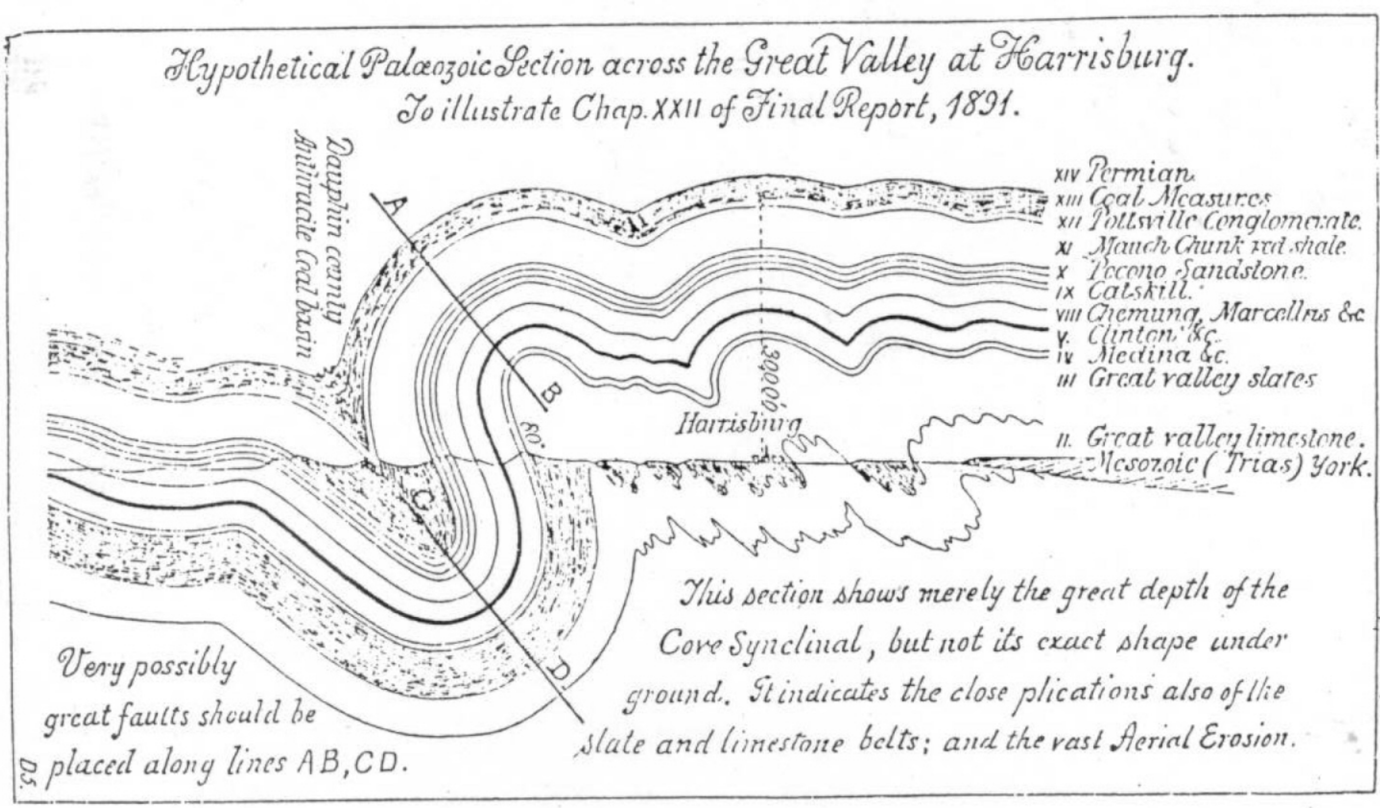
Guidebook for the 4th Annual Field Trip of the

HARRISBURG AREA GEOLOGICAL SOCIETY

April 27, 1985

PENNSYLVANIA'S POLYGENETIC LANDSCAPE



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by

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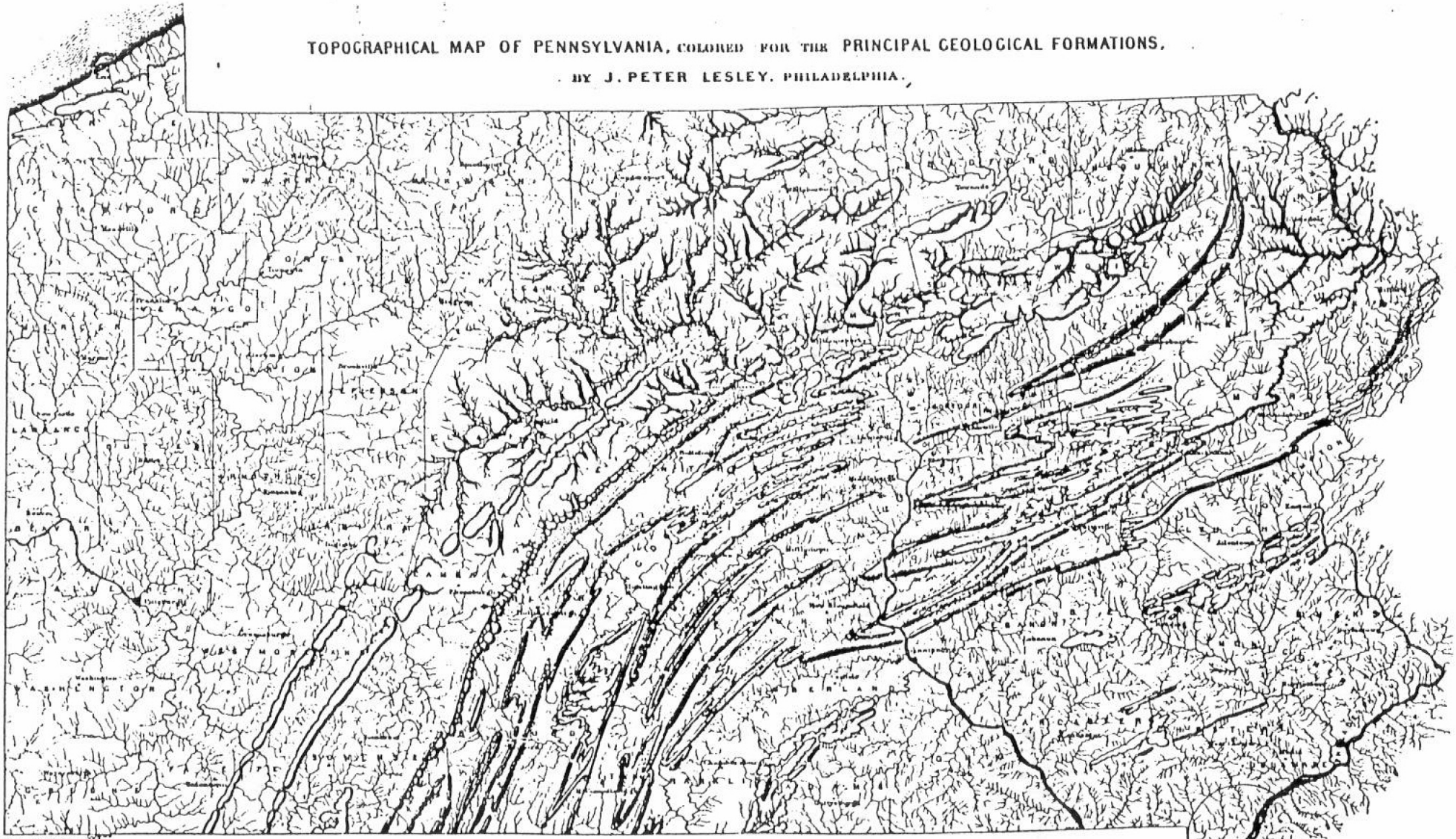
TOPOGRAPHICAL MAP OF PENNSYLVANIA, COLORED FOR THE PRINCIPAL GEOLOGICAL FORMATIONS.

BY J. PETER LESLEY. PHILADELPHIA.



Upper Coal Series — Lower Coal Series — Coal Measures — Devonian — Upper Silurian — Lower Silurian — New Red — Cambrian, Huronian, Laurentian, Azoic or Primary.

Note. The Middle Silurian (IV) Upper Devonian (X) and Conglomerate (XII) are uncolored.

Frontispiece (Lesley, 1876)

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ACKNOWLEDGEMENTS

I would like to thank the following people for reading and commenting on a preliminary draft of this guidebook: Theresa and Uldis Kaktins, Robert LaFleur, Noel Potter, Jr., and Glenn Thompson. Their comments caused several improvements in the guidebook. I also want to thank Rodger Faill and David MacLachlan for stimulating discussions during the evolution of the text.

Front cover: Lesley (1892, p. 277)
Back cover: Lesley (1892, p. 281)

PENNSYLVANIA'S POLYGENETIC LANDSCAPE

"Whatever theoretical learnings the investigator may have, he cannot gainsay these field facts and relationships. . .they are the court of last appeal."
J. Harlan Bretz (1962, p. 438)

INTRODUCTION

Landscape is an integral part of our lives. We cannot escape it. It dictates where we should build our structures, the routes we should travel, what should be agricultural, and what should be left untouched. We frequently do not pay adequate attention to the message of landscape because of our technological capability, but that is sometimes to our regret.

Landscape has aesthetic qualities unmatched by the works of man and, perhaps, even the firmament. Landscape imparts inspiration to some and sustenance to others. To many, landscape presents an intellectual challenge. We desire explanations. We want to know the how, why, and when of landscape. Pennsylvania, because of the diversity of its landforms, has been the focus of much discussion about the origin of landscape.

Two aspects of Pennsylvania landscape have been of particular fascination: (1) the origin of the drainage system, with special emphasis on the apparent disregard for structure displayed by the streams, and (2) the age of the landscape we see today.

The following text will review the important concepts of Pennsylvania landscape development, present an evaluation of those concepts, discuss climate as an important factor, and present a hypothesis for Pennsylvania polygenetic landscape development. The field trip will demonstrate several of the indicators of polygenetic landscape development and indicators of landscape longevity.

ASSORTED IDEAS

The first thoughts on the origin of Pennsylvania landscape are now lost in the mists of antiquity, but we can turn back at least as far as the early 18th century for an interesting explanation of the origin of water gaps. According to this hypothesis, the gaps were formed when oceanic waters, which existed in large lakes dammed by the mountain ridges subsequent to uplift of the land, burst forth in a catastrophic fashion and cut the water gaps to their present form. The gravels found downstream from the water gaps are mute evidence of this occurrence. Miller (1939, p. 13-24) gives several references which offered variations of this idea.

During subsequent years the concept of erosion evolved and its function in the development of landscape became a basic geologic assumption. H. D. Rogers (1858) discusses various aspects of landscape form developed by erosion and attributes many water gaps to erosion by streams which attacked rock weakness caused by transverse faults. The reality of such transverse faults has received considerable subsequent discussion.

The most influential geologist to discuss the landscape of Pennsylvania was William Morris Davis. His paper (1889) on "The rivers and valleys of Pennsylvania" presented not only a hypothesis for the landscape development of a specific area, but also a system of progressive landscape evolution for general application.

Davis elaborated on several ideas about landscape development in Pennsylvania that became the focus of discussion by several future workers. First, he considered that following final Alleghenian uplift, the drainage divide would have been at least in the area of the present Piedmont if not farther east. Thus the initial drainage would have been to the north and northwest. He hypothesized a major river, the Anthracite River, which headed in the Anthracite region and drained north out of Pennsylvania (Figure 1). This river received as tributaries all

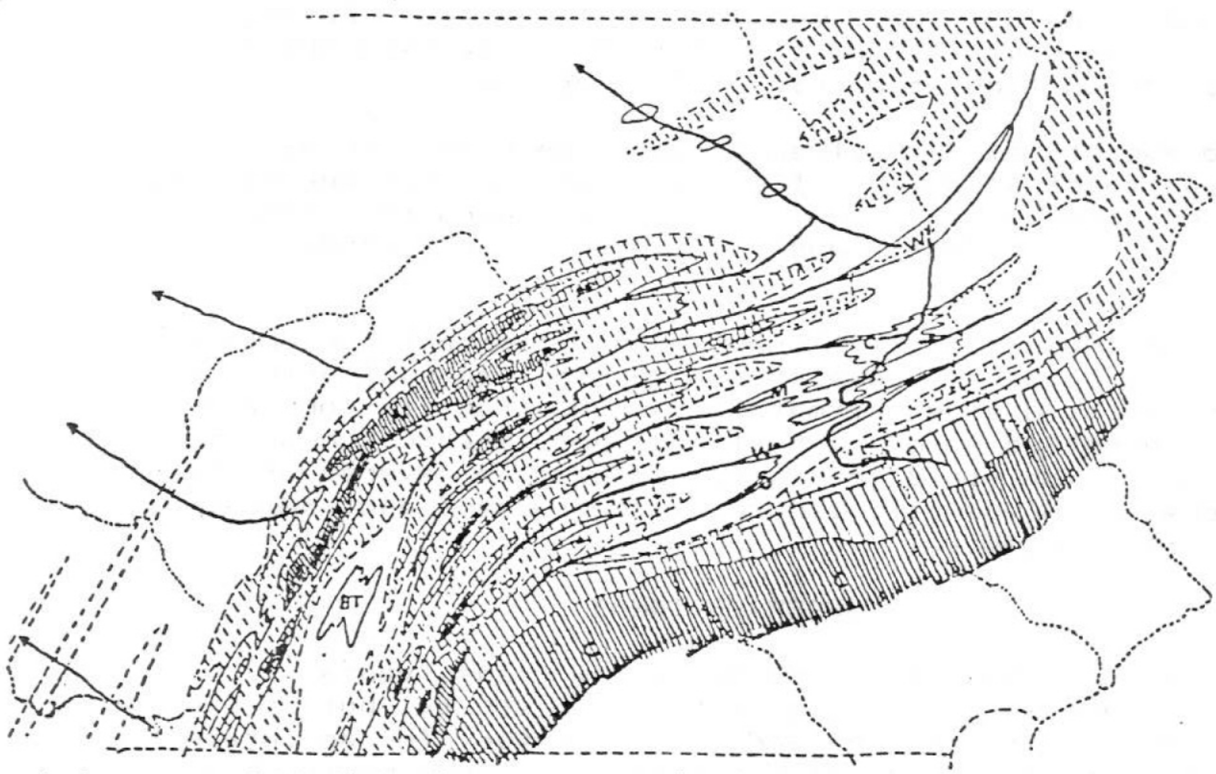


Figure 1. Initial drainage system in Pennsylvania as envisaged by W. M. Davis (1889).

of the consequent drainage arising in the eastern parts of the synclinal troughs of the structurally high central part of the state. In order to develop the drainage of today, he invoked two peneplanations, three uplifts, and an elaborate scheme of stream piracies.

During the years to follow, relatively little criticism developed with regard to Davis's scheme of drainage devopment for Pennsylvania. Instead many workers discussed the various aspects of his geographical cycle and in particular concentrated on the ultimate form of the cycle, the peneplain (Sevon and others, 1983). Although a multitude of peneplain and partial peneplain levels have been hypothesized for Pennsylvania and adjoining regions, only the four levels shown in Figure 2 have received much attention and discussion in the literature.

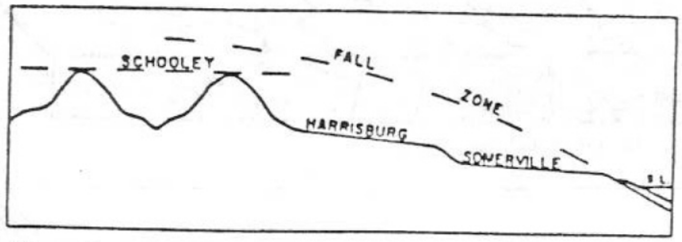


Figure 2. The four main Appalachian peneplain surfaces.

In 1931 Johnson proposed a new hypothesis for drainage development in the Appalachians which generally replaced the scheme of Davis. The success of this hypothesis is indicated by its continued presence in historical geology texts (e.g., Dott and Batten, 1976). Johnson did not worry about the initial position of the drainage divide, arguing that the early development of drainage was totally obliterated by subsequent events and could not now be reconstructed. He called upon erosion following the filling of the Triassic basins to create the Fall Zone peneplain (Figure 3.2). This peneplain was transgressed by Cretaceous seas at least as far as the present Allegheny Front (Figure 3.3) and a covering of sediments totally obliterated previous drainage. Following subsequent uplift, a new east-flowing, consequent drainage system developed. This simple scheme allowed the superimposition of drainage across any structural or lithologic barrier. Johnson hypothesized 3 uplifts and 3 peneplanations during which drainage adjusted to structure. The success of Johnson's model is attributable to its simplicity, apparent lack of provability, and, probably, the beauty of the illustrations which accompanied his paper (Figure 3). This model was strongly supported by Strahler (1944; 1945) who answered the criticisms leveled against Johnson.

The major opposition to Johnson's hypothesis was that of Meyerhoff (Meyerhoff and Olmstead, 1936; Meyerhoff, 1972) and Thompson (1949). A principal part of Meyerhoff's model is that following the Alleghenian orogeny the drainage divide would have been in the general vicinity of its present position and that the initial drainage would have flowed east. Meyerhoff developed the present drainage pattern by a sequence of headward erosion and stream piracy. He believed strongly that the location of water gaps is controlled by weakness in the rocks. He also advocated superimposition on underlying structure of drainage which devoloped as subsequents on the less steep slopes of asymmetric folds or overthrusts. This mechanism was used to account for drainage transverse to numerous apparent structural and lithologic barriers. In addition, he argued that the early development of east flowing drainage is evidenced by clasts present in some of the conglomerates in the Triassic rocks of the Gettysburg-Newark basin. Meyerhoff did not attempt to disprove Johnson's model or the central concept of the peneplain

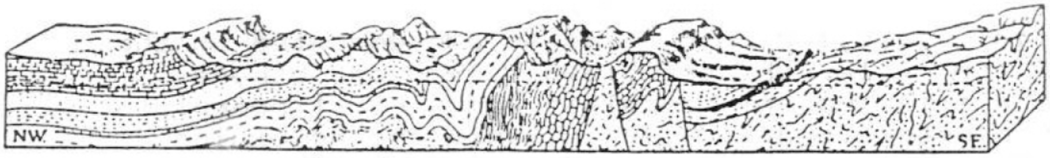


FIG. 1.—Rejuvenated Appalachians in post-Newark time

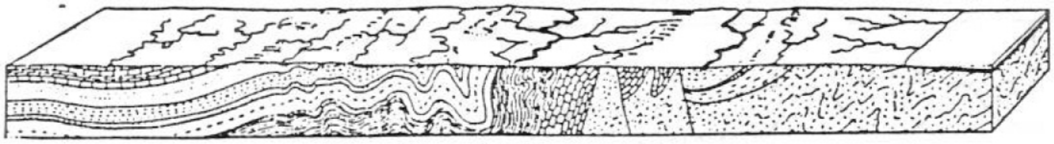


FIG. 2.—The Fall Zone peneplane

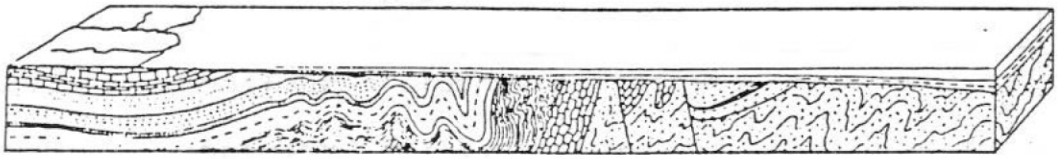


FIG. 3.—Encroachment of Cretaceous sea and deposition of coastal plain beds

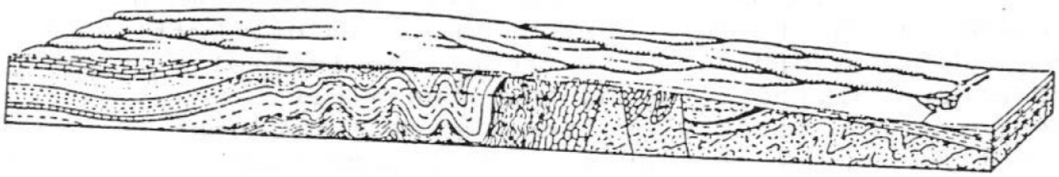


FIG. 4.—Arching of Fall Zone peneplane and its coastal plain cover. Regional superposition of southeastward-flowing streams

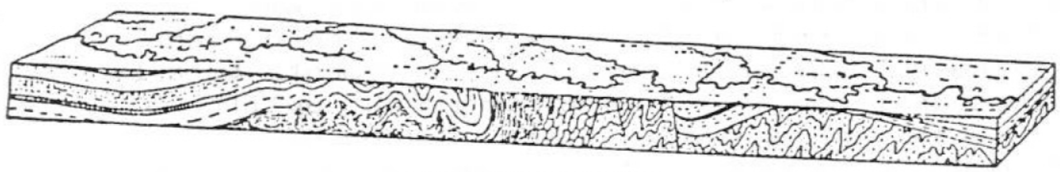


FIG. 5.—The Schooley peneplane

FIG. 6.—Arching of Schooley peneplane

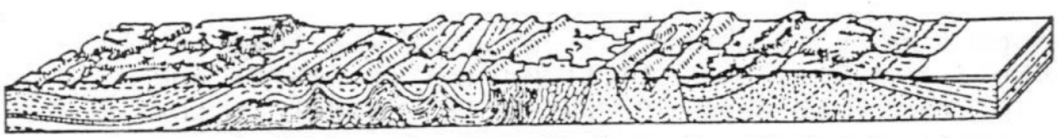


FIG. 7.—Dissection of Schooley peneplane and erosion of Harrisburg peneplane on belts of non-resistant rock

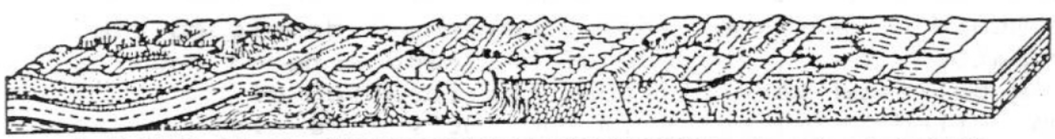


FIG. 8.—Uplift and dissection of Harrisburg peneplane and erosion of Somerville peneplane on the weakest rock belts

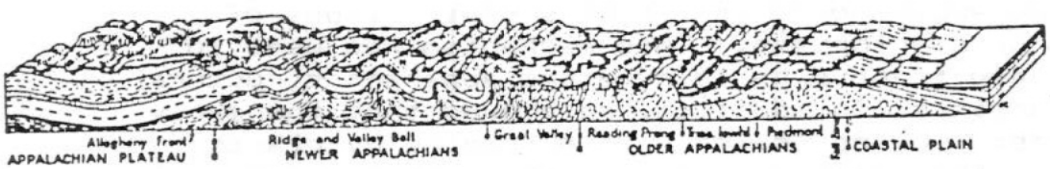


FIG. 9.—Uplift and dissection of Somerville peneplane to give present conditions

Figure 3. Sequential history of development of Appalachian landscape (from Johnson, 1931a, Figures 1-9).

advocated by both Davis and Johnson. Rather, he proposed a model based on what he interpreted to be the evidence displayed in the arena of contention, the field. Except for criticism by Mackin (1938) and Strahler (1945) in the course of their defense of Johnson, Meyerhoff's ideas have recieved little attention, particularly after his 1972 paper. This is probably in part due to a general lack of discussion of landscape development in the Appalachians.

Thompson (1949) offered a different version of drainage development in Pennsylvania which was essentially a northern Appalachian statement of the ideas he developed for the southern Appalachians (Thompson, 1939). Thompson accepted that the initial drainage divide would have been somewhere in the present Piedmont or farther east and developed a model of drainage development based on consecutive headward stream piracies along an asymmetric drainage divide which has progressively migrated westward. He indicated that structure--weak rocks and weak zones in resistant rocks--are the strong influences in drainage development, particularly when combined with the advantage of a high gradient typical of east-coast streams (in comparison with those flowing to the Mississippi). Thompson does not believe that peneplanation is a necessary aspect of Appalachian landscape development, and, except for initial position of the drainage divide, is not substantially different in his approach from Meyerhoff.

The final protagonist is Hack (1960) who has argued vigorously against the geographical cycle of Davis. Hack strongly disputes the possibilty of peneplanation and believes that an equilibrium state is reached wherein, under comparable conditions, all parts of the landscape are lowered at the same rates. Unequal topography results from erosion prior to the establishment of equilibrium conditions. Although the title of his paper suggests that climate may be an important factor, climate is given only a cursory mention in reference to the difference between slope development in arid and humid climates. In more recent papers (Hack, 1979; 1982) he suggests that recent tectonism has upset the equilibrium condition and that landscape in some areas is in the process of readjusting.

The previous review is short but covers the main concepts involved in the discussion of drainage and landscape development in Pennsylvania. Several items important to these concepts which require further discussion are:

1. The position of the drainage divide after the Alleghenian orogeny.
2. The direction of initial drainage after the Alleghenian orogeny.
3. The time of origin of southeastern drainage flow.
4. The reality of peneplanation in Pennsylvania.
5. The reality of Cretaceous transgression onto a peneplained surface.
6. The reality of repeated uplift.
7. The relation of transverse drainage to lithologic or structural weakness.
8. The rate of denudation in the Appalachians and the

age of the landscape.

I will attempt to analyze each of these items in terms of what we know about Pennsylvania geology today.

DISCUSSION OF SPECIFIC TOPICS

1 and 2. Initial position of the drainage divide and the direction of drainage.

At the present time it is possible to construct much more realistic cross sections for Pennsylvania than it was 20 years ago (even though the cross sections on the front and back covers show the basic structure). Figure 4 presents 3 cross sections with hypothetical surfaces which may have existed in Pennsylvania following the Alleghenian orogeny. Cross section A-A' is more hypothetical than the other cross sections and assumes that Levine (1985) and MacLachlan (1985) are correct that the Anthracite region was once covered by a thrust sheet. These cross sections indicate that the hypothetical surface topography following deformation would have been quite irregular and that topographic highs existed both in the Piedmont and the vicinity of the Allegheny Front.

There is some indirect evidence which suggests that the Piedmont highland area may not have extended very far east of present Blue Mountain. I have suggested (Sevon, 1981b; 1985) that polymictic diamictites present at the base of the Spechty Kopf and Rockwell Formations (Mississippian-Devonian) in Pennsylvania and Maryland represent the last materials derived from the Acadian mountains and that the remainder of the clastics contributed to the Appalachian basin during the Paleozoic were derived by cannibalizing the proximal parts of the alluvial plain which became source areas as the result of earliest Alleghenian deformation. Perry (Perry and deWitt, 1977; Perry, 1978) suggested that the diamictites represent the inception of Alleghenian deformation. If these suggestions are true, then it is possible that a considerable part of the original alluvial plain was destroyed by erosion prior to the culmination of deformation which may have been accomplished by the Early Permian (Van der Voo, 1979) and that there was not much highland in the Piedmont area. We also know that whatever highland area existed had to be eroded prior to deposition of Late Triassic sediments and this also suggests that the highland may have been volumetrically small.

Another factor about which we can only speculate is the reaction of the surface materials to Alleghenian deformation. Poorly consolidated materials at the surface of a mountain system similar to the Appalachians, the Zagros Mountains on the borderlands of Iran and Iraq, acted incompetently during deformation and developed a deformational pattern which is disharmonic with that of underlying more competent beds (Oberlander, 1965). In addition, poorly consolidated surface materials were rapidly eroded during deformation and deposited in developing troughs thus further modifying the deformational topography. A similar scenario is probable in the Appalachians,

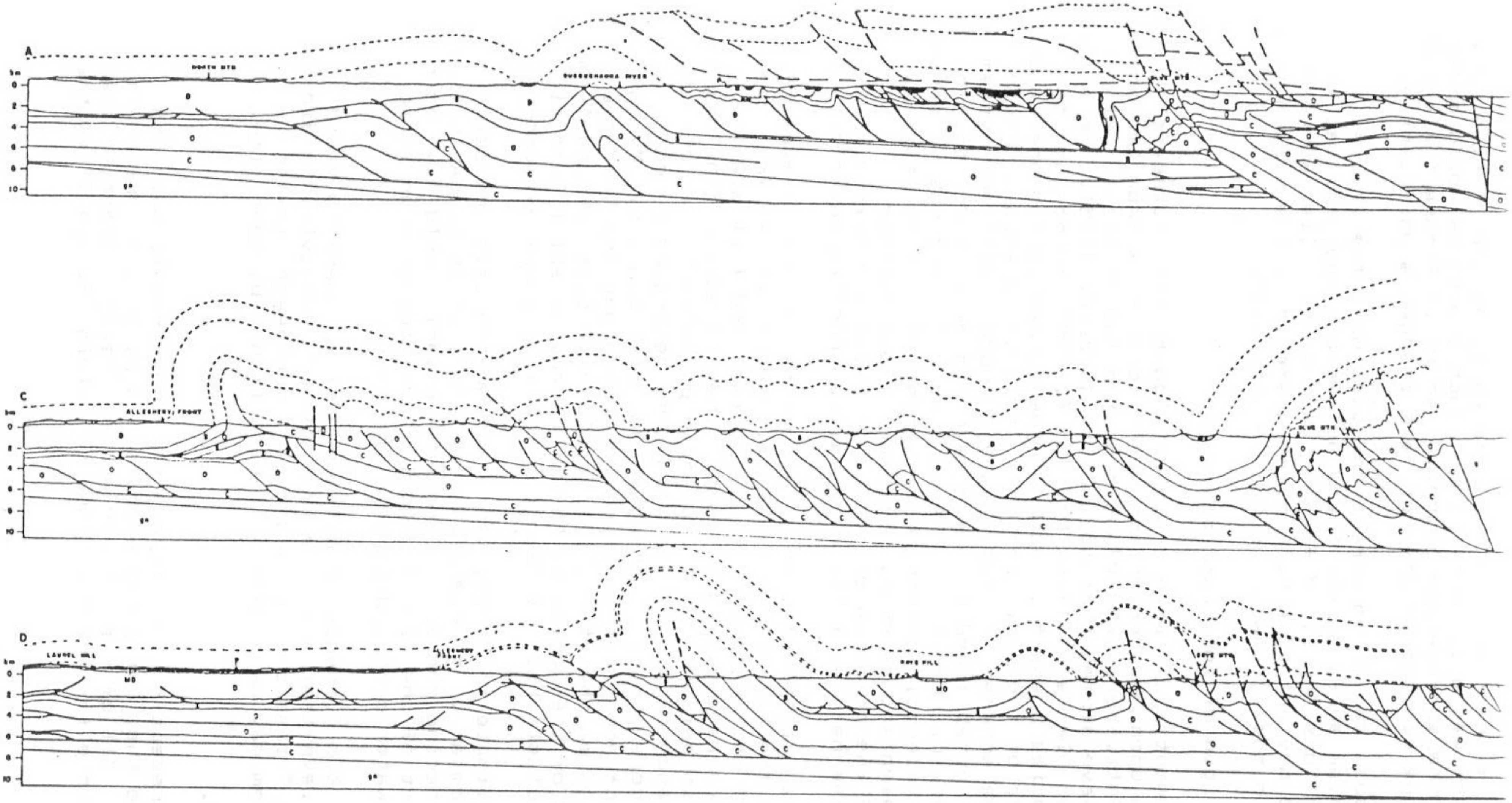


Figure 4. Cross sections with reconstructions of presumed surface configuration following the Alleghenian orogeny. Cross sections are from Berg and others (1980) and the cross sections letters are the same. Vertical and horizontal scale are the same.

particularly if deformation started as early as the Mississippian when deposition was still occurring. Such processes would change considerably the surface configuration shown in Figure 4 although the major slope components may not have changed significantly.

We probably can do no more than guess what the initial post-Alleghenian surface resembled, but we can suggest that it may have been considerably different than many earlier workers envisaged and may not have had an integrated drainage system that flowed only to the northwest or to the southeast.

3. Time of origin of southeast drainage.

The argument about when drainage flow to the southeast began centers upon whether or not significant flow from the north entered the Gettysburg-Newark basin during the Triassic. Almost all workers have denied that possibilty (Judson, 1975). Meyerhoff (Meyerhoff and Olmstead, 1936; Meyerhoff, 1972) maintained that clast lithologies present in some of the border conglomerates on the north side of the basin are definitely of Paleozoic origin and could have entered the basin only through a drainage system that was well established in the area north of Blue Mountain by the Late Triassic. Carlston (1946) concurred about the presence of clasts of Paleozoic origin, but attributed them to derivation from nearby highland sources. Glaeser (1966) further substantiated the presence of clasts of Paleozoic origin, but did not discuss the nature of the streams transporting the clasts.

MacLachlan (personal communication) believes that many of the clasts in the Hammer Creek Formation were derived from Upper Paleozoic rock units north of Blue Mountain and that a well established drainage system did enter the Triassic basin from the north. He also believes that the basin probably had an outlet, but that evidence of that outlet has been destroyed by erosion of the younger rocks on the southern margin of the basin. My own observations of north-margin conglomerates along the Delaware River convinced me that the clasts could have been derived from conglomerates of the Duncannon Member of the Catskill Formation and that the clasts had not been derived from a nearby outcrop.

If the climate in Pennsylvania during the Late Triassic was arid to semiarid as generally conceived, it is probable that any stream entering the Gettysburg-Newark basin would have been dry during part of the year and would have made only periodic sediment and water contributions to the basin.

Although the evidence is not conclusive, there is valid reason to believe that drainage from central Pennsylvania did flow into the Triassic basin and that a southeast flowing drainage system may have been well established by that time.

4. Peneplains.

At the present time it is almost impossible to say with any confidence that there has ever been a peneplain surface in Pennsylvania. All of the earlier workers readily admitted that the only evidence for the Fall Zone peneplain (Figure 2) is the unconformity beneath the Cretaceous sediments. This surface projects up to 2300 m above the present crest of the Blue Ridge in northernmost North Carolina (Rodgers, 1967) and similarly elsewhere in the Appalachians thus eliminating any possiblity of remnant evidence of its former presence.

The Schooley peneplain (Figure 2) has long been interpreted to correspond to the crests of the mountains composed of resistant Silurian, Mississippian, and Pennsylvanian sandstones and conglomerates. These crests are just below the elevation of the projection of an unconformity beneath Eocene sediments (Rodgers, 1967). However, workers such as Hack (1960; 1975) have argued against the use of accordant summits as evidence of former peneplain levels, particularly because of their general lack of real accordance. Lacking any other evidence for its existence, we are forced to question the reality of a Schooley peneplain.

One of the reasons for desiring peneplain surfaces was the presumed ability of drainage systems to wander at will across the peneplain surface or for a new drainage pattern to develop on a tilted peneplain surface. When erosion was rejuvenated by uplift, the drainage system of the peneplain would be superimposed upon underlying structure and apparently anomalous tranverse drainage paths could be explained easily. Such manipulations may not be necessary. Oberlander (1965) indicated that streams establish drainage down the regional slope regardless of structural trends and Ambrose (1964) indicated that once a drainage pattern is adjusted to structure it will persist indefinitely and, if buried and exhumed, it will be reactivated virtually intact.

The Harrisburg peneplain (Figure 2) presents a more serious problem. First of all it is not a true peneplain in the sense of Davis, it is a partial peneplain. Campbell defined the Harrisburg peneplain in 1903. He redefined it as the Chambersburg peneplain in 1933, but the name Chambersburg has seldom been used. The Harrisburg peneplain, called the Valley Floor or Highland Rim peneplain in some southern states, has received widespread recognition as a real topographic form throughout the Appalachians. I have cited the presence of saprolite on the Martinsburg Formation (1975) and the presence in exotic topographic positions of boulders transported from adjacent uplands (1981a) as evidence of the reality of this surface. Although denied by Hack (1975), the most telling evidence for the existence of the Harrisburg surface is the widespread occurrence of secondary mineral deposits considered to have close association with the development of the surface (Hewett, 1916; Miller, 1939 & 1941; Bridge, 1950; King and Ferguson, 1960). Pierce (1966) discussed all of these attributes and recognised the Harrisburg as a a real erosion surface although he doubted that it represents a partial peneplain.

The final presumed peneplain, the Somerville (Figure 2), is also only a partial peneplain and its reality is questionable. The Somerville surface, as defined by Davis and Wood (1890), referred to the broad, relatively flat, surface of central New

Jersey. This surface presumably correlates with the present floor of some of the limestone valleys in Pennsylvania, but the reality of such correlation has not been established. Pierce (1966) pointed out that the presumed Somerville apparently represents solution lowering of limestone to near the level of present axial drainage, but that in places the surface cannot be distinguished from the Harrisburg and probably does not represent any real surface. Whatever the reality of a Somerville erosion surface, it is not widespread nor is it a peneplain.

5. Cretaceous transgression.

The validity of Johnson's (1931) hypothesis rested entirely upon the existence of a Cretaceous transgression into at least the central part of Pennsylvania and presumably at least partially as far in adjacent states. Interpretations of depositional environments for the Cretaceous rocks which occur along the east coast of the United States (Olsson, 1963; Glaser, 1969; Jordan, 1983) indicate that Cretaceous deposition was in either nonmarine or near shore environments and that the Cretaceous shoreline never extended much farther inland than the present coastline. Dryden and Dryden (1940) showed through heavy mineral studies that the Piedmont was a source area for sediments during the Cretaceous and therefore was not inundated. In addition, Pierce (1965) discussed a Late Cretaceous lignite of nonmarine origin which occurs in the Great Valley of Pennsylvania, further establishing the lack of a Cretaceous transgression. Pitman (1978) indicated that the shoreline position on the passive Atlantic margin is a complex interplay of subsidence, sea-level rise and fall, and sedimentation, all of which prevented the shoreline from ever moving much westward of the Fall Zone after the Jurassic. Johnson's hypothesis must be considered invalid.

6. Uplift.

Most workers who utilized peneplanation in their models invoked periods of erosion followed by periods of uplift to accomplish the development of Pennsylvania landscape. Hack (1960; 1975; 1979; 1982), Meyerhoff (1972), and Thompson (1949) advocated continuous uplift. Rodgers (1967; 1970) suggested that there has been slow, semi-continuous deformation in the form of a broad, simple arch since the Triassic and that the rate has decreased almost regularly to the present. Owens (1970) is the most specific and cited as evidence of repeated tectonic activity 7 regressive and transgressive cycles represented in coastal plain sediments of Late Cretaceous through Eocene age. In contrast, Olsson (1963) suggested that deposition in the same area during the same period of time occurred gradually on a stable continental shelf during a period of tectonic stability. Current understanding of basement configuration in Pennsylvania, based on interpretation of the geology and supported by geophysical data, is that of a southeastward sloping surface and Root (1973) suggested that the basement configuration has been the same since before the Alleghenian orogeny. Faill (1985), on the other hand, suggested that dip of the basement surface changes in eastern Pennsylvania to a westward dip, creating an open-ended trough which deepens to the southwest under the Anthracite region. He hypothesized that this trough resulted in a depression which protected the Anthracite region from erosion.

Walcott (1972), using geodetic releveling data, indicated (Figure 21, p. 875) a ridge of uplift extending northward along the axis of the Appalachians with an uplift of 2 mm/year. Brown and Oliver (1976), also using releveling data, indicated uplift, relative to the coast, of up to 6 mm/year with local peaks at Harrisburg, Tyrone, and possibly Pittsburgh. They suggested that the uplift is eposodic, independent of near-surface structure, and related to processes responsible for establishing the Atlantic drainage divide. Both this work of Brown and Oliver and later work by Brown (1978) discussed in considerable detail the problems of leveling, but offered no satisfactory answer about the reality of the reported uplift. As new and more reliable methods of leveling are developed we will be able to better evaluate the status of current uplift in the Appalachians.

The above information does not give a clear indication about the matter of uplift in Pennslylvania. The lack of great differences in the present elevations of preserved Pennsylvanian age rocks in the Anthracite area, the Broadtop Basin, and the Allegheny Plateau tends to suggest that any uplift subsequent to Alleghenian deformation must have affected the area as a whole. Hallam (1984) indicates that sea level during the Pennsylvanian would have been about 300 m higher than present. Therefore, nearly half of the elevation above present sea level of undeformed Pennsylvanian-age rocks in western Pennsylvania can be accounted for by sea level drop since the Pennsylvanian. It seems possible that there has been relatively little crustal uplift in Pennsylvania and that the only high elevations in the past were those created by folding and faulting during the Alleghenian.

7. Transverse drainage.

Despite numerous repetitions of the idea that drainage transverse to resistant rocks and structure achieves its position because of weakness in the rock (Rogers, 1858; Ashley, 1935; Meyerhoff and Olmstead, 1936; Meyerhoff, 1972; Thompson, 1939; 1949), the idea has received severe criticism from some people (Mackin, 1933; 1938; Strahler, 1945). Recent geologic work in Pennsylvania indicates that the position of many major water gaps is related to a structural weakness of some kind (Epstein, 1966; Theisen, 1983) and Pierce (1966) has pointed out that even small sags in the ridges are related to structural weaknesses. There is also a striking similarity between the location of water gaps in Blue and Kittatinny Mountains and the position of the centers of sediment-dispersal systems which changed little throughout the middle and late Paleozoic (Sevon, 1979).

8. Rate of denudation and landscape age.

The diversity of opinion about the age of Pennyslvania landscape is exemplified by the following statements:

"Concept 7. Little of the earth's topography is older

than Tertiary and most of it no older than Pleistocene."
(Thornbury, 1969, p. 25)

". . . one can conclude that the great bulk of erosion of the Appalachians took place in the Cretaceous or earlier, and that the present mountains have had a relief not much less than the present since well back in the Tertiary, perhaps since the Eocene."
(Rodgers, 1967, p. 422)

Although it is not necessary that these statements be mutually exclusive, I believe that their implied meaning is conveyed by the statements. This diversity of opinion is also indicated by the many interpretations of the age of the presumed Schooley peneplain: estimates which range from Jurassic to post-Late Tertiary (Sevon and others, 1983, Table 1, p. 158). Most of the various estimates of the age of Appalachian landscape are opinions based on little or no factual evidence. Ashley (1935) using 20.000 feet of uplift and the time since uplift deduced that the present surface, which represents but one peneplanation, has been lowered not less than 100 feet for the hardest rocks and several hundred feet for the softer rocks during each million years since the beginning of uplift. Ahnert (1970) said that the mean denudation rate is directly proportional to the mean basin relief and without uplift an area will be reduced to 10 percent of its initial value in 11 million years (18.5 m.y. if isostatic adjustment occurs). Mathews (1975) used a calculated volume of Cenozoic Atlantic Ocean deposits to deduce an average of 2 km of denudation in the Appalachians during the Cenozoic. He assumed peneplain development and chose special explanations to resolve a variety of problems concerning Cretaceous and Tertiary sediments.

A number of workers have utilized stream sediment data or the volume of oceanic sediment or a combination of the two in order to derive a rate of denudation for the Appalachians. Menard (1961) calculated a past rate of erosion from the volume of oceanic sediment and attained a rate of 62 m/m.y. His value for modern rates of erosion (using suspended load only) is 8 m/m.y. Schumm (1963) calculated an average erosion rate of 30-91 m/m.y., but found a conflict with estimated rates of orogeny of 7620 m/m.y. He suggested that planation of 1500 m of relief would be possible in any time between 15 and 110 m.y. Judson and Ritter (1964) calculated an average erosion rate of 48 m/m.y. for the North Atlantic drainage, but the diversity of their data (their Table 1, p. 3397) is very revealing: Delaware River, 18.3 m/m.y.; Schuylkill River, 68.2 m/m.y.; and Juniata River, 12.2 m/m.y. These data reflect faithfully the modern land usage in the different drainage basins and raises serious questions about how much meaning can be attached to the use of modern stream sediment data for interpreting past erosion rates. Gilluly (1964) deduced from stream data an erosion rate of 21.8 m/m.y. and from offshore sediment volume a rate of 3.5 m/m.y. (from Triassic to present). Godfrey (1975) calculated an erosion rate of 2.5 m/m.y. for a small watershed underlain by quartzite in Maryland, but stipulated that the figure applied only if the climate was a constant. I calculated an erosion rate of 23-38 m/m.y. for the Martinsburg Formation in the Opossum Creek drainage basin (Sevon, 1981a) (See Stop 6).

Rates of denudation on limestone terrain are a somewhat different problem because much if not most of the lowering of the landscape is by groundwater removal of the solubles leaving a residual soil of insolubles. Jennings (1983) and White (1984) present good reviews of this topic. Use of data presented by Jennings (1983, Fig. 7, p. 585) and an assumed Cumberland Valley runoff of 500 mm/year results in an estimated limestone removal rate of 40 m/m.y. under current climatic conditions. A similar calculation using data from White (1984, Fig. 10.5, p. 235) yields a denudation rate of about 25 m/m.y. A denudation rate for the Cumberland Valley should be calculated from water data available for the area.

Bloom (1978) has an excellent review of the rate of landscape evolution and points out that denudation rates in the Appalachians of 40 m/m.y. are grossly comparable to rates calculated by other means such as reconstructed fold geometry. He also points out that any of these rates is a generality which does not take into account variations in rates of erosion over long intervals of geologic time. The problem with all of this work is that it indicates that the landscape should have been reduced to a low level a long time ago, but it is not.

In contrast to the various rates of erosion calculated from stream sediment, I calculated an atmospheric weathering rate of 0.26 m/m.y. for a resistant sandstone in Pennsylvania (Sevon, 1984). Upton (1982) determined a weathering rate of about 0.42 m/m.y. for a granite in Maine. These values indicate that some of the harder rocks disintegrate at a very slow rate which will result in very slow lowering of the landscape. Brunsden (1979) presents a variety of other data related to weathering which does not help to clarify the situation.

All of the above discussion does not give a real sense of the rate of landscape evolution nor the age of the present landscape. However, there is one part of Appalachian landscape which seems to be real, widely recognized, and at least generally dated: the Harrisburg erosion surface. This surface, in many places highly dissected, is easily recognizable along the base of Blue Mountain in Pennsylvania and elsewhere throughout the Appalachians as a pronounced change in topographic gradient. A large quantity of economically important secondary mineral occurrences (iron, manganese, and bauxite) are associated with this surface from Vermont to Arkansas (Bridge, 1950; Cloud and Brown, 1944; Hewett, 1916; King and Ferguson, 1960; Miller, 1939 & 1941; Overstreet, 1964). These deposits appear to have formed during the late stages of development of the Harrisburg surface although the deposits may have formed over a long interval of time and all may not have formed at the same time. The surface has been dated by flora associated with the mineral deposits in several localities (Bridge, 1950; Overstreet, 1964) and by flora found in lignites associated with the surface as far north as Brandon, Vermont (Clark, 1891; Berry, 1919; Barghoorn and Spackman, 1949). The data indicate that development of the surface occurred throughout the Late Cretaceous and early Tertiary and apparently culminated in the Early Eocene. Cleaves and Costa (1979) suggested that Maryland's Piedmont landscape underwent intense weathering into the Miocene before the current cycle of erosion was initiated. Thus the landscape which we see in Pennsylvania today represents only moderate dissection of a basic landscape of ridges, such as Blue Mountain, and gently sloping valley lowlands which were formed by Middle Eocene.

The previous discussion should give some indication as to the state of knowledge about landscape development in Pennsylvania. However, there is another factor which I believe has been grossly neglected in the thinking about Pennsylvania landscape--climate.

CLIMATE--THE IGNORED FACTOR

Although many workers have mentioned climate in passing, very few have given it any real attention as a factor in the evolution of Pennsylvania landscape. Peltier (1950; 1975) generalized about the variations in process associated with different climates, but believed (1975, p. 143) that the landscape we see today either was formed within the last 50,000 years or was strongly modified during that time. Budel (1982) demonstrated the very strong influence that climate has on landscape development and believed strongly that widespread and long-lasting climatic intervals as ancient as those of the Late Cretaceous are still reflected in the landscape of many parts of the world. Brunsden (1979) presented a review of the variable nature of weathering and its relation to climate.

Of particular importance is the relationship between climate and sediment production and removal. Garner (1959; 1974) pointed out that climate is the controlling factor in the variation of clastic-fragment size and in on-land sediment accumulation. In wet climates fine-grained sediments are produced and the overall landscape is altered slowly by erosion because of the protective nature of vegetation. In dry climates there will be much erosion of the landscape and production of much coarse detritus, but the materials will be stored nearby because of the lack of water necessary to transport the sediment out of the drainage basin. During periods of transition from dry to wet climates, material will be moved out of storage until immobilization of sediment by vegetation. Similar climatic effects were noted by Quinn (1957).

Budel (1982) discussed at considerable length the consequences of weathering and erosion under different climatic regimes. He emphasized that extreme modification of landscape occurs during extreme climatic conditions. Thus the periglacial environment associated with the Pleistocene represents an extreme as does the warm humid climate of the tropics. Budel viewed much of the world's landscape in terms of inherited climate-controlled landscape development upon which there is a more recent overprint of climatic modification. Garner (1974) refers to these as polygenetic landscapes.

The following discussion will review the considerable climatic variation in the Appalachians during the geologic past and the probable relationship of the these climates to landscape development in Pennsylvania. This discussion will follow a progression from older to younger.

LATE PALEOZOIC. During the Late Carboniferous the climate in Pennsylvania was presumably temperate and supportive of the swamps in which the modern coal resources of the State developed. During the Permian the climate gradually changed from temperate to arid (Schwarzbach, 1961). Thus, if Alleghenian deformation was underway during the Permian as previously suggested, the developing folds would have been subject to rapid erosion and local storage of materials.

MESOZOIC. The Triassic is generally interpreted to have been at least semi-arid in Pennsylvania, thus a continuation of conditions initiated during the Permian. Hay and others (1982) suggested that local topography may have been a primary influence on Triassic basin climatic conditions, that the average elevation of the crest of the Appalachians was 2 km above base level, and that sea level may have been 60 m lower than present. The sea level low is in agreement with Hallam (1984), the remainder is at least a good guess about probable conditions at that time. Probably all of Pennsylvania and much of the Appalachians was at least semi-arid because of the general proximity to the equator and considerable distance from any ocean (possibly as far as thousands of kilometers). Such conditions, as previously suggested, would have been favorable for periodic input into the Gettysburg-Newark basin rather than continuous flow-through of perennial streams (assuming that southeastern drainage was initiated by that time).

Initial Jurassic climatic conditions were a continuation of Triassic conditions, but there is no record of the conditions during the remainder of the Jurassic in Pennsylvania. World trends during the Jurassic (Schwarzbach, 1961) indicate continued warm temperatures and increasing moisture. In addition, the Atlantic Ocean was in existence during much of the Jurassic and it would have contributed to greater humidity along the North American east coast. The COST No. B-3 offshore well (Scholle, 1980) and geophysical data indicate a total of 9 km of Jurassic sediments which suggests that a large amount of clastic material was eroded from the Appalachians during this time. This would be appropriate for a period of climatic transition from arid to wet during which previously eroded material, temporarily stored on land, would be transported to the ocean. Late Jurassic (?) marginal marine coals also occur in the COST No. B-3 well and they presumably indicate the presence of abundant vegetation in at least the coastal areas.

Early Cretaceous climate is not indicated by sediments on the east coast, but the COST No. B-2 (Scholle, 1977) and COST No. B-3 (Scholle, 1980) wells indicate that there was a gradual but definite decrease in clastic input throughout the Cretaceous. This suggests a continuing change to more humid climate with sufficient vegetation to prevent.erosion of coarse material.

Erosion presumably continued to lower the landscape, but an appreciably slower rate. Such climatic conditions result in increased solution weathering and it is tempting to suggest that the upward increase in amount of carbonate in the Cretaceous sediments penetrated by the COST wells is a reflection of this. However, change in the amount of oceanic carbonate deposition is a function of many variables (Force, 1984) and cannot be attributed to terrestrial weathering alone.

The Late Cretaceous was a period of maximum transgression and climatic moderation throughout the world with vegetation flourishing into both polar regions. Pennsylvania must have been almost subtropical along with much of the rest of the world. Under such conditions overall relief is changed very slowly while intense weathering progresses to great depths. Such conditions give rise to the double planation surfaces of Budel (1982, p. 38). Conditions in the Great Valley of Pennsylvania were suitable for coal swamps (Pierce, 1965) and Cleaves and Costa (1979) suggested that the Piedmont uplands in Maryland were undergoing intense weathering during the Late Cretaceous.

TERTIARY. Tertiary climate is very well documented in the western part of the United States, but only moderately well documented for the Atlantic coastal area and even less well documented for the Appalachians. In general the early part of the Tertiary was a continuatiion and intensification of the climatic conditions of the Late Cretaceous. Some variation occurred, but warm and humid conditions continued to the middle or the end of the Eocene. In the Great Plains the climate was humid and warm temperate to subtropical as far north as North Dakota into the Early Oligocene (Hickey, 1977; Retallack, 1983). A thick and widespread paleosol developed throughout much of the Great Plains during this time (Pettyjohn, 1966). During the Oligocene the climate of the Great Plains began to change towards that of the present.

In the east the climate is known mainly from the Eocene flora of the southeastern states along with some correlations with isolated Eocene floras farther north and the presumed requirements for the formation of the secondary mineral deposits associated with the Harrisburg surface. There were fluctuations of cooling and warming during the Paleocene and Eocene, but overall the trend was one of warming to the Middle Eocene and then gradual cooling to the end of the Eocene (Wolfe, 1978). Bauxitization in the southeastern states and Arkansas occurred in Late Paleocene through Early Eocene (Gordon and others, 1958; Overstreet, 1964) in a humid tropical climate. Overstreet (1964) describes the climate as follows: rainfall considerably exceeded evaporation most of the time and temperature exceeded 25 C most of the time. This climate moderated farther north, but warm humid conditions were present as far north as Vermont where deep weathering produced clay deposits and iron and manganese ores in association with the Brandon lignite (Burt, 1928) on the regional equivalent of the Harrisburg surface. A cooling trend occurred from the Middle Eocene into the Oligocene.

A major lowering of sea level in the Early Oligocene correlates with development of glacial ice in the Antarctic as well as general worldwide decline in temperature (Olsson and others, 1980). There were fluctuations in temperature and moisture during the Oligocene, Miocene, and Pliocene, but in general the overall trend was that of climatic cooling which culminated in the Quaternary with continental glaciation (Blackwelder, 1981; Donnelly, 1982). The general change in middle to late Tertiary climate was worldwide and is reflected by increased amounts of sediment in the world's ocean basins (Davies and others, 1977; Scholle, 1977 and 1980; Donnelly, 1982). The change in rate of sediment deposition results from increased erosion caused by irregularity of precipitation and alternating wet and dry periods of considerable length. Rea and others (1985) reported that a change from continental humidity to aridity is also reflected in the ocean record of land-derived dust.

Not everything is perfect with regard to interpretation of Atlantic coast Tertiary climates. Alt (1974) suggested an arid climate for the southeastern United States during the Miocene while Isophording (1970) suggested that subtropical conditions existed as far north as northern New Jersey during the Miocene and Pliocene. The Miocene corresponds to the Tertiary period of maximum sedimentation rate and thickest accumulation of sediments in the COST No. 2 well (Scholle, 1977) which favors Alt more than Isophording, but both papers leave some unanswered questions. Owens (1970) suggested that 7 transgressive-regressive cycles occurring in Atlantic Coastal Plain sediments of Late Cretaceous through Eocene age are the result of repeated uplift followed by renewed erosion in the Appalachians. I think that the cycles were probably controlled by climatic variations rather than a product of epeirogenesis. Finally, Houser (1982) suggested that some alluvial deposits in southwestern Virginia represent deposition during long continued erosion throughout the Cenozoic and have no relationship to any changes in climate or rates of downcutting.

QUATERNARY. The Quaternary represents the period of most severe climatic conditions in Pennsylvania. During the last 350,000 years continental glaciers have advanced into the state from the north at least 3 times and it is probable that there was at least one earlier glaciation. Climate beyond the limits of glaciation was severe and Watts (1979; 1983) indicated that tundra vegetation existed up to 100 km beyond the ice border at even the lower elevations about 18,000 years ago. Various types of periglacial deposits such as frost wedges (Cronce and others, 1985), patterned ground, block fields (Smith, 1953; Potter & Moss, 1968; Sevon and others, 1975), and solifluction deposits (Hoover, 1983) indicate severe temperature conditions, particularly at higher elevations. Although there is at present no positive evidence that permafrost existed in Pennsylvania during the glacial maxima, there is no reason to believe that conditions were not conducive for permafrost in at least the higher elevations of the state near the ice border.

Budel (1982) believed that this period of climatic extreme is one of excessive erosion which greatly modified the topography inherited from a much earlier development under different climatic conditions. He argued that severe disintegration of rock occurs because of the ice rind effect, the disruption of rock by trezzing and thawing at the base of the active zone and the top of the permafrost zone. He also argued that mobility of materials on slopes is extreme because of surface thawing during the summer months and the large amount of water in the thawed layer.

Formerly mobilized slope materials are evident throughout Pennsylvania beyond the glacial border. Particularly prominent are the many steep slopes covered with a thick accumulation of blocks derived from outcrops of resistant rocks at the ridge top. The narrow valley of the Juniata River south of Lewistown is probably the best example of this. There is no evidence that these accumulations are being added to at the present time and, except where disturbed by man, the slopes exhibit little or no evidence of current movement. The materials were derived from outcrops at the top of the ridges as a result of extreme breakage along fracture and bedding planes. The amount of material indicates that there may have been a significant lowering of the ridge. Cooper (1944) estimated the volume of material in an alluvial fan below a ridge in Virginia and concluded that the ridge was lowered 23 m to produce the fan. No such estimates have been made for Pennsylvania, but it is probably safe to assume that some ridges were lowered even more than 23 m during the Pleistocene. Godfrey (1975) indicated that the ridges in Maryland were being lowered more rapidly during the Pleistocene than today, but did not suggest any rate.

Shale-chip rubble deposits derived from shales of the Reedsville, Martinsburg, and Mahantango Formations also attest to the vigor of the Pleistocene climate. Some of these deposits have cryoturbation structures in their upper parts and rarely they show evidence of cyclicity, presumably associated with different ice advances.

Although most slopes in nonglaciated Pennsylvania have some covering of unconsolidated material presumably developed by weathering and down slope movement during the Pleistocene, most perennial rivers and streams large enough to have a floodplain are flowing on bedrock or a very thin layer of alluvium. This suggests either that very little material reached the streams during the Pleistocene (and is thus still stored on the slopes) or that the valleys were flushed of material during periods of transition from dry glacial climate to wet interglacial climate. Probably both aspects are important.

Finally, we want to consider how much downcutting was accomplished by major streams such as the Susquehanna River during the Pleistocene. Budel (1982) argued that the polar zone is one of excessive valley cutting because of the ice-rind effect (disruptive action of ice at the base of the annual frost zone) which prepares the bed and margins of the stream valley for erosion. Such erosion is apparently most effective where permafrost exists. There are remnant terrace gravels along the Susquehanna River which become progressively older with increasing elevation above the river. However, at present we do not know whether the different terrace gravels represent deposition on a bedrock surface which was subsequently cut to a lower level prior to deposition of a younger gravel or whether the river valley was cut to approximately its present level prior to the Pleistocene and the various terrace deposits represent valley fill followed by erosion. I favor the latter hypothesis.

The preceding discussion indicates that the landscape of Pennylvania has developed under the influence of a variety of different climates. Each climatic regime impacted the landscape in a different way, but interpretation of the effects of different climates becomes increasingly difficult with the length of time separating us from that climate. However, I think that a reasonable model of landscape development for Pennsylvania (and in a sense for the Appalachians as a whole) can be formulated.

A POLYGENETIC MODEL FOR PENNSYLVANIA'S LANDSCAPE

The story of Pennsylvania landscape really begins in the Early Silurian when the Appalachian basin began to receive the first of several clastic wedges from a mountain source which lay to the east. Before sedimentation ceased, 3 quartz-rich sediment units were deposited which were to become the prominent ridge formers of today: the Tuscarora-Shawangunk (Silurian), the Pocono-Burgoon (Mississippian), and the Pottsville (Pennsylvanian). Wilson and Fairbridge (1971) suggested that these units were cemented by water circulation under tropical climate during 3 periods of peneplanation. However, the silica overgrowth cement of these units (Sibley and Blatt, 1976) more likely resulted from dewatering fluids flowing upwards from underlying units through the well sorted and basically monomineralic beds for a long period of time (Galloway, 1984; Stonecipher and others, 1984). Additional factors of heat and pressure resulting from deep burial affected the Tuscarora more than the Pocono and Pottsville and may account for the greater resistance to weathering of that unit.

At the end of the Paleozoic the extensive marginal marine coal swamps which typified much of Pennsylvania during the Pennsylvanian were replaced by lacustrine and fluvial environments of the Permian as the climate gradually became more arid. Sometime during the Carboniferous, the Alleghenian orogeny began to affect Pennsylvania. Intense thrusting resulted in the development of a series of folds in central Pennsylvania as well as a large thrust sheet overlying what is now the Anthracite area (Figure 4). Initially there must have been a major drainage divide in the area of the present Piedmont, but we can only speculate as to its size and areal extent. If I am correct (Sevon, 1981b; 1985) that post-Devonian sediments in Pennsylvania were eroded from older, more proximal Appalachian basin sediments rather than an Appalachian mountain range, then there may have been only a small volume of material available for overthrust stacking in the Piedmont area during the Alleghenian. If the Alleghenian was underway during much of the Carboniferous as suggested by Perry (1978) then considerable erosion of this area may have occurred before Alleghenian culmination.

A second major drainage divide was the westernmost large fold at what is now the Allegheny Front (Figure 4). Drainage flowing westward from this high would not have developed any substantial streams under the arid conditions of the time. When more water became available as a result of climatic change, the high area was sufficiently subdued that there was inadequate water source for the development of major westward flowing streams. Thus the drainage system west of the Allegheny Front developed through headward lengthening of streams into Pennsylvania from the west and north. This major divide became gradually lower to the northeast and did not exist north of the present northern Anthracite field (Figure 4, A-A'). The regional north dip in this area would have favored development of a north flowing stream.

In the intervening Valley and Ridge area the theoretical post-folding topography would have consisted of a series of elongate highs and lows with crest elevations decreasing progressively to the southeast. The Anthracite region may have been relatively flat on top of the thrust sheet or it may have been very irregular, but the surface probably had no predominant slope direction. The Broad Top was probably an enclosed basin with no external drainage.

Materials at the surface were probably uncemented or poorly cemented and easily eroded during the process of thrusting and folding. However, because of the lack of rainfall, most of the sediment would have been stored in the fold troughs rather than moved out of the area. The drainage system which developed on the slowly folding surface was initially consequent and followed the topographic lows of the synclinal troughs. As erosion continued much of the topography may have been smoothed by filling of the topographic lows with sediment from adjacent highs. The Broad Top topgraphic low (Figure 4, C-C') would have been filled with sediment and preserved from erosion much longer than could be expected without such cover. As erosion of the weaker surface sediments and rocks proceeded, anticlines were breached and some of the drainage pattern which would persist to the present was established as streams cut into older and better cemented rocks and either adjusted to structure or established paths transverse to structure. Oberlander (1965) recognized a variety of different mechanisms by which drainage paths are established and many if not all probably operated in Pennsylvania.

There must have been a topographic barrier along the margins of the Anthracite thrust sheet. I suggest that the basic course of the Susquehanna River may have been established adjacent to that barrier and that the resulting stream would have flowed north into New York. Such control for the initial position of the Susquehanna River would help to explain the most anomalous part of its course, the part which traverses the Wyoming-Lackawanna Basin. There is nothing to suggest where the northeastern boundary of the Anthracite thrust sheet may have been, but it is possible that it could have controlled the initial position of the Delaware River northwest of Port

Jervis.

The resulting initial drainage system in central Pennsylvania probably drained northeastward to the margin of the Anthracite thrust sheet and then northward to New York in the ancestral Susquehanna River. The basic position and pattern of the Susquehanna River may have been established very early in drainage development and locked into place by structure. Drainage to the southwest of the of central Pennsylvania must have followed fold-created troughs, presumably to an ancestral Potomac River.

The Piedmont highland was attacked by erosion from two sides. Some of the highland was eroded and transported to the north, probably into storage. At the same time the area was eroded from the southeast. Very little can be said about what happened except that the highland was greatly reduced in stature prior to the deposition of the first Triassic sediments. In all probability the the surface of Pennsylvania was exposed to weathering and erosion for at least 30 million years prior to the development of the Triassic basin.

The area that became the Gettysburg-Newark basin in the Late Triassic was not a peneplained surface as has been suggested by some earlier workers (e.g., Davis, 1889; Johnson, 1931), but rather an area with local stream valley relief up to 60 m (McLaughlin, 1960). Limestone areas had sinkholes and cave systems (Ganis and Hopkins, 1984; Cloos and Pettijohn, 1973). Sedimentological evidence indicates that sediment entered from both north and south after the basin was established. I suggest that the water gaps in Blue Mountain were cut either prior to or during the Triassic basin episode and that materials eroded from the Valley and Ridge were deposited in the Gettysburg-Newark basin. By the end of the Triassic the climate was becoming less arid. As the volume of water coming from the Valley and Ridge increased, the already established rivers ceased to terminate in the Gettysburg-Newark basin and flowed on southeast to the newly opened Atlantic Ocean.

For the next 150 million years Pennsylvania was subjected to erosion and the devlopment of the drainage system we see today. During much of that time the climate was becoming increasingly warm and humid, however, a period of time that long probably had lengthy episodes of aridity which are not reflected in the known rock record. The rock record in the COST wells (Scholle, 1977; 1980) indicates a large amount of clastic sedimentation during the Jurassic and a declining amount of clastics in the Cretaceous--a record correlating nicely with the changing climate. During this time a process of headward erosion and stream piracy such as elaborated by Thompson (1939; 1949) and Meyerhoff (1972) would have developed the southeast drainage system that exists today. This period of erosion removed all of the sediments earlier eroded and stored in the intensely folded part of the Valley and Ridge and much more. It also removed all of the Anthracite thrust sheet. Relief generation was the result of differential resistance to weathering and erosion as argued by Hack (1960). His state of dynamic equilibrium may or may not have been achieved during the course of landscape development in Pennsylvania and there is little likelihood that past equilibrium conditions can be demonstrated today. The end result of this long period of erosion was to bring the landscape to the general form that we see today.

The Late Cretaceous, Paleocene, and Early Eocene subjected Pennyslvania to an extended period of humid subtropical climate during which chemical weathering was at an extreme while physical appearance of the landscape changed slowly. This very long period of extreme climatic conditions allowed the landscape to achieve a state of adjustment (dynamic equilibrium?) which resulted in a climax landscape--the Harrisburg erosion surface. The Harrisburg, a double planation surface of Budel (1982), consisted of relatively uniform, gently sloping, lowlands extending from the bases of steep-sloped, high ridges. Relief on the lowland surface probably was a few meters to a few tens of meters at most in contrast to the height of the ridges which rose up to hundreds of meters above the lowlands. An integrated stream system carried a large solution load and some fine-grained clastics but no coarse material. Vegetation was at least seasonally abundant and protected the surface from erosion except for sheet wash during periods of heavy rain. Solution weathering extended to depths of many meters and developed saprolites in many different rock types (Berg, 1975, p.23; Cleaves and Costa, 1979; Sevon, 1975). The deep weathering developed thick clay deposits throughout the east coast area (e.g., Burt, 1928; Potter, 1982, p. 10-13; Bridge, 1950) and the many secondary mineral deposits previously discussed. Vegetation accumulating swamps occurred at least locally and may have been more abundant than the record of preserved lignite indicates. This period of erosion presumably ended about the Middle Eocene when climatic flucuations began and continued to the present.

The timing of events related to the Harrisburg surface is not by any means exact. The development of the surface occurred over a period of time which may have been as long as 45 m.y. During this long period conditions changed sufficiently to allow the production of a variety of different products (lignites, mineral deposits, saprolites, etc.) which probably were not all formed at the same time. In addition, although the Harrisburg surface is recognized as a topographic entity today, the weathering event which produced the surface affected the highlands also. The results of that weathering exist in some places (Berg and others, 1981, p. 144), but are not generally recognized for what they really represent.

The first climatic change must have been to a more arid condition in which vegetation became sparse on the landscape and erosion by infrequent torrential rainfall commenced. Coarse debris, now occurring as isolated clasts of pebble to boulder size, was transported from steep-slope positions onto lowlands of the Harrisburg surface for distances of up to 5 km from the base of the steep slopes (Pierce, 1966, p. 105; Sevon, 1981a). Subsequent erosion has left these clasts isolated from their original source (Stop 6). The occurrence of roundstone diamictons deposited on the Harrisburg surface has been noted by

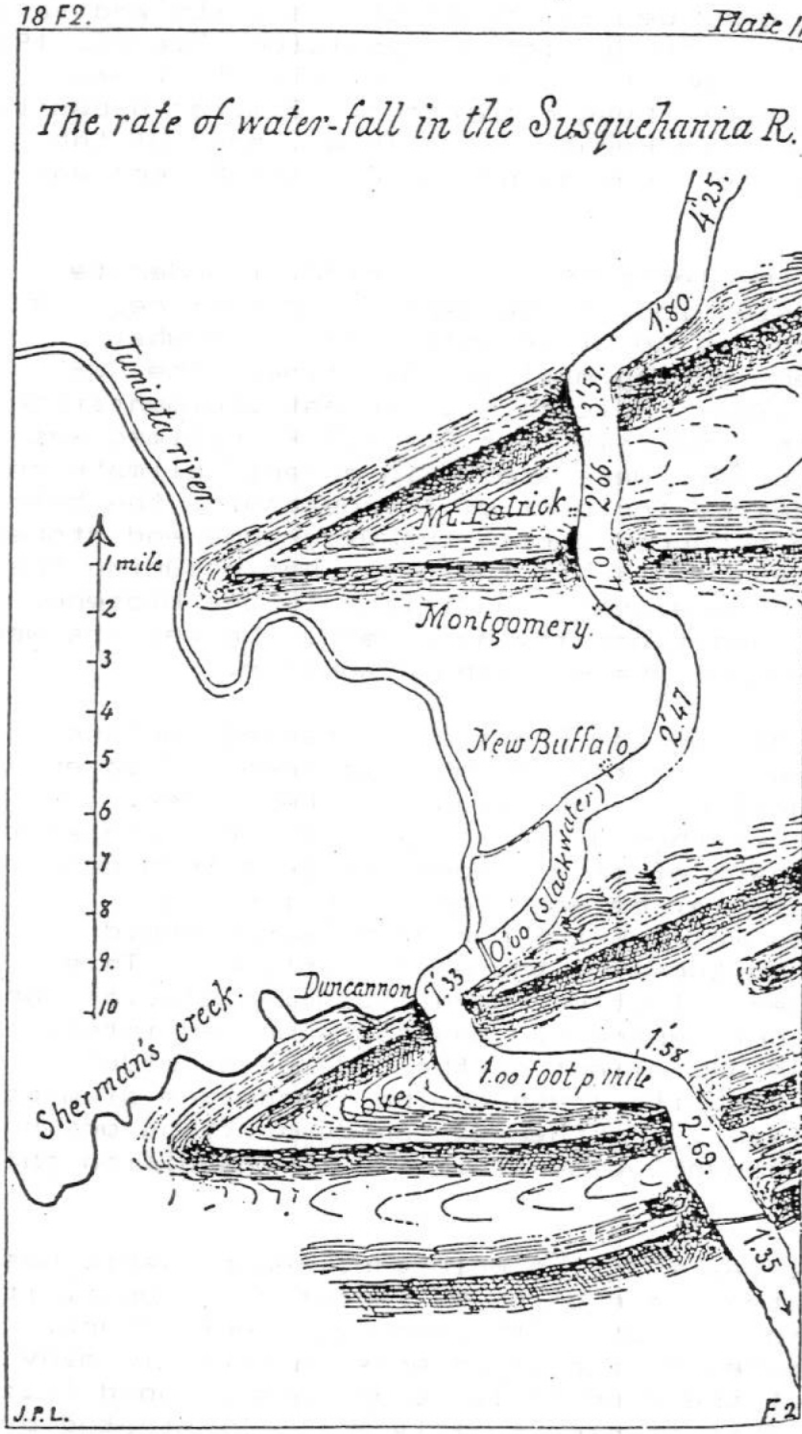
King (1950, p. 57-62) and King and Ferguson (1960, p. 92) in areas south of Pennsylvania and occurrences in Pennsylvania have been discussed in detail by Pierce (1966, p. 74-95). These deposits almost certainly represent mudflows which occurred under arid climate conditions. In addition, carbonate solution depressions up to 10 m deep beneath diamicton deposits and valley erosion up to 18 m deep since diamicton deposition (Pierce, 1966, p. 81) gives some indication of the amount of time that has elapsed since deposition of these diamictons. Similar deposits certainly exist elsewhere in Pennsylvania (e.g., some of the anomalous diamictons on terraces along the Juniata River) and other states.

The remainder of the Tertiary was a period of moderate erosion and gradual dissection of the Harrisburg surface. As indicated earlier, there is no clear indiction as to what climatic conditions were during most of this time. The COST wells (Scholle, 1977; 1980) indicate the largest sedimentation rate during the Miocene, the time that Alt (1974) claimed was arid. However, if materials were eroded in an arid climate and stored on land as suggested for part of the Mesozoic, the bulk of the erosion could have occurred during the Oligocene and stored sediment could have been carried to the ocean basin during the transition from arid to more humid conditions in the Miocene. Whatever the climatic conditions may have been, the results were the continued dissection of the Harrisburg surface.

The climatic extreme of the Pleistocene caused further modification of the landscape through mass movement of material on the slopes and reduction of the height of the ridges. Solifluction stripped weathered rock created as long ago as the Eocene from the upper part of many slopes and left them bare. The Sangamonian interglacial between the Illinoian and Wisconsinan glaciations was a brief period of warm, humid conditions comparable to those of the early Tertiary. This climate had a pronounced effect on fresh Illinoian glacial and periglacial deposits, but apparently was too short an interval (220,000 years) to have any effect on the bedrock or older undisturbed surficial deposits (such as the roundstone diamictons on the Harrisburg surface). Further stream downcutting occurred and the landscape was brought essentially to the condition that we see today.

During the 10,000 years of the Holocene, Pennsylvania has been protected from extensive erosion by forest cover until it was destroyed by man in the late 19th century. Agricultural practices have contributed to increased erosion rates in many areas of the State, but the overall landscape has changed little during the Holocene. This is particularly well illustrated by the fresh character of much of the constructional topography formed by the Late Wisconsinan glaciation in parts of the State.

The landscape that we see today in Pennsylvania is truly polygenetic in origin. Many of the seemingly odd features and deposits which occur within the State can be understood only in the context of landscape polygenesis in varying and different climates. The hills that we see may not be eternal, but many of them are older than we might think!



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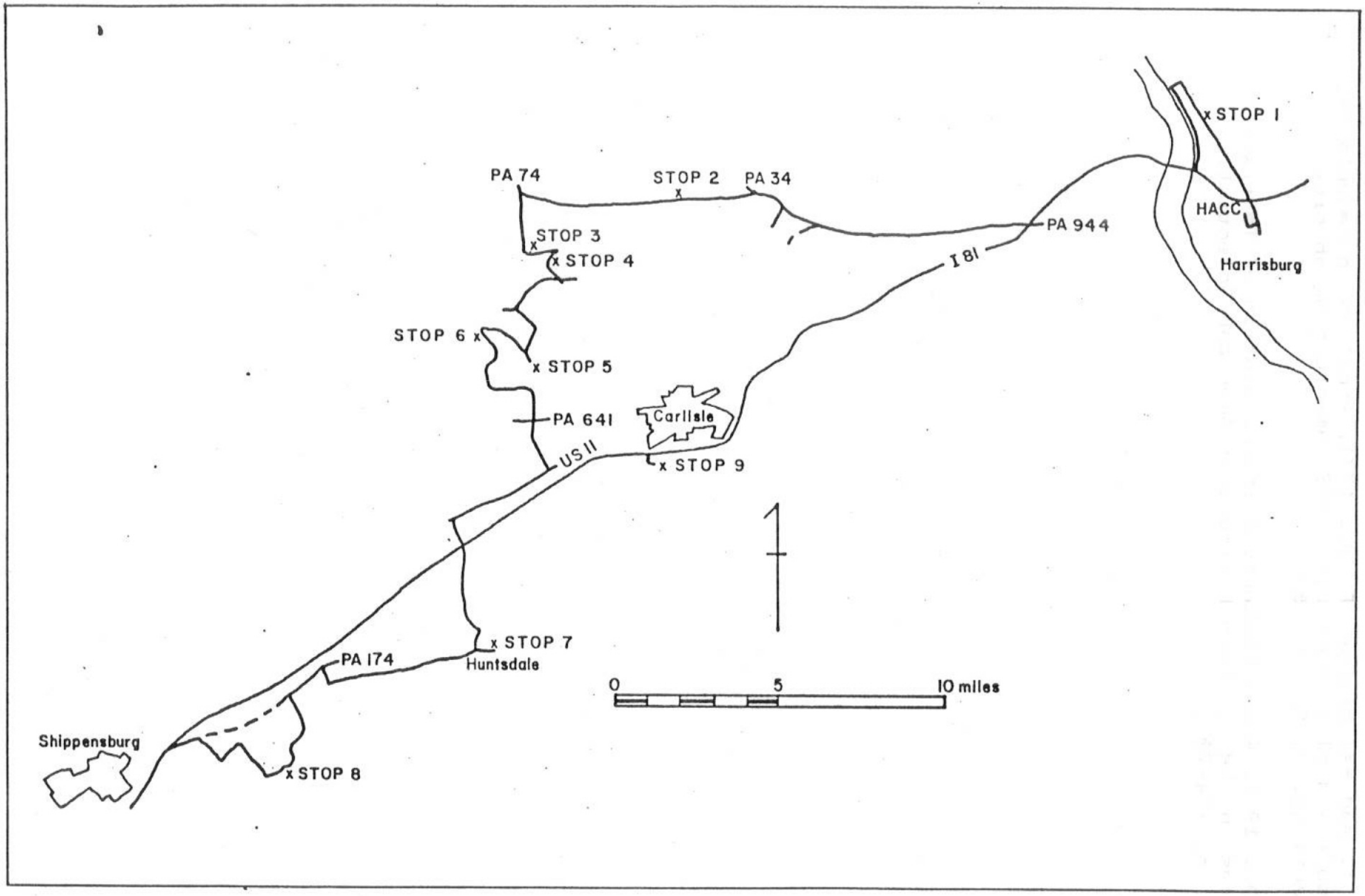


Field trip route.

ROAD LOG AND STOP DESCRIPTIONS

MILEAGE		
INC	CUM	
0.0	0.0	**LEAVE** Harrisburg Area Community College east parking lot from telephone booth area.
0.2	0.2	**TURN LEFT** to Cameron Street.
0.3	0.5	STOP SIGN. **TURN LEFT** to Cameron Street.
0.2	0.7	STOP LIGHT. **TURN LEFT** onto Cameron Street. Go straight ahead on US Routes 22 and 322.
3.3	4.0	STOP **1.** Pull off onto roadway shoulder to right just before the fence.

SUSQUEHANNA WATER GAP

At this stop we can view the Susquehanna River water gap and also a magnificent exposure which reveals why the water gap is located here. Theisen (1983) studied this outcrop in detail and concluded (with the help of R. P. Nickelsen, Bucknell University) that the complicated structure results from pre-folding wrench faulting. He noted that the continuous resistant-rock outcrops of the Tuscarora Formation which cross the Susquehanna River from the west terminate abruptly near the east shore of the river. Cotter (1982; 1983) has studied the facies of the Tuscarora Formation and noted that this is an area of transition in depositional environments.

This outcrop illustrates almost the maximum number of reasons why any stream should choose to establish its course in this position. There is so much faulting (Figure 5) that it is suprising that this ridge was standing before it was cut for the roadway. Of particular note is the almost total absence of what would be a normal sequence of the Tuscarora Formation. Figure 6 illustrates the contrasting sequences exposed on opposite sides of the river. We will see at Stop 3 (Waggoners Gap) a more typical display of the resistant Tuscarora. In all probability, the Tuscarora rocks outcropping here represent an unusual display of nearshore environments not present elsewhere in the State. From the geomorphological point of view they represent a zone of weakness because of the large amount of shale and siltstone in the sequence.

The rocks are overturned slightly at this point, but probably not enough to influence drainage development in the manner envisaged by Meyerhoff (Meyerhoff and Olmstead, 1936). Probably more critical is the small thickness of resistant rocks which is reflected in the narrow width of the ridge crest, a factor favorable to stream cutting according to Epstein (1966).

All told, this outcrop is an excellent illustration of the several weaknesses which probably caused the Susquehanna River to erode its course here. Although we cannot know what the rock condition was when the Susquehanna River established its course here at a much higher elevation, we can postulate that similar conditions were present.

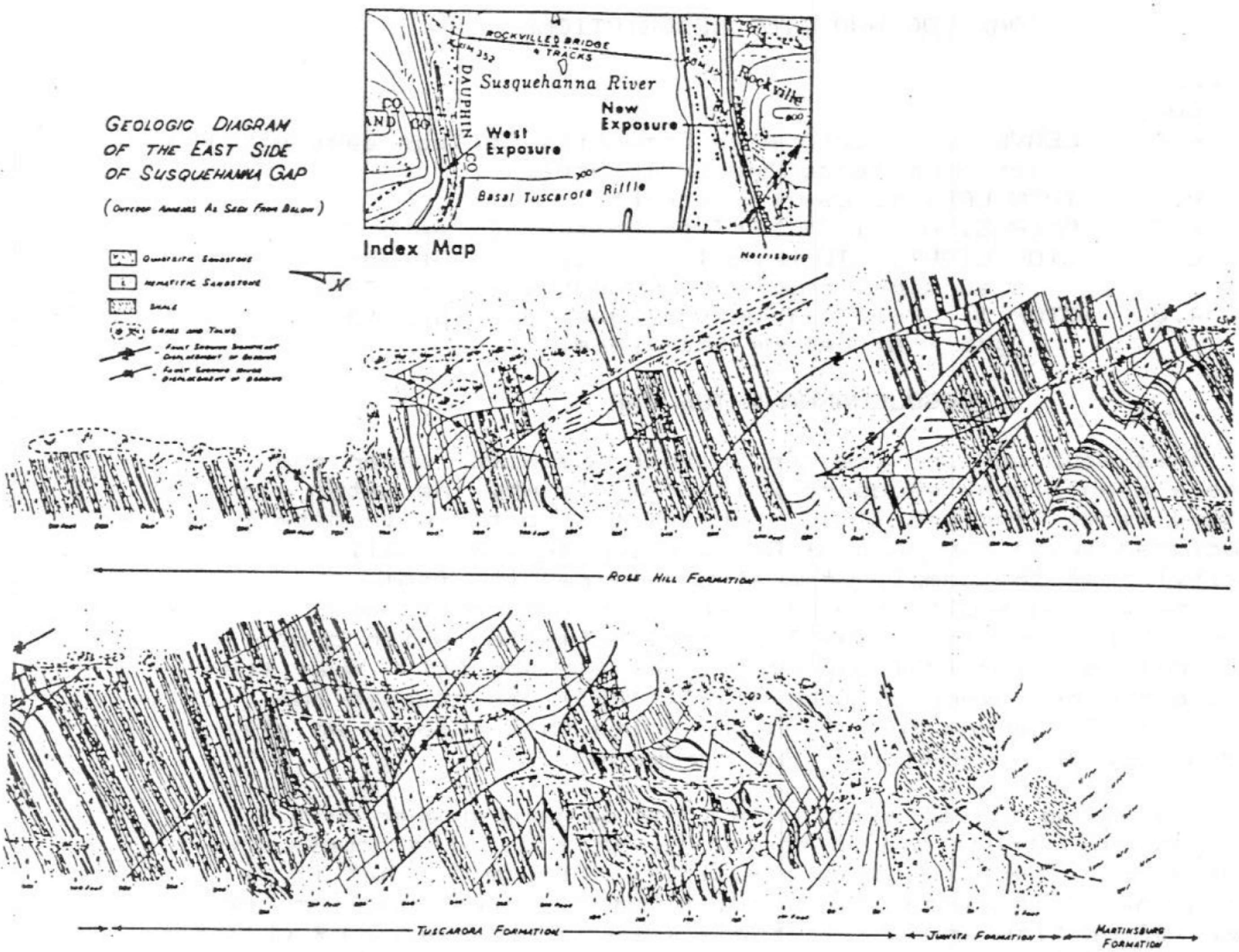


Figure 5. Cross section of Blue Mountain roadcut, U. S. Route 22-322 (from Theisen, 1983).

		LEAVE STOP 1. PROCEED STRAIGHT AHEAD.
1.1	5.1	EXIT RIGHT to PA Route 443, Fishing Creek.
0.2	5.3	STOP SIGN. TURN LEFT.
0.3	5.6	STOP SIGN. TURN LEFT onto Front Street.
1.7	7.3	STOP LIGHT. PROCEED STRAIGHT AHEAD.
0.8	8.1	EXIT RIGHT to Interstate Route 81 S. Good views to right of Blue Mountain, Susquehanna River water gap, and the Rockville Bridge: longest stone arch bridge in the world, built in 1902 at a cost of $800,000.
5.0	13.1	EXIT RIGHT at Exit 20 to PA Route 944, Wertzville Road.
0.3	13.4	STOP SIGN. TURN RIGHT onto PA Route 944 W.
7.2	20.6	ROAD FORK. BEAR RIGHT (Straight ahead) onto Sunnyside Drive, PA Route 944 bears left. Good outcrops of colluvium (see Stop 4) ahead on right.
1.2	21.8	STOP SIGN. PROCEED STRAIGHT AHEAD on PA Route 34. Sterretts Gap. Elevation 930 feet.
1.2	23.0	TURN LEFT onto Fox Hollow Road (T303) just before Sportsman Inn on left.

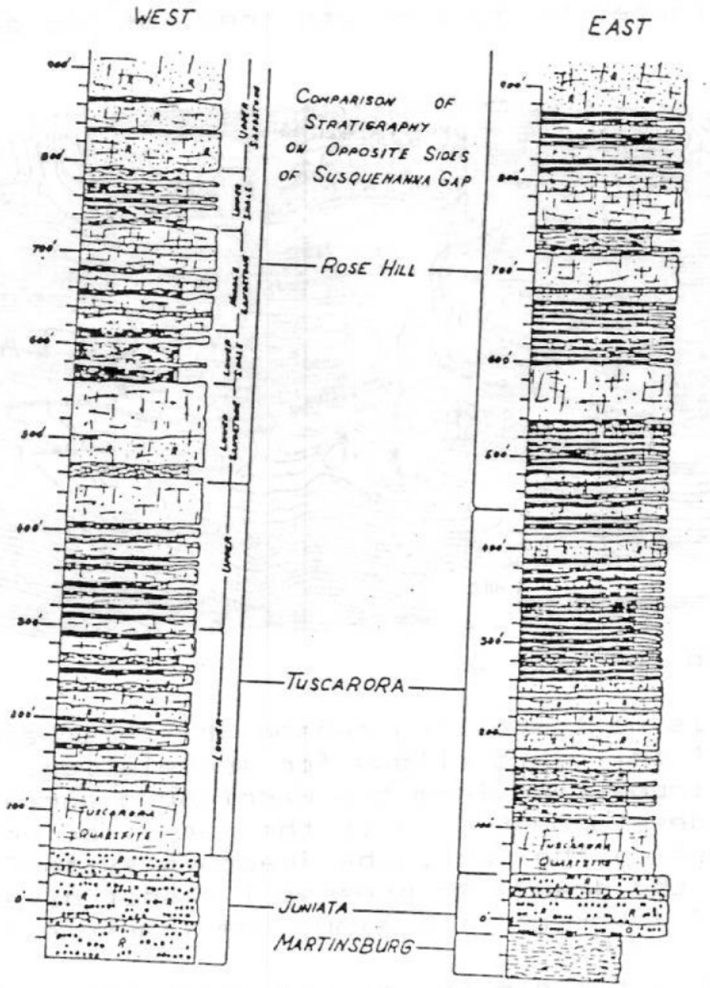


Figure 6. Susquehanna water gap-Blue Mountain stratigraphy (from Theisen, 1983).

2.3 25.3 **STOP 2.** Park in pull-off on right just before T-intersection.

WATER GAP IN LITTLE MOUNTAIN

The purpose of this stop at an unnamed gap in Little Mountain (Figure 7) is to examine two different aspects of landscape development: the reason for the gap and the nature of some colluvial deposits.

Little Mountain parallels Blue Mountain which is situated about 1.6 km to the south. Little Mountain is upheld by resistant sandstones of the Montebello Member of the Mahantango Formation. The mountain follows a relatively undeviating east-west trend for many kilometers in this part of Perry County, but is broken frequently by water gaps through which flow relatively small streams. Why?

Aerial photographs reveal no abnormalities in the geology of this area. The outcrops within the gap appear to correlate across the narrow reach of the gap. There is no apparent facies change across the gap, although the conglomerate present on the east side may not be continuous to the west. There are fracture systems which approximate the north-south trend of the gap.

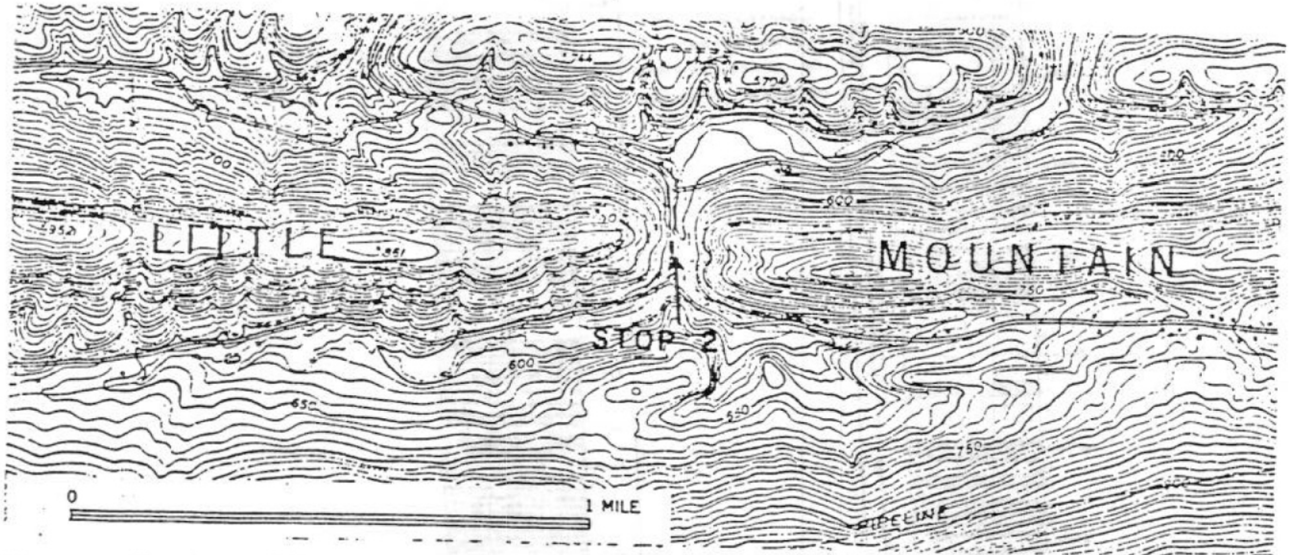


Figure 7. Location map for Stop 2.

All told, there is no compelling reason why this water gap should be where it is. This allows for speculation. Is the gap a result of superimposition from the Harrisburg surface, or an earlier period of development? Is it the result of erosion along the only weakness in the rock, the fracture system? Or is it purely the luck of the draw? At present I cannot give an absolute answer, but I favor erosion along the fracture system.

On the west side of the gap there is a small steep-sloped valley between two resistant rock ridges. The valley floor is the slightly convex top of a colluvial deposit with numerous boulders of sandstone projecting from the surface. This deposit is typical of similar deposits which occur throughout the State. The deposits result from gravity-driven transport of weathered debris during extreme climatic conditions. These deposits were presumably formed during the Pleistocene when freeeze-thaw temperature fluctuations contributed to extensive rock disintegration and down-slope movement of material by accelerated creep or solifluction. It is possible to argue that tree-trunk configuration indicates some down-slope movement at the present time, but on a regional basis the evidence would be inconclusive and would suggest that marked movement occurs only where the bases of deposits have been disturbed by man.

If we accept that these colluvial deposits are a residual from the Pleistocene, then we must also accept that the topography upon which they were formed is older than the Pleistocene. The problem we face is that there is no way to accurately date the age of the valley or the colluvium which now resides in the valley bottom. The age-dating must be relative and it must be based on the context of regional investigation.

LEAVE STOP 2. PROCEED AHEAD (bear left) on

Fox Hollow Road.

5.0 30.3 STOP SIGN. TURN LEFT onto PA 74 E.

3.0 33.3 STOP 3. Park in pull-off area on right side at crest of mountain.

WAGGONERS GAP--CREST OF BLUE MOUNTAIN

Waggoners Gap is a very popular place for a number of reasons. The view on a clear day is not quite forever, but it is very good both to the north and the south. There is a pad from which hang gliders like to launch and the crest of the ridge is a fine place to watch for hawks or just enjoy. There is an excellent exposure of the Tuscarora Formation (Silurian) and the upper part of the Juniata Formation (Ordovician) along the road on the south side of the gap. This exposure has been thoroughly discussed by Cotter (1982) and is part of his comprehensive paper in 1983. Stephens and others (1982) also have a brief discussion of the exposure.

This field trip will not examine the roadside exposure, but will look at the Tuscarora Formation as it appears at the crest to the east of the road. A small access road and trail lead to the barren crest which is about 100 m east of the road.

The crest of Blue Mountain at Waggoners Gap would, in classical terms, constitute a small sag in the remnant of the former Schooley peneplain. On a clear day one can see the next ridge crest to the north, composed of the same resistant rock. These ridge crests, occurring at similar (but not the same) elevations, comprised the accordant summits upon which hypothetical peneplains were built. Sags in these ridges presumably are related to structural control of some sort (Pierce, 1966), but the nature of that control is not immediately apparent at this sag. If the arguments put forward in the text are correct, this is not the remnant of a peneplain, but rather a disintegrated part of a ridge which stands high because it is composed of very resistant rock.

The barren slope below the crest on the north side of the ridge shows the nature of the disintegrated rock comprising the slope. The large blocks disappear downslope and laterally under vegetation which only covers over the blocks--they are still present beneath the vegetation. The barren area at this site has not yet been overwhelmed by vegetation (my hypothesis). The slope shows no evidence of movement of the blocks at the present, note for example the large lichens on the blocks, and there is little reason to believe that the blocks themselves would move downslope unless disturbed by man (undercutting a lower part of the slope). Some downslope movement of the whole deposit may be occurring as a result of basal sliding, but there is no evidence of this.

The broken nature of the psuedo-outcrop at the actual ridge crest is a clear indicator of where the blocks on the slope were derived. Although there appears to be almost no undisturbed outcrop, the nature of bedding and joint planes is clearly evident. Presumably, accelerated disintegration as a result of freeze and thaw along these planes of weakness was the producer of the blocks. The mechanism of movement which carried the blocks to their present positions is somewhat uncertain. If we follow the example of Cooper (1944) and try to reconstruct how much ridge must have disintegrated in order to produce the block debris, then we must conclude that the ridge could have been considerably higher and accumulation may have been, at least in part, by free fall from the upper part of a nearly vertical rock face. Thus, we would be looking at the upper part of a talus. Presumably there was some movement by rolling and/or gliding. In addition, there would have been some some interstitial ice which, aided by gravity, would have resulted in some downslope movement.

There is probably some continuing disintegration of rock at the present time, but the climate is not as extreme today as it was during the Pleistocene when this accumulation of blocks presumably formed. We will discuss evidence of multiple events during the Pleistocene at Stop 4. The rock shows very little evidence of weathering in the form of granular disintegration. I have indicated that the rate of atmospheric weathering is very slow for a resistant sandstone in northeastern Pennsylvania (Sevon, 1984) and believe that the rock present here is probably more resistant and thus will remain unchanged on the slope for a long time to come. Godfrey (1975) suggested that similar quartzite in Maryland was being weathered by chemical action at a rate of 6 m/m.y. He also demonstrated an erosion rate of 2.5 m/m.y. for a drainage basin underlain by quartzite, but the crest of Blue Mountain may not be a comparable erosion site. Thus, if there is little or no lowering of the ridge by block disintegration, little or no downslope movement of the accumulation of blocks, and little atmospheric disintegration of the blocks, then the ridge is essentially in a state of landscape equilibrium. This is the situation which would be expected for the present climate (Budel, 1982).

If we accept that little lowering of the crest of Blue Mountain is occurring at present, then we should contemplate the scene to the south before we leave. To the south is the Cumberland Valley and South Mountain. The text discussion provided figures of landscape lowering of 23-38 m/m.y. for the shale areas and 40 m/m.y. for the limestone areas. Even if the figures are in error by an order of magnitude, there is considerably more erosion occurring in the valley than here and a state of dynamic equilibrium does not exist. It is interesting to ponder whether or not such a condition is possible.

From this stop we will proceed down the mountain onto the Cumberland Valley surface, some of which will be discussed in terms of the Harrisburg peneplain. We will travel across an excellent example of karst terrain and eventually look at materials at the base of South Mountain. We should also reflect upon the fact that following Alleghenian deformation the area from here to South Mountain and for an unknown distance beyond was covered by at least 6 km of rocks which were eroded by the time of Triassic deposition (C-C', Figure 4). In some parts of Pennsylvania almost none of the stack of comparable-age rock has been eroded.

LEAVE STOP 3. PROCEED STRAIGHT AHEAD on PA Route 74 E. Excellent outcrop of Tuscarora Fm. and top of Juniata Fm. on left.

1.4 34.7 STOP 4. Park in pull-off on right just before guard rail on curve. Outcrop is along road about 200 feet back towards Stop 3.

MULTIPLE GENERATIONS OF COLLUVIUM

The roadcut at this stop shows two colluvium deposits which are interpreted to have moved to their present position during different periods of the Pleistocene. The slope disturbance made by creating this roadcut has initiated accelerated movement of at least the surface materials as evidenced by blocks on the surface of the cut. There is no visible evidence that creation of the roadcut has caused movement at greater depths.

Most of the exposed material is composed of a red-colored colluvium with 5YR hues and chromas of 6-8 (wet color). The matrix is composed of sand with some silt and clay binder and is quite cohesive. Cobbles and blocks of sandstone occur within the matrix and show various degrees of weathering. The upper part of the roadcut comprises a thin layer of sandstone blocks and a small amount of loose, brown, sandy matrix. The roadcut exposure shows lateral variation in the thickness of the surface layer of blocks. A particularly thick mass of blocks near the east end of the roadcut resembles a stone stripe in cross section, but the surface above the roadcut does not indicate a stripe.

The surface above the roadcut is covered with boulders which continue upslope to a small scarp-like change in slope gradient which is relatively free of surface rocks. This break in slope continuity presumably represents the upper end of a slope segment which moved as a lobe-like mass through the process of solifluction. Such lobes have mound like fronts with large concentrations of boulders. The front of this lobe was removed for the roadway.

Sequences similar to the one present here occur on the footslopes of many ridges in the nonglaciated parts of Pennsylvania. These colluvial deposits were studied in detail by Hoover (1983) who concluded that the red coloration and clay concentration represents an in situ paleosol of at least pre-Wisconsinan age. This paleosol has been truncated and buried by younger brown colluvium of presumed Wisconsinan age.

It is relatively easy to interpret two ages of colluviation at this site, but assigning ages is not so easy. The red color of the lower colluvium is used by many workers in Pennsylvania as evidence that the colored material has been subjected to weathering during the Sangamonian interglacial and therefore the weathered material must have been deposited during the Illinoian glacial period, but not necessarily by glacial ice. My observations in Pennsylvania indicate that any material which was newly formed during the Illinoian glaciation and started the

Sangamonian interglacial with no inherited soil development would have the imprint of the warm, moist weathering of that period in the form of red coloration. Materials which already possesed an older soil development would not have received the same weathering imprint and would thus lack the red color even though the materials experienced the same weathering. Moss (1976) suggested that red-colored colluvial deposits farther east along the base of Blue Mountain were periglacial in origin and weathered during the Sangamonian. The only problem with this interpretation is that we have no means of positively dating the period of weathering.

Marchand (1978) suggested that the red-colored drift materials in the central part of the Susquehanna drainage basin represent more than one age and that some may be older than Illinoian. This interpretation is still being argued and there has been no attempt to apply the concept to colluvium.

Red-colored colluvium occurs farther south in the Appalachians and King (1964) has speculated that the red color may be inherited from red-colored saprolite. This idea has not been evaluated in Pennsylvania. If the red color is derived from red saprolite, then age-dating the red colluvium becomes more difficult.

I prefer the interpretation that the red colluvium was formed during the Illinoian and weathered during the Sangamonian.

One other aspect of hillslope development can be discussed here. This hillslope, like many others in the Appalachians, is covered with cobbles and boulders of resistant sandstones and quartzites which do not appear to be weathering at an appreciable rate nor does the slope seem to be moving. There is a small gully where the bus is parked. Some material may be moving down that channel, but the materials are large and probably the gully is protected from much downcutting. Mills (1981) suggests that such gullies will migrate laterally because it is easier to cut into the matrix of the colluvium than to cut down through the boulder paved stream bed. Over a long period of time the positions of the gully and the interfluve will be reversed and an amount of hillslope lowering will have occurred. This process of interfluve reversal is called gully gravure. I personally feel that such a process would be self defeating on this slope because eventually the total slope would be nothing but boulders too difficult to erode, which is not too different from its present condition.

		LEAVE STOP 4. PROCEED STRAIGHT AHEAD on PA Route 74 E (Enola Road).
1.0	35.7	Beautiful stone house on left with matching stone barn on right. Both are made out of white Tuscarora and red Juniata sandstones.
0.2	35.9	TURN RIGHT onto PA Route 944 W. Views ahead to right of Blue Mountain and Waggoners Gap.
1.6	37.5	TURN LEFT onto L21033 at top of hill.
0.8	38.3	TURN RIGHT onto 487.
0.8	39.1	STOP SIGN. TURN RIGHT onto 459.

0.1	39.2	TURN LEFT to PA Fish Commission Opossum Lake.
0.5	39.7	STOP 5. LUNCH. Parking lot at end of road.

LUNCH

Opossum Lake is very popular for year-round fishing. The lake is stocked and the returns for effort are apparently rewarding. The well-maintained grounds are also popular for picnics and general relaxation. Noel Potter and I have discussed the possibilty of coring the lake bottom in an attempt to derive another rate of erosion figure, but to date we have not pursued the winter activity. Enjoy your lunch.

		LEAVE STOP 5. RETURN to road 459.
0.5	40.2	TURN LEFT onto 459 at T-intersection.
0.5	40.7	TURN RIGHT onto 455 (unmarked) at T-intersection.
1.4	42.1	TURN LEFT onto 458 (unmarked).
0.1	42.2	STOP 6. Pull off onto right side of road.

THE HARRISBURG SURFACE

This area is typical of much of the dissected lowland which occurs immediately south of Blue (Kittatinny) Mountain from New Jersey to Maryland. The lowland is underlain by shales, siltstones, and occasional sandstones of the Ordovician Martinsburg/Hamburg Formation and comprises a series of small drainage basins which head on Blue Mountain and drain southward into larger streams. These drainage basins are characterized by gently rolling topography, rounded hilltops and valleys, an overall "smoothness" of topography, and a visual concordance of uplands (Figure 8).

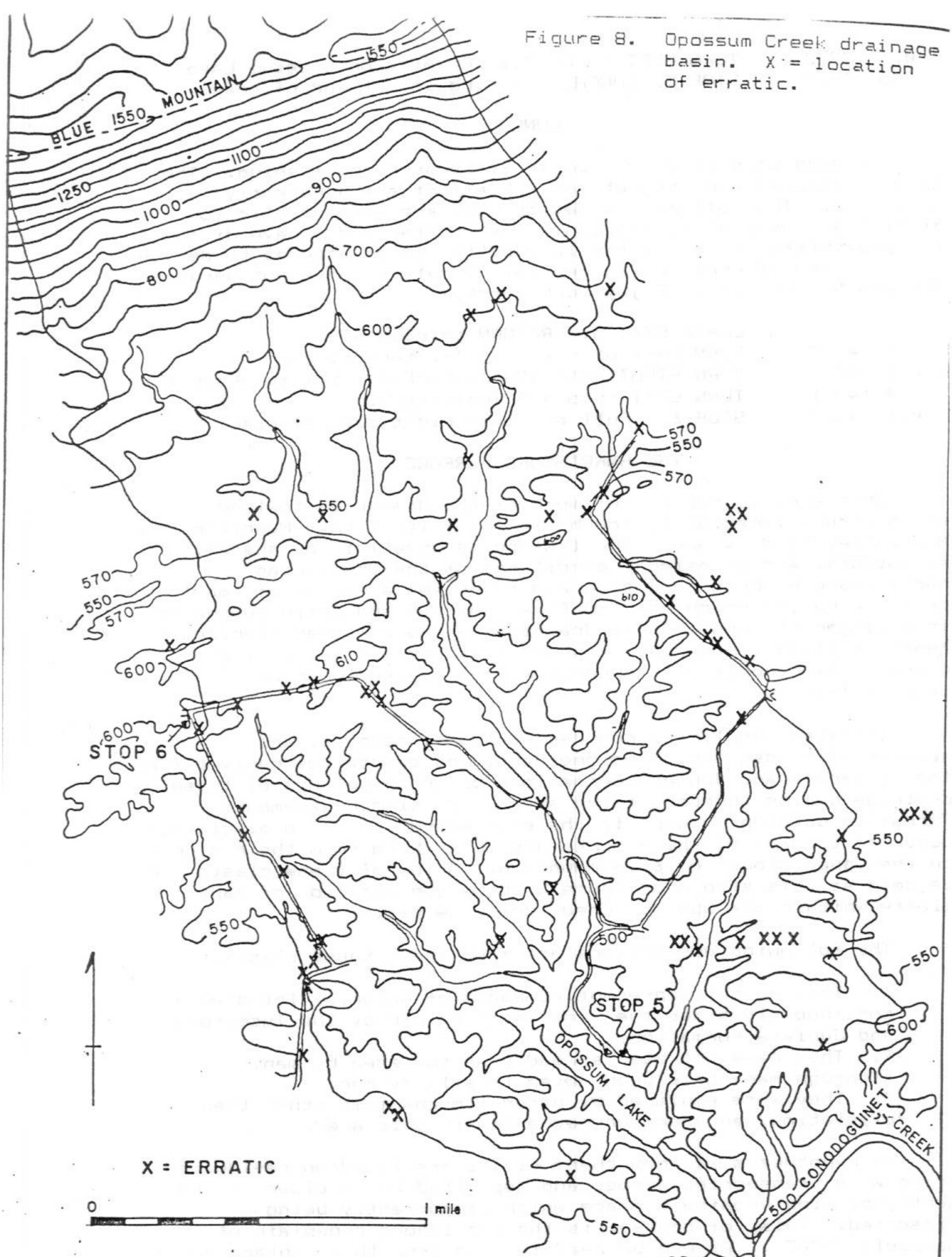
Isolated angular to rounded boulders, cobbles, and pebbles of sandstones, conglomerates, and quartzites derived from the Tuscarora and Juniata Formations occur on uplands of these drainage basins throughout the area of Martinsburg/Hamburg Formation outcrop (except in the east where Illinoian glaciation occurred). Many of these rocks are up to 5 km from their source on the upper slopes of Blue Mountain. A few of these clasts can be seen at this stop and Figure 8 shows the location of many clasts whithin the Opossum Creek drainage basin.

The following assumptions are made about these clasts:

1. They do not represent remnants of material let down continuously since the area was overlain by the Tuscarora and Juniata Formations.
2. They have not been spread over the area by man, although many have been moved locally by man.
3. They were emplaced by natural mechanisms other than glaciation, an unproven mechanism in this area.

My hypothesis is that these clasts are let-down residuals which were transported across and deposited on an older, higher, gently sloping erosion surface which is currently being dissected. This, of course, is the Harrisburg peneplain of Campbell (1903). As can be readily seen from this vantage point

Figure 8. Opossum Creek drainage basin. X = location of erratic.



and from Figure 8, there has been sufficient dissection of the original surface to totally isolate the clasts from their source. I suggest that the only reasonable mechanism by which these clasts could be transported to positions so far from Blue Mountain is debris flows during a climate considerably different from today--arid. The age of the Harrisburg surface and the variations in climate which have presumably occurred in the area are discussed in the text. Another possible--but in my opinion improbable--mechanism for emplacement of the clasts is by normal stream transport at a time when stream channels corresponded to the present uplands. If a protective veneer of large clasts developed on the stream bed, then the stream could erode laterally to a new position in the manner of gully gravure advocated by Mills (1981) and discussed at Stop 4.

In an earlier discussion of this area (Sevon, 1981a) I attempted to evaluate the age of the surface by calculating the amount of material eroded since the Harrisburg surface existed and the length of time required to erode that material. I reconstructed a hypothetical Harrisburg surface using the present gradient of Opossum Creek as the surface gradient and making the surface higher than existing elevations in the lower part of the drainage basin. A grid was established and the elevation difference between the present topography and the hypothetical Harrisburg surface was calculated for each 3419 sq. m area within the drainage basin. This calculation indicated a total of 930,078,890 M.T. of material removed.

In order to establish a reasonable rate of erosion for the Martinsburg/Hamburg Formation, I used suspended-load values from Reed (1980), dissolved-load values from Stuart and others (1967) reduced by 35 percent to offset the influence of man (Meade, 1969), and a bed-load value based on Gregory and Walling (1973). Using the suspended-sediment values of 41 M.T./sq km/yr (for non-hurricane years) and 66 M.T./sq km/yr (for years including hurricanes Agnes and Eloise), dissolved-load values of 17-29 M.T./sq km/yr, and a bed-load value of 5 percent of total load, I derived a minimum erosion rate of 61 M.T./sq km/yr (23 m/m.y.) and a maximum erosion rate of 100 M.T./sq km/yr (38 m/m.y.). When these values are applied to the calculated amount of material removed since the existence of the hypothetical Harrisburg surface, the time required to erode the drainage basin to its present configuration ranges from 694,607 to 1,138,408 years. These values present a problem.

If the erosion rates established for this drainage basin are reasonable, and I think they are the best which can be calculated from available data, then how can we resolve the conflict between preserving parts of a surface which is at least as old as Eocene and an erosion rate which should have totally destroyed the surface millions of years ago. The answer may have two parts. One part is man. Man has sufficiently changed the local landscape, particularly the natural vegetation, that any derived rate of erosion at the present time is probably enlarged by some factor. The second part is that the erosion rate may actually be real--on a temporary basis. The derived times would place the inception of erosion sometime in the Pleistocene. If what we discusssed at Stops 2, 3, and 4 is correct, then there is reason to believe that the Pleistocene climate may have accelerated the process of rock disintegration and erosion in the shales underlying the Harrisburg surface. Thus, a surface which had been deeply weathered, but not deeply eroded prior to the Pleistocene would have undergone severe erosion during the several extreme climatic changes of the Pleistocene. We may be still in a period of excessive erosion associated with a change in climate.

This site and discussion have not answered the questions that are posed by the geology, but I hope that the reality of polygenetic aspects of the landscape are made clearer by the problems present.

		LEAVE STOP 6. PROCEED STRAIGHT AHEAD.
0.8	43.0	STOP SIGN. TURN RIGHT onto 459.
0.8	43.8	TURN LEFT onto 456 at old brick schoolhouse.
0.5	44.3	STOP SIGN. TURN LEFT onto 457.
1.7	46.0	Curve in road, fields to right and left have terrace gravels from Conodoguinet Creek. Have just crossed from shale terrain to limestone terrain.
0.1	46.1	Cross Conodoguinet Creek.
0.1	46.2	STOP SIGN. TURN LEFT onto McCalisters Road.
1.7	47.9	STOP SIGN. PROCEED STRAIGHT AHEAD across PA Route 641.
0.1	48.0	BEAR LEFT following road through Elliottson. Road passes through excellent karst terrain between here and Stop 9.
1.5	49.5	STOP SIGN. TURN RIGHT onto US Route 11 S.
3.3	52.8	TURN LEFT onto Mt. Rock Road.
3.0	55.8	STOP SIGN. PROCEED STRAIGHT AHEAD across PA Route 174. Now on Chunk Road.
1.2	57.0	STOP SIGN. TURN RIGHT at T-intersection.
0.4	57.4	STOP SIGN. TURN LEFT at T-interesction. center of Huntsdale. Huntsdale Fish Culture Station (back on right) has a small visitors center, a nice brochure for a self-guiding walking tour of the station, and some enormous fish. If fish are you, plan a visit here.
0.5	57.9	TURN LEFT onto small gravel driveway marked No Trespassing.
0.1	58.0	STOP 7. This is PA Fish Commission property and permission to visit here should be obtained from the Huntsdale Fish Culture Station.

HUNTSDALE ALLUVIAL-FAN GRAVELS

This former borrow pit, now used for burial of dead fish by the Huntsdale Fish Culture Station, is also the site of a former iron furnace. Evidence of the iron furnace operation is the black (charcoal) and red (burned) soil colors above the gravel at the west end of the pit. Mr. Ted Dingle, retired chief of the fish culture station said that he found metal artifacts at the site when he was a boy.

The vertical exposure on the north side of the pit exposes subrounded to rounded clasts of quartzite derived from the Cambrian Antietam Formation which occurs to the south within South Mountain. This site is on the distal part of an alluvial fan formed by an intermittent stream flowing from Irishtown Gap Hollow (Figure 9). The gravels are variably but generally poorly sorted. Bedding is evident, but not everywhere clearly defined. Places along the exposed face show (1) good stratification, (2) chaotic orientation of clasts with no stratification, and (3) probable channelling into older gravels. Both mudflow and waterflow mechanisms of deposition are represented here. Both mechanisms would be expected on an alluvial fan.

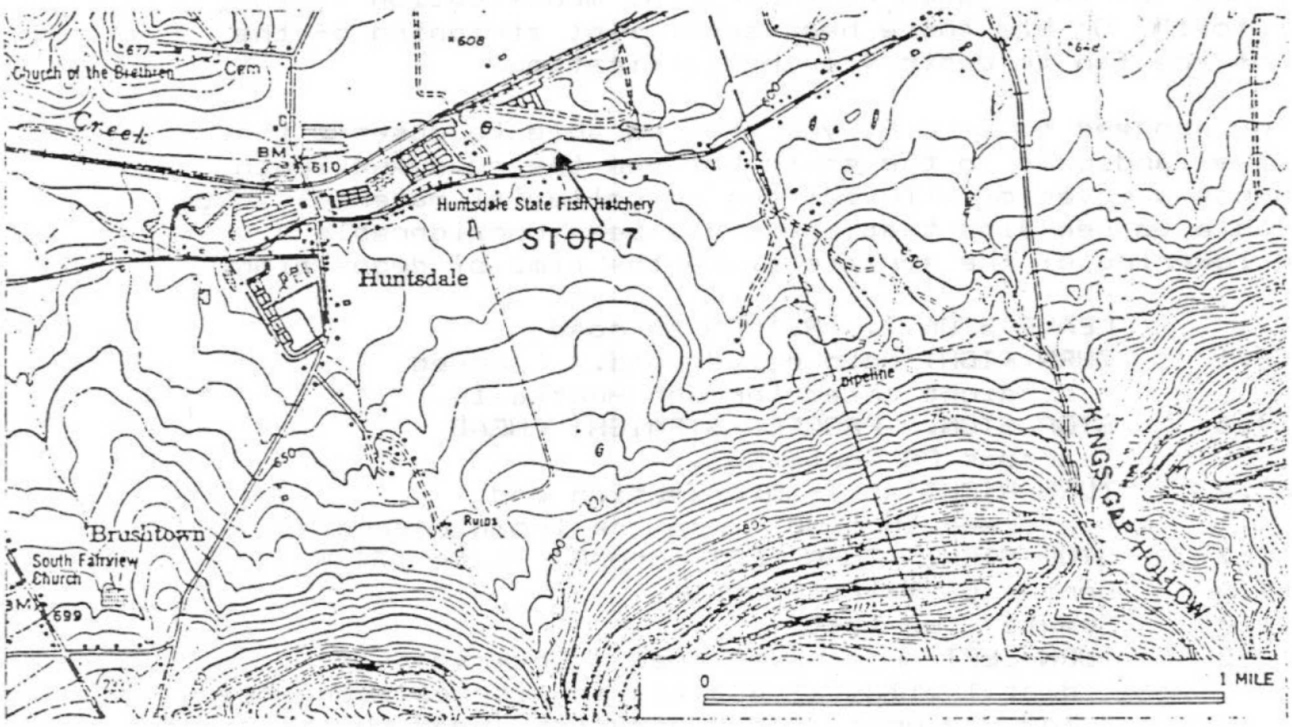


Figure 9. Location map for Stop 7. Note excellent definition of alluvial fans by contours (10' contour interval).

Moist soil color in the upper part of the deposit is between strong brown (7.5YR4/6) and dark yellowish brown (10YR4/6) and results from disseminated organic material. Clay movement has occurred throughout the exposed interval (3-4 m). This soil is not typical of soils developed in the woodland areas of the east, but rather of those developed farther west under prairie conditions (E. Ciolkosz, personal communication).

The topographic signature of this fan (Figure 9) is distincitive, but also shows clearly that at present the depositing stream is incised into the former fan surface. All indications are that the incision results from solution lowering of the stream bed rather than from active stream erosion. The surface of the fan also has some depressions which are presumably upward propogations of sub-fan sink hole development. Such depressions are common on the alluvial and colluvial deposits where they overlie limestone along the margin of South Mountain.

The question to be asked but not satisfactorily answered at this locality is, when were the alluvial fan gravels deposited? The answer presumably rests in a proper interpretation of the age of the soil and the length of time required to lower the stream course to its present level by solution. The soil does not seem to be related to known Pleistocene soils in Pennsylvania and therefore must be older. If we follow the proposed model of landscape development for Pennsylvania, then this soil developed under somewhat dry conditions after the Early Eocene. The time when the gravels were deposited may have been as early as Oligocene and as late as Pliocene. At present we cannot suggest an absolute time. The problem that this hypothosis creates is obvious: why has there been no subsequent modification of the original soil? Or has there been sufficient stripping of the surface of the fan to destroy such modification?

As we proceed to Stop 8, you will be able to observe that much of the landscape to the south between the road and South Mountain has a cover of alluvial and/or colluvial material. You will be able to see also that there has been considerable solution lowering of the surface since the time of deposition.

		LEAVE STOP 7. RETURN to road.
0.1	58.1	TURN RIGHT onto paved road. Proceed straight ahead through Huntsdale.
1.5	59.6	STOP SIGN. PROCEED STRAIGHT AHEAD across PA Route 233.
3.8	63.4	TURN RIGHT at T-intersection and proceed through narrow railroad underpass.
0.3	63.7	STOP SIGN. TURN LEFT onto PA Route 174 W.
0.9	64.6	Center of Walnut Bottom.
1.4	66.0	Cemetary on left.
0.2	66.2	TURN LEFT onto paved road. Observe distal alluvial gravels in ditches along road and the undrained depression ahead on the right.
0.2	66.4	TURN RIGHT onto Chestnut Grove Road. Alluvial gravels in ditches and good view to left of solution lowered landscape (between here and South Mountain).
0.4	66.8	TURN LEFTonto Gushell Road (320). Note undrained depressions ahead on right and left.
0.5	67.3	State Forest boundary.
0.1	67.4	TURN RIGHT at road intersection.
0.6	68.0	STOP 8. Park at gate of C. L. Goodhart Sand and Gravel quarry. Permission must be obtained to visit the quarry.

SAPROLITE AND COLLUVIUM

Quartzite of the Antietam Formation is quarried at this location (Figure 10) and processed to produce sand. However, the items of interest here are the deep red colluvium and the saprolite developed on the Antietam.

Red (2.5YR4/8) colluvium is exposed along the lowest level on the north side of the quarry in its eastern part. The colluvium is composed of clay, silt, sand, and angular to subangular clasts of quartzite. The weathering extends downward into broken bedrock. Most exposures of the colluvium show no suggestion of bedding, but rarely there is a subtle hint of stratification or alignment of clasts. The quartzite clasts vary in degree of weathering from relatively hard to totally disintegrated. Some exposures display a reticulate structure in the form of thin, vein-like, light gray zones of weathering. The reticulate structure is very angular with numerous perpendicular intersections.

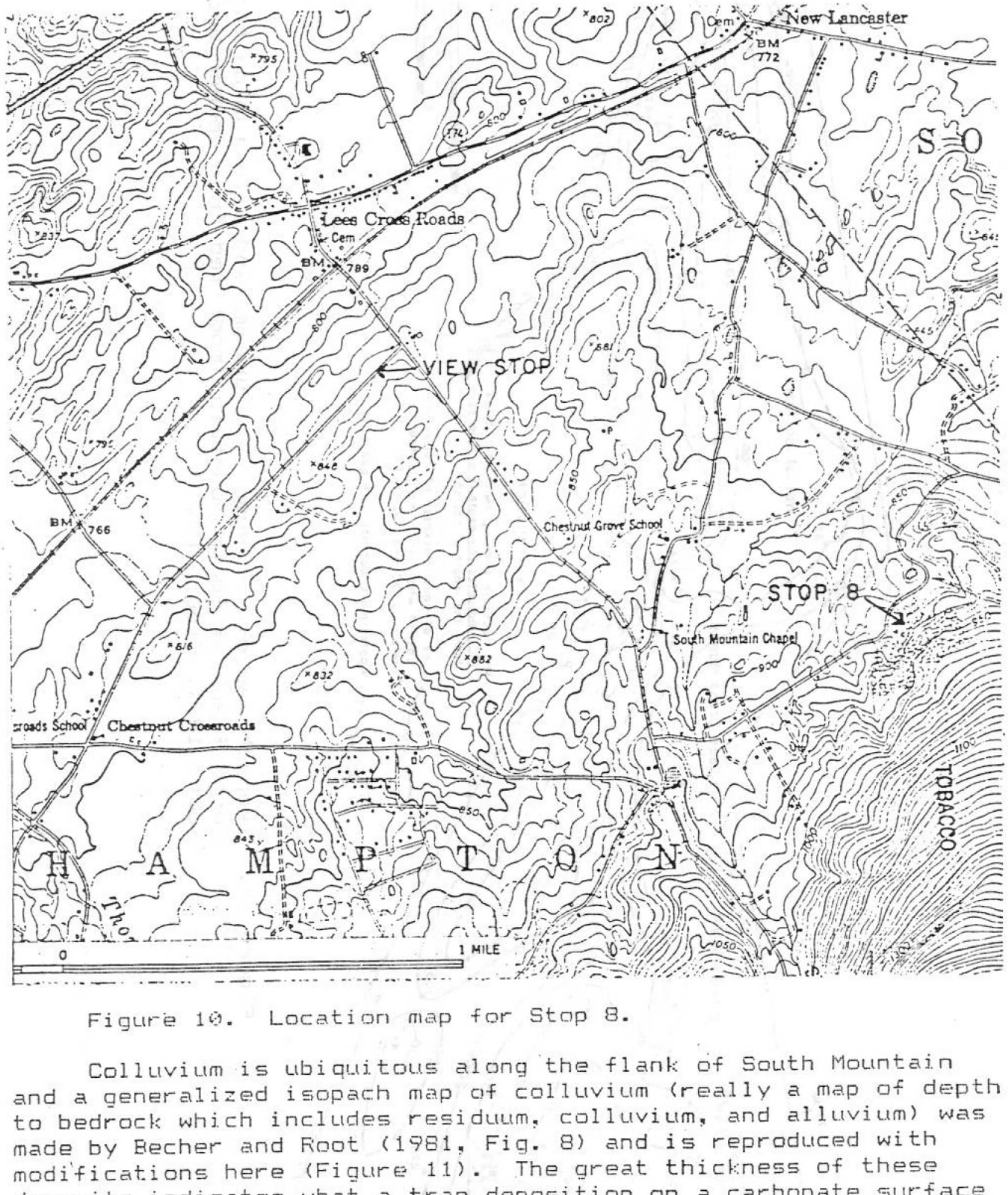


Figure 10. Location map for Stop 8.

Colluvium is ubiquitous along the flank of South Mountain and a generalized isopach map of colluvium (really a map of depth to bedrock which includes residuum, colluvium, and alluvium) was made by Becher and Root (1981, Fig. 8) and is reproduced with modifications here (Figure 11). The great thickness of these deposits indicates what a trap deposition on a carbonate surface turns out to be. Solution of the carbonates creates a sink in

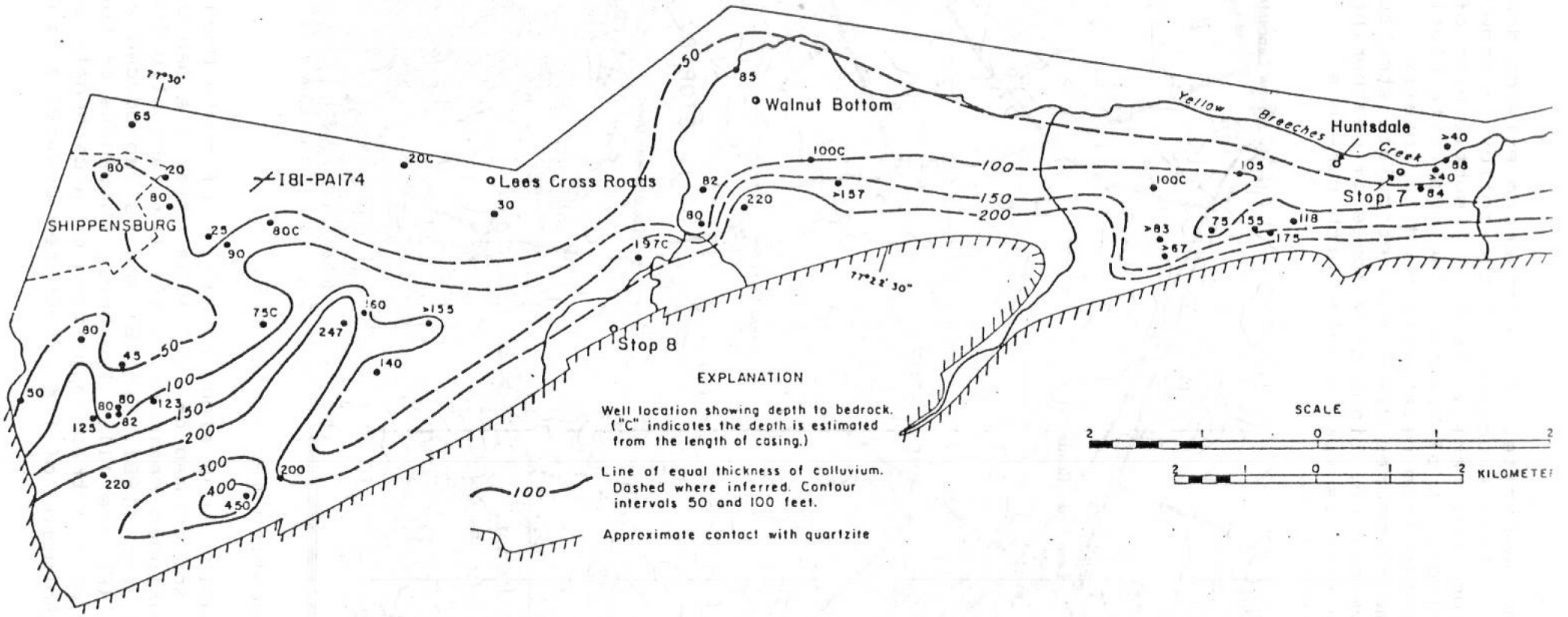


Figure 11. Isopach map of residuum, colluvium, and alluvium on the north flank of South Mountain (modified from Becher and Root, 1981, Figure 8).

which more resistant and less soluble rocks become indefinitely mired.

At intermediate levels in the eastern part of the quarry, a well-developed saprolite is exposed in several erosional gullies. These gullies show Antietam quartzite weathered to the extent that it is totally incohesive and can be cut easily with a knife. Original bedding features are preserved. The top of the saprolite is truncated by a north-dipping erosion surface and some colluvium overlies the saprolite. Soil prisms (weathering prisms) extend from the colluvium downward into the saprolite, but there is no suggestion as to the soil which may have developed here during the course of weathering.

The main question at this stop is "What is the age of the saprolite and the colluvium?" The colluvium is much redder than the Illinoian (?) colluvium we saw at Stop 4. The clasts within the colluvium are probably more weathered than those at Stop 4. If we assume that the colluvium here is of a different age than the colluvium at Stop 4, then what age might we give to this material? Are we examining very old material? If we make the association of color with other areas, then we think of the saprolite development on the Piedmont rocks to the south. The saprolite on those rocks is early Tertiary in age. However, do not forget the saprolite exposed here. It has no red coloration nor do the prisms penetrating the saprolite. If we conclude, logically, that the prisms succeed saprolite development, then we have a real problem. It would appear that the model is reversed. The saprolite, presumably formed under humid tropical conditions, should be developed prior to the colluvium, which should a be developed under the same climatic conditions.

The age-dating problem at this locality is real. I suggest: that the saprolite is probably a product of weathering during the Late Cretaceous and early Tertiary; that the red colluvium was derived from the saprolite and inherited at least some of its color from the saprolite; that the saprolite present today represents the bottom of a considerable thickness of former saprolite, most of which has been removed; and that the weathering prisms represent a later stage of soil development, possibly the one present at Stop 7. Naturally, I cannot prove any of this and would not be suprised if the real story is much different.

		LEAVE STOP 8. PROCEED STRAIGHT AHEAD.
0.7	68.7	STOP SIGN. TURN RIGHT onto Strohn Road. Observe alluvial gravels along road.
0.2	68.9	BEAR LEFT at road fork.
1.0	69.9	STOP SIGN. TURN LEFT onto High Road.
0.2	71.1	Foundation excavation of house on right exposed alluvial gravels derived from South Mountain to depth of 2 m+. Observe the amount of solution lowering of the landscape which has occurred between here and the gravel source.
0.7	71.8	TURN RIGHT onto Goodhart Road.
1.0	72.8	STOP SIGN. TURN LEFT onto PA Route 174 W.
1.1	73.8	TURN RIGHT onto Interstate 81 N.

15.9	89.7	EXIT RIGHT at Exit 12 to PA Route 465.
0.2	89.9	STOP SIGN. TURN RIGHT onto PA Route 465.
0.1	90.0	TURN LEFT onto paved road. Brennemans Furniture on right and Osterlund Truck Services, Inc. ahead on left.
0.2	90.2	STOP 9. Park at road circle.

PINNACLE WEATHERING ON LIMESTONE

by
Noel Potter, Jr.
Dickinson College
Carlisle, PA

This is an optional stop depending on time. The site was excellent, but it is rapidly being covered with fill for the purpose of development and may soon be totally covered. The area at the east end beyond the fill may still be exposed and is worth a visit.

This area was stripped in the mid-1960's to obtain fill for construction of Interstate Route 81. The excavation exposed spectactular pinnacles on the limestone beneath the former soil. surface. The approximate level of the former surface can be inferred from the south wall of the excavation. Most of the pinnacles now exposed were probably completely buried before excavation.

The purpose of this stop is to show the extremely irregular surface of pinnacles that develops on carbonates beneath the soils in the Cumberland Valley, and to contrast this with the soils that we have seen developed on quartzites and shales earlier in the trip. In addition, the pinnacle surface presents a nice lesson about the engineering problems that can occur during construction on carbonate areas.

The rocks are part of the Beekmantown Group (Lower Ordovician), the Rockdale Run Formation. They are nearly vertical in orientation and on the north limb of an anticline so that stratigraphic top is to the north (toward Interstate Route 81). Alternating beds of limestone (gray) and silty dolomite (tan) are common and some beds near the south edge of the exposure contain chert. Graded beds, cross beds, and algal stromatolites occur and can be used to establish stratigraphic tops.

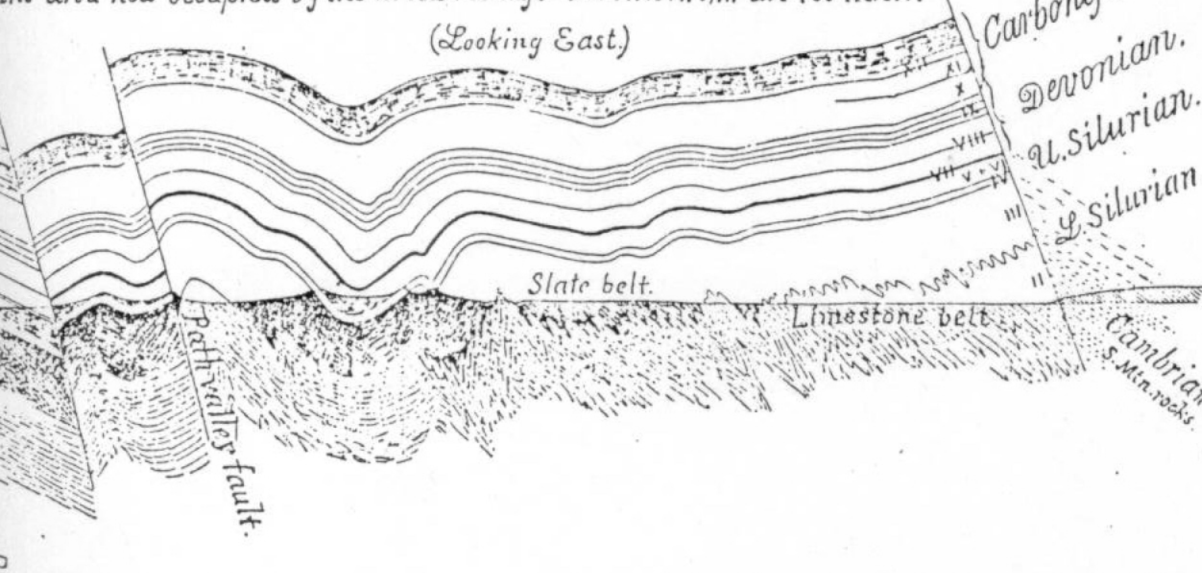
Gullies between the pnnacles trend about N70E parallel to bedding and show the control of differing lithologies on solution of the carbonates. A second set of gullies, controlled by joints, trends about N20W. These gullies parallel a prominent set of nearly vertical, calcite-filled joints along which preferential solution has occurred.

At this locality we are far from the sources of quartzites of Blue and South Mountain and the soil is derived entirely from the underlying carbonates. Most of the soil material is silt and clay, but there are some quartz sand grains, occasional chert fragments, and a few small (<1 cm), irregular, pitted pieces of limonite. The source of the limonite is not obvious, but it must be a weathering product of the carbonates. One possibility is that the limonite has oxidized from pyrite that occurs in the carbonates. Pyrite is found only rarely in the carbonates of the Cumberland Valley and the suggested relationship with limonite is inferred from the York-Lancaster valleys where pseudomorph cubes of limonite after pyrite are common in the soil and pyrite cubes are common in the carbonates. Perhaps here the pyrite is present, but much less abundant.

The rocks here have an average insoluble residue content of about 10 percent. If the south wall of the excavation is used as a datum, then 5 m would be a rough estimate of the original average thickness of soil over these rocks. This thickness implies that about 50 m of rock was weathered to produce the residual soil. An equilibrium between new soil produced by solution of the rocks and soil eroded from the surface presumably exists. How long did it take to produce the soil present here? Jennings (1983, p. 585, Fig. 7) and White (1984, p. 241, Fig. 10.8) both present comparable data which can be used to estimate solution rates on the basis of water runoff (precipitation minus evaporation). The present runoff of about 500 mm/yr in the Cumberland Valley results in a solution rate of about 20 m/m.y. using White or a solution rate of about 40 m/m.y. using data of Jennings as massaged by Sevon (regression line for only nontropic soil-covered karst data in Jennings Figure 7). This implies that, if the present climate were a constant, it would take about 2.5-5 m.y. to produce the soil preserved here. However, we know that the climate has changed considerably during the past 2.5-5 m.y. and we must therefore question the value of the estimate. This age problem is not quite the same as those at Stop 6, Stop 7, and Stop 8. It seems that there are no easy answers.

		LEAVE STOP 9. RETURN to PA Route 465.
0.2	90.4	TURN RIGHT onto PA Route 465 at T-intersection.
0.1	90.5	TURN RIGHT onto Interstate Route 81 N.
23.6	114.1	EXIT RIGHT at Exit 23 to Cameron Street.
0.3	114.4	BEAR RIGHT to Cameron Street.
0.9	115.3	STOP LIGHT. TURN RIGHT.
0.2	115.5	TURN RIGHT to Harrisburg Area Community College.
0.2	115.7	BEAR RIGHT to east parking lot.
0.2	115.9	Telephone booth area. END OF TRIP.

This cross section is geogrphically accurate; the topographical elevations are on a true scale; but the geological Subdivisions are merely indicated to show the amount of Erosion that has occured, and the reason for believing that the whole Palæozoic system once covered the area now occupied by the Great Valley. – N.B. Nos. II & III are too thick.



Cross section of the Great Valley from near Cowan's Gap south through Scotland to the South Mountain in Franklin County, Pa.

Ch. XXII, plate 4.