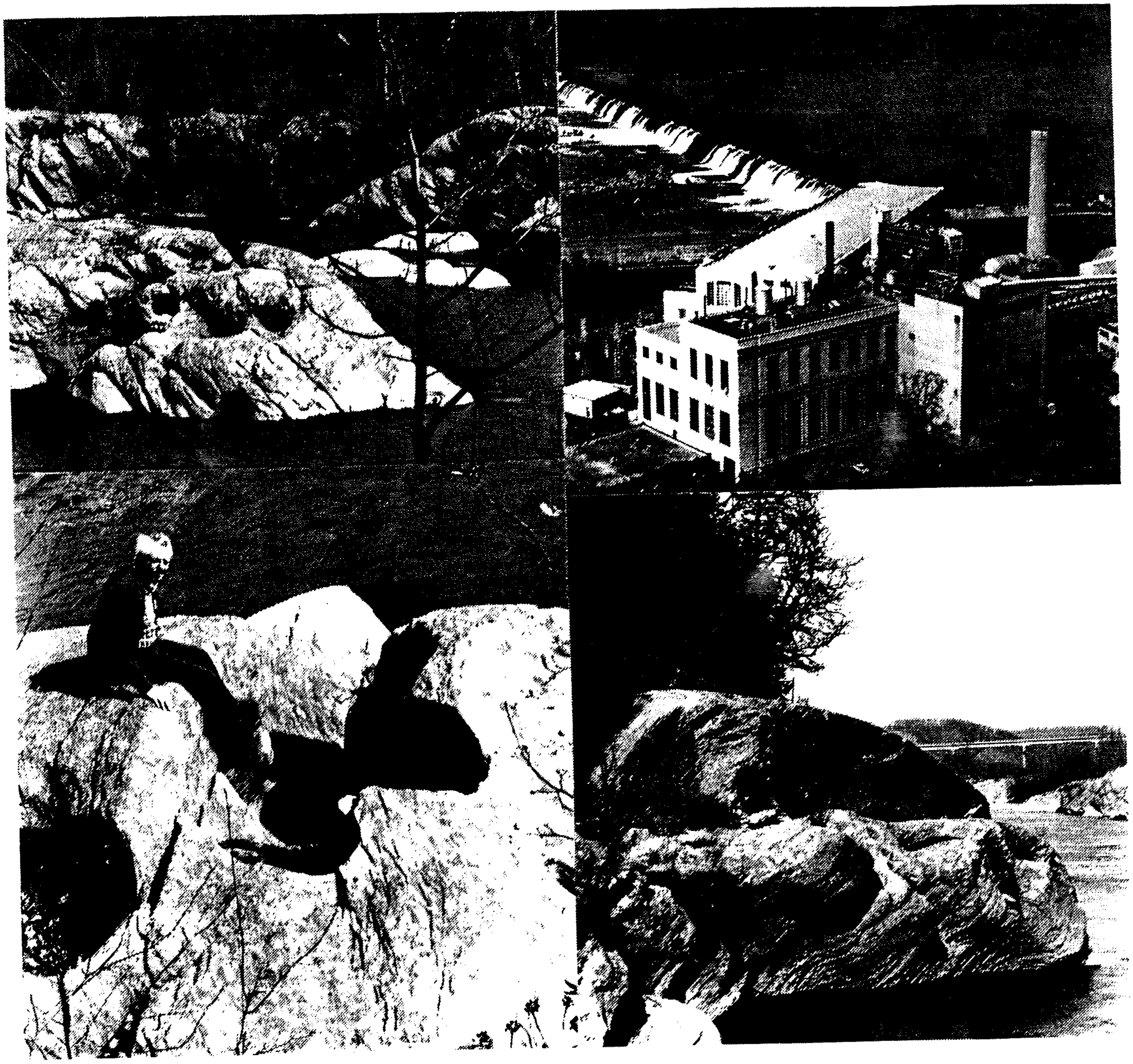
THE GEOLOGY OF THE LOWER SUSQUEHANNA RIVER AREA

A New Look at Some Old Answers

Guidebook for the 7th Annual Field Trip of the HARRISBURG AREA GEOLOGICAL SOCIETY



Coordinated by Glenn Thompson

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* Cover by Karen Wenger

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INTRODUCTION

If John Playfair (1748-1819) had lived in the lower Susquehanna River region of Pennsylvania he may never have written the famous law memorializing his name. In the latter portion of the eighteenth century the Scotsman, James Hutton, theorized about the inter-relatedness of a wide variety of earth phenomenon. Hutton had argued against the catastrophic origin of valleys which allegedly then became water courses by accident. It is common knowledge among students of the history of geological science that Huttons' writings were awkward and cumbersome. It is further recognized that Playfair had rescued Huttons' key ideas and arguments by publishing in 1802 an expository book, "Illustrations of the Huttonian Theory of the Earth". In this work (p. 102) he wrote:

> "Every river appears to consist of a main trunk fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys communicating with one another, and having such a nice adjustment of their declivities, that none of them join the principal valley, either on too high or too low a level, a circumstance which would be infinitely improbable if each of those valleys were not the work of the stream which flows in it."

If Playfair had observed the tributaries entering the Susquehanna River from Harrisburg south to its mouth in Chesapeake Bay, he might have concluded those streams do not illustrate the nicely adjusted gradients used as evidence that rivers and their tributaries are integrated systems. It is observable that for the Susquehanna reach indicated above, all of the tributaries show signs of nonadjustment, some to the extreme of falling directly into the main trunk itself. It appears in some cases to resemble a hanging valley situation of alpine glacial origin. An investigation of the Holtwood area (Stops 2,3 & 5), central in the reach cited, will produce a set of additional anomalous features including intense potholing, bedrock islands with tiered surfaces planed (?) to distinct levels, perched boulders ("fluvial erratics") on island tops, incised tributary meanders and a puzzling set of elongate depressions, the "deeps", in the river bed itself.

Beyond the river and its tributaries lies the problem of weathering and erosion of the interfluves. It is legitimate to ask if the landscape is in a steady state with all parts lowering at the same rate (Hack, 1960). On the other hand the region may sit somewhat stagnant for long time intervals doing little more than weathering, this to be punctuated occasionally by periods of intensified erosion. Bill Sevon will suggest these questions may be illuminated and perhaps resolved in the study of saprolites (Stops 1 & 6).

The bedrock of the gorge including Holtwood is almost exclusively Wissahickon schist. It has been observed to be sufficiently unvarying to be described as "monotonously uniform" (Mathews, 1917). This concept will be investigated by Rodger Faill at

Stop (4). One lithologic variation occurs as a diabase dike immediately below the Safe Harbor Dam, and the schist is differentiated southward into the Peters Creek formation. An extension of this dike will be explained by Charles Scharnberger at Stop (7). Upriver, the Susquehanna crosses other lower Paleozoic rocks of varying resistance, this yielding a variety of river margin landforms.

It is the purpose of this HAGS field trip to acquaint its participants with the geomorphic and lithologic features of the Lower Susquehanna River Valley, to describe some of the research analyses done by myself and others and to critically evaluate the conclusions to date. In addition it is hoped that further research may be stimulated, and in the wildest dream, that some previously undiscovered feature may be located and added to the above list. In the broadest sense it has been my own conclusion that these features are genetically related together as manifestations of Pleistocene floods and their erosive effects in the main trunk (Thompson, 1985). I welcome the eyes, minds and experiences this field trip will bring together with the hope it may stimulate productive criticisms and challenges to past ideas and conclusions.

INDIANS OF THE GORGE

by

Karen Wenger

The lower Susquehanna Valley is one of the richest areas for archaeological study in the East, primarily because the area was so attractive to various Indian groups across the ages. The woods of Pennsylvania were rich in game, and the rivers and streams had an abundance of fish. The waterways also provided a valuable transportation source for the early residents who canoed the waters in their dug-outs.

Archaeologist are pretty much in agreement that the region around Washington Borough was the favorite site along the Susquehanna for Indian habitation. Native Americans of one sort or another have lived there ever since they entered the valley. We might surmise that its popularity then was for the same reasom farmers like it today. The soil was rich, the climate was comparably mild, and the growing season was a bit longer than it is in the surrounding areas.

However, we find plenty of signs of Indian activity within the Holtwood Gorge itself. Bare Island, which is in the field trip area, was extensively excavated by the Pennsylvania State Museum in 1958. Although most of the artifacts were somewhat jumbled due to subsquent animal and Indian activity, the ages of the projectile points, choppers (tools used for scraping hides), stone bowls, and other implements could be compared with artifacts found in other areas whose dates are established. The researchers concluded that most of their findings came from various time periods of what is known as Susquehanna Archaic. The Archaic Period lasted approximately 7000 years between 8000 B.C. and 1000 B.C. This culture extended from New England to the southeastern states with some groups living around the upper Great Lakes, eastern Canada, and the Western Plains, too.

Archaic sites along the Susquehanna and its tributaries are common. Archaeologists think these people lived a hunting and gathering life based on the seasons. During the mild months, they probably established base camps along the river or on the river islands where they could catch fish and mollusks and gather plants they valued for food, medicine, dyes, and ingredients for making things such as baskets. In the winter, they may have settled in more sheltered areas along the tributary creeks, selecting spots where nut trees grew and deer browsed. Deer were most likely a vital part of their existence not only for their meat, but also for their skins from which clothings, blankets, and pouches were made. Their bones and antlers could be used to make tools such as sewing needles, fish hooks, awls, and fasteners.

Stone tools dating from the time include knives, grooved axes, adzes, pestles, mullers, choppers, and banner stones. Banner stones were weights used in the atlatl, a spear throwing device which increased the distance a man could throw a spear five-fold. Bows and arrows had yet to be invented.

In the early part of this period, no fire resistant cooking vessels existed, so archaeologists suggest that the Indians cooked their food by placing fire heated rocks into a leather or bark cooking pot which contained the food to be cooked. Later in the Archaic period, Indians started to make bowls out of soapstone which could resist the fire's heat. Perhaps the Indians in the lower Susquehanna, due to their relative proximity to the steatite "quarries" near Christiana, were the first in the valley to have noncombustible cooking pots.

Younger artifacts, including a few pottery shards, were also discovered on Bare Island, but their numbers are few. Making pottery as well as gardening are two activities which differentiate the Archaic Period from the one following: the Woodland Period. Gradually the Indians were gaining more control over thier food supply by learning how to grow a few crops, which at first may have included sunflower seeds and plants unfamiliar to us as food. Hunting, fishing, and gathering were still practiced during the Woodland Period; it's just that the Indians had added a new way to get food to their list of survival skills.

Since the number of Woodland artifacts on Bare Island is small, however, it looks like the island was used less by the Indians who lived after 1000 B.C.

Other Indians at a later time also inhabited the gorge. The Shenk's Ferry people lived all along the river from about 1300 A.D. to 1550 A.D. This time span sits within the Late Woodland Period, when Indians living in the Susquehanna region are finally given names based on where researchers have found their artifacts. The reason behind this is that now Pennsylvania's Indians were living a settled, agrarian life. On the other hand, archaeologists don't know if the Indians who used Bare Island came from different groups just passing through of from repeaters who returned on a regular basis.

At any rate, the Shenk's Ferry people inhabited the gorge, specifically at Casselman's Run, Shenk's Ferry, and along the Conestoga Creek. Their major claim to fame is that they were the last prehistoric Indians to live in our area. The Susquehannocks knew them; the Europeans did not. One of their towns near Bainbridge was excavated by Temple University in 1965. From this we have learned a little about their culture. They lived in villages. The one near Bainbridge was surrounded by a stockade suggesting a need to defend themselves from attackers. They raised corn, hoed it with stone hoes, buried their dead underneath their hearths, and dug numerous, shallow pits whose purpose is yet to be discovered.

Whatever happened to these people is unknown, but foul play is suspected. Susquehannock remains are also found at the Shenk's Ferry sites at Shenk's Ferry, Casselman's Run, Bainbridge, and Camp Hill. In addition, a few Susquehannock style burial plots were found among the Shenk's Ferry artifacts indicating a brief, joint occupation.

The Susquehannocks came from upstate New York where they had split off from the Iroquois and slowly worked their way into southern Pennsylvania using the Susquehanna River as their conduit. Perhaps there was a feud with their New York brethren which made them leave. It's also possible that they wanted to put themselves in a position where they could trade with the Europeans who were fishing along the Atlantic coast in the late sixteenth century. Although there wasn't much contact between the native Americans and the newcomers, some did exist between the coastal Indians and the fishermen which inland Indians could have heard about.

At any rate, the Susquehannocks moved down river and onto the Shenk's Ferry sites. Shortly thereafter, by 1580, the Shenk's Ferry culture was non-existent. One shared site at Creswell built by the Susquehannocks implies that the Shenk's Ferry-ites were either taken as captives or adopted. This is not to say that some Shenk's Ferry folks didn't simply leave the river for parts unknown to join with other groups to the west. The Creswell town covered ten acres and was divided into two areas. On a hill closer to the river, Susquehannock articles were found such as various brass and iron fragments, and clamshell beads---items the Susquehannocks problably received in trade. On a nearby hill are Shenk's Ferry graves, pottery shards, and saucer-shaped pits. The two separate hills containing separate cultural remains indicate a division between the two groups, even if they did live together for awhile.

The Susquehannocks were the last natives to spend any time on the lower Susquehanna River. The area was convenient for them, because they were reasonably close to the Dutch on the Delaware River, the English on the Chesapeake Bay, and the Swedes at New Castle, Delaware, with whom they traded furs for steel knives and axes, cloth, blankets, mirrors, guns and powder, and minor trinkets. They were also close to the land where fur-bearing animals liked to live. Even though the Susquehannaocks were basically stone age farmers, they quickly established themselves as leaders in the growing international business of fur trade.

After their stay at the Creswell site, the Susquehannocks moved a short distance north to Washington Borough. Moving a village ever twenty years or so was common practice among Late Woodland Indians. Since they didn't fertilize their fields, and since their staple crop, corn, is a heavy feeder, the ground wore out in fifteen to twenty years. It was easier to move to a new, fertile area than it was to stay put and farm distant fields.

It was during their sojourn there, between 1600 and 1625, that captain John Smith saw them at the head of the Chesapeake Bay. And it was during this peroid that trading with the Europeans became an important part of their economy.

From Washington Borough the Indians moved to two sites, one upstream at Billmyer, and one downstrean near the mouth of the Conestoga River. The Conestoga River location was their last residence within the gorge. From Billmyer and the Conestoga River they moved across the river from Washington Borough where the Senecas, rivals in the fur trade, wiped them out. The Susquehannocks ceased to exist as a people by 1680.

To be thorough in this treatment of Indians in the gorge, I shall add a footnote. Because the Senecas, an Iroquois tribe, defeated the Susquehannocks, all the Susquehannock territory, which included a broad band of land surrounding the river, became theirs. With the Susquehannock out of the picture, a vacancy existed, one which the Iroquois wanted to fill with other Indians as a buffer between themselves and the Europeans living closer to the coast. One of these "buffer" groups was a band of Shawnees with a Frenchman, an AWOL soldier from La Salle's millitia, as one of their leaders. This Frenchman, Martin Chartier by name, had married a Shawnee woman, which gained him tribal acceptance, and brought his tribe to the mouth of the Pequea in 1697. There they established a trading business, obtaining furs from their Shawnee contacts to the west and selling the pelts to Philadelphia businessman.

Other Shawnees moved to Columbia, Paxtang, New Cumberland, Lemoyne, the Wyoming Valley, and the West Branch of the Susquehanna. By 1730, most of those in southeast Pennsylvania had moved westward to Ohio in an effort, most likely, to get away from the white people's civilization, which was spreading rapidly across Pennsylania.

The exodus of Indians from this state is a sad one, which begins at this point. William Penn's willingness to treat the natives fairly was an admirable one, but it had too many strikes against it. For one thing, those working on his behalf and those succeeding him didn't share his opinions on how to deal with the Indians. And for another, so many people wanted to leave Europe and move to Pennsylvania with its open policies of religious freedom and land ownership that the Indians became quickly crowded out.

Af

SAPROLITE

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INTRODUCTION

Because this field trip is focusing its attention on the Piedmont Province and the schistose rocks which comprise much of the province, it is appropriate to discuss the saprolites which are locally present on Piedmont rocks in Pennsylvania and commonly present in states south of Pennsylvania. This section will review saprolite description, origin, and significance.

DESCRIPTION

The term saprolite was originally applied to rocks in North Carolina in the following manner:

> "The surface rocks are decomposed, and almost everywhere to a considerable depth. Perhaps 50 feet would be a fair estimate of the thickness of the rotten layer, for which I have suggested the name saprolite, and it is only occasionally that local erosion has laid bare fresh rocks fit for microscopical study." (Becker, 1895, p. 302)

Becker does not elaborate further on the characteristics of saprolite nor does he discuss the origin beyond use of the words decomposed and rotten.

Modern use of the term saprolite generally implies the following characteristics: "it is isovolumetric with the underlying bedrock, as indicated by the retention of texture and fabric of the parent material, and it exhibits gradational chemical and mineralogical changes of composition going from the parent to the geomorphic surface." (Pavich, 1985, p. 308) In addition, there is little or no "movement of alteration products. Leaching has changed feldspars to clay minerals and oxidation of ferrous iron to ferric iron has given the saprolite a brownish color. A saprolite is the product of chemical changes that have taken place in situ under continual moist conditions." (Carroll, 1970, p. 19-20) Saprolites are typically soft and can be easily cut with a knife.

Hunt (1972, p. 150-155) gives an excellent general description of the physical character of saprolite in the Piedmont and much of his description is repeated here.

"Saprolites grade downward from iron-rich aluminous clay at the surface to unaltered bedrock at depth (Figure 7.15) [Figure 1]. In some places they are more than a hundred feet deep. . . . The layering that is typical of residual deposits is perhaps best developed in those parts of the Piedmont Province where the parent materials are granite, gneiss, and schist. Above the fresh bedrock is a layer of weathered bedrock. This layer, variable in thickness, is tough and must be broken with a hammer, but the rock is sufficiently weathered that, when struck by a hammer, it doesn't ring like fresh rock but gives a dull thud.

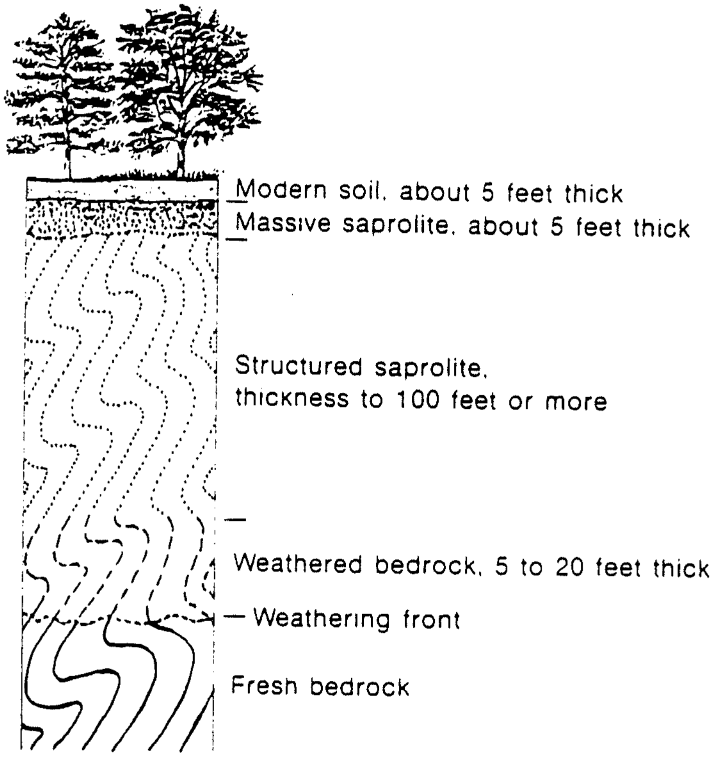


Figure 1. "Typical "ghost" layering in saprolite in the Piedmont Province includes weathered bedrock, structured saprolite, massive saprolite, and the modern soil." (Figure 7.15, Hunt, 1972, p. 152)

"It is discolored brown or yellow with hydrated iron oxides, especially along partings. Clayey alteration of minerals in the rock can be seen with a microscope, but the minerals are still firm. Density of the weathered rock is 5 to 10 percent less than that of the fresh rock. In dense rocks this weathered layer is thin; in porous types it may be many feet thick.

"Above the weathered bedrock is a layer called structured saprolite, because it perfectly preserves the structure of the parent rock, but the mass is altered largely to clay stained with iron oxide, and its density is only half that of the original rock. . . .

"In many places the structured saprolite is capped by a layer of massive saprolite a few feet thick. This material has about the same general appearance and feel as the structured saprolite except that it is massive--that is, without structure. The boundary with the underlying structured saprolite is a gradational zone that is usually no more than 1/2 to 1 inch thick. Any quartz veins present in the structured saprolite would end upward at this boundary, although scattered pieces of vein quartz would be widely distributed in the massive layer above the veins. On hillsides this massive layer is produced mainly by mass wasting, or creep; on flat uplands it is probably produced by frost heaving or by the mixing action of roots and burrowing animals."

SAPROLITE DEVELOPMENT

Saprolite is produced by the complex interactions of chemical weathering caused by ground water. The zone of maximum weathering occurs at the rock-saprolite interface (Figure 2). "At constant volume, slow movement of water to channel favors more concentrated weathering solutions and more rapid denudation than does rapid flow at shallow depths." (Dethier, 1986, p. 505) Additionally, "chemical denudation increases with runoff because larger volumes of . . . water are available to displace mineralized pore waters and to flush readily soluble constituents from particle surfaces." (Dethier, 1986, p. 521)

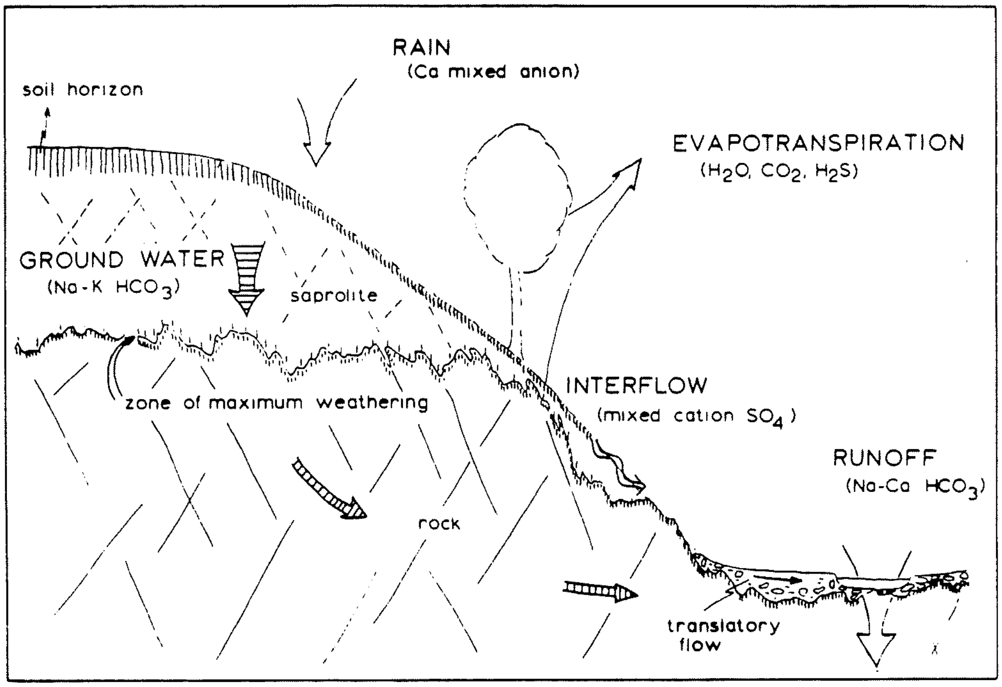


Figure 2. **General weathering model for saprolite development.** (Figure 7, Cleaves and others, 1970, p. 3028)

"Infiltration of water through the soil, movement along foliation planes and joints in the saprolite, and movement along joints and fractures in bedrock are controlled by the permeability of those zones and local hydraulic gradients. The movement of water through the weathered regolith is probably most strongly controlled by rock structure. For most of the metamorphic rocks of the Piedmont, the steeply dipping, remnant rock foliation of the saprolite facilitates movement of water. Due to the dominant vertical foliation, movement of water in the saprolite is anisotropic and preferentially downward. Lateral movement is most likely along major shallow dipping joints and at the weathered rock interface between rock and saprolite. That zone is of higher permeability than the saprolite (Nutter and Otton, 1969). Interconnected open voids, which are produced by mineral dissolution, and open joints are pathways for water movement in the weathered rock zones." (Pavich, 1986, p. 567)

"The chemical weathering is a constant volume process, whereby 50 to 60 percent of the original rock mass is removed as dissolved solids in percolating groundwater. In the transition from rock to saprolite, original rock minerals are replaced by secondary minerals of lesser density, bulk density decreases and porosity increases." (Cleaves, 1974, p. 1) "The alteration of primary rock minerals in a felsic schist was determined as part of a geochemical mass balance study of a 38.4 hectare watershed (Cleaves, Godfrey, and Bricker, 1970). . . . Modal analysis of six thin sections shows that the major rock forming minerals are quartz 42%, muscovite 24%, plagioclase 11%, biotite 10%, and staurolite 9%. . . . the major weatherable minerals are plagioclase and biotite.

"Chemical weathering is accomplished by precipitation percolating through the saprolite and rock. As the water reacts with the minerals some of the reactants are removed in solution and eventually discharged into the surface water (alkali cations, alkaline earth cations, bicarbonate, and dissolved silica). Other reactants are reconstituted as oxides and clay minerals. Mineral weathering sequences in the watershed are: plagioclase alters to kaolinite and gibbsite; biotite to vermiculite and kaolinite with 7A-10A and 10-14A intermediate phases; and muscovite to illite and kaolinite." (Cleaves, 1983, p. 48-49) These secondary minerals occupy the space of the original minerals, but have a lower density. The rock framework is maintained by the quartz which is not dissolved sufficiently to change the rock volume. Color is added to the saprolite by ferric oxides produced during the weathering process.

The Wissahickon Formation in the Holtwood area is an albite-chlorite schist. Individual beds vary widely in lithology as is evident from the outcrops along the railroad track south of Holtwood Dam (Stop 4). Composition of the rock based on a thin section from near Shenks Ferry north of Holtwood Dam comprises the following (Knopf and Jonas, 1929, p. 31):

quartz	21 percent
plagioclase (Ab 100). .	14
muscovite	45
chlorite.	13
magnetite	4
ilmenite.	3
apatite	1

No analyses of mineralogical changes which occur during the transformation of this fresh rock to saprolite have been made in Pennsylvania, but the alterations should be similar to those described above for Maryland.

Extensive chemical weathering, even in the same watershed, does not always produce saprolite. Cleaves and others (1974) and Cleaves (1983) have pointed out that chemical weathering of rock types such as serpentinite is a non-isovolumetric process because there is no quartz to form a framework. Thus, when antigorite, the only significant weatherable mineral in serpentinite, is weathered there is little accumulation of secondary minerals and the rock is slowly denuded by solution.

Although the development of saprolite is generally assumed to be a subaerial process, Pavich and Obermeier (1985) have argued convincingly that chemical weathering can occur at the top of a rock unit buried by another younger rock unit and thus be the result of ground water movement along the interface between the two rocks. A lack of recognition of the true origin of the saprolite could lead to an invalid conclusion about when the saprolite formed. There does not appear to be any problem regarding this situation in the Holtwood area.

Above the saprolite is the soil zone which has been formed by changes in the saprolite. "Alteration of saprolite to soil involves changes in volume and mass relative to the parent saprolite. Density increases upward slightly with the slight rise in percent clay, and then rises markedly with the increase in percent clay in the B horizon. . . . The total mass lost during the alteration of saprolite to soil is about 75% . . . The residual 25% of the mass derived from the saprolite is mainly clay-sized material." (Pavich, 1986, p. 565)

RATE OF CHEMICAL WEATHERING AND SAPROLITE DEVELOPMENT

The use of mass balance studies in a variety of different watersheds has allowed several investigators to deduce rates at which saprolites are forming at the present time. Bricker and others (1968) did one of the first studies in a small forested watershed on Wissahickon schist in Maryland and concluded that (p. 128) "The products of weathering are removed as particulate matter (0.28 metric tons per year) and dissolved material (1.5 metric tons per year)." With a rate of chemical weathering nearly 5 times that of mechanical, saprolite is forming more rapidly than the surface is being lowered. Cleaves and others (1970), in a further evaluation of the studied watershed, concluded that the 5:1 chemical:mechanical weathering ratio is a present day anomaly and that for the long term a 1:1 ratio is more appropriate. Their translated chemical denudation rate is 2 m/my.

Cleaves and others (1974, P. 443) translated their weathering studies into the following rates:

	Serpentinite	Felsic schist
Chemical weathering (m/my)		
Short-term measured	2.2	1.2
Long-term inferred	2-2.5	1.2-1.3
Mechanical weathering (m/my)		
Short-term measured	0	0.2
Long-term inferred	0.03-0.5	1.2-1.3

They conclude (p. 443-444) that "These contrasts in watershed characteristics and differences in short-term erosion rates suggest a basic difference in style of denudation for the two areas. On the serpentinite at Soldiers Delight, chemical weathering combined with large-scale solutional removal of material results in substantial land surface reduction;

mechanical weathering is a secondary factor in denudation. On the schist terrane at Pond Branch, on the other hand, chemical weathering removes about half of the rock mass but leaves behind a deep quartz-iron oxide-clay mineral saprolite; reduction of the land surface is minor. Mechanical erosion is the primary mechanism that reduces the land surface. Although the contrasting styles of denudation are inferred from two small watersheds, the same processes are believed to operate elsewhere in the Piedmont crystalline rocks."

Afifi and Bricker (1983) studied a forested drainage basin in Virginia underlain by Massanutten sandstone and a secondary tributary underlain by Bloomsburg shale. They calculated chemical denudation rates for the areas of 2 m/my and 10 m/my respectively. Saprolites are not forming on these rocks and thus the chemical weathering is a direct contributor to surface lowering. Velbel (1985) calculated a rate of saprolization for an area near Otto, North Carolina of 38 m/my, but indicated that real saprolization rates may vary in the area from 38 m/my to 150 m/my depending on which mineral is being transformed or destroyed. Pavich (1986, p. 577) reported a saprolite formation rate of 3.3 m/my for an area in southern Maryland, but went on to say that "this calculation of chemical mass loss rate derived from the measured total dissolved solids leaving the basin in base flow is probably a conservative, or minimal, figure from which extrapolation to a longer time period can be made safely. The actual chemical mass loss may be greater by a factor of 2, thereby significantly reducing the time required to produce the observed saprolite."

Obviously there is no general accord with regard to the rate at which saprolite forms. Although the reported rates vary considerably, there is a definite indication of control related to rainfall and temperature. The following basic climatic data shows the air temperature-rainfall-groundwater temperature trend for the Atlantic coastal states:

Place	Mean Annual Temperature (degrees C)	Mean Annual Rainfall (in mm)	Groundwater Temperature (degrees C)	Number of Wells
York, PA	11.7	1032	12.6	171
Washington, D.C.	13.9	1036	13.3	46
Richmond, VA	14.3	1119	14.5	58
Greensboro, NC	14.6	1072		
Atlanta, GA	16.4	1197	18.8	4
Charleston, SC	18.3	1250	22.4	7
Jacksonville, FL	20.8	1355	23.6	273

These data indicate a mean annual and groundwater temperature relationship, and a southward increase in groundwater temperature greater than that of mean annual temperature.

Jenny (1941, p. 143) points out that: "For every 10° C rise in temperature the velocity of a chemical reaction increases by a factor of two to three. The rule [Van't Hoff's] holds for a large number of chemical reactions, particularly slow ones and applies equally well to numerous biological phenomena." This is true for everything except carbonates which have an inverse relationship. "It is also known that CO2 partial pressure in water is temperature-dependent, with colder waters able to contain more CO2 than warmer waters. Thus, CaCo3 should dissolve more readily in cooler climates than warmer climates." (Birkeland, 1974, p. 68) In summary, the higher the rainfall and the higher the temperature, the more rapid is the rate of saprolite development. This has two-fold implications: (1) The rate of saprolite development increases southward along the east coast of the United States in present climate. (2) The rate of saprolite development varied considerably during the past when different climates affected the Piedmont.

SIGNIFICANCE

There are two, almost diametrically opposed, schools of thought regarding the significance of saprolite in the Piedmont. One school, advocated by Pavich (1985, 1986), argues that the rate of saprolite development, the rate of uplift, and the rate of erosion in the Piedmont are so well balanced that the landscape of the Piedmont is in a state of dynamic equilibrium, and that the landscape we see today is the product of continued landscape evolution with no ancient aspects.

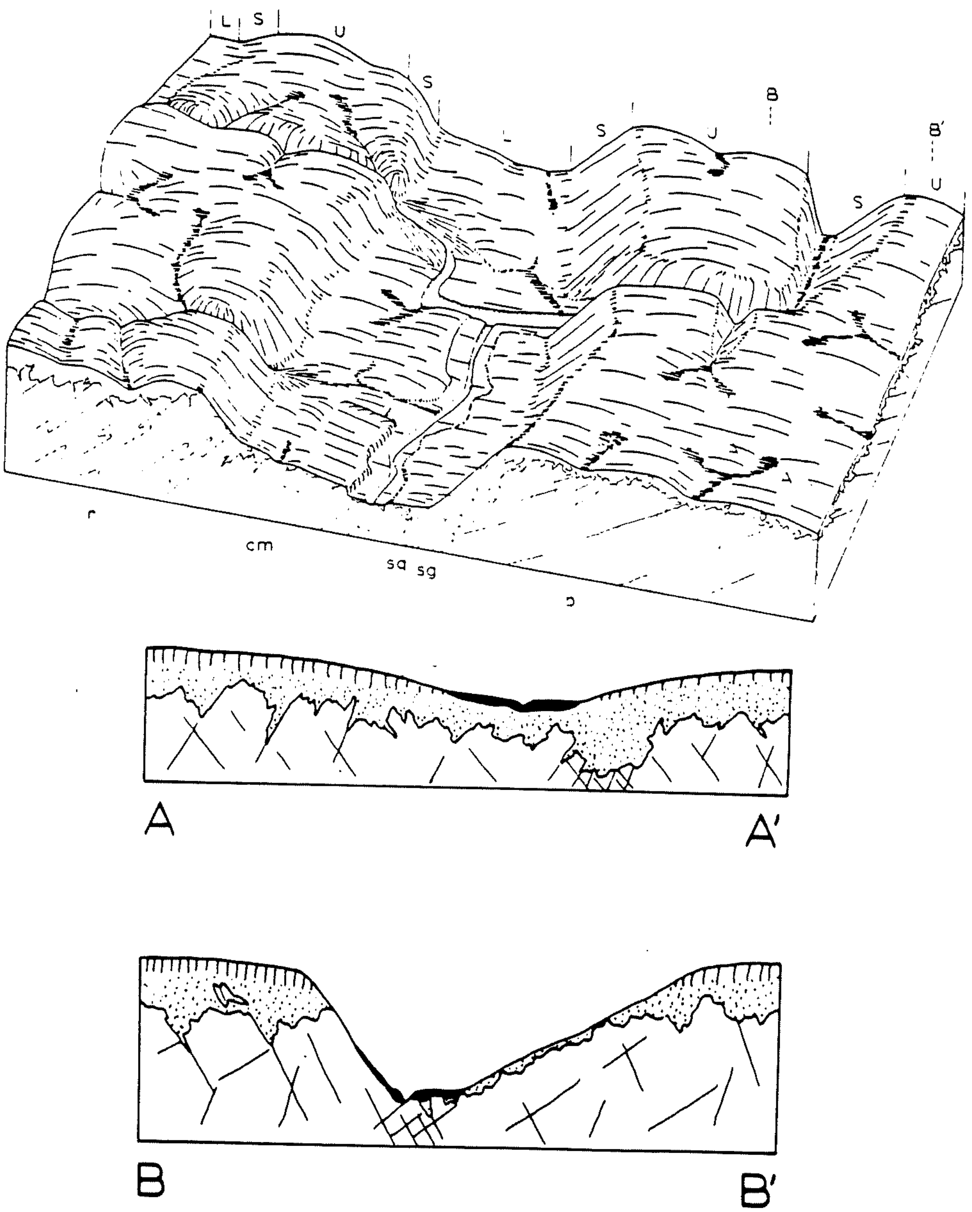
Opposed to this view is that of Cleaves and Costa (Cleaves and Costa, 1979; Costa and Cleaves, 1984) who argue that the Piemont has been a positive area subject to erosion and saprolite development since at least the Triassic, that the main time of saprolite development was during the Late Cretaceous and Early Tertiary, and that erosional incision of the landscape has occurred since the Miocene.

I favor the viewpoint that at least some of the present landscape is old (Sevon, 1985a, 1985b) and believe that the saprolites we see in Pennsylvania are more the remnants of ancient weathering than they are the result of recent weathering. However, this issue is not yet resolved.

LANDSCAPE MODELS

A generalized model for Piedmont landscape of Maryland is shown in Figure 3. The model is characterized by broad, slightly dissected to undissected, upland surfaces underlain by thick saprolite. Major perennial streams have cut through the upland saprolite to the underlying bedrock. Some presently developing saprolite occurs on stream valley slope.

A generalized model for Piedmont landscape in the Holtwood area (Figure 4) differs from Maryland in that there are no broad uplands--the landscape is all in slope with saprolite occurring only at the crests of erosionally rounded hills. Slopes are frequently covered with colluvium of variable thickness composed of transported saprolite and rock rubble. Some streams, particularly those near the Susquehanna River, have incised into bedrock and developed narrow, steep-sloped valleys. Other valleys, those farther from the Susquehanna or those with small flow, have smooth valley bottoms covered with alluvium/colluvium



Landform sketch symbols are: U, upland; S, slopeland; L, lowland. Geologic units are: lr, Loch Raven Schist; cm, Cockeysville Marble; sq, quartzite member of Setters Formation; sg, gneiss and schist members of Setters Formation; b, Baltimore Gneiss. Alluvial fans are present where streams flow from schist onto marble. Along sides of diagram, stipple pattern represents saprolite and modern soil profile, diagonal lines represent jointing, and dashed lines represent foliation.

Schematic Cross Sections symbols are: diagonal lines represent joining in bedrock; stipple pattern represents structured saprolite; short vertical lines immediately beneath land surface represent massive saprolite (where present) and areas where modern soil profile is deep. Section A-A′: First order perennial stream flowing on saprolite. Stream trend portrayed as independent of rock structure. Section B-B′: Section across major perennial stream. Portrays stream incision into a zone of densely jointed bedrock; valley assymetry illustrated as controlled by joining. Massive and structured saprolite zones truncated by stream erosion.

Figure 3. Landscape model for Maryland Piedmont reproduced from Cleaves and Costa, 1979, p. 10-11.

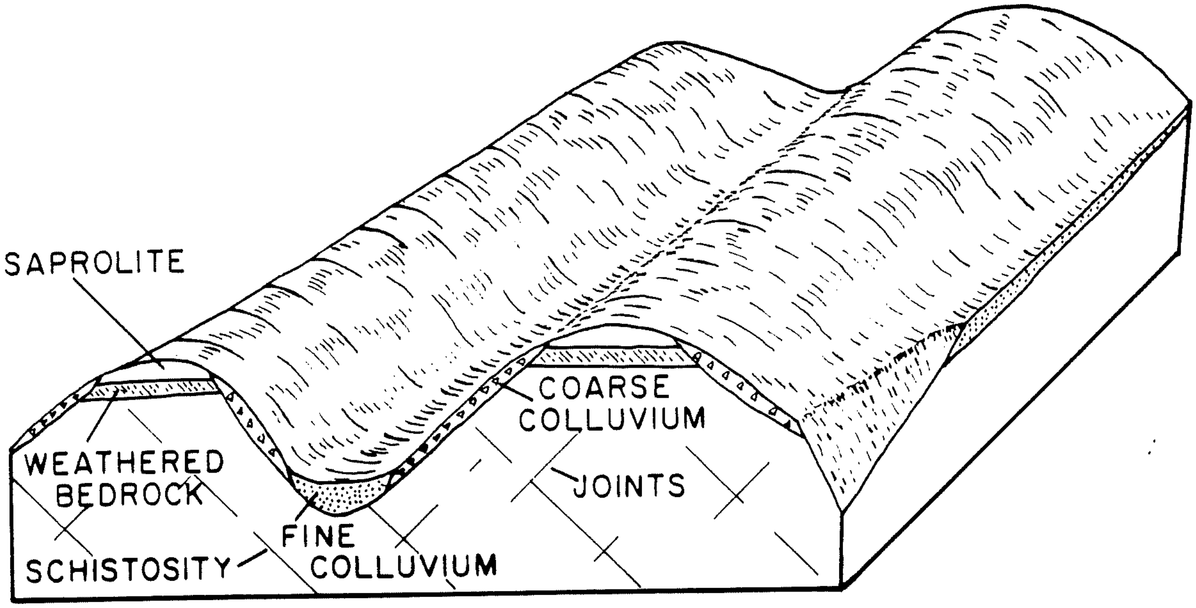


Figure 4. Landscape model showing the position of **weathered** bedrock, saprolite, and colluvium relative to the rounded topography developed on schists of the Wissahickon Formation in the Holtwood area.

composed of fine-grained material derived from saprolite.

Some questions generated by these models are: (1) when was the main period of saprolite development, (2) when did the present cycle of landscape erosion start, (3) when was the main period of colluviation, and (4) why is there a difference in the landscape models between Pennsylvania and immediately adjacent Maryland? Some short answers, with no explanations, may serve as a starting point for thought and discussion: (1) Late Cretaceous to end of Oligocene, (2) Miocene, (3) Pleistocene, and (4) because the vigor of erosion has been greater in Pennsylvania.

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SOME ROCKS OF THE WISSAHICKON FORMATION

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The excellent bedrock exposures in Holtwood gorge of the lower Susquehanna River valley provide a detailed view of a very small part of the Wissahickon Formation, the largely pelitic metasedimentary body that underlies much of the Piedmont in Pennsylvania. 'Wissahickon' is a tortured term, one that has had a long, convoluted history (see Higgins, 1972). Recent work in Maryland (e.g., Muller, 1985; Edwards, 1986) has led to a stratigraphic nomenclature that replaced 'Wissahickon' there; in Pennsylvania, we are still far from that point. The depositional and tectonic history of these rocks need to be delineated before a coherent stratigraphy can be created. Until then we are left with 'Wissahickon'.

Regional setting

The name Wissahickon has been applied to pelitic/micaceous rocks from easternmost Pennsylvania (southeastern Bucks County) westward across Chester, Lancaster, and York Counties and into Maryland. The age of these rocks is still unknown. They lie south of a belt of south-dipping Cambrian and Ordovician carbonates that similarly stretches from Bucks County into Maryland; the Martic line separates them. If the Wissahickon rocks are Precambrian, then the Martic line must be an overthrust; on the other hand, if the line is a conformable contact, then the Wissahickon is of Lower Paleozoic age. The consensus now favors the latter interpretation, but this presently quiescent controversy does not directly bear on the Holtwood exposures.

South of the Holtwood area, and presumably conformably overlying the Wissahickon are the Peters Creek Formation, the Cardiff conglomerate, and the Peach Bottom black slate. These units occupy the hinge of a regional fold, the Peach Bottom syncline. Also open to question is whether the Peach Bottom structure is a syncline, an anticline, or a thrust fault. A short distance north of the Holtwood dam is the Tucquan anticline, the westward extension of the Mine Ridge. Holtwood gorge lies in the common limb of this fold pair.

Structure

The most striking aspect of these rocks is the presence of a pronounced foliation (referred to as S1) that dips moderately to the southeast. This fabric is caused primarily by the parallel alignment of the phyllosilicate minerals muscovite and chlorite. Locally, a second, more steeply south dipping foliation, a cleavage, pervades the more micaceous rocks. This S2 foliation was formed by the very fine-scale folding (crenulation) of the S1 foliation. The intersection of these two foliations creates a lineation that appears as a fine crinkling on the S1 foliation, plunging with some variability to the southwest. Apparently, this was a rather complex deformation--the multiple, divergent crenulation lineations that appear on some S1 surfaces suggest a changing stress orientation during this tectonic event. Although meso-scale folds are present here and there, they are small (cm to dm in size) and of limited extent. In general one can say these rocks are not folded on a mesoscopic scale.

Metamorphism

It is quite evident that these rocks have been metamorphosed. The shiny reflectance on the S1 foliation is characteristic of muscovite, and the dark green color suggests the presence of chlorite. Quartz is common, most of it occurring in very thin layers of interlocking grains which are often crossed by thin sigmoidal stringers of chlorite/muscovite. Quartz is also found in large (up to 8 by 30 cm) pods and lenses, particularly in the more pelitic portions. These masses apparently grew in place, accumulating the excess quartz produced by the conversion of clays to phyllosilicates.

In the more psammitic parts a few layers contain a profusion of orthoclase (and possibly quartz) porphyroblasts, lending to the rock an aspect of conglomeratic sandstone. The orthoclase porphyroblasts are unusual--most of them are chock-full (10 to 15 percent) of inclusions consisting of opaques (hematite?), zircons, and very fine transparent acicular material. In addition, thin sections reveal the presence of calcite, almost always in association with the orthoclase porphyroblasts. Accessory minerals [identified by Robert Smith, Pennsylvania Geological Survey] include black plates of ilmenite or hematite, irregular patches of magnetite (some layers in outcrop are quite magnetic), brown rods of the tourmaline group mineral dravite, a bit of spessartine garnet, and limonite after pyrite.

The amounts of the various minerals vary from place to place in the gorge. Some of the rocks are very phyllitic, consisting primarily of muscovite and chlorite (>80 percent). Others are more psammitic, containing significant proportions of feldspar and quartz. The absence of clay minerals suggests that equilibium had probably been achieved, that the metamorphism persisted long enough to convert all the clays into muscovite and chlorite plus quartz. These rocks were raised only to a lower greenschist grade of regional metamorphism as indicated by the presence of chlorite and muscovite, and the absence of almandine garnet.

Sedimentology

Considering that these rocks have been metamorphosed (producing the S1 foliation) and deformed (giving the S2 cleavage), one can query of the nature of the protoliths. Because the metamorphic grade was quite low, the sedimentary aspects of the original rocks are still present. The pelitic phyllites are rather homogeneous and compositional layering does not stand out. But the S1 foliation is not flat; rather it is uneven. Looking edge on at the S1 foliation one notices that the rocks contain ripples, lenses of granular quartz surrounded by phyllosilicate material. The ripples indicate that these protoliths were sedimentary rocks deposited in shallow water. In the coarser grained rocks, a distinct layering is preserved, parallel to the S1 foliation. Within the psammitic beds, one can see parallel laminae and flat troughs with low angle crossbedding. The crossbedding indicates that this coarser material was transported and deposited by currents. Truncation of the crossbedding demonstrates that stratigraphic tops are to the southeast, and that the rocks are right-side-up.

In addition, the porphyroblasts in the conglomeratic-looking beds do not show the crystal faces characteristic of orthoclase--instead, the grains are rather well rounded. This suggests that the porphyroblasts did not grow in place as a consequence of the metamorphism, but that they are detrital and have been transported to this site by currents. [Robert Smith has suggested that the porphyroblasts may have formed as euhedral phenocrysts in a glassy lava flow. Immersion in sea water would have dissolved the glassy fraction, leaving the orthoclase crystals to be reworked, rounded, and carried by littoral or turbidity currents to the depositional site.] The orthoclase occurs not only as porphyroblasts but also as silt-size grains in the more pelitic beds. Therefore, a source of orthoclase must have been present throughout the deposition of most of the sedimentary sequence in the gorge.

Walking southeastward along the railroad, upward through the section, one notices that the rocks gradually become more psammitic, followed abruptly by a fine grained sequence. The upward coarsening pattern repeats itself a number of times throughout the gorge(ous) exposures on a variety of scales, from meters to hundreds of meters. This field excursion takes us through one large cycle, which contains at its top several thinner upward fining cycles. This sedimentary pattern is characteristic of deltas, the primary environment in which land-derived material is deposited in an adjacent body of water. The repetition of cycles reflects the switching of distributary channels from one locale to another on the delta.

Geologic history

The relatively fine-grained character of most of this rock indicates that the delta was generally a low energy environment with a small tidal range, subdued wave action, and moderate long shore currents. The modern Mississippi River delta would be an appropriate analogue. The presence of the coarse orthoclase detritus suggests that some of the source area was a volcanic terrane, and that the source was nearby (orthoclase does not withstand mechanical working very well). This depostional site then must have been adjacent to an island arc, and was perhaps a back-arc basin. So little is known of the Piedmont in Pennsylvania that we have no idea how large this basin was, or how much of the surrounding Wissahickon was part of the same basin.

Subsequent to the deposition of an as yet unknown thickness of sediment in the basin, metamorphism commenced. That the resulting foliation parallels the original bedding indicates this event was a regional burial metamorphism with little or no deformation associated with it. This metamorphism is generally considered Taconian in age because of cooling dates and Alleghanian overprinting. At some later time, probably during the Acadian or possibly Alleghanian, tectonic stresses were applied to these rocks, folding the phyllosilicate minerals into a pervasive crenulation and producing the marked lineation of bedding surfaces (S1 foliation) in the more pelitic beds. It is possible that this S2 crenulation was coeval with the uplift of Mine Ridge and the growth of the Tucquan anticline to the north.

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JURASSIC DIKE AT ROCKHILL

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GENERAL DESCRIPTION

At Rockhill, Conestoga Township, Lancaster County, there is an excellent exposure of one of the diabase dikes which cut across the Paleozoic structure of southeastern Pennsylvania beyond the margins of the Triassic-Jurassic extensional basin. The outcrop is located along the east bank of the Conestoga River, about 2.5 miles (4 kilometers) south of Millersville. On the Lancaster County side of the Susquehanna River, the dike can be traced from Safe Harbor, 2.5 miles (4 km.) south of Rockhill to S.R. 462, about 5.5 miles (9 km.) north of Rockhill. The outcrop is fairly continuous, but there are many small discontinuities and off-sets. The strike of the dike changes from about N30°E near Safe Harbor to N20°W near Route 462 (Fig. 1). This dike has been referred to as the Safe Harbor Dike (Inners and Wilshusen, 1978), although the faculty and students at Millersville University usually have called it the Rockhill Dike (e.g., Sachs, 1973). This dike has not been dated, but dates of similar rocks fall in the range 190-200 million years (Erickson and Kulp, 1961; Fanale and Kulp, 1962), which is now considered to be Early Jurassic.

PETROLOGY

Sachs (1973) examined samples from Rockhill in thin section as part of a senior research paper at Millersville State College (now Millersville University). The result of a point count of 879 grains is presented below and compared with a petrographic analysis of a similar dike at Hellam, York County.

Rockhill Dike (Sachs, 1973)		Hellam Dike (Inners and Wilshusen, 1978)	
Labradorite	53%	Labradorite	40%
Pyroxene	43	Pyroxene	41
Pyrite (*sic*)	4	Ilmenite and Magnetite	5
		Sericite	10
		Chlorite	4
		Biotite	trace
		Apatite	trace

If we assume that what Sachs identified as pyrite is actually Fe-Ti oxides, and add sericite to labradorite and chlorite to pyroxene (the former mineral in each case being an alteration product of the latter), then the two analyses are very similar, although the dike at Rockhill may have a slightly higher ratio of plagioclase to pyroxene than the dike at Hellam. The samples from both dikes are fine-grained and equigranular, with plagioclase more euhedral than the pyroxene. Inners and Wilshusen describe this texture as subophitic.

Sachs also describes a 3 cm. wide chilled margin at the contact of the Rockhill dike with the Conestoga Formation. The chilled margin is divided into three zones: 1.) a very thin, gray devitrified glass, 2.) a 0.5 to 1.0 cm. thick black devitrified glass, and 3.) a microcrystalline basalt zone, grading into diabase. Sachs identified augite, diopside, tremolite and quartz in phenocrysts and amygdules within the chilled margin, as well as xenocrysts of Conestoga Limestone containing diopside and tremolite.

Smith *et al.* (1975), classified the Mesozoic diabase of Pennsylvania into three categories on the basis of geochemistry: the Quarryville, York Haven and Rossville types. The Safe Harbor/Rockhill dike is classified as York Haven type, meaning that it is a quartz-normative tholeiite that experienced a relatively complex history of partial crystallization and assimilation in both the upper mantle and the crust before emplacement.

STRUCTURE

The thickness of the dike at Rockhill is about 35 feet (10.6 meters), which is about the maximum thickness that it attains. Bria (1978) investigated the width of the dike using a proton magnetometer. One of his traverses and the interpretation is shown in Figure 2. While there is evidence (discussed below) that the dike dips steeply to the west, a vertical model gives the best fit to the observed anomaly.

The dike is not a completely continuous body, but rather is broken into a number of segments which generally show a left-lateral separation, sometimes with a gap and sometimes with an overlap between segments. Some of the segments change strike by as much as 27° and some have a Z-shaped map pattern (Bria, 1978; Scharnberger *et al.*, 1979). This pattern probably reflects a pattern of extension fractures in the country rock at the time of magma injection and could be interpreted as the result of horizontal shear. The gradual change in strike from NE near Safe Harbor to NW north of Rockhill must be accommodated by any hypothesis. The origin of the outcrop pattern may be a topic for some lively discussion at the field trip stop.

The outcrop at Rockhill is complexly jointed. A set of quasi-columnar joints is present, with the columns plunging consistently to the east (Fig. 3). Assuming that the columns formed perpendicular to the walls of the dike, a westward dip in the range 70° to 88° for the dike is implied. The dike changes strike from N10°E at Rockhill to N12°W near the northern termination of this dike segment about 1.25 mi. (2 km.) north of Rockhill. The "fan" of bearings of the columns shown in Figure 3 reflects this change in strike. Columns in the southern part of this dike segment generally plunge more steeply than columns in the northern part. The columns do not occur throughout the outcrop but only in a few places, usually with 2 or 3 columns occurring together. The columns are seldom hexagonal in cross-section, but often approach a circular shape. The reason for this particular column morphology also may be a topic for discussion. Several large columns which have weathered out of (or been excavated from) the outcrop can be seen lying by the side of the path leading north from the parking lot.

GEOMORPHOLOGY

The dike seems to have exercised some control over the path of the Conestoga River in this vicinity. A meander bend of the river loops around the northern end of the dike segment which terminates north of Rockhill and, for a short distance, the river flows in a "chute" between two overlapping segments of the dike. Then the river flows almost due south without meandering for about 2.5 mi. (4 km.), keeping the dike on its east bank. However, considering that the river has many entrenched meanders in its upstream reach east of the dike, it is not clear why the dike should prevent the river from continuing to meander once it is west of the dike. (This should be more fuel for discussion.)

In many places the dike makes a low ridge above the surrounding limestone terrain. At Rockhill, the dike outcrops are well below the crest of the adjacent ridge, which stands with 120 ft. (36 m.) of relief above the river. Farther north, the dike outcrop belt rises in elevation until the dike does coincide with the highest ground. The ridge inside the meander loop mentioned above has the same trend as the dike, which crops out along its crest.

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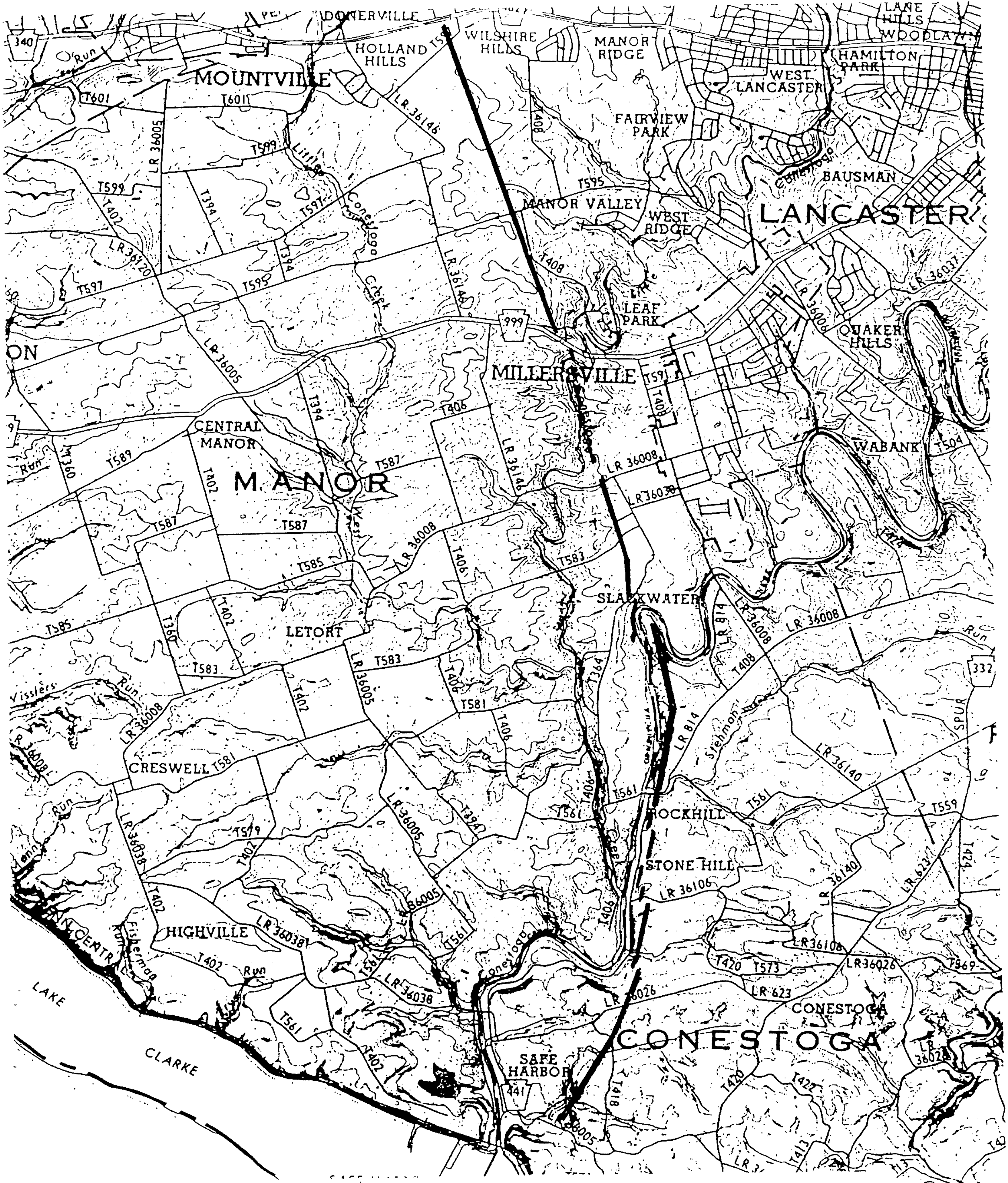


Fig. 1. Map of the Rockhill (Safe Harbor) dike, Manor and Conestoga Townships, Lancaster Co., PA. Scale approx. 1:53,300; width of dike exaggerated.

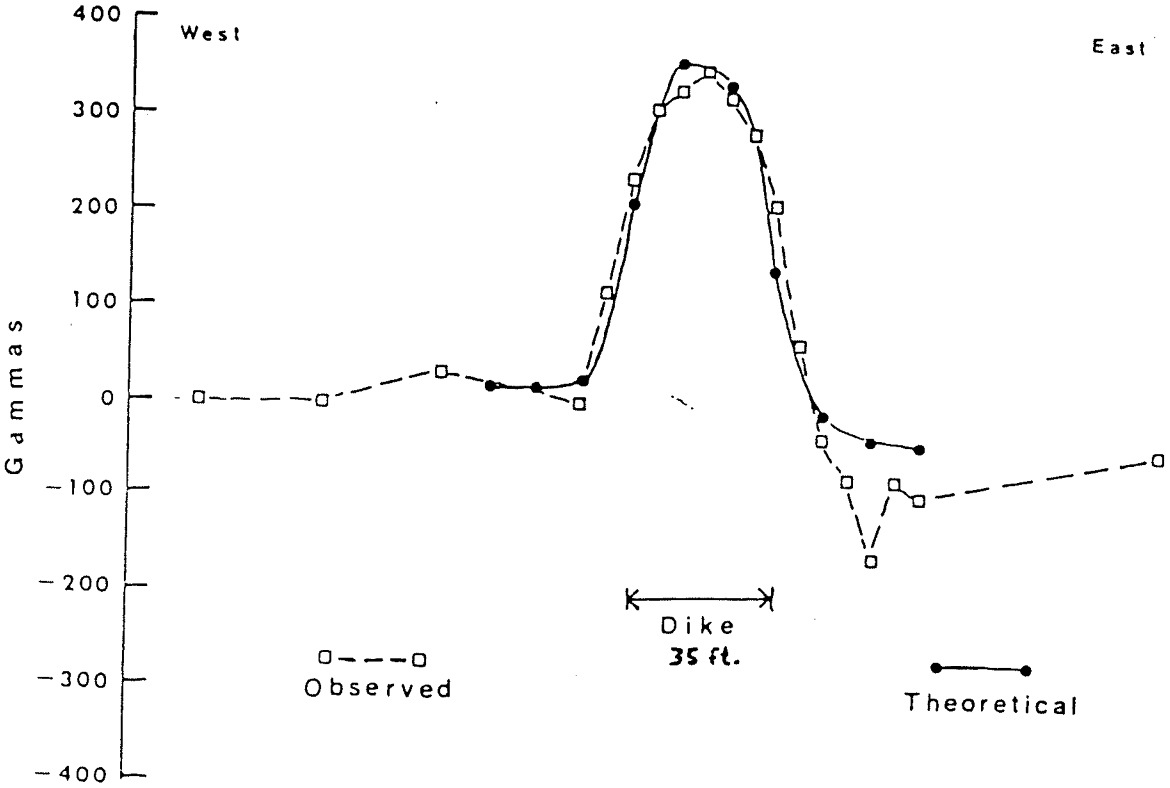


FIG. 2. Observed and theoretical total-field magnetic profiles across the dike north of Rockhill (Bria, 1978)

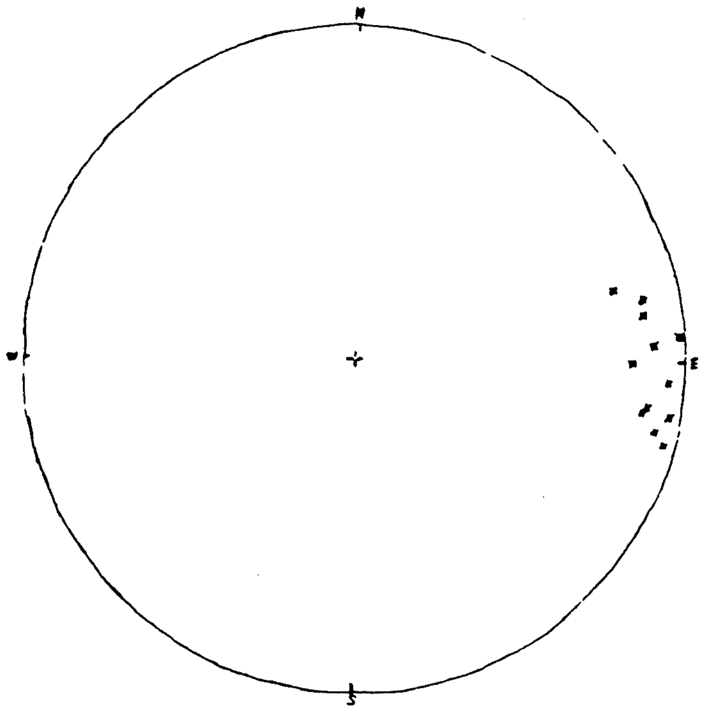


FIG. 3. Plunge of columnar structures in vicinity of Rockhill.

THE SUSQUEHANNA RIVER GORGE AT HOLTWOOD, PA.

Glenn H. Thompson, Jr.

Elizabethtown College

The Susquehanna River separates Lancaster and York Counties (Fig. 1) in part by flowing through a dramatic gorge in which two hydroelectric impoundments, Holtwood Dam and Safe Harbor Dam, have all but obscured the natural river bottom. In addition, backwater from the Maryland located Conowingo Dam reaches nearly to Holtwood thus indunating much of that portion as well. The gorge is generally accessable from Penna. Rt. 372 west of Buck in Lancaster County. The best viewpoints are from the Pinnacle just north of Holtwood, from the observation park above Holtwood Dam (Stop 3) and from Susquehannock State Park (Stop 2) to the south. Of special interest for viewing the river, one may traverse the river's entire breadth by walking across the Norman Wood bridge. Foot trails such as the Connestoga and the Mason-Dixon give added access to the gorge margins. It must be added that large areas of dry river bed are especially inviting, however they can become DANGEROUS in short time intervals as hydroelectric needs vary.

Notwithstanding abrupt leaps in the presently impounded long profile (Fig. 2), the original river displays a convex-up configuration steepening its gradient down stream through the gorge. Variations of this profile characteristic are present in other Appalachian-Piedmont rivers (Hack, 1973, 1982) as well. This unusual profile is also mirrored in the local tributaries (Thompson, 1985).

The gorge depth (to present water surfaces) varies irregurarly from approximately 60 meters to a maximum of 157 meters at the Pinnacle. The river varies in width from 2.6 km. at Washington Boro immediately to the north to a minimum of 0.37 Km to the Pinnacle, thus reducing the width by a factor of seven.

The general geology of the gorge area has been discussed by Knopf & Jonas (1929), Jonas & Stose (1930) and by Stose & Jonas (1939). Additionally, special topics including "the deeps" (Mathews, 1917), terrace gravels (Stose, 1928), the Westminster anticline (Campbell, 1933), a paleo falls system (Thompson, 1985), bedrock erosion of the river bed (Sevon & Thompson, 1987) and a general field site description (Thompson, 1987) have been investigated and reported.

PECULIAR FEATURES OF THE SUSQUEHANNA GORGE AT HOLTWOOD, PENNA.

"THE DEEPS": Preconstruction engineering studies for lower Susquehanna River hydroelectric impoundments have provided river bottom survey information of better than usual detail (Fig. 3 & 4). Based upon this kind of data and upon actual observations made during cofferdam induced river bed draining during dam construction, E. B. Mathews (1917) wrote,

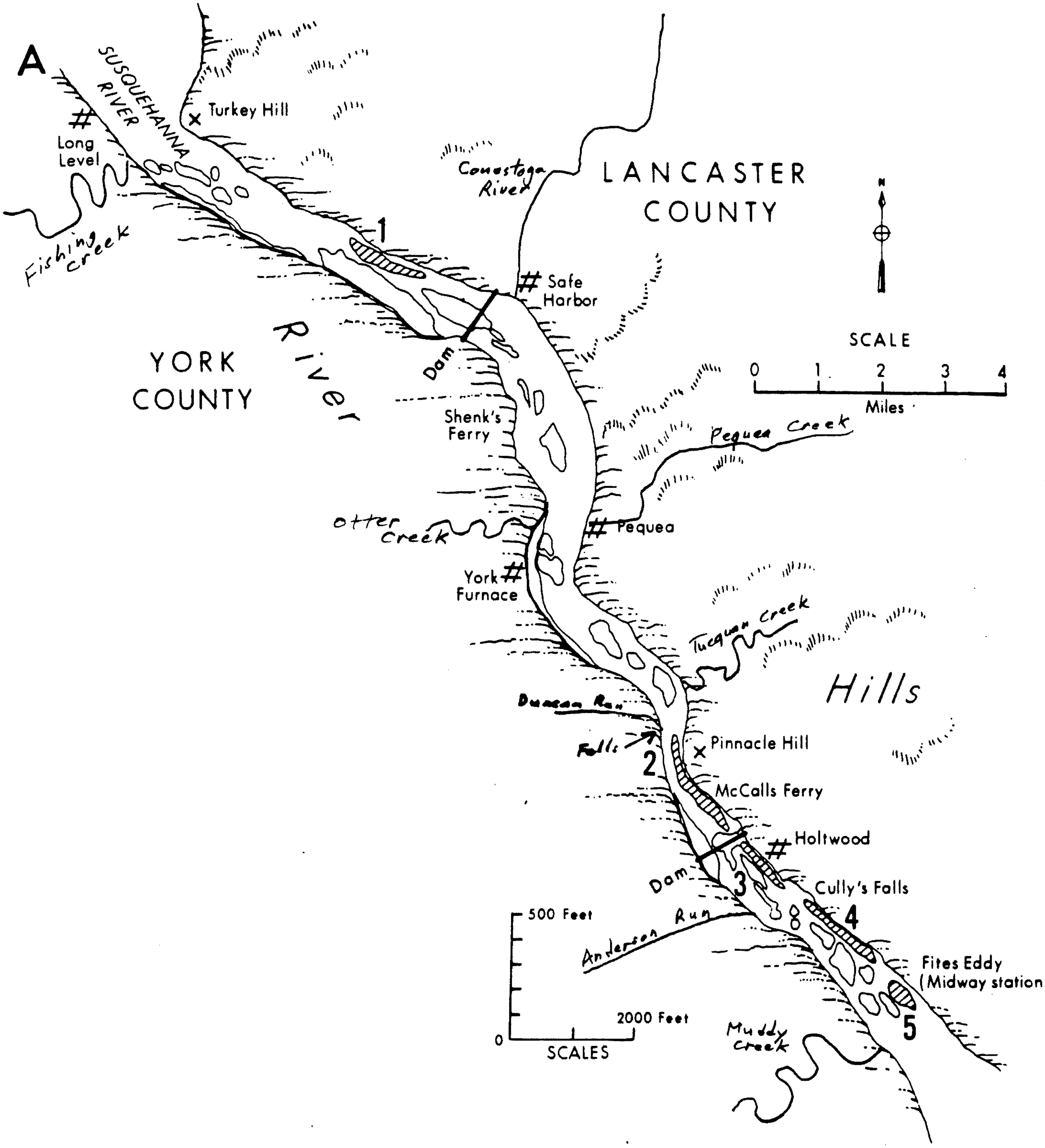


Fig. 1. General Map of the Lower Susquehanna River Gorge (from AEG 1978 Field Trip Guidebook)

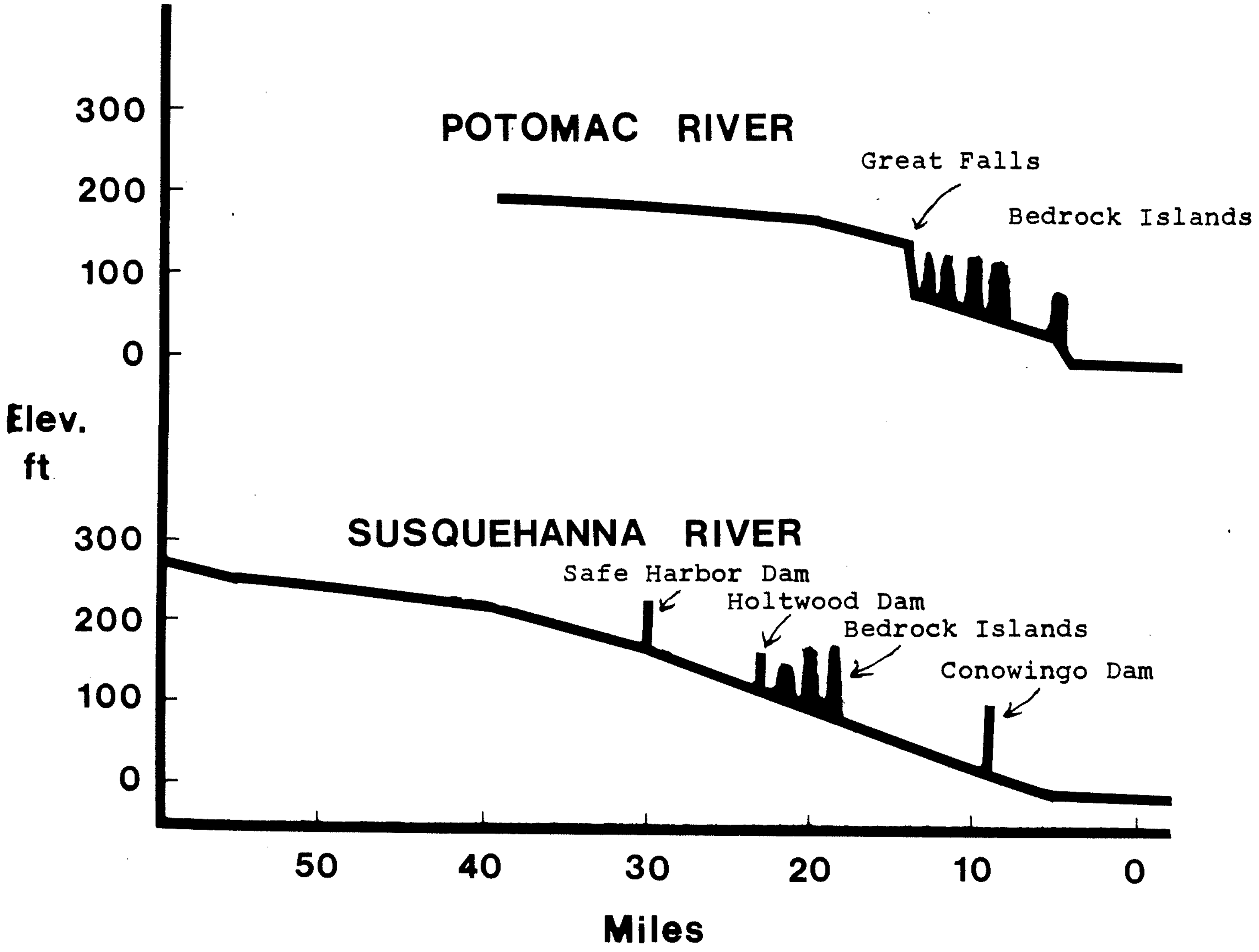
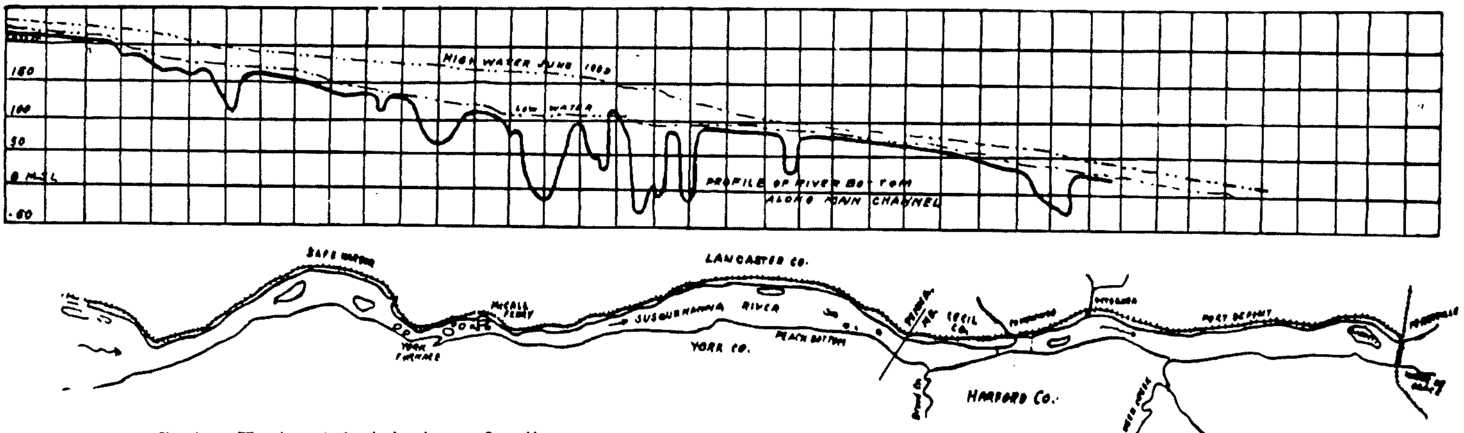


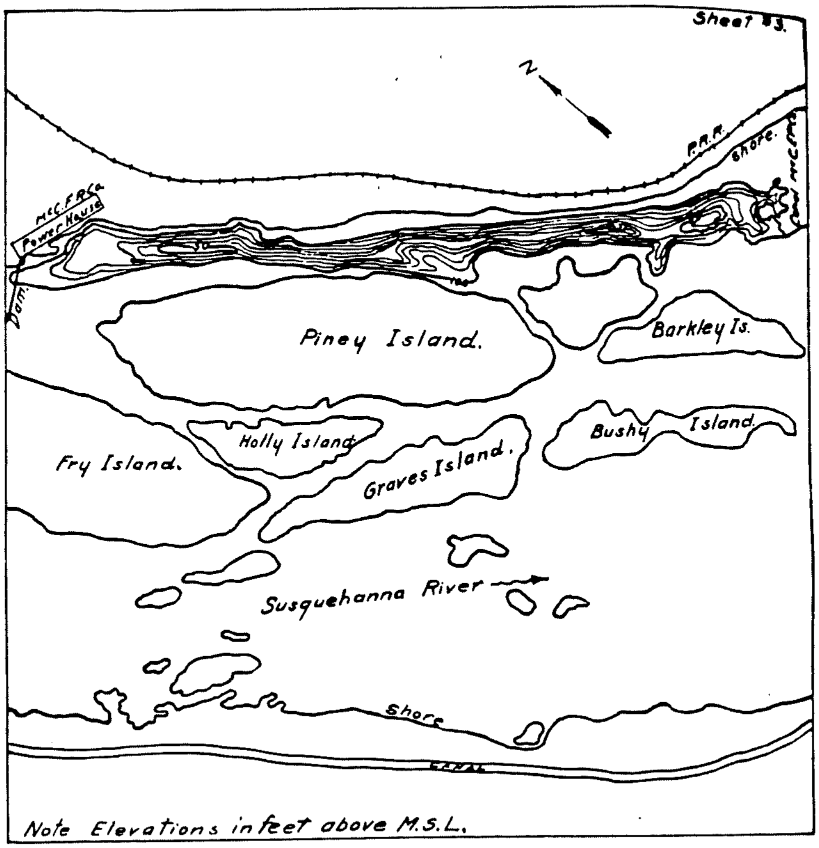
Fig. 2. Longitudinal Profiles of the Potomac and Susquehanna Rivers



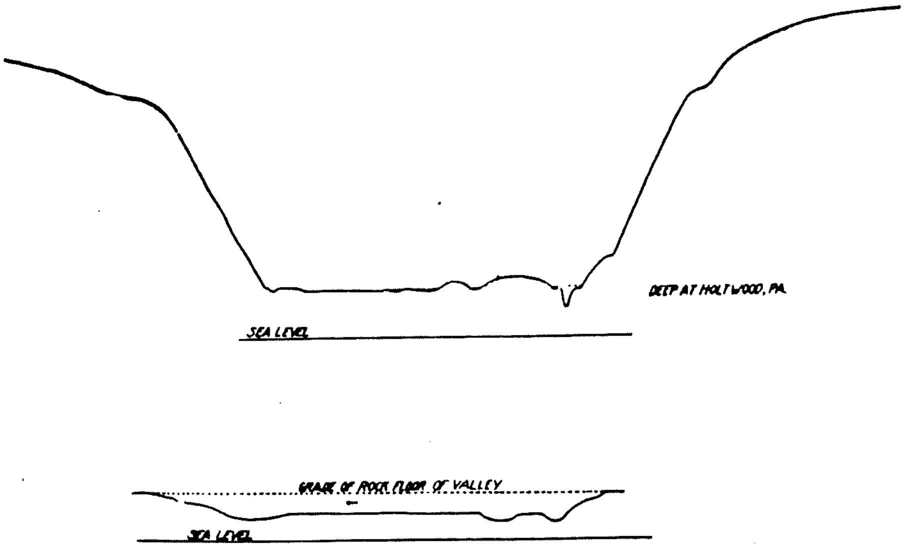
Scale: Horizontal, 1 inch = 6 miles

Fig. 3. *Plan and Profile of Susquehanna River, showing Location of "Deeps"*

(from Mathews, 1917)



-*Map of "Deep" at Holtwood, Pennsylvania*
Scale: 1 inch = 1,000 feet



-*Profiles of "Deep" at Holtwood, Pennsylvania*
Scale: Horizontal, 1 inch = 2,000 feet; vertical, 1 inch = 500 feet

Fig. 4. (from Mathews, 1917)

> "The portion of the survey under present consideration extends from Turkey Hill, 3 miles south of Washingtonboro, Pennsylvania, to tide near Port Deposit, Maryland. Throughout the entire distance the river flows in a flat-bottomed rock gorge with stream-cut walls, which rise to the general level of the Piedmont Upland. The river bottom is generally studded with numerous rocky inlets, which rise but a few feet above the normal river surface, and a few steep-sided islands, whose wooded tops may reach 100 feet above the water. Under ordinary conditions the bed of the river is covered with less than 15 feet of water, and in dry season may be largely exposed as a rock floor from one-half to one and one-half miles in breadth. Within this flat bottom of the broad gorge the survey discovered six long spoon-shaped depressions, some of them over 100 feet deep, with their deepest portions extending below tide level."

Mathews further described each "deep" in detail, one of which had been observed while drained and is in present use as the tail race for the Holtwood Dam. He continued,

> "This "deep" lies close to the left bank of the Susquehanna, between it and Piney Island, and has been utilized by the engineers as a tail race for their power plant. During construction of the dam it was exposed by a diversion of the water to a depth of nearly 50 feet. The water surface was about 110 feet above tide and the rock floor about 100 feet. From the latter rise Fry and Piney islands to a height of 140 and 160 feet respectively. The hills above the power plant rise rapidly to an elevation of over 500 feet. This depression is a gorge of 4,000 feet long, with a width of from 200 feet to 300 feet within the rock floor of the river, which at this point is about 100 feet above tide. The general level of the bottom of the gorge is 60 feet above tide, or 40 feet below its rim, and shows three local depressions (figure 4). That opposite the upper end of Piney Island reaches to 50 feet above tide, while the two at the lower end, opposite Barkley Island, reach 40 feet above tide. The rock barrier between it and the foot of Culleys Falls was removed, so that it is now continuous with the "deep" described later. The withdrawal of the water gave exceptional opportunity for studying the walls. Everywhere were deep vertical pot-holes of varying diameter and perfection, so closely placed that they suggested the fluting of a pipe organ or the fracture of a block by the use of "plug and feathers". Some of the pot-holes extended below water level, while others showed nests of boulders part way down the sides of the gorge."

Mathews went on to summarize his paper,

> "Their peculiarity lies in their extreme ratio of length to breadth, their depth of cutting (at times below sealevel), and their bottom profiles, which rise downstream and do not persist as canyons."

It seems obvious the "deeps" have an origin in the hydrodynamics of fluvial bedrock erosion. Investigators are yet wondering about the particular conditions under which they develop. Speculations run rampant, and good questions are scarce. Certainly to be considered are such factors as flood turbulence and periodicity, water depth, bed and suspended load and the possibility of ice influence. Are the "deeps" genetically related to present day conditions, or are they relicts of earlier climatic perturbations?

BEDROCK ISLANDS: The Susquehanna River upstream from Columbia is typified by shallowness and scattered alluvial islands. The river there is intermittently cut across by ledges of dipping resistant rock and is sometimes broken by massive dikes or sills such as at Hill Island and the area between Falmouth and Goldsboro. In direct contrast the river in the gorge area is studded exclusively with islands composed of unremoved portions of local bedrock. These islands are shaped in plan to suggest hydrodynamic processes and are dramatically modified by joint controlled channeling. A casual inspection will reveal several distinct levels of their summits, some with nearly accordant heights. A second revelation displays the fact that their summit heights tend to increase in the downstream direction. This has been interpreted (Thompson, 1985) to imply ancient river bed levels which were simultaneously lowered and abandoned due to flood erosion of a migrating falls/rapids system not unlike the present Great Falls of the Potomac.

Closer scrutiny of the islands will produce two additional features of interest. First, there are multitudes of potholes. These vary in size from tiny to enormous, the largest observed being nearly seven meters deep and three meters in diameter at the base. It is suggested (Sevon & Thompson, 1987) these potholes (Fig. 5) have aided river bed erosion by weakening jointed sections to the point where hydraulic plucking could remove whole blocks at a time leaving dissected voids on the channel margins. Second, large rounded boulders often exceeding one meter in diameter are found scattered about on the island tops. These are perhaps "fluvial erratics" deposited as bedload when the present island tops were part of the river bed and were subsequently stranded as islands formed by removal of surrounding rock.

TRIBUTARIES: The tributaries which feed into the gorge area range from small to moderately large. These include unnamed creeks less than 1 km. long plus larger named tributaries such as Otter creek (22 km.), Pequea Creek (77 km.) and the Conestoga River (107 km.). These tributaries display, without exception, convex-up long profiles. In moderate to longer tributaries the upper reaches display gentle gradients and well developed floodplains. As the streams approach the main river they steepen and in many cases tumble and fall into the gorge itself. To a limited extent these features may be directly observed in Anderson Run, a 4 km. long stream paralleling Rt. 372

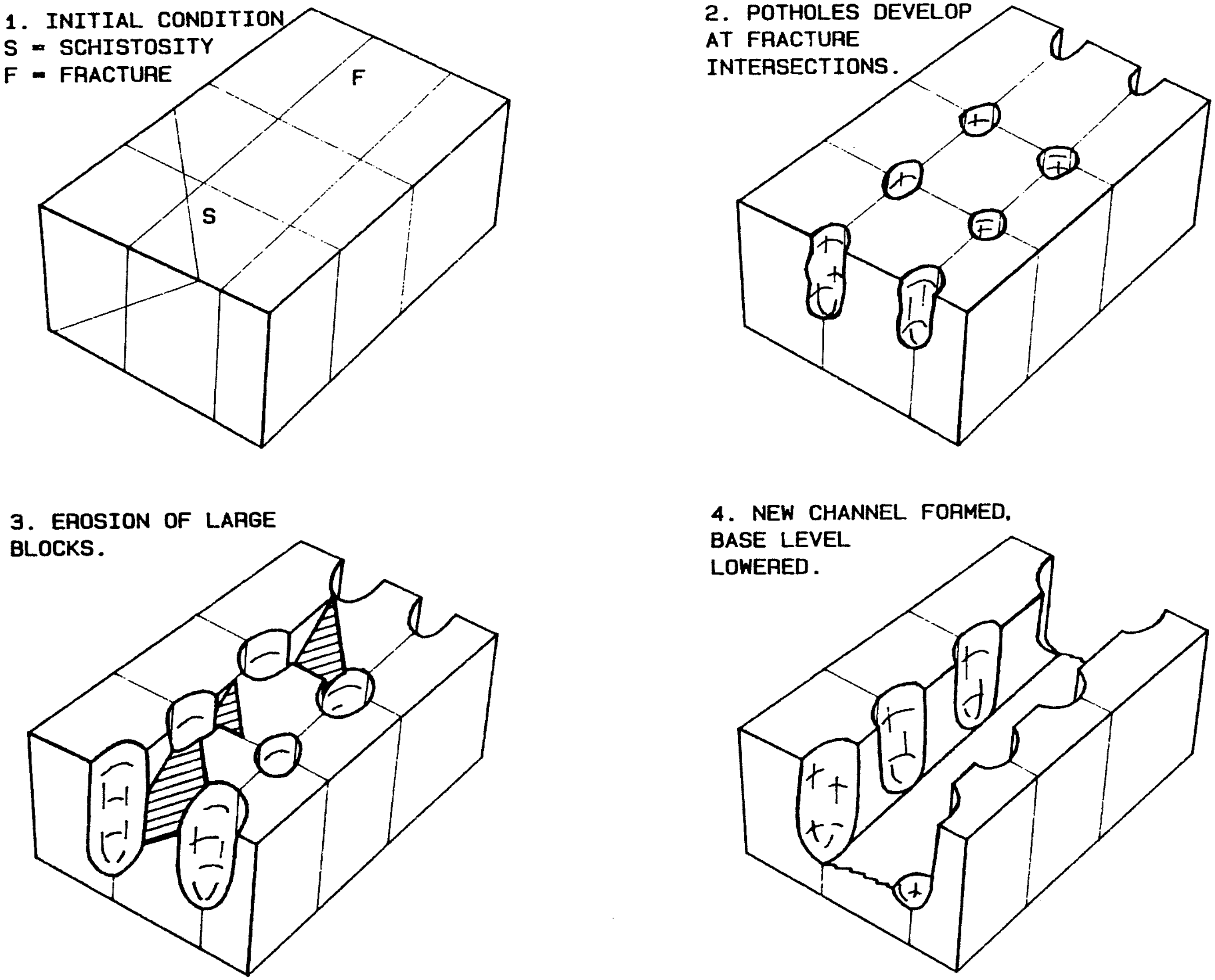


Fig. 5. River bed erosion by pothole assisted block removal. (from W. D. Sevon)

immediately west of the Norman Wood Bridge. In addition to the profile characteristics presented above, some of the streams such as the Tuquan and Otter Creeks are contained in what appears to be incised meanders. It is problematic whether or not the incision is inheritated from ancient floodplain meanders or if it is a reflection of structural characteristics. The latter alternative is favored by Charles Scharnberger of Millersville University (pers. comm.), who, with his students, has mapped and compared joint patterns with stream patterns.

In my own analysis (Thompson 1985) of tributary profiles I concluded the convex-up character was generated when high energy glacial meltwaters from upper parts of the Susquehanna invaded the gorge area causing rapid bed erosion and lowering. This left the tributaries "hanging" unadjusted to the main trunk channel. The inflection point where normal profiles change to convex-up is generally located at a distance upstream from the trunk somewhat proportional to the size of the tributary itself. My testing program included developing a gradient indexing system suited to the needs of the area, that is emphasizing the lower reaches where the nick points exist. Then I did a comparison with the Potomac River in the Great Falls area. That site contains a main trunk falls/rapids system and it is the recipient of tributaries as well, thus serving as a control with measurable characteristics.

I first measured Potomac tributary overall gradients and in plotting them (Fig. 6) they clearly divide into two distinct populations. Those entering the Potomac below the falls drop deeper into its gorge from similar headwater elevations therefore displaying higher gradients. A similar analysis (Fig. 7) of Susquehanna tributaries yields similar results, though with some complications.

I then decided to divide the tributaries into quartiles and examine the gradient ratios of the lowermost two sections. That is, 50% of each tributary would be subject to analysis. The system is named the PROPORTIONAL GRADIENT INDEX (PGI) and is set up so that gradient ratios greater than one (1) would represent normal or concave-up profiles and those with gradient ratios less than one (1) would represent convex-up profiles (Fig. 8). The results of this analysis are presented in Figure (9).

As expected the Potomac PGI shifts from less than one (<1) to greater than one (>1) at the site of Great Falls. This suggests that erosional retreat of a falls takes place faster than the downstream tributaries can adjust their profiles. In the case of the Susquehanna, PGI's are consistently <1 and display a marked further reduction in the gorge at Holtwood. This suggests the entire lower Susquehanna River was subject to rapid bed erosion with pronounced changes concentrated in the gorge proper, probably by reduction of a falls/rapids zone. The regional effect of this reduction was to leave the energy deficient tributaries "hanging". It is likely the energy for this erosion originated in intense and prolonged flood discharges associated with Pleistocene deglaciation periods and from annual

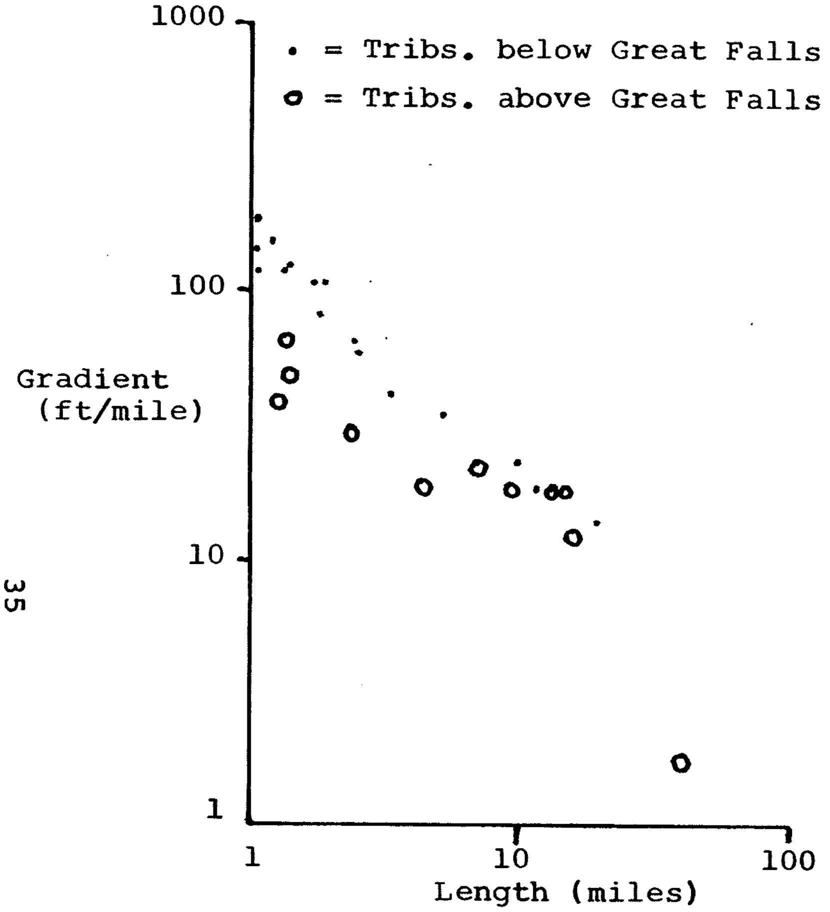


Fig. 6. Tributaries of the Potomac River near Great Falls; Stream Gradient vs. Total Length

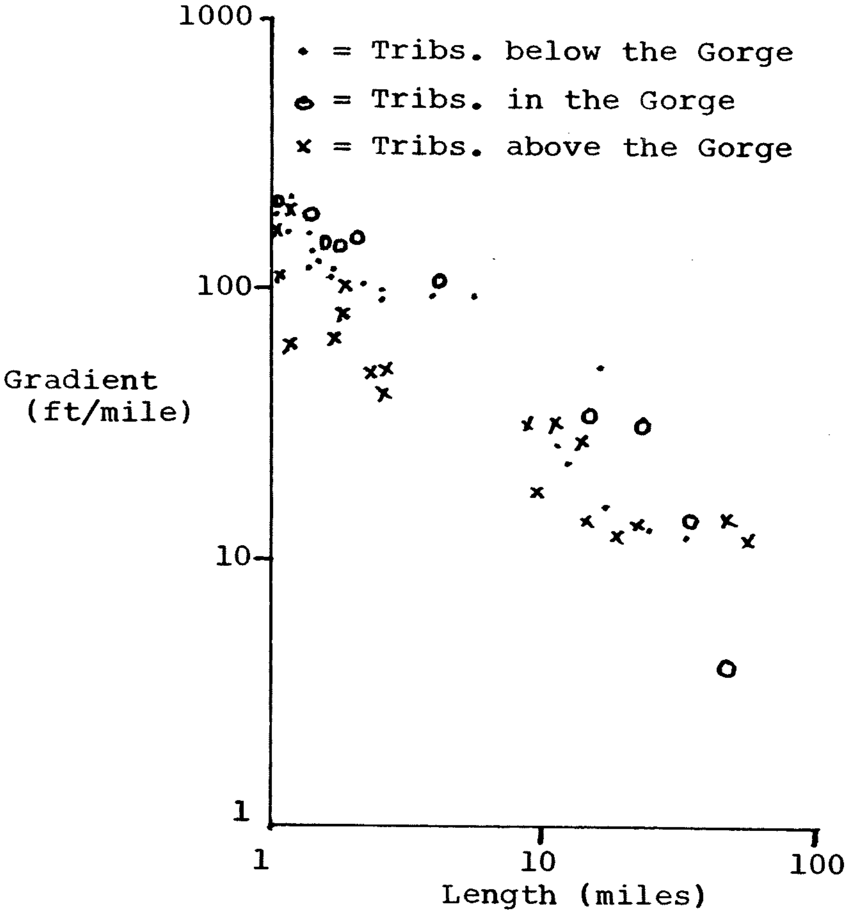


Fig. 7. Tributaries of the Susquehanna River in the vicinity of the Gorge at Holtwood, Pa.

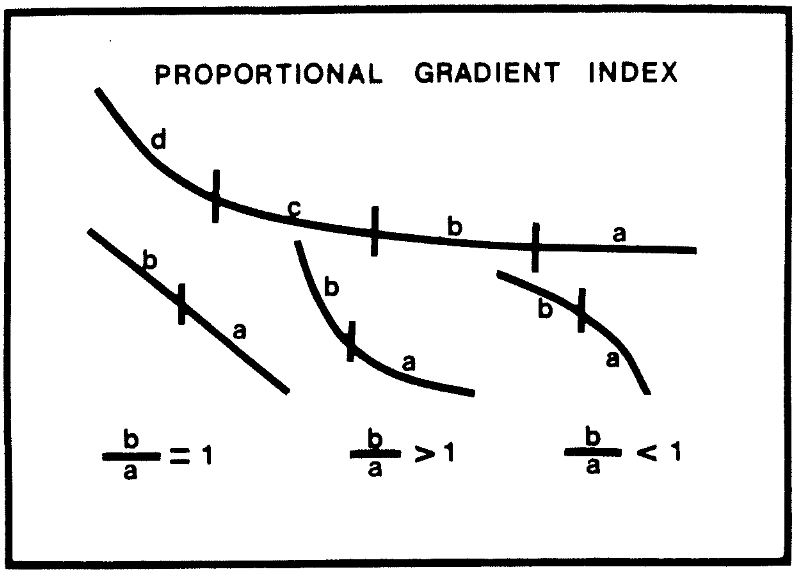


Fig. 8. Determination of PROPORTIONAL GRADIENT INDEX (Thompson, 1985). The long profile of any stream is divided into quartiles, and the gradients of the lower two (a & b) are then calculated. Their gradients are set in the ratio form, b/a, thus yielding a dimensionless index. A PGI $>$ 1 is concave-up or normal, and a PGI $<$ 1 is convex-up or abnormal. The departure value from 1.0 is a relative index of concavity or convexity. This system treats all sizes of streams equally by selective emphasis on the lower 50%, thus making it proportional.

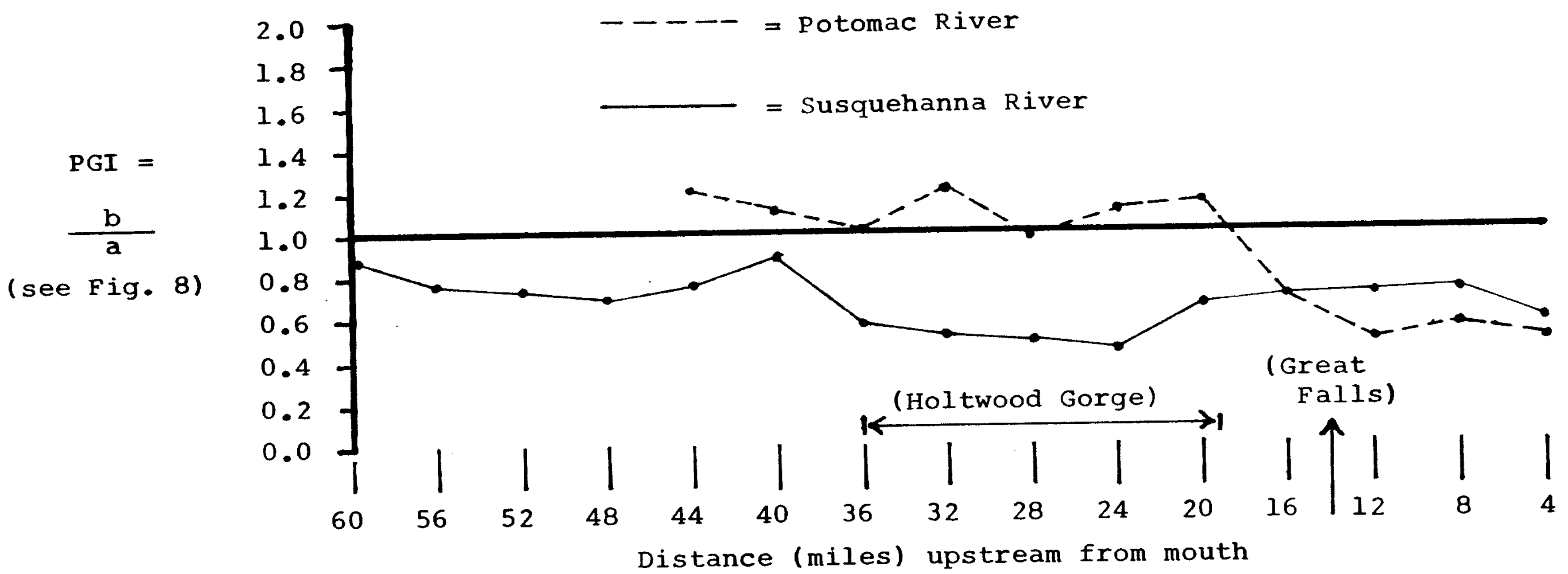


Fig. 9. Average Proportional Gradient Indices (PGI's) for the Potomac and Susquehanna Rivers. Each point represents the average PGI for all tributaries entering the 4 mile reach on the adjacent downstream side.

summer melts of continental ice sheets terminating in the upper Susquehanna drainage basin. If the higher island tops represent the preglacial river bed elevations, then the minimum general channel lowering amounted to 30 or more meters. The tiered effect of island tops perhaps represents alternating periods of erosion and stability. It seems probable, therefore, that the abrupt preglacial falls/rapids nickpoint was episodically modified to the present convex-up profile, and that former river bed remnants are preserved as island tops.

COMPARISON WITH CHANNELED SCABLANDS OF WASHINGTON:

The specific features of the bizzare landscape that is called the "channeled scablands" was first cast into a flood produced scenario by J. Harlan Bretz of the University of Chicago in 1923. The resulting controversy and the long story of documentation has been adequately presented by Victor Baker (1978). Even today there are arguments, not about the flood origin itself, but about the actual number of floods numbering perhaps to about 40 (Waitt, 1980, 1984, 1985). Working from a faculty research grant from Elizabethtown College and accompanied by Noel Potter and Bill Sevon, I went to eastern Washington in the summer of 1987 to observe firsthand and compare the flood erosion features there with those of similar presumed origin in the lower Susquehanna.

Hydraulic erosion features in the scablands include gigantic potholes, dry waterfalls, longitudinal grooves, rock terraces and dramatic channeling in the form of coulees. The bedrock is highly jointed (columnar) basalts, layered as the result of many successive extrusive events. There are in addition, loess mantled interfluves untouched by anastomosing floods and a set of fluvial deposits including megaripples, pendant bars and fluvial erratics. These are well described and explained by Baker & Nummedal (1978). With regard to erosion features in the scablands it is difficult to make comparisons. Owing to tremendous energies available and combined with a prominently jointed bedrock, the results seem to be more from plucking than from scouring. Nonetheless some similarities suggest a common origin for certain features, especially the potholes.

My observations in the Susquehanna have yielded the generalization that, although ubiquitous in certain reaches, there is a pattern to their locations. That is, they are concentrated at places where the river displays a convex-up profile (at nickpoints) and that deep potholes are located at levels higher than the present day river bed.
These observations are consistent with those from the scablands and with those personally made at Taylor's Falls on the St.Croix River northeast of Minneapolis, Minn. The pattern is also observable at the Great Falls of the Potomac and at the falls of the James River at Richmond, Virginia. It is suggested this is a predictable location pattern, and it is likely, therefore, to be a significant clue to their origin.

Potholes are bedrock voids more or less circular, cylindrical to slightly conical usually displaying a near vertical orientation. They are conventionally attributed to abrasive action of "tools" or pebbles swirled about by rapidly revolving currents. Questions significant to pothole enlargement include the relative importance of tool grain size, solution, fluid transfer of rotational energies, cavitation, and water temperature and depth above the void itself. It has been my experience to vacillate among the relative importances of these factors. Beyond these I am hypothesizing an additional factor which may help to explain some of their mysteries. That factor is their location.

Much searching in the gorge at Holtwood, especially during periods of very low water, has produced no potholes more than one meter deep in the lowest part of the river bed. All the larger potholes including those which seem to be compound in nature are found on rock terraces and on rock islands at varying heights above the mean water level. In the scablands, in spite of their extreme scale, the same generalization holds true. Studies in the scablands (Baker & others in Graf, 1987) conclude strong vortices ("kolks" of Matthes, 1947) were responsible for plucking basalt columns loose from the bedrock and then lifting them out of the enlarging void (Fig. 10). This certainly requires, in addition to a vortex, a strong upwelling as well. This notion may explain the common presence of pebbles without much sand in conventional potholes; that is, the sand has been lifted out leaving larger grains as lag.

In this paper I wish to present a hypothesis to simultaneously explain pothole location and vortices with a strong component of upwelling. This is not unlike the fluid dynamics of an atmospheric tornado, and it is in contrast to the often observed model of whirlpools leading into a bathtub drain. In the latter example the water surface displays a conical depression. If upwelling is present, however, a surface bulge or boil should result, and these are commonly observed on the surfaces of turbulent rivers.

It is an axiom in atmospheric science that "divergence aloft" induces upward air motion and subsequent surface level convergence. Upper air divergence is frequently the result of varying wind speeds especially where the leading portion of an air parcel is increasing in speed, thus running away from the trailing portion. This promotes rising air from beneath to fill in the void. When this happens at a relatively small scale such as in a thunderstorm, low level rising and converging air parcels may begin to rotate and will increase in velocity as the radius of curvature decreases. This is from the conservative property of angular momentum most commonly known as the "ice skater effect", and leads ultimately to the production of tornadoes.

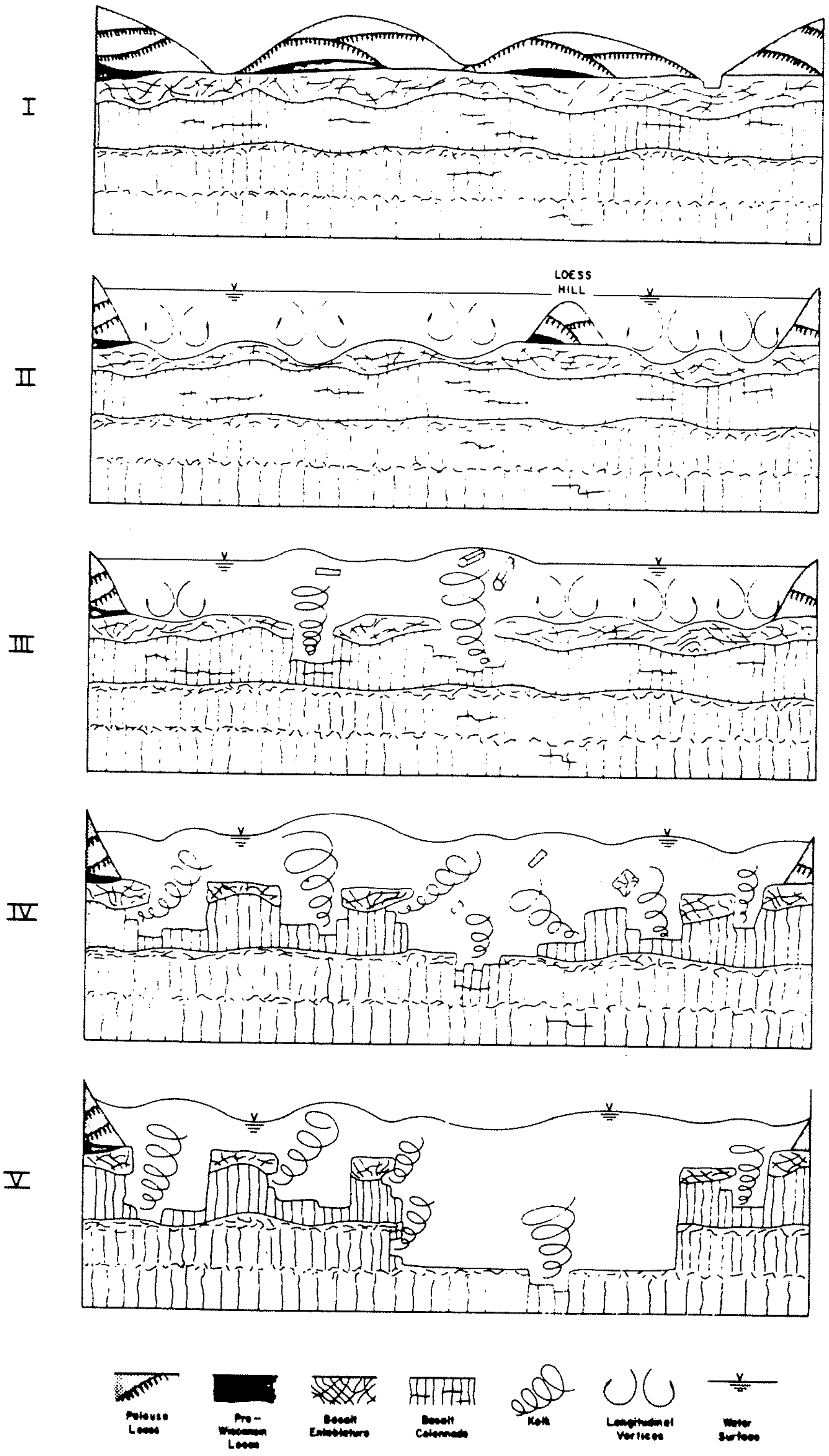


Fig. 10. Flood erosion by "kolks" in the channeled scablands (from Baker & Others in Graf, 1987)

With regard to a river perhaps flowing in the flood regime I suggest an analogous situation may exist where the water surface is convex-up, thus creating the condition where flow velocity increases downstream. These nickpoints, therefore, with water of sufficient depth, should induce the production of similar, though subaqueous, violent vortices. The rotary energy to spin tools and lift fines out of voids may come from "underwater tornadoes". It is not likely these vortices are stationary in location. Instead, it is suggested that the condition leading to their formation is stationary, and that the location therefore induces a vortex series to form and parade there in a limited zone, each providing a momentary spin and lift as it passes by.

My observations of large potholes have shown them to be concentrated on ledges and on the upstream side of nickpoints precisely where water surface divergence would occur. The single exception to this observation is in the case of the "deeps" which may be the result of unusually extreme conditions. The ledge location hypothesis is vividly obvious in the Channeled Scablands where large potholes may be observed even on rock promontories dividing portions of several "dry falls". I take for granted that rather resistant rock is required to allow for pothole formation, but I plead there is more than mere lithology to the story. My own unknowns at present include water depth limitations and turbulent flow theory. I am presenting a hypothesis, tested somewhat by consistent observations, however without rigorous dynamic theory. If the observations and the water surface divergence induced vortices hypothesis has merit, I now hope someone with adequate theoretical background will pick it up and go.

A final comparative observation of flood produced scabland landforms is quite interesting, expecially since it involves similar shapes of islands composed of disparately distinct materials. Scabland flood island shapes are described and discussed by Baker & Nummedal (1978) in their guidebook to the region. The optimal streamline shaping there, it is concluded, originates from hydrodynamic forces acting as flood waters rushed across the lower elevations of loess mantled plains leaving remnants streamlined though otherwise unscathed due to their superior elevations.

In the study of streamlined landforms reported above, Baker and Nummedal (1978) analyzed several parameters including linear and areal measurements. One graph (Fig. 11) of these results has been utilized to plot the length vs. width measurements of two Susquehanna bedrock island clusters. These clusters are assumed to be single islands separated only by joint erosion. Their plots fall well within the deviation envelope rigorously developed for scabland flood erosion forms, thus lending further credence to the hypothesis that the lower Susquehanna River has been subject to ancient hydraulic processes of intensities and frequencies greater than are in operation there today.

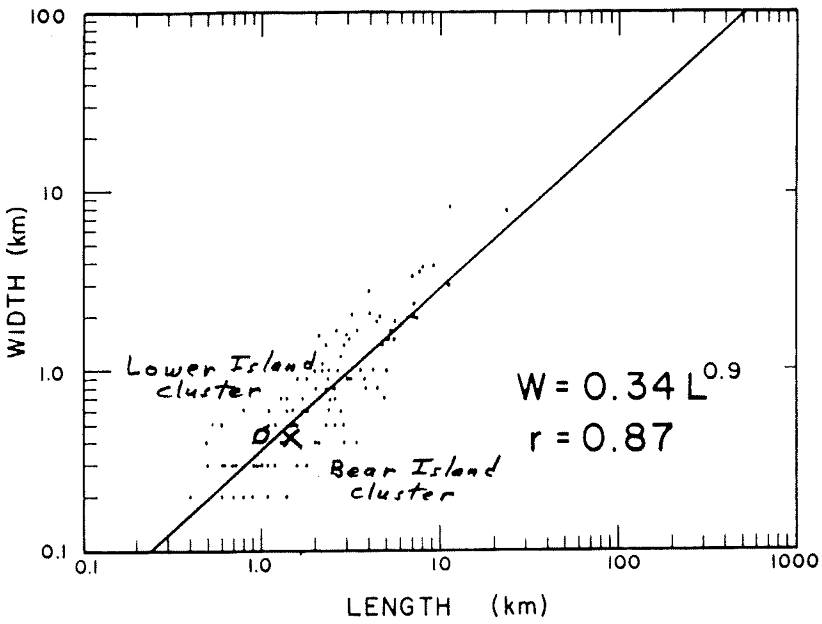


Fig. 11. Width of scabland streamlined forms vs. length of the form. Sus. River bedrock island forms added. (from Baker & Nummedal, 1978)

SUMMARY: It has been facetiously said the first rule of science is, "If it happens, it is possible". The Susquehanna River gorge at Holtwood is the setting for a concentration of unusual and/or extreme fluvially produced landforms. They are there, and our curiosity dictates that we search for the cause(s). It has been my contention these gorge, tributary and island features are genetically related in a single cause--frequent, intensely erosive flood discharges, with Pleistocene climatic conditions being the most likely suspect as a source. Much analytical and theoretical work remains to be done at this and other morphologically similar sites, the conclusions of which may offer either welcomed support or discredit to my work.

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ROAD LOG

Mileage		Description
0.0	0.0	Begin trip at parking lot of Elizabethtown College on College Avenue across from College Lake Placida. Exit lot; TURN LEFT, then RIGHT on Campus Road.
0.6	0.6	Stop sign; straight across
0.5	1.1	Stop sign; straight across
0.4	1.5	TURN LEFT on Schwanger Rd.
0.4	1.9	TURN LEFT on Cloverleaf Rd.
0.4	2.3	TURN RIGHT on Rt. 283 East toward Lancaster
12.6	14.9	Exit Rt. 283 to Rt. 72 South through Lancaster; Rt. 72 becomes Rt. 222 South and Prince St.
4.5	19.4	Crossing Conestoga River; continue on Rt. 222 South
2.3	21.7	Begin divided highway; shortly Rt. 222 exits left; trip route continues straight ahead as Rt. 272 South
2.4	24.1	Excellent view on Martic Hills, a structure-lithology problem of the Piedmont province
1.3	25.4	Crossing Pequea Creek; note broad flood plain and low gradient typical of middle and upstream segments of Susquehanna River tributaries in this area; gradient steepens sharply approaching entry to main river
4.9	30.3	Village of Buck; TURN RIGHT at bottom of steep hill; follow Rt. 372 West
2.7	33.0	TURN LEFT at sign to Susquehannock State Park
0.9	33.9	Crossing Muddy Run, a creek impounded (look right) as part of a hydro-electric pump-storage generating facility
1.1	35.0	TURN RIGHT on River Rd.
0.5	35.5	TURN LEFT on Silver Spring Rd.
0.8	36.3	STOP ONE (1) (bus TURN LEFT)

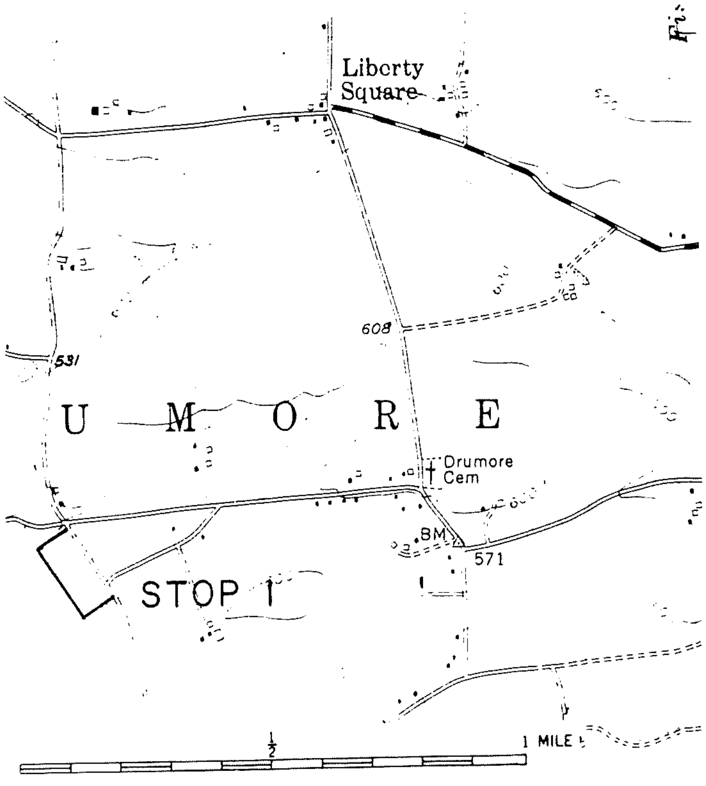

Figure 1. Location map for Stop 1 (part of the Holtwood, Pa. 7½ minute topographic quadrangle)

STOP 1

The bus will stop at the Stop sign at the road intersection (Figure 1) and people will disembark there. Proceed across the paved road ahead and up the narrow unpaved lane. The bus will proceed via paved road to the top of the hill for pickup.

Along both sides of the narrow lane are good cuts of colluvium composed of weathered fragments of schist enclosed in a sandy, silty, clayey matrix of transported saprolite. The matrix is typically red (2YR 4/8-5/8) in wet color and very sticky when wet. The schist rock fragments have pitted outer surfaces and are generally weathered throughout. Some fragments, when broken, show internal banding indicative of different degrees of weathering progressing from most intense on the margins to least intense in the center. The surface pits result from weathering of large mineral grains, probably magnetite. At the surface the colluvium appears to be thoroughly mixed and lacking layering or orientation of larger fragments although deep excavation might reveal such orientation. The colluvium is derived from broken and weathered bedrock and saprolite which originally occurred higher on the hillside. Presumably many slopes in the Holtwood area are underlain by similar deposits, but are seldom exposed.

The narrow lane joins a paved road near the crest of a rounded, hill spur which is about 20-30 feet below the crest of the main hill just to the south. A few tens of feet south of the junction of the lane and the paved road is a small but good exposure on the west side of the road. It is necessary to excavate slightly to see the material and any excavated material should be replaced. The red and reddish yellow sandy material exposed here is saprolite derived from the Wissahickon schist. There is layering in the material with a nearly horizontal attitude. Because the schistosity in the area has a moderately steep south dip, it is probable that this material has been reoriented by creep although it could be massive saprolite. The thickness of the material is unkown, but it cannot be too thick considering the presence of the coarse colluvium along the lane. The material, sand, silt, and clay, represents the end products of saprolite development and is the same material forming the matrix of the coarse colluvium. Thus, the matrix seen along the lane was probably derived from now eroded higher parts of this hill crest.

0.3	36.6	TURN RIGHT sharply
0.2	36.8	Pick up participants and continue southward on paved road
0.6	37.4	TURN RIGHT into Susquehannock State Park
1.1	38.5	STOP TWO (2)

STOP 2

The overlook at Susquehannock State Park (Figure 2) affords an opportunity to view rock, river, and landscape. Exposures of schist with south-dipping schistosity occur along the railroad track both to the north and the south. Note that the Susquehanna River narrows to the north and becomes very gorge-like in character. To the south, the river channel widens to about three times its upstream size. This position of river-channel widening corresponds to the change from the Wissahickon schist to the north and the Peters Creek schist to the south. Whether the widening is a reflection of a change in lithology only, or whether it also involves structure is an unanswered question.

Probably few places in Pennsylvania afford the viewer of a better example of accordant uplands than this overlook. Views to the south, west, and north, display a remarkable coincidence in elevation of the upland tops. To the naked eye they appear accordant: having the same elevation. It was upon this feature of visual accordance that multiple peneplain levels were identified in the first third of this century. The accordant level viewed here is the Harrisburg peneplain (Campbell, 1903). A hand level is of little help here because this overlook is below the level of the apparently accordant summits. However, examination of some of the local topographic quadrangle maps (Holtwood, Airville, Safe Harbor, Red Lion) reveals that there is some accordance in elevation for upland surfaces and that these elevations rise from about 600 feet in this area to about 900 feet around Red Lion about 20 miles to the northwest. The crest of these upland elevations continues to the southwest and east. North of the crest the uplands gradually decrease in elevation to the north. The crest is a drainage divide.

Campbell (1933), on the basis of what he interpreted to be warped terrace gravels (Figure 3), suggested that this crest was the axis of the Westminster anticline (Figure 4) which had warped the Harrisburg peneplain. The Harrisburg peneplain is generally considered to be early to middle Tertiary in age (Sevon, 1985) and thus the Westminster anticline, if real, qualifies as a fairly recent tectonic feature. The presence of the narrow gorge to the north, the several islands south of Holtwood Dam, and the anomalously steep gradients of streams entering the Susquehanna River through the length of the gorge are features which may be interpreted as supporting the reality of the anticline and its geologic recency.

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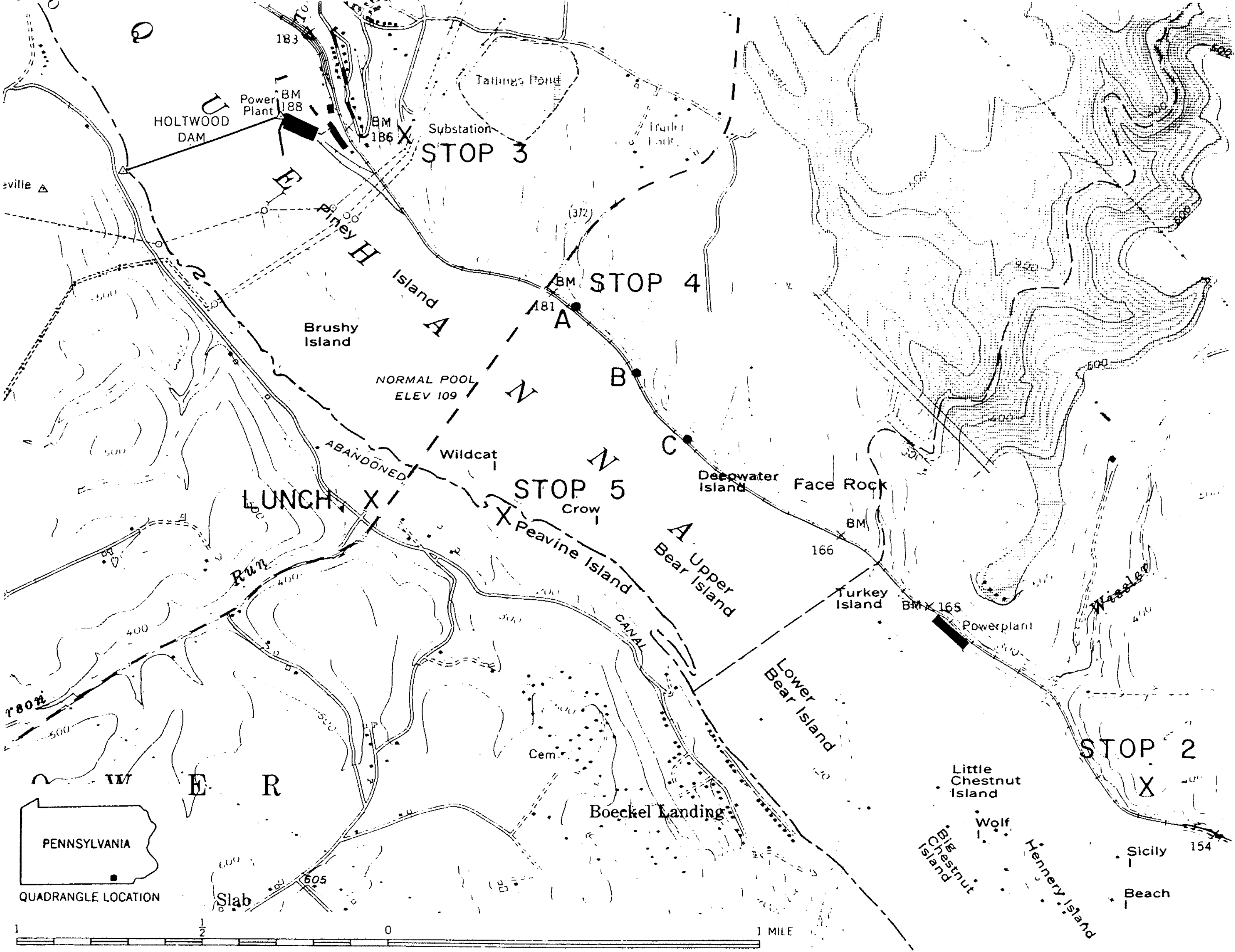

Figure 2. Location map for Stops 2, 3, 4, 5, and lunch (part of the Holtwood, PA 7.5-minute topographic quadrangle).

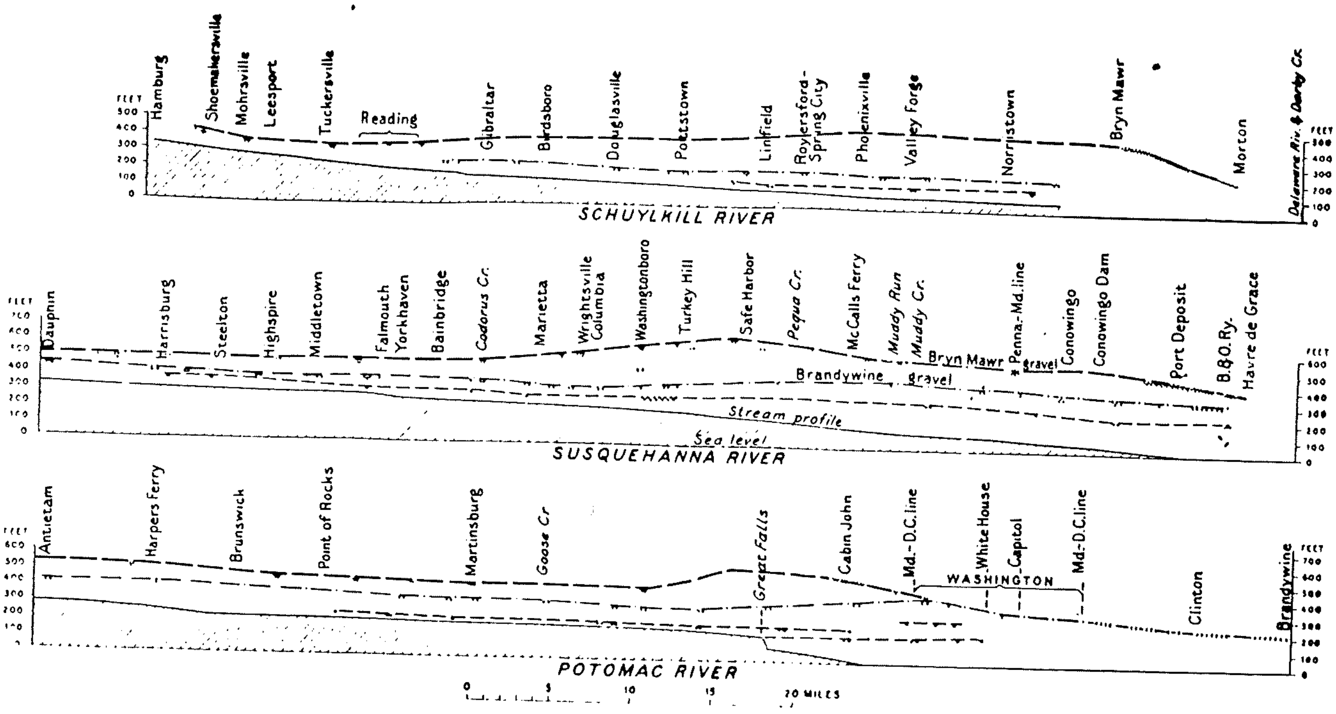

Figure 3. "Profiles of three Rivers of the northern Appalachian Piedmont Region, showing Deformation of gravel-covered Berms" (Campbell, 1933, Figure 1, p. 559).

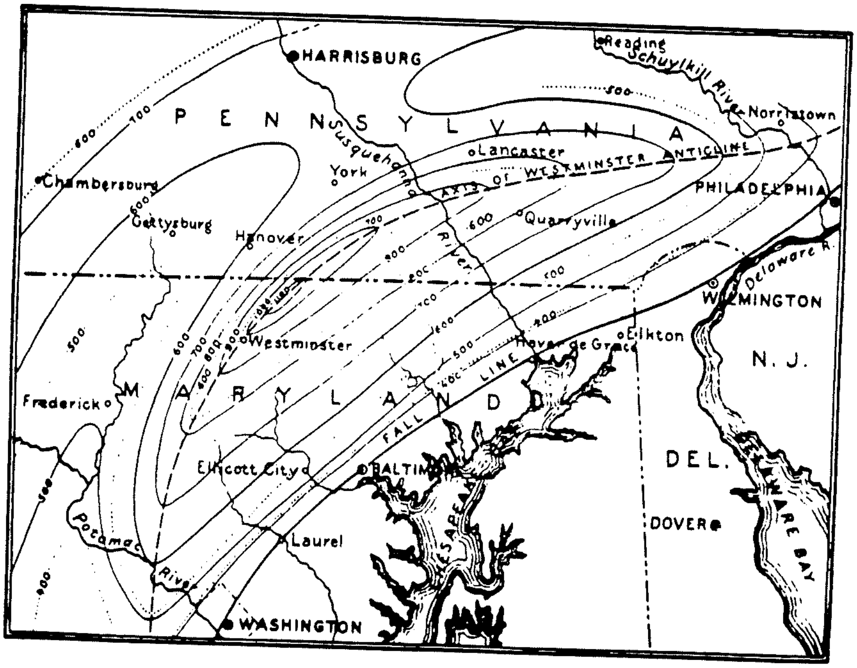

Figure 4. "Map of the Westminster Anticline. Dotted lines show the deformation of the Bryn Mawr berm, and solid lines, the deformation of the Chambersburg (Harrisburg) peneplain." (Campbell, 1933, Figure 3, p 568)

		Exit parking lot
1.1	39.6	TURN LEFT (slight back tracking)
0.8	40.4	TURN LEFT sharply
0.3	40.7	Pass straight through at beginning point of Stop 1
0.8	41.5	TURN LEFT on River Rd. (Muddy Run reservoir ahead)
0.5	42.0	Crossing Muddy Run Dam penstock area; continue across breast; look left (southwest) into deeply incised of Muddy Run; valley depth is about 120 meters (400 ft)
1.4	43.4	Stop sign at Rt 372: continue straight across on Old Pinnacle Rd. through tailings impoundments receiving waste products from the steam generating plant nearby at Holtwood
0.5	43.9	TURN RIGHT on New Village Rd.
0.6	44.5	TURN LEFT on Old Holtwood Rd. and down steep hill; watch out for heavy coal hauling trucks driven more by habit than by eyesight
0.6	45.1	TURN LEFT on nearest of two roads and up a steep grade to overlook
0.5	45.6	STOP THREE (3)

Stop 3 HOLTWOOD OVERLOOK:

From this viewpoint one can observe the general character of the gorge plus some of its special features. Though they must be viewed from a distance, one can see the bedrock islands with their accordant surfaces, potholes, fluvial erratics and joint controlled channeling. The tail race waters from the Holtwood Dam discharge through one of the deeps described above by Mathews. The electric generating plant below is somewhat unique in that it employs both hydro and steam generating. Originally coal for the steam powered unit was derived locally by river dredging operations, the coal itself the result of upriver anthracite mining and processing.

		Exit overlook area and back track to Rt. 372 (RIGHT at bottom of hill; RIGHT on New Village Rd; follow paved road back to Rt. 372.
2.2	47.8	TURN RIGHT on Rt. 372 West
0.6	48.4	STOP FOUR (4) Park on wide berm to the right before Norman Wood bridge; Orange blazes here mark the Conestoga Trail originating about 60 miles to the north at Lebanon Pump Station and proceeding across the bridge to its terminus at Historic Lock Twelve

Stop 4 WISSAHICKON EXPOSURES IN HOLTWOOD GORGE

This Stop extends for 700 m along the Conrail tracks on the east side of the Susquehanna River, southeast of Holtwood Dam and the Norman Wood bridge (Pa.`Route 372) across the river. It consists of three stations (Fig. 2), but between these are a number of other good exposures which are worth examining.

Station A. Park vehicle(s) along Pa. Route 372 a short distance from the east end of the Norman Wood bridge. North of the road, just east of a promontory overlooking the river, a path leads down to a stream. Follow this path downstream to the railroad tracks, and turn southeastward, passing the outcrop just northwest of the bridge. Station A is the first large outcrop beyond, sone 175 meters southeast of the bridge.

The medium-dark-gray silty phyllite here is a fine grained, rather homogeneous rock. The prominent dipping S1 foliation (168-45) pervading the entire outcrop was developed during the regional lower greenschist facies metamorphism. This foliation reflects the parallel alignment of small flakes of muscovite and chlorite that were generated from the original clays. Isolated quartz pods and irregular masses probably grew at this time, serving as precipitation sites for the excess quartz from the clay-to-phyllosilicate reactions. A second foliation, S2, is present here as well. It is a crenulation cleavage that dips more steeply to the southeast. Its most obvious manifestation is the crenulation lineations on the S1 foliation/ bedding surfaces, and they plunge gently to the southwest. This S2 crenulation cleavage is a deformation, probably developed in conjunction with the Tucquan anticline, that post-dated the Taconian metamorphism.

Station B. Proceed southeastward along tracks and stop at the south end of the westward concave curve in the tracks, just north of a notch containing a small waterfall.

Along much of the section from A to here the rocks have maintained a constant character. At Station B, they have become noticably coarser, and bedding has become more distinct. The rocks are thin to medium bedded, and large lenticular to wavy ripples are separated by the dark green mud layers. Scour features appear at the bottoms of some of the sandstone beds. The persistance of the southwest plunging crenulation lineation on the more micaceous S1 foliation/bedding surfaces indicates that the S2 cleavage is still present, although it is not as strongly developed in the sandy beds here as in the muddier beds to the northwest. Large (up to 8 x 30 cm) quartz pods are present as well.

Station C. Continue southeastward along tracks around the eastward concave curve, past the block signal C238, and along the straight stretch. Stop halfway to the nest curve, at the large, recent landslide, where fresh rock is spread over a large level apron west of the tracks.

Southeastward from Station B the rocks become even coarser grained and thicker bedded. These sequences are separated by finer grained intervals, and they represent shorter upward fining cycles within the upper coarser part of the large cycle that began at the bridge. Some of the beds passed between Station B and here are conglomeratic, containing small pebbles of orthoclase. Here, at Station C, large trough crossbeds imply a considerably higher energy environment, probably near a distributary channel. Truncation of crossbeds indicate that bed tops are toward the southeast, and thus the rocks are right-side up.

COMMENTS ON LANDSLIDE by William D. Sevon

The very large exposure here shows well the variety of surfaces present in the rock along which weathering and slope failure can occur. The lighter-colored, fresh appearance of a large area near the top of the outcrop indicates the location from which a mass of rock detached during the winter of 1987-88. The volume of rock was apparently large, but conversations with railroad maintenance personnel indicate that it was nothing unusual for this location where slope failures are frequent. The warning fence adjacent to the track was destroyed and has been replaced. The fallen rock was cleared from the track and the base of the slope, and pushed over the river bank. This process has been repeated numerous times in the past and is likely again in the future. The repeated failures presumably are caused by increased cleft and pore-water pressures developed within the rock during times of increased water content such as heavy rainfall or snowmelt.

Proceed across bridge; TURN RIGHT (mile 49.3) and enter parking area for Lock Twelve

LUNCH STOP using facilities of the park

Note: For reasons of time limitations, this particular trip will be unable to visit all points of interest in the gorge area. It is, however, recommended that other sites are instructive. Drive 0.7 miles north on the dirt road along the river's west bank to the site of a large power transmission tower. At low water levels, one may here examine in detail the geomorphic interactions of lithology, structure and hydraulic erosion. Between the lunch stop and the site just described, one may discover several small tributaries and their scenic waterfalls developed perhaps as the main trunk eroded downward at rates sufficient to leave the less energetic tributaries "hanging".

Following Rt. 372 West from the bridge will bring Anderson Run into view. This small stream displays in a short distance the morphologic oddities typical of gorge tributaries.

STOP FIVE (5)

Stop 5 Peavine Island Group: Access to several islands has been simplified by construction of a segment of the Mason-Dixon Trail. The blue-blazed trail in part follows the abandoned canal downriver. Pick up the trail below the parking lot where it passes beneath the west end of the Norman Wood bridge. Soon it crosses the north end of Lock Eleven, follows the top of the west wall and crosses diagonally to the southeast over flat boulders to Peavine Island. The trail then ascends a small cliff, turns left, then right and across the island top to its recrossing of the abandoned river/canal channel and up a steep hill to the road. Following this road to the right will take one back to the parking lot. During this mile long walk we will stray from the trail toward the river to observe at close hand a variety of potholes, fluvial erratics and joint controlled channels. Discussion will center on attempting to imagine the hydrodynamic conditions necessary to produce these features.

		Leave Stop 5 and retrace route eastward back across the bridge
3.5	51.9	TURN LEFT on River Rd.; sign for Tucquan Park Campground and proceed straight at stop signs
1.4	53.3	Passing turnoff to the Pinnacle, an excellent place to view the steep-walled gorge; directly across the river a small stream may be seen falling directly into the main trunk (Caution: depending on gate status, this could be inconvenient for busses)
1.2	54.5	Crossing Tucquan Creek, a designated nature preserve; a walk down the creek will bring to view changes from upland flood plain to a deeply incised reach where the gradient steepens and its waters tumble picturesquely toward the Susquehanna River.
1.4	55.9	TURN RIGHT following River Road. There may be some confusion with Delta Rd. at this intersection.
0.5	56.4	Excellent view to the northwest from upland elevation of 215 meters (700 ft) to view plateau-like topography and gorge of Susquehanna River near Turkey Hill
1.8	58.2	TURN LEFT at Martic Forge Hotel (Rt. 324), cross Pequea Creek and immediately TURN RIGHT on River Road.
3.2	61.4	STOP SIX (6)

STOP 6

Bus will park in small pull-off area in front of gated drive on the right side at the hill crest (Figure 5). The outcrop is on the west side of the road. Be careful about traffic on this curve and hill crest.

This outcrop displays an excellent example of saprolite developed on Wissahickon schist. Remember that the rocks and its facies variations present here are very similar to what was seen at Stop 4. The attitude of the schistosity is about N50E, 40N: we are on the north limb of the Westminster anticline. The schist has been almost completely weathered chemically and the residual product is sufficiently soft in most places to be sliced with a knife. The degree of softness is variable depending upon the original texture of the rock: the coarser grained the original rock, the softer the present saprolite. The sandy facies are easily cut with a knife; the more shaly facies are easily broken, but not easily cut. The original schistosity, joints, and textures are preserved, nearly to perfection, throughout the rock even though the mineralogy has changed considerably.

Quartz and muscovite appear to be the main minerals present although other minerals, particularly kaolinite, are probably present. Pieces of some of the more coherent rock have small pits on the surface from whence larger minerals, possibly magnetite, have been weathered. Occasional lenses of unweathered quartz occur. There is moderate iron coloration, but nothing as intense as seen at Stop 1. The reddish-yellow colors occur mainly in the upper part of the outcrop and largely disappear down the hill in lower parts of the saprolite.

There is no massive saprolite at this outcrop. The upper 3 or 4 feet of the exposed saprolite has a different schistosity attitude, but that is the result of creep which has overturned the schistosity and given it a low angle downhill orientation. This saprolite is probably in the lower part of the original zone of saprolite weathering and is probably not too many feet above the zone of transition into unweathered rock.

0.2	61.6	Abandoned quarry on right in Jurassic dike; presumably used for railroad ballast.
0.4	62.0	Passing turnoff to Safe Harbor Dam and Hydro-electric generating facility.
0.7	62.7	STRAIGHT AHEAD at intersection (River Road turns left)
1.3	64.0	Small tributary on right falls through cleft in Jurrasic dike now paralleling road and Conestoga River.
1.1	65.1	STOP SEVEN (7) Bear right at intersection, then park in lot on left (across from Rockhill Tavern) marked "Pa. Fish Commission, Rockhill Access".

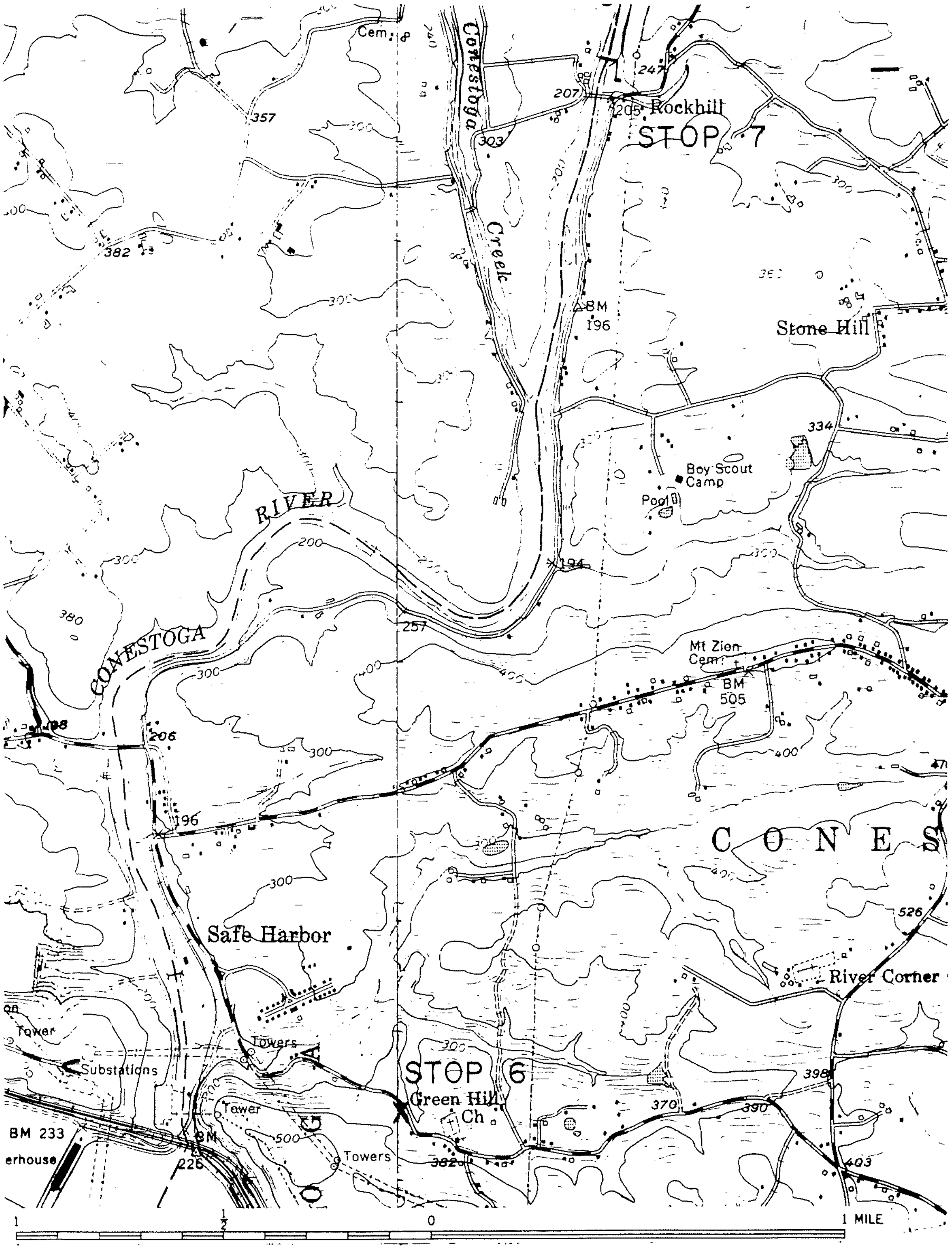

Figure 5. Location map for Stops 6 and 7 (parts of the Safe Harbor and Conestoga, PA 7.5-minute topographic quadrangles).

Stop 7 JURASSIC DIKE AT ROCKHILL:
Park in the small lot directly across the road from the Rockhill Tavern. The outcrop is to the right from the inner end of the parking area. The diabase dike is described by Scharnberger elsewhere in this guidebook.

		Leave parking lot, reverse direction and return to River Road turnoff.
2.5	67.6	TURN RIGHT on River Road crossing Conestoga River
3.0	70.6	Creswell landfill to the left: this landfill has been focus of a controversy regarding groundwater well contamination.
1.7	72.3	Passing over alluvial terraces, the site of 10,000 years continuous Indian habitation.
1.8	74.1	Passing intersection of Rt 999, entering Washington Boro. River Road becomes Rt. 441 North.
3.3	77.4	Enter Columbia; TURN RIGHT at stop sign;
0.2	77.6	TURN LEFT on Third St. (at traffic light)
0.2	77.8	TURN LEFT at traffic light on Chestnut St. and proceed across Columbia/Wrightsville bridge.
1.4	79.2	TURN RIGHT immediately at west end of bridge, down hill, then LEFT at the stop sign. Park on right after passing beneath old factory walkway. This is the John Wright Factory Outlet containing STOP EIGHT (8), a tasting at the Stephen Bahn Winery Shop.

Stop 8 STEPHEN BAHN WINERY: At this special stop we will perform oral analysis tests on liquids varying in color and vintage. The notion to stop here stemmed from a discussion with Noel Potter who picked and pressed for its inclusion. After allowing the idea to ferment for some months, it was decided to uncork a new precident which could possible age into a HAGS tradition.

		Return to Elizabethtown: Exit parking lot directly up the hill one (1) block; TURN LEFT. At second stop sign TURN LEFT and backtrack across bridge to Columbia. TURN LEFT at the traffic light and proceed north on Rt. 441. This proceeds over Chickies Hill through cuts in lower Cambrian metamorphosed quartzites, phyllites, etc.
6.2	85.4	TURN RIGHT at traffic signal on Rt. 743 North following this to Elizabethtown.
6.4	91.8	TURN LEFT on Market St. (Rt. 743 North)
0.5	92.3	TURN RIGHT on College ave and proceed straight to original departure point.
0.8	93.1	END FIELD TRIP and have nightmares about fluvial erosion, stream adjustment, saprolites, origin of Wissahickon schist, the age of dikes marked TRd on most geologic maps, early Americans and York County wines.