Egg Hill. Georges Valley is to the left. The mountain beyond is First Mountain, here the first of the famous Seven Mountains when the route is oriented in a southeastern direction.
112.5	1.5	**STOP.**

STOP 3.9: BROWN SHALE PIT.

This shale pit is in a lower backslope (26% slope) landscape position, and it exposes about 2 m of brown, Wisconsinan Age colluvium at the top. There are wedge forms in the colluvium and in the underlying weathered shale. There are also numerous involutions in the colluvium and the weathered shale. The weathered shale grades into hard, unweathered shale with depth. The soil at the surface is best called a Laidig (Typic Fragiudult), although it does not appear to have a fragipan. There does not appear to be any pre-Wisconsinan colluvium at this site, other than what is incorporated into the brown colluvium. It appears that, prior to the Wisconsinan colluviation, a soil was developed in the shale and, during colluviation, the soil was truncated down to the weathered shale. The weathered shale probably represents the C and Cr horizons of a pre-Wisconsinan soil.

112.5	0.0	Continue ahead SSW on paved road.
115.2	2.7	**TURN RIGHT** and **STOP** at the Tom Swank Shale Operation.

STOP 3.10: SWANK SHALE PIT

At this stop, shale bedrock is exposed and an ice wedge cast is developed in the shale on the upper face of the quarry. This site is one of the sites studied by Cronce (1988). One of the interesting features of this wedge, as well as some other wedges in the area, is that the major bending of the shale bedrock adjacent to the wedge is on the down-slope side of the wedge. This tends to indicate a greater amount of ice wedge growth on the down slope side of the wedge, a response to less resistance of the rock on that side. This wedge and other periglacial features indicate that the mean annual air temperature (MAAT) during the Woodfordian in this area was -5 to -10°C. Today, the MAAT in nearby State College is about 10°C. Thus, there has been a 15 to 20°C MAAT change in this area in the last 18,000 to 20,000 years.

The soil exposed here is moderately deep to an R horizon (hard bedrock) and is typical of the upland soils of these shale areas. It is a Berks soil (Typic Dystrochrept) and has bedrock at about 85 cm. There is little or no transition zone between the soil and the unweathered rock. This indicates that the soil material probably has moved somewhat down slope and is not a residual soil. This would be expected, because this is a shoulder landscape position, and these positions are relatively unstable.

There also is a stratified slope deposit (grèze litée?) (an oriented and rhythmically-bedded shale-chip deposit) on the northeast slope (~50° aspect) of the pit. The shale-chip deposit is at least 5 meters thick, and the soil at its surface shows a good cambic horizon, which is atypical of soils on these deposits. This is a small deposit, one of many in the central Pennsylvania area (Ciolkosz, *et al.*, 1986b; Jobling, 1969). Most of these deposits have a northeast aspect. Apparently, this aspect is the most conducive to the frost processes necessary to produce large quantities of shale chips and their movement down slope. The soil development in this deposit indicates that it is of late Wisconsinan Age. See Gardner, *et al.* (1991) for a recent discussion of this type of deposit.

115.2	0.0	Depart the Tom Swank Shale Operation, and **TURN RIGHT** on paved road.
115.9	0.7	Stop sign at intersection with PA Route 144. **TURN LEFT** on PA Route 144 south.
116.6	0.7	"Y" intersection, **TURN RIGHT** and stop. Then, **TURN RIGHT** on US Route 322 north. The ridge on the left skyline is First Mountain. Penns Valley is now about 7.3 km wide, with Nittany Mountain forming the northern side.
119.5	2.9	Small paved road on right goes into Tusseyville. Continue straight ahead on US 322 north. Ahead at 11:00 is the northeastern end of Tussey Mountain, a long, linear, strike ridge that replaces First Mountain as the first of the Seven Mountains. Penns Valley narrows as we head west, continuing on U. S. BUSINESS Route 322 toward Boalsburg.
125.9	6.4	Intersection of U. S. BUSINESS Route 322 with PA Route 45 in Boalsburg. Continue straight ahead on U. S. BUSINESS Route 322 through Boalsburg. The shrine on the right opposite the Boalsburg Cemetery is the Pennsylvania 28th Division Shrine and Museum.
128.7	2.8	Overnight stop at motel in the southeastern outskirts of State College.

STATE COLLEGE, PENNSYLVANIA TO BLACKWATER FALLS STATE PARK, DAVIS, WEST VIRGINIA, *VIA* APPALACHIAN MOUNTAIN SUBSECTION OF MIDDLE SECTION OF THE RIDGE AND VALLEY PROVINCE, AND UNGLACIATED ALLEGHENY PLATEAU SECTION OF APPALACHIAN PLATEAUS PROVINCE:

The morning itinerary consists of a ride and a soils tour in Nittany Valley. Nittany Valley has evolved through breaching of the crestal area of the Nittany Anticlinorium and deep erosion of the underlying stratigraphic sequence. TABLE R.4.1 shows the rock units exposed in the Nittany Valley area. Block diagrams illustrating the structure of Nittany Valley are shown in FIGURE R.4.1.

0.0 0.0 Depart State College overnight stop. Proceed from Business Route US 322 onto (New) Whitehall Road, turning west onto (New) Whitehall Road at traffic light just west of trailer park. Continue ahead on Whitehall Road.

After leaving the State College conurbation, the view southeast is across the southeastern portion of the carbonate-bedrock-floored valley toward Tussey Mountain on the southeastern skyline. Here, Tussey Mountain is topographically expressed as a double ridge. The near (lower) ridge is underlain by the Oswego (or Bald Eagle) Sandstone of Ordovician age. The topographic bench beyond the near ridge is underlain by less resistant strata assigned to the Juniata Formation; the Juniata is composed of thin-bedded, reddish brown siltstones and sandstones of Upper Ordovician age. The ridge crest is underlain by silica-cemented orthoquartzite sandstones of the Tuscarora Formation of basal Silurian age.

One overall topographic characteristic of possible periglacial origin on Tussey Mountain is the smoothed, rounded topographic expression of mountain surfaces that are developed on the middle and upper slopes. This slope development has occurred despite the high resistance to weathering and erosion of the Oswego Formation and the extremely high resistance of the Tuscarora Formation.

Another major landscape characteristic of possible periglacial origin is well developed on the footslopes and toeslopes of Tussey Mountain and is expressed as a suite of depositional landforms. First, colluvial aprons extend valleyward along the mountain front between the small water gaps. These thick, colluvial aprons bury the underlying shale and carbonate bedrock units and may extend hundreds of meters out into the valley. Little is known about their stratigraphy or thickness, except at a few localities where wells have been drilled. Second, and most striking, are the fanlike depositional landforms that extend valleyward from the small water gaps developed through the Oswego Formation and that head in the Juniata and Tuscarora Formations. Two excellent examples in view are Shingletown Gap (State College, PA quadrangle) and Musser Gap (McAlevy's Fort, PA quadrangle).

In map view, on the 7.5-minute quadrangle scale, both of these features appear highly dissected, suggesting that they may be of some antiquity, unless, of course, such features were "born dissected!" Again, almost nothing is known about the stratigraphy or thickness of the underlying unconsolidated sediments. Many workers refer to these features as "Pleistocene or Quaternary alluvial fans," although we do not know the relative importance—especially at depth—of the environments, mechanisms, and ages of sediment origin, entrainment, and deposition.

TABLE R.4.1. Geologic column of rock units exposed in Nittany Valley in central Pennsylvania ((From Parizek and White, 1985, Table 5.1, p. 59-60).

SYSTEM	SERIES	FORMATION / MEMBER	SECTION	THICKNESS (ft)	LITHOLOGIC DESCRIPTION	No. of Wells
ORDOVICIAN	MIDDLE	Snyder Formation		190	Limestone, 4 inch to 1-foot beds, fine to medium grained; interbedded dolomite, oölitic beds, mud-cracked beds, clay partings, and coarse bioclastic beds.	↓
ORDOVICIAN	MIDDLE	Hatter Formation		100	Limestone, 4-inch to 2-foot beds, fine to medium grained, with laminated argillaceous and arenaceous dolomite, fossiliferous, worm borings. (Unconformity)	↓
ORDOVICIAN	MIDDLE	Clover Limestone		80	Limestone, 2-inch to 2-foot beds, fine to very fine grained, laminated with fine to coarse-grained limestone.	↓
ORDOVICIAN	MIDDLE	Milroy Limestone		300±	Limestone, fine-grained, silty; laminated with wavy dolomitic bands.	2
ORDOVICIAN	LOWER	Bellefonte Dolomite: Tea Creek Member		200	Dolomite; fine-grained to sublithographic, thin shale partings, gashed weathered surfaces; 1 to 4 foot-beds.	22
ORDOVICIAN	LOWER	Bellefonte Dolomite: Dale Summit Member		0 to 14	Sandstone, fine to coarse-grained, conglomeratic.	22
ORDOVICIAN	LOWER	Bellefonte Dolomite: Coffee Run Member		1000	Dolomite, interbedded fine-to medium-grained, cyclic successions.	22
ORDOVICIAN	LOWER	Axemann Limestone		400	Limestone, fine to coarse-grained, oölitic, interbedded thin layersof impure dolomite, fine to medium-grained, partly conglomeratic, chert locally.	
ORDOVICIAN	LOWER	Nittany Dolomite		1200	Dolomite, fine-to coarse-grained alternating in cyclic manner, spherical chert nodules, oolitic chert, thin limestone and sandy beds.	15
ORDOVICIAN	LOWER	Stonehenge Limestone		600	Limestone aphanitic to fine-grained, argillaceous and dolomitic in part, flat pebble conglomerate abundant.	
CAMBRIAN	UPPER	Gatesburg Formation: Mines Member		150 to 230	Dolomite, interbedded coarse-to fine-grained, chert abundant, oolitic, thin sandy beds near base, vugular.	
CAMBRIAN	UPPER	Gatesburg Formation: Upper Sandy Member		500±	Dolomite; with interbedded orthoquartzites, and sandy dolomites, some shaly dolomites, fine to medium grained, vugular.	22
CAMBRIAN	UPPER	Gatesburg Formation: Ore Hill Member		260	Dolomite; fine to medium grained thick-bedded near top, fine-grained argillaceous dolomite near center; coarse-grained, massive bedded at base.	
CAMBRIAN	UPPER	Gatesburg Formation: Lower Sandy Member		700±	Dolomite, interbedded orthoquartzites, thin-bedded fine-to medium grained dolomite, medium to coarse-grained orthoquartzite; thin bedded shaly dolomite.	
CAMBRIAN	UPPER	Warrior Formation		600	Limestone, in part dolomitic, thick-bedded, with thin-bedded shale and sandy units.	

TABLE R.4.1.(continued). Geologic column of rock units exposed in Nittany Valley in central Pennsylvania ((From Parizek and White, 1985, Table 5.1, p. 59-60).

SYSTEM	SERIES	FORMATION / MEMBER	SECTION	THICKNESS (ft)	LITHOLOGIC DESCRIPTION	NO. of Wells
DEVONIAN	LOWER	Helderberg Formation		150 to 350±	Shale, thin-bedded, calcareous. Limestone, thin-bedded, cherty. Sandstone, locally medium to coarse-grained.	1
SILURIAN		Keyser Formation		155	Limestone, thick-bedded to nodular.	
		Tonoloway Formation		400+	Limestone, thin-bedded to laminated, fine-grained, some calcareous shales.	1
		Wills Creek Formation Bloomsburg Formation McKenzie Formation Rose Hill Formation		1500+	Shales, calcareous in part.(undifferentiated)	
		Tuscarora Formation		400 to 550	Quartzitic Sandstone, fine to very coarse-grained, thin to thick bedded, mountain former.	
ORDOVICIAN	UPPER	Juniata Formation		1000+	Sandstone, fine-to coarse-grained, impure; interbedded siltstones and shales.	
		Oswego Sandstone		700 to 800	Sandstone, fine-to coarse-grained, interbedded shale near base.	1
		Reedsville Shale		1000	Shale, sandy in upper portion.	8
		Antes Shale		200	Shale, calcareous, soft.	
	MIDDLE	Coburn Limestone		275	Limestone, thin-bedded, fine to coarse grained, shale partings.	3
		Salona Limestone		175	Limestone, thin-bedded, fine-grained, shale partings.	
		Nealmont Formation		70	Limestone, impure bioclastic, fine to medium grained near top; thin to thick-bedded impure, fine-grained limestone near base.	5
					(Unconformity)	
		Linden Hall Formation: Valentine Member Oak Hall Member Valley View Member		180	Limestone, thick to thin-bedded, very fine to medium-grained. (Valentine Mb. laminated thick to thin bedded units.);(Valley View,Mb. 2-inch to 1 foot bedded well laminated limestone, thin clay laminae.); (Oak Hall,Mb. thick-bedded, fine to coarse-grained limestone.)	
		Linden Hall Formation: Stover Member			Limestone, thick bedded, bioclastic zones, thin bentonite beds, dolomite streaks.	

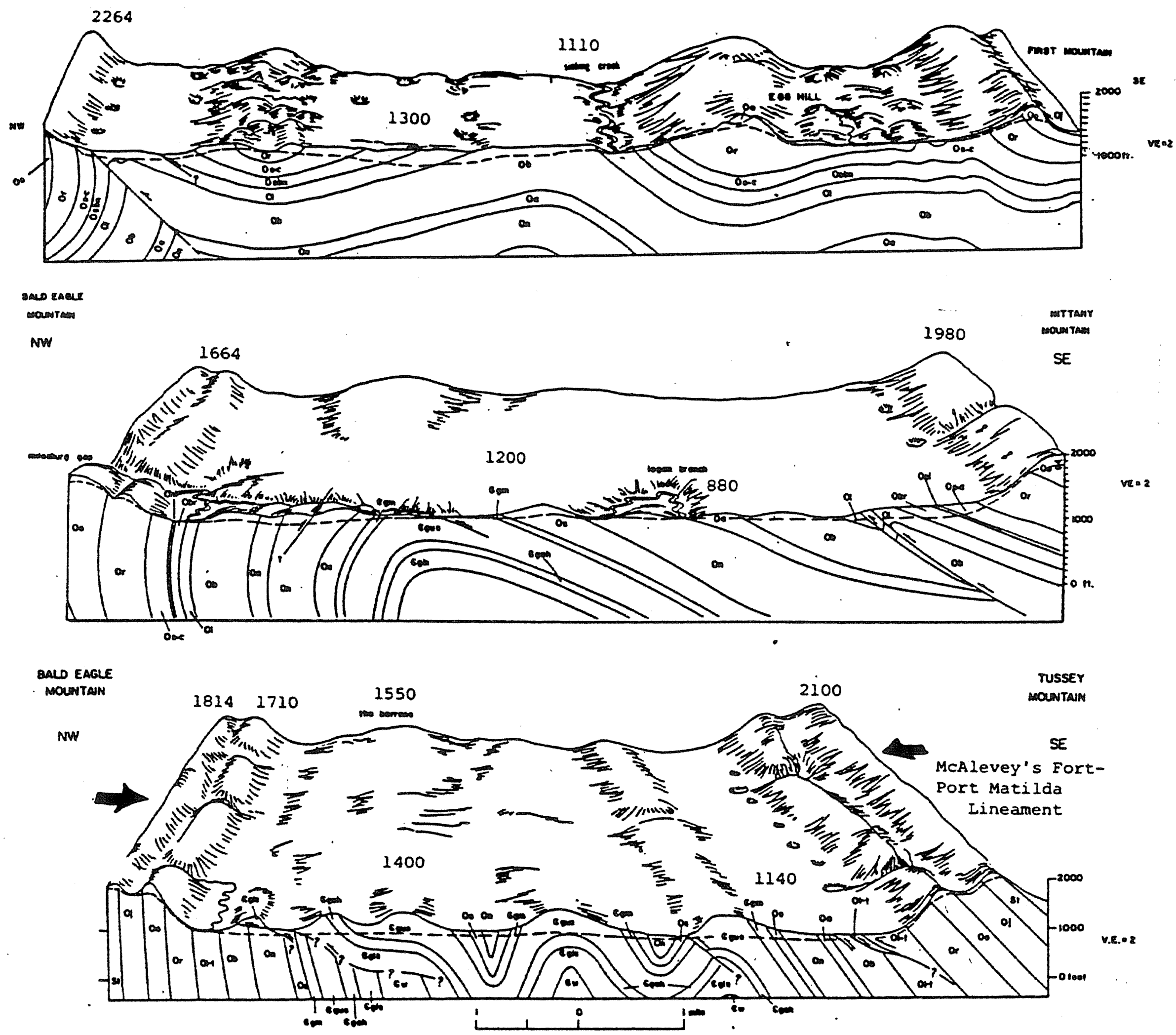


FIGURE R.4.1. Three cross-sectional diagrams (A, B, C) of the structure in Nitttany Valley, Pennsylvania. From Parizek and White (1985, Figure 3, p. 68). Note arrows on diagram C that indicate the trend of the McAlevy's Fort-Port Matilda Lineament.

3.0	3.0	Intersection with PA Route 26. Continue straight ahead on Whitehall Road toward Fairbrook.
6.8	3.8	Fairbrook. **LEFT TURN** on road to SSE, directly toward Tussey Mountain.
7.6	0.8	Stop. "T" intersection with PA Route 45. **TURN RIGHT** and prepare for immediate left turn.
7.7	0.1	**LEFT TURN** onto road on the Rocksprings Experiment Station of The Pennsylvania State University
7.9	0.2	**STOP** at soil pit sites.

STOP 4.1: PENN STATE AGRONOMY FARM AT THE ROCK SPRINGS EXPERIMENT STATION

This site is on the footslope of Tussey Mountain, in the Pine Grove Mills quadrangle. In one of the soil pits, a Buchanan (Aquic Fragiudult) soil is exposed. In the second pit, a Murrill (Typic Hapludult) soil is exposed. The Murrill pedon (014-045) was sampled in 1977. It has a base saturation a little too high for a true Ultisol, and it is better classified as an Ultic Hapludalf (see pedon 039-046 for data on a typical Buchanan soil). Both of these soils have developed in brown colluvium of Wisconsinan age, but the Buchanan has a fragipan, and the Murrill does not. The main reason for this difference may be that a much greater amount of limestone residual soil material was mixed with the Murrill than with the Buchanan colluvial material. Bruckert and Bekkary (1992) claim that fragipans do not form in material that overlies permeable rock, such as limestone.

As dense, impermeable, subsurface horizons that restrict the downward movement of water and roots, Fragipans (Bx horizons) tend to have very coarse prismatic structure. They are found in transported parent materials other than recent alluvium and have a medium texture (not too sandy and not too clayey). They tend to form relatively rapidly (6,000 to 18,000 years) and, once formed, they start to degrade by oxidation, leaching, and argillic horizon formation (Ciolkosz, *et al.*, 1989). Some researchers have proposed that fragipans are a manifestation of soil permafrost (Fitzpatrick, 1956; van Vliet and Langohr, 1981). This view is held primarily in Europe and is not widely accepted in the United States. The information in Smeck and Ciolkosz (1989) is a rather comprehensive overview of information on the characteristics, classification and origin of fragipans, whereas Ciolkosz, *et al.* (1992) present specific information on fragipans developed in soils in Pennsylvania.

Buchanan Silt Loam

This pedon was described by E. J. Ciolkosz on June 9, 1992, and is located on the Penn State University Agronomy Farm at Rock Springs, Pennsylvania. The soil is developed in Wisconsinan Age colluvium. The brown colluvium exposed in this pit has some pre-Wisconsinan material mixed into it. There are also numerous rubified rock fragments in the colluvium. The site is located on a footslope with a 4% gradient on a north aspect, and was in corn stubble. The soil is somewhat poorly drained and is classified as a Fragiaquult. At a depth of 1 1/2 to 2 m, there is a distinctive increase in rock fragment content, particularly of large fragments (25 to 60 cm). This zone may mark a distinctively different colluvial flow. This site was not sampled for laboratory characterization analysis. The following is an abridged description by E. J. Ciolkosz:

Ap 0-20 cm Dark brown (7.5 YR 4/2) moist light brown (7.5 YR 6/3) dry silt loam, moderate fine subangular blocky structure, friable, slightly sticky and slightly plastic, 25% sandstone rock fragments, abrupt smooth boundary.

Bt1 20-40 cm Strong brown (7.5 YR 5/6) silty clay loam, moderate fine subangular blocky structure, friable, sticky and moderately plastic, few thin clay films on ped faces, 25% sandstone rock fragments, clear wavy boundary.

Bt2 40-50 cm Strong brown (7.6 YR 5/6) silty clay loam, with common 10 YR 5/6 and 10 YR 5/4 mottles, moderate medium and fine subangular blocky structure, friable, sticky and moderately plastic, common moderately thick clay films on ped faces, 25% sandstone rock fragments, clear wavy boundary.

Bx1 50-99 cm Strong brown (7.5 YR 4/6) gritty clay loam with gray (10 YR 6/1)* prism faces, 10% black (N 2/0) Fe-Mn coatings on small peds, moderate very coarse prismatic parting to weak medium platy structure, very firm and brittle, moderately sticky and moderately plastic, thick continuous clay films on prism faces and common moderately thick in pores, 30% sandstone rock fragments, gradual wavy boundary.

Bx2 99-130 cm Dark brown (7.5 YR 4/4) gritty clay loam with gray (10 YR 6/1)* prism faces, 20% black (N 2/0) Fe-Mn coatings on small ped faces, moderate coarse prismatic parting to moderate medium platy structure, very firm and brittle, slightly sticky, moderately plastic, thick continuous clay films on prism faces and common moderately thick in pores, 30% sandstone rock fragments, gradual wavy boundary.

Bx3 130-165 cm Same as Bx2, except there is moderate medium and coarse platy structure, only a few thin clay in the pores, 45% rock fragments and a clear wavy boundary.

Bx4 165-203 cm Same as Bx3, except there is 30% black (N 2/0) coating on the small peds, and it is firm.

Bx5 203-240 cm Same as Bx4, except the matrix color is dark yellowish brown (10 YR 4/4), there are 40% black (N 2/0) Fe-Mn coatings on the small peds, and the rock fragment content is 65%.

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*A 5 to 10 mm yellowish brown (10 YR 5/8) zone borders each side of the gray prism face.

7.9	0.0	**TURN AROUND**, return way came to PA Route 45.
8.1	0.2	**RIGHT TURN** on PA Route 45 east toward Pine Grove Mills.
11.7	3.6	Junction with PA Route 26 in downtown Pine Grove Mills at blinker light. Continue straight ahead, now on PA Routes 45 east and 26 north.
13.0	1.3	"Y" intersection, **BEAR LEFT** on PA Route 26 north.
14.5	1.5	"Y" intersection, **BEAR LEFT** onto Science Park Road.
16.3	1.8	Circle Ville. Here, Science Park Road becomes Valley Vista Road. Continue across intersection on Valley Vista Road toward Park Forest Village. Continue around right curve past Park Forest Village.
18.4	2.1	Junction with US Business Route 322. **LEFT TURN** onto US Business Route 322 north, which becomes US route 322 north.
19.4	1.0	The road to the left (southwest) goes to Scotia, an old mining center for sedimentary iron ores that accumulated in The Barrens. The Barrens is an extensive area on the northwest side of Nittany Valley where weathering produced deep, residual, sandy regolith overlying the Gatesburg Formation of Cambrian age near the crest of the Nittany Anticlinorium.
19.7	0.3	On right, exposure of Warrior Limestone that underlies the Gatesburg Formation here near the core of the Nittany Anticlinorium. The valley bottom directly ahead is a narrow floodplain of a headwater branch of Buffalo Run. Between here and the village of Buffalo Run, we will cross the trace of the northeastern extension of the Birmingham Fault Zone, a master thrust fault system that arises from the low-angle décollement beneath this part of the Ridge and Valley province. As a result, many rock units have been cut out of the stratigraphic sequence in this area.
20.6	0.9	Village of Buffalo Run, at intersection of PA Route 550. We are now on the essentially vertical northwestern limb of the Nittany Anticlinorium. Continue ahead on US Route 322 north, as we begin the ascent of the southeastern footslope of Bald Eagle Mountain
20.8	0.2	Matternville. The shale pit on the left (southwest) was excavated into a stratified slope deposit (grèze litée?) formed from shale fragments derived from the Reedsville Formation.
21.0	0.2	The bedrock exposed in the road cut on the right is the Oswego (or Bald Eagle) Formation. This rock unit underlies the southeastern one of two double (or "camelback") ridges that constitute the crestal portion of Bald Eagle Mountain in this area.
21.2	0.2	The intervening small strike valley here is developed on grayish red shales, siltstones, and flaggy sandstones of the Juniata Formation.
21.4	0.2	**PICTURE STOP 4..2: NORTHWESTERN CREST OF BALD EAGLE MOUNTAIN OVERLOOKING THE BALD EAGLE VALLEY AND THE ALLEGHENY FRONT.**

This picture stop is in the Julian, PA quadrangle. Exposures of the Tuscarora Formation exhibit structural complexities in road cuts on the left (SE) side of US 322 that are visible ahead. Bald Eagle Valley is part of a long strike valley of regional extent that can be traced topographically from the vicinity of Williamsport, Pennsylvania southwest toward its headwaters. The part of Bald Eagle valley directly beneath this overlook is developed on carbonates and shales of Silurian age. The slope directly below us is undoubtedly mantled by a thick, and complex, diamicton apron that probably extends out onto the valley floor, except where trimmed by Bald Eagle Creek. The valley floor and the "bread-loaf"-shaped hills beyond to the northwest are on shale units of Devonian age. Visually ascending the Allegheny Front, the first prominent topographic break is underlain by sandstones of the Catskill Formation of Devonian age; it is followed by an escarpment underlain by the Pocono Formation of Mississippian age; then is the skyline underlain by extremely resistant quartz sandstones and conglomerates of the Pottsville Group of basal Pennsylvanian age.

O'Leary (1972) researched the recent development of topography along the Allegheny Front in Centre County, Pennsylvania. According to O'Leary (1972, p. 121-122), topographic development of the Allegheny Front in Centre County followed a five-fold sequence of drainage evolution that was controlled by joint patterns and resistant lithologies. O'Leary (p. 114) stressed that bedrock control of the Allegheny Front rests in two major factors: jointing and lithology. The specific process groups responsible for the development of the Allegheny Front were: chemical weathering under a forest cover, stream piracy, headward erosion (especially aided by spring sapping), and probably also the intermittent effects of catastrophic storms (O'Leary, 1972, p. 112-114). O'Leary (p. 115-116) interpreted the present character of Allegheny Front as a product of stream dissection and rhombohedral-shaped "blocking out" of topography along fracture traces and lineaments that follow the regional joint system, some elements of which, incidentally, trend obliquely to the escarpment!

21.4	0.0	**CONTINUE** on US 322 north down the northeastern side of Bald Eagle Mountain.
24.2	2.8	Junction with undivided US 220, **AND AN IMPORTANT NOTE:** Someday to be completed as the Appalachian Thruway, a four-lane divided highway will link Williamsport, PA with Cumberland, MD as part of a joint governmental effort to improve highway transportation networks in the Appalachian Region. Several parts of this project have been completed, are open to traffic, and will be used as part of this route. Other sections have not been completed, and the route there will follow existing US 220 alignments. This situation should be borne in mind in the future when using the road log in this guidebook from this point to Cumberland, MD. The following road log, to Cumberland, MD, is therefore generalized and lacks detail found in other parts of the road logs in this guidebook. **CONTINUE** on US 322 north and US 220 south toward Port Matilda.
26.7	2.5	Split of US 322 north from US 220 south in downtown Port Matilda. Continue south on US 220.
34.7	8.0	Junction with PA 350. **TURN LEFT** on US 220 bypass.
36.6	1.8	Note slope stability problems associated with road cuts in regolith on steep northwestern side of Bald Eagle Mountain.
39.8	3.2	Town of Tyrone, a historic paper mill town on right.
43.3	3.5	Temporary end of expressway. **EXIT** toward old US 220.
43.7	0.4	Grazierville. **LEFT TURN** on old US 220.
44.6	0.9	Tipton. Continue on old US 220 south.
53.6	9.0	Greenwood. Continue on US 220 south.
55.8	2.2	**LEFT TURN** onto 220 bypass; the Bud Shuster Highway.
58.1	2.3	City of Altoona.
62.0	3.9	Borough of Duncansville.
74.2	12.2	Claysburg-King Exit. **TURN RIGHT** and exit for STOP 4.3.
74.4	0.2	**RIGHT TURN** on old US 220 north.
75.4	1.0	Sproul. Continue ahead on old 220.
77.7	2.3	Claysburg. Continue ahead on 220.
79.4	1.7	**STOP.** Remains of formerly extensive stratified slope deposit (grèze litée?) on left, south of repair shop (west side of highway).

STOP 4.3: STRATIFIED SLOPE DEPOSIT

Little remains of this once-magnificent, two-story, stratified slope deposit (see FIGURE R.4.2). The land owner states that the deposit once extended a long distance toward Old US 220. Enough remained visible in 1992, however, to permit investigation of the contact relationships between the lower "red" shale-chip deposit and the overlying "gray" shale-chip deposit.

In August, 1992, a thin, brown, oriented shale chip deposit about 2 m of which remained, could be seen to overlie a thick, weathered, red, oriented shale chip deposit that is apparently 5 or 6 m thick. The thick, red, shale chip deposit contains at least two paleosols. If the red shale chip deposit became weathered during Sangamon time, then the contained paleosols are Pre-Wisconsinan in age.

FIGURE R.4.2. View of upper (brown) stratified slope deposit containing at least two wedge-shaped casts. Roaring Spring, PA quadrangle.

79.4	0.0	**GO BACK** way came on old US 220 south.
84.4	5.0	Junction with ramp for new US 220 south.
84.6	0.2	**CONTINUE** on US 220 Thruway south, the Bud Shuster Highway.
85.5	0.9	Leave Blair County, enter Bedford County.
99.8	14.4	Exit for I-70 and I-76; continue ahead (south) on 220.
103.4	3.6	Temporary end of Appalachian Thruway, two-way traffic ahead. Continue ahead on US 220 south.
118.0	14.6	Centerville. Continue south on US 220.
126.9	8.9	Leave Bedford County, Pennsylvania, enter Allegany County, Maryland.
130.6	3.7	Intersection. **TURN LEFT** and continue on US 220 south.
131.1	0.5	**RIGHT TURN**, continuing on US 220 south through city of Cumberland.
136.5	5.4	Leave Cumberland, continuing south on US 220.
139.1	2.6	Potomac Park, continue on 220 south.
141.2	2.1	Cresaptown, continue on 220.
146.1	4.9	Rawlings, continue on 220 south.
154.0	7.9	Note high alluvium, presumably of ancestral North Branch Potomac River, on right (west) side of 220 (see Allamong, 1991 for details).
154.7	0.7	Cross North Branch Potomac River which to the right (west) exits a gorge through the Allegheny Front. Leave Allegany County, Maryland, enter the town of Keyser in Mineral County, West Virginia. Allamong (1991) studied alluvial and colluvial deposits in the New Creek Valley ahead.

A geologic column that shows the exposed rock units in the Ridge and Valley and Appalachian Great Valley in West Virginia is shown in TABLE R.4.2.

TABLE R.4.2. Stratigraphic column and commonly-used abbreviations for rock units on geologic maps for the Ridge and Valley and Appalachian Great Valley areas of eastern West Virginia. From Lessing, *et al.* (1991).

Mississippian	Mpk	Pinkerton Sandstone
	Mm	Myers Shale
	Mmclm	Little Mt. Mb.
	Mh	Hedges Shale
	Mp	Purslane Sandstone
	Mr	Rockwell Formation
Devonian	Dhs	Hampshire Formation
	Dch	Chemung Group
	Dbh	Brallier/Harrell Formations
	Dmtc	Clearville Mb.
	Dmt	Mahantango Formation
	Dmn	Marcellus/Needmore Shale
	Do	Oriskany Sandstone
	Dhl	Helderberg Group
Silurian	Stw	Tonoloway Limestone
	Swc	Wills Creek Formation
	Sb	Bloomsburg Formation
	Smcr	McKenzie/Rochester Formations
	Sk	Keefer Sandstone
	Srh	Rose Hill Formation
	St	Tuscarora Sandstone
Ordovician	Oj	Juniata Formation
	Oo	Oswego Sandstone
	Om	Martinsburg Formation
	Oc	Chambersburg Limestone
	Onm	New Market Limestone
	Orp	Row Park Limestone
	Obps	Pinesburg Station Dolomite
	Obrr	Rockdale Run Formation
	Obs	Stonehenge Limestone
	Obss	Stoufferstown Mb.
Cambrian	Єc	Conococheague Formation
	Єcbss	Big Springs Station Mb.
	Єe	Elbrook Formation
	Єwy	Waynesboro Formation
	Єt	Tomstown Dolomite
	Єa	Antietam Formation
	Єh	Harpers Formation
	Єw	Weverton Formation
	PЄc	Catoctin Formation
	PЄ	Precambrian

156.3	1.6	Leave Keyser, continue on US 220 south.
159.2	2.9	Junction with WV route 972. Continue straight ahead (south) on 972 (US 220 goes left (east).
161.4	2.2	Junction of WV south 972 with US 50. Continue on US 50 west.
163.4	2.0	Claysville.
164.0	0.6	Junction with WV Route 93. Continue south on WV 93.
166.8	2.8	Laurel Dale, continue ahead on WV 93.
167.9	1.1	Leave Mineral County, enter Grant County.
176.3	8.4	Scherr. Junction WV Route 42. **RIGHT TURN** on WV 42. We now ascend the Allegheny Front, passing over a thick sequence of clastic rocks of Devonian age. Leave Appalachian Mountain subsection of the Middle section of the Ridge and Valley province and enter unglaciated Allegheny Plateau section of Allegheny Plateaus province. This geomorphic subdivision is the Kanawha section of Fenneman and Johnson (1946).
180.4	4.1	Junction with WV Route 93 just west of crest of Allegheny Front. **LEFT TURN** onto WV Route 93 south toward Davis.
	3.2	Crest of dam for Mt. Storm Lake, the water body for the large VEPCO coal-mine mouth power plant on the west side of the impoundment. Continue ahead on WV 93 toward Davis. This area is rich in large-scale sorted patterned ground features, and many examples of sorted stripes and sorted nets can be seen from the highway, especially when deciduous vegetation is not in leaf.
194.0	14.0	Davis. End of WV Route 93, junction with WV Route 32. **LEFT TURN** onto WV Route 32 south.
194.4	0.4	**RIGHT TURN** onto road to Blackwater Falls State Park. From Davis to Blackwater Falls the soils are skeletal Dystrochrepts (Dekalb) on sandstone and Fragiaqualfs (Brinkerton) on lower slope colluvium. Note evidence of strip mining.
194.8	0.4	Note topography characterized by broad, benchlike surfaces and the gentle sideslopes between them.
195.3	0.5	Enter Blackwater Falls State Park.
195.6	0.3	**LEFT TURN** toward Blackwater Falls Lodge.
195.9	0.3	Bridge over Blackwater River.
197.3	1.4	Enter Blackwater Falls Lodge area
197.4	0.1	**REST AND OVERNIGHT STOP:** Park in Blackwater Falls Lodge parking lot (Blackwater Falls, WV quadrangle). FIGURES R.4.3 and R.4.4 shows the Lodge and Falls area.

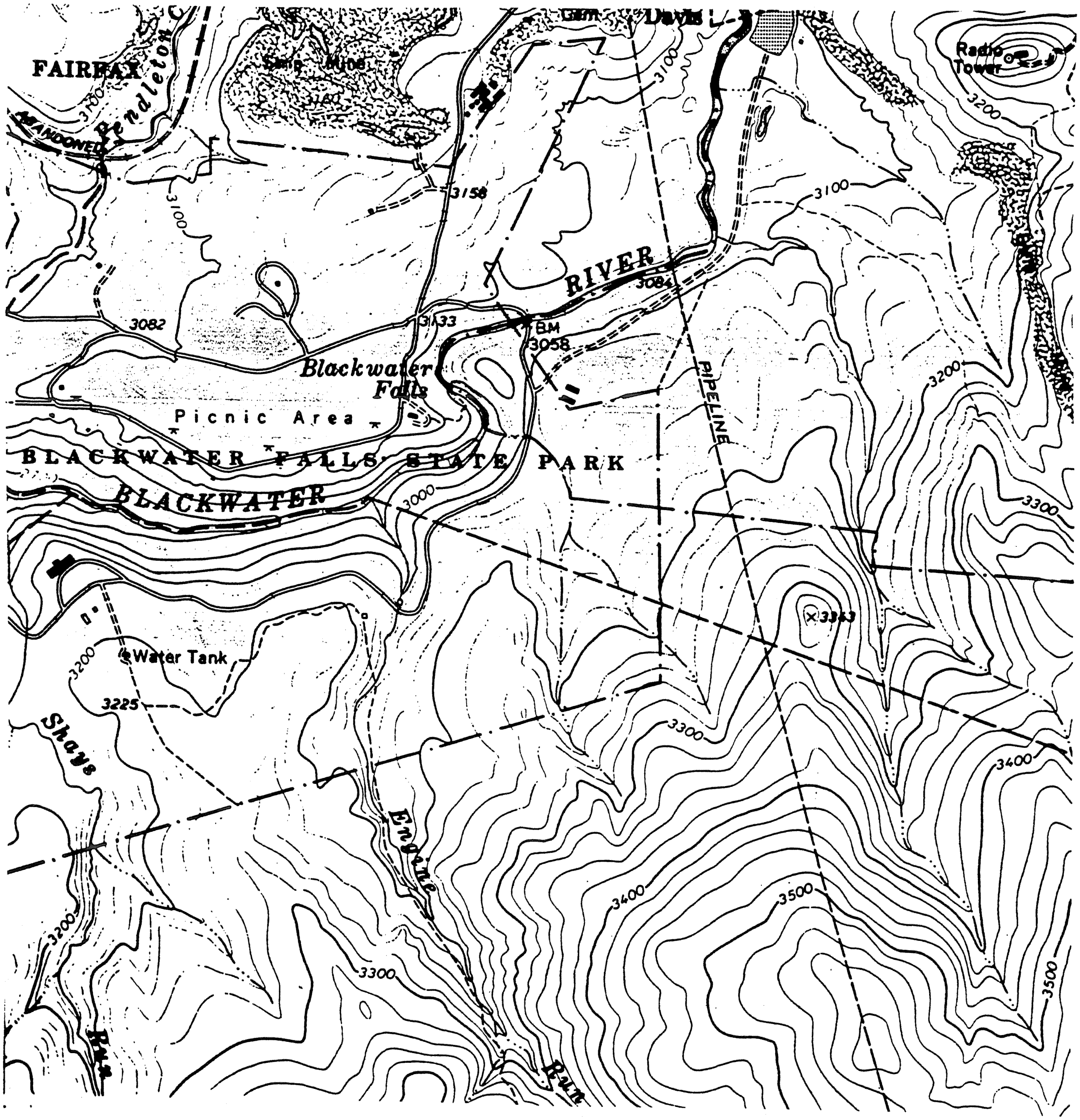


FIGURE R.4.3. The lodge area in Blackwater Falls State Park (From Blackwater Falls, WV quadrangle). Note areas on north part of map portion where bituminous coal has been strip mined. The dip of bedrock of Pennsylvanian age is gently to the northwest. Orthoquartzite sandstones of the Pottsville Group crop out in the southern to central part of the map portion and in the Blackwater River Gorge; these rocks are overlain by the coal-bearing rock units.

FIGURE R.4.4. Gorge of Blackwater River, as seen from the rear of Blackwater Falls State Park Lodge (Blackwater Falls quadrangle). Light-colored cliffs and scree just below the center skyline are composed of orthoquartzite sandstones and conglomerates of the Pottsville Group. From Clark, et al. (1989, Figure 47, p. T150: 72). Reproduced with permission of American Geophysical Union.

AFTER REST STOP, OR ON FOLLOWING MORNING, RETURN WAY CAME TO STRIP MINING AREA (VISIBLE FROM MILE 194.4 AND ON FIGURE 4.4). TURN LEFT ON WV ROUTE 32 NORTH AND THEN LEFT AGAIN INTO STRIP MINING AREA FOR STOP 4.4.

STOP 4.4: ^{14}C-DATED COLLUVIUM.

The Pendleton Creek basin is 195 km from the nearest Late Pleistocene continental glacial border and has an area of 9.65 km^2. The average elevation of the study site is 975 m (FIGURE R.4.5). Surface mining has systematically removed alluvium and colluvium down to bedrock, at times giving excellent exposures transverse to the stream.

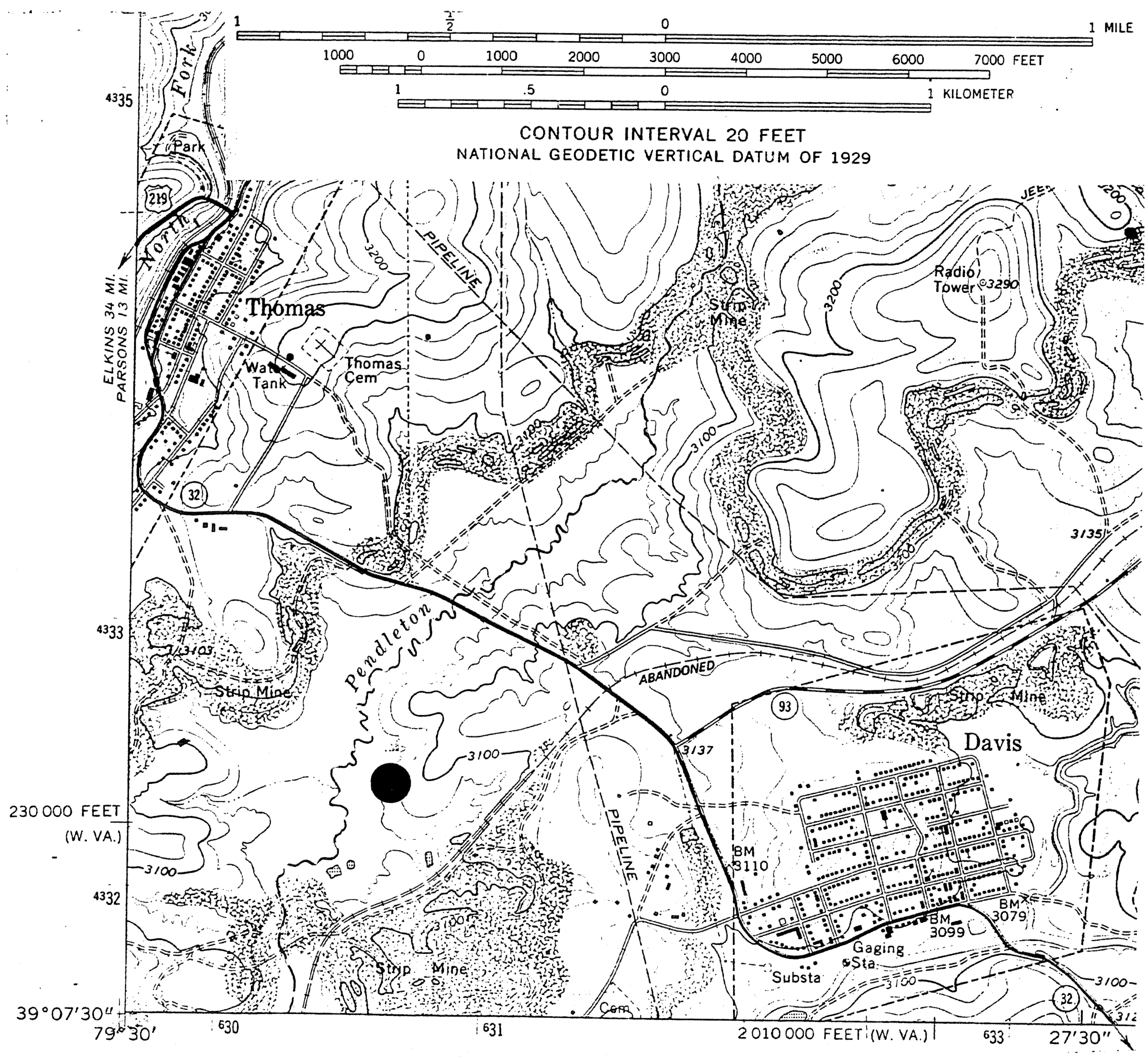


FIGURE R.4.5. Pendleton Creek research area (large black dot). From Davis, WV quadrangle.

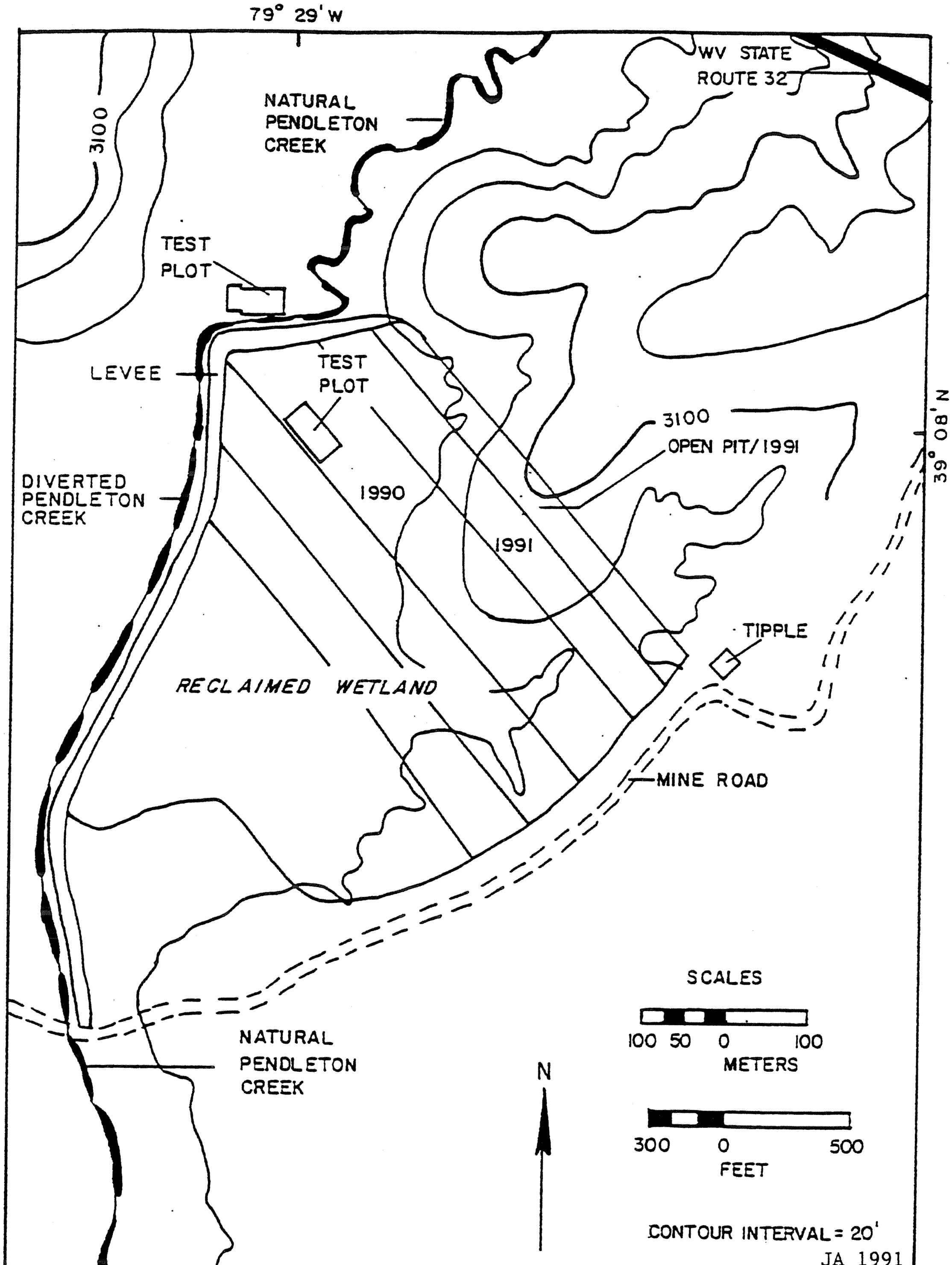
Coarse colluvium, 3 to 5 m thick, is the lowest regolith unit known in the Pendleton Creek Valley. Dates on wood fragments from the colluvium range from 21,780 to 28,700 yr BP, but "inverted ages" from one exposure show that some of the organic material may be reworked; hence the youngest age may be the most reliable.

The colluvium is incised and infilled by 1 to 2 m of immature alluvium that has yielded dates of 16,900±920 yr BP for a low terrace on the southeast side of the valley and 12,420±590 yr BP for a low terrace on the northwest side. Alluvium of Early Holocene age (<9,600 yr BP) underlies most of the Pendleton Creek bottomland. A major lithologic break from coarse-grained, immature, channel sediments to fine-grained, mature overbank sediments is dated at 6250±100 yr BP.

Sediment supply and stage in Pendleton Creek were controlled largely by rates of episodic alluviation, which probably were higher under periglacial or near-periglacial conditions during the Late Wisconsinan.. As mining continues, the Buffalo Coal Company has established a reclamation program that includes creation of bodies of standing water, relocated stream channels, wetlands, and well-drained uplands (FIGURE R.4.6). The stratigraphy of the reclaimed wetland is bedrock spoil (a substantial thickness to reflect depth to coal) covered with a veneer of high-chroma spoil (colluvial and/or alluvial material) with a top dressing of organic-rich spoil (as available from the original valley-fill material).

The original sequence of valley-fill material and selected profiles (FIGURE R.4.7, and FIGURE R.4.8A-D: PROFILES PC 8, 9, 11, 14) reflect exposures in 1985-1986. These exposures, and a substantial number of ^{14}C dates, led to the recognition and integration of a sequence of colluviation and distinct alluvial events (FIGURE R.4.9).

In late fall, 1990, the extension of the working face exposed 4 to 6 m of unconsolidated strata of Late Quaternary age that included a buried peat horizon up to 3.0 m thick and that extended for approximately 50 m. Within this peat were clay-rich zones, silt with peat layers, and thin diamicts. To date (1992), two ^{14}C dates bracket this peat sequence. Near the base, a date of 30,000±380 yr BP was obtained, and at the top of the buried peat a date of 22,220±130 yr BP was obtained.



Schematic of Reclamation and active mining, Pendleton Creek, WV as of fall, 1991.

FIGURE R.4.6. Schematic of reclamation and active mining, Pendleton Creek, WV, as of fall 1991.

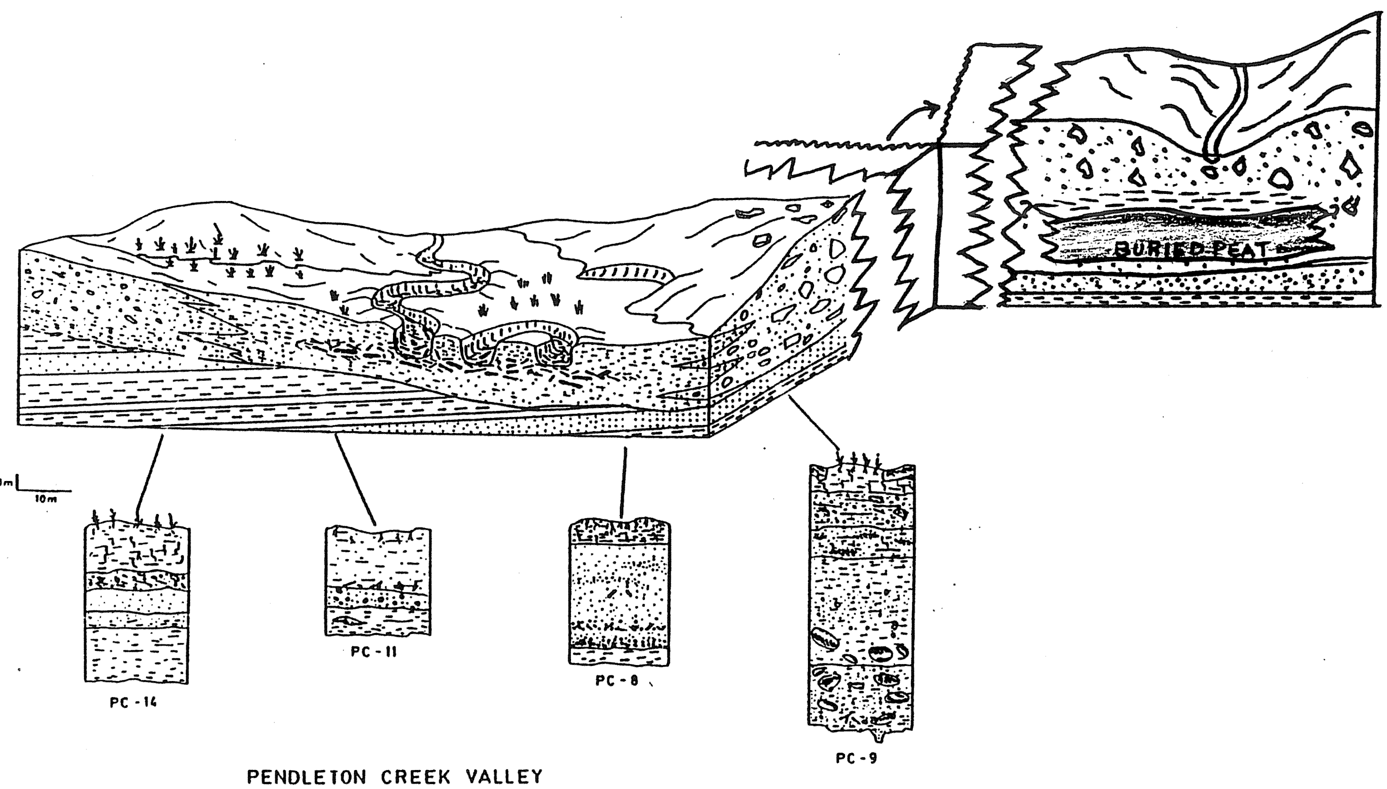
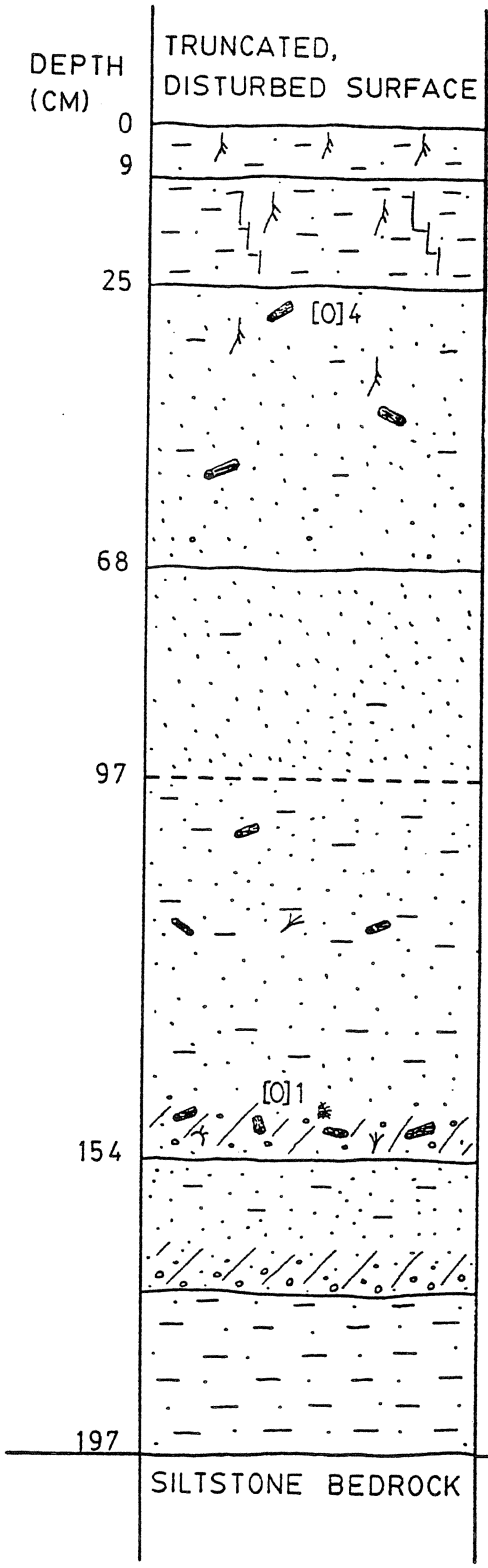


FIGURE R.4.7. Block diagram sketch of stratigraphic relationships in the Pendleton Creek Valley, WV.

PC-8 PROFILE



10YR-3/1 (V. Dk. Gray). Weak fine to medium granular, silty clay loam. Common fine roots.

10YR-3/2 (V. Dk. Grayish-brown). Moderate coarse prisms, clayey silt loam. Few fine roots.

10YR-4/2 (Dk. Grayish-brown). Massive and single grain, mixed loamy sand and sandy loam. Less than 5% wood fragments. Few fine roots.
[O]4 = 2430 ± 120.

10YR-3/2 (V. Dk. Grayish-brown). Massive, loamy sand.

10YR-4/2 (Dk. Grayish-brown). Massive and single grain, mixed loamy sand and pebbly loamy sand. Horizon is crossbedded and contains sets of fining upward cycles. 5% woody organic fragments.
[O]1 = 2840 ± 80.

2.5Y-4/2 (Dk. Grayish-brown) mottled 10YR-5/6 (Yellowish-brown). Single grain, stratified, mixed loam and pebbly sandy loam. Horizon is crossbedded and fines upward.

10YR-5/6 (Yellowish-brown) mottled 7.5YR-5/8 (Strong Brown). Massive, silty clay loam. Residuum.

FIGURE R.4.8A. Profile PC-8 in Pendleton Creek Valley, WV.

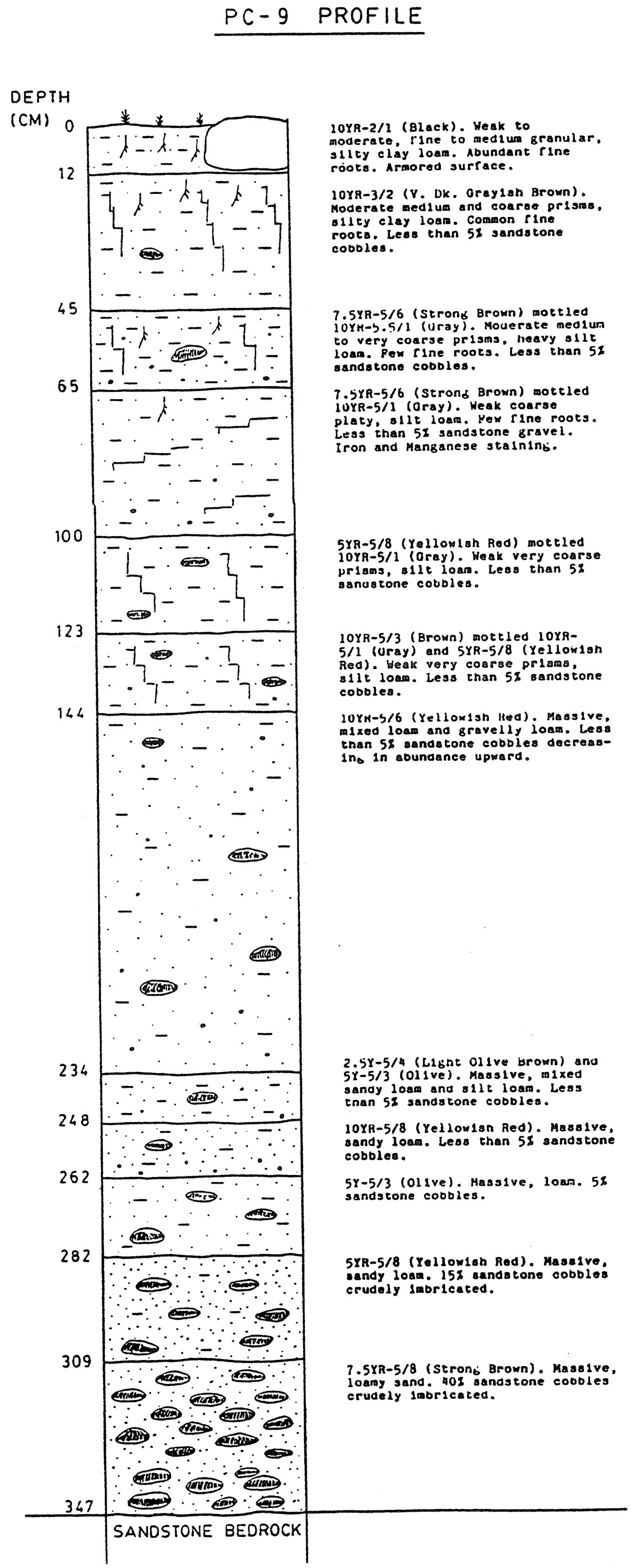


FIGURE R.4.8B. Profile PC-9 in Pendleton Creek Valley, WV.

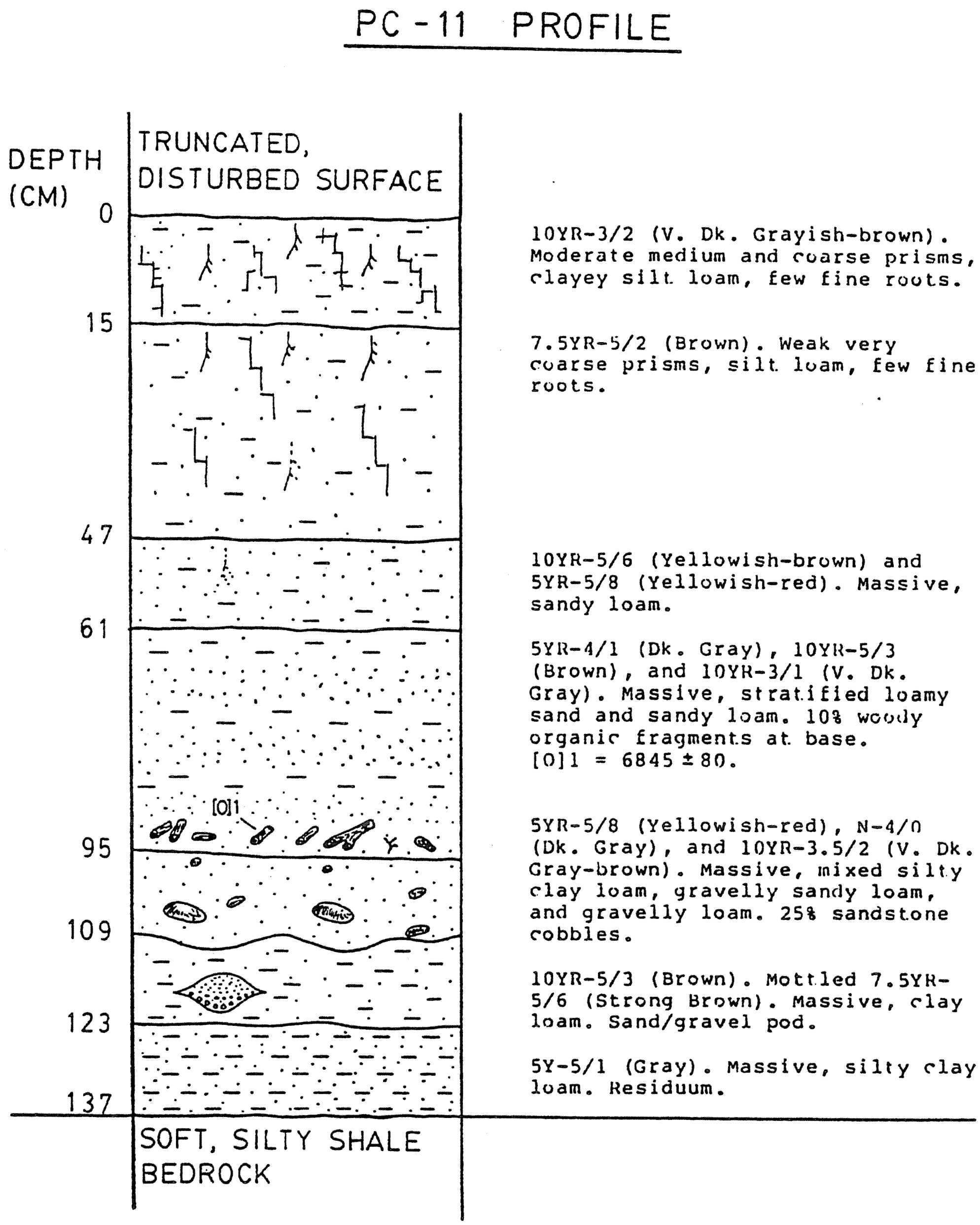


FIGURE R.4.8C. Profile PC-11 in Pendleton Creek Valley, WV.

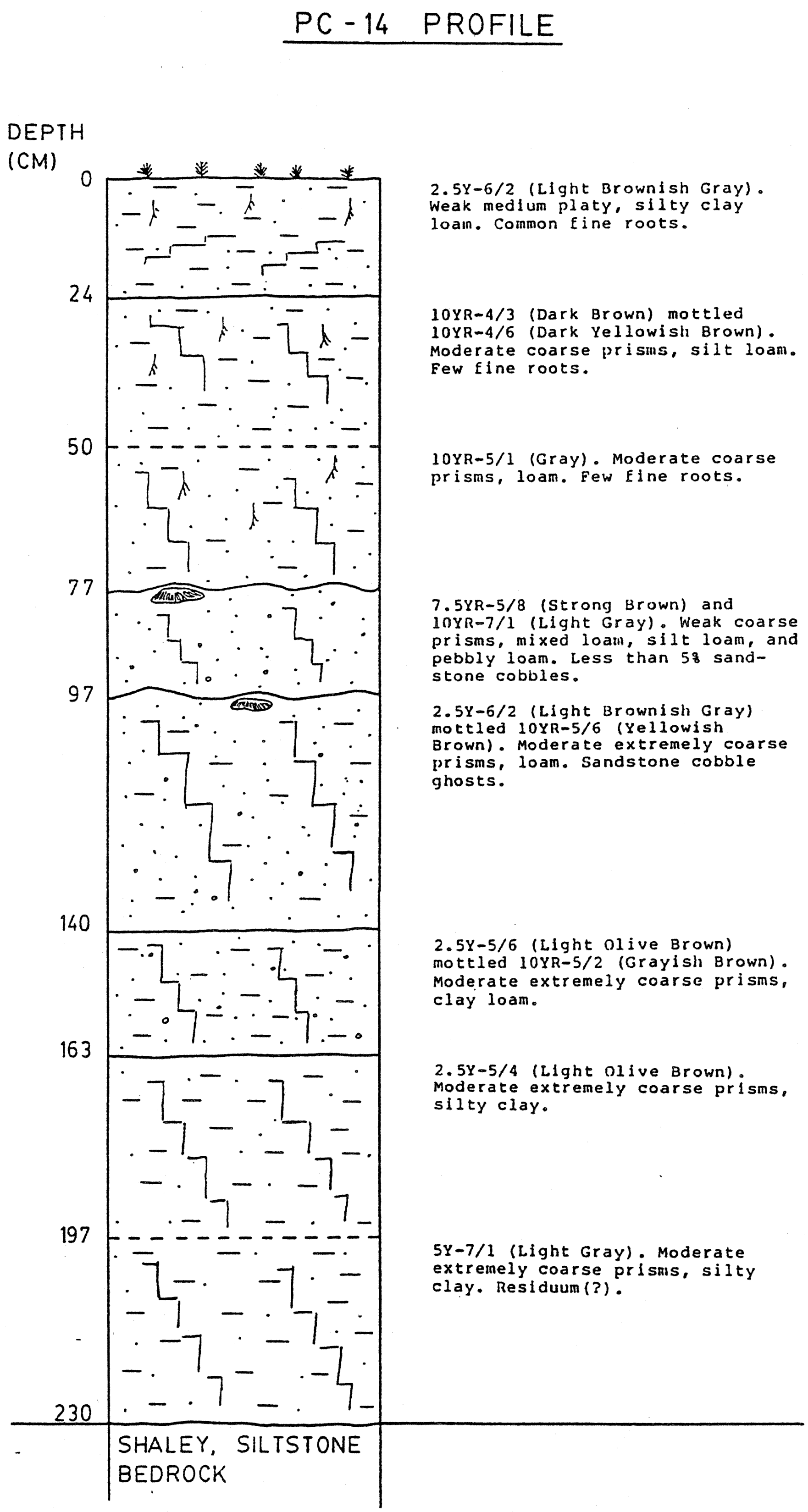


FIGURE R.4.8D Profile PC-14 in Pendleton Creek Valley, WV.

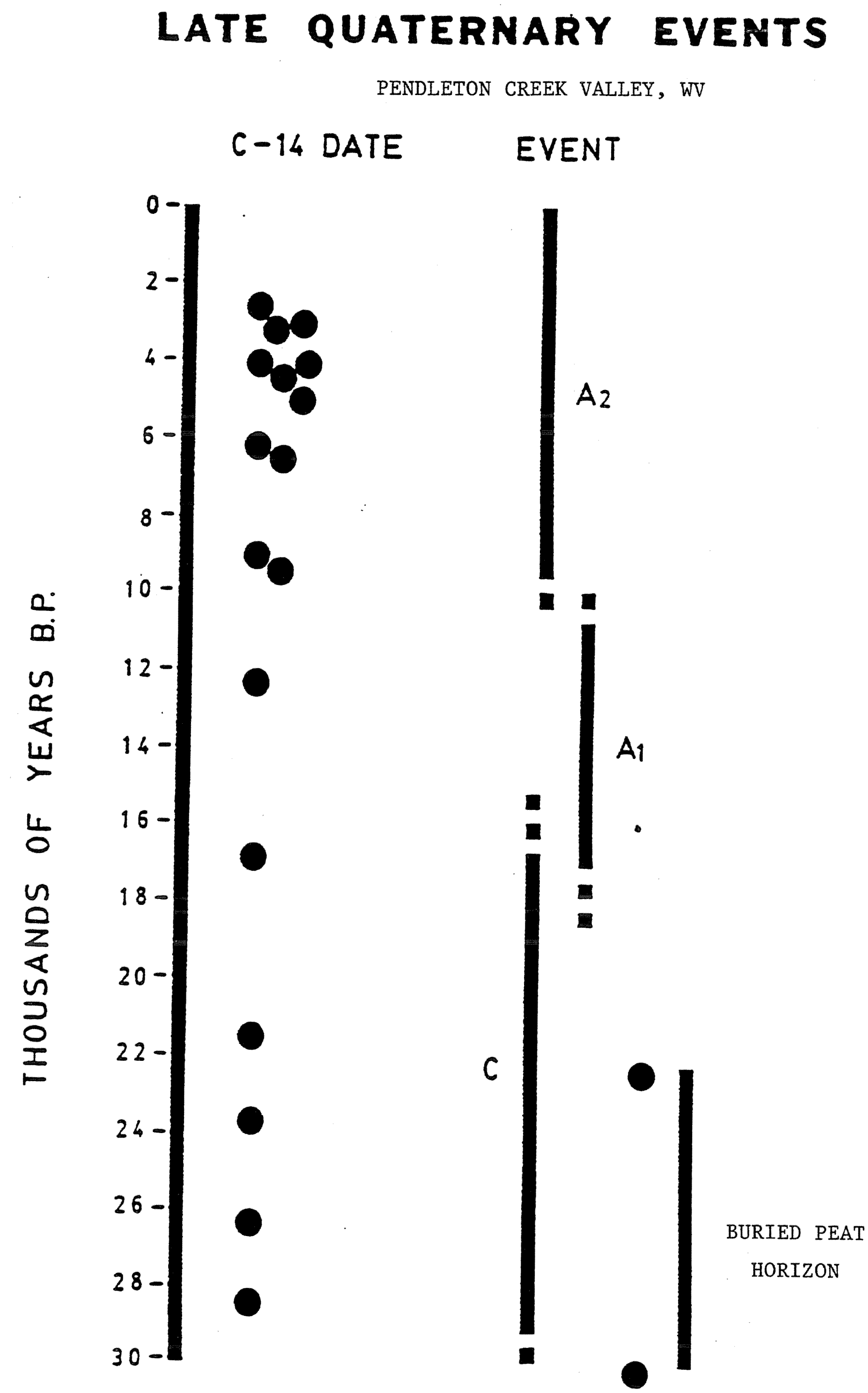


FIGURE R.4.9. Late-Quaternary events in Pendleton Creek Valley, WV.

This new discovery will provide substantial information on the time of colluviation in the Pendleton Creek Valley. The peat zone was extensively sampled, and the samples were frozen to await further study. This site also provided numerical age dates needed to correlate soils developed in colluvium in the valley.

The colluvial soil (PC-50), described by Secindiver and McCloy, and selected analyses demonstrate the effects of weathering and soil formation. The colluvial soil is interpreted as being no older than 22,000 yr BP. It may be as young as 17,000 yr BP. As care was taken to locate and describe a site influenced by substantial erosion during the "alluvial phase," we believe this site to be of value to soil scientists and to geologists, alike. Much study is yet to be done (pollen analysis, clay mineralogy, characterization of the packages of colluvium). While we regret that the "classic" exposures are gone from this valley, we are confident that they represented events in similar valleys in the open-fold portion of the unglaciated Allegheny Plateau section.

BLACKWATER FALLS STATE PARK, WEST VIRGINIA TO SKYLAND LODGE, SHENANDOAH NATIONAL PARK, VIRGINIA, *VIA* EASTERN EDGE OF UNGLACIATED ALLEGHENY PLATEAU SECTION OF THE APPALACHIAN PLATEAUS PROVINCE, THE APPALACHIAN MOUNTAIN SUBSECTION AND THE GREAT VALLEY SUBSECTION OF THE MIDDLE SECTION OF THE RIDGE AND VALLEY PROVINCE, AND THE NORTHERN BLUE RIDGE SECTION OF THE BLUE RIDGE PROVINCE:

Total	Interval	Description
0.0	0.0	Leave Blackwater Falls State Park Lodge. For the part of this route on the Plateau, colluvial soils and associated periglacial features will be seen, along with overall structural geomorphic features.
0.1	0.1	**BEAR LEFT** out of parking lot.
1.5	1.4	Blackwater River.
1.8	0.3	Stop sign. **RIGHT TURN**, exit Park and continue to West Virginia 32.
3.0	1.2	Junction Route 32, **TURN RIGHT**, continue through Davis on 32.
3.7	0.7	Bridge over Blackwater River, ascend dip slope of Canaan Mountain.
6.4	2.7	Canaan Heights.
6.9	0.5	Crest of Canaan Mountain. Descend into Canaan Valley.
7.0	0.1	Begin exposure of Mauch Chunk Group rocks on right.
7.5	0.5	End of Mauch Chunk exposure. Here, light-colored colluvium rests on red residuum of Mauch Chunk. Note drainageway with brown soil and armored colluvium containing large blocks from the Pottsville Formation.
7.6	0.1	Exposure of gully incised deeply into Mauch Chunk saprolite and filled with colluvium.
7.7	0.1	End of cut, residual soils are now at the land surface.
7.8	0.1	Deep hollow colluvial fill armored with blocks of Pottsville lithology. There may be two soil sequences near the surface here.
7.9	0.1	Saprolite exposed beneath colluvium.
8.0	0.1	Deep colluvial fill.
8.1	0.1	Beginning of Mauch Chunk bedrock exposure.
8.2	0.1	End of bedrock exposure.
8.3	0.1	Descend into Canaan Valley.
8.9	0.6	Topographic spur underlain by residual soil formed on Mauch Chunk.
10.4	1.5	Valley floor underlain by Greenbrier Group limestones.
11.3	0.9	Blackwater River.
11.6	0.3	Exposure of Greenbrier Group limestones.
12.3	0.7	Freeland Road on left, continue.
13.1	0.8	Entrance to Canaan Valley State Park, continue.
13.4	0.3	Exposures of Greenbrier Group limestones left and right.
14.5	1.1	Quarry in Greenbrier Group limestones on right.
15.2	0.7	Road cut through Greenbrier Group limestones.
15.3	0.1	**LEFT TURN** onto Jennington-Lead Mine road, Route 45. Descend toward valley of Red Creek in the Stony River Syncline.
17.3	2.0	Note excellent view of Mt. Porte Crayon (1454 m) to east on the crest of the Roaring Plains. Bedding of resistant Pennsylvanian-age sandstones and conglomerates is essentially horizontal.
18.1	0.8	Pocono Formation at creek crossing.
18.8	0.7	Greenbrier Group limestone exposed above, on left.
19.3	0.5	Vista (best after leaf fall) of valley of Red Creek, where sediments were highly reworked by the November 1985 flood.

19.6	0.3	Descend to valley floor of Red Creek over colluvial footslopes.
20.3	0.7	Debouch onto floodplain of Red Creek. Extensively modified flood plain was heavily reclaimed after storm.
20.6	0.3	Channel was completely reconstructed here.
21.0	0.4	On left is exposure of part of Mauch Chunk Group plunging into trough of Stony River Syncline.
21.2	0.2	New bridge over Red Creek, then exit Tucker County.
21.3	0.1	Enter Randolph County and the Dolly Sods Wilderness Area, U. S. Forest Service, ascend back (dip) slope of Allegheny Front.
21.6	0.3	Colluvium derived from Pottsville rocks on Mauch Chunk exposure.
22.0	0.4	Colluvium derived from Mauch Chunk overlain by colluvium from Pottsville Group source rock.
22.6	0.6	Mauch Chunk saprolite overlain by colluvium rich in parent material derived from Pottsville Group rocks, at culvert.
22.9	0.3	Compacted colluvium with lateral flow zones at several depths.
23.3	0.4	Note outcrop on left, next large blocks on colluvium.
23.5	0.2	Narrow block stream on left; note blocks on edge.
24.5	1.0	Dolly Sods Picnic Area (1128 m), then enter Grant County.
25.1	0.6	Junction U.S. F. S. 75 with 19. **LEFT TURN** onto Route 75. This is the New Stone Road along the crest of the Allegheny Front. The Grant-Tucker county line follows along the crest of the front. Note extreme stoniness of soil in places; blocks are from basal part of Pottsville Group and are often concentrated into sorted stripes and small block fields and block streams on both sides of the road.
25.8	0.7	**STOP 5.1: RIGHT TURN** into parking loop (Hopeville, WV quadrangle). Stop. Walk along trail to large sandstone outcrop at cliff edge. Discussion and picture stop. Here, cryoplanation terraces (as interpreted by Clark and Hedges, 1992, Figure 2.7) can be seen from the cliff edge. Bedding dips to the northwest, but terrace treads slope gently to the east at the feet of the risers. On the gentle dip slopes, there are sorted stripes, sorted nets, and small block fields derived from orthoquartzite beds of the Pottsville Formation.
25.9	0.1	Depart loop, **TURN RIGHT** (north) on 75 and continue along Allegheny Front.
29.9	4.0	Red Creek Campground on left.
32.4	2.5	**STOP 5.2**: Parking lot for Bear Rocks and Stack Rock. Here are prominent tors that could be interpreted as periglacial relicts (Clark and Hedges, 1992, Figures 2.5 and 2.6).
		CONTINUE AHEAD, proceeding (east) down Allegheny Front. Road is narrow and winding, so exercise caution.
37.5	5.1	**TURN RIGHT** (south) on Jordan Run Road.
40.8	3.3	Note exposure, on left (east) side of road, revealing a typical diamicton developed from weathering of the Oriskany Sandstone and cherty, lenticular beds in the upper Helderberg Group. A dissected, bouldery fan can be seen behind the church on the right (west) side of the road.
42.9	2.1	Bouldery surface of dissected alluvial (?) fan south of bridge over Big Run (at bend in road). Most of the boulders were derived from the Pottsville Group, which crops out on top of the Allegheny Front, 4.5 km to the west. Slopes in the upper reaches of Big Run exceed 0.4, so snow avalanches, alpine mudflows, and debris flows are likely former means of transport of these large clasts.

43.1	0.2	Junction on right with U.S.F.S. 19. Route 19 also traverses the Allegheny Front to Dolly Sods. Continue ahead on Jordan Run Road. The excursion focus is now on structural geomorphic and fluvial geomorphic topics.
43.7	0.6	Outcrop of Oriskany Sandstone on left; this is the northwest limb of the Hopeville Anticline.
44.0	0.3	Ahead is the Hopeville scour from the 1985 flood.
44.1	0.1	Stop. Intersection of Jordan Run Road with West Virginia 55 and 28. Optional **RIGHT TURN** onto 55 and 28. Otherwise, **TURN LEFT** on 55 and 28.
44.3	0.2	**SHORT OPTIONAL DISCUSSION STOP 5.3:** Left turn into church parking lot (Hopeville, WV quadrangle). The Hopeville Scour, where 11 people died, had the greatest loss of human life of any single location during the November 1985 flood (Kite and Linton, 1987, p. 58-59). Aside from the human tragedy, this stop illustrates the concern that many earth scientists have about the effects that cataclysmic events might have on the longevity of pre-existing landforms and materials in the Appalachians. If time permits, this is a good place for discussion.
44.6	0.3	Time permitting, optional walk or van shuttle for interested participants to the Hopeville Canyon overlook (FIGURE R.5.1) where the flood produced pervasive stripping of alluvium, transported large boulders, deposited sheets of imbricated cobbles and boulders, removed trees, and truncated distal ends of alluvial and colluvial fans (Kite and Linton, 1987, p. 57). Turn around, retrace route on 55 and 28.

FIGURE R.5.1 Hopeville Canyon Overlook. Essentially entire floodplain area was reworked by mechanized equipment shortly after the record November, 1985 flood. Flood waters were at least 3-4 m deep (much deeper in bedrock-defended narrow reaches) at the peak of the November, 1985 flood discharge. Near ridges are underlain by Oriskany Sandstone of Devonian age folded into an anticlinal-synclinal conjugate pair. From Clark, *et al.* (1989, Figure 48, p. T150: 74). Reproduced with permission of American Geophysical Union.

45.2	0.6	**RETRACE WAY CAME.** On left is Jordan Run Road, continue ahead.
45.6	0.4	Look right, across river, for debris fans truncated by 1985 flood.
46.7	1.1	Bridge over Jordan Run near entrance to Smoke Hole Caverns.
47.0	0.3	Essentially vertical Tuscarora Sandstone on west limb of anticlinorium.

47.3	0.3	**PICTURE STOP 5.4:** In the core area of the Wills Mountain Anticlinorium in North Fork Gap (Hopeville, WV quadrangle). On right is a major debris fan, partially mobilized during the 17-18 June 1949 cloudburst, and truncated by the 1985 event to reveal internal stratigraphy (see Kite and Linton, 1987, p. 60-64; Tharp and Kite, 1989). Continue ahead through North Fork Gap, a major transverse water gap through the Wills Mountain Anticlinorium. Structural features that may have influenced the location of breaching here have been discussed by Clark (1987a, b, c).
48.5	1.2	Tuscarora Sandstone outcrop and exposure on southeast limb of fold.
48.8	0.3	Note new bridge on right to Smoke Hole Road. During the 1949 flood, a major debris flow came out of the valley to the right across the river (see Clark, 1987a, 1987b, for details). Continue ahead.
49.3	0.5	Cliff on right across river is upheld by Oriskany Sandstone.
52.0	2.7	Shale formations of Middle Devonian age are preserved here up plunge from the Bedford Synclinorium, to our left. Farther north, the Bedford Synclinorium is a major structure that is responsible for some Appalachian "Devonian shale barrens" northeast of here (Platt, 1951). These valleys are in relatively dry rain shadows, and the thin soils developed on low-permeability shale bedrock have very low moisture retention, permitting the growth of the unique vegetation types (Platt, 1951).
53.5	1.5	Begin exposure of shale in quarry on left.
53.6	0.1	End of exposure.
55.0	1.4	Petersburg, junction with Route 42, **CONTINUE AHEAD** on high terrace level of ancestral South Branch Potomac River, then descend into downtown Petersburg. The soils in this area are shallow to moderately deep skeletal Dystrochrepts (Weikert, Berks) on the acid brown shales. The valley from here to Moorefield has Typic Udifluvents (Potomac) on the floodplain and Typic Fragiudults and Hapludults on the terraces.
55.9	0.9	Stoplight, intersection with US 220. The portion of Petersburg built on the present floodplain was devastated by both the 1949 and 1985 floods. The 1985 flood, moreover, was responsible for destruction that reached, and in some localities overtopped, the lowest terrace (T1)! **LEFT TURN** onto routes 220, 55 and 28. Nearing the eastern edge of town, the ridge visible ahead and to the right is underlain by the Oriskany Sandstone of Lower Devonian age. Southworth (1988a) reported large ancient landslides in the Petersburg area, including one on this ridge.
56.6	0.7	Lunice Creek, a stream that drains a large portion of this shale valley and is characterized by an extremely flashy discharge curve. The ridge to the left is underlain by Oriskany Sandstone in the nose of a plunging anticline.
57.2	0.6	On right, in cliff across river, note structure—especially faulting—in cliff containing Silurian-Devonian transitional sequence.
57.5	0.3	Petersburg Gap, a water gap that ponded flood waters during both the 1949 and 1985 floods. Long alignments of both the highway and the railroad were either damaged or destroyed by these floods.
58.3	0.8	Leave Grant County, enter Hardy County, and cross new bridge.
58.6	0.3	Cross newly-reconstructed alignment of South Branch Potomac Railroad. On the left, the broad floodplain of South Branch Potomac River is on shales of Middle Devonian age in the synclinal South Branch Valley.
59.9	1.3	On right is a view of Baker Rocks, one of the most spectacular outcrops of the Oriskany Sandstone to be seen on the excursion. Nearly vertical beds are on the northwest limb of the Elkhorn Mountain Anticline.
61.9	2.0	Baker Rocks sign on right.

62.9	1.0	On right, alluvial/colluvial aprons cover shale bedrock. Alluvial/colluvial soils range from very young fluvents of the floodplain to Hapludults on the higher terraces and alluvial aprons.
65.4	2.5	Highway is on terraces of South Branch Potomac River. The terrace soils are mostly classified as Hapludults.
67.5	2.1	Moorefield, chicken capitol of West Virginia. Moorefield was also devastated by the 1985 flood, with part of the damage and destruction related to still another tight water gap downstream from the town. This gap, named The Trough, was noted by Tewalt (1977) as an especially narrow constriction that has ponded flood waters in the past.
68.1	0.6	Cross creek.
68.6	0.5	Stoplight, **TURN RIGHT** onto Route 55 east, ascending terrace(s) of South Branch, Potomac River. Beyond this point, "ridge and ravine" topography developed on folded, fine-grained, clastic sequences of Devonian age is well illustrated to the vicinity of Baker.
68.8	0.2	Cross railroad tracks, bedrock units are mainly shales of Middle Devonian age, in places capped by high alluvial terraces. The soils from here to Baker are shallow to moderately deep skeletal Dystrochrepts on the acid shales (Berks, Weikert) and sandstones (Dekalb).
71.3	2.5	Cross creek and ascend through Devonian section.
79.8	8.5	South Branch Mountain (700 m).
83.8	4.0	Needmore community.
83.9	0.1	Baker Run bridge.
86.2	2.3	Enter community of Baker, note intersection with West Virginia Route 259, but **BEAR LEFT** and continue on Route 55 east.
88.4	2.2	Hanging Rock Anticline, bedrock is Oriskany Sandstone.
88.5	0.1	Begin exposure on left in Baker Cave Quarry. Note intense folding and faulting in predominantly limestone rocks of Upper Silurian age.
88.6	0.1	End exposure in Upper Silurian and Lower Devonian carbonate rocks.
88.8	0.2	The river on right is Lost River.
89.2	0.4	Tuscarora Sandstone exposed on limb of Hanging Rock Anticline.
89.6	0.4	Hanging Rock.
89.7	0.1	McCauley community.
91.0	1.3	Crest of ridge, descend toward floodplain of Lost River.
93.3	2.3	Shale pit.
93.7	0.4	**POSSIBLE DISCUSSION STOP 5.5:** Lost River (Baker, WV quadrangle). This stop highlights the swallet and bed of Lost River, a well-known karst locality. Cross bridge to picnic area and park for lunch and short walking tour to and from Lost River Swallet (FIGURE R.5.2). Ponor drainage was plugged some time during the 1985 flood, and Lost River became a temporary (?) perennial stream, after at least a hundred-year history of only ephemeral flow over this reach.

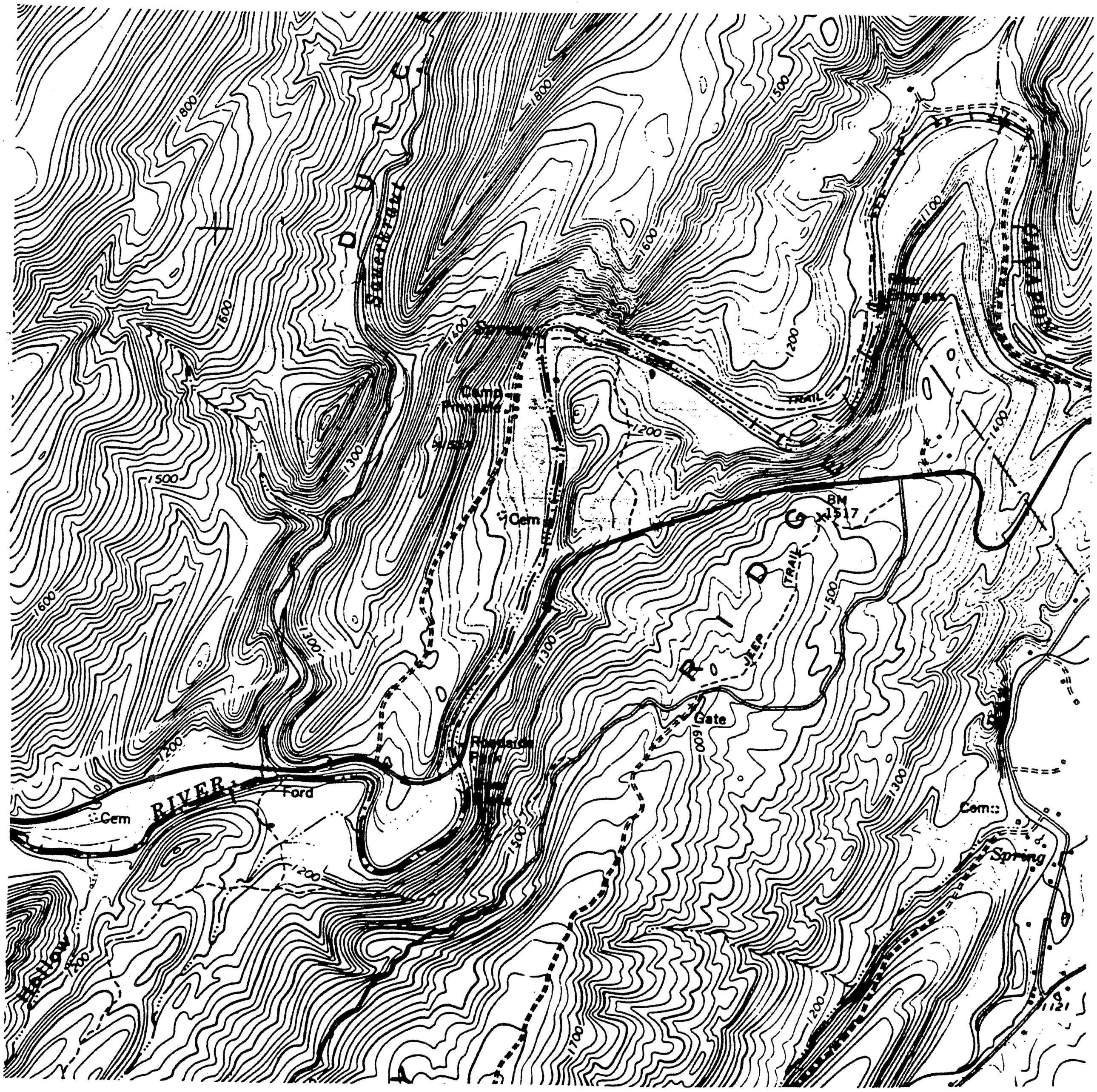


FIGURE R.5.2 Lost River and Lost River Sinks. (From Baker, WV, quadrangle).

AT THIS POINT, THE TOUR CAN EITHER CONTINUE STRAIGHT AHEAD ON WEST VIRGINIA ROUTE 55 EAST INTO VIRGINIA AND CONTINUE ON VIRGINIA ROUTE 55 TO INTERSTATE 81, OR, THE TOUR CAN BACKTRACE TO PROCEED AS FOLLOWS:

		TURN AROUND, retrace route. The excursion now follows the trend of an eastern Ridge and Valley strike belt of fine-grained clastic rocks of Devonian age. Noteworthy geomorphic features are on both the floodplain and the valley sides.
101.7	7.5	Baker, **LEFT TURN** on West Virginia Route 259 at the intersection of Routes 29, 55, and 259. At this intersection, Lost River cuts through Warden Ridge, a hard sandstone with shallow Dekalb soils that are classified as Typic Dystrochrepts. **TURN LEFT** onto 55-259. Here, the route follows Lost River upstream to its headwaters and the interfluve with the north fork of the Shenandoah near the Virginia-West Virginia boundary. The nearly level floodplain and low terrace soils are classified as either Entisols (Fluvents and Aquents) or as Inceptisols (low terraces). Parent materials of these soils are derived from the surrounding sandstone and shale residual upland soils.
108.1	6.4	It is quite typical of upper watersheds, in this part of the Appalachians, to tend to become choked with colluvium. Eventually, low terrace and floodplain soils are replaced by higher terrace and footslope fan terrace soils, most having fragipans. At the confluence of Kimsey Run and Lost River, the sediment load forced Lost River to the far east side of the valley. Upstream, there is a low terrace nearly one-half mile wide as Lost River swings back to the west side of the valley. Cross Lost River. Lost River now flows in a valley underlain by a thick shale sequence of Middle Devonian age.
108.3	0.2	Note the bouldery deposit produced by a very large slope failure on the left (east). Oriskany Sandstone underlies the sparsely vegetated source area on the slope above this hummocky, tree-covered landform (Lost City, WV/VA quadrangle). Southworth (1987; 1988b), in a discussion of prehistoric giant rockslides, cited this locality as an example of a debris avalanche deposit. Southworth (1987) calculated the volume of deposit here to be 6,000,000 m^3, and attributed the failure to undercutting of the slope by Lost River.
108.7	0.4	Enter community of Lost City. The mountainous area to the left (east), the Great North Mountains, is capped by the Tuscarora Sandstone on the northwest flank of the Adams Run Anticline. The shale hills to the right (west) are underlain by the Devonian Hampshire and Chemung Formations in the Sideling Hill Syncline. Here at Lost City, Whitehead Run and Lower Cove Run deposit modern sediment loads. Here also, terrace soils, many with fragipans, occur between low shale hills. South of this confluence to Mathias are large fan terraces or aprons of colluvium/alluvium with soils that have fragipans.
109.1	0.4	Note margins of a fan-pediment-terrace complex on the left (east) side of Route 259.
109.3	0.2	**STOP 5.6:** Stratigraphy of a complex alluvial landform (Lost City, WV/VA quadrangle). Examine the quarry exposure 100 m east of Route 259. Although the morphology seen from the ground suggests an incised alluvial fan, the internal stratigraphy exposed in the pit is more like that of a pediment or an erosional terrace. The stratigraphy, and the topography shown on the quadrangle, suggest that this landform is an example of what Mills (1983) has termed a fan-pediment. Most of the material exposed in the face is Devonian

shale. Some alluvium may have been eroded from the top of this landform, but this exposure and many similar to it on suitable lithologies and in similar footslope positions throughout the Ridge and Valley province show that bedrock makes up most of the volume of fan-pediments. Although the sandstone-bearing alluvium is thin relative to the local relief of the landform, it may be an important armor protecting the easily eroded shale bedrock.

The exact mode of origin for these landforms is not clear, but unlike alluvial (?) fans to be seen on a later stop near the base of the much higher Northern Blue Ridge Mountains, these features clearly are not the product of thick alluvial and colluvial aggradation. The history suggested at this locality is minor aggradation followed by either "lateral planation" or incision. What geomorphic event, however, is the main deviation from the long-term norm in this setting? In speculation, could we be observing forms and materials that are products of Quaternary environments so unstable that equilibrium landforms and their underlying geomorphic materials could not develop? Alternating Quaternary morphogenetic systems may have played an important role in the genesis of these landforms, but it is not yet clear either what these geomorphic environments were, or what specific factors favored erosion versus deposition.

Continue south on Route 259.

110.9 1.6 Note large, incised fan-pediment to the east (left) near Lost City.

111.5 0.6 Cross Lost River.

115.2 3.7 Enter Mathias. Note Route 12 to Lost River State Park on right. Proceed south on Route 259. South of Mathias, there are extensive aprons of colluvial soils, nearly all having fragipans. The colluvial source is Cove Mountain to the east. Fragipan soils form under certain conditions mentioned earlier, but a major requirement is for younger colluvium/alluvium to cover an older soil to a depth usually between 80 and about 125 cm. Cove Mountain provides a source of water for the required lateral movement of water at the contact between the younger and older soils, and the gentle slopes induce the perching that results in fragipan genesis.

119.4 4.2 This high (540 m) portion of the valley is the drainage divide between the Shenandoah River basin and the South Branch Potomac River basin. The watershed divide between Lost River and Capon Run is choked with colluvium. Most of the soils have fragipans. Of interest, Capon run cuts through Cove Mountain to the east, and its headwaters come from Great North Mountain.

122.2 2.8 Leave Hardy County, West Virginia; enter Rockingham County, Virginia. As Route 259 descends Capon Run, the floodplain gradually widens. At the intersection of Routes 259 and 820, Capon Run and German River merge to form the North Fork Shenandoah River. Sediments along the river have a very high gravel, cobble, and boulder content, indicating past high flood velocities. As the valley widens, the coarse fragment load is dropped except in scour channels. Again, stacked alluvial and colluvial soils occur, most having fragipans.

127.6 5.4 Prior to the flood of November, 1985, Riverside Church was located southwest of this intersection on the floodplain of the North Fork of Shenandoah River. The church was destroyed by high velocity flow that developed at the head of a chute that can be seen near Route 259. The floodplain enjoyed relatively little modification on either side of the head of the chute, and the building probably would have withstood the flood had it been located 10 m closer to or farther from the river. Some parts of the floodplain clearly are less safe than others, and pre-existing microtopography obviously can play a role. Wisely, the congregation rebuilt the church on high ground far away from the river.

134.6 7.0 Chimney Rock, on the left behind the VFW hall, is an outcrop of resistant, vertically-bedded Oriskany Sandstone.

135.0 0.4 **STOP 5.7:** Brocks Gap (Timberville, VA quadrangle). Note the floodplain scour produced in the November 1985 flood. The roadcut in Brocks Gap exposes Late Ordovician (Martinsburg Formation, Oswego Sandstone, and Juniata Formation) and Early Silurian (Tuscarora Sandstone) clastic sedimentary rocks. The eastern (stratigraphically lower) end of this sequence is disrupted by two minor backthrusts associated with the Little North Mountain Thrust Fault (Brent, 1960). The thrust itself lies about 0.5 km east of this water gap, and outcrops of Upper Cambrian Conococheague Limestone occur just beyond the fault (Brent, 1960). Sherwood, *et al.* (1987) prepared an interpretation of the structural convolutions at the north end of Brocks Gap (FIGURE R.5.3).The tectonic complexities at this great structural front have profound geomorphic ramifications, having influenced both the topographic development and the juxtaposition of the strikingly different Ridge and Valley and Shenandoah Valley landscapes. These bedrock structuro-lithologic relations also underscore the problems associated with understanding the development of transverse water gaps. What were the breaching mechanisms, and what structure(s) localized a gap here, rather than elsewhere?

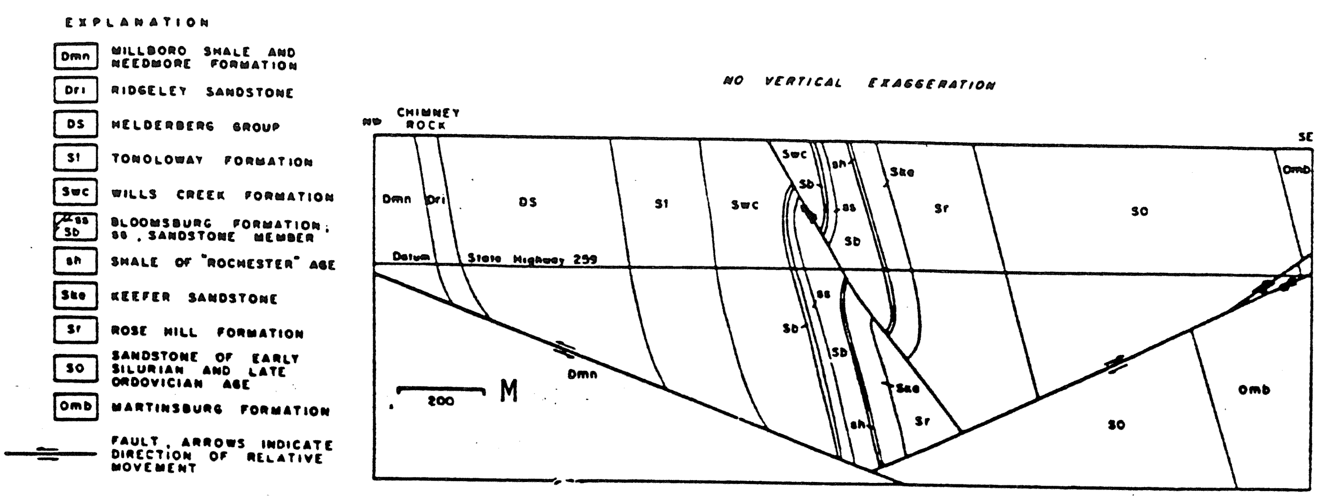


FIGURE R.5.3 Structural cross section at the north end of Brocks Gap. (From Sherwood, *et al.*, 1987, Figure 3, p. 18). Brocks Gap is another outstanding example of a Central Appalachian transverse water gap that may have been localized by structural weaknesses. The Little North Mountain Thrust Fault complex is one of the several great structural fronts seen on the excursion.

In this area, Little North Mountain separates the relatively rugged topography of the "Ridge and Valley" Middle section (Table 1), which is underlain by rocks of Middle Ordovician to Mississippian ages, from the rolling topography of the "Shenandoah Valley" informal district, which is underlain by Middle Cambrian to Late Ordovician carbonate and shale bedrock. A major theatre of operation during the American Civil War, the Shenandoah Valley is best known in geomorphology as the primary field area for the development of the dynamic equilibrium concept in landscape evolution (Hack, 1960; 1965).

135.7 0.7 **TURN RIGHT** (southwest) on County Road 613, at the community of Cootes Store. Cootes Store is located on a higher terrace of the Monongahela soil, a fairly widely distributed fragipan soil along both the Shenandoah and Potomac Rivers. Route 613 runs parallel to strike to the southwest. Here, the road is on dolomites having a fairly high content of silt, clay, and chert impurities. The iron oxide content gives rise, through weathering, to red clayey soils typical of the Shenandoah Valley district of the Great Valley section. Frederick and Lodi are well known names associated with these Hapludults and Paleudults. Rock outcrops are a common feature of the landscape in this part of Northern Virginia. At the intersection of 613 and 783, there are numerous dolomite outcrops and abundant karst features.

143.0 7.3 **TURN RIGHT** (southwest) at Singers Glen. Stay on Route 613. Singers Glen is in a wide valley of rolling hills, all underlain by carbonate bedrock. To the west, the lower slopes of Little North Mountain are blanketed with stony colluvial soils, most having fragipans. Hilly areas in the Shenandoah Valley generally are underlain by carbonate rocks that include interbedded or lenticular chert or sandstone. The same bedrock types tend to yield thick residual soils (Hack, 1965). Two different types of hills occur east of Singers Glen. The lower, linear hills about 400 m east of Route 613 typify topography underlain by sandstone beds in the Conococheague Limestone. In contrast, two higher, rounded knolls (Green Hill and Round Hill) about 1.3 km east are underlain by thick lenses of massive chert in the Rockdale Run Dolostone of the Lower Beekmantown Group. The soils on Round Hill and Green Hill are therefore extremely cherty, and these hills are left wooded for good reason.

146.5 3.5 **TURN LEFT** (southeast) on Rockingham County Road 763. Route 763 cuts approximately across strike of bedding that varies slightly in its resistance to weathering. The road goes over the resulting low hills or around them on curves.

1 47.1 0.6 **TURN RIGHT** (southwest) on Road 752. Route 752 turns along the strike and parallels Muddy Creek to the intersection of Route 33.

149.0 1.9 Cross Road 726 at Mount Clinton.

150.7 1.7 **TURN LEFT** (east) on U. S. Route 33. The trip continues to the southeast on Route 33, crossing over belts of both "dirty" and "clean" carbonates. Both Alfisols and Ultisols are mapped, depending on depth to rock. Most of the Alfisols have yellowish brown or strong brown clayey subsoils, in contrast to the red clay subsoils of the Ultisols.

152.4 1.7 **PICTURE STOP 5.8:** View of Mole Hill, a volcanic plug (Bridgewater, VA quadrangle). Mole Hill, the rounded knoll (FIGURE R.5.4) to the south, might superficially appear to be very similar to numerous chert-capped knolls developed on Beekmantown Group dolostones. Although cherty soils occur on its flanks, unmetamorphosed olivine basalt is the only lithology present at the top of Mole Hill. Previously mapped as a Triassic intrusive rock (Brent, 1960), radiometric dating of the basalt gave a Middle Eocene age (47 ± 1 Ma), similar to that of Trimble Knob near Monterey (Wampler, 1975; Rader, *et al.*, 1986).

The soil survey of Rockingham County does not differentiate the olivine basalt soils of Mole hill from the surrounding cherty dolomite soils on the lower slopes. This is due to the Soil Conservation Service requirement of a minimum of 2,000 acres of a new soil before a new soil series is established.

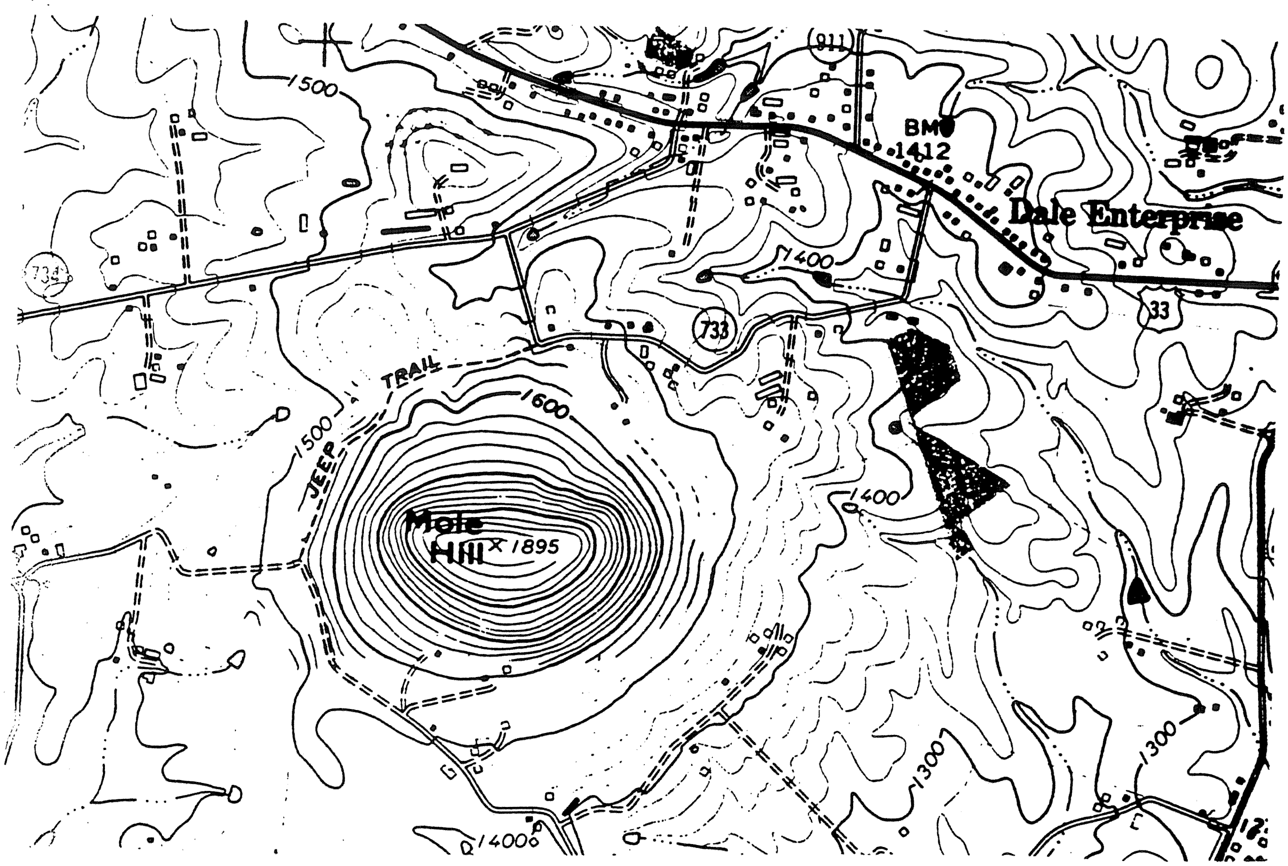


FIGURE R.5.4 Topographic map portion showing Mole Hill. (From Bridgewater, VA quadrangle.

PROCEED EAST on US Route 33 through Harrisonburg. Cherty Middle Ordovician Lincolnshire Limestone underlies most of the low linear ridges traversed over the next 5 miles (8 km). FIGURE R.5.5 illustrates the overall bedrock geology in the Harrisonburg area.

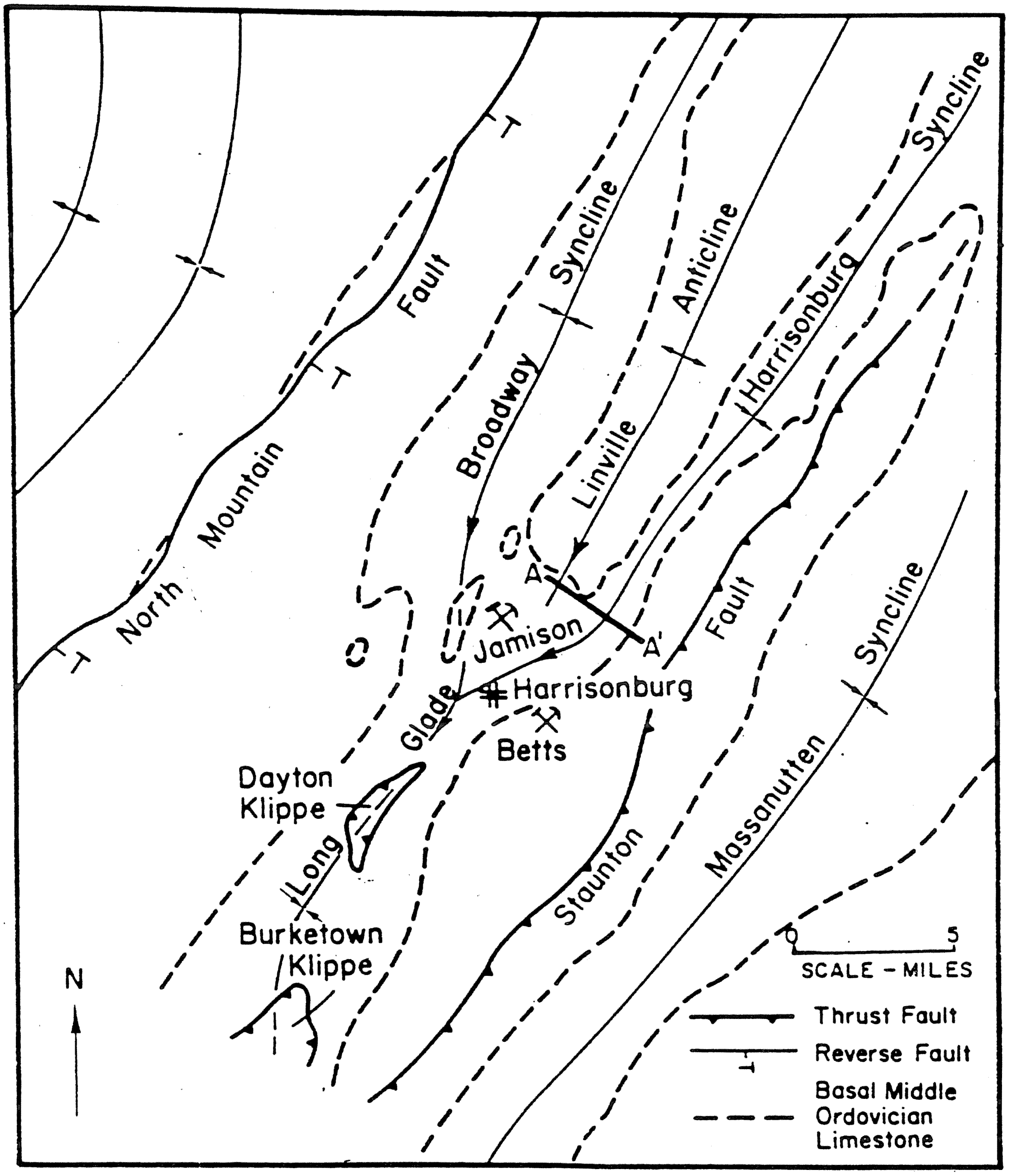


FIGURE R.5.5 Geologic sketch map of the Harrisonburg, Virginia area. The "North Mountain Fault" is one of the several major Appalachian tectonic fronts seen on the excursion. (From Lowry, *et al.*, 1971, Figure 6, p. 99).

156.7 4.3 Travel one-half way around Rockingham County court house in downtown Harrisonburg. Continue east on Route 33 (E. Market St.). Typical of central business districts in most present-day American communities, few prosperous commercial establishments remain in the old downtown area. This is a stark contrast with the untrammeled commercial development at the next stop.

159.1 2.4 **POSSIBLE STOP 5.9:** Valley Mall (Harrisonburg, VA quadrangle). Extensive and environmentally unsound construction in the last 25 years has made this part of Harrisonburg an excellent locality to observe the thick Ultisols that form from sandy, cherty dolostones of the Beekmantown Group. Frederick (Typic Paleudult) and Lodi (Typic Hapludult) soils occur here (Hockman, *et al.*, 1982). The B horizons may total up to 20 m in thickness. The sites and conditions of exposures change with time, depending on construction activity and the weather, so the exact location of this stop cannot be determined far in advance.

Continue east on Route 33.

160.8 1.7 Approximate trace of the Pulaski-Staunton Thrust Fault. The fault shows about 1200 m of displacement here, but dies out 35 km northeast of this locality (Brent, 1960). The fault has no consistent topographic expression throughout Rockingham County.

166.4 5.6 **TURN LEFT** (north) at Spotswood High School. Proceed to upper parking lot.

167.0 0.6 **STOP 5.10:** View of alluvial (?) fans and fan-pediments (over Harrisonburg, VA quadrangle). Alluvial (?) fans below the foothills of the Blue Ridge (6 to 12 km to the south and east; see FIGURE R.5.6) are dissimilar from typical fan-pediments below the resistant sandstone ridges in the Ridge and Valley province, such as Massanutten Mountain (3 km to the north). These differences are related to bedrock geology, both in the headward drainage basin and under the fluvial (?) landform.

FIGURE R.5.6. Pseudoradar map of parts of Shenandoah Valley, Massanutten Mountain, and Blue Ridge. (From Shenandoah National Park raised relief map, original scale 1:125,000.)

The overall lithologic, stratigraphic, and structural setting (FIGURES R.5.3, R.5.5, R.5.6) places resistant rocks over weak and/or soluble lithologies. Abundant coarse clasts in Blue Ridge soils, and karst solution of bedrock at the foot of the Blue Ridge combine to favor development of large fans. Precambrian Catoctin Metabasalt and Pedlar Formation charnokite (hypersthene granodiorite) underlie the highest (> 1000 m) knolls in the Blue Ridge (Brent, 1960; Gathright, 1976).

Slightly lower (800-900 m) ridges are capped by resistant rocks in the Late Precambrian to Early Cambrian Chilhowee Group on the western limb of the Blue Ridge Anticlinorium (Brent, 1960). The most resistant of the Chilhowee Group rocks, the Erwin Quartzite and the Weverton Formation, are duplicated in folds that can be seen from this viewpoint when the deciduous trees lack their foliage.

These resistant rocks, particularly the Erwin Quartzite, yield great quantities of coarse colluvium, and alluvium in streams that drain the western Blue Ridge. Sediment has accumulated into large, coalescing aprons that have developed on easily weathered carbonates and shales of Cambrian age that underlie the eastern Shenandoah Valley. The highest portions of these aprons occur at elevations up to 500 m, 150-200 m above the South Fork of the Shenandoah River. Sediments are typically over 50 m thick (King, 1950), but have been modified by stream incision and the solution of underlying carbonates, creating the complex topography to be discussed at a later stop.

Massanutten Mountain is underlain by the Lower Silurian Massanutten Sandstone, a hard, silica-cemented, quartz arenite that is partially equivalent to the Tuscarora Sandstone (Roberts and Kite, 1978). The sandstone is exposed in cliffs on Massanutten Peak, 3 km northwest of this stop; it is one of the most resistant lithologies in the Ridge and Valley province. The Massanutten Synclinorium, the major structure underlying the mountain, plunges to the north here, so all of the visible slopes of Massanutten Peak are obsequent slopes. On Massanutten Mountain, the Massanutten Sandstone rests unconformably on the Ordovician Martinsburg Formation, and the Oswego Sandstone and the Juniata Formation are missing. Streams draining the obsequent slopes flow through a 1.5 to 3.0 km wide belt of Martinsburg Formation (Brent, 1960). These shales produce few clasts of boulder or cobble size, and almost all of the coarse alluvium in these streams is derived from the resistant cap rock. The streams are deeply incised into the shales and have steep gradients. Coarse alluvium does not occur in thick accumulations at the base of Massanutten Mountain, possibly because the slopes produce less coarse materials than the Blue Ridge, and perhaps because there is no well-developed subsurface karst sediment trap. King (1950) mapped several gravel fan deposits near Massanutten Mountain, but these are only thin layers of coarse alluvium that cap predominantly bedrock. In fact, the arrangement of bedrock and alluvium is similar to that in the fan-pediment exposed near Lost River, West Virginia. Hack (1965) referred to these forms as piedmont alluvial aprons, which he likened to pediments.

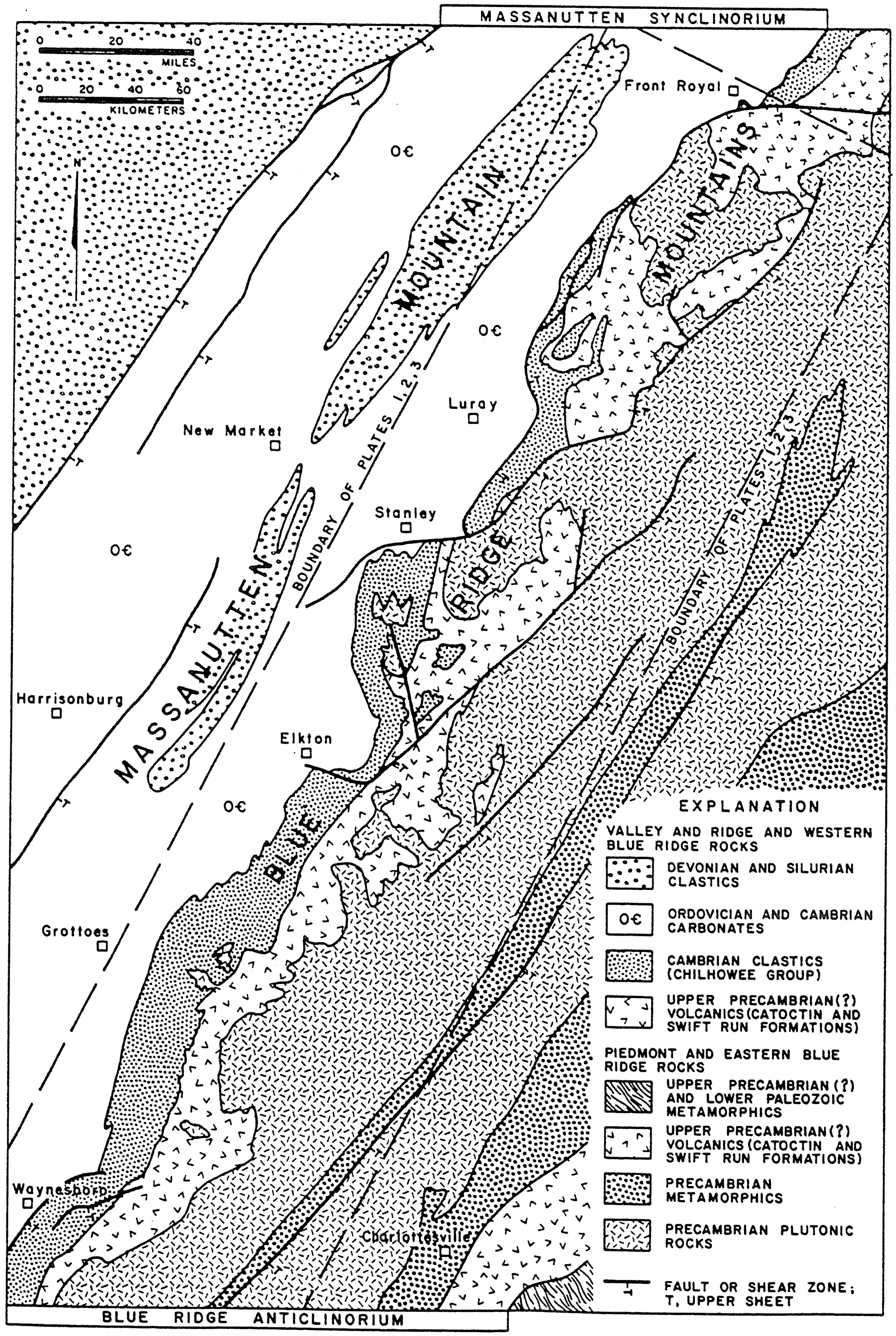


FIGURE R.5.7. Generalized geologic map of Shenandoah National Park and adjacent areas to the northwest. (From Gathright, 1976, Figure 5B, p. 9.)

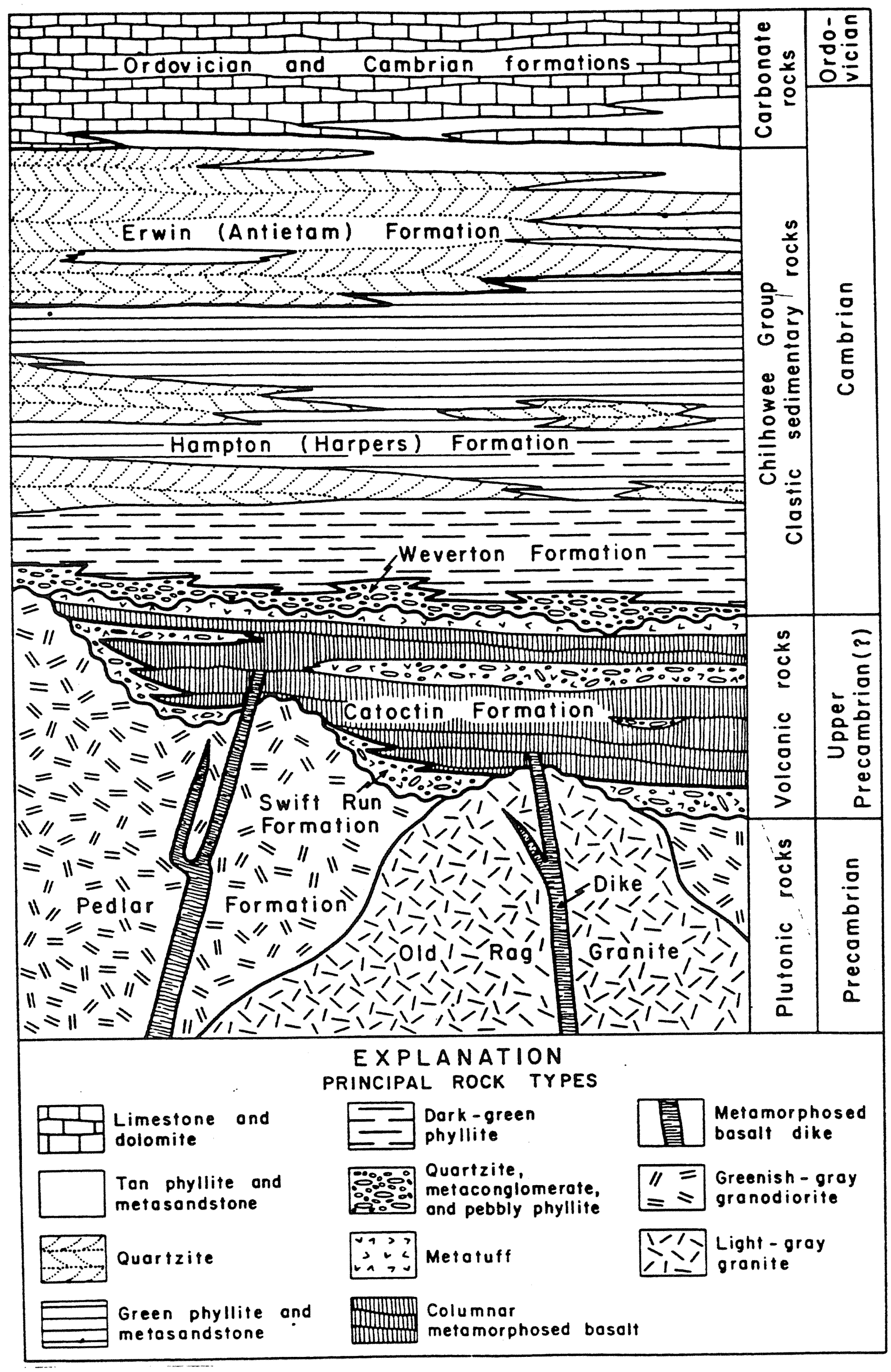


FIGURE R.5.8. Generalized columnar section of rock formations in Shenandoah National Park. (From Gathright, 1976, Figure 6, p. 11.)

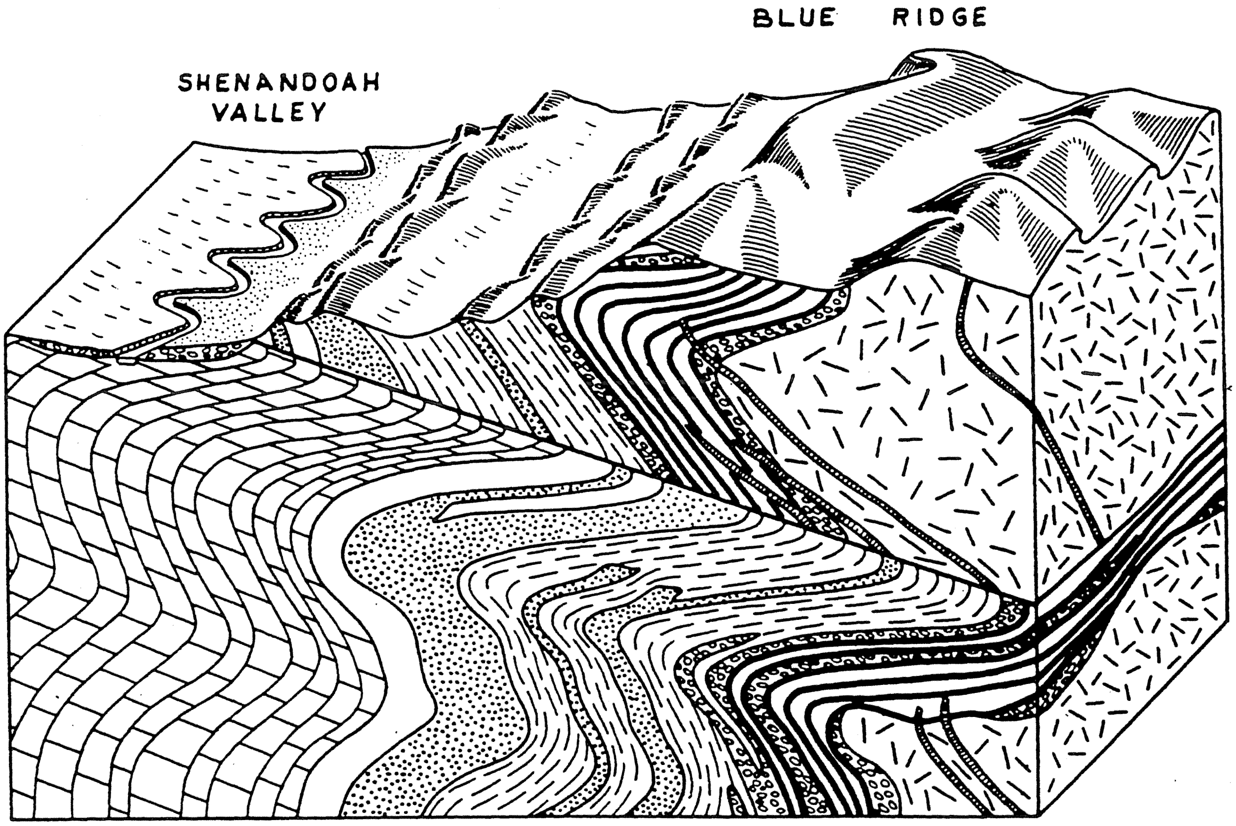


FIGURE R.5.9. Schematic block diagram showing relations among lithology, structure, and topography in the Blue Ridge-Shenandoah Valley area in vicinity of Shenandoah National Park. (From Gathright, 1976, Figure 37, p. 54.)

		RETURN to Route 33.
167.4	0.4	**TURN LEFT** (east) on Route 33.
169.4	2.0	**TURN RIGHT** (southeast) at McGaheysville on Route 649.
170.6	1.2	View of Blue Ridge Mountains and extensive diamicton aprons that have been deposited on their lower western flanks.
171.5	0.9	**STOP 5.11:** Terraces of the South Fork Shenandoah River occur on both sides of Route 649 (McGaheysville, VA quadrangle). King (1950) identified three terrace gravel units along the South Fork of the Shenandoah River in a 20 km reach downstream from this site, but admitted that some of the classification was arbitrary. Later, Hack (1965) concluded that objective correlation of terraces higher than about 10 m AMRL was impracticable in the Shenandoah Valley. Neither King nor Hack differentiated terraces formed by the South Fork from those formed by its tributaries. Hence, terraces mapped by King and Hack generally include incised alluvial fans lumped together with incised floodplain surfaces. Recently, Bell (1986) differentiated six terraces or former floodplain remnants (T0 to T5) and at least two alluvial fan surfaces

(AF1 and AF2) in this part of Rockingham County. Bell (1986) observed that terrace T4, 16 to 23 m AMRL is well developed, but very few fluvial deposits occur between 11-16 m AMRL. Bell determined that the sediment in T4, roughly equivalent to King's (1950) younger terrace gravels, were coarser than alluvium in either lower or higher terraces. Sinkholes are better developed on T4 than on other fluvial surfaces (King, 1950; Bell, 1986). Higher terrace deposits have very limited extent, in part because of collapse and erosion. Most Shenandoah River high terrace surface and near surface alluvium (above T4) is intermixed with colluvium derived from clayey residual soils (Bell, 1986).

Bell's work suggests Late Cenozoic episodes of floodplain development alternating with down-cutting. Hack's basic thesis certainly is correct: the dynamic equilibrium concept better explains the valley's gross topography than did the older concept of the geographical cycle (Davis, 1889). Most large-scale landforms appear to reflect bedrock structure, lithology (Hack, 1980), and overall drainage adjustment or lack of it (Hack, 1973). However, smaller landforms, like Bell's T4, pose problems to a continuum equilibrium model. For example, why are there terraces and terrace remnants at all, if a stream or river is always in balance with its processes of erosion, transportation, and deposition? And, why do some elevation intervals AMRL throughout the Appalachians, especially in the Ridge and Valley province, contain prominent fluvial remnants, whereas others are barren? A speculative approach might entertain the view that environmental perturbations, as climate, anorogenic sea level change, and epeirorogeny have severely impacted Appalachian fluvial systems during Late Cenozoic time.

171.7 0.2 Cross South Fork Shenandoah River. November 1985 flood damage was generally less severe in this drainage basin than in the Upper Potomac, but some evidence of channel widening, scour, and tree tip may still be visible.

172.1 0.4 **TURN LEFT** (north) on U. S. Route 340.

172.7 0.6 **STOP 5.12:** Terrace surfaces near the Adolph Coors brewery site (McGaheysville, VA quadrangle).

According to Bell (1986), T2 surfaces dominate northwest of Route 340. The near-surface occurrence of a fluted projectile point at an archeological site 1 km west of here (R. A. Johnson, personal communication, 1980) shows that most deposition of T2 sediments predates the Early Holocene. On the southeast side of Route 340, the T3 terrace is dominant (Bell, 1986), but locally it is buried under relatively young alluvial-fan deposits. Old alluvial deposits of these (T2 and T3?) terraces are typically between 10 and 12 m thick. The alluvium overlies 15-30 m of saprolite that developed on top of the underlying Cambrian Rome Formation or Shady Dolostone. A 10 to 15 m high scarp separates T3 and the small fans from older alluvial fans.

The stratigraphy of the older fans is quite complex, showing many different types of sediment and evidence of collapse into underlying solution features (Sherwood, *et al.*, 1987), including shallow ponds on upper fan surfaces (Craig, 1969). Kochel and Johnson (1984) studied shallow excavations and concluded that sandy gravels in these fans were deposited by braided streams, with little evidence of debris flow. Well logs and mining excavations, however, show that gravel thicknesses commonly exceed 50 m, and that the gravels are underlain by even greater thicknesses of saprolite and residuum (King, 1950). Water-well drillers report depths to bedrock as great as 240 m (J. E. Mason, personal communication, 1988), far below the level of the South Fork.

Iron and manganese oxides have formed in the thick soils through supergene enrichment (Hack, 1965). Many mines and test pits have been excavated into these ores, but most are now inactive. Bauxite has been noted in portions of some thick soils (King, 1950; Hack, 1965), possibly relict from a hot, wet Early Cenozoic climate. Lignite inclusions in similar materials elsewhere in the American Southeast have yielded Paleocene plant fossils (Bridge, 1950).

Proceed north on Route 340.

174.7 2.0 Note 12 to 15 m high scarps on right side of road. These scarps mark the boundary between the oldest mapped alluvial fans and the younger terraces (Bell, 1986).

175.5 0.8 Erwin Quartzite underlies the hill (Giants Grave) ahead. There is very little fan development here. The floodplain of the South Fork is located just a few meters west of the Erwin Quartzite outcrops, so the river is in a position periodically to truncate alluvium deposited by streams flowing out of the Blue Ridge foothills.

177.8 2.3 **TURN RIGHT** (east) on Route 33 at Elkton.

181.5 3.7 Enter Shenandoah National Park.

183.8 2.3 The overturned contact between the plutonic rocks of the Pedlar Formation (part of the Blue Ridge Complex) and the younger Catoctin Metabasalts may be seen in an overgrown outcrop on the right. A possible paleosol occurs on the Pedlar in this exposure and in the same stratigraphic position as the Swift Run Formation, which is exposed in nearby outcrops. The Late Precambrian unconformity at the top of the Middle Proterozoic Pedlar Formation represents a landscape with 200 to 300 m of relief (Reed, 1969). Conglomerate beds within the Catoctin Formation indicate high-energy environments of deposition and suggest nearby provenances for these sediments.

184.0 0.2 **TURN LEFT** (north) on Skyline Drive near the crest of Swift Run Gap. The Pedlar Formation is exposed here.

184.2 0.2 Shenandoah National Park: Swift Run Visitors Gate. Proceed north on Skyline Drive.

185.3 1.1 Hensley Hollow Overlook: Exposures of phyllite and conglomerate of the Swift Run Formation. Pebbles and cobbles in the outcrop include clasts of granodiorite, vein quartz, and phyllite (Gathright, 1976). North of here, the route is temporarily in Greene County; then, the Skyline Drive straddles the Greene County-Rappahannock County line for several miles. The route then departs Rockingham County, and Skyline Drive weaves across the Greene-Page County boundary.

198.5 13.2 **STOP AREA 5.13:** Entrance to Big Meadows Lodge, Restaurant, and Campground (Big Meadows, VA quadrangle). Turn left and follow signs to the lodge. Park and take the trail west of the lodge to Blackrock, a magnetite-bearing outcrop of Catoctin Metabasalt. This vantage point offers an excellent view of Massanutten Mountain, Page Valley, and the western foothills of the Blue Ridge.

The hogbacks of Massanutten Mountain are underlain by the Silurian Massanutten Sandstone. The prominent "wind gap" to the northwest (New Market Gap) marks a position where the resistant Massanutten Sandstone has been breached, exposing the Martinsburg Formation at the drainage divide. The positions of this "wind gap" and others like it in the Central Appalachians have been attributed to erosion by ancient streams, since diverted by piracy

(Watson and Cline, 1913), but most gaps that have been studied are associated with structural discontinuities (Hack, 1965). New Market Gap coincides with a local structural high in the Massanutten Synclinorium.

The "Page Valley" district has also been considered as the eastern third of the Shenandoah Valley. It is underlain by Cambro-Ordovician limestone, dolostone, and shale. This local name comes from Page County, which lies between the crest of Massanutten Mountain and the Blue Ridge. South Fork Shenandoah River flows through Page Valley, which varies from 5 to 15 km in width.

The western limits of the Blue Ridge foothills are underlain by Late Precambrian Catoctin greenstone and by metamorphosed clastic sedimentary rocks of the Chilhowee Group (Allen, 1967). The Blue Ridge Escarpment occurs at the eastern edge of Page Valley; here, this structural geomorphic feature is the exhumed trace of the Stanley Thrust Fault (Gathright, 1976).

RETURN to Skyline Drive, which now switches back and forth across the Page-Madison county line, and **PROCEED NORTH** toward Skyland.

198.9 0.4 Entrance to Byrd Visitor Center. Note the high-level grassy wetlands that give Big Meadows its name.

201.6 2.7 Spitler Knob Overlook. This viewpoint offers another view of the structural geomorphology seen from Blackrock. Pedlar Formation granodiorite underlies this overlook.

203.2 1.6 **IN CLEAR WEATHER OPTIONAL PICTURE STOP 5.14:**

Old Rag Overlook (on Big Meadows quadrangle overlooking area of Old Rag Mtn., VA quadrangle). Old Rag Mountain, 8 km to the east, is underlain by 1.1 Ga Old Rag Granite. The rugged, weathered outcrops of coarse-grained, quartz-potassium feldspar granite are the oldest rocks exposed in this part of the Blue Ridge province (Gathright, 1976).

The summit area of Old Rag Mountain is noted for the presence of Opferkessel (Hedges, 1969). Opferkessel are not developed on boulders on the forested lower talus slopes of Old Rag Mountain. The first outcrops that contain these pits occur at about 2750 feet (838 m) elevation on the east ridge of the mountain. A few small rock basins developed along joints are seen in this area. Thereafter, basins occur in most outcrops for the remainder of the distance to the summit at 3291 feet (1003 m). Greatest development of the basins has occurred in the summit area, where they are found in the tops of boulders left by spheroidal weathering and on level, exposed bedrock (FIGURE R.5.10). The largest example found on the summit is about 10 feet long, 6 feet wide, and 1 foot deep (3 x 1.8 x 0.3 m). At the summit, there is no visible association of basins with joints. The basins have well-defined spillways. Their walls are undercut at the levels of the spillways, and their floors are nearly flat. Most basins contain little or no gravel or other residua.

The summit area of Old Rag Mountain is not accessible by motor vehicle. Hikers should make the trip only in daylight and in good weather; there is no water or shelter on the mountain. The trail is about 3 miles (5 km) long and the vertical ascent is about 2300 feet (700 m) from the road head, which can be reached by marked local roads leading south from US Route 211 east of Thornton Gap.

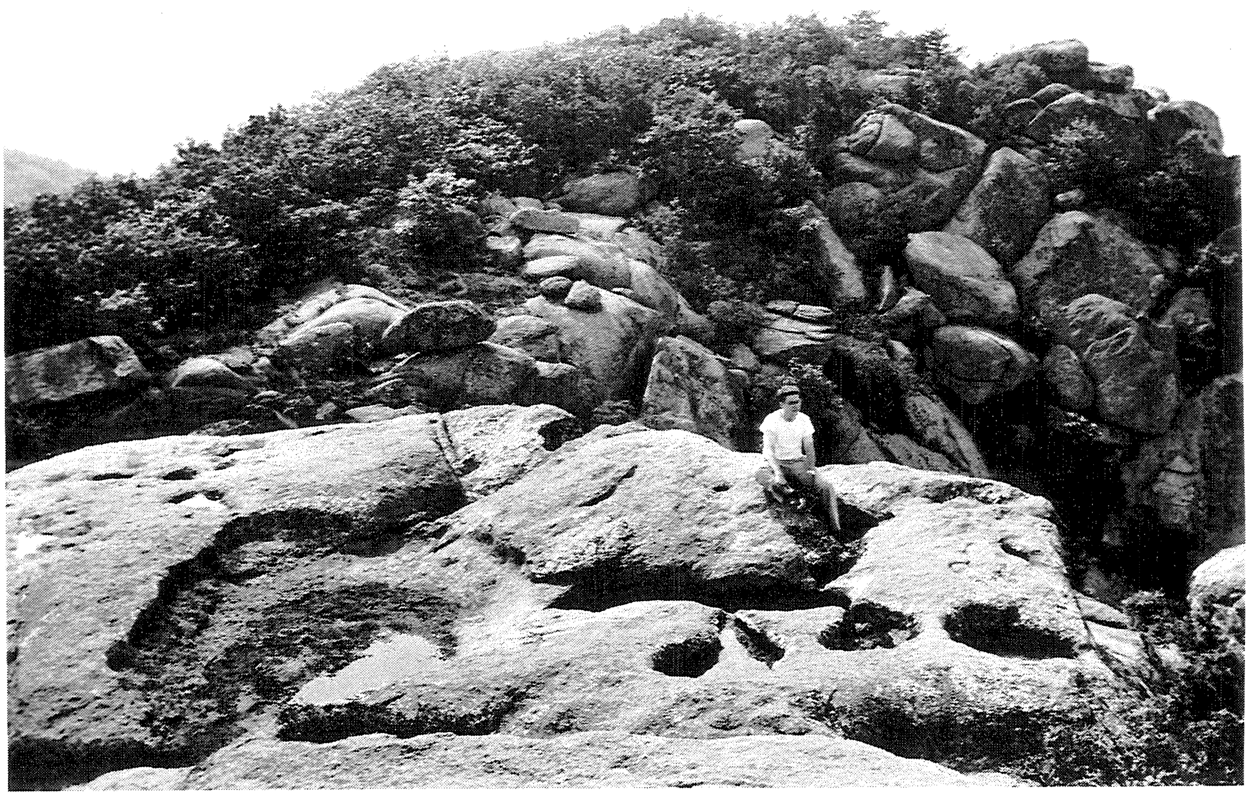


FIGURE R.5.10. Opferkessel in the summit area of Old Rag Mountain, Shenandoah National Park, Virginia (Hedges, 1969).

207.2 4.0 South entrance to Skyland (Big Meadows, VA quadrangle). Clear weather allows excellent views of Massanutten Mountain, New Market Gap, and "Page Valley" from the lodge area.

OVERNIGHT STOP: SKYLAND LODGE, SHENANDOAH NATIONAL PARK.

SKYLAND LODGE, SHENANDOAH NATIONAL PARK, VIRGINIA, TO DULLES INTERNATIONAL AIRPORT, VIRGINIA, AND WASHINGTON, DC *VIA* NORTHERN BLUE RIDGE SECTION OF BLUE RIDGE PROVINCE, SHENANDOAH VALLEY OF VIRGINIA, MASSANUTTEN MOUNTAIN, AND PIEDMONT PROVINCE

Total	Interval	Description
0.0	0.0	Skyland: **PROCEED NORTH** on Skyline Drive.
1.2	1.2	**POSSIBLE PICTURE STOP 6.1:** Thorofare Mountain Overlook (Old Rag Mtn. VA quadrangle). Excellent view of Thorofare Mountain, and also of Old Rag Mountain in clear weather. As we continue north, Skyline drive wends across the Madison-Page county line.
3.1	1.9	**POSSIBLE PICTURE STOP 6.2:** Stony Man Overlook. (Old Rag Mtn. VA quadrangle). The bedrock at this locality is fine-grained Middle Proterozoic Pedlar Formation, here a granodiorite (Gathright, 1976). Published dates on Pedlar rocks range from 1.0 to 1.2 Ga (Lukert and Mitra, 1986), but cross-cutting relationships show that the Pedlar Formation is younger than the Old Rag Granite, which is exposed 8 km to the southeast (Gathright, 1976). Latest Proterozoic Catoctin Metabasalt crops out on Stony Man, 1.7 km to the south. Dates of about 600 Ma have been obtained from Catoctin metabasalts (Mose, *et al.*, 1985). Columnar jointing and amygdaloidal flows show that most of the Catoctin flows were subaerial (Lukert and Mitra, 1986). Pillow structures found at a few localities (Lukert and Mitra, 1986) may be evidence of eruption on lake floors. Leave Madison County. Skyline Drive now threads along the Page-Rappahannock county line.
8.9	5.8	Buck Hollow Overlook. Foliated Pedlar granodiorite with 5 to 7 cm long garnet-bearing felsic lenses (Gathright, 1976).
9.4	0.5	**STOP 6.3:** North end of Marys Rock Tunnel (Thornton Gap, VA quadrangle). Stop at overlook to view a metabasalt dike cross-cutting Pedlar granodiorite. The dike presumably fed one or more flood basalts in the Catoctin Formation (Gathright, 1976).
10.3	0.9	Turn right onto entrance ramp for U. S. 211 east at Thornton Gap. Thornton Gap is on part of the trace of the Stanley Thrust Fault (Gathright, 1976). The Stanley Thrust Fault is a major transverse fault that juxtaposes the Pedlar Formation against the Catoctin Formation in Thornton Gap. Note topographic expression of lithology and structure here. In some areas where detailed, large-scale, bedrock mapping has been completed, spatial correspondence between major topographic sags in the crest of the Blue Ridge and bedrock geology can be demonstrated (Allen, 1963, 1967; Gathright, 1976; Gathright and Nystrom, 1974). Continue on US 211 west toward Luray, VA.
14.6	4.3	Shenandoah National Park Headquarters.
17.1	2.5	**TAKE** Route 211 bypass west.
21.1	4.0	**STOP AND CAVERN TOUR AHEAD 6.4:** Turn right into Luray Caverns grounds (Luray, VA quadrangle). The hill overlying Luray Caverns and Ruffner's Cave is named Cave Hill. Of the many commercialized caves on or

near the excursion route, Luray Caverns (see FIGURES R.6.1 and R.6.2) were selected because of the known bedrock geologic relationships and the unusual speleological relationships.

According to Butts (1940/1941) and Edmunson (1945), Cave Hill is located about in the center of a strike belt of Beekmantown Dolomite of Early Ordovician Age. The strike belt is about 2 miles (3.3 km) wide and about 3,000 feet (914 m) thick. Butts (1940/1941) showed this strike belt as containing an overturned anticline west of Cave Hill and an overturned syncline east of Cave Hill. The immediately surrounding bedrock geology and the cave passageways were mapped by Hack and Durloo (1977 Revision).

The host rocks are most unusual for the production of large speleological features. Luray Caverns are not developed in limestone, but largely in coarse-grained (0.1-0.5 mm diameter) "sugary" dolostone beds that contain intergrowths and boxwork of silica as well as impurities of quartz, chert, feldspar, and clay that may exceed 10 percent of the rock in some horizons. Cavern geometry is characterized by large, open rooms that show evidence of lithologic and structural control along horizontal to gently-inclined (0-15°) bedding and steeply-dipping joints. These halls often have low ceilings. When ceilings are high, Hack and Durloo (1977 Revision) suggested that stoping may have been involved, although conspicuous breakdown is absent. The rooms are interconnected by passageways that in their narrower and higher-ceiling portions clearly follow subvertical joint trends. There are two solution levels in Luray Caverns; the developed area is almost exclusively in the upper level.

The ubiquitous cave deposits consist of both flowstone and dripstone formations and of clastic materials. Flowstone and dripstone features are composed of calcite and include stalactites, stalagmites, columns, aprons, and linings that cover large areas of the exposed bedrock surfaces, especially on the walls and floors. The clastic deposits are largely clay minerals, including montmorillonite, kaolinite, goethite, and mixed-layer mica. Silt-size and larger rock fragments are mostly composed of disintegrated siliceous boxwork, quartz, and chert (Hack and Durloo, 1977 Revision). Clastic cave sediments coat walls and floors, compose mud cones that may rise to the ceilings, or form stratified floor deposits that are commonly interbedded with other materials. These cave deposits are interpreted to have originated from both internal residues from solution and from soils developed on Cave Hill above Luray Caverns (Hack and Durloo, 1977 Revision).

Hack and Durloo concluded that the visible cavern system developed close to or above the paleo-water tables, and that neither deep-phreatic nor invasion-stream theory is necessary to explain the observed relationships.

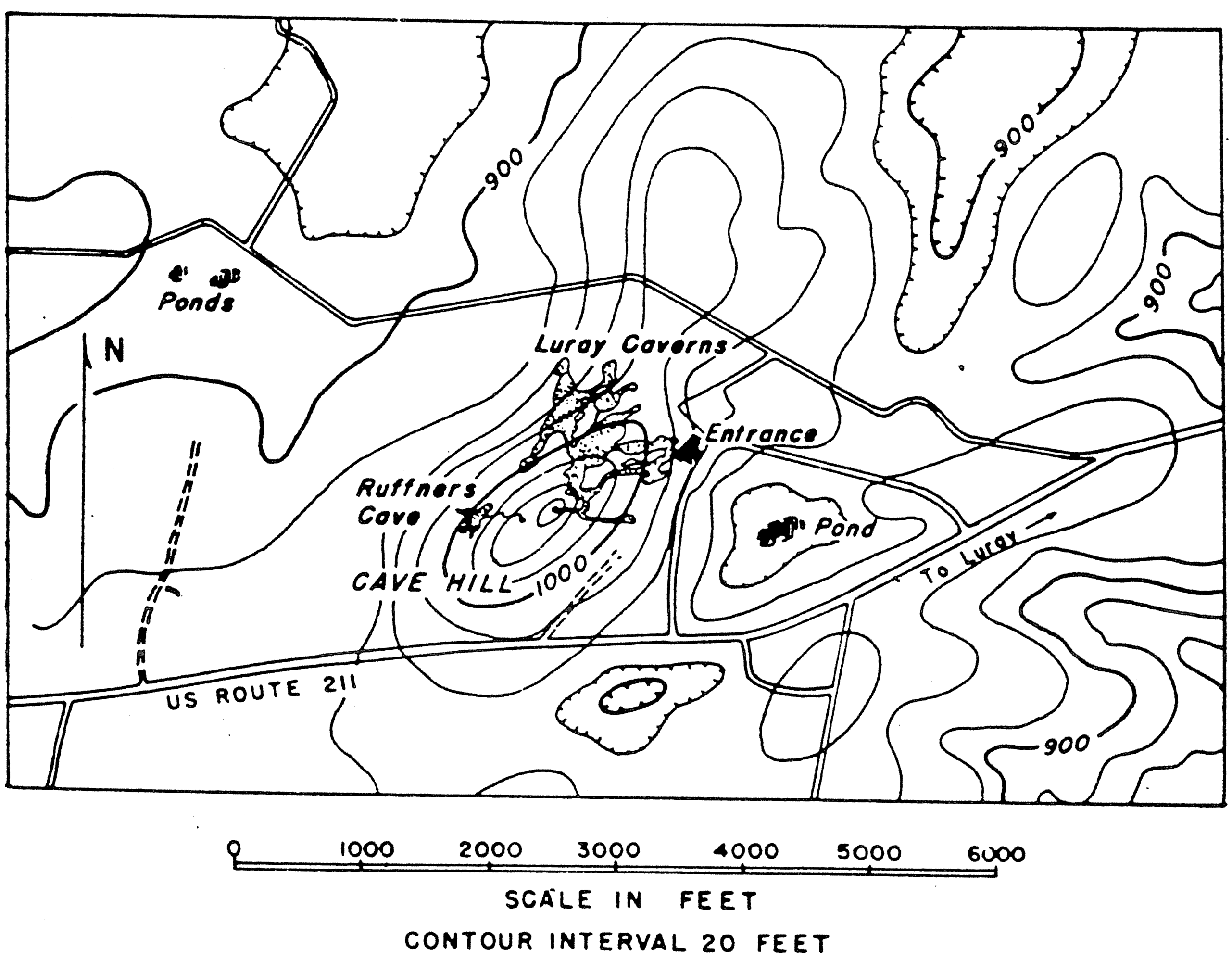


FIGURE R.6.1. Topographic relationships of Luray Caverns, Virginia (from Hack and Durloo, 1977 Revision, Figure 1, p. 3). Note relationships of both Ruffners Cave and Luray Caverns with topography of overlying Cave Hill.

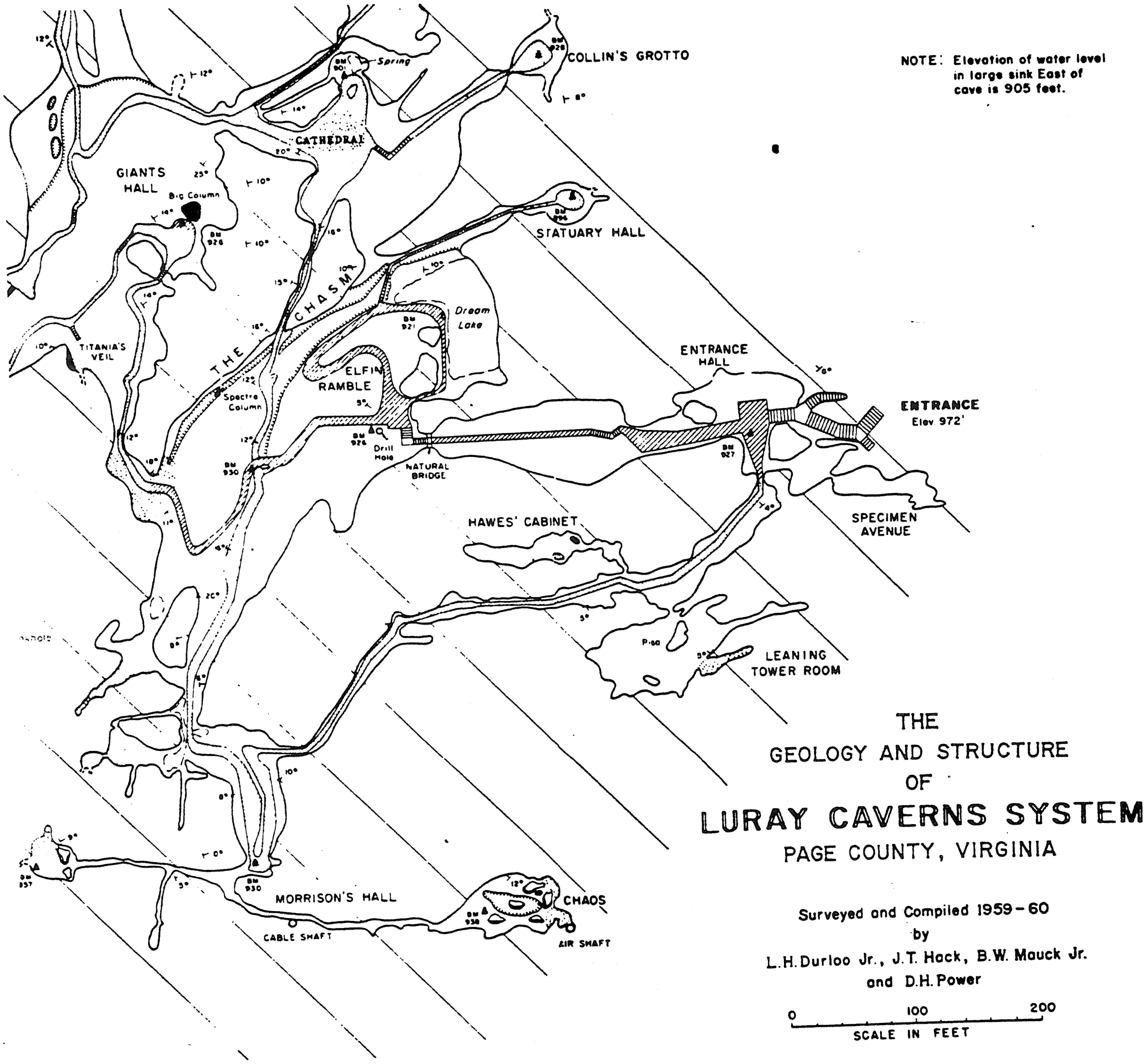


FIGURE R.6.2 . Map of part of Luray Caverns (from Hack and Durloo, 1977 Revision, Plate 1).

BACK TRACK east on Route 211 bypass.

22.8 1.7 **TURN LEFT** (south) on Route 340.

23.2	0.4	**TURN RIGHT** on Mechanic St. (County Road 675) near Potomac Edison Building.
25.9	2.7	Note sinkholes developed over Cambro-Ordovician carbonates.
26.6	0.7	Cross South Fork Shenandoah River; bear left on Route 675 at end of bridge.
27.0	0.4	**BEAR RIGHT** on Route 675.
29.8	2.8	Note view of South Fork Shenandoah River and Blue Ridge Mountains to east.
31.2	1.4	Leave Page County, enter Shenandoah County. Note Camp Roosevelt nearby. The route is now in the Passage Creek drainage basin, generally called Fort Valley, which is underlain by Siluro-Devonian carbonates and shales.
34.9	3.7	**TURN RIGHT** on Route 678 (north) at Kings Crossing.
40.5	5.6	Stay on Route 678 at intersection with Route 803 and Route 769.
42.1	1.6	**TURNLEFT** (west) on Route 758.
42.8	0.7	Road becomes gravel surfaced. Continue west.
43.8	1.0	Stay on Route 758, crossing Route 770.
44.2	0.4	Note boulders of Massanutten Sandstone.
46.1	1.9	**STOP 6.5:** Top of Massanutten Mtn. (Rileyville, VA quadrangle, overlooking area of Toms Brook, VA quadrangle). Follow the trail along the ridge crest south to the lookout tower. Note weathered outcrops of steeply-dipping Lower Silurian Massanutten Sandstone along the trail. The Woodstock Fire Tower is approximately 300 m south of Route 758. The platform provides a view of the intrenched meanders of North Fork Shenandoah River. The elongate shape of these meanders has been attributed to the orientation of joints in the underlying shales of the Upper Martinsburg Formation (Hack and Young, 1959). Cambro-Ordovician carbonate rocks predominate beneath the floor of the Shenandoah Valley west of the river bends. Near Brocks Gap, Little North Mountain is capped by the Tuscarora Sandstone (partial Massanutten Sandstone equivalent) and marks the boundary between Shenandoah Valley and the rest of the Ridge and Valley province.
		RETRACE ROUTE to east on Route 758.
48.4	2.3	**TURN LEFT** (north) on Route 770.
49.8	1.4	Route 770 becomes paved surface.
50.3	0.5	**TURNLEFT** (west) on Route 678. Note erosional (strath) terraces to east. Osterkamp and Hupp (1984) have concluded that the distribution of floral assemblages along Passage Creek is determined largely by stream flow recurrence. They identified four alluvial landform types: depositional bar, active-channel shelf, floodplain, and terrace.
53.0	2.7	Note prickly-pear cactus on Devonian shale outcrop. Fort Valley has many so-called "shale barrens"; surfaces whose ecology is dominated by xerophilous plants. Platt (1951) noted typical shale barrens located along Passage Creek at 1 and 2 miles (1.6-3.3 km) south of Elizabeth Furnace. These shale barrens also develop because of the existence of orographic rain shadows in Massanutten Mountain and because shallow soils formed on steep shale slopes with southerly aspects retain little soil moisture.
57.1	4.1	Elizabeth Furnace, site of an abandoned iron works. Mining of supergene iron ores was an important aspect of the Appalachian economy during the 19th century. Iron works such as Elizabeth Furnace provided many related jobs: limestone was quarried as flux, wood was cut and converted to charcoal to fire the furnace, and railroads were built and maintained to move the iron to market. Appalachian iron ores tend to occur in small deposits with high silica

		content, so the industry collapsed when large iron reserves were developed in the western-upper Great Lake States.
59.4	2.3	Outcrops of Massanutten Sandstone along Passage Creek.
59.6	0.2	Leave Shenandoah County, enter Warren County.
61.1	1.5	**TURN RIGHT** (east) on route 55.
62.3	1.2	Cross Passage Creek.
63.4	1.1	Enter Buckton.
66.3	2.9	**TURN LEFT** (north) on Route 340 at Front Royal.
66.5	0.2	Cross North Fork Shenandoah River. Note the wide floodplain and well-developed terraces. The North Fork meets the South Fork 1.15 km east of this bridge.
67.3	0.8	**TURN RIGHT** (east) on Interstate 66.
68.0	0.7	Cross Shenandoah River north of the confluence of the North and South Forks.
72.0	4.0	Pass through Manassas Gap. As interpreted by Fenneman (1938, p. 168-171) and Thornbury (1965, p. 102-103), Manassas Gap was originally the water gap of Goose Creek, and is the southernmost of the Snickers (335 m)-Ashby (305 m)-Manassas (274 m) trio of gaps formed by inferred longitudinal progressive stream piracy of the headward-working Shenandoah River. (Much earlier, in 1895, Willis had inferred that Snickers Gap was formed through the capture of the headwaters of transverse Beaverdam Creek. Willis hypothesized that an ancestral, longitudinal, Shenandoah River underwent rapid headward erosion in weak strike-belt rocks to effect the piracy of Beaverdam Creek, which flowed on resistant rock).
		Site-specific localizing factors of the three gaps may relate to structural weaknesses, or to local thinning of the Catoctin Formation. For example, a major topographic lineament runs through Ashby Gap. The lineament appears to be a high-angle fault with two or more episodes of movement (Gathright and Nystrom, 1974). The crest of the Blue Ridge is relatively low here, probably in part because the Catoctin Formation is much thinner and possibly also because of the close proximity of the master streams, which are larger and more effective agents of erosion in these distal portions of their courses.
75.3	3.3	Leave Warren County, enter Fauquier County.
79.9	4.6	Note outcrops of Catoctin Metabasalt.
92.7	12.8	Cross Broad Run.
95.7	3.0	Good view of Bull Run Mountains to the left (north). These ridges are underlain by resistant Catoctin Metabasalts cropping out on the eastern limb of the Blue Ridge Anticlinorium.
96.8	1.1	Cross Broad Run again.
97.0	0.2	Thorofare Gap through Bull Run Mountains.
97.4	0.4	Cross Broad Run for the third time. Leave Fauquier County, enter Prince William County. This location is the approximate boundary between the Blue Ridge and Piedmont provinces. The Mesozoic Culpeper Basin underlies this part of the Piedmont province (Leavy, *et al.*, 1983).
108.2	10.8	**TAKE EXIT** to Route 234. Turn left (north) on Route 234.
109.1	0.9	**TURNRIGHT** (east) into Manassas National Battlefield Park, administered by the National Park Service.
109.3	0.2	Park at Visitor Center.

OPTIONAL STOP 6.6: Manassas Battlefield Park (Gainesville, VA quadrangle). The battlefield lies in the Culpeper Basin, a Mesozoic extensional feature that developed during the opening of the North Atlantic Ocean (Lindholm, 1978). Bedrock geology of this area is predominantly the Triassic-Jurassic Newark Supergroup, composed mostly of red clastic rocks, ranging from shale to fanglomerate, with lesser amounts of silty limestone and occasional coals (Ridky and O'Connor, 1979; Leavy, *et al.*, 1983). The Mesozoic basins in the Piedmont province are generally characterized by a topography of rolling lowlands having low relief, except where resistant diabase intrusions crop out. Soils at the battlefield are dominated by the Arcola series (a Typic Hapludult formed in residuum weathered from siltstone and fine-grained sandstone) and the Panorama series (an Ultic Hapludalf formed partly in residuum and partly in old alluvium) (Elder, 1989). Both are good soils for many engineering uses and either fair or good for agriculture (Elder, 1989). The main limitation for soils in the Culpeper Basin is that residual soils tend to be shallow. Most of the soils in this part of the Piedmont are either Ultisols or Alfisols (Elder and Pettry, 1975).

Two of the most important engagements of the War Between the States (American Civil War) occurred at this battlefield, which was called Manassas by Confederate (Southern) reporters and Bull Run by Union (Northern) reporters. Manassas Junction, 8 km south of the battlefield, was the connection between two strategic railroads, including the Manassas Gap Railroad, which ran parallel to modern-day I-66. Both battles were Confederate victories and contributed greatly to the reputation of General "Stonewall" Jackson. The battle of First Manassas (21 July 1861) was the earliest major engagement of the war, and more than 3,600 soldiers were killed. This engagement provoked a grim awakening of the then naive American people to the realities of civil war. Second Manassas was one of the "high-water marks" of the Confederacy, setting the stage for the first of two unsuccessful invasions of the Northern states. Over 19,500 were killed or wounded in this action between 29 August and 1 September 1862.

		RETURN to Route 234.
109.5	0.2	**TURN LEFT** (south) on Route 234. Return to I-66.
110.4	0.9	**TURN LEFT**(east) on I-66.
.	.	Leave Prince William County, enter Fairfax County.
128.1	17.7	Note I-495 (Capitol Beltway); continue east on I-66.
139.5	11.4	Cross Potomac River and enter Washington, D.C. **END OF EXCURSION.**

OPTIONAL "QUICK" ROUTE FROM SKYLAND LODGE, SHENANDOAH NATIONAL PARK, VIRGINIA, TO WASHINGTON NATIONAL AIRPORT, WASHINGTON, DC *VIA* NORTHERN BLUE RIDGE SECTION OF BLUE RIDGE PROVINCE AND PIEDMONT PROVINCE:

Total	Interval	Description
0.0	0.0	Skyland: **PROCEED NORTH** on Skyline Drive.
1.2	1.2	**POSSIBLE PICTURE STOP 6.1:** Thorofare Mountain Overlook (Old Rag Mtn. VA quadrangle). Excellent view of Thorofare Mountain, and also of Old Rag Mountain in clear weather. As we continue north, Skyline drive wends across the Madison-Page county line.
3.1	1.9	**POSSIBLE PICTURE STOP 6.2:** Stony Man Overlook. (Old Rag Mtn. VA quadrangle). The bedrock at this locality is fine-grained Middle Proterozoic Pedlar Formation, here a granodiorite (Gathright, 1976). Published dates on Pedlar rocks range from 1.0-1.2 Ga (Lukert and Mitra, 1986), but cross-

cutting relationships show that the Pedlar Formation is younger than the Old Rag Granite, which is exposed 8 km to the southeast (Gathright, 1976). Latest Proterozoic Catoctin Metabasalt crops out on Stony Man, 1.7 km to the south. Dates of about 600 Ma have been obtained from Catoctin metabasalts (Mose, *et al.*, 1985). Columnar jointing and amygdaloidal flows show that most of the Catoctin flows were subaerial (Lukert and Mitra, 1986). Pillow structures found at a few localities (Lukert and Mitra, 1986) may be evidence of eruption on lake floors. Leave Madison County. Skyline Drive now threads along the Page-Rappahannock county line.

8.9	5.8	Buck Hollow Overlook. Foliated Pedlar granodiorite with 5 to 7 cm long garnet-bearing felsic lenses (Gathright, 1976).
9.4	0.5	**STOP 6.3:** North end of Marys Rock Tunnel (Thornton Gap, VA quadrangle). Stop at overlook to view a metabasalt dike cross-cutting Pedlar granodiorite. The dike presumably fed one or more flood basalts in the Catoctin Formation (Gathright, 1976).
10.3	0.9	**TURN RIGHT** onto entrance ramp for U. S. 211 at Thornton Gap. Thornton Gap is on part of the trace of the Stanley Thrust Fault (Gathright, 1976). The Stanley Thrust Fault is a major transverse fault that juxtaposes the Pedlar Formation against the Catoctin Formation in Thornton Gap. Note topographic expression of lithology and structure here. In some areas where detailed, large-scale, bedrock mapping has been completed and published, spatial correspondence between major topographic sags in the crest of the Blue Ridge and bedrock geology can be demonstrated (Allen, 1963, 1967; Gathright, 1976; Gathright and Nystrom, 1974). Continue on US 211 east down the eastern flank of the Blue Ridge toward Washington, DC. After leaving Shenandoah National Park, and after entering the Piedmont province, some isolated and forested small mountains can be seen on the surface of the Piedmont. Some early workers considered these hills to be "monadnocks" or outliers of the Blue Ridge that had become separated from it by erosion.
33.7	23.4	Enter Amissville.
35.0	1.3	Leave Rappahannock County, enter Culpeper County. The Culpeper Basin—an extensional basin of Late Mesozoic age containing shales, siltstones, and sandstones of Triassic age—is named for this area.
39.0	4.0	Leave Culpeper County, cross Rappahannock River, and enter Fauquier County.
44.2	5.2	Enter Warrenton. Continue on US 211 East.
46.0	1.8	**END** US 211. Continue ahead on North Business US 15 and US 29, and then continue on North US 15 and US 29.
53.3	7.3	This is The James Madison Highway. Leave Fauquier County and enter Prince William County.
57.0	3.7	Enter Gainesville. Continue on US 29 North.
57.7	0.7	Junction with I-66. **TURN RIGHT** on I-66 East.
62.0	4.3	Exit 47 (old Exit 11). This is the exit for Manassas Battlefield Park. Continue ahead on I-66 East.
72.6	10.6	Exits 57 A-B (old exit 15). This is the exit for George Mason University and US 50. Continue ahead on I-66 East.
89.7	17.1	**TURN OFF** I-66 onto Exit 75 (110 South), pass the Pentagon, and continue ahead toward Washington National Airport.
92.9	3.2	**EXIT** onto East 233 into the Washington National Airport area. **END OF EXCURSION**

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APPENDIX A: COUNTIES TRAVERSED BY C. 20c.

County or other unit	State Soil Survey date		Other references, with theses, published reports, and/or quadrangle, or other, soil, geomorphic, or geologic maps
District of Col.	DC	1976	Froelich (1975); Froelich and Hack (1975)
Prince Georges	MD	1967	Cooke, *et al.* (1952); Withington and Froelich (1974)
Howard	MD	1968	Cloos, *et al.* (1964); Withington and Froelich (1974)
Baltimore	MD	1976	Cleaves, *et al.* (1979); Crowley and Reinhardt (1979); Reinhardt and Crowley (1979)
Harford	MD	1975	Cleaves, *et al.* (1979); Southwick, *et al* (1969)
Cecil	MD	1973	Gates, *et al.* (1991); Higgins and Conant (1990); Pazzaglia and Gardner (1992)
Lancaster	PA	1985	Pazzaglia and Gardner (1992)
Dauphin	PA	1972	Pennsylvania Geological Survey (1975); Trexler and Wood (1968); Wood (1968)
Lebanon	PA	1981	Wilshusen (1983); Trexler and Wood (1968); Wood (1968); Wood and Kehn (1968)
Schuylkill	PA	1982	Arndt (1971); Trexler and Wood (1968); Wilshusen (1983); Wood (1968); Wood and Arndt (1973); Wood and Kehn (1968); Wood and Trexler (1968); Wood, *et al.* (1968)
Luzerne	PA	1981	Inners (1988b)
Carbon	PA	1962	Epstein, *et al.* (1974); Inners (1988b); Sevon (1969, 1975a, 1975b, 1987); Wilshusen (1983)
Columbia	PA	1967	Arndt (1971); Inners (1981, 1988b)
Montour	PA	1985	Faill (1979); Inners (1988b)
Northumberland	PA	1985	Chase (1977); Faill (1979); Wood and Trexler (1968)
Lycoming	PA	1986	Faill (1979)
Union	PA	1985	Marchand and Crowl (1991)
Centre	PA	1981	Cronce (1988); Gold (1985); Jobling (1969); Rapp (1967)
Blair	PA	1981	
Bedford	PA	in press	de Witt (1974); de Witt and Colton (1964); Sevon (1986)
Allegany	MD	1977	Dennison (1963); DeWitt and Colton (1964)
Mineral	WV	1978	Allamomg (1991); Clark (1967, 1989b); Reger (1924)
Grant	WV	1989	Allamong (1991); Clark (1967, 1989b); Reger (1924)
Tucker	WV	1967	Carter and Ciolkosz (1980); Reger (1923); Stanley and Ciolkosz (1981)
Randolph	WV	1967 (part) 1982 (main)	Reger (1931)
Hardy	WV	1930	Tilton, *et al.* (1927)
Rockingham	VA	1982	Brent (1960); Gathright (1976); Butts (1940/1941) Gathright and Frischmann (1986); King (1950)
Greene	VA	1986	Allen (1963); Gathright (1976)
Page	VA	in press	Allen (1967); ; Gathright (1976); King (1950)
Madison	VA	1975	Allen (1963); Gathright (1976)
Shenandoah	VA	1991	Rader and Biggs (1976); Young and Rader (1974)
Rappahannock	VA	1961	Gathright (1976)
Warren	VA	1984	Gathright (1976); Rader and Biggs (1975, 1976)
Fauquier	VA	1956	
Prince William	VA	1989	
Fairfax	VA	1963	Drake, *et al.* (1979)
Loudon	VA	1960	

APPENDIX B: U. S. G. S. QUADRANGLES TRAVERSED BY C. 20c.

Name	State	Selected interest points, geomorphic features, or soils
Washington West	MD-DC-VA	Includes part of District of Columbia, U. S. Capitol
Kensington	MD	
Beltsville	MD	
Laurel	MD	
Savage	MD	
Relay	MD	
Baltimore West	MD	
Baltimore East	MD	
Middle River	MD	
White Marsh	MD	
Edgewood	MD	
Bel Air	MD	STOP 1.1 and STOP 1.2
Delta	MD	
Conowingo Dam	MD-PA	Conowingo Dam and Power Plant
Wakefield	PA	
Quarryville	PA	
Conestoga	PA	Meanders of Pequea Creek and Conestoga River.
Lancaster	PA	Meanders of Conestoga River.
Columbia East	PA	
Manheim	PA	Furnace Hills.
Elizabehtown	PA	Ridges underlain by dolerite.
Middletown	PA	Dolerite ridges; Susquehanna River; Swatara Creek.
Steelton	PA	Susquehanna River.
Harrisburg East	PA	Blue Mountain.
Hershey	PA	Meanders of Swatara Creek.
Grantsville	PA	Blue, Second, Stony, Peters Mts.; Devils Race Course.
Indiantown Gap	PA	Swatara Creek water gap through Blue Mtn.
Tower City	PA	Second through Bear Mtn.; appearance of strip mines.
Pine Grove	PA	Blue through Broad Mts.; water gaps of Swatara Creek.
Tremont	PA	Broad through Mahanoy Mts.
Minersville	PA	Second through Broad Mts.
Ashland	PA	Broad through Little Mts.
Shenandoah	PA	Broad and Locust Mts.; world class strip mines.
Delano	PA	Picture STOP 2.1 + Bears Head (sorted patterned ground).
Conyngham	PA	Spring through Sugarloaf Mts.
Sybertsville	PA	Nescopeck Mtn.
Freeland	PA	Hells Kitchen on Green Mtn.
White Haven	PA	Buck through Nescopeck Mts. ; East end strip mining.
Hickory Run	PA	STOP 2.2: HICKORY RUN BOULDER FIELD.
White Haven	PA	
Freeland	PA	STOP 2.3: TORS ON GREEN MOUNTAIN.
Hazleton	PA	STOPS 2.4A AND 2.4B: TORS AND COLLUVIUM.
Conyngham	PA	View of Sugarloaf Mtn.
Sybertsville	PA	STOP 2.5: TWO-STORY COLLUVIUM EXPOSURE.
Berwick	PA	Nescopeck Creek: water gap and ingrown meanders.
Mifflinville	PA	Tenmile Run: underfit valley. North Branch Susquehanna River.
Bloomsburg	PA	Fishing Creek; Buckhorn (overnight stop).
Millville	PA	
Washingtonville	PA	

Riverside	PA	Devils Feather Bed in Montour Ridge.
Milton	PA	West Branch Susquehanna River.
Muncy	PA	STOP 3.1: MUNCY LOESS MANTLED TERRACE.
		West Branch Susquehanna River.
		East end Bald Eagle Mountain.
Mountoursville South	PA	Wind gap in Bald Eagle Mountain; Devils Turnip Patch.
Allenwood	PA	South White Deer Ridge; East end Nittany Mountain.
Milton	PA	West Branch Susquehanna River.
Northumberland	PA	STOP 3.2: NONSORTED PATTERNED GROUND.
Lewisburg	PA	
Northumberland	PA	STOP 3.3: MONTANDON AEOLIAN FEATURES.
		Confluence of West Branch Susquehanna River with
		Susquehanna River.
Lewisburg	PA	Bucknell University.
Milton	PA	
Allenwood	PA	STOP 3.4: SUNRISE CHURCH
Williamsport SE	PA	STOPS 3.5A AND 3.5B: ROCK CREEP AND
		COLLUVIUM
		Running Gap between Nittany and Buffalo Mts.
Carroll	PA	STOP 3.6: SAND MOUNTAIN LOOKOUT TOWER.
Hartleton	PA	STOP 3.7: HALFWAY RUN.
		The Hook and The Gooseneck (famous water gaps).
Woodward	PA	Paddy through Nittany Mountains. Brush Valley.
Millheim	PA	STOP 3.8: STOLTZFUS SOIL PIT.
		Brush Valley between Shriner and Nittany Mountains.
		Eight small water gaps in Shriner Mountain.
Madisonburg	PA	Brush and Nittany Mountains.
		Penns, Brush, and Nittany Valleys.
Spring Mills	PA	STOP 3.9: BROWN SHALE PIT.
		Egg Hill. Penns and Georges Valleys. Seven Mountains
Centre Hall	PA	STOP 3:10: SWANK SHALE PIT.
		Penns Valley. First, Tussey, and Nittany Mountains.
State College	PA	OVERNIGHT STOP.
		Paper session at The Pennsylvania State University.
Julian	PA	The Barrens. Bald Eagle Mountain and Bald Eagle Valley.
State College	PA	Penns and Nittany Valleys.
		Tussey and Nittany Mountains.
McAlevy's Fort	PA	Tussey and Thickhead Mountains (sorted stripes).
		Big Flat and Little Flat (sorted nets and polygons).
		Bear Meadows Natural Area (Pleistocene-Holocene)
Pine Grove Mills	PA	STOP 4.1: COLLUVIAL SOILS.
McAlevy's Fort	PA	
State College	PA	
Julian	PA	PICTURE STOP 4.2: ALLEGHENY FRONT
		OVERVIEW.
Port Matilda	PA	The Barrens. Bald Eagle Mountain and Bald Eagle
		Valley. Allegheny Front.
Franklinville	PA	
Tyrone	PA	Little Juniata River water gap between Bald Eagle
		Mountain and Brush Mountain.
Tipton	PA	Brush Mtn. Dissection of Allegheny Front.
Bellwood	PA	Brush Mtn.
Altoona	PA	Allegheny Front. Strip mines on Plateau.
Hollidaysburg	PA	Horseshoe Curve. Allegheny Front.

Roaring Spring	PA	STOP 4.3: STRATIFIED SLOPE DEPOSITS. Two-story stratified slope deposit and paleosols. Dunning Mountain. Frankstown Branch Juniata River.
New Enterprise	PA	Morrison Cove between Tussey, Evitts, and Dunning Mts.
Alum Bank	PA	Dissection of Allegheny Front.
Bedford	PA	Kinton Knob on Wills Mtn. Raystown Branch Juniata River.
Rainsburg	PA	Friends Cove. Cumberland Valley between Evitts and Wills Mts.
Beans Cove	PA	Beans Cove between Tussey and Evitts Mts. Cumberland Valley.
Hyndman	PA	Cumberland Valley between Evitts and Wills Mts. Breaching of Wills Mountain Anticlinorium
Evitts Creek	MD-PA-WV	Rocky Gap in Evitts Mountain. Cumberland Valley (with Shriver Ridge) between Evitts and Wills Mountains.
Cumberland	MD-PA-WV	The Narrows in Wills Mountain. Wind gap in Haystack Mountain. Confluence of Wills Creek with North Branch Potomac River.
Cresaptown	WV-MD	North Branch Potomac River between Knobly and Dans Mts.
Lonaconing	MD-WV	Dans Mountain (Allegheny Front).
Keyser	WV-MD	North Branch Potomac River enters Ridge and Valley.
Westernport	WV-MD	Gorge of North Branch through Allegheny Front.
Antioch	WV	Dolls Gap in New Creek Mountain.
Mount Storm	WV-MD	Allegheny Front.
Greenland Gap	WV	Greenland Gap. Cosner Gap. Allegheny Front.
Mount Storm Lake	WV	Cabin Mountain. Canaan Valley.
Davis	WV-MD	STOP 4.4: ^{14}C DATED COLLUVIUM. Pendleton Creek. Old lumber town. Blackwater River.
Blackwater Falls	WV	Blackwater Falls State Park Lodge . Canaan Valley.
Laneville	WV	Dolly Sods. Flatrock Plains. Roaring Plains. Mt. Porte Crayon.
Hopeville	WV	Dolly Sods. Allegheny Front.
Blackbird Knob	WV	STOP 5.1: CRYOPLANATION TERRACE. Cryoplanation terrace on Allegheny Front.
Maysville	WV	
Blackbird Knob	WV	STOP 5.2: TORS AND CRYOPLANATION TERRACES. Bear Rocks. Stack Rock. Diamicton deposits in valley of Jordan Run.
Hopeville	WV	STOP 5.3: REST AND SHORT DISCUSSION STOP: THE HOPEVILLE SCOUR. North Fork South Branch Potomac River between Allegheny Front and North Fork Mountain.
Petersburg West	WV	PICTURE STOP 5.4: FANS. North Fork Gap. Confluence: North Fork and South Branch Potomac Rivers.
Maysville	WV	Kline Gap through New Creek and Knobly Mts. Shale Barrens.
Petersburg East	WV	South Branch R. Baker Rocks. Elkhorn Mt.

Rig	WV	Petersburg Gap South Branch and South Branch Valley.
Moorefield	WV	South Branch. Potato Row.
Needmore	WV	South Branch and Short Mountains. Baker Run. Big Ridge.
Baker	WV	STOP 5.5: SWALLET. Lost River and Lost River Sinks. Baker Run. Hanging Rock
Lost City	WV/VA	STOP 5.6: FANS. Lost River. Little Ridge.
Orkney Springs	VA/WV	Lost River. Cove Mountain.
Bergton	VA/WV	Lost River-Capon Run divide. Cove and West Mts.
Fulks Run	VA	North Fork Shenandoah River. Church and Little Mts. Third Hill.
Timberville	VA	STOP 5.7: BROCKS GAP. North Fork Shenandoah River. Chimney Rock. Brocks Gap. Little North Mountain. North Mountain Fault. Shenandoah Valley district of Great Valley subsection.
Broadway	VA	North Fork Shenandoah River. Shenandoah Valley.
Singers Glen	VA	Carbonate bedrock. Chert knolls. Sandstone ridges. Little North Mountain.
Bridgewater	VA	PICTURE STOP 5.8: MOLE HILL (volcanic plug of Eocene age).
Harrisonburg	VA	STOP 5.9: (EXPOSURES PERMITTING): Valley Mall (exposures of Ultisols). Cherty ridges. South end of Massanutten Mountain.
Grottoes	VA	Views of Massanutten Mountain and Blue Ridge.
McGaheysville	VA	PICTURE STOPS 5.10, 5.11, AND 5.12: Fan-pediments (?) on Massanutten Mountain. View of fanlike features at foot of Blue Ridge. River terraces of South Fork Shenandoah River. Saprolites and residual ore deposits.
Elkton West	VA	South Fork Shenandoah River terraces. Giants Grave. Massanutten Mountain.
Elkton East	VA	Blue Ridge. Skyline Drive.
Swift Run Gap	VA	Enter Shenandoah National Park: Skyline Drive, Blue Ridge stratigraphy, Pedlar Formation, nonconformity, Swift Run Formation, Catoctin Metabasalts.
Fletcher	VA	Skyline Drive.
Big Meadows	VA	PICTURE STOPS 5.13 AND 5.14: Skyline Drive: Big Meadows, Blackrock view of Massanutten Mountain, Page Valley, Blue Ridge Escarpment.
Old Rag Mtn.	VA	OPTIONAL PICTURE STOPS 6.1 AND 6.2. Skyline Drive: Old Rag Mountain. Old Rag Granite (1.0-1.1 Ga). Thorofare Mountain.
Thornton Gap	VA	Skyline Drive. Pass Mountain. Park Headquarters. OPTIONAL STOP 6.3.
Luray	VA	Page (South Fork Shenandoah) Valley. OPTIONAL STOP 6.4: Luray Caverns and Cave Hill.
Hamburg	VA	Shenandoah River, Massanutten Mountain, Fort Valley
Edinburg	VA	Page Valley
Rileyville	VA	OPTIONAL STOP 6.5. Passage Creek, Fort Valley, shale barrens, Massanutten Mountain.
Toms Brook	VA	Intrenched meanders: North Fork Shenandoah River.

Strasburg	VA	Elizabeth Iron Furnace, supergene ores, Passage Creek, Blue Hole, North and South Forks Shenandoah River, Massanutten Sandstone, Massanutten Mountain,
Front Royal	VA	Confluence of North and South Forks Shenandoah River, terraces
Linden	VA	Blue Ridge, Manassas Gap
Upperville	VA	Naked Mountain
Orlean	VA	Cobbler Mountain
Marshall	VA	Watery Mountains, Pignut Mountain
Thorofare Gap	VA	Thorofare Gap, Bull Run Mountains (to north), Pond Mountains (to south), Blue Ridge-Piedmont boundary, Mesozoic basin (Culpeper Basin)
Gainesville	VA	OPTIONAL STOP 6.6: Manassas National Battlefield Park
Manassas	VA	Bull Run Regional Park
Fairfax	VA	
Vienna	VA	
Falls Church	VA	Great Falls National Park
Washington West	MD-DC-VA	

APPENDIX C: SOIL CHARACTERIZATION LABORATORY, AND OTHER, DATA

Pennsylvania State University
Soil Characterization Laboratory

S74-PA-041-023 (1-12) Duncannon Silt Loam

CLASSIFICATION: Typic Hapludalf; Coarse-silty, mixed, mesic

DATE PRINTED: 06/04/92

SOIL SERIES NAME: Duncannon
SOIL SURVEY NO.: S74-PA-041-023 (1-12)
DESCRIPTION TYPE: Full pedon desc for lab characterization
PEDON TYPE:
DIAGNOSTIC FEATURES (depth cm):
ASSOCIATED SOILS:
COUNTY: Lycoming
TOWNSHIP: Clinton
LATITUDE (D-M-S): 41-12-03-N
LOCATION: 7 mi NE of Montgomery near Turkey Run, 100 yds N of W entrance of State Correctional Institute in woods.
REGIONAL LANDFORM: Ridge and valley
GEOMORPHIC COMPONENT:
SLOPE LENGTH (above,meters):
SLOPE SHAPE (up-down,across): ,
SLOPE (%): 4
SLOPE ASPECT (degrees): 45
MICRORELIEF (amount,pattern kind): , ,
PARENT MATERIAL WEATHERING:
1. Slight
2. Moderate
PARENT MATERIAL MODE OF DEPOSITION:
1. Loess
2. Glacial till
BEDROCK DIP (degrees):
BEDROCK FRACTURE:
PARENT MATERIAL (PA system): Loess
FLOOD PATTERN (freq.,beg. mon.,days): , ,
PONDING PATTERN (freq.,beg. mon.,days): , ,
WATER TABLE (depth cm,days,kind): , ,
DRAINAGE: Well drained
EROSION: Slight
STONINESS: Class 0
WEATHER STATION:

SAMPLED SERIES NAME: Duncannon
SOIL TYPE : Silt Loam
LAB SAMPLE NO.: 9546 - 9557
CONTROL SECTION (cm):
MLRA: 147, Northern Appalachian Ridges and Valleys
USGS 7.5' QUAD SHEET: Muncy
LONGITUDE (D-M-S): 076-50-22-W
LOCAL LANDFORM:
HILLSLOPE COMPONENT:
SLOPE LENGTH (total,meters):
POSITION ON SLOPE:
ELEVATION (meters): 186
PARENT MATERIAL ORIGIN:
1. Sandstone-shale
2. Sandstone-shale
BEDROCK STRIKE (degrees):
MOISTURE REGIME: Udic
PERMEABILITY: Moderate
HYDRAULIC CONDUCTIVITY:
PERCOLATION RATE (in/hr):
RUNOFF: Slow
PLOWED: Yes

	ANNUAL	WINTER	SUMMER
SOIL TEMPERATURE(C):	9.7	0.0	0.0
AIR TEMPERATURE(C):	0.0	0.0	0.0

PRECIPITATION(cm): 100
LAND USE: Forest land not grazed
VEGETATION: Eastern White Pine; Red Maple; Hickory; Birch; Red Oak
DESCRIBERS NAMES: E. J. Ciolkosz, G. J. Latshaw, Gary Martin
DATE DESCRIBED: 06/19/74
YIELD ID#:
MAP UNIT SYMBOL:
PHOTO #:
TRANSECT ID#:
NOTE ID#:
NOTES: Ice wedges casts in the till filled with loess
PA CLASSIFICATION: ULTIC, , HAPL, UD, ALF, COARSE-SILTY, MIXED, MESIC,

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Soil Characterization Laboratory

S74-PA-041-023 (1-12) Duncannon Silt Loam

CLASSIFICATION: Typic Hapludalf; Coarse-silty, mixed, mesic DATE PRINTED: 06/04/92

1 Oi-- 5 to 3 cm; partially decomposed organic material(hemic)

2 Oa-- 3 to 0 cm; black (N 2/0) matrix; decomposed organic matter(sapric); Decomposed leaf litter black (2/0).

3 A-- 0 to 5 cm; black (10YR 2/1) matrix; silt loam; moderate fine and medium granular structure; very friable, slightly sticky, slightly plastic; pH 4.8; 11% sandstone & shale rock fragments, 1% gravel 2 mm-1.9 cm, 1% gravel 1.9-7.6 cm, 1% cobbles 7.6-25 cm, 8% > 25 cm; abrupt wavy boundary

4 E-- 5 to 18 cm; brown (10YR 4/3) matrix; silt loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; pH 4.6; 11% sandstone & shale rock fragments, 1% gravel 2 mm-1.9 cm, 1% gravel 1.9-7.6 cm, 1% cobbles 7.6-25 cm, 8% > 25 cm; clear smooth boundary

5 Bt1-- 18 to 36 cm; dark brown (7.5YR 4/4) matrix; silt loam; weak medium and coarse blocky structure; friable, slightly sticky, moderately plastic; few faint clay films in root channels and/or pores and few faint patchy clay films on faces of peds; pH 4.6; 11% sandstone & shale rock fragments, 1% gravel 2 mm-1.9 cm, 1% gravel 1.9-7.6 cm, 1% cobbles 7.6-25 cm, 8% > 25 cm; gradual smooth boundary

6 Bt2-- 36 to 51 cm; dark brown (7.5YR 4/4) matrix; silt loam; weak medium blocky structure; friable, slightly sticky, slightly plastic; common faint clay films in root channels and/or pores and common faint patchy clay films on faces of peds; pH 4.4; 11% sandstone & shale rock fragments, 1% gravel 2 mm-1.9 cm, 1% gravel 1.9-7.6 cm, 1% cobbles 7.6-25 cm, 8% > 25 cm; gradual wavy boundary; Reddish brown (5YR 4/4) coatings.

7 Bt3-- 51 to 69 cm; strong brown (7.5YR 5/6) matrix; silt loam; moderate medium blocky structure; friable, slightly sticky, moderately plastic; common faint clay films in root channels and/or pores and common faint patchy clay films on faces of peds; pH 4.4; 12% sandstone & shale rock fragments, 6% gravel 2 mm-1.9 cm, 6% gravel 1.9-7.6 cm, 1% cobbles 7.6-25 cm; gradual smooth boundary

8 Bt4-- 69 to 91 cm; reddish brown (5YR 4/4) matrix; gravelly silt loam; moderate medium blocky structure; firm, slightly sticky, moderately plastic; common faint clay films on faces of peds and in pores; pH 4.6; 15% sandstone & shale rock fragments, 5% gravel 2 mm-1.9 cm, 5% gravel 1.9-7.6 cm, 5% cobbles 7.6-25 cm; clear wavy boundary

9 2Btb1-- 91 to 122 cm; red (2.5YR 4/6) matrix; gravelly silt loam; weak coarse prismatic structure; friable, slightly sticky, moderately plastic; common distinct clay films on faces of peds and in pores; pH 5.0; 20% sandstone & shale rock fragments, 10% gravel 2 mm-1.9 cm, 5% gravel 1.9-7.6 cm, 5% cobbles 7.6-25 cm; gradual smooth boundary

10 2Btb2--122 to 160 cm; red (2.5YR 4/6) matrix, yellowish red (5YR 5/6) ped faces; gravelly silt loam; weak coarse prismatic structure; friable, slightly sticky, moderately plastic; common distinct clay films on faces of peds and in pores; pH 5.0; 20% sandstone & shale rock fragments, 10% gravel 2 mm-1.9 cm, 5% gravel 1.9-7.6 cm, 5% cobbles 7.6-25 cm; gradual smooth boundary; Yellowish red ped coatings (5YR 5/6).

11 2Btb3--160 to 178 cm; red (2.5YR 4/6) matrix, yellowish red (5YR 5/6) ped faces; gravelly silt loam; weak coarse prismatic structure; friable, slightly sticky, moderately plastic; common faint clay films on faces of peds and in pores; pH 5.0; 30% sandstone & shale rock fragments, 10% gravel 2 mm-1.9 cm, 10% gravel 1.9-7.6 cm, 10% cobbles 7.6-25 cm; gradual smooth boundary; Yellowish red (5YR 5/6) ped coatings.

12 2Btb4--178 to 229 cm; red (2.5YR 4/6) matrix; gravelly silt loam; weak coarse prismatic structure; friable, slightly sticky, moderately plastic; few faint clay films in root channels and/or pores; pH 5.0; 45% sandstone & shale rock fragments, 10% gravel 2 mm-1.9 cm, 10% gravel 1.9-7.6 cm, 10% cobbles 7.6-25 cm, 15% > 25 cm

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S74-PA-041-023 (1-12) Duncannon Silt Loam

CLASSIFICATION: Typic Hapludalf; Coarse-silty, mixed, mesic DATE PRINTED: 06/04/92

NO	DEPTH (cm)	HORIZON	ROCK FRAGMENT DISTRIBUTION (MM) (PCT) > 250	250-76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	FIELD
1	5- 3	Oi	0.0	0.0	0.0	0.0	0.0	0.0	0.0		PDOM
2	3- 0	Oa	0.0	0.0	0.0	0.0	0.0	0.0	0.0		DOM
3	0- 5	A	0.0	0.0	0.0	0.8	0.7	1.5	0.0	SIL	SIL
4	5- 18	E	0.0	0.0	0.0	16.9	1.5	18.4	10.9	SIL	SIL
5	18- 36	Bt1	0.0	0.0	0.0	2.3	1.7	4.0	2.4	SIL	SIL
6	36- 51	Bt2	0.0	0.0	0.0	13.3	2.9	16.1	10.5	SIL	SIL
7	51- 69	Bt3	0.0	0.0	4.6	3.4	1.3	9.3	6.1	SIL	SIL
8	69- 91	Bt4	0.0	0.0	10.4	7.0	1.4	18.7	13.0	SIL	SIL
9	91-122	2Btb1	0.0	0.0	5.3	8.6	1.2	15.1	9.7	SICL	SIL
10	122-160	2Btb2	0.0	0.0	2.6	10.8	0.5	13.9	9.4	SICL	SIL
11	160-178	2Btb3	0.0	24.2	15.3	3.3	1.6	44.3	0.0	CL	SIL
12	178-229	2Btb4	0.0	0.0	43.7	15.2	1.1	60.0	0.0	CL	SIL

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

NO	SAND: V COARSE 2.0-1.0	COARSE 1.0-0.5	MEDIUM 0.5-0.25	FINE 0.25-0.10	0.10-0.05	V FINE 0.10-0.07	0.07-0.05	SILT: CO 0.05-0.02	MED 0.02-0.005	FINE 0.005-0.002	C+M 0.05-0.005	M+F 0.02-0.002	TOTAL SAND 2.0-0.05	TOTAL SILT 0.05-0.002	TOTAL CLAY < 0.002
1															
2															
3	2.0	3.8	6.8	5.0	9.7	5.0	4.7	30.3	27.0	6.9	57.3	34.0	27.3	64.3	8.4
4	0.2	0.8	3.4	3.5	6.3	1.8	4.5	32.5	29.1	9.3	61.6	38.4	14.2	70.9	14.9
5	0.1	0.7	3.6	3.6	5.6	1.8	3.8	42.2	16.5	8.0	58.7	24.4	13.6	66.6	19.8
6	0.3	0.9	3.9	2.0	9.1	3.9	5.2	27.4	28.8	7.7	56.2	36.5	16.2	63.9	19.9
7	0.1	1.0	4.2	1.5	8.5	4.7	3.8	23.9	32.1	8.5	56.0	40.6	15.3	64.5	20.2
8	0.3	0.9	3.7	3.4	5.5	1.5	4.0	18.9	33.4	9.0	52.3	42.3	13.8	61.2	25.0
9	0.4	0.9	4.8	3.9	3.6	1.1	2.5	7.0	32.3	9.3	39.3	41.6	13.6	48.6	37.8
10	0.3	1.3	6.1	4.2	5.0	1.8	3.2	10.5	30.4	8.1	40.9	38.5	16.9	49.0	34.1
11	0.7	2.5	9.7	4.4	8.4	4.0	4.4	17.9	18.2	4.7	36.1	22.9	25.7	40.8	33.5
12	1.3	3.4	10.6	6.6	6.1	2.4	3.7	16.3	13.1	7.9	29.4	21.0	28.0	37.3	34.7

NO	BULK DENSITY (G/CC) 1/3 ATM MOISTURE: ENTIRE CLOD	TOTAL SOIL < 2MM+FRAGS	< 2 MM IN CLOD	OVEN DRY < 2 MM IN CLOD	COLE < 2 MM	MOISTURE (PCT) RETAINED AT 1/3 ATM: ENTIRE CLOD	< 2 MM IN CLOD	15 ATM < 2 MM SIEVED	AVAILABLE WATER < 2 MM MATERIAL: WEIGHT (PCT)	CM/CM OF SOIL	TOTAL SOIL < 2 MM + FRAGMENTS: WEIGHT (PCT)	CM/CM OF SOIL	PORE SPACE FINE EARTH < 2MM (PCT)	TOTAL SOIL FE+RF (PCT)
1														
2								50.0						
3								15.8						
4	1.24	1.45	1.23	1.28	0.017	26.6	27.0	6.9	20.1	0.247	16.4	0.239	53	47
5	1.44	1.45	1.41	1.47	0.017	20.9	21.6	8.1	13.5	0.190	13.0	0.188	46	45
6	1.46	1.60	1.44	1.50	0.014	20.6	21.3	8.2	13.1	0.189	11.0	0.176	45	40
7	1.54	1.61	1.52	1.56	0.010	19.8	19.9	7.7	12.2	0.185	11.1	0.178	42	39
8	1.56	1.70	1.53	1.57	0.009	18.3	18.9	9.5	9.4	0.144	7.6	0.130	41	36
9	1.43	1.57	1.41	1.50	0.020	22.8	23.5	13.9	9.6	0.135	8.2	0.128	46	41
10	1.57	1.65	1.52	1.61	0.019	19.2	19.9	12.9	7.0	0.106	6.0	0.099	42	38
11								14.1						
12								14.8						

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S74-PA-041-023 (1-12) Duncannon Silt Loam

CLASSIFICATION: Typic Hapludalf; Coarse-silty, mixed, mesic DATE PRINTED: 06/04/92

NO	DEPTH (cm)	HORI-ZON	CLAY MINERALS (PCT OF < 0.002 MM MATERIAL) KAOL	ILL	VERM	MONT	CHL	INT	QUARTZ
1	5- 3	Oi	0	0	0	0	0	0	0
2	3- 0	Oa	10	25	60	0	0	0	5
3	0- 5	A	10	25	50	0	0	15	0
4	5- 18	E	15	30	50	0	0	5	0
5	18- 36	Bt1	15	35	45	0	0	5	0
6	36- 51	Bt2	15	35	50	0	0	0	0
7	51- 69	Bt3	15	30	55	0	0	0	0
8	69- 91	Bt4	15	25	60	0	0	0	0
9	91-122	2Btb1	15	20	60	0	0	5	0
10	122-160	2Btb2	15	20	60	0	0	5	0
11	160-178	2Btb3	20	20	55	0	0	5	0
12	178-229	2Btb4	0	0	0	0	0	0	0

NO	EXTRACTABLE CATIONS (MILLIEQUIVALENTS PER 100 GRAMS OF < 2.0 MM MATERIAL) CA	MG	NA	K	TOTAL BASES	ACIDITY	CEC (SUM)	CEC (NH4)	AL	BASE SAT SUM (PCT)	NH4 (PCT)	CA/MG
1												
2	10.0	1.5	0.10	1.07	12.7	49.8	62.5		2.0	20.3		6.7
3	1.2	0.0	0.04	0.21	1.5	44.1	45.6		4.6	3.3		
4	0.4	0.0	0.06	0.14	0.6	14.5	15.1		2.5	4.0		
5	0.4	0.0	0.05	0.14	0.6	13.9	14.5		4.3	4.1		
6	0.6	0.0	0.04	0.12	0.8	11.4	12.2		4.8	6.6		
7	0.8	0.1	0.04	0.10	1.0	11.9	12.9		3.8	7.8		8.0
8	0.8	0.4	0.06	0.13	1.4	16.8	18.2		4.6	7.7		2.0
9	1.0	0.6	0.06	0.15	1.8	18.3	20.1		6.3	9.0		1.7
10	1.0	0.5	0.06	0.14	1.7	13.9	15.6		4.7	10.9		2.0
11	1.0	0.5	0.05	0.14	1.7	16.7	18.4		4.9	9.2		2.0
12	1.7	0.5	0.05	0.14	2.4	15.5	17.9		4.3	13.4		3.4

NO	pH (1:1 SOIL:SOLUTION) WATER LAB	WATER FIELD	1 N KCL LAB	1 N KCL FIELD	0.01 M CACL2 LAB	0.01 M CACL2 FIELD	CACO3 EQUIV-ALENT (PCT)	ORGANIC MATTER C (PCT)	N (PCT)	C/N	IRON OXIDES FE2O3 (PCT)	HNO3 EXTRACT-ABLE K (LB/ACRE)
1	4.9		4.0		4.2							
2	5.2		4.2		4.3			8.37	1.20	7.0	1.2	
3	4.8		4.0		4.1			1.93	0.37	5.2	1.7	
4	4.7		4.1		4.2			1.09	0.09	12.1	1.7	
5	4.5		3.9		4.0			0.32	0.04	8.0	1.8	
6	4.4		3.8		3.9			0.15			1.8	
7	4.7		3.9		4.0			0.11			1.8	
8	5.0		3.8		4.1			0.15			1.8	
9	5.1		3.9		4.1			0.11			2.0	
10	5.1		3.8		4.1			0.14			1.3	
11	5.2		3.8		4.0			0.13			1.9	
12	5.2		3.8		4.1			0.12				

Pennsylvania State University
Soil Characterization Laboratory

S74-PA-049-013 (1-8) Lakin Sand

CLASSIFICATION: Typic Udipsamment; Sandy, mixed, mesic

DATE PRINTED: 06/04/92

SOIL SERIES NAME: Lakin
SOIL SURVEY NO.: S74-PA-049-013 (1-8)
DESCRIPTION TYPE: Full pedon desc for lab characterization
PEDON TYPE:
DIAGNOSTIC FEATURES (depth cm):
ASSOCIATED SOILS:

SAMPLED SERIES NAME: Plainfield
SOIL TYPE : Sand
LAB SAMPLE NO.: 9618 - 9625
CONTROL SECTION (cm):

COUNTY: Northumberland
TOWNSHIP: West Chillisquaq
LATITUDE (D-M-S): 40-56-36-N

MLRA: 147, Northern Appalachian Ridges and Valleys
USGS 7.5' QUAD SHEET: Northumberland
LONGITUDE (D-M-S): 076-50-53-W

LOCATION: 1.6 mi S of Montandon, 200 ft E of Pa 149 and 0.2 mi N of Chillisquaque Cr. on right of way of highway.

REGIONAL LANDFORM: Ridge and valley
GEOMORPHIC COMPONENT:
SLOPE LENGTH (above,meters):
SLOPE SHAPE (up-down,across): ,
SLOPE (%): 6
SLOPE ASPECT (degrees): 270
MICRORELIEF (amount,pattern kind): , ,

LOCAL LANDFORM:
HILLSLOPE COMPONENT:
SLOPE LENGTH (total,meters):
POSITION ON SLOPE:
ELEVATION (meters): 159

PARENT MATERIAL WEATHERING:
1. Slight
PARENT MATERIAL MODE OF DEPOSITION:
1. Eolian sand
BEDROCK DIP (degrees):
BEDROCK FRACTURE:

PARENT MATERIAL ORIGIN:
1. Gray & brown acid sandstone
BEDROCK STRIKE (degrees):

PARENT MATERIAL (PA system): Aeolian sands
FLOOD PATTERN (freq.,beg. mon.,days): , ,
PONDING PATTERN (freq.,beg. mon.,days): , ,
WATER TABLE (depth cm,days,kind): , ,
DRAINAGE: Well drained
EROSION: Moderate
STONINESS: Class 0
WEATHER STATION:

MOISTURE REGIME: Udic
PERMEABILITY: Rapid
HYDRAULIC CONDUCTIVITY:
PERCOLATION RATE (in/hr):
RUNOFF: Slow
PLOWED: Yes

	ANNUAL	WINTER	SUMMER
SOIL TEMPERATURE(C):	9.9	0.0	0.0
AIR TEMPERATURE(C):	0.0	0.0	0.0

PRECIPITATION(cm): 100
LAND USE: Abandoned cropland
VEGETATION: Locusts; Northern Dewberry; Wild Garlic; Cherry
DESCRIBERS NAMES: I. W. Ratcliff, C. D. Kohler, G. D. Yoder
DATE DESCRIBED: 06/20/74
YIELD ID#:
MAP UNIT SYMBOL:
NOTES:

PHOTO #:
TRANSECT ID#:
NOTE ID#:

PA CLASSIFICATION: TYPIC, , UD, PSAMM, ENT, SANDY, MIXED, MESIC, CLASSIFICATION: Typic Udipsamment; Sandy, mixed, mesic DATE PRINTED: 06/04/92

1 Ap-- 0 to 20 cm; dark brown (7.5YR 4/4) matrix; loamy sand; weak fine subangular blocky structure; very friable, non sticky, non plastic; many roots; pH 5.4; clear smooth boundary

2 Bw1-- 20 to 46 cm; brown (7.5YR 5/4) matrix; loamy sand; structureless single grain; loose, non sticky, non plastic; common roots; pH 5.8; gradual wavy boundary

3 Bw2-- 46 to 86 cm; strong brown (7.5YR 5/6) matrix, reddish brown (5YR 4/3) matrix; loamy sand; structureless single grain; loose, non sticky, non plastic; common roots; pH 6.2; diffuse wavy boundary

4 C1-- 86 to 147 cm; light yellowish brown (10YR 6/4) matrix, dark reddish gray (5YR 4/2) matrix; fine sand; structureless single grain; loose, non sticky, non plastic; few roots; pH 6.4; clear smooth boundary

5 2Bwb1--147 to 173 cm; reddish yellow (7.5YR 6/6) matrix; loam; with few fine distinct reddish yellow (7.5YR 6/8), and few fine distinct light brown (7.5YR 6/3), and few fine distinct pinkish gray (7.5YR 6/2) mottles; weak medium prismatic structure; friable, slightly sticky, moderately plastic; few roots; pH 5.2; gradual wavy boundary

6 2Bwb2--173 to 196 cm; reddish brown (5YR 5/3) matrix; silt loam; with many coarse distinct reddish yellow (5YR 6/8) mottles; weak coarse platy structure; friable, slightly sticky, moderately plastic; few roots; pH 5.2; clear wavy boundary

7 2Bwb3--196 to 231 cm; brown (7.5YR 5/4) matrix; loam; structureless massive; friable, non sticky, non plastic; pH 5.2; gradual wavy boundary

8 2Cwb4--231 to 251 cm; brown (7.5YR 5/4) matrix; fine sandy loam; structureless massive; friable, non sticky, non plastic; few faint clay films in root channels and/or pores; pH 5.2

S74-PA-049-013 (1-8) Lakin Sand

CLASSIFICATION: Typic Udipsamment; Sandy, mixed, mesic

DATE PRINTED: 06/04/92

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH (cm)	HORIZON	> 250	250-76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD
1	0- 20	Ap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	S	LS
2	20- 46	Bw1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	S	LS
3	46- 86	Bw2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	S	LS
4	86-147	C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	S	FS
5	147-173	2Bwb1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	FSL	L
6	173-196	2Bwb2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	SIL	SIL
7	196-231	2Bwb3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	SIL	L
8	231-251	2Cwb4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	FSL	FSL

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

NO	SAND: V COARSE 2.0-1.0	SAND: COARSE 1.0-0.5	SAND: MEDIUM 0.5-0.25	SAND: FINE 0.25-0.10	SAND: 0.10-0.05	SAND: V FINE 0.10-0.07	SAND: 0.07-0.05	SILT: CO 0.05-0.02	SILT: MED 0.02-0.005	SILT: FINE 0.005-0.002	SILT: C+M 0.05-0.005	SILT: M+F 0.02-0.002	TOTAL SAND 2.0-0.05	TOTAL SILT 0.05-0.002	TOTAL CLAY < 0.002
1		2.1	53.9	31.6	3.1	2.0	1.1	3.8	1.2	1.2	5.0	2.4	90.7	6.2	3.1
2	0.1	2.1	64.9	25.0	1.8	1.3	0.5	2.2	0.4	0.7	2.6	1.2	93.9	3.4	2.7
3	0.1	1.2	58.7	32.0	3.7	3.3	0.4	2.0	0.3	0.7	2.3	1.0	95.7	3.0	1.3
4		2.0	48.0	41.7	3.7	2.6	1.1	2.4	0.3	0.3	2.7	0.6	95.4	3.0	1.6
5		0.9	21.1	25.8	14.5	7.3	7.2	15.2	10.1	2.9	25.3	13.0	62.3	28.2	9.5
6		0.2	7.4	3.6	18.7	9.5	9.2	31.3	20.4	5.5	51.7	25.9	29.9	57.2	12.9
7	0.4	1.2	10.4	9.5	12.0	3.3	8.7	25.2	22.7	6.1	47.9	28.8	33.5	54.0	12.5
8	0.2	1.0	21.1	27.0	14.2	8.2	6.0	16.0	13.5	2.5	29.5	16.0	63.5	32.0	4.5

NO	BULK DENSITY (G/CC): 1/3 ATM MOISTURE: ENTIRE CLOD	BULK DENSITY: 1/3 ATM MOISTURE: TOTAL SOIL < 2MM+FRAGS	BULK DENSITY: 1/3 ATM MOISTURE: < 2 MM IN CLOD	BULK DENSITY: OVEN DRY: < 2 MM IN CLOD	COLE < 2 MM	MOISTURE (PCT) RETAINED AT: 1/3 ATM: ENTIRE CLOD	MOISTURE: 1/3 ATM: < 2 MM IN CLOD	MOISTURE: 15 ATM: < 2 MM SIEVED	AVAILABLE WATER: < 2 MM MATERIAL: WEIGHT (PCT)	AVAILABLE WATER: < 2 MM MATERIAL: CM/CM OF SOIL	AVAILABLE WATER: TOTAL SOIL < 2 MM + FRAGMENTS: WEIGHT (PCT)	AVAILABLE WATER: TOTAL SOIL: CM/CM OF SOIL	PORE SPACE: FINE EARTH < 2MM (PCT)	PORE SPACE: TOTAL SOIL FE+RF (PCT)
1								1.9						
2								1.7						
3								1.7						
4								1.1						
5	1.53	1.53	1.53	1.57	0.008	12.4	12.4	5.6	6.8	0.104	6.8	0.104	41	41
6	1.39	1.39	1.39	1.43	0.010	24.0	24.0	7.4	16.6	0.231	16.6	0.231	47	47
7	1.58	1.58	1.58	1.61	0.006	20.7	20.7	7.2	13.5	0.213	13.5	0.213	39	39
8	1.50	1.50	1.50	1.54	0.007	11.8	11.8	3.6	8.2	0.123	8.2	0.123	42	42

Pennsylvania State University
Soil Characterization Laboratory

S74-PA-049-013 (1-8) Lakin Sand

CLASSIFICATION: Typic Udipsamment; Sandy, mixed, mesic DATE PRINTED: 06/04/92

NO	DEPTH (cm)	HORIZON	KAOL	ILL	VERM	MONT	CHL	INT	QUARTZ
			CLAY MINERALS (PCT OF < 0.002 MM MATERIAL)						
1	0- 20	Ap	20	40	35	0	0	0	5
2	20- 46	Bw1	20	45	30	0	5	0	0
3	46- 86	Bw2	20	50	25	0	5	0	0
4	86-147	C1	20	60	15	0	5	0	0
5	147-173	2Bwb1	20	50	25	5	0	0	0
6	173-196	2Bwb2	20	45	30	5	0	0	0
7	196-231	2Bwb3	20	40	30	10	0	0	0
8	231-251	2Cwb4	20	55	20	5	0	0	0

EXTRACTABLE CATIONS
(MILLIEQUIVALENTS PER 100 GRAMS OF < 2.0 MM MATERIAL)

NO	CA	MG	NA	K	TOTAL BASES	ACIDITY	CEC (SUM)	CEC (NH4)	AL	BASE SAT SUM (PCT)	BASE SAT NH4 (PCT)	CA/MG
1	2.9	3.6	0.07	0.07	6.6	6.1	12.7		0.8	52.0		0.8
2	3.3	3.6	0.03	0.05	7.0	6.9	13.9		0.5	50.4		0.9
3	4.1	3.7	0.06	0.06	7.9	4.4	12.3		0.1	64.2		1.1
4	3.7	3.6	0.05	0.06	7.4	5.7	13.1		0.1	56.5		1.0
5	5.6	3.8	0.05	0.13	9.6	7.9	17.5		0.6	54.9		1.5
6	5.7	3.8	0.06	0.15	9.7	11.7	21.4		3.2	45.3		1.5
7	4.8	3.8	0.06	0.14	8.8	14.8	23.6		4.5	37.3		1.3
8	3.8	3.7	0.06	0.08	7.6	9.3	16.9		2.6	45.0		1.0

NO	pH (1:1 SOIL:SOLUTION) WATER LAB	WATER FIELD	1 N KCL LAB	1 N KCL FIELD	0.01 M CACL2 LAB	0.01 M CACL2 FIELD	CACO3 EQUIVALENT (PCT)	ORGANIC MATTER C (PCT)	ORGANIC MATTER N (PCT)	C/N	IRON OXIDES FE2O3 (PCT)	HNO3 EXTRACTABLE K (LB/ACRE)
1	4.7		4.0		4.2			0.29	0.04	7.2	1.8	
2	5.0		4.3		4.4			0.02			1.0	
3	5.6		4.9		5.1			0.13			1.3	
4	5.8		5.1		5.3						1.0	
5	5.4		4.3		4.8			0.07			1.3	
6	5.2		4.0		4.4			0.08			1.6	
7	5.0		3.9		4.2			0.03			1.6	
8	4.9		4.0		4.2			0.13			1.0	

Pennsylvania State University
Soil Characterization Laboratory

S77-PA-014-045 (1-9) Murrill Silt Loam

CLASSIFICATION: Ultic Hapludalf; Fine-loamy, mixed, mesic

DATE PRINTED: 05/22/92

SOIL SERIES NAME: Murrill
SOIL SURVEY NO.: S77-PA-014-045 (1-9)
DESCRIPTION TYPE: Full pedon desc for lab characterization
PEDON TYPE:
DIAGNOSTIC FEATURES (depth cm):
ASSOCIATED SOILS:
COUNTY: Centre
TOWNSHIP: Ferguson
LATITUDE (D-M-S): 40-42-58-N

SAMPLED SERIES NAME: Murrill
SOIL TYPE : Silt Loam
LAB SAMPLE NO.:
CONTROL SECTION (cm):
MLRA: 147, Northern Appalachian Ridges and Valleys
USGS 7.5' QUAD SHEET: Pine Grove Mills
LONGITUDE (D-M-S): 077-55-39-W

LOCATION: Penn State Rock Springs Agro. Farm, 2.5 mi SW of Pine Grove Mills, 400 ft SE into field

REGIONAL LANDFORM: Ridge and valley
GEOMORPHIC COMPONENT:
SLOPE LENGTH (above,meters):
SLOPE SHAPE (up-down,across): ,
SLOPE (%): 4
SLOPE ASPECT (degrees): 315
MICRORELIEF (amount,pattern kind): , ,

LOCAL LANDFORM:
HILLSLOPE COMPONENT:
SLOPE LENGTH (total,meters):
POSITION ON SLOPE:
ELEVATION (meters): 408

PARENT MATERIAL WEATHERING:
1. Slight
2. Slight
3. Slight

PARENT MATERIAL MODE OF DEPOSITION:
1. Colluvium
2. Colluvium
3. Colluvium

PARENT MATERIAL ORIGIN:
1. Gray & brown acid sandstone
2. Gray & brown acid shale
3. Limestone

BEDROCK DIP (degrees):
BEDROCK FRACTURE:

BEDROCK STRIKE (degrees):

PARENT MATERIAL (PA system): Limestone colluvium
FLOOD PATTERN (freq.,beg. mon.,days): , ,
PONDING PATTERN (freq.,beg. mon.,days): , ,
WATER TABLE (depth cm,days,kind): , ,
DRAINAGE: Well drained
EROSION: Slight
STONINESS: Class 0
WEATHER STATION:

MOISTURE REGIME: Udic
PERMEABILITY: Moderately slow
HYDRAULIC CONDUCTIVITY:
PERCOLATION RATE (in/hr):
RUNOFF: Very slow
PLOWED: Yes

	ANNUAL	WINTER	SUMMER
SOIL TEMPERATURE(C):	9.1	0.0	0.0
AIR TEMPERATURE(C):	0.0	0.0	0.0

PRECIPITATION(cm): 100
LAND USE: Pasture land and native pasture
VEGETATION: Grass; Crownvetch
DESCRIBERS NAMES: R. Pennock
DATE DESCRIBED: 04/18/77
YIELD ID#:
MAP UNIT SYMBOL:
NOTES:

PHOTO #:
TRANSECT ID#:
NOTE ID#:

PA CLASSIFICATION: TYPIC, , HAPL, UD, ULT, FINE-LOAMY, MIXED, MESIC, S77-PA-014-045 (1-9) Murrill Silt Loam

CLASSIFICATION: Ultic Hapludalf; Fine-loamy, mixed, mesic DATE PRINTED: 05/22/92

1 Ap-- 0 to 23 cm; brown (10YR 4/3) matrix; silt loam; moderate medium granular structure; friable, slightly sticky, slightly plastic; few medium roots 2-5 mm; pH 5.5; abrupt smooth boundary

2 Bt1-- 23 to 51 cm; dark yellowish brown (10YR 4/4) matrix; silt loam; moderate fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; few medium roots 2-5 mm; few faint discontinuous clay films on faces of peds and in pores; pH 5.4; clear smooth boundary

3 Bt2-- 51 to 81 cm; dark yellowish brown (10YR 4/4) matrix; loam; moderate medium and coarse subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots 1-2 mm; few faint discontinuous clay films on faces of peds and in pores and many black (10YR 2/1) iron-manganese coatings on faces of peds; pH 5.3; 5% sandstone rock fragments, 5% gravel 2 mm-1.9 cm; clear smooth boundary

4 Bt3-- 81 to 107 cm; dark brown (7.5YR 4/4) matrix; gravelly loam; weak coarse subangular blocky structure parting to weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few faint discontinuous clay films in pores and common faint coatings on rock fragments; pH 5.3; 15% sandstone rock fragments, 15% gravel 2 mm-1.9 cm; clear smooth boundary

5 Bt4--107 to 122 cm; dark yellowish brown (10YR 4/4) matrix; gravelly loam; weak medium and coarse subangular blocky structure parting to weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common faint discontinuous clay films on faces of peds and in pores; pH 5.4; 20% sandstone rock fragments, 20% gravel 2 mm-1.9 cm; clear smooth boundary

6 Bt5--122 to 132 cm; dark yellowish brown (10YR 4/4) matrix; gravelly loam; weak medium and coarse subangular blocky structure parting to weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many distinct discontinuous clay films on faces of peds and in pores; pH 5.4; 15% sandstone rock fragments, 15% gravel 2 mm-1.9 cm; clear wavy boundary

7 2Btb--132 to 142 cm; dark reddish brown (5YR 3/3) matrix; clay; with many medium distinct reddish brown (5YR 4/4), and many medium distinct dark brown (7.5YR 3/2) mottles; strong medium subangular blocky structure; friable, moderately sticky, moderately plastic; many distinct continuous clay films on faces of peds and in pores and few black (10YR 2/1) iron-manganese coatings on faces of peds; pH 5.4; clear wavy boundary

8 2Cb--142 to 150 cm; very dark gray (10YR 3/1) matrix; silt loam; structureless massive; very friable, moderately sticky, slightly plastic; pH 7.2; abrupt irregular boundary

9 2R--150 to 165 cm; limestone

S77-PA-014-045 (1-9) Murrill Silt Loam

CLASSIFICATION: Ultic Hapludalf; Fine-loamy, mixed, mesic DATE PRINTED: 05/22/92

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH (cm)	HORI-ZON	> 250	250-76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD
1	0- 23	Ap	0.0	0.0	0.0	0.7	2.3	3.0	1.8	SIL	SIL
2	23- 51	Bt1	0.0	0.0	0.0	2.9	17.1	20.0	13.8	SIL	SIL
3	51- 81	Bt2	0.0	0.0	0.0	1.5	9.6	11.1	7.5	L	L
4	81-107	Bt3	0.0	0.0	0.0	3.7	20.7	24.4	17.8	L	L
5	107-122	Bt4	0.0	0.0	0.0	2.7	25.2	27.8	20.2	L	L
6	122-132	Bt5	0.0	0.0	0.0	7.4	28.9	36.3	0.0	CL	L
7	132-142	2Btb	0.0	0.0	0.0	0.0	8.7	8.7	5.3	C	C
8	142-150	2Cb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	CL	SIL
9	150-165	2R	0.0	0.0	0.0	0.0	0.0	0.0	0.0		*LO

* LO - limestone

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

NO	SAND: V COARSE 2.0-1.0	SAND: COARSE 1.0-0.5	SAND: MEDIUM 0.5-0.25	SAND: FINE 0.25-0.10	SAND: 0.10-0.05	SAND: V FINE 0.10-0.07	SAND: 0.07-0.05	SILT: CO 0.05-0.02	SILT: MED 0.02-0.005	SILT: FINE 0.005-0.002	SILT: C+M 0.05-0.005	SILT: M+F 0.02-0.002	TOTAL SAND 2.0-0.05	TOTAL SILT 0.05-0.002	TOTAL CLAY < 0.002
1	1.7	2.0	2.4	3.3	5.4	2.5	2.9	25.0	29.9	10.6	54.9	40.5	14.8	65.5	19.7
2	5.8	3.9	3.0	1.5	6.1	3.8	2.3	18.0	26.4	9.6	44.4	36.0	20.3	54.0	25.7
3	10.4	8.0	7.0	5.8	7.6	4.7	2.9	15.1	17.4	7.1	32.5	24.5	38.8	39.6	21.6
4	13.6	8.7	7.9	8.8	8.4	5.1	3.3	13.4	14.2	6.0	27.6	20.2	47.4	33.6	19.0
5	14.9	11.3	7.4	4.5	8.5	5.4	3.1	11.4	13.3	7.1	24.7	20.4	46.6	31.8	21.6
6	13.9	8.6	5.9	2.5	5.8	3.5	2.3	7.3	9.8	7.0	17.1	16.8	36.7	24.1	39.2
7	1.4	1.2	1.3	0.7	7.0	2.9	4.1	14.4	10.6	6.3	25.0	16.9	11.6	31.3	57.1
8	0.6	0.7	1.1	4.2	24.7	11.4	13.3	22.1	9.7	4.8	31.8	14.5	31.3	36.6	32.1
9															

NO	BULK DENSITY (G/CC) 1/3 ATM MOISTURE: ENTIRE CLOD	1/3 ATM MOISTURE: TOTAL SOIL < 2MM+FRAGS	1/3 ATM MOISTURE: < 2 MM IN CLOD	OVEN DRY: < 2 MM IN CLOD	COLE < 2 MM	MOISTURE (PCT) RETAINED AT 1/3 ATM: ENTIRE CLOD	1/3 ATM: < 2 MM IN CLOD	15 ATM: < 2 MM SIEVED	AVAILABLE WATER < 2 MM MATERIAL: WEIGHT (PCT)	< 2 MM MATERIAL: CM/CM OF SOIL	TOTAL SOIL < 2 MM + FRAGMENTS: WEIGHT (PCT)	TOTAL SOIL: CM/CM OF SOIL	PORE SPACE FINE EARTH < 2MM (PCT)	PORE SPACE TOTAL SOIL FE+RF (PCT)
1	1.42	1.45	1.42	2.53	0.026	19.6	20.3	9.2	11.1	0.158	10.8	0.156	45	45
2	1.52	1.69	1.50	1.56	0.013	20.8	21.7	11.9	9.8	0.147	7.8	0.132	42	36
3	1.66	1.66	1.56	1.58	0.010	15.5	19.0	10.8	8.2	0.128	7.3	0.121	40	37
4	1.66	1.78	1.57	1.69	0.025	15.2	18.8	9.9	8.9	0.140	6.7	0.120	40	33
5	1.63	1.78	1.52	1.56	0.007	16.9	20.0	11.3	8.7	0.132	6.3	0.112	42	33
6								15.2						
7	1.41	1.49	1.40	1.61	0.047	26.2	26.4	20.5	5.9	0.083	5.4	0.080	46	44
8								13.5						
9														

Pennsylvania State University
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S77-PA-014-045 (1-9) Murrill Silt Loam

CLASSIFICATION: Ultic Hapludalf; Fine-loamy, mixed, mesic DATE PRINTED: 05/22/92

NO	DEPTH (cm)	HORIZON	CLAY MINERALS (PCT OF < 0.002 MM MATERIAL) KAOL	ILL	VERM	MONT	CHL	INT	QUARTZ
1	0- 23	Ap	25	30	40	0	0	0	5
2	23- 51	Bt1	25	35	30	5	0	0	5
3	51- 81	Bt2	25	45	20	5	0	0	5
4	81-107	Bt3	25	50	15	5	0	0	5
5	107-122	Bt4	20	60	15	5	0	0	0
6	122-132	Bt5	20	60	10	5	0	0	5
7	132-142	2Btb	20	60	10	10	0	0	0
8	142-150	2Cb	15	60	10	15	0	0	0
9	150-165	2R	0	0	0	0	0	0	0

NO	EXTRACTABLE CATIONS (MILLIEQUIVALENTS PER 100 GRAMS OF < 2.0 MM MATERIAL) CA	MG	NA	K	TOTAL BASES	ACIDITY	CEC (SUM)	CEC (NH4)	AL	BASE SAT SUM (PCT)	BASE SAT NH4 (PCT)	CA/MG
1	7.9	3.9	0.20	0.17	12.2	9.1	21.3			57.3		2.0
2	7.8	1.6	0.19	0.16	9.8	10.1	19.9		0.3	49.2		4.9
3	5.0	1.5	0.19	0.15	6.8	10.5	17.3		1.0	39.3		3.3
4	3.5	1.5	0.19	0.15	5.3	11.2	16.5		1.1	32.1		2.3
5	4.8	2.6	0.20	0.17	7.8	10.1	17.9		0.5	43.6		1.8
6	7.9	4.1	0.19	0.21	12.4	13.4	25.8		1.0	48.1		1.9
7	14.6	5.2	0.20	0.41	20.4	11.2	31.6			64.6		2.8
8	10.9	2.4	0.19	0.19	13.7	4.7	18.4		0.7	74.5		4.5
9												

NO	pH (1:1 SOIL:SOLUTION) WATER LAB	WATER FIELD	1 N KCL LAB	1 N KCL FIELD	0.01 M CACL2 LAB	0.01 M CACL2 FIELD	CACO3 EQUIVALENT (PCT)	ORGANIC MATTER C (PCT)	N (PCT)	C/N	IRON OXIDES FE2O3 (PCT)	HNO3 EXTRACTABLE K (LB/ACRE)
1	6.4		5.0		5.8			1.49	0.14	10.6	2.3	
2	5.8		4.3		5.3			0.27	0.07	3.9	2.9	
3	5.1		4.2		4.5			0.14			2.8	
4	4.9		4.0		4.5			0.21			2.8	
5	5.2		4.0		4.6			0.14			2.0	
6	5.1		4.1		4.6			0.22			2.4	
7	5.5		4.3		4.0			0.32	0.08	4.0	4.1	
8	6.1		5.5		5.8			0.54	0.07	7.7	3.5	
9												

Pennsylvania State University
Soil Characterization Laboratory

S71-PA-039-041 (1-9) Buchanan Taxadjunct Loam

CLASSIFICATION: Aquic Fragiudult; Fine-loamy, mixed, mesic

DATE PRINTED: 05/22/92

SOIL SERIES NAME: Buchanan Taxadjunct
SOIL SURVEY NO.: S71-PA-039-041 (1-9)
DESCRIPTION TYPE: Full pedon desc for lab characterization
PEDON TYPE:
DIAGNOSTIC FEATURES (depth cm):
ASSOCIATED SOILS:
COUNTY: Lehigh
TOWNSHIP: Washington
LATITUDE (D-M-S): 40-46-02-N
LOCATION: 2.3 mi E of Lehigh Furnace on Rt. 39119, 650 ft N into field.
REGIONAL LANDFORM: Ridge and valley
GEOMORPHIC COMPONENT:
SLOPE LENGTH (above,meters):
SLOPE SHAPE (up-down,across): ,
SLOPE (%): 3
SLOPE ASPECT (degrees): 180
MICRORELIEF (amount,pattern kind): , ,
PARENT MATERIAL WEATHERING:
1. Slight
2. Slight
PARENT MATERIAL MODE OF DEPOSITION:
1. Colluvium
2. Colluvium
BEDROCK DIP (degrees):
BEDROCK FRACTURE:
PARENT MATERIAL (PA system): Grayish brown sandstone colluvium
FLOOD PATTERN (freq.,beg. mon.,days): , ,
PONDING PATTERN (freq.,beg. mon.,days): , ,
WATER TABLE (depth cm,days,kind): , ,
DRAINAGE: Moderately well drained
EROSION: Moderate
STONINESS: Class 0
WEATHER STATION:

SAMPLED SERIES NAME: Buchanan
SOIL TYPE : Loam
LAB SAMPLE NO.: 8844 - 8852
CONTROL SECTION (cm):
MLRA: 147, Northern Appalachian Ridges and Valleys
USGS 7.5' QUAD SHEET: Lehighton
LONGITUDE (D-M-S): 075-39-05-W
LOCAL LANDFORM:
HILLSLOPE COMPONENT:
SLOPE LENGTH (total,meters):
POSITION ON SLOPE:
ELEVATION (meters): 219
PARENT MATERIAL ORIGIN:
1. Gray & brown acid sandstone
2. Gray & brown acid shale
BEDROCK STRIKE (degrees):
MOISTURE REGIME: Udic
PERMEABILITY: Slow
HYDRAULIC CONDUCTIVITY:
PERCOLATION RATE (in/hr):
RUNOFF: Slow
PLOWED: Yes

	ANNUAL	WINTER	SUMMER
SOIL TEMPERATURE(C):	10.0	0.0	0.0
AIR TEMPERATURE(C):	0.0	0.0	0.0

PRECIPITATION(cm): 115
LAND USE: Cropland
VEGETATION:
DESCRIBERS NAMES: E. Ciolkosz, E. Sautter
DATE DESCRIBED: 08/15/71
YIELD ID#:
MAP UNIT SYMBOL:
NOTES:
PA CLASSIFICATION: AQUIC, , FRAGI, UD, ULT, FINE-LOAMY, MIXED, MESIC,

PHOTO #:
TRANSECT ID#:
NOTE ID#:

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1 Ap-- 0 to 28 cm; brown (10YR 4/3) matrix; silt loam; moderate fine and medium subangular blocky structure; friable, non sticky, slightly plastic; pH 6.0; 10% sandstone rock fragments; abrupt smooth boundary; 10% sandstone gravel.

2 Bt1-- 28 to 41 cm; light yellowish brown (10YR 6/4) matrix; gravelly loam; moderate fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; distinct continuous clay films on faces of peds; pH 6.0; 15% sandstone rock fragments; clear wavy boundary; 15% sandstone gravel.

3 Bt2-- 41 to 51 cm; strong brown (7.5YR 5/6) matrix; gravelly clay loam; with many medium distinct light yellowish brown (10YR 6/4) mottles; moderate medium subangular blocky structure; friable, slightly sticky, moderately plastic; distinct continuous clay films on faces of peds; pH 5.8; 20% sandstone rock fragments; abrupt wavy boundary; 20% sandstone gravel and cobbles.

4 Bx1-- 51 to 76 cm; yellowish red (5YR 5/6) matrix, light gray (10YR 7/2) prism faces, pale brown (10YR 6/3) ped faces; gravelly clay loam; with common medium distinct pale brown (10YR 6/3), and few fine prominent light gray (10YR 7/2) mottles; weak very coarse prismatic structure parting to moderate medium subangular blocky structure; firm, brittle, slightly sticky, moderately plastic; faint continuous clay films on faces of peds; pH 5.0; 20% sandstone rock fragments; clear wavy boundary; Prism and ped faces. 20% sandstone gravel and cobbles.

5 Bx2-- 76 to 97 cm; yellowish red (5YR 5/6) matrix, light gray (10YR 7/2) prism faces; gravelly clay loam; with few fine prominent light gray (10YR 7/2), and many medium distinct very pale brown (10YR 7/3) mottles; weak very coarse prismatic structure parting to moderate very coarse platy structure and moderate medium subangular blocky structure; very firm, brittle, slightly sticky, moderately plastic; distinct continuous clay films on faces of peds; pH 5.0; 20% sandstone rock fragments; gradual wavy boundary; Prism faces. 20% sandstone gravel and cobbles.

6 Bx3-- 97 to 114 cm; yellowish red (5YR 5/6) matrix, light gray (10YR 7/2) prism faces; gravelly clay loam; with few fine prominent light gray (10YR 7/2), and many medium distinct very pale brown (10YR 7/3) mottles; weak very coarse prismatic structure parting to moderate very coarse platy structure and moderate medium subangular blocky structure; very firm, brittle, moderately sticky, moderately plastic; faint continuous clay films on faces of peds and distinct clay films in root channels and/or pores; pH 4.8; 20% sandstone rock fragments; gradual wavy boundary; Prism faces. 20% sandstone gravel.

7 Bx4--114 to 137 cm; yellowish red (5YR 5/6) matrix, light gray (10YR 7/2) prism faces; gravelly clay loam; with few fine prominent light gray (10YR 7/1), and many medium distinct very pale brown (10YR 7/3) mottles; weak very coarse prismatic structure parting to moderate very coarse platy structure and moderate medium subangular blocky structure; very firm, brittle, moderately sticky, moderately plastic; faint continuous clay films on faces of peds and distinct clay films in root channels and/or pores; pH 4.8; 20% sandstone rock fragments; gradual wavy boundary; Prism faces. 20% sandstone gravels.

8 Bx5--137 to 163 cm; yellowish red (5YR 5/6) matrix, light gray (10YR 7/2) prism faces; gravelly clay loam; with few fine prominent light gray (10YR 7/1), and many medium distinct very pale brown (10YR 7/3) mottles; weak very coarse prismatic structure parting to moderate very coarse platy structure and moderate medium subangular blocky structure; very firm, brittle, moderately sticky, moderately plastic; faint discontinuous clay films on faces of peds and distinct clay films in root channels and/or pores; pH 4.8; 20% sandstone rock fragments; gradual wavy boundary; Prism faces. 20% sandstone gravel.

9 Bx6--163 to 190 cm; yellowish red (5YR 5/6) matrix, light gray (10YR 7/2) prism faces; gravelly clay loam; with few fine prominent light gray (10YR 7/1), and common medium distinct very pale brown (10YR 7/3) mottles; weak very coarse prismatic structure parting to moderate very coarse platy structure and moderate medium subangular blocky structure; firm, brittle, moderately sticky, moderately plastic; faint discontinuous clay films on faces of peds and in pores; pH 4.8; 20% sandstone rock fragments; Prism faces. 20% sandstone gravel.

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ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH (cm)	HORI-ZON	> 250	250-76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD
1	0- 28	Ap	0.0	0.0	7.9	11.2	8.1	27.1	18.1	L	SIL
2	28- 41	Bt1	0.0	11.3	18.4	6.9	7.6	44.2	34.3	L	L
3	41- 51	Bt2	0.0	29.7	25.4	4.9	8.2	68.2	60.3	CL	CL
4	51- 76	Bx1	0.0	0.0	9.0	4.3	6.2	19.5	13.2	CL	CL
5	76- 97	Bx2	0.0	0.0	4.0	7.6	7.9	19.5	13.9	CL	CL
6	97-114	Bx3	0.0	0.0	7.3	6.5	6.9	20.8	14.9	CL	CL
7	114-137	Bx4	0.0	0.0	9.0	7.9	4.8	21.6	15.7	CL	CL
8	137-163	Bx5	0.0	0.0	6.7	5.3	8.0	20.0	14.4	CL	CL
9	163-190	Bx6	0.0	0.0	14.6	14.9	8.5	38.1	30.0	CL	CL

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

	SAND							SILT							
	V COARSE	COARSE	MEDIUM	FINE		V FINE		CO	MED	FINE	C+M	M+F	TOTAL SAND	TOTAL SILT	TOTAL CLAY
	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05	0.10-0.07	0.07-0.05	0.05-0.02	0.02-0.005	0.005-0.002	0.05-0.005	0.02-0.002	2.0-0.05	0.05-0.002	< 0.002
1	3.7	7.9	12.2	8.2	4.0			18.0	22.0	9.1	40.0	31.1	36.0	49.1	14.9
2	5.3	8.4	10.8	7.8	4.5			15.0	20.6	9.2	35.6	29.9	36.8	44.9	18.3
3	5.6	7.4	9.9	6.9	2.4			12.3	18.3	9.2	30.6	27.5	32.2	39.8	28.0
4	4.7	7.4	8.4	7.3	4.9			11.6	16.9	9.4	28.5	26.3	32.7	37.9	29.4
5	4.8	7.5	9.2	6.9	5.4			10.8	16.9	9.3	27.7	26.2	33.8	37.0	29.2
6	5.3	6.5	8.1	7.1	4.3			10.3	17.5	9.5	27.8	26.9	31.3	37.2	31.5
7	3.7	7.3	8.9	6.7	4.6			10.4	18.7	9.5	29.1	28.2	31.2	38.6	30.2
8	3.9	6.7	8.4	8.0	4.7			10.9	18.4	8.9	29.3	27.4	31.7	38.3	30.0
9	6.3	8.4	9.5	6.7	4.9			10.7	16.8	8.8	27.5	25.6	35.8	36.3	27.9

	BULK DENSITY (G/CC)					MOISTURE (PCT) RETAINED AT			AVAILABLE WATER				PORE SPACE	
	1/3 ATM MOISTURE			OVEN DRY		1/3 ATM		15 ATM	< 2 MM MATERIAL		TOTAL SOIL < 2 MM + FRAGMENTS		FINE EARTH	TOTAL SOIL
NO	ENTIRE CLOD	TOTAL SOIL < 2MM+FRAGS	< 2 MM IN CLOD	< 2 MM IN CLOD	COLE < 2 MM	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM SIEVED	WEIGHT (PCT)	CM/CM OF SOIL	WEIGHT (PCT)	CM/CM OF SOIL	< 2MM (PCT)	FE+RF (PCT)
1	1.50	1.71	1.40	1.48	0.021	23.2	23.8	5.4	18.4	0.258	13.4	0.230	46	38
2	1.68	1.99	1.53	1.59	0.014	16.1	20.9	7.5	13.4	0.205	7.5	0.148	41	27
3	1.70	2.23	1.60	1.67	0.013	14.9	17.6	11.3	6.3	0.101	2.0	0.045	38	15
4	1.63	1.76	1.56	1.65	0.020	21.2	23.7	11.7	12.0	0.187	9.7	0.170	40	35
5	1.71	1.82	1.64	1.67	0.011	15.7	17.8	11.0	6.8	0.112	5.5	0.100	37	32
6	1.73	1.86	1.67	1.72	0.010	15.4	17.2	11.2	6.0	0.100	4.8	0.088	36	30
7	1.75	1.86	1.67	1.71	0.011	15.9	18.1	11.6	6.5	0.109	5.1	0.095	36	30
8	1.72	1.86	1.68	1.77	0.019	16.3	17.4	11.2	6.2	0.104	5.0	0.092	35	30
9	1.75	2.01	1.67	1.70	0.008	14.2	16.6	10.6	6.0	0.100	3.7	0.074	36	25

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NO	DEPTH (cm)	HORI-ZON	CLAY MINERALS (PCT OF < 0.002 MM MATERIAL) KAOL	ILL	VERM	MONT	CHL	INT	QUARTZ
1	0- 28	Ap	10	15	55	0	0	15	5
2	28- 41	Bt1	20	35	40	0	0	5	0
3	41- 51	Bt2	25	55	20	0	0	0	0
4	51- 76	Bx1	25	65	10	0	0	0	0
5	76- 97	Bx2	0	0	0	0	0	0	0
6	97-114	Bx3	25	65	10	0	0	0	0
7	114-137	Bx4	0	0	0	0	0	0	0
8	137-163	Bx5	25	65	10	0	0	0	0
9	163-190	Bx6	25	65	10	0	0	0	0

EXTRACTABLE CATIONS
(MILLIEQUIVALENTS PER 100 GRAMS OF < 2.0 MM MATERIAL)

NO	CA	MG	NA	K	TOTAL BASES	ACIDITY	CEC (SUM)	CEC (NH4)	AL	BASE SAT SUM (PCT)	BASE SAT NH4 (PCT)	CA/MG
1	3.9	0.3	0.07	0.15	4.4	15.2	19.6		0.5	22.4		13.0
2	2.9	0.2	0.35	0.15	3.6	7.3	10.9		0.6	33.0		14.5
3	3.3	0.3	0.08	0.13	3.8	7.3	11.1		0.8	34.2		11.0
4	1.6	0.3	0.10	0.12	2.1	10.2	12.3		2.2	17.1		5.3
5	1.0	0.3	0.06	0.13	1.5	12.8	14.3		2.7	10.5		3.3
6	0.8	0.3	0.06	0.14	1.3	9.9	11.2		2.9	11.6		2.7
7	0.8	0.3	0.08	0.13	1.3	13.1	14.4		2.9	9.0		2.7
8	0.6	0.3	0.08	0.13	1.1	11.1	12.2		3.0	9.0		2.0
9	0.5	0.3	0.08	0.13	1.0	11.6	12.6		2.6	7.9		1.7

NO	pH (1:1 SOIL:SOLUTION) WATER LAB	WATER FIELD	1 N KCL LAB	1 N KCL FIELD	0.01 M CACL2 LAB	0.01 M CACL2 FIELD	CACO3 EQUIV-ALENT (PCT)	ORGANIC MATTER C (PCT)	ORGANIC MATTER N (PCT)	C/N	IRON OXIDES FE2O3 (PCT)	HNO3 EXTRACT-ABLE K (LB/ACRE)
1	5.6		4.3		4.9			1.71	0.16	10.7	1.5	
2	5.9		4.4		5.2			0.36			1.6	
3	5.7		4.1		5.0			0.29			2.0	
4	5.2		3.9		4.5			0.16			1.3	
5	5.2		3.8		4.4			0.04				
6	5.2		3.8		4.3			0.03			1.8	
7	5.2		3.7		4.3			0.01				
8	5.2		3.7		4.3			0.04			2.7	
9	5.2		3.8		4.3			0.05			2.4	

PEDON DESCRIPTION

LOCATION: Buffalo Coal Company surface mine in the Pendleton Creek watershed in Tucker county. West Virginia south of Route 32 between Thomas and Davis. Davis Quadrangle.

ELEVATION: 3100 feet

PARENT MATERIAL: Colluvium over residuum; sandstone and shale.

DRAINAGE CLASS: Somewhat poorly/poorly

SLOPE/ASPECT: 6-8%/west

VEGETATION: Sphagnum moss, iron weed, common fescue grass, wild strawberry, ferns.

DESCRIBED BY: David McCloy and John Sencindiver.

DATE DESCRIBED: June 11, 1990

(colors are for moist soil)

Oi -- 9 to 6 cm; root mat of sphagnum moss.

Oe -- 6 to 0 cm; very dark grayish brown (10YR 3/2); weak granular structure; very friable; many very fine and fine roots; extremely acid; abrupt smooth boundary.

E -- 0 to 6 cm; brown (7.5YR 5/2) silt loam; common medium brown (7.5YR 4/4) and dark brown (7.5YR 3/3) mottles; moderate medium subangular blocky structure; friable; few very fine and fine roots; few very fine and fine pores; extremely acid; abrupt irregular boundary.

Bt1 -- 6 to 25 cm; brownish yellow (10YR 6/6) and strong brown (7.5YR 5/8) silty clay loam; common fine light gray (10YR 7/2) and common fine and medium yellowish red (5YR 4/6) mottles; weak coarse prismatic breaking to moderate medium and coarse subangular blocky structure; firm; few very fine and fine roots along ped faces; 1% sandstone fragments; few very fine and fine pores; few thin discontinuous clay coatings on ped faces and in pores; thin continuous light olive brown (2.5YR 5/6) silt coatings; extremely acid; clear wave boundary.

Btx1 -- 25 to 47 cm; light yellowish brown (10YR 6/4), light gray (10YR 7/2) and strong brown (7.5YR 5/6) clay loam; common fine and medium black (N 2/0) mottles and coatings; moderate coarse prismatic structure; very firm; common very fine roots along ped faces; 2% sandstone fragments; common fine and medium pores; few thin continuous clay coatings along ped faces and in pores; continuous thin light grey (2.5Y 7/2) and olive yellow (2.5Y 6/6) silt coatings on ped faces; very strongly acid; gradual wavy boundary.

Btx2 -- 47 to 104 cm; pale brown (10YR 6/3) and yellowish brown (10YR 5/6) clay loam; common medium strong brown (7.5YR 5/8) and few fine and medium black (N 2/0) mottles; weak coarse prismatic structure; very firm; few very fine roots along prism faces; 5% sandstone fragments; few fine and medium pores; few thin continuous yellowish brown (10YR 5/8) clay coatings in pores; continuous thin light gray (N 7/0) silt coatings on prism faces; very strongly acid; gradual wavy boundary.

2C -- 104 to 201 + cm; yellowish brown (10YR 5/4) clay loam; few medium strong brown (7.5YR 5/8) and few fine black (N 2/0) mottles; massive; very firm; 15% sandstone and shale fragments; common fine and medium pores; few thin clay coatings in pores; continuous thin very pale brown 10YR 7/3) silt coatings along fractures; strongly acid.

Note: Black mottles appear to be organic; probably weathered coal or charcoal fragments.

Profile PC-50 Chemical Properties

Horizons	Acidity (BaCl-TEA)	Ca	Mg	K	Na	CEC (Sum)	Base Sat %	Org. Matter %	pH 1:1 Water
		(NH$_4$OA$_c$, pH 7.0)							
Oi	--	--	--	--	--	--	--	--	--
Oe	50.5	0.54	0.20	0.37	0.11	51.7	2.4	21.5	3.47
E	25.4	0.26	0.07	0.14	0.07	25.9	2.1	11.8	3.56
Bt	18.3	0.18	0.04	0.08	0.07	18.7	2.0	4.4	4.01
Btx1	13.8	0.64	0.20	0.14	0.08	14.9	7.1	4.1	4.52
Btx2	13.9	2.63	1.89	0.19	0.08	18.7	25.6	4.8	4.82
2C	5.7	5.35	3.68	0.16	0.04	14.9	61.9	5.2	5.66

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Pedon #PC-50 Physical Properties
Particle Size Distribution as Percent of <2mm Material

	SAND					Total Sand	Total Silt	Total Clay
Horizon	VC	C	M	F	VF			
Oi	--	--	--	--	--	--	--	--
Oe	3.2	5.3	1.6	4.0	2.9	17.0	62.0	21.0
E	1.6	2.7	1.5	7.1	6.6	19.5	65.5	15.0
Bt	1.9	1.5	1.6	10.8	8.3	24.1	48.8	27.1
Btx	3.9	2.1	1.2	3.6	3.7	14.5	58.0	27.5
Btx2	5.4	3.1	1.5	4.6	4.6	19.2	53.9	26.9
2c	4.7	3.1	1.5	4.7	5.3	19.3	56.3	24.4

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Profile PC-50 Physical Properties

	Rock Fragments ---- % by weight ----					
Horizon	<2mm	2-6mm	6-20mm	>20mm	Bulk Density (33kPa) g/cm^3	Cole
Oi	--	--	--	--	--	--
Oe	98.9	0.6	0.5	0.0	--	--
E	98.0	0.8	1.2	0.0	--	--
Bt	86.9	9.4	2.7	1.00	1.54	0.030
Btx1	88.7	4.9	4.6	1.8	1.62	0.028
Btx2	71.3	12.2	12.6	3.9	1.66	0.034
2C	71.0	17.2	7.2	4.6	1.71	0.038

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SOIL PROFILE DESCRIPTIONS

Unit 1 N202 E198.5

AC	0.0 - 30.5 cm, dark brown (10YR 3/3) sandy clay loam; weak, very fine granular; very friable to loose; '85 flood deposit; a few pebbles scattered through the horizon; abrupt, smooth boundary.
C	30.5 - 40.7 cm, dark yellowish brown (10YR 3/4) sandy loam; weak, fine granular; very friable to loose; '85 flood deposit; abrupt, smooth boundary.
2Ab	40.7 - 52.0 cm, dark brown (7.5YR 3/2) sandy clay loam; weak, fine granular and crumb; very friable; weakly developed horizon; clear, smooth boundary.
2ABb	52.0 - 73.7 cm, dark brown (7.5YR 3/2) sandy clay loam; weak, fine crumb; friable; clear, smooth boundary.
2Bwb	73.7 - 101.6 cm, brown to dark brown (7.5YR 4/4) sandy clay loam; weak, fine and very fine crumb; very friable to loose; contains lenses of small pebble and granular size material; abrupt, smooth boundary.
3Cb	101.6 - 116.8 cm, gravels of fluvial origin with apedal sandy and granular material as interstitial filling; some imbrication and stratification present; base not exposed.

This soil is mapped as belonging to the Potomac series. The Potomac soil is a sandy skeletal, Typic Udifluvent (basically a young, sandy soil of fluvial origin with minimal pedologic development). The description is very appropriate for this soil, since it shows evidence of minimal pedogenic development, probably a result of frequent fluvial disturbance.

Unit 2

AC	0 - 5.1 cm, very dark grayish brown (10YR 3/2) clay loam; weak, very fine crumb; very friable; horizon probably a post '85 flood restoration; abrupt, smooth boundary.
C	5.1 - 14.0 cm, horizon of mixed brown to dark brown (7.5YR 4/4) and dark brown (10YR 3/3) clay loam clods; weak, medium and fine subangular blocky; friable; horizon probably a post '85 flood restoration; horizon contains fluvially rounded cobbles to 13.0 cm and abundant thin, angular, carbonaceous shale fragments; abrupt, wavy boundary.
2Ab	14.0 - 24.2 cm, very dark grayish brown (10YR 3/2) clay loam; moderate, fine and medium subangular blocky; friable; top of horizon probably truncated; abrupt, smooth boundary.

2ABb 24.2 - 35.6 cm, very dark grayish brown (10YR 3/2) clay loam; moderate, medium subangular blocky; friable to firm; scattered granular size shale fragments; abrupt, smooth boundary.

2BAb 35.6 - 47.0 cm, dark brown (7.5YR 3/2) clay loam; moderate, medium and fine subangular blocky tending to platy; friable to firm; clay mineralogy may include expandable lattice clays because of vertically aligned platelets between weakly expressed prismatic columns; abrupt, smooth boundary.

2Bt1b 47.0 - 63.5 cm, dark brown (7.5YR 3/2) clay loam; moderate, fine subangular blocky tending to platy; friable to firm; abundant argillans (7.5YR 4/4) and some organs (10YR 4/3); clear, smooth boundary.

2Bt2b 63.5 - 94.0 cm, brown to dark brown (7.5YR 4/4) clay loam; moderate, prismatic breaking into medium and fine subangular blocky; friable to firm; abundant argillans (7.5YR 4/6) and organic material along root channels; abrupt, smooth boundary.

2Bb 94.0 - 111.8 cm, brown to dark brown (7.5YR 4/4) clay loam; moderate, prismatic breaking to fine and medium platy; friable to firm; abrupt, smooth boundary.

2Bxb 111.8 - 188.0 cm, reddish brown (5YR 4/4) clay; moderate, medium and fine platy; firm to very firm; base concealed.

This soil is mapped as belonging to the Monongahela series and very clearly fits the description for that soil. In the new taxonomy, the Monongahela is a Typic Fragiudult (a typical humid climate old(er) terrace soil with a fragipan. This soil has some age to it and may correspond with T1 or T2 surfaces described by Jacobson.

Unit 5 N470 E248.5

AC 0 - 20.3 cm, brown to dark brown (7.5YR 4/4) sandy loam; weak, very fine granular and crumb to apedal; very friable to loose; very faint laminations, '85 flood deposit material; abrupt, smooth boundary.

2Ab 20.3 - 26.7 cm, dark brown (7.5YR 3/2) loam; moderate, medium and fine blocky; friable; topsoil horizon before '85 flood, likely truncated; abrupt, smooth boundary.

2ABb 26.7 - 34.3 cm, dark brown (7.5YR 3/2) loam; moderate to weak, fine subangular blocky; friable; distinction from above horizon on visible structural differences; abrupt, smooth boundary.

2Bwb 34.3 - 49.6 cm, dark brown (7.5YR 3/4) loam; moderate, medium and fine subangular blocky; friable; argillans present but not abundant; abrupt, smooth boundary.

2Btb 49.6 - 58.4 cm, dark brown (7.5YR 3/4) sandy clay loam; moderate, fine subangular blocky, friable; abundant argillans; abrupt, smooth boundary.

3Ab 58.4 - 69.8 cm, dark brown (7.5YR 3/2) sandy clay loam; moderate, fine subangular blocky; friable to slightly firm; abundant charcoal fragments; clear, smooth boundary.

3BAb 69.8 - 87.6 cm, dark brown (7.5YR 3/2) sandy clay loam; moderate, fine and medium subangular blocky; friable; some argillans present on ped surfaces; clear, smooth boundary.

3Bt 87.6 - 111.8 cm, dark brown (7.5YR 3/2) clay loam; moderate, fine subangular blocky; friable; abundant argillans, bluish cast to many ped surfaces suggestive of frequent prolonged saturation; clear, smooth boundary.

3Bx1 111.8 - 142.3 cm, brown to dark brown (7.5YR 4/4) clay loam; moderate, fine subangular blocky tending to platy; friable to firm; manganese nodules present, fluvially rounded cobbles and small boulders set into fine matrix in upper portion of horizon; clear, smooth boundary.

3Bx2 142.3 - 152.4 cm, brown to dark brown (7.5YR 4/4) clay loam; moderate, fine platy; friable to firm; rounded thin carbonaceous shale fragments of fluvial origin present; base concealed.

This soil is mapped as belonging to the Monongahela series (Typic Fragiudult). While the clay content in this soil is only 75% of that found in Unit 2, the soil in physical characteristics is very similar to Unit 2. The two superimposed, buried soils in this profile are suggestive of a long, complex history for this site. The charcoal present in the 3Ab horizon is sufficiently abundant that radiocarbon dating of this horizon should be possible. I would anticipate that this soil should fit with either the T1 or T2 surfaces of Jacobson, with a good chance of fitting into the latter of these two a distinct possibility.

<u>Unit 6</u>

A 0 - 12.7 cm, dark brown (10YR 3/3) loam; moderate, fine and very fine crumb; friable; numerous platy carbonaceous shale fragments and medium to small sized fluvially rounded pebbles, horizon likely post '85 flood surface restoration; abrupt, smooth boundary.

C 12.7 - 16.5 cm, dark yellowish brown (10YR 4/6) clay loam; weak, fine subangular blocky; friable to very friable; numerous small pebbles and granules of shale and sandstone, horizon probably post '85 flood surface restoration; abrupt, smooth boundary.

2ACb 16.5 - 27.9 cm, very dark grayish brown (10YR 3/2) clay loam; moderate, fine subangular blocky tending toward platy; friable to firm; faint stratification in upper portion of the horizon and more sandy to bottom, mottles present are brown to dark brown (10YR 4/3), numerous sandstone pebbles and small cobbles set into fine matrix; abrupt, wavy boundary.

3Ab 27.9 - 55.9 cm, very dark grayish brown (10YR 3/2) clay loam; moderate, fine and medium subangular blocky; friable to very friable in top 20 cm of horizon, friable in bottom 7.5 cm; abrupt, smooth boundary.

3Bt 55.9 - 88.9 cm, dark brown (10YR 3/3) silty clay loam; moderate to strong, medium and fine subangular blocky; friable to firm; argillans abundant, some siltans; clear, smooth boundary.

3Bw 88.9 - 129.5 cm, dark brown (10YR 3/3) clay loam; moderate to weak, medium subangular blocky, friable to firm; base concealed.

In the new soil taxonomy, this soil would probably be classified as either a Typic Fluvaquent or more likely a Typic Fluvaquult. The soil is mapped in the Lindside/Lobdell complex, but the soil found at Unit 6 does not fit well with the typical profile description for either of these soils. This soil shows some age with the minimal amount of clay translocation that has occurred and would most likely fit with either Jacobson's T0 or T1 surface, more likely the latter.

Unit 7 N500 E575

Ap 0 - 17.8 cm, dark brown (7.5YR 3/2) loam; weak, fine subangular blocky and blocky; friable; abrupt, smooth boundary.

BA 17.8 - 30.5 cm, dark brown (7.5YR 3/3) loam; fine and medium subangular blocky; friable to slightly firm; argillans noticeable on ped surfaces; abrupt, smooth boundary.

Bt 30.5 - 63.5 cm, brown to dark brown (7.5YR 4/4) clay loam; medium and fine subangular blocky; friable; abundant argillans on ped surfaces; abrupt, smooth boundary.

BC 63.5 - 73.7 cm, brown to dark brown (7.5YR 4/4) clay loam; moderate, medium subangular blocky; slightly firm; some argillans on ped surfaces; abrupt, smooth boundary.

2C 73.7 - 114.3 cm, strong brown (7.5YR 4/6) fluvially rounded cobble layer with medium granular interstitial filling; base concealed.

The soil described here probably was mapped as part of the Lindside series. Unlike the Lindside soil (an Inceptisol), however, this profile contains translocated clay. In the taxonomy, this soil would probably be classified an an Ultisol. Adjacent Ultisol soils in the study area (such as the Monongahela) possess a fragipan though this one clearly did not. This soil has some age to it, but not the amount associated with the profiles identified here as belonging to the Monongahela series. For the surfaces Jacobson identifies, this soil would likely belong to T0, though there is an outside chance it might make T1.

Unit 8 N505 E494.5

Ap 0 - 15.2 cm, dark brown (7.5YR 3/2) loam; moderate, medium and fine subangular blocky; friable; fluvially rounded cobbles to 8.0 cm scattered through the horizon; abrupt, smooth boundary.

Bw 15.2 - 29.2 cm, dark brown (7.5YR 3/3) loam; moderate, medium and fine subangular blocky; friable to firm; abrupt, smooth boundary.

2Ab 29.2 - 45.7 cm, dark brown (7.5YR 3/2) clay loam; moderate, medium subangular blocky; friable to firm; clear, smooth boundary.

2Bt1b 45.7 - 74.9 cm, dark brown (7.5YR 3/3) clay loam; moderate, prismatic breaking to medium and fine subangular blocky; friable to firm; abundant argillans of brown to dark brown (7.5YR 4/4), abundant root channels lined with siltans and organs; clear, smooth boundary.

2Bt1b 74.9 - 96.5 cm, brown to dark brown (7.5YR 4/4) clay loam; moderate, prismatic breaking to fine and medium subangular blocky; friable; abundant argillans of strong brown (7.5Yr 4/6), fewer root channels than horizon above; clear, smooth boundary.

2B 96.5 - 124.5 cm, brown to dark brown (7.5YR 4/4) clay loam; moderate, medium subangular blocky tending to platyness; friable to firm; base concealed.

This soil belongs to the Monongahela series. The soil profile is basically similar to the soils exposed in Units 2 and 5.

Unit 10 N500 E535

Ap 0 - 12.7 cm, very dark grayish brown (10YR 3/2) loam; weak, fine crumb; very friable; abrupt, smooth boundary.

AB 12.7 - 25.4 cm, dark brown (7.5YR 3/2) loam; moderate, fine crumb; friable; abrupt, smooth boundary.

Bw 25.4 - 50.8 cm, dark brown (7.5YR 3/3) loam; moderate, fine subangular blocky; friable; abrupt, smooth boundary.

2Ab 50.8 - 68.6 cm, very dark gray (10YR 3/1) clay loam; moderate, medium and fine subangular blocky; friable; clear, smooth boundary.

2Bwb 68.6 - 99.1 cm, brown to dark brown (7.5YR 4/4) clay loam; moderate, medium subangular blocky; friable to slightly firm; faint mottling present; clear, smooth boundary.

2Bb 99.1 - 147.3 cm, brown (7.5YR 5/4) loam; moderate to strong, medium subangular blocky; friable; abundant mottling of strong brown (7.5YR 5/7); bottom concealed.

This soil most likely belongs to the Lobdell series, a Fluvaquentic Eutrochrept (basically a youthful soil of fluvial origin showing a tendency toward prolonged periods of wetness). The pedogenic development of this soil is less than most other soils described in this report, being only a little more developed than the profile described for Unit 1. This soil would likely fit best with the Jacobson surface T0.

SOIL TEXTURES

UNIT 1

Horizon	Increment (cm)	Sand %	Silt %	Clay %	Textural Class
AC	0.0 - 30.5	66.4	12.7	20.9	Sandy Clay Loam
C	30.5 - 40.7	66.5	15.5	18.0	Sandy Loam
2Ab	40.7 - 52.0	57.6	19.1	23.3	Sandy Clay Loam
2ABb	52.0 - 73.7	53.5	22.2	24.3	Sandy Clay Loam
2Bwb	73.7 - 101.6	60.4	17.9	21.7	Sandy Clay Loam

UNIT 2

Horizon	Increment (cm)	Sand %	Silt %	Clay %	Textural Class
AC	0.0 - 5.1	36.0	33.5	30.5	Clay Loam
C	5.1 - 14.0	38.9	29.4	31.7	Clay Loam
2Ab	14.0 - 24.2	34.3	35.4	30.3	Clay Loam
2ABb	24.2 - 35.6	32.2	36.4	31.4	Clay Loam
2BAb	35.6 - 47.0	31.5	34.0	34.5	Clay Loam
2Bt1b	47.0 - 63.5	24.4	39.1	36.5	Clay Loam
2Bt2b	63.5 - 94.0	24.1	41.1	34.8	Clay Loam
2Bb	94.0 - 111.8	22.9	40.3	36.8	Clay loam
2Bxb	111.8 - 188.0	24.3	34.8	40.9	Clay

UNIT 5

Horizon	Increment (cm)	Sand %	Silt %	Clay %	Textural Class
AC	0.0 - 20.3	58.7	25.4	15.9	Sandy Loam
2Ab	20.3 - 26.7	43.5	34.3	22.2	Loam
2ABb	26.7 - 34.3	48.4	29.9	21.7	Loam
2Bwb	34.3 - 49.6	49.0	28.3	22.7	Loam
2Btb	49.6 - 58.4	48.9	26.0	25.1	Sandy Clay Loam
3Ab	58.4 - 69.8	52.6	20.3	27.1	Sandy Clay Loam
3BAb	69.8 - 87.6	55.0	23.5	21.5	Sandy Clay Loam
3Bt	87.6 - 111.8	36.8	33.3	29.9	Clay Loam
3Bx1	111.8 - 142.3	36.7	33.7	29.6	Clay Loam
3Bx2	142.3 - 152.4	36.4	32.3	31.3	Clay Loam

UNIT 6

Horizon	Increment (cm)	Sand %	Silt %	Clay %	Textural Class
A	0.0 - 12.7	39.3	34.1	26.6	Loam
C	12.7 - 16.5	34.9	34.0	31.1	Clay Loam
2ACb	16.5 - 27.9	24.3	39.0	36.7	Clay Loam
3Ab	27.9 - 55.9	23.9	46.2	29.9	Clay Loam
3Bt	55.9 - 88.9	18.9	43.2	37.9	Silty Clay Loam
3Bw	88.9 - 129.5	32.2	34.6	33.1	Clay Loam

UNIT 7

Horizon	Increment (cm)	% Sand	Silt	Clay	Textural Class
Ap	0.0 - 17.8	36.5	41.9	21.6	Loam
BA	17.8 - 30.5	34.7	40.4	24.9	Loam
Bt	30.5 - 63.5	30.5	39.8	29.7	Clay Loam
BC	63.5 - 73.7	36.5	35.2	28.3	Clay Loam

UNIT 8

Ap	0.0 - 15.2	44.6	33.4	22.0	Loam
Bw	15.2 - 29.2	44.8	34.0	21.2	Loam
2Ab	29.2 - 45.7	26.2	40.8	33.0	Clay Loam
2Bt1b	45.7 - 74.9	25.9	40.7	33.4	Clay Loam
2Bt2b	74.9 - 96.5	36.3	34.0	29.7	Clay Loam
2B	96.5 - 124.5	34.6	35.9	29.5	Clay Loam

UNIT 10

Ap	0.0 - 12.7	47.8	32.0	20.2	Loam
AB	12.7 - 25.4	47.4	30.8	21.8	Loam
Bw	25.4 - 50.8	47.0	29.2	23.8	Loam
2Ab	50.8 - 68.6	27.4	37.3	35.3	Clay Loam
2Bwb	68.6 - 99.1	26.8	38.3	34.9	Clay Loam
2Bb	99.1 - 147.3	42.6	31.2	26.2	Loam