GUIDEBOOK

58th Annual Field Conference of Pennsylvania Geologists

Geology of the Southern Somerset County Region, Southwestern Pennsylvania

Hosts: Pennsylvania Geological Survey
Maryland Geological Survey
University of Pittsburgh at Johnstown

September 30 and
October 1 and 2, 1993
Somerset, Pa.

Guidebook for the

58th ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

GEOLOGY OF THE SOUTHERN SOMERSET COUNTY REGION, SOUTHWESTERN PENNSYLVANIA

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University of Pittsburgh, Johnstown

Headquarters Motel: Ramada Inn, Somerset, PA

Cover: "Bigfoot" has been sighted in Somerset County. Attendees at the Annual Field Conference will probably not see him because of their intense concentration on the rocks.
Artwork: John A. Harper

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SURFACE BEDROCK STRATIGRAPHY

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The purpose of the following section is to briefly summarize the work done on the Pennsylvania lithostratigraphy by Flint (1965) and to report changes or reinterpretations of his stratigraphic correlations or descriptions based on ongoing coal and water resource investigations being conducted in Somerset County by the Pennsylvania Geological Survey (PGS).

New geologic information on the Pennsylvanian strata of this region has been obtained from various sources in recent years. The PGS has undertaken several coreboring coal-exploration programs that have provided the necessary geologic data to fill in "gaps" in its database. In addition, many coal mining companies and consulting firms have generously made available to the PGS numerous deep diamond drill core records for this region. Furthermore, field investigations of surface-mine highwalls, pipeline trenches, and natural exposures, have added to the general knowledge of the stratigraphy in this area of the county.

THE PENNSYLVANIA SYSTEM

The Pennsylvania strata in southern Somerset County has been subdivided into four groups which are, from the base upward, Pottsville, Allegheny, Conemaugh and Monongahela (Flint, 1965). This sequence is approximately 1,770 feet thick, which is the thickest occurrence of Pennsylvanian strata in the bituminous coal measures of Pennsylvania. The sequence contains 25 distinct coal beds that generally occur at intervals of 50 feet or less. All but a few of these coalbeds have been commercially mined at some time, if only on a local basis. Some beds achieve thicknesses up to 10 feet, but more commonly 3-6 feet is the maximum thickness. However, all coalbeds are subject to local thinning or complete disappearance due to channel cut-outs and non-deposition. The bulk of the sequence comprises, in decreasing order of abundance, claystone, clay shale, siltstone, sandstone, and limestone. The general trend of the Pennsylvanian system in this area is that the lower stratigraphic units contain more sandstone and the higher stratigraphic units contain more limestone and calcareous claystones. Marine limestones, shales, and red beds occur near the middle of the section.

POTTSVILLE GROUP

Rocks of the Pottsville Group lie unconformably on top of the Mississippian Mauch Chunk Formation and extend upward to the base of the underclay beneath the Brookville coal. They consist mainly of very well cemented, medium-grained to conglomeratic sandstone, with minor amounts of siltstone and claystone and thin discontinuous coals.

No limestone or red beds are present. Brackish marine shales have been reported by Swartz and others (1919) in northern Maryland and in Fayette County (Pennsylvania Bureau of Forestry drill project, 1981) but none have been found in the Pottsville in Somerset County. The group was subdivided to the northwest in Mercer County (Poth, 1963) into four formations: the Sharon, Connoquenessing, Mercer, and Homewood. Flint (1965) recognized elements of these formations in southern Somerset County but did not attempt to map them. Figure 1 shows Flint's generalized section of the Pottsville Group. No further progress in identifying these units on a formational basis has been made in this region. However, recent acquisition of core drilling information has made it possible to obtain thickness values for the entire group in the Youghiogheny and Berlin basins. The range in thickness is from 275 feet to as little as 50 feet. Variations of up to 100 feet were observed in drill holes with spacings only 1 mile apart. Figure 2 shows a cross section (A-A') constructed with information obtained from the PGS drilling projects, U. S. Geological Survey files, private coal companies, and pipeline trench investigations. Figure 3 shows the location of cross section A-A'. Waagé (1950) used data from deep core holes to show a gradual thinning of the Pottsville from slightly over 300 feet to 60 feet along the western side of the Georges Creek basin to within a mile of the Pennsylvania-Maryland border near Wellersburg, PA. A more accurate determination of data in the area of his most northern drill hole was made by a PGS coal-exploration drill hole (cedh)

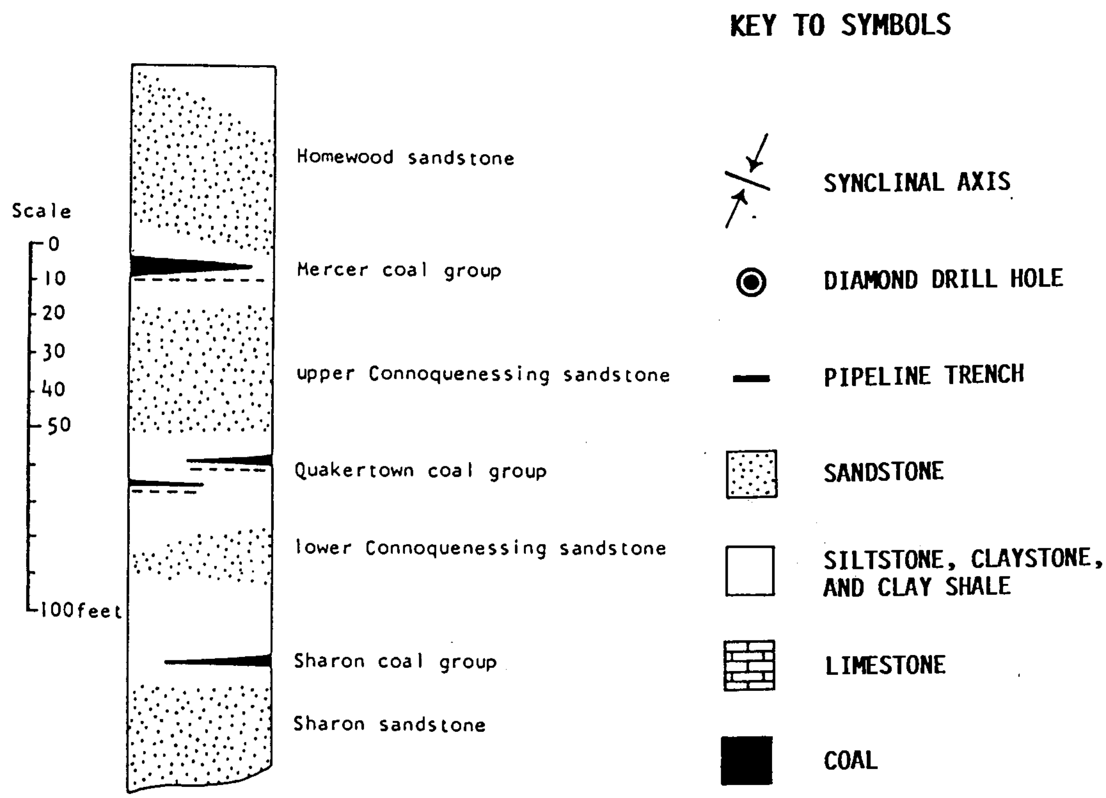

Figure 1. Generalized section of the Pottsvile Group of southern Somerset County, PA.

(TGS 90-1C-1) that indicated the presence of only 20-30 feet of Pottsville.

This varability in thickness appears to be occurring in the basal portion of the group and suggests an infilling of topographic lows on a pre-existing Mauch Chunk surface. At this time there is not enough data to suggest any definite trends in the southern Somerset County area.

ALLEGHENY GROUP

The Allegheny group averages 280 feet thick and includes strata from the base of the Brookville coal to the top of the Upper Freeport coal. Figure 4 is a generalized section for the interval in southern Somerset County. The Allegheny group is composed predominantly of clay shale, claystone, siltstone, sandstone, and coal. Nonmarine limestone beds (usually less than 5 feet thick) or calcareous claystone with limestone nodules sometimes underlie the coal beds in the upper third of the group. The Johnstown limestone underlies the Upper Kittanning coal and is stratigraphically the <u>lowest</u> limestone in the Pennsylvanian of this area. The thickness of coal seams varies from 0 to 8 feet, but is usually somewhere below the middle of this range. Coal beds or coal bed horizons (underclay) occur on the average at 50 foot intervals. No red beds or marine limestones occur. Sandstones are lenticular and comprise fluvial channel deposits of fine- to medium-grained sandstone which is sometimes conglomeratic, especially in the lower 1/3 of the group. Sandstone thicknesses commonly range from 10-20 feet, but units can coalesce to form 100-foot-thick sequences. Claystones occurring as underclay zones are generally rootworked and impure, but sometimes can be of refractory quality.

Brackish marine shales occur above the Clarion, Lower Kittanning and Middle Kittanning coal beds in several locations. Although no Vanport limestone has been encountered, Shaulis and Cuffey (1985) report finding jellyfish fossils in sandstones just below the Lower Kittanning coal bed (near Cairnbrook, PA) which they interpreted as a stranding on a nearshore bar. Flint (1965) also reports finding *Marginiferia* at that horizon near Fort Hill, PA some 25 miles to the southwest. Shales bearing a freshwater fauna, *Hemicycloidea*, occur above the Lower Freeport, in the Wellersburg area (PGS cedh, TGS-90-1C-1), and Flint reports a shale containing estherids at this stratigraphic horizon in several locations.

The Allegheny group was subdivided for mapping purposes into three formations (Flint, 1965): (in ascending order) Clarion, Kittanning, and Freeport. In his 1965 report, Flint goes into great detail concerning both regional and local stratigraphic relationships of the coal beds and intra-formational units. The ongoing PGS geologic studies are in agreement with the coal bed names and their stratigraphic position in the group, as shown in Figure 4. However, because of their lithologic similarity and discontinuous nature, the sandstones are not considered stratigraphically significant except on a very local basis.

KEY INTERVAL OF THE ALLEGHENY GROUP

For purposes of stratigraphic identification, one interval exists in the Allegheny group with unique lithologic characteristics. This is the 30- to 40-foot-thick section of rocks that starts just above the Middle Kittanning coal (if split, the Upper), comprises dark shale with brackish marine fauna (commonly containing *Lingula*, *Dunbarella*, and *Aviculopecten)* and ends just below the Upper Kittanning coal with a freshwater limestone (Johnstown) (containing *Spirorbis* and ostracodes) or calcareous claystone with limey nodules. This sequence is the "key interval" for correlation that occurs within the group.

CONEMAUGH GROUP

Conemaugh strata was named for exposures along the Conemaugh River Valley in western Pennsylvania by Platt (1875). Its lower boundary is at the top of the upper Freeport coal beds; its upper boundary, at the base of the Pittsburgh coal bed. The unit coincides with Rogers (1858) Lower Barren Measures so named for the lack of minable coal beds or any other bed of economic significance. This interval of rocks was referred to by various authors as a series, formation, or a group. Flint (1965) proposed group status and subdivided it into two rock stratigraphic units, the Glenshaw (lower) and the Casselman (upper) Formations based on the presence or absence of marine limestone beds. The group has a regional, eastward thickening trend varying from approximately 500 feet thick at the Pennsylvania-West Virginia line to 1,000 feet thick in southeastern Somerset County (Figure 5).

GLENSHAW FORMATION

The Glenshaw Formation is bounded at the base by the top of the Upper Freeport coal bed and on top by the top of the Ames limestone. Figure 6 shows a generalized section of the Glenshaw Formation in southern Somerset County. It increases in thickness eastward from 325 feet in the Youghiogheny syncline to approximately 413 feet in the Wellersburg syncline (PGS cedh, TGS-90-1C-1). The formation consists of repeated sequences of sandstone, siltstone, claystone (including red beds), limestone, and coal. Numerous faunal zones occur within these sequences. Stratigraphically the most significant among them are four major marine zones that are, from lowest to highest in stratigraphic positions, the Brush Creek, Pine Creek, Woods Run, and Ames. These four marine zones are laterally persistent across much of the bituminous coal measures in Pennsylvania. Although these beds display unique individual characteristics farther to the west, in the southern Somerset County area they are near their depositional margins and are lithologically similar (Skema and others, 1990). In southern Somerset County, they usually appear as a thin, dark, micritic, coquinite limestone containing marine fossils overlain by dark shale with marine to brackish fossils, except for the Pine Creek. In some places the Pine Creek can also occur as a dark shale containing brackish fossils, but it commonly appears as a greenish marine limestone overlain by red claystone that contains marine to brackish fossils at its base. Therefore, in order to make definite stratigraphic correlations, it is necessary to perform either detailed paleontological investigations which can be difficult and time consuming, or look at the relative positions of these zones in a stratigraphic succession. The latter is seldom possible to do in this region without access to long drill core records that penetrate the entire formational sequence. Fortunately, recent acquisitions of this kind of data has made correlations of these beds more certain across the region. In addition to the four major marine zones, a PGS cedh (TGS 81-1C) near Lavansville revealed the presence of a previously unreported *Lingula*-bearing shale over the Mahoning coal. Also, another PGS cedh (TGS 90-1C-1) near Wellersberg shows the existence of an additional coal with a brackish marine zone above occurring between the Woods Run marine zone and Upper Bakerstown coal. Core drilling records from across the border in

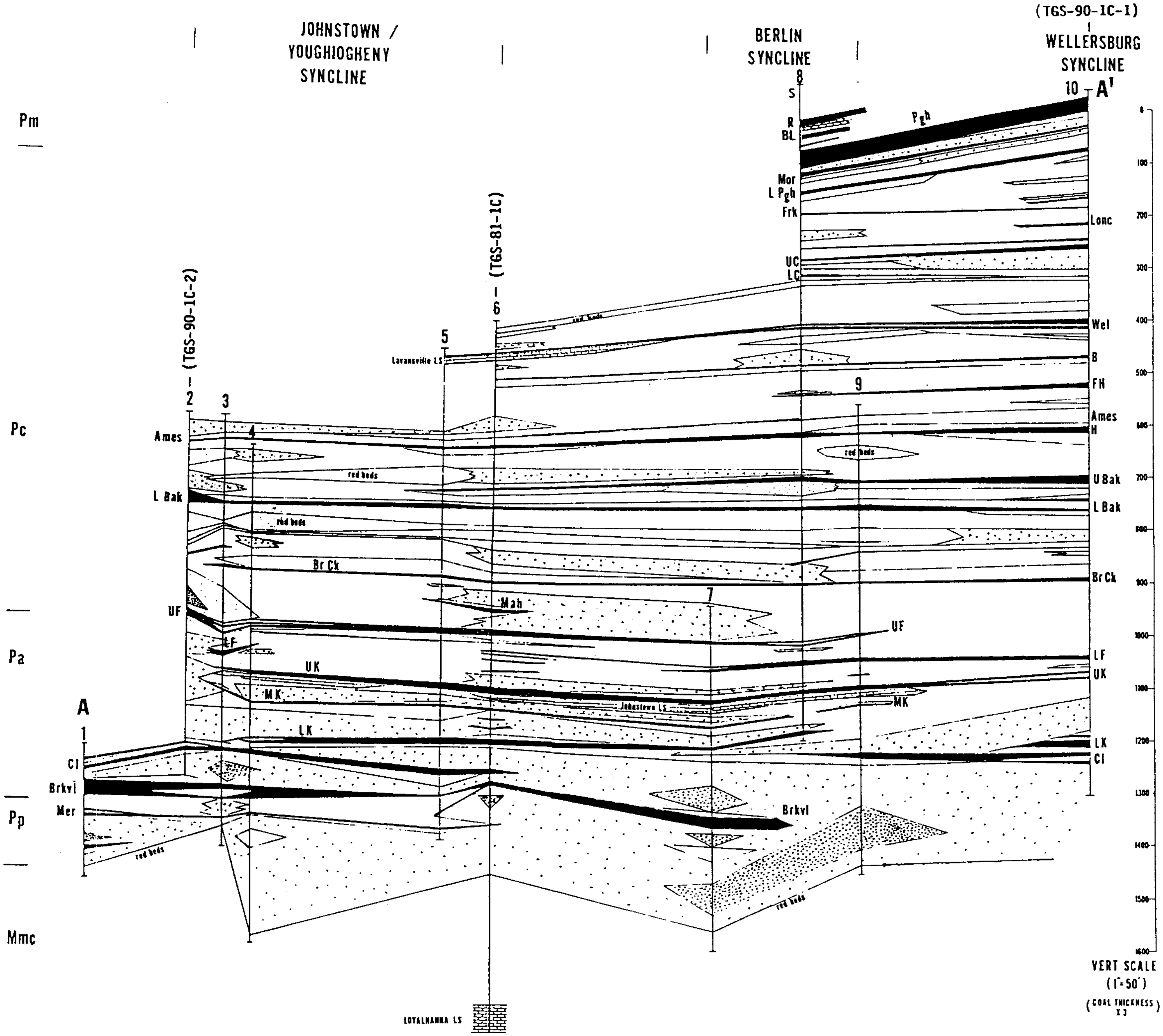

Figure 2. Geologic cross section A-A' across southern Somerset County constructed from data derived from coreboring and pipeline trench investigations. See Figure 3 for the location of the cross section.

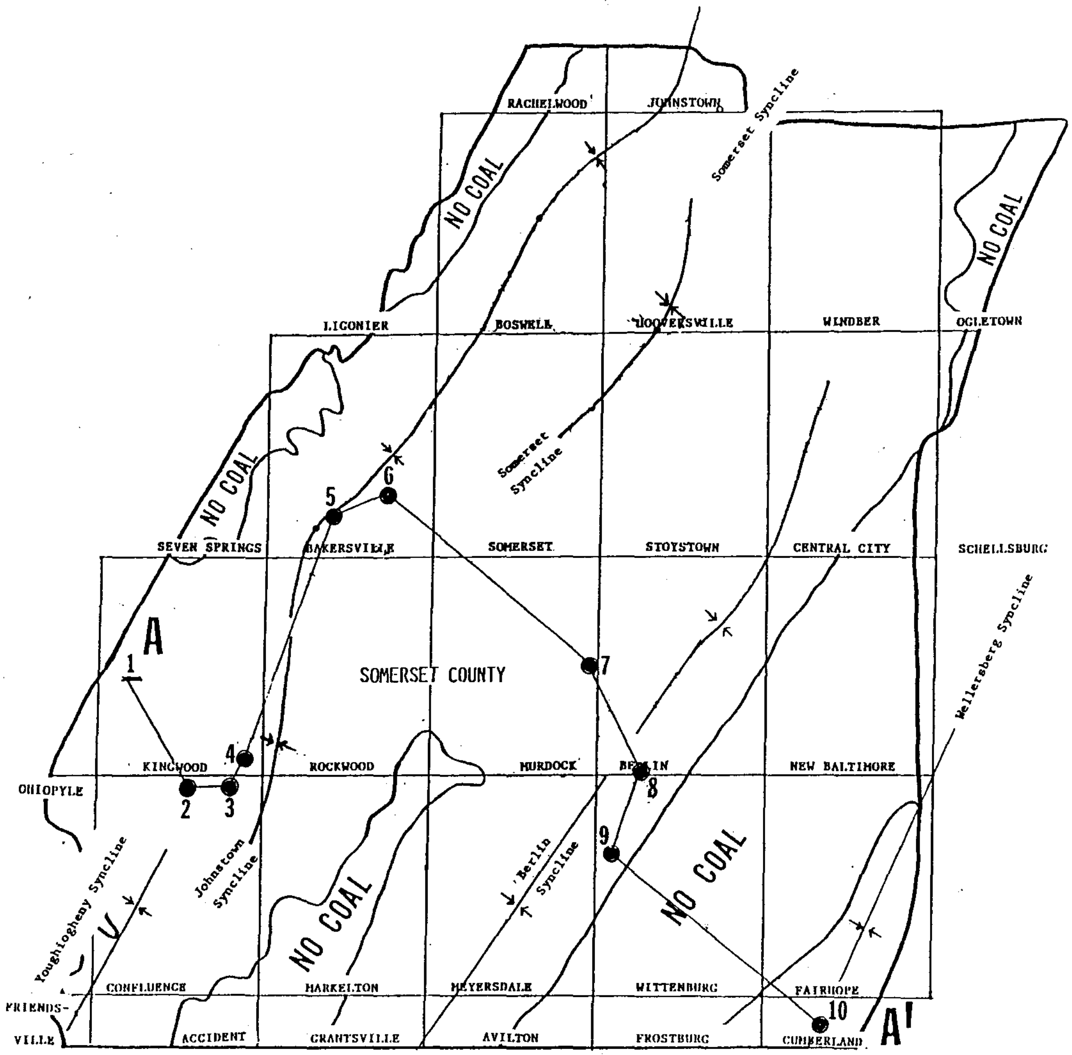

Figure 3. Location of cross section A-A' in Somerset County, PA.

northern Maryland also indicate the presence of this horizon. It is not clear if this horizon represents two separate marine events or a complex split of the Woods Run marine zone. Freshwater faunal zones have also been reported to occur in several locations above the Upper Freeport coal (Flint, 1965), and above the Upper Bakerstown coal in the Wellersburg area (PGS cedh, TGS 90-1C-1).

CORRELATION CORRECTIONS

Richardson (1934) reported an extensive fresh water limestone deposit covering approximately 1/3 of a 7.5-minute quadrangle, centered around the community of Lavansville, PA. He referred to this deposit as the Ewing limestone and reported that it occurs between the Ames limestone and Pittsburgh red bed. Flint (1965) recognized the error in nomenclature because the name of Ewing formerly had been assigned to the limestone below the Upper Bakerstown coal (Sturgeon, 1958). He renamed this limestone the Lavansville, but, unfortunately, accepted Richardson's stratigraphic position. A PGS cedh (TGS-81-1C) (Figure 2) positioned 70 feet above the Lavansville limestone at its type locality showed the Lavansville to be <u>170 feet above</u> the Ames limestone and not a few feet below as Richardson had reported. The drill hole data also showed that the Lavansville limestone belongs under the Wellersburg coal horizon at the position of the Wellersburg limestone (Flint, 1965). This miscorrelation in all probability lead to another miscorrelation further southwestward in the basin on the west flank of the Youghiogheny syncline near the town of Humbert. A thick (7.5 feet) but narrow deposit of coal named the Humbert Coal by Flint was identified to be stratigraphically

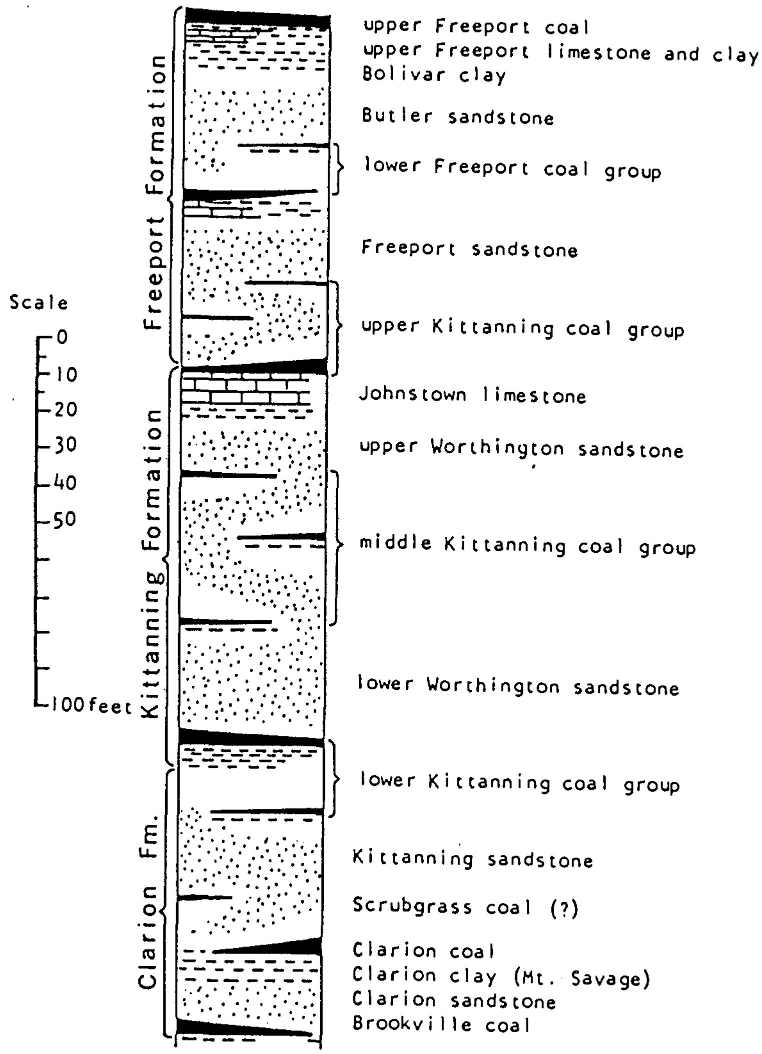

Figure 4. Generalized section of the Allegheny Group of southern Somerset County, PA (Flint, 1965).

equivalent to the Mahoning red bed horizon. Another PGS cedh (TGS-90-IC2) (Figure 2) positioned above this deposit showed that this coal occurred exactly <u>170 feet higher</u> than the position of the Mahoning red beds, and correlated to the Lower Bakerstown coal horizon. **Comment**. During the mid-1970's when I was working as a geologist for one of the local coal companies around Somerset, I was involved in several core drilling attempts to locate the "Humbert Coal" which during the coal boom years of the 1970's was highly sought not only because of its potential thickness, but also reported excellent quality. In each attempt, we unknowingly were prospecting in the areas where the Mahoning red beds had been correctly mapped. We never found any Humbert coal.....Drilling Company stocks up....Coal Company stocks down.....Geologist Stocks unchanged..."the Mahoning red beds were successfully located again.".... Recently acquired deep mine maps on this coal occurrence show it to be a narrow sinuous deposit that thins to nothing on either side. The Humbert coal probably was the result of an infilling with peat deposits of a channel cut off or oxbow lake with peat deposits during Lower Bakerstown time.

CASSELMAN FORMATION

The Casselman Formation is defined by Flint (1965) as lying between the top of the Ames Limestone and the base of the Pittsburgh Coal bed. Figure 7 shows a generalized section of the Casselman Formation in southern Somerset County. This formation, like the Glenshaw, thickens east-southeastward from an average of 515 feet in the Berlin syncline to 587 feet in

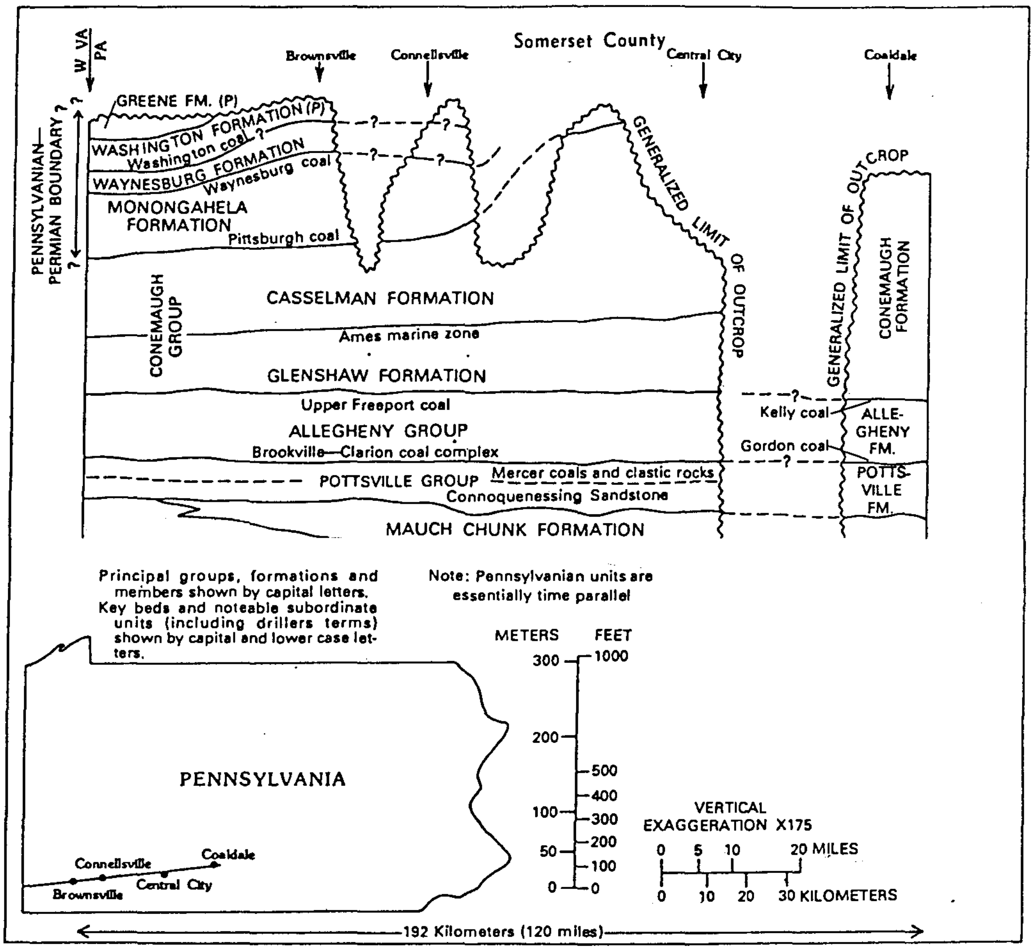

Figure 5. Generalized stratigraphic cross section of Pennsylvanian rocks from Bedford County through Washington County, PA (modified from Edmunds, 1979).

the Wellersburg syncline (PGS cedh, TGS 90-1C-1). It differs lithologically from the Glenshaw in that it contains fewer red beds, generally thin, non-persistent coals (Flint reports as many as 15), more freshwater limestones and no marine horizons, except for one brackish marine zone. This zone is identified as the Skelly which was reported by Flint (1965) and located over the Federal Hill Coal near Meyersdale, PA. Intra-formational correlations are difficult to perform due to the general lack of any persistent key beds, however, drilling records recently acquired from the PGS projects and from private companies indicate that the Niverton shale which overlies the Clarysville coal (Swartz and Baker, 1922) may have potential as a key bed. The Niverton contains an abundance of freshwater fauna, such as ostracodes genus, *Pleurophorus* (Swartz and Baker), as well as *Anthraconada* (PGS cedh, TGS 90-1C-1) and appears to be persistent in thickness and character in the Berlin and Wellersberg synclines.

MONONGAHELA GROUP

In southern Somerset County the lower 210 feet of the Monongahela group is preserved along the synclinal axes in the deep portions of the Berlin and Wellersburg basins. The group has been divided into the Uniontown (upper) and Pittsburgh (lower) Formations in western Pennsylvania by Berryhill and Swanson (1962). The Monongahela strata in Somerset County is all contained within the Pittsburgh Formation which lies between the base of the Pittsburgh coal and the base of the Uniontown coal in western PA. However, in Somerset County the top portion of the formation has been lost to erosion. Figure 8 shows a generalized section of the Monongahela Group in Somerset County. The rock types present are similar to the Casselman Formation except the coal beds are thicker and more persistent, and there are no red beds or brackish marine zones. Only one noteworthy faunal occurrence has been reported: freshwater

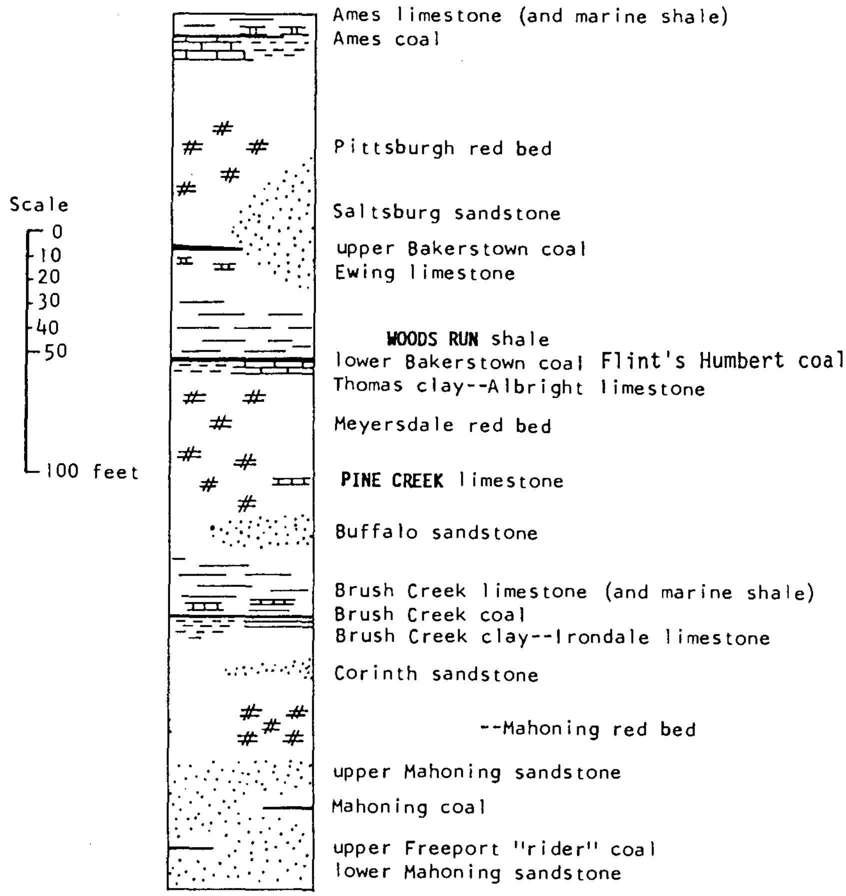

Figure 6. Generalized section of the Glenshaw Formation of the Conemaugh Group of southern Somerset County, PA (modified from Flint, 1965).

pelecypods were found (PGS field investigations) in a silty clayshale just above the Pittsburgh coal near Pine Hill, PA.

The eastward thickening trend observed in the Glenshaw and Casselman Formations appears to continue in the Pittsburgh Formation if current member identifications are used. The most widespread persistent bed in the formation is the Pittsburgh coal. In western Pennsylvania, eastern Ohio, and northern West Virginia it is a nearly continuous traceable deposit. However, the identification of the Pittsburgh coalbed in southern Somerset County has always been speculative because of a 30-mile-wide erosional separation from the nearest contiguous Pittsburgh coalbed to the west in Fayette County.

There is some evidence to suggest that not one, but three coal seams in southern Somerset County, the Morantown, Pittsburgh, and Blue Lick coal are correlative to the Pittsburgh coal bed in Fayette County for the following reasons:

1. The Pittsburgh coal in western Pennsylvania generally has a freshwater limestone occurring below its base.
2. There is apparently no Blue Lick coal equivalent in Fayette County or farther west in the basin.
3. In the Berlin and Wellersburg synclines, the Morantown coal, which nearly always has a good limestone below it, frequently comes up to within less than two feet of the base of the Pittsburgh coal.
4. The Morantown, Pittsburgh, and Blue Lick are all separated from each other by only siliciclastics.
5. The interval between Blue Lick and Pittsburgh coals gradually narrows southwesterward along the Berlin syncline — from 50 to 5 feet before the interval is lost to erosion. ("Miner" notation: Both of these seams were deep mined simultaneously and where the interval between the two seams was 10 feet or less,

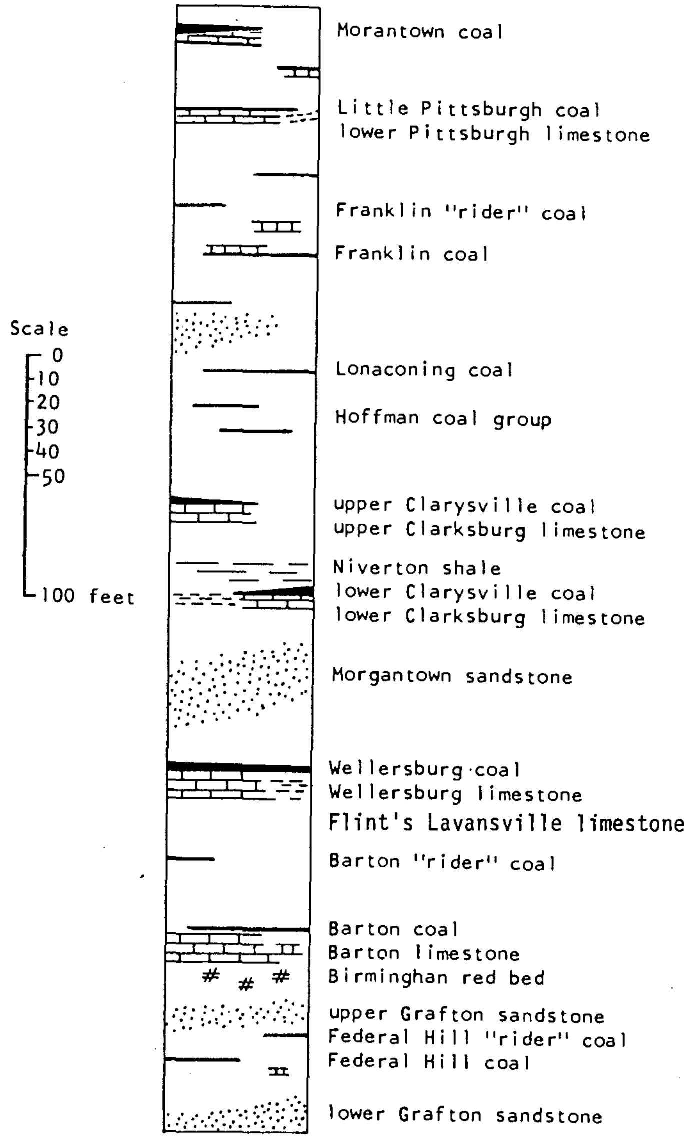

Figure 7. Generalized section of the Casselman Formation of the Conemaugh Group of southern Somerset County, PA (modified from Flint, 1965).

miners report that they could clearly hear each other talking. Were they having seamy conversations or just intraformational discussions?)

6. The Redstone coal in Fayette, Green and Washington Counties is commonly the first coal above the Pittsburgh to have a limestone under it. This is also the case in southern Somerset County.

If the following assumptions are correct, (1) that a freshwater limestone bed may be stratigraphically significant for correlation purposes and, (2) that coal beds separated by siliciclastic strata that thin to a common point may be considered depositionally related and of a common origin, then it should be suggested that the base of the Pittsburgh Formation be lowered to the base of the Morantown coal, and that the Morantown coal be considered as part of a Pittsburgh coal complex along with the Pittsburgh and Blue Lick coalbeds. The remaining members of the formation would keep their current stratigraphic identities, which are listed here as follows in order of ascending stratigraphic occurrences: the Redstone Limestone followed by the Redstone coal, then Fishpot Limestone, Sewickley coal, and a previously unreported 3-foot-thick, brecciated limestone (Benwood?), overlain by a bony shale horizon (upper Sewickley?), (Shaulis, PGS field investigations) followed by the Sewickley sandstone which is the highest stratigraphic unit in the county.

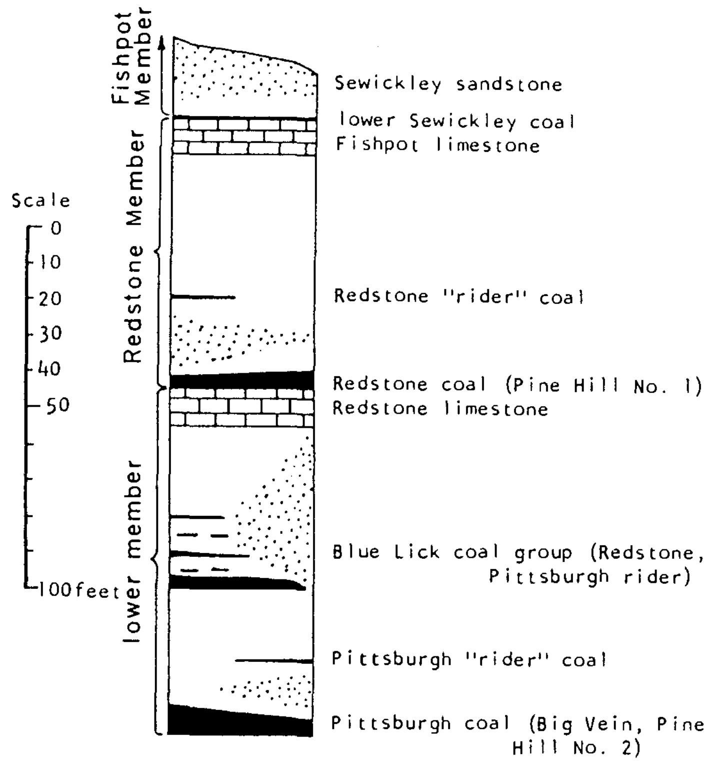

Figure 8. Generalized section of the Monongahela Group of southern Somerset County, PA.

STRATIGRAPHICALLY RELATED GEOMORPHOLOGIC FEATURES

Dividing Ridge, Negro Mountain, and Laurel Hill stand out as examples of how the resistant sandstones of the Pottsville group can form ridges in southern Somerset County.

A lesser known and more obscure stratigraphically-related geomorphologic feature is the isolated mounds created by erosion of the transgressive-regressive sequences of the Brush Creek and Ames marine zones. These mounds are created by the differential erosion of coarsening upward sequences that begin with a marine limestone or shale and ends with a fine- to medium-grained sandstone.

This sandstone at the end of the sequence acts as a cap rock and forms the flat-top surface of the mound. The less resistant rocks weather back gradationally creating steep, sloping sides (30°). The shapes vary from haystack to slightly elongate with the long dimensions usually being only several hundred feet, but many are smaller. Their height is generally 30-40 feet. For that reason, they usually appear on a 7.5-minute quadrangle map as small isolated ovals of only one 20-foot contour interval. Fort Hill is a good example of one of the larger mounds in the Brush Creek. Farmers often report finding numerous Indian artifacts on tops of these features (stratigraphically-related, archeo-geomorphologic structures?).

REGIONAL ASPECTS OF THE MAUCH CHUNK FORMATION: THE HARD LUCK DELTA REVISITED

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INTRODUCTION

Superficially, the Mauch Chunk Formation appears to be a relatively simple and monotonous sequence of almost entirely nonmarine, fine to medium-grained red clastics overlying the nonred coarse clastics of the Pocono Formation and underlying the nonred coarse clastics of the Pottsville Formation. Closer examination, however, reveals serious stratigraphic problems. Most of the difficulties arise from the failure of earlier workers to deal regionally with the fact that twice during its long history the efforts of the Mauch Chunk depositional system to build a respectable delta complex were destroyed by erosional intervals that created major unconformities.

Although the unconformities have long been recognized, their impact on the size and extent of the Mauch Chunk Formation has been viewed as secondary. The Mauch Chunk delta has generally been viewed as a rather feeble depositional system that produced a fairly thick sequence in central eastern Pennsylvania, but which rapidly lost competency and thinned to a relatively thin sequence away from its source. This was not the case.

AGE AND REGIONAL CORRELATIONS

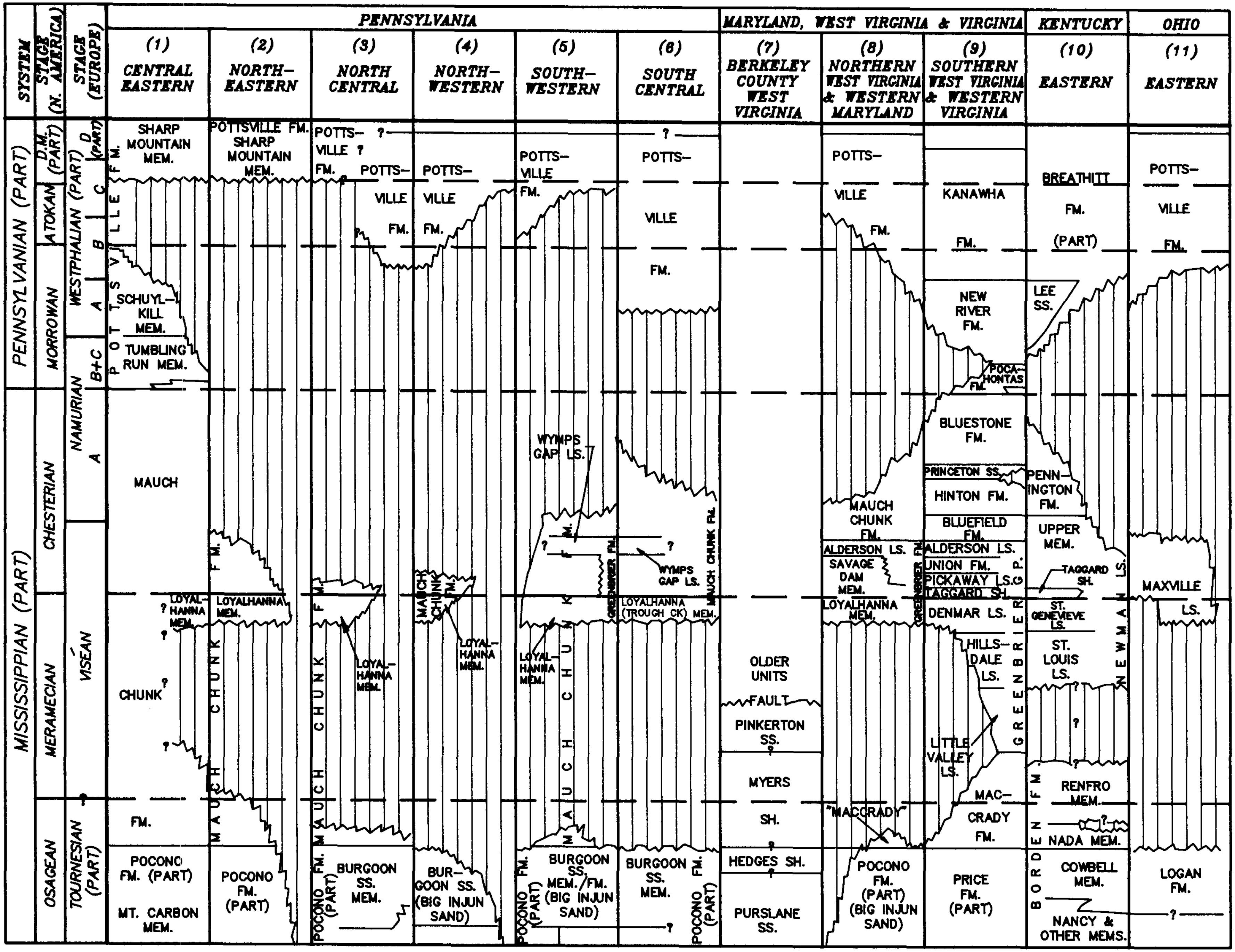
Correlations of the Mauch Chunk Formation and equivalents are given in Figure 9. Most of the Mauch Chunk is devoid of any recognizable fossils that could be used in dating and correlation. Some magnetostratigraphic studies have been done, but the results are very preliminary (DiVenere and Opdyke, 1991). However, certain stratigraphic controls can be established.

The upper contact of the Mauch Chunk with the Pottsville Formation in the type area in central eastern Pennsylvania, around the Southern and Middle Anthracite Fields, (Figure 9, column 1), is conformable and is at or very close to the Mississippian-Pennsylvanian boundary. This permits correlation with the conformable Bluestone-Pocohontas boundary in southern West Virginia and Virginia (Figure 9, column 9).

Also in eastern Pennsylvania, the basal contact at the Mauch Chunk with the underlying Mt. Carbon Member of the Pocono Formation is likewise conformable. Fossil occurrences in the Mt. Carbon Member and equivalent Burgoon Member in western Pennsylvania are limited to plants of the *Triphyllopteris* zone (zone 2 of Read and Mumay, 1964) which is usually associated with Osagian age. However, Wagner (1984) states that the *Triphyllopteris* zone actually extends well into Meramecian time as well. Fortunately, stratigraphic equivalencies throughout the central Appalachians are reasonably well established among the upper Pocono Formation (Mt. Carbon and Burgoon), the Purslane Sandstone of Maryland, the drillers' Big Injun Sand in the subsurface of western Pennsylvania, Ohio, West Virginia, and eastern Kentucky, the upper Price Formation of southern West Virginia and Virginia, the Logan Formation of Ohio, and the Cowbell Member of the Borden Formation in Kentucky (Figure 10A). The late Osagian terminal date of the marine Price, Cowbell, and Logan should extend to the other units as well. This conclusion may be further enhanced by the fact that all of these units, except the Logan, are at some place conformably succeeded by a considerable sequence of redbeds, suggesting a regional event, probably climatic, which altered the depositional environment at that time. If it can be accepted that the top of the Mt. Carbon Member is late Osagian, it follows that the conformable base of the overlying Mauch Chunk is the same.

If the foregoing conclusions are correct, then the Mauch Chunk Formation in the type area of central eastern Pennsylvania spans a time interval from late Osagian Mississippian to early Morrowan Pennsylvanian (Figure 9, column 1). This is essentially equivalent to the section from the base of the Maccrady to the top of the Bluestone in western Virginia and southern West Virginia (Figure 9, column 9 and Figure 10B).

A third dateable interval within the Mauch Chunk Formation is the 100 to 250 foot-thick



Graphics prepared by TETHYS Consultants, Inc.

Figure 9. Middle and Upper Mississippian and Lower and Middle Pennsylvanian correlations of the central Appalachians.

(30 to 75 m) sequence in southwest and southcentral Pennsylvania, western Maryland and northern West Virginia (Figure 9, columns 5, 6, 8 and 9) which is demonstrably a facies of the marine upper Greenbrier Limestone Group (Denmar or Fredonia, depending upon the author, through Alderson Formations). The Loyalhanna Member at the base of the Mauch Chunk has been correlated most recently with the Denmar Limestone (de Witt and McGrew, 1979; Brezinski, 1989; see also Yielding, 1984). Earlier correlations were with the Fredonia Limestone (Reger, 1931; Cooper, 1948; Weller and others, 1948; Amsden, 1954). In either case the age was considered to be late Meramecian (St. Genevieve) as originally proposed by Butts (1924). The Wymps Gap Limestone at the top of this interval is correlated with the Alderson Limestone at the top of the Greenbrier (Flint, 1965; Adams, 1970; Brezinski, 1989) which is lower to middle Chesterian age, probably late Gasperian to early Hombergian. The Reynolds Limestone, approximately 25 feet (8 m) above the Wymps Gap/Alderson is considered part of the lower Bluefield Formation and should be no younger than later Hombergian (Glen Dean) and likely older (see Henry and Gordon, 1992, Figure 3).

The Reynolds persists only a short distance into southwest Pennsylvania. The Wymps Gap is present across most of the southwest quarter of the state including at least part of the Broad Top area. The relatively thin (up to 100 feet, 30 m), but very persistent and distinctive Loyalhanna Member is a key bed crucial to unravelling the stratigraphy of the Mauch Chunk Formation. The Loyalhanna is present throughout most of southwest, central and northeast Pennsylvania (see Figure 9). In addition to its value as a dateable marker bed, the Loyalhanna has a close association with a major regional unconformity that profoundly affects the extent, persistence, and thickness of the lower part of the Mauch Chunk Formation and equivalents.

THE LOWER UNCONFORMITY

Examination of Figures 9 and 10C show clearly the presence of an extensive Meramecian age unconformity that severely impacts the early part of the Mauch Chunk delta sequence. The development of the unconformity is most obvious if traced from western Virginia where 1,700 feet of late Osagian to early Meramecian marginal marine redbeds of the Maccrady Formation are conformably overlain by the marine Greenbrier Limestone Group of early to middle Meramecian through middle Chesterian age (Warne, 1990).

Passing northward into West Virginia, an unconformity developed in early to middle Meramecian time which progressively cuts out the Maccrady. The last Maccrady disappears along a line across central West Virginia. North of that line the unconformity usually rests on the top of Price/Pocono Formation or equivalents, but locally cuts as low as the top of the Catskill Formation in an elongate area between Braxton and Randolph counties.

The original topographic expression of the erosion surface apparently rose from western Virginia to central West Virginia as demonstrated by the onlap wedging-out of the middle Meramecian lower formations of the transgressing Greenbrier in that direction (Figure 9, column 9). In northern West Virginia, Maryland, southeastern Ohio and, southwest Pennsylvania, the erosional and nondepositional gap has opened to the extent that the upper part of the late Meramecian Denmar Limestone (or equivalent Loyalhanna or Maxville) usually rests unconformably on the late Osagian upper surface of the Pocono Formation including Burgoon, Purslane, or Big Injun (in subsurface work, the sandy Loyalhanna may be included at the top of the Big Injun), or, in Ohio, the Logan Formation. Although the presence of an unconformity between the Burgoon and Loyalhanna in Pennsylvania has been questioned (Edmunds and others, 1979), it is very unlikely that the terminal age of the Pocono Formation could be extended to late Meramecian. Considering not only the apparent great age difference, but also the depositional nature of the unique Loyalhanna as well as some supporting direct evidence, it appears probable that the unconformity is present at or shortly below the base of the Loyalhanna wherever that unit is present. Although clear direct evidence is lacking, it also seems probable that the unconformity extends well beyond the known limits of the Loyalhanna.

At Denmar/Loyalhanna time, it appears that the slow, transgressive encroachment of the sea reached a position on the erosion surface where its topographic expression had flattened out to what was essentially a broad, almost level plain. This topography permitted the shallow marine depositional environment of the Denmar/Loyalhanna to expand abruptly far beyond the Greenbrier's previous limits so as to encompass all of northern West Virginia, western

Graphics prepared by TETHYS Consultants, Inc.

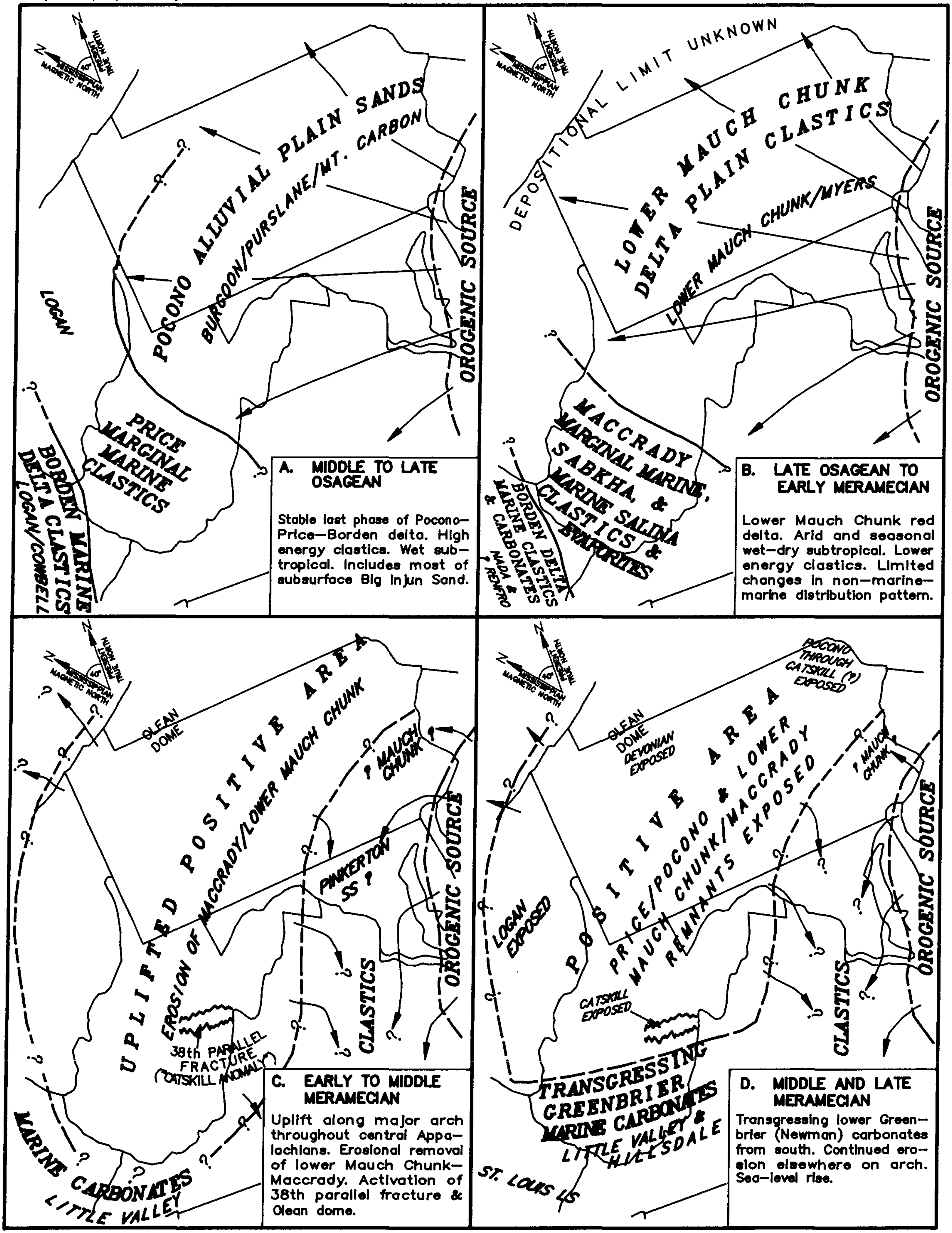


Figure 10. Osagean through Chesterian Mississippian and earliest Morrowan Pennsylvanian paleogeography and depositional environments of the central Appalachians (A-D).

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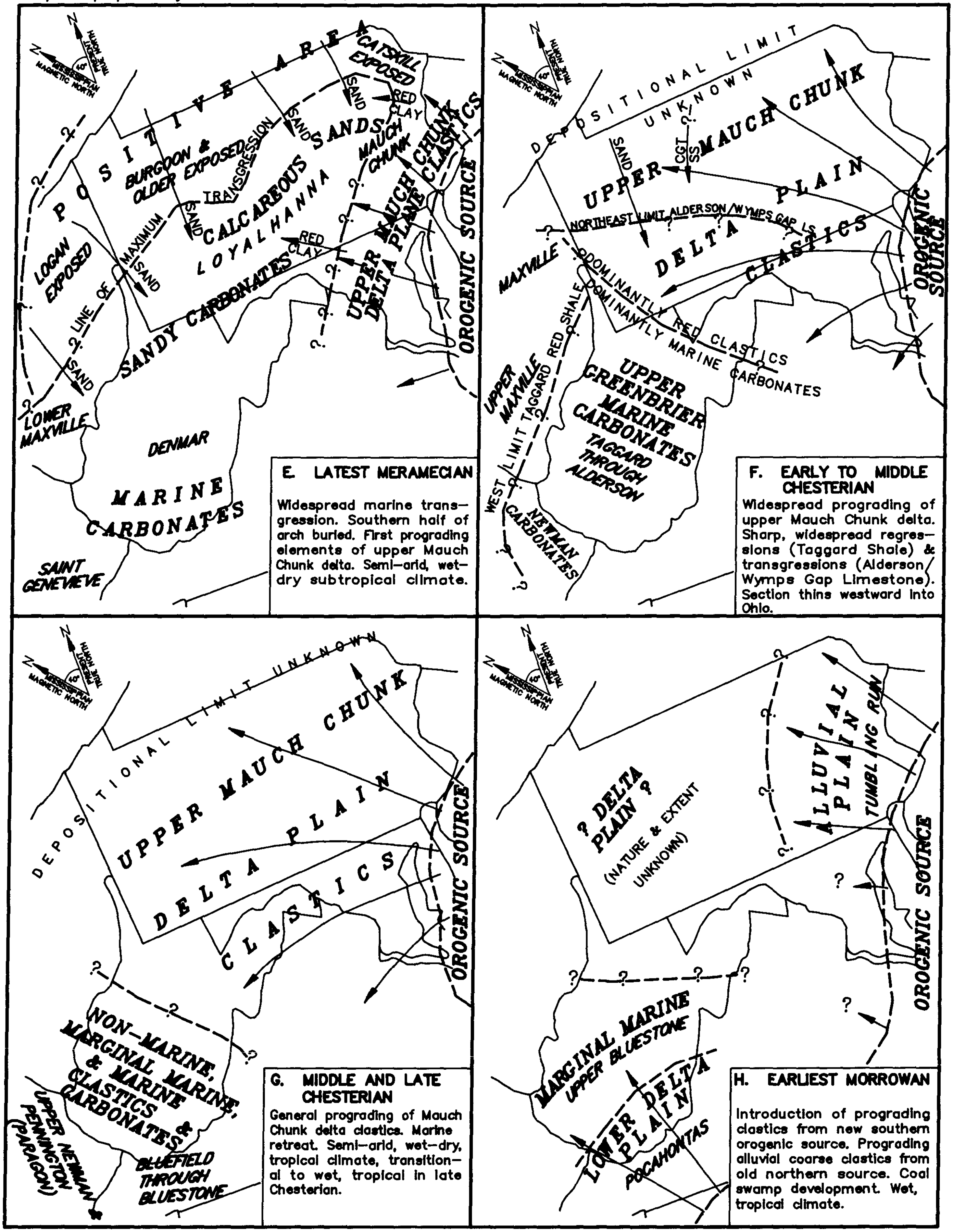

Figure 10. Osagean through Chesterian Mississippian and earliest Morrowan Pennsylvanian paleogeography and depositional environments of the central Appalachians (E-H).

Maryland, southeastern Ohio, all of the southwest quarter of Pennsylvania, central Pennsylvania at least as far north as Clinton, Lycoming, and Sullivan Counties, and at least across northern Luzerne and Carbon Counties in northeast Pennsylvania.

The disappearance of the Loyalhanna may occur in any one of three ways: erosional cut-out below the Pennsylvanian unconformity at the base of the Pottsville, onlap wedging against the topographically rising sub-Loyalhanna erosion surface, or by facies change into laterally equivalent rocks. Its absence in the subsurface in Beaver County probably results from erosional cut-out. In Clearfield County, redbeds which are interpreted to be stratigraphically higher than the Loyalhanna persist several miles northwest of the line of Loyalhanna disappearance, suggesting onlap wedging. It is possible, but not clearly demonstrated in central eastern Pennsylvania, that the Loyalhanna may be lost to facies change. Berg (1980) has reported the occurrence of non-calcareous sandstones with high-angle crossbeds that he interprets as aeolian sand dunes at the Loyalhanna position in Centre County. In most places, the nature of the Loyalhanna disappearance is simply not understood.

As already mentioned, the subcrop of the lower to middle Meramecian unconformity in Virginia and southern West Virginia is the Maccrady Formation. It is usually the top of various upper Pocono equivalents in the rest of West Virginia, Maryland, eastern Ohio, and southwest and southcentral Pennsylvania. In northcentral Pennsylvania (Figure 9, column 3), the Loyalhanna Member and presumably, the subjacent unconformity are underlain by up to 200 feet (60 m) of rocks containing a significant proportion of redbeds that in turn overlie the Pocono Formation (Faill and Wells, 1977, p. 15; Edmunds and others, 1979, Figure 12E; Ussler, 1973). Recent work by this author in northeast Pennsylvania (Figure 9, column 2) indicates the presence of the Loyalhanna Member overlying more than 100 feet (30 m) of green-gray sandstones and red shales on Wilkes-Barre Mountain in the southeast side of the Northern Anthracite field and at Rockport overlying about 300 feet (90 m) of redbeds (see Sevon, 1975, measured section 6, units 32 and 33). The apparent rapid thinning of the Pocono Formation in the Scranton area <u>prior</u> to the complete disappearance of the overlying Mauch Chunk suggests that loss of the Pocono there is of the sub-Loyalhanna unconformity, rather than the later sub-Pottsville unconformity.

Other, more limited instances of redbed-bearing sequences interposed between the Pocono and Mauch Chunk also occur. Flowers (1956, figure 3 and p. 12) noted the presence of red shales and siltstones between the Greenbrier and Pocono across Taylor and western Preston Counties in northern West Virginia (Figure 9, column 8). Flowers suggested possible equivalence with the Maccrady Formation. Ashburner (1878, p. 105) gives a questionable second-hand report of 141 feet of mostly red sandstone below the Loyalhanna near Todd in the northern part of the Broad Top synclinorium. Several miles to the south, near New Grenada, Brezinski (1984, p. 3 and p. 111, section 2b) shows 33 feet (10 m) of red siltstone below the Loyalhanna. Flint (1965, p. 26) noted that, throughout southern Somerset County, the upper 50 feet (15 m) of the Pocono Formation is variegated red, purple, green, and gray sandstone.

Most of these instances of significant sub-Loyalhanna redbeds are correctly identified as part of the Mauch Chunk Formation, but incorrectly interpreted as immediate temporal predecessors of the Loyalhanna. This is not too unreasonable considering the usual physical obscurity of the unconformity. The limited information available indicates, however, that the unconformity is between the Loyalhanna and the underlying redbeds and that these lower redbeds are unconformable with the Pocono below. In that case, the sub-Loyalhanna redbeds would be much older than the late Meramecian Loyalhanna itself and only slightly younger than the late Osagian terminal age of the Pocono.

The early-to-middle Meramecian unconformity is very widespread throughout the central Appalachians (Figure 10C). The southern margin extends more or less east-west across western Virginia and into southeastern Kentucky (Wayne, 1992). Its western edge is unclear, but, according to Warne (1990) and Weir and others (1966), probably exists between the Renfro Formation and St. Louis Limestone along the outcrop belt of Mississippian-age rock from Pulaski County to Mason County, Kentucky on the Ohio River (Figure 9, column 10). It is clearly still present to the western limit of late Mississippian in eastern Ohio between the Maxville Limestone (some of which may be St. Louis equivalent) and the underlying Logan Formation. The unconformity covers all of West Virginia and western Maryland to the eastern outcrop limit except, possibly, the Berkeley County section (Figure 9, column 7) that has been structurally translated at least 30 miles (48 km) west of its original position (Lessing and others, 1992). It is present in both the Broad Top synclinorium and Meadowgrounds syncline in southcentral Pennsylvania.

The extent of the unconformity across northeast Ohio and northern Pennsylvania is difficult to impossible to determine directly. Its stratigraphic position is cut out by the later basal Pennsylvanian unconformity in northwest Pennsylvania north of a line through Beaver, northern Armstrong, Clearfield and Potter counties (Figure 9, column 4). Its position is also cut out north of Scranton by the Middle Pennsylvanian unconformity in the northeast (Figure 9, column 2). Although the Geologic Map of Pennsylvania (Berg and others, 1980) indicates its absence, Mauch Chunk may be present in northcentral Pennsylvania as far north as Tioga County (Figure 9, column 3). Much of this may be pre-Loyalhanna.

The Loyalhanna Member and, therefore, the unconformity are tentatively identified several miles east of the Eastern Middle Anthracite field at Rockport. There is no direct evidence that either is present in the Mauch Chunk surrounding the rest of the area of the Southern and Middle Anthracite fields, but the possibility should not be discounted.

The middle Meramecian positive area was an impressive feature, measuring at least 500 miles (800 km) along its southwest-northeast oriented axis and up to at least 175 miles (280 km) wide (Figure 10C). The area probably was a positive tectonic arch or foreland bulge rather than an erosional highland related to eustatic sea level drop. There is no corresponding Meramecian gap recognized across the mid-continent area as would be expected if the latter were the case. This structure is very similar conceptually to the eastward-migrating, Meramecian peripheral foreland bulge proposed for eastern Kentucky and western West Virginia by Ettensohn and Chesnut (1989, p. 152-154 and fig. 6B).

Along the southern end of the arch, pre-Greenbrier rocks appear to be tilted to the south and erosionally beveled to the north so that the 1,700 foot-thick (520 m) Maccrady Formation is eliminated in the 100 miles (160 km from western Virginia to central West Virginia. Subsequently, it appears to have required at least several hundred feet of Greenbrier onlap to override the relief on the erosion surface across the same distance (Figure 10D). A similar, but less pronounced, westward dip and beveling appears to occur in eastern Kentucky between the Renfro Formation and the overlying St. Louis Limestone. In some respects, the northwest limit of the arch is so vague that a question arises as to whether it simply merges with the southeast side of the Cincinnati-Waverly-Findlay arch (or arches).

In the 50 to 70 miles (80 to 110 km) between the western end of the Southern Anthracite field and the Berwick anticline north of the Eastern Middle Anthracite field in eastern Pennsylvania, the thickness of the Mauch Chunk Formation declines by somewhere between 1,000 and 3,000 feet (300 and 900 m). There is no direct proof that this loss is caused by the presence of the Meramecian unconformity, but, if present, it would likely reflect a similar tilting and beveling situation.

Some notable secondary structural features are superimposed upon the general form of the arch (Figure 10C and 10D). In the zone across central West Virginia where the 38th-parallel lineament crosses the axis of the arch at an oblique angle, all pre-Greenbrier units are buckled upward, producing a transverse anticline along the trend of the lineament (Yielding and Dennison, 1986). The sub-Greenbrier unconformity has cut the top off the transverse anticline down to the top of the Catskill Formation although thinning of Greenbrier units indicates some topographic relief remained.

In the area of the Northern Anthracite field in northeast Pennsylvania, the sub-Loyalhanna unconformity cuts out the remaining lower Mauch Chunk and some of the underlying Pocono Formation in a northward direction, indicating southward tilting of pre-Loyalhanna rocks. This tilting is obscured by additional regional southward tilting that occurred in Middle Pennsylvanian time associated with the unconformity below the Sharp Mountain Member of the Pottsville Formation. The Sharp Mountain unconformity cuts out the Loyalhanna unconformity just north of Scranton.

The southward tilt of Lower Mississippian and older rocks in northwest Pennsylvania was imposed at the same time as the Meramecian arch was formed (Edmunds and others, 1979). Although these rocks are now unconformably overlain by Pennsylvanian Pottsville, the sub-Pottsville tilting is not related entirely to the early Pennsylvanian unconformity, but was partially inherited from the earlier Meramecian structure.

Disposal of the large volume of early Mauch Chunk, Maccrady, and other rocks eroded from the arch as well as the presumed continued influx of sediments from the eastern orogenic highlands presents a problem. There is no evidence of any significant clastic input associated with the middle Meramecian carbonates to the west or south of the arch. In fact, the arch may have acted as a block to incoming clastics, permitting carbonate deposition in that area. Some material eroded from the arch may have been transported northwest across the Findlay Arch to be deposited as part of the Michigan Formation in the Michigan Basin. Transport to the north and northeast is theoretically possible, but seems unlikely. Examination of the sequential onlap patterns of the post-unconformity Greenbrier and Mauch Chunk indicate that the topographically highest part of the erosion surface and, therefore, the drainage divide, was near the northwest side of the arch in Ohio and along the Pennsylvania-New York border. This would suggest that most of the positive area drained to the southeast and that the material eroded from the arch, as well as sediment from the eastern orogenic source, was directed southeast and south into central Virginia and the Carolinas (Figure 10C and 10D). The stratigraphically unique Pinkerton Sandstone (1,150 feet remaining) of Berkeley County in the eastern panhandle of West Virginia may be part of that material.

THE UPPER UNCONFORMITY

After the brief but broad transgression of the Loyalhanna marine tongue had buried much of the Meramecian erosion surface and the remnants of the old, lower Mauch Chunk delta (Figure 10E), clastics of the new, upper delta built rapidly across Pennsylvania and beyond. The lower few hundred feet formed a nonmarine-marine interface with the upper limestones of the Greenbrier Formation across western Maryland, northern West Virginia, southwest Pennsylvania and Ohio (Figure 9, column 8 and Figure 10F). Additional prograding of the upper delta pushed the strand line farther south and west where the Mauch Chunk clastics are a facies of the middle and late Chesterian Bluefield/Bangor and Hinton/Bluestone/Pennington marine and marginal marine sequence (Figure 9, columns 8, 9, and 10; Figure 10G).

The general thickness and extent of the upper delta sequence is difficult to determine, because no sooner was it completed, than widespread erosion associated the early Morrowan eustatic drop in sea level destroyed much or, in large areas, all of it (Figure 9). Although it is likely that upper delta sediments originally spread across northwest Pennsylvania, northeastern Ohio, and much of New York, they were completely removed.

The upper contact with the overlying Pennsylvanian rocks is conformable and the section of the upper delta is complete only in two areas. In southern West Virginia the upper delta is equivalent to the top 400 or 500 feet (120 to 150 m) of the Greenbrier Group plus the overlying Bluefield through Bluestone Formations which collectively exceed 3,000 feet (900 m) (Figure 9, column 9). In central eastern Pennsylvania, around the Southern and Middle Anthracite fields, the upper contact is also conformable. If the tentative identification of the Loyalhanna at Rockport is correct, it can be estimated that approximately the upper 2,000 to 2,500 feet of Mauch Chunk is equivalent to the upper delta.

In the area of the Northern Anthracite field, it cannot be determined if the early Morrowan unconformity was ever present or not. In that area, the Atokan age unconformity below the Sharp Mountain Member of the Pottsville progressively cuts out Mauch Chunk and older rocks (Figure 9, column 2).

THE REMAINS OF THE MAUCH CHUNK DELTA

Relatively little remains to mark the 20 to 25 million year attempt of the Mauch Chunk delta to build a delta complex that easily should have equalled or exceeded the Catskill delta.

The most clearly complete section is the relatively distal marine and marginal marine Maccrady through Bluestone sequence in western Virginia which is between 6,000 and 6,500 feet (1,800 and 2,000 m) thick (Figure 9, column 9). From there north to western Pennsylvania and eastern Ohio, both unconformities operated to eventually eliminate all Mauch Chunk and equivalents (Figure 9, columns 4, 5, 8, and 11). In western Pennsylvania and nearby parts of adjacent states the remaining Mauch Chunk and equivalents are almost all upper delta. Maximum remaining section is about 800 to 900 feet (240 to 275 m) thick in southern Somerset County and adjacent Maryland.

The Berkeley County, West Virginia section, which has been transferred at least 30 miles

(48 km) west of its original position (Lessing and others, 1992), consists of 1,300 feet (400 m) of Myers red shale overlain by 1,150 feet (350 m) of light gray Pinkerton Sandstone. The base of the Myers is late Osagian age and the top of the Pinkerton is not younger than middle Meramecian (Figure 9, column 7). As such, it is equivalent to the lower Mauch Chunk delta sequence. Post-Pinkerton rocks of Meramecian and Chesterian age are faulted out and not preserved.

At the south end of the Broad Top coal field almost 1,500 feet (460 m) of Loyalhanna and younger Mauch Chunk upper delta rocks are preserved (Figure 9, column 6). Some pre-Loyalhanna lower delta section may be preserved in Coles Valley, east of the coal field.

In northcentral Pennsylvania (Figure 9, column 3), small remnants of both the lower and upper delta seem to be present. The former is represented by up to 150 or 200 feet (45 to 60 m) of pre-Loyalhanna redbeds and the latter by about 60 feet (18 m) of Loyalhanna calcareous sandstone and 50 to 75 feet (15 to 23 m) of poorly exposed section, assumed to be Mauch Chunk shales, between the Loyalhanna and the overlying Pottsville Formation.

In the area of the Northern Anthracite Field in northeastern Pennsylvania, the Mauch Chunk Formation is between zero and 1,000 feet (300 m) thick (Figure 9, column 2). Although up to a few-hundred feet of lower delta rocks are present, the majority of the section is Loyalhanna and post Loyalhanna upper delta.

In central-eastern Pennsylvania (Figure 9, column 1) at the southwest end of the Southern Anthracite field, the Mauch Chunk Formation is estimated to achieve a maximum thickness of at least 4,000 feet (1,200 m) and probably 5,000 feet (1,500 m). In the area of the type section at the east end of the Southern Anthracite field, the formation is about 3,000 feet (900 m) thick. Along the south side of the Berwick Anticline, north of the Eastern Middle Anthracite field, the Mauch Chunk is estimated to be roughly 2,500 to 3,000 feet (750 to 900 m) thick, declining eastward.

Both top and bottom of the Mauch Chunk are conformable, although some question can be entertained as to whether or not some of the middle may be unconformably missing. At Rockport, near the east end of Mauch Chunk outcrop, the Loyalhanna Member has been tentatively identified at a position 300 feet (90 m) above the base of the Formation (see Sevon, 1975, measured section 6, units 32 and 33). If correct, this 300 feet would be all that remains of the lower Mauch Chunk delta. The complete upper delta would be, very roughly, 2,200 feet (670 m) thick.

All things considered, it is clear that the luckless Mauch Chunk delta had a very hard life, and, in the end, less was saved than was lost.

Flint, 1965

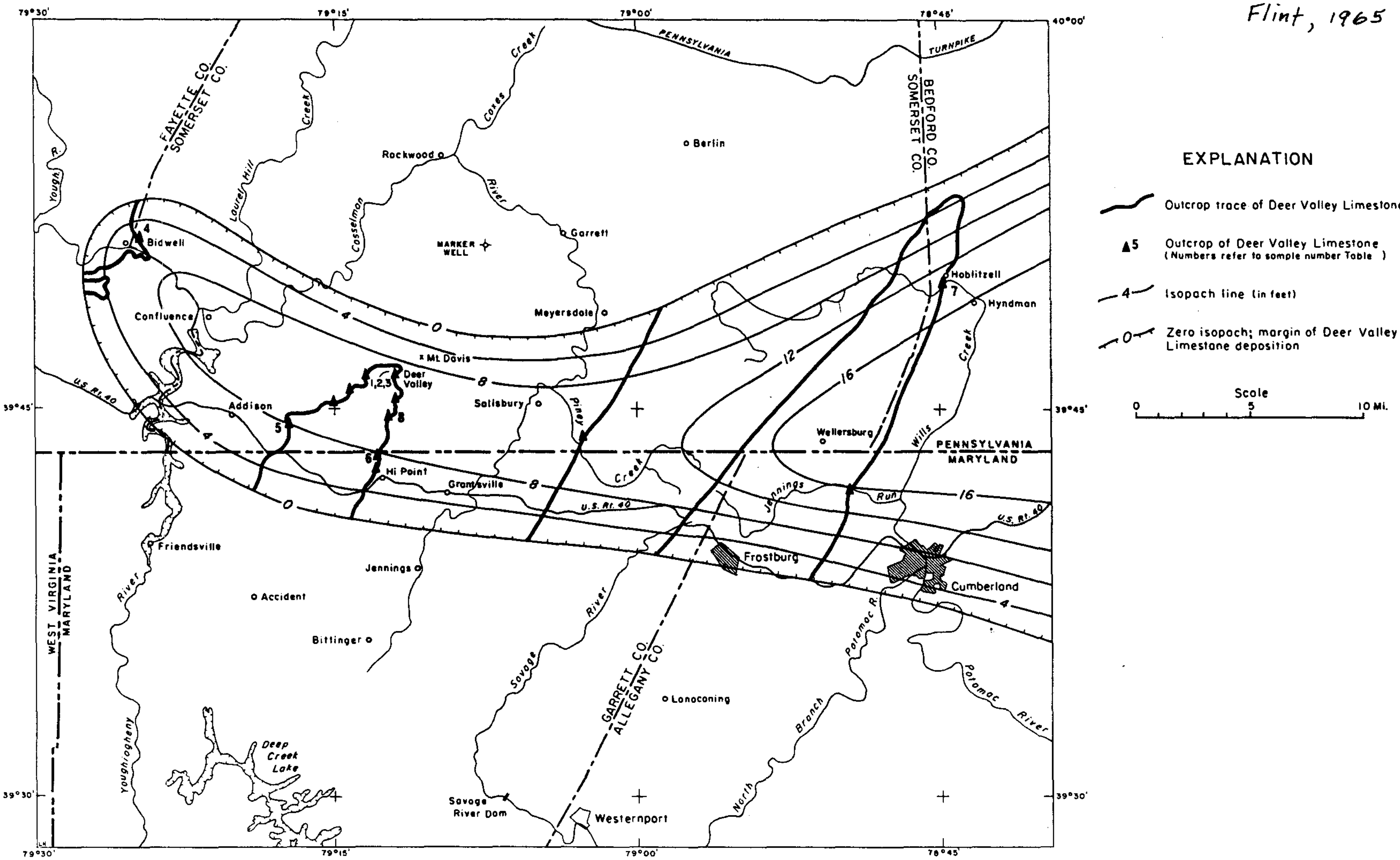

Plate 3. Isopach map of the Deer Valley limestone.

Editor's insert

SOME ASPECTS OF SUBSURFACE STRATIGRAPHY

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The subsurface stratigraphy in southwestern and south-central Pennsylvania has been described and redescribed many times, most recently by Harper and Laughrey (1987; 1989), Harper (1989), and Ryder and others (1992). I encourage those readers interested in pursuing this subject to consult these recent articles and the literature cited by their authors. The following discussion provides a brief update on the following selected intervals: (1) the Upper Cambrian Gatesburg Formation and Lower to Middle Ordovician Beekmantown Group; (2) the Lower Devonian Ridgeley Sandstone; and (3) the Upper Devonian Elk Group through Catskill Formation.

CAMBRIAN AND ORDOVICIAN

The deepest well to date in the Appalachian basin, the Amoco Production Co. #1 Leonard Svetz, was drilled on Laurel Hill anticline in Middlecreek Township, Somerset County in 1974. The well penetrated 21,460 feet of Paleozoic rocks, ranging in age from the Middle Pennsylvanian to the Late Cambrian, ending within the Gatesburg Formation. Harper (1989) and Ryder and others (1992) reported that this well penetrated to the Ore Hill Member of the Gatesburg, but Riley and others (in press) suggest that total depth was within the Upper Sandy Member. The well is significant for many reasons, not the least of which is that it penetrated what might be the most complete section of Ordovician rocks anywhere in the eastern United States.

At sometime during the Early Ordovician the passive southern margin of Laurentia converged with the adjacent edge of Gondwana, resulting in uplift and erosion. The erosional surface that developed across the Laurentian shelf, called the Knox unconformity, can be recognized throughout most of the present Appalachians and, perhaps, most of North America (Mussman and Read, 1986). It exposed progressively older rocks from east to west across eastern North America. In Ontario, upper Middle Ordovician rocks lie on Middle Cambrian rocks, whereas in central Pennsylvania there is still some question as to whether the unconformity even exists. The position of the unconformity in this area traditionally has been placed between the Bellefonte and Loysburg Formations (for example Chavetz, 1969; Mussman and Read, 1986; Read, 1989). However, Harris and Repetski (1982) used conodont data to conclude that it occurs <u>within</u> the Beekmantown Group (Figure 11). Ryder and others (1992) suggested that a thick cherty zone documented by Knowles (1966) and Lees (1967) near the base of the Bellefonte Formation in central Pennsylvania may represent the Knox unconformity. Hobson (1963) described chert nodules, stringers, and beds essentially from the same portion of the equivalent Ontelaunee Formation of southeastern Pennsylvania. Folk and Pittman (1971) noted that the cherts present in the Gatesburg Formation, which appear to be similar to the Beekmantown cherts, are replacement phenomena of former evaporites. Comprehensive petrographic study of the Beekmantown cherts could help determine if they had a similar origin, thereby implying a period of subaerial exposure within middle Beekmantown time.

Chaffin (1981) documented a broad regional gravity anomaly centered over Somerset ("Somerset gravity high"), but, because he could not explain the anomaly on the basis of sedimentary cover or basement thickness alone, he incorporated a small upward deflection of the upper mantle into his model to improve the fit. Chaffin determined that approximately 2.6 km (8,500 feet) of carbonates would be required to produce the gravity anomaly without the adjustment, but he found no evidence for such thicknesses in available isopach data (e.g., Chen, 1977 estimated only 4,000 feet or 1.2 km of carbonates in this area). The Svetz well provides the necessary evidence; it penetrated more than 5,900 feet of Ordovician and Cambrian carbonates and barely scratched the surface of the Cambrian. Based on known thicknesses of Cambrian carbonates in adjacent areas, the basement beneath Somerset can be projected at least 3,200 feet deeper than the bottom of the Svetz well. Thus, a minimum of 9,100 feet (2.7 km) of Cambrian and Ordovician carbonates certainly accounts for the observed gravity anomaly, and places the basement at approximately 25,000 feet beneath Somerset. Kulander and Dean (1978) projected the range of basement depth in this area from 24,000 to 27,000 feet. Riley and

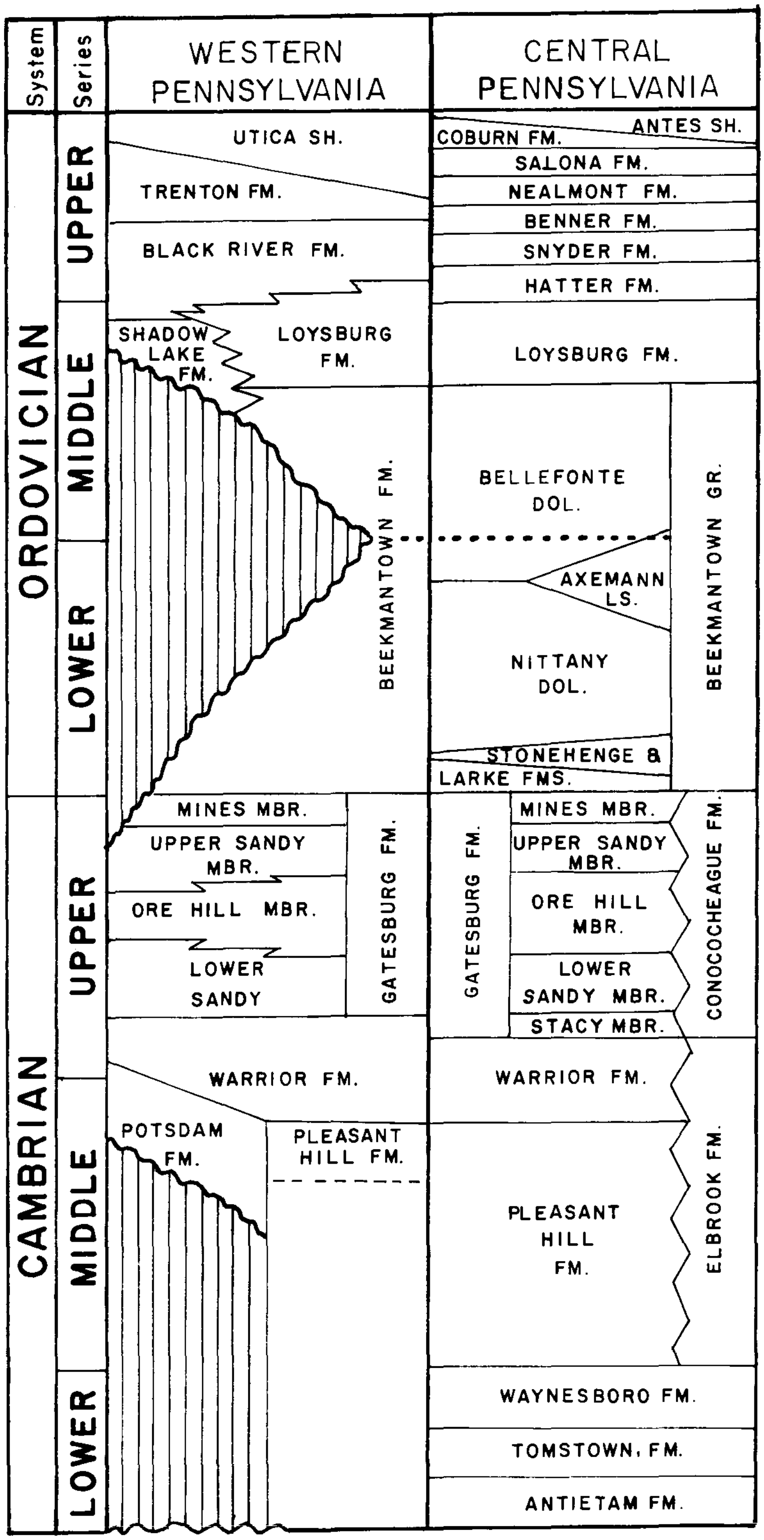

Figure 11. Stratigraphic correlation chart for the Cambrian and Ordovician carbonate section in western and central Pennsylvania (modified from Riley and others, in press, Figure 3). The "dotted" line within the Beekmantown Group indicates a thick sequence of chert that might represent the Knox unconformity in central Pennsylvania.

others (in press) indicate that this area occupies a portion of the Rome trough, a basement graben extending from Kentucky to New York. The Rome trough was reactivated several times during the Cambrian and Ordovician as indicated by anomalous thickening of certain formations, for example the Upper Sandy Member of the Gatesburg Formation which is more than 640 feet thick in the Svetz well.

The Ordovician section in the Svetz well also includes 5,100 feet of limestones and dolostones of which 4,100 feet can be assigned to the Beekmantown Group. These carbonates contain a wide variety of minor components, including chert, pyrite, siltstone, sandstone, anhydrite, gypsum, native sulfur, and at least two beds of metabentonite. The metabentonites occur between 17,900 and 18,000 feet, within an interval determined to be of lower to middle Chazyan age based on conodonts (Ryder and others, 1992). Several metabentonite beds were described from drill cuttings (Geological Sample Log Co. P-621) within the same stratigraphic interval of the Bellefonte Formation in the Shell Oil Co. #1 Duckworth well in Hampshire County, West Virginia, 50 miles SSE of the Svetz well. Although it is possible that these metabentonite occurrences represent contamination from uphole in both wells, such a coincidence is unlikely. They might, in fact, represent the earliest episode of volcanism associated with plate margin convergence in the Early Paleozoic of eastern North America. In an ideal situation, this uncertainty could be resolved by dating the samples using radioisotopes. However, K/Ar dates from the micas most likely would be unreliable because of the depth from which the cuttings were recovered. The small volumes of the cuttings (generally less than 200 grams per 10-foot interval) also prohibits the accurate dating of uranium and thorium from zircon and monazite which require amounts greater than a kilogram (R. C. Smith II, 1993, personal communication). Perhaps a more thorough study of the Bellefonte Formation in outcrop eventually will resolve the question.

LOWER DEVONIAN

The Lower Devonian Ridgeley Sandstone(Oriskany sand of drillers) is one of the most important reservoirs for natural gas in the Appalachian basin. In Somerset County it is <u>the</u> most important reservoir; only a few wells produce from Middle Devonian Huntersville Chert or Upper Devonian sandstones. Somerset County owes its status as a major gas producer to Amoco Production Company which, from the mid-1970's to the early 1980's, spearheaded the exploration and development of Ridgeley gas fields in southwestern Pennsylvania. Because of this activity, the Ridgeley Sandstone in Somerset County recently has received a great deal of attention in the form of internal corporate reports, symposium talks, and industry-funded master's theses.

The Ridgeley Sandstone averages more than 100 feet thick in Somerset County, and includes as many as three vertically stacked, but horizontally discontinuous, sequences of quartz arenite separated by thick sequences of arenaceous and argillaceous limestone (Welsh, 1984) (see Figure 12). The quartz arenites consist of well-rounded, well-sorted, medium-grained sand consisting mostly of monocrystalline quartz (Foreman and Anderhalt, 1986). The limestones consist primarily of bioclastic calcarenites composed mainly of brachiopod valve fragments, echinoderm plates, and ostracodes. The quartz sand in these latter rocks typically is subangular and ranges in size from coarse silt to fine sand. Undifferentiated clays and lithic grains comprising mostly mudstone clasts and chert constitute the remaining major components. Minor detrital components include feldspars (mostly microcline), zircon, tourmaline, mica, and polycrystalline quartz derived from igneous or metamorphic rocks. Authigenic minerals include vermicular kaolinite and pyrite.

Environmental interpretations of the Ridgeley Sandstone have relied mainly on studies of exposures in the Ridge and Valley Province. Most authors agree that the Ridgeley represents deposition in a near-shore marine environment, but there the agreement ends. Early workers, such as Swartz (1913) proposed a high-energy beachface environment for the Ridgeley in the Ridge and Valley; this was supported later by fossil studies (Seilacher, 1968). Other authors have suggested tidal ridges and submarine dunes (Basan and others, 1980), shallow to deeper subtidal (Barrett and Isaacson, 1981), and marine shelf bar (Welsh, 1984) environments. There obviously is no single model that fits all Ridgeley occurrences and, because the interpretations were made from different outcrops and well data, there shouldn't be one. Welsh's (1984) work with drill cores and gamma ray logs from Ridgeley wells in Somerset County presents the

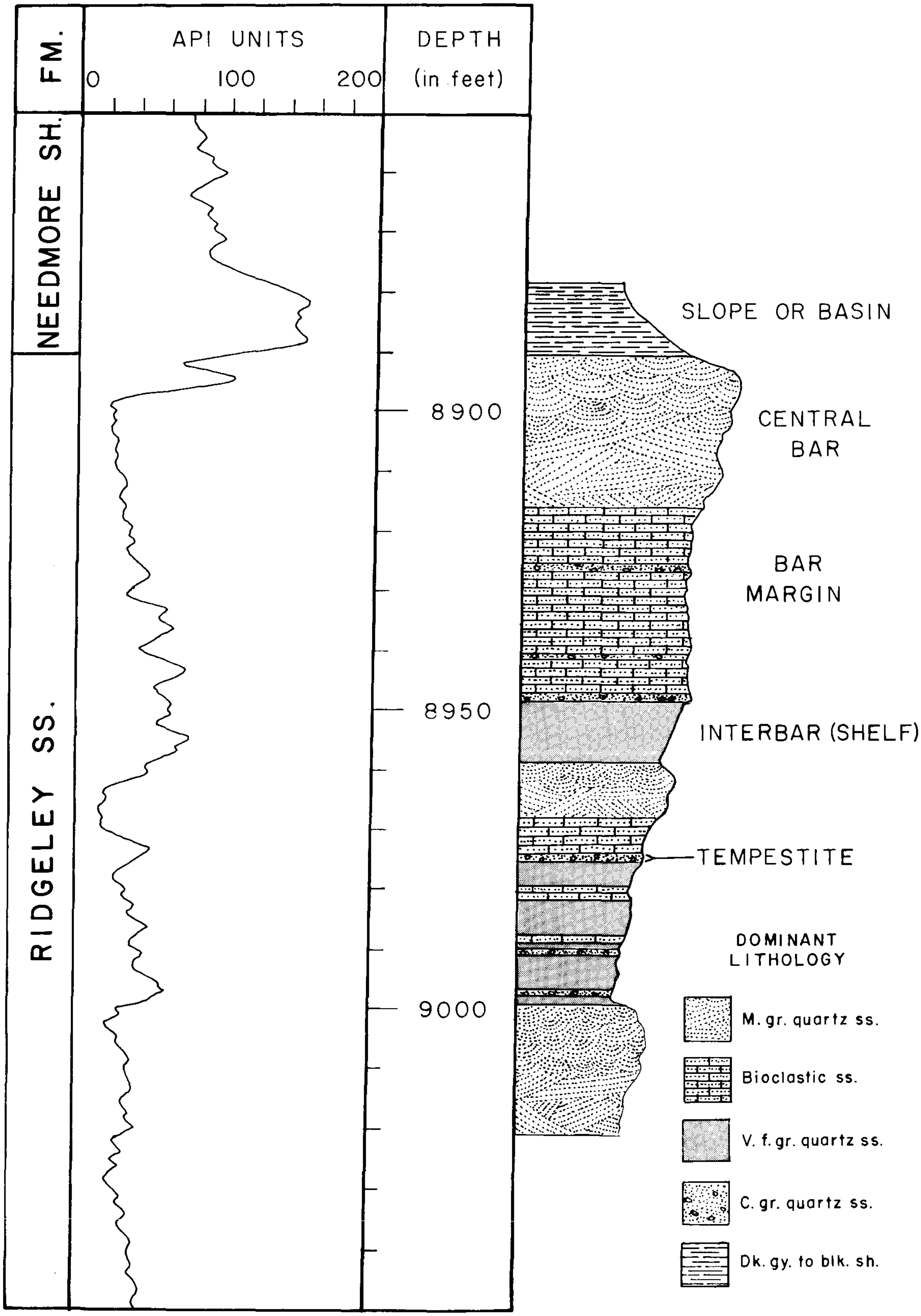

Figure 12. Gamma ray log, graphical core description, and environmental interpretation of the Lower Devonian Ridgeley Sandstone in the Amoco Production Co. #1 Romesburg well in Somerset County (modified from Welsh, 1984, Figure 11 & Plate 2).

best environmental interpretation in this area. He interpreted the Ridgeley sequence to include the following genetic units: central bar, bar margin, interbar, and tempestite. Figure 12 shows the relationship of these units to the gamma ray log for the Amoco #1 Romesburg well in Black Township. Notice the repetition of units through the section. These are the vertically stacked quartz arenites and interbedded arenaceous limestones. Each unit contains diagnostic sedimentary structures, trace fossils, and petrologic features that make it easily identifiable in cores, but only the central bar can be determined by using just gamma ray logs.

Foreman (1986; also Foreman and Anderhalt, 1986) summarized the diagenetic history of the Ridgeley from two cores in Fayette and Somerset Counties. The early burial phase included the development of syntaxial quartz overgrowths and microcrystalline quartz, syntaxial calcite overgrowths, and minor pyrite cement. During maximum burial non-ferroan sparry calcite developed, followed by non-ferroan microcrystalline dolomite. Late-stage (fracturing and uplift) cement formation included the development of megaquartz, chalcedony, both non-ferroan and ferroan calcite, and both non-ferroan and ferroan dolomite. Basilone (1984), in a study of the origin and implication of fluid inclusions from filled fractures in the Ridgeley, determined that the fractures opened at a depth of 22,000 feet and remained open through a long episode of uplift. Fracturing followed most diagenetic events, hydrocarbon migration and emplacement within the Ridgeley reservoirs preceded the formation of quartz and ferroan calcite that filled the fractures.

UPPER DEVONIAN

The Upper Devonian rocks of Somerset County originated as marine, transitional, and non-marine sediments of the Catskill deltaic system. Sevon and others (1978; also Sevon, 1985b) identified eight major drainage systems in the Catskill delta that acted as input centers in central Pennsylvania during the Late Devonian. Laughrey and Harper (1986) developed a similar configuration for the Upper Devonian rocks of western Pennsylvania, including Somerset County, based on the net thickness of sandstone in the subsurface (Figure 13). In Sevon's terminology, the Upper Devonian rocks of Somerset County originated as sediments supplied by the Fulton sediment-dispersal system. This resulted in a complex of mostly red-colored delta-plain and alluvial-plain facies to the southeast. In western Pennsylvania, however, marine sedimentation dominated, resulting in rocks ranging from basinal black shales and slope (clinoform) turbidites to shoreline sandstones and fluvial-deltaic mudstones. Complexities in stratigraphic nomenclature result from the distribution of prograding facies (Figure 14). To complicate things even further, the dotted line winding through Somerset County in Figure 13 represents the arbitrary cutoff separating western Pennsylvania nomenclature (Venango, Chadakoin, Bradford, Elk) from that used in the south-central Ridge and Valley (Catskill, Foreknobs, Scherr).

The Elk Group and facies equivalent Scherr Formation consist of interbedded, delta-front shales and siltstones with minor but significant sandstones. The presence of sandstone separates the Elk Group from the underlying slope turbidites of the Brallier Formation. In West Virginia, equivalent rocks contain thick sequences of unproductive shale and siltstone separating thinner sequences of hydrocarbon-rich sandstones and siltstones with drillers' names such as Benson, Alexander, and Riley. The Benson sand currently is the most important Upper Devonian gas reservoir in West Virginia, but for some as yet unknown reason it is totally unproductive in southwestern Pennsylvania.

The Bradford Group, the western facies equivalent with the Foreknobs Formation, consists of a complex sequence of sandstones, siltstones, and shales representing near-shore, shelf, and slope sedimentation during repeated cycles of sea level change and depositional pulses. Bradford Group rocks represent the most important natural gas reservoirs in the Upper Devonian of Pennsylvania.

The Venango Group has no single facies equivalent in outcrop. Harper and Laughrey (1989) divided this unit into three subunits or zones, the Lower Sandy, Middle Red Shale, and Upper Sandy zones. The Upper Sandy, a sequence of fluvial-deltaic and near-shore marine sandstones, siltstones, and shales, has been called "Oswayo Formation" by most authors. The Middle Red Shale is a distal tongue of the Catskill Formation. The Lower Sandy is very similar lithologically to the Upper Sandy; it has been referred to alternately as "Chemung" and

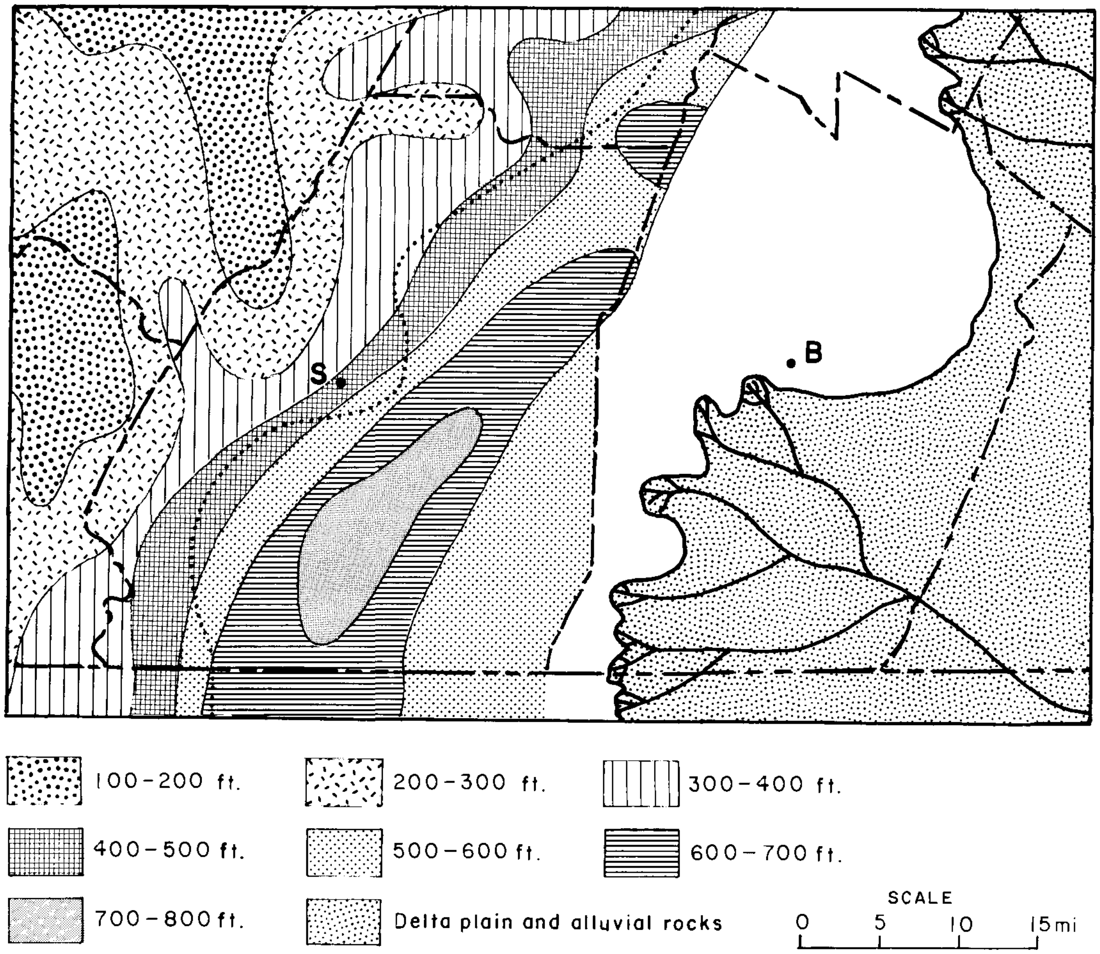

Figure 13. Map of the Somerset (S) and Bedford (B) area showing thickness and distribution of Upper Devonian sandstones (based on 50 percent sand measured on gamma ray logs), and the interpreted depositional framework of the Catskill deltaic system (modified from Laughrey and Harper, 1986, fig. 3). Deltas include the Fulton and (in part) Broad Top sediment dispersal systems of Sevon (1985b, Figure 2). The dotted line winding through Somerset County is the arbitrary cutoff between western and central Pennsylvania Upper Devonian stratigraphic nomenclature (Piotrowski and Harper, 1979).

"Foreknobs" where it crops out in the Youghiogheny River gorge through Laurel Hill at Ohiopyle. The Venango Group contains some of the more important oil producing rocks in Pennsylvania and several very important gas reservoirs in West Virginia.

The Catskill Formation is one of the thickest and most important rock sequences in eastern and central Pennsylvania. As such, it has received a great deal of attention since first reported by the geologists of the First Pennsylvania Geological Survey. In western Pennsylvania, the Catskill is merely a subsidiary unit representing the final Late Devonian pulse of progradation by the Catskill deltaic system; it doesn't even contain mentionable quantities of exploitable mineral resources. The change from typically thick central Pennsylvania Catskill Formation to the western Pennsylvania Catskill tongue (Middle Red Shale zone of the Venango Group) occurs at the approximate position of the Laurel Hill anticline, suggesting paleostructural control of deposition.

Chronostratigraphic correlation of the Late Devonian sequences across western Pennsylvania is difficult at best because easily identifiable synchronous surfaces and isochronous units are sparse, of limited geographic extent, or simply unidentifiable. Biostratigraphy has been of little help because of the lack of raw fossil data and published paleontological information. This lack results from sampling methods - the vast majority of Late Devonian rocks in this area occur only in the subsurface, and it is difficult to get good specimens of

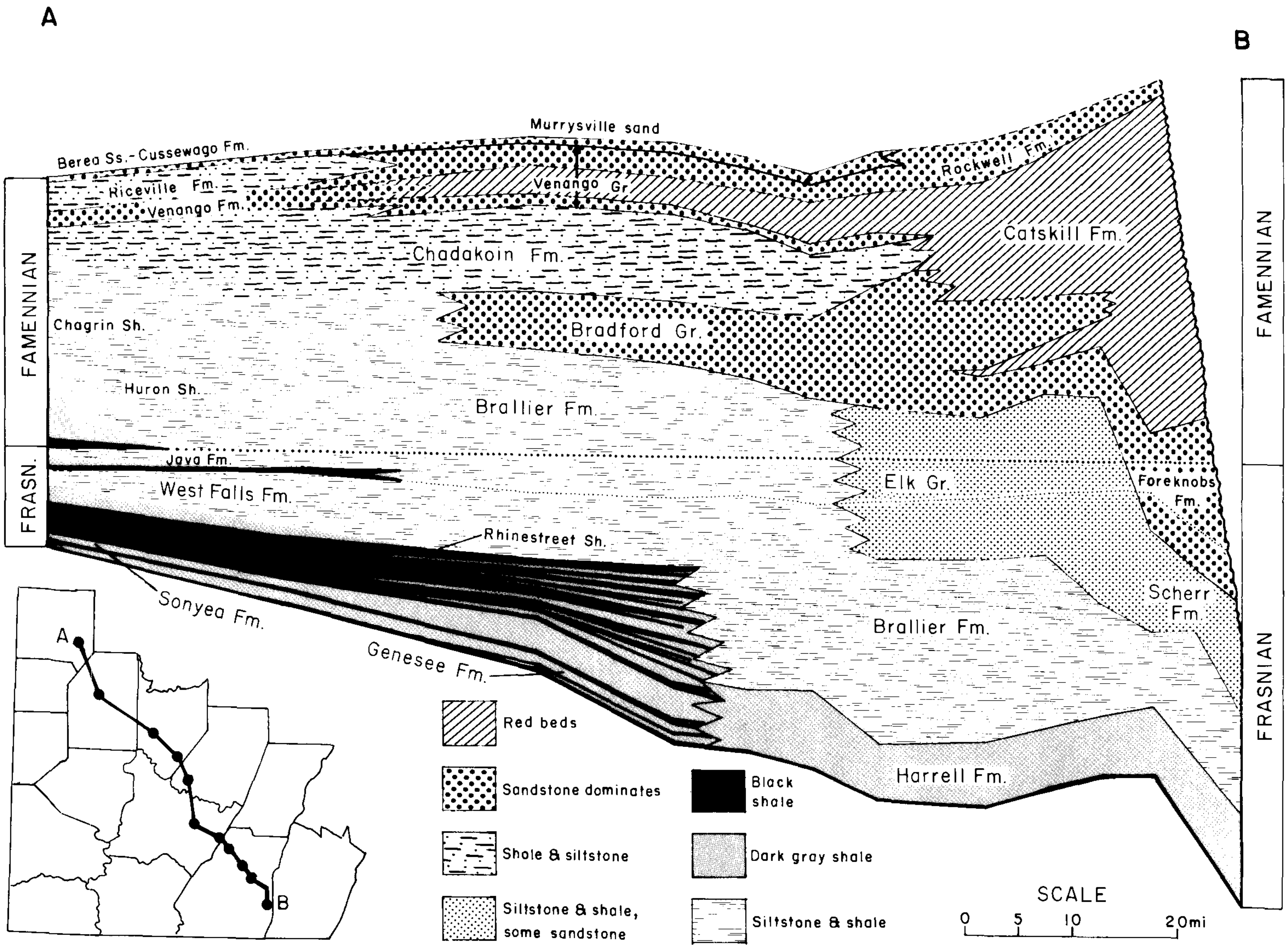

Figure 14. Interpreted cross section of Late Devonian rocks between Mercer and Somerset Counties, Pennsylvania, based on geophysical logs, sample descriptions, and drillers records. Datum (dotted line) is the Frasnian-Famennian boundary.

recognizable brachiopods and cephalopods using a drill bit. The possibility exists that conodont and/or spore material might be recoverable from drill cuttings of sufficient quality and quantity. Drillers, however, commonly are more interested in the quantity of oil and gas, and the speed with which they can get from the surface to the reservoir, than in the quality of recoverable drill cuttings. Volcanic ash beds, which commonly represent ideal synchronous surfaces, are scarce in the Late Devonian. Only two, the Belpre and Centre Hill ash beds that occur in the West Falls and Java Formations, respectively (Figure 14), have been considered geographically extensive enough to range into westernmost Pennsylvania (Berg and others, 1986). Neither has been confirmed farther east either in the subsurface or at the surface.

The search for suitable isochronous events led Dennison (1971) to use eustatic sea level curves in an attempt to correlate the Brallier, Scherr, and Foreknobs with the standard Late Devonian section in New York. Sea level changes are not really isochronous in the true sense of the word, but the interval of time represented by a transgression typically is so small, geologically, as to be relatively insignificant. The possibility that Late Devonian sea level curves can be used has been established by several studies (e.g. Warne, 1986; also Warne and McGhee, 1991) that seem to substantiate Dennison's results with only minor modifications.

Dennison (1970) and McGhee and Dennison (1976) divided the Foreknobs Formation into five members (in ascending order the Mallow, Brierly Gap, Blizzard, Pound, and Red Lick Members) based primarily on the amount and thickness of sandstone beds in the section. The two members dominated by thick sandstones, the Brierly Gap and Pound, are important for cross-state chronostratigraphic correlation. In eastern Somerset County the Brierly Gap member consists of 50 feet of fine- to medium-grained, gray, massive, locally conglomeratic sandstone interbedded with subsidiary siltstones and shales (Warne and McGhee, 1991). The Pound Member is a 25- to 30-foot-thick sequence of fine- to medium-grained, gray, crossbedded sandstone containing some conglomeratic layers and a few interbedded siltstones and shales. These members occur at 345 and 1,095 feet, respectively, above the base of the Foreknobs at New Baltimore, eastern Somerset County (Warne, 1986). Based on eustatic sea level cycles, Dennison (1971) tentatively correlated the top of the Brierly Gap Member with the Pipe Creek Shale of the Java Formation of New York, and the Pound Member with the Dunkirk Shale. The base of the Dunkirk Shale represents the rock equivalent of the boundary between the Frasnian and Famennian global stages. Using paleontological data, McGhee and Dennison (1980), Warne (1986), and Warne and McGhee (1991) confirmed this correlation.

I attempted to determine if this correlation held true through the subsurface by tracking gamma ray signatures of the Dunkirk and Pipe Creek shales (basal black shales of the Huron and Java Formations, respectively, in Figure 14). Throughout northwestern Pennsylvania these units can be recognized in geophysical logs by their characteristic gamma ray spikes that result from increased radioactivity generated by uranium and thorium enrichment in organic-rich black shales. These spikes die out less than halfway across the plateau as the basinal black shales grade laterally into slope turbidites of the Brallier Formation, but characteristic shale "packages" corresponding to the Pipe Creek and Dunkirk continue farther eastward. Similarly, as Warne (1986) demonstrated, the Brierly Gap and Pound Members can be correlated at least part way into the subsurface of western Pennsylvania from the outcrop belt. Although my correlations were cursory at best, I could find what appeared to be Brierly Gap and Pound equivalents as far west as western Somerset County where they became indistinguishable from the interbedded sandstones, siltstones, and shales of the Elk Group. However, the position of these rocks within the Elk Group corresponds to the Benson sand of drillers. Piotrowski and Harper (1979) suggested the Benson was equivalent in part with the Dunkirk and stratigraphically lower black shales (such as the Pipe Creek). Thus, by indirect means, this work provides evidence that McGhee and Dennison (1980) were correct. This is reflected in Figure 14 where the datum for the cross section, the heavy dotted line in the approximate center of the diagram, represents the Frasnian-Famennian boundary. This supposed isochronous line connects the Dunkirk Shale in Mercer County with the position of the Pound Member in the Foreknobs Formation of eastern Somerset County. The finer dotted line below is also a probable isochronous line, connecting the Pipe Creek Shale with the Brierly Gap Member.

One observation springs from this work: subsurface correlation suggests that the Brierly Gap and Pound members more correctly should be considered stratigraphically equivalent with the siltstone units <u>below</u> the Pipe Creek and Dunkirk shales, rather than with the black shales themselves. This might be a good project for a graduate thesis.

STRUCTURAL GEOLOGY OF THE SOMERSET-BEDFORD COUNTIES AREA, PENNSYLVANIA

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OROGENIC HISTORY OF THE SOMERSET-BEDFORD AREA

The Passive Margin

The geologic history of post-Grenvillian rocks in Somerset and Bedford Counties area began some 650 Ma ago at the beginning of the Iapetan Wilson cycle, when rifting to the southeast broke the Neoproterozoic super-continent into Laurentia and South America(?). The Iapetus Ocean developed between them (Figure 15). The subsequent development of a passive margin at the edge of Laurentia caused the Mesoproterozoic Grenvillian metamorphic rocks that underlie the Somerset-Bedford area to descend. Initially, siliciclastic sediments from the northwest accumulated on the Grenvillian basement. However, a carbonate bank developed at the Laurentian margin to the southeast, and, through time, it gradually enlarged to the northwest. By the Middle Cambrian (perhaps even late in the Early Cambrian), this carbonate shelf had spread to the Somerset-Bedford area (Figure 16). Carbonate deposition continued in this area, and by the Late Ordovician, perhaps as much as 2,700 m (9,000 feet) of carbonate rock had accumulated (Ryder and others, 1992).

The Taconian Orogeny

The next phase of the Iapetan Wilson cycle began in the late Middle Ordovician with the change from oceanic extension to continental convergence. This convergence caused partial closing of Iapetus and the Taconian orogeny along the Laurentian margin, events that eventually completely transformed the Somerset-Bedford area. The orogeny created a mountain system to the southeast at the continental margin that separated the carbonate shelf to the northwest from Iapetus. In its stead, a regional intracratonic basin, the Appalachian basin, developed on top of the former carbonate shelf, and it received the sediment eroded from the Taconian mountains.

The Appalachian Basin

The Appalachian basin deepened over the next 170 Ma and accumulated sands, silts, muds, and carbonates derived from the southeast. Accelerated basin subsidence and increased sediment supply caused by the Middle Devonian Acadian orogeny produced a prograding alluvial plain that spread across most of the basin (Figure 17). More complicated tectonic movements during the subsequent Carboniferous Period resulted in a complex shifting of depositional environments that are preserved in the coals and intervening clastics of the Allegheny Plateau. The stage was thus set for the growth and development of the geologic structures now present in the Somerset-Bedford area.

The Alleghanian Orogeny

The Alleghanian deformation of rocks of the Appalachian basin and the underlying Lower Paleozoic carbonate shelf sequence was a décollement tectonism. Above a regional, layerparallel (subhorizontal) fault, the rocks were faulted and folded in a fairly systematic fashion; below this basal décollement, the rocks were largely undeformed (that is, unaffected by the Alleghanian) (Figure 18). Regionally, the direction in which the rocks moved on the décollement was perpendicular to the structural trends, changing from the west-northwest (in the Somerset County area) to north-northwest in the Susquehanna River valley and anthracite region to the northeast. This change in movement direction produced the arcuate pattern of folds in Pennsylvania. To the southwest of Somerset (to Roanoke, Virginia), the movement direction was uniformly to the west-northwest.

From under the present Coastal Plain sediments (to the southeast in New Jersey) to the

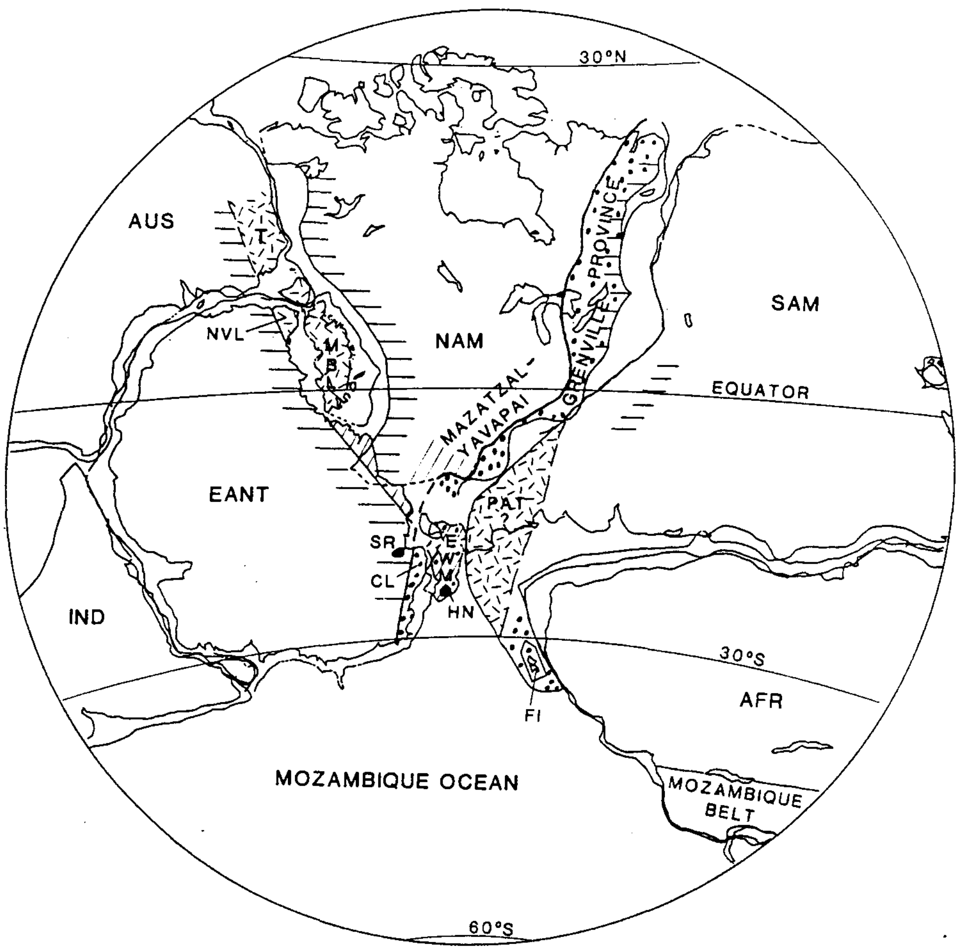

Figure 15. Separation of Laurentia-South America late in the Neoproterozoic produced the Iapetus Ocean off the (present) southeast margin of Laurentia. Reconstruction of continental positions at the start of the Cambrian. NAM, Laurentia (North America); SAM, South America; EANT, eastern Antarctica. From Dalziel (1991).

limit of Alleghanian folding to the northwest, displacement on the décollement was converted into deformation of the overlying rocks. The amount of displacement thus diminished progressively to the northwest: rocks in the Piedmont of southeastern Pennsylvania (and Maryland and Delaware) were moved the greatest amount; those in the Somerset area much less. The style of deformation also changed from southeast to northwest, corresponding in large part with the physiographic provinces. In the Piedmont, the predominant style was low-angle thrusting. In the Valley and Ridge province to the northwest, the style was a combination of faulting and folding. The Allegheny Plateau, the northwesternmost province, exhibits only folding (at least at the surface, with one or two exceptions). The structural boundaries between adjacent provinces mark where the fundamental changes in structural styles occur.

Décollement Tectonics

All of the largest (first-order) structures in all the provinces originated as splays (thrust faults) rising from the basal décollement. Under the present Coastal Plain, the décollement originated somewhere fairly deep within the crust (Figure 18). Under the Piedmont of southeastern Pennsylvania, the décollement lies within the upper part of the crust. At some point, perhaps just north of Chesapeake Bay, the décollement emerged from the crust, entered the carbonate shelf sequence, and became parallel to bedding, probably in the more argillaceous Lower-Middle Cambrian Waynesboro Formation. At the Allegheny structural front, the décollement ramped upward some 2,600 m to the Silurian Salina Formation.

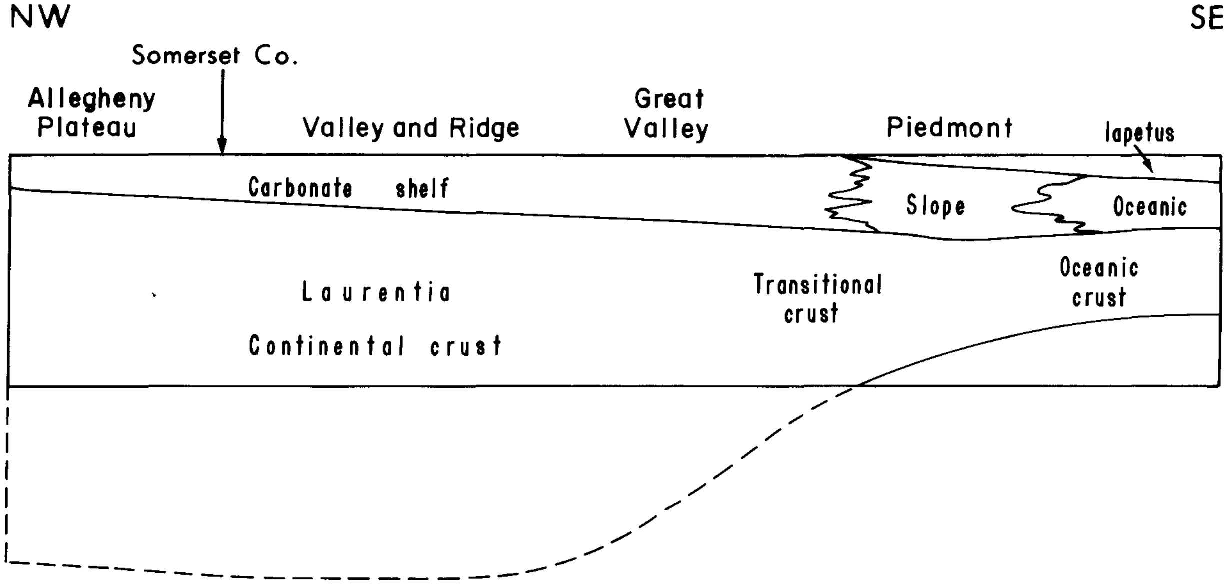

Figure 16. Cross section of the Laurentian southeast margin during the Middle Ordovician. The broad carbonate shelf that developed on the continental margin thinned to the northwest over several hundred kilometers. The carbonate shelf graded southeastward into continental slope and ocean basin sediments. Vertical exaggeration, ~3X.

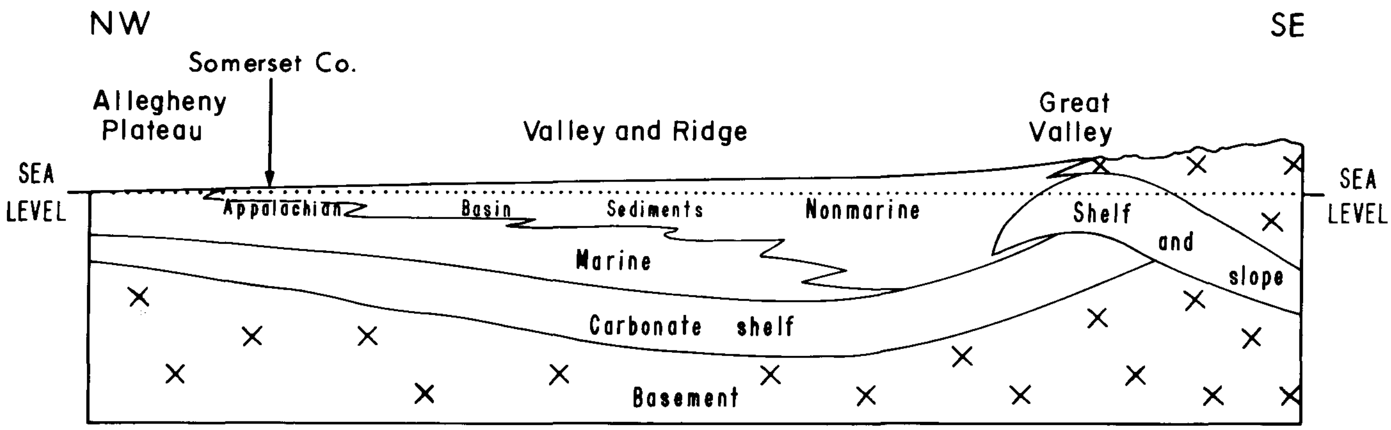

Figure 17. Cross section of the Appalachian basin that developed over the carbonate shelf after the Taconian orogeny created a mountain system at the continental margin late in the Ordovician. The basin received sediment from the southeast throughout the remainder of the Paleozoic because of renewed uplift and subsequent orogenies. By the end of the Devonian, sediment thickness in the basin reached as much as 9,000 m in eastern Pennsylvania; in the Somerset area, the thickness was nearly 4,000 m. Vertical exaggeration, ~3X.

In the previously deformed rocks of southeastern Pennsylvania, low-angle thrusts extend upward through the presently exposed rocks, cutting across many of the pre-existing, earlier structures. In the Valley and Ridge province, there were no pre-existing structures——the existing rocks were the subhorizontal Paleozoic layers of the carbonate shelf and Appalachian basin. In the lower parts, splays from the décollement cut upwards across this subhorizontal layering. As the faults climbed through the stratigraphic section, the movements on these thrusts were gradually transformed into large folds (Figure 18). Many of the faults ended before reaching the present erosion surface, their movement having been completely converted into fold development. Only those splays with the greatest displacements, or in the structurally highest anticlines along the Allegheny structural front, are presently exposed.

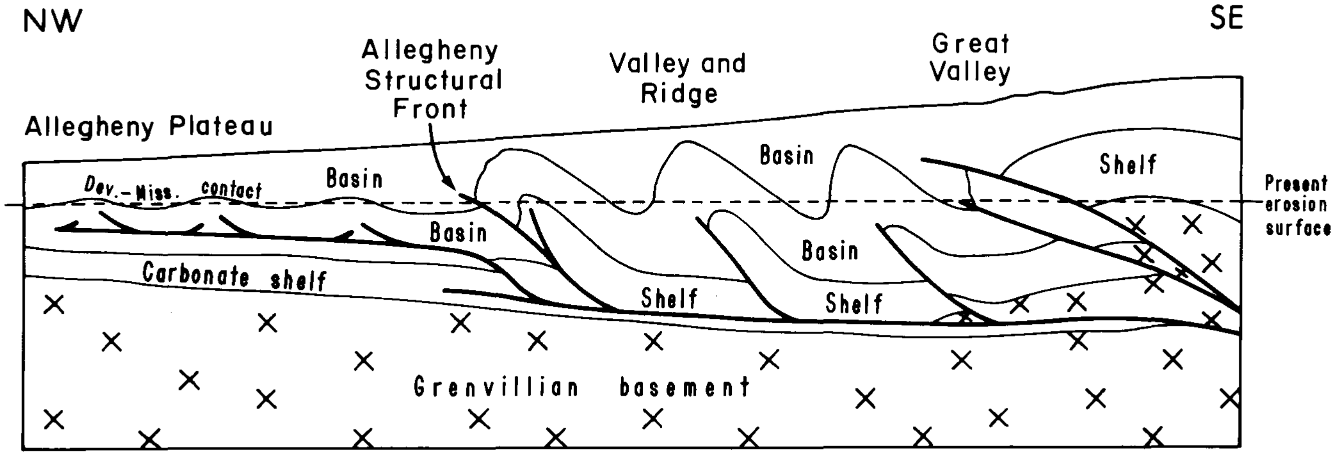

Figure 18. Cross section of the Alleghanian décollement in Pennsylvania, rising from within the crust in the southeast, entering and paralleling the carbonate shelf deposits under the Great Valley and Ridge and Valley province, and ramping up to the Silurian level under the Allegheny Plateau. Vertical exaggeration, ~3X.

In southcentral Pennsylvania, these include the Hyndman, Little Scrub Ridge, and Friends Cove thrust faults; other, similar faults occur in the anticlines to the northeast.

The Allegheny Structural Front And The Allegheny Plateau

The Allegheny structural front separates the Valley and Ridge province from the Allegheny Plateau province to the northwest. It generally is a relatively narrow (1 to 2 km wide) zone in which bedding attitude decreases (gradually or abruptly) from a steep (even overturned) or moderate northwest dip to a low (less than 10 degrees) northwest dip (Figure 18). It corresponds with the major shift of the décollement from the Waynesboro to the Salina.

The major structures in the Allegheny Plateau province in general, and in Somerset County in particular, consist of large (first-order), low-amplitude (relative to those in the Valley and Ridge) anticlines. In general, these folds extend down only to the décollement in the Salina Formation (Figure 18). Under each anticline, splays from this décollement horizon rise through the overlying Devonian section, but rarely penetrate or pass through the higher Carboniferous strata.

The amount of displacement on the décollement under the Plateau is an order of magnitude less than that under the Valley and Ridge. Whereas the large movements on the Valley and Ridge splays produced anticlines with structural relief on the order of 5 km, the much smaller movements on the Plateau splays created anticlines with structural relief of 300 m or less. The amount of displacement on the Salina décollement was thus correspondingly less than that in the Valley and Ridge.

The Waynesboro-level décollement does continue under the Allegheny Plateau for some distance, perhaps as far as Chestnut Ridge to the west of Somerset County. The movement on it here was much less in the Plateau than under the Valley and Ridge, because most of the displacement ramped up to the Salina level. However, small splays from the Waynesboro level décollement do occur under the larger anticlines (Chestnut Ridge, Laurel Hill, Negro Mountain, and Deer Park). They may have contributed to their development, and possibly even triggered their growth by causing the Salina splays to cluster over the deeper "humps", accentuating the anticlinal growth in the younger stratigraphic units.

The Anticlines In The Somerset/Bedford Area

The easternmost stop (STOP 4) on this Field Conference lies within the Hyndman fault zone (de Witt, 1974). This zone dips steeply to the east-southeast (Figure 19), and is the surface expression of the Waynesboro-level splay that produced the Wills Mountain anticline, the westernmost first-order anticline in this part of the Valley and Ridge province. Bedding in the western limb of Wills Mountain dips moderately west-northwest to vertical, especially

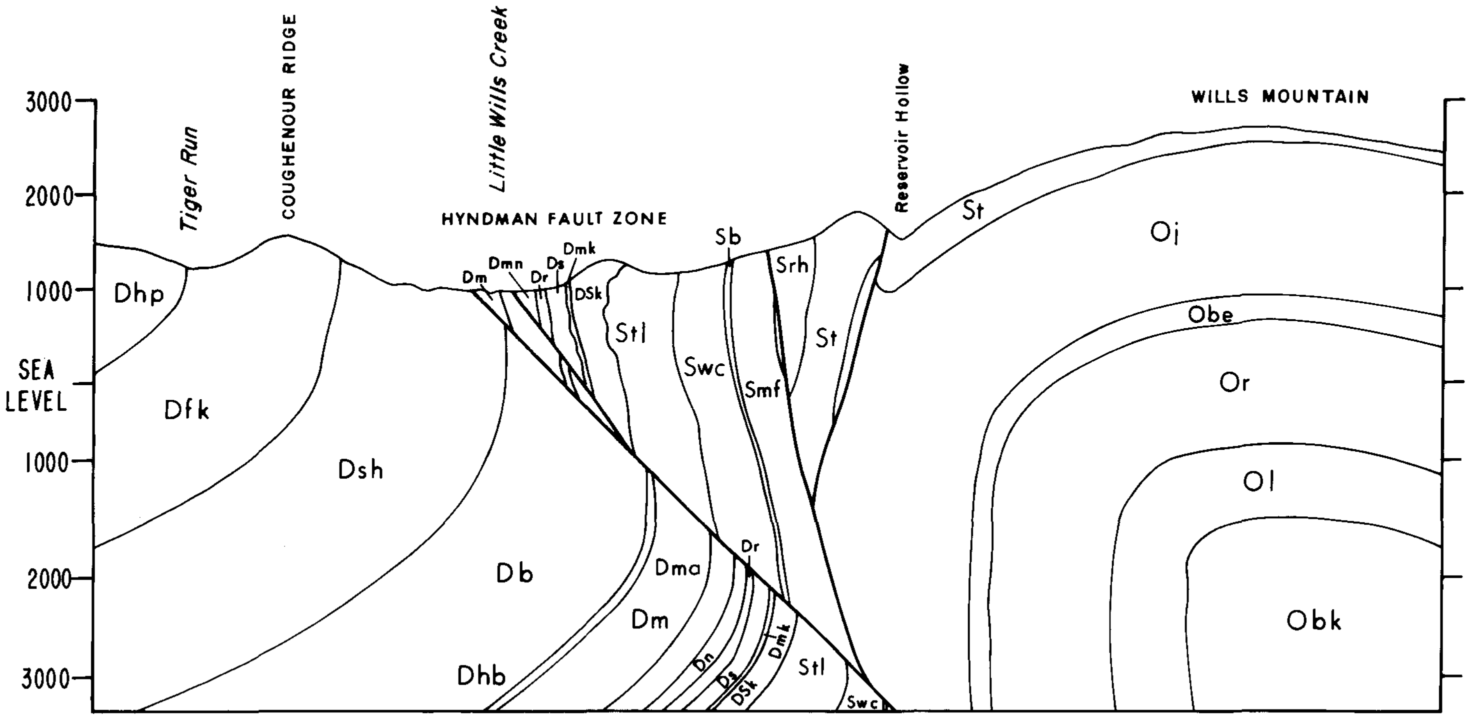

Figure 19. Cross section through the Hyndman fault zone just east of the Allegheny structural front, at the Somerset-Bedford County line. This fault zone is the surface expression of the splay from the décollement that produced the Wills Mountain anticline in the Valley and Ridge Province. Key: Ordovician: Obk - Beekmantown; Ol - unnamed limestone; Or - Reedsville; Obe - Bald Eagle; Oj - Juniata. Silurian: St - Tuscarora; Srh - Rose Hill; Smf - Mifflintown; Sb - Bloomsburg; Swc - Wills Creek; Stl - Tonoloway. Devonian-Silurian: Dsk - Keyser. Devonian: Dmk - Mandata; Ds - Shriver; Dr - Ridgeley; Dn - Needmore; Dma - Marcellus; Dm - Mahantango; Dhb - Harrell; Db - Brallier; Dsh - Scherr; Dfk - Foreknobs; Dhp - Hampshire. Modified from de Witt, 1974, cross section B-B'.

within or near the Hyndman fault zone.

The remainder of the stops in this Field Conference lie within the Allegheny Plateau, on either the Deer Park or Negro Mountain anticlines or the intervening Berlin syncline (Figure 20). Although the two anticlines are adjacent to one another, they exhibit significant differences. The eastern one, the Deer Park anticline, has 1,500 m structural relief; Negro Mountain, less than 500 m. The Deer Park anticline is distinctive among the Plateau folds in this area because its trend of 218 degrees is more southwesterly than the 210 degree trend of the other major folds, Chestnut Ridge, Laurel Hill, and Negro Mountain. These latter folds parallel the Allegheny structural front and the Wills Mountain anticline, whereas the Deer Park anticline cuts across the other anticlines, in particular the Negro Mountain fold, which terminates against the Deer Park in eastern West Virginia. The reason(s) for this anomalous trend is not understood.

SUMMARY

Somerset County has experienced essentially the same post-Grenvillian geologic history as the rest of Pennsylvania, a history culminated structurally by Alleghanian décollement tectonism. That tectonism produced the broad, low-amplitude folds presently being eroded to produce the major landforms of the county.

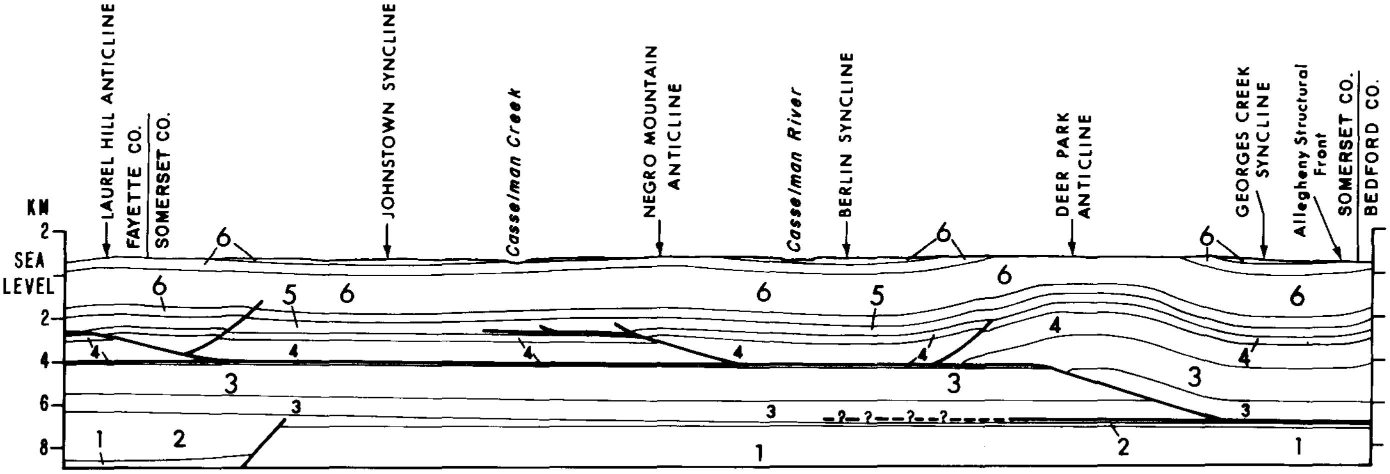

Figure 20. Cross section of the Deer Park and Negro Mountain anticlines in Somerset County, illustrating the décollement ramp from the Cambrian to Silurian, and possible fault configurations under the two anticlines. 1 - Continental crust (Laurentia); 2 - Chilhowie; 3 - Lower Paleozoic carbonate shelf deposits; 4 - Silurian Appalachian basin deposits; 5 - Lower Devonian Appalachian basin deposits; 6 - Middle and Upper Devonian-Pennsylvanian Appalachian basin deposits. (Modified from Faill, in press, cross section J-J'). No vertical exaggeration.

GEOMORPHOLOGY OF THE ALLEGHENY MOUNTAIN SECTION OF THE APPALACHIAN PLATEAUS PROVINCE AS EXPRESSED IN THE SOMERSET COUNTY AREA, SOUTHWESTERN PENNSYLVANIA

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"If lowland study is too much work
Climb up and seek a glacial cirque,
And never from your search refrain——
You may at least find a moraine."
(Büdel, 1982, p. 121)

INTRODUCTION

The Allegheny Mountain section of the Appalachian Plateaus province in the field conference area is underlain by predominantly clastic sedimentary rocks of Devonian, Mississippian, and Pennsylvanian age which have been folded into elongate, plunging anticlines and synclines. The midship location of the Somerset County area in this geomorphic section (Figure 21) provides opportunities for study of many aspects of the geology of this highly interesting and diverse part of the Appalachian Plateaus geomorphic province.

The Allegheny Mountain section in Pennsylvania is on the northeastern end of a major, elliptical, topographic high in the Central Appalachians. Recognized as early as the 1920s by Wright (1925), this feature includes the highest elevations in: the Ridge and Valley province (Beartown Mountain, VA, 1434 m), the Appalachian Plateaus (Spruce Knob, WV, 1482 m), and in all of Pennsylvania (Mt. Davis, 979 m). Several major drainage divides are located within, or cross, this geomorphic entity. A number of geologic features associated with this topographic high in West Virginia and Virginia were studied by Dennison and Johnson (1971) and will be noted in the section on Long-Term Geomorphic Evolution.

Attributes of the bedrock lithology and structure, and the effects of climate and geomorphic and pedologic processes have resulted in large contrasts in the geomorphology and soils between areas in ridges and those in valleys, and have influenced the types and the patterns of land use. The northeast-southwest orientation of the major folds results in a similar trend of the lithologic units and the surficial materials except at the noses of plunging folds and in areas of structural complexity. Almost all of the ridge crests and their steeper sideslopes are forested, whereas much of the lower valley sides and the valley floors have at one time or another been cleared for settlement, agriculture, mineral and fuel extraction, and urbanization. As a result, a striking pattern of alternating northeast-southwest trending belts of woodland and cleared areas occurs throughout the area.

Names of localities and geological features follow the usage of the Pennsylvania Geological Survey and the U. S. Geological Survey. Except where otherwise noted, quadrangle names of maps are for the 7.5-minute series of the U. S. Geological Survey.

REGIONAL GEOMORPHOLOGY

The Somerset County area is within the Allegheny Mountain section of the Appalachian Plateaus province of the Appalachian Highlands major geomorphic division. The Appalachian Plateaus province is composed of at least fourteen definable and defensible geomorphic sections (Table 1), of which the Allegheny Mountain section is one of the most varied and spectacular from the standpoints of topography and drainage. Both elevation and relief are relatively high when compared to most other sections of the Plateaus province. This geomorphic section is also noted for major landform and drainage characteristics which have not developed in the other sections of the Plateaus province, such as its parallel-trending

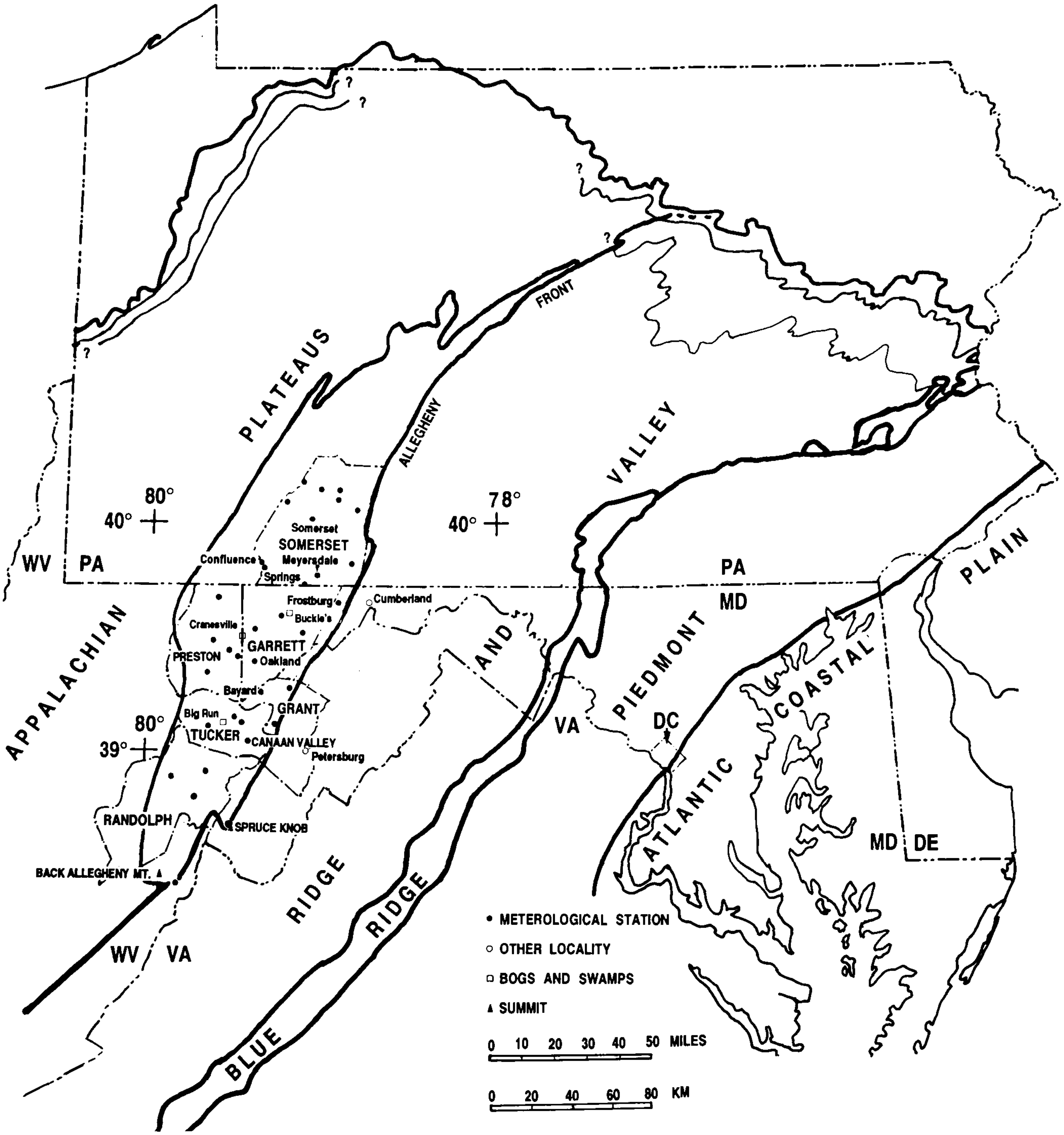

Figure 21. Location map showing position of Somerset County and selected other counties in relation to the Allegheny Mountain section (area in Appalachian Plateaus province bounded by heavy solid line) of the Appalachian Plateaus geomorphic province. Regional geomorphic boundaries in Pennsylvania from Berg and others (1989), and elsewhere as modified from Fenneman (1938). Glacial borders in northeastern and northwestern Pennsylvania are from D. D. Braun (in Clark, G. M., ed., 1992/1993): Heaviest glacial border is Late-Wisconsinan, Late-Glacial Maximum (ca. 18 Ka); line of intermediate thickness with question marks is an older glacial boundary (Illinoian?); lightest weight line with question marks represents a much older glacial limit.

Table 1. Provisional subdivisions of the Appalachian Plateaus geomorphic province appropriate for the field conference area. Modified from Thornbury (1965).

HIERARCHY (modified from Thornbury, 1965)	NOTATIONS
Appalachian Plateaus province	
Mohawk section	Fenneman and Johnson (1946)
Catskill Mountains section	Fenneman and Johnson (1946)
Glaciated Low Plateau section	Berg and others (1989)
Glaciated Pocono Plateau section	Berg and others (1989)
Glaciated Pittsburgh Plateau section	Berg and others (1989)
High Plateau section[1]	Berg and others (1989)
Mountainous High Plateau section[2]	Berg and others (1989)
Pittsburgh Low Plateau section[3]	Berg and others (1989)
Allegheny Mountain section[4]	Berg and others (1989)
Parkersburg Plateau section	Outerbridge (1987, Plate 1)
Ohio Plateau section	Outerbridge (1987, Plate 1)
Logan Plateau section	Outerbridge (1987, Plate 1)
Cumberland Mountains section	Fenneman and Johnson (1946)
Cumberland Plateau section	Fenneman and Johnson (1946)

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

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

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

[4] Fenneman and Johnson (1946), however, used broken lines (to "indicate boundaries much generalized or poorly known") to encompass areas now in the Pittsburgh Low Plateau section and the Mountainous High Plateau section in parts of Indiana, Jefferson, Clearfield, Centre, Elk, Cameron, Clinton, Potter, Tioga, and Lycoming counties northeastward to the Late Wisconsinan glacial border.

narrow ridges and wide valleys (Figure 22), and its many large transverse water gaps which transect both the anticlinal mountains and the single limbs of folds. To the southwest, erosional levels fall through the stratigraphic section and, in West Virginia, folds at the surface become large, doubly-plunging anticlines and synclines. There, the major anticlines have been breached by erosion so that long, wide, canoe-shaped anticlinal valleys such as those in the Canaan Valley and the Tygart River Valley occur. These anticlinal valleys are interspersed with broad synclinal uplands such as the Cabin Mountain-Stony River area.

The Allegheny Mountain section is an elongate geomorphic subdivision which extends southwest from Clinton County, Pennsylvania, 370 km to wrap around the Bald Knob area on Back Allegheny Mountain, West Virginia (Figure 21). Width of the section is highly variable, but in the latitude range of Somerset County it is from about 60 to 80 km. To the northeast, northwest, and west of the section is the Pittsburgh Low Plateau section. There, the section is separated from the Pittsburgh Low Plateau section along the western slopes of Chestnut Ridge, at 847 m maximum elevation, and Laurel Hill, at about 853 to more than 914 m in elevation in Pennsylvania. The southeastern and eastern boundary of the section is the Allegheny Front, where this escarpment is defined. In the area of east-central and southeastern Somerset county, however, the Allegheny Front is not defined, and the province boundary is wrapped around the nose of the Wellersburg Syncline and continues southwestward along its southeastern limb on Little Allegheny Mountain. The Allegheny Front appears again in Maryland as Dans Mountain, and becomes a truly impressive feature in West Virginia before losing its identity southwest of Spruce Knob. In this chapter we use the boundaries established by Berg and others (1989) for the section in Pennsylvania, and a modification of the classical boundaries of Fenneman and Johnson (1946) for the section borders in Maryland and West Virginia (Figure 21). These subdivisions recognize the unique landscape style of this part of the Plateaus province by differentiating it from adjacent areas in the Appalachian Plateaus and Ridge and Valley provinces. Scale is also a prominent consideration when thinking about landscape subdivisions. A tabular classification of landscapes ranked by scale has been proposed by Godfrey and Cleaves (1991), and is shown in Table 2, along with topical examples of areas which can be classified.

CLIMATOLOGY

Palaeoclimatology

Introduction

Some basic understanding of past climates and their causes is helpful in tracing the geomorphic development of the Allegheny Mountain section. Frakes and others (1992) provide an overview of the complexity of the alternating four Warm Modes and four Cool Modes which have characterized Phanerozoic climatic history. These authors also highlight major unresolved research problems which prevent fuller understanding about the causes and chronology of global climatic change. In what follows, we restrict the discussion to the time frame which encompasses palaeoclimatic history from the Alleghanian Orogeny to the development of essentially modern climates in the Holocene.

Pennsylvanian and Permian Periods of the Paleozoic Era

During the Pennsylvanian Period, many basins of deposition in the area of the present-day Allegheny Mountain section had climatic and tectonic conditions conducive to the accumulation and burial of vast areas and great thicknesses of plant materials and clastic sediments that accumulated in many different kinds of depositional environments. These sedimentary basins eventually gave way to environments characterized by increasing aridity that were accompanied by pronounced oxidizing terrestrial conditions during the Permian Period. Climatic scenarios during appropriate parts of this time window have been played out by Beaumont (1978, 1979) for relationships between stratigraphy and isostasy, and by Sevon (1985a) for probable palaeogeomorphological conditions. As aridification intensified, wetlands and forests of the Pennsylvanian gave way in the Permian to more arid conditions under which sediment continued to accumulate.

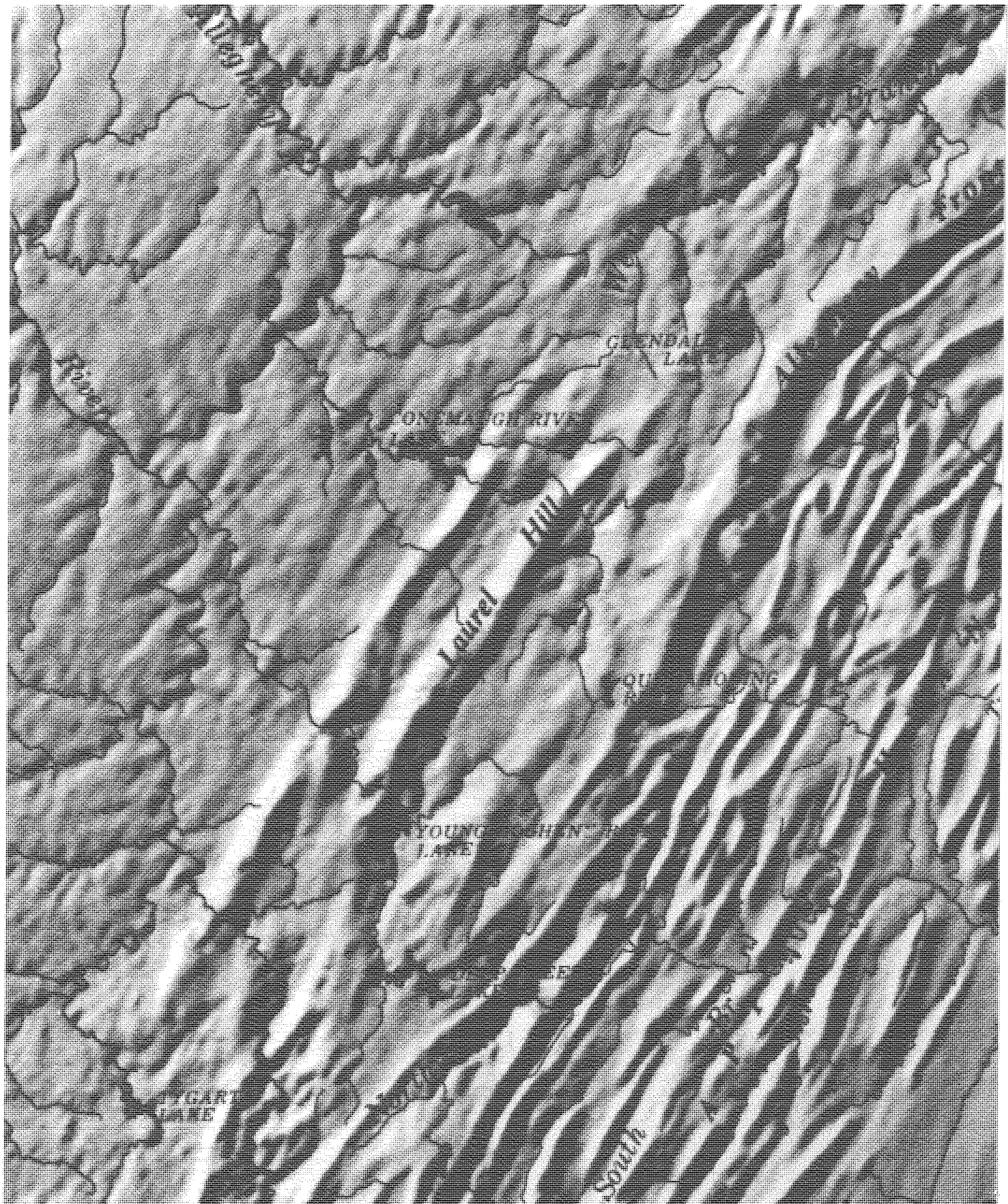

Figure 22. Portion of digital shaded-relief map of the conterminous United States showing an area centered on Somerset County, Pennsylvania (From: "Landforms and drainage of the conterminous United States". Reproduced with permission of Raven Maps and Images, 34 North Central Avenue, Medford, OR, 97501). For technique used in production of such maps see Thelin and Pike (1991).

Table 2. Ranking of landscape units by decreasing map area occupied, with examples appropriate for the field conference area. Modified from Godfrey and Cleaves (1991).

Rank	Area (km^2)	Basis (Dominant Entity)	Example(s)
Realm	10^7	Largest Plate-Tectonic Units	North American Plate
Major Division	10^6	Sub-Continental Entities	Appalachian Highlands
Province	10^5	Regional Similarity	Appalachian Plateaus
Section	10^4	One Tectonic-Landscape Style	Allegheny Mountain
Subsection	10^3	Structure-Landform Similarity	Breached Anticline
District	10^2	Form-Material Relationships	Negro Mountain
Subdistrict	10^1	Direct Material-Form Linkage	Casselman Gorge
Zone	10^0	Few Form-Relief Parameters	Upland Flat; Diamicton Apron
Locale	10^{-1}	Individual Landforms	Rock City (Baughman Rocks)
Compartment	10^{-2}	Single Form-Relief Units	Slope Break (cliff edge)
Feature	10^{-3}	Specific Microform	Opferkessel; Expanded Joint

Mesozoic Era

The Allegheny Mountain section lacks a sedimentary record of events which transpired during the Mesozoic Era. Evidence about climatic conditions during the Mesozoic comes from areas to the east and southeast such as scattered localities in the Ridge and Valley province, and on the Piedmont, Coastal Plain, and from offshore records. Hallam (1985) reviewed the climatic history of the Mesozoic Era. Additional information is provided by Schlee and others (1988), Chandler and others (1992), Scholle (1977, 1980), Pierce (1965), and others. The climate during the Triassic and Jurassic was hot and arid, but climatic fluctuations occurred giving rise to periods of wetness. Increasing amounts of rainfall occurred in the Cretaceous, particularly the latter part leading to the climates of the Cenozoic. The effects of these Mesozoic climates in Somerset County is unknown.

Cenozoic Era

Tertiary Period. No sediments of Tertiary age are known from the Allegheny Mountain section. The Atlantic Coastal Plain province, however, contains a depositional record of certain Cenozoic events in parts of the Appalachian Highlands. Offshore, the depositional record in the Atlantic Continental Margin contains a very valuable and often much less discontinuous long-term record of former conditions in the bordering Appalachian Highlands (Poag, 1992). Cenozoic climates in eastern North America apparently varied considerably during the first half of the Cenozoic Era, but followed a major trend of increasing warmth and rainfall accompanied by a lack of pronounced seasonality. Frakes and others (1992, Chapter 9) indicate that a major climatic change began in the Middle Miocene with a trend of cooling and rainfall change that culminated in the Pleistocene.

Poag and Sevon (1989) reported in detail on sedimentary deposits of the U.S. Middle Atlantic continental margin and showed a consistent pattern of decreasing siliciclastic deposition and increasing chemical sedimentation from the Late Cretaceous to the Middle Miocene. The data indicate a decreasing amount of physical erosion and an increasing amount of chemical denudation in the Appalachian source area. For reasons not yet clear, this pattern changed significantly in the Middle Miocene, when large quantities of clastic sediment began to be transported offshore and deposited. Barron (1989) indicated that the Appalachians would have been an area of focused precipitation throughout the Cenozoic, but with gradually decreasing rates.

Tiffney (1985) discussed the vegetational changes that occurred in northeastern North America during the Cenozoic. He noted that the warm-temperate to subtropical vegetation which gradually developed over much of North America during the Eocene was gradually replaced as the climate began world-wide cooling and increased seasonality.

A speculative scenario for the Allegheny Mountain section which can be created from the above is that, during the first part of the Cenozoic (to the Middle Miocene), the climate was sufficiently wet and warm to support a cover of abundant vegetation which inhibited physical erosion but enhanced chemical and biochemical erosion. These conditions caused deep weathering of rock, but allowed only a minimal amount of this weathered rock to be eroded in clastic form. As both climate and associated vegetation changed, some kind of geomorphic threshold must have been crossed in the Middle Miocene. Then, large amounts of clastic sediment were eroded from the Appalachians and transported to the Middle Atlantic offshore basin by eastward flowing drainages. Presumably, similar erosion occurred in the Allegheny Mountain section, but, because much of that section drains to the Gulf of Mexico, its record is uncertain. Erosion slowed during the Pliocene, but was renewed in the Pleistocene, especially during cold intervals which fostered vigorous glacial and periglacial erosion (Braun, 1989; Godfrey, 1975).

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

At the Pleistocene-Holocene boundary, there occurred dramatic changes in climate, vegetation, and geomorphic process-response mechanisms. Environments, processes, and their effects on materials and landforms rapidly approached essentially modern aspects in Early Holocene time. The Middle Holocene time interval——termed the Altithermal or the Hypsithermal——had elevated temperatures and decreased effectiveness of precipitation, as compared to now. The Late Holocene time interval began with climatic conditions similar to those of today. It was followed by the Neoglacial geologic-climatic time unit (Porter and Denton, 1967), an episode of minor climatic deterioration that terminated with the end of The Little Ice Age (Grove, 1991). To judge from evidence elsewhere at about the same latitude in the Central Appalachians, environments at the higher elevations in the Allegheny Mountain section would also have been severe enough to produce minor remobilization of regolith that had apparently been stabilized throughout earlier Holocene time. On floodplains, accumulation of sediments suggest that one or more episodes of intensified aggradation may have occurred in the Neoglacial. Some of these events may predate the effects of European settlement. For example, Foss (1973) found evidence of enhanced colluviation during this time interval at the Thunderbird Archeological Site along the South Fork of the Shenandoah River in Warren County, Virginia. It is thus necessary for researchers to apply rigorous field and laboratory criteria to the study of forms and materials that could have developed under marginal periglacial conditions such as those that occurred during Neoglacial time.

Subsequent climates in the excursion area probably have approximated those shown in historical records.

One geomorphically important effect of the Early and Late Holocene climates during spring, summer, and fall seasons was the increased availability of moisture-laden air masses from the Atlantic Ocean and the Gulf of Mexico (Delcourt and Delcourt, 1981). Such moisture supplies, coupled with the increased moisture capacity of warmer air columns, provided conditions permitting increased likelihood of catastrophic precipitation events that could modify landscapes rapidly (Jacobson and others, 1989a, b). Newson (1980) distinguished two types of floods, based upon their different kinds of geomorphic effectiveness: "slope floods" that produce severe hillslope and toeslope modification, and "channel floods" that mainly impact floodplain areas. Both types of storms can be observed in the same geographical area during a short span of time under the same overall climate.

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

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

The hillslope and channel flood effects discussed above need to be borne in mind when discussing the survivability of supposed relict geomorphic deposits and landforms, especially those as old as Pleistocene. For example, there may be few to no relict features on certain steep hillslope areas and on affected floodplains. On the other hand, Jacobson and others (1989b) concluded that the effects of cataclysmic geomorphic events have had a relatively small role in the overall evolution of topography in the Central Appalachians. In addition, it is possible that the catastrophic geomorphic activities demonstrated south of Pennsylvania are not equally important in Pennsylvania. Although there has been less investigation of such activity in Pennsylvania, obvious evidence of catastrophic geomorphic events (comparable to those farther south) is generally lacking. This may or may not be climatically related.

Present-Day Climate

The Allegheny Mountain section is within the belt of humid continental warm summer climate. This climate occurs in the middle-latitude zone of conflict between polar and tropical air masses. During the winter, continental polar air masses dominate, and their effects can be severe especially in exposed sites and at high elevations. The cold winter weather is interrupted by surges of maritime tropical air. Because of the influence of large water bodies, rainfall is distributed fairly uniformly throughout the year. During the summer, however, maritime and continental air masses bring higher temperatures and somewhat increased rainfall. The overall climate therefore has a large annual range of temperature, high summer humidity, and a wide range in the number of frost-free days. The average time period between the last spring frost and the first fall frost, or "growing season" can range from about 150 days in broad valleys at low elevations to less than 100 days at high elevation stations and in cold air drainage sites. Mean annual air temperatures range from about 6.6 to about 10°C. Mean annual precipitation varies widely. Valley areas may be rain shadow areas with less than 900 mm per year, and windward high elevation sites may receive 1500-2000 mm per year. Such great variety in detail is a result of complex interactions among: differences in elevation, exposure, latitude, distance from water bodies, and other factors. Leffler (1981b) computed an annual lapse rate of 5.8°C/km which he believed to be representative of the Appalachian Mountain areas he studied and which center roughly on the Allegheny Mountain section.

The factors listed above produce considerable local variations in climate, especially in the more mountainous parts of the section. When dealing with potential microclimate differences, the following factors should be borne in mind. The ridge crests, especially on their windward edges, will receive more and higher velocity winds than the valleys. Second-order, air-density- and topographic-driven winds may be channeled downslope, particularly in hollows and ravines. Especially during the earlier parts of the day, the valleys may be cold sinks, with the warmest temperatures occurring on the shoulders of the slope. At any elevation where there are local topographic depressions, "frost pockets" may occur as they do in the High Plateau section in Elk County, Pennsylvania (Hough, 1945). Slope orientation (aspect) is very important on clear sunny days, when the difference of light between north- and south-facing slopes amounts to 46 units (say, in g cal/cm^2 hr^{-1}). In diffuse light, all slopes should receive the same amount.

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

There is much variation in elevation and relief in the Allegheny Mountain section. Temperature and precipitation values within about a 1.5^{o} latitudinal belt which includes the southern half of Somerset County can be seen in Figures 23, 24, and 25. Some effect of latitude on temperature is inherent in this latitudinal range. Leffler (1981b) estimated average annual temperature decreases of -1.06 and -1.08 ^{o}C per degree increase in latitude at elevations between 500-1000 m for the latitude range of the Allegheny Mountain section.

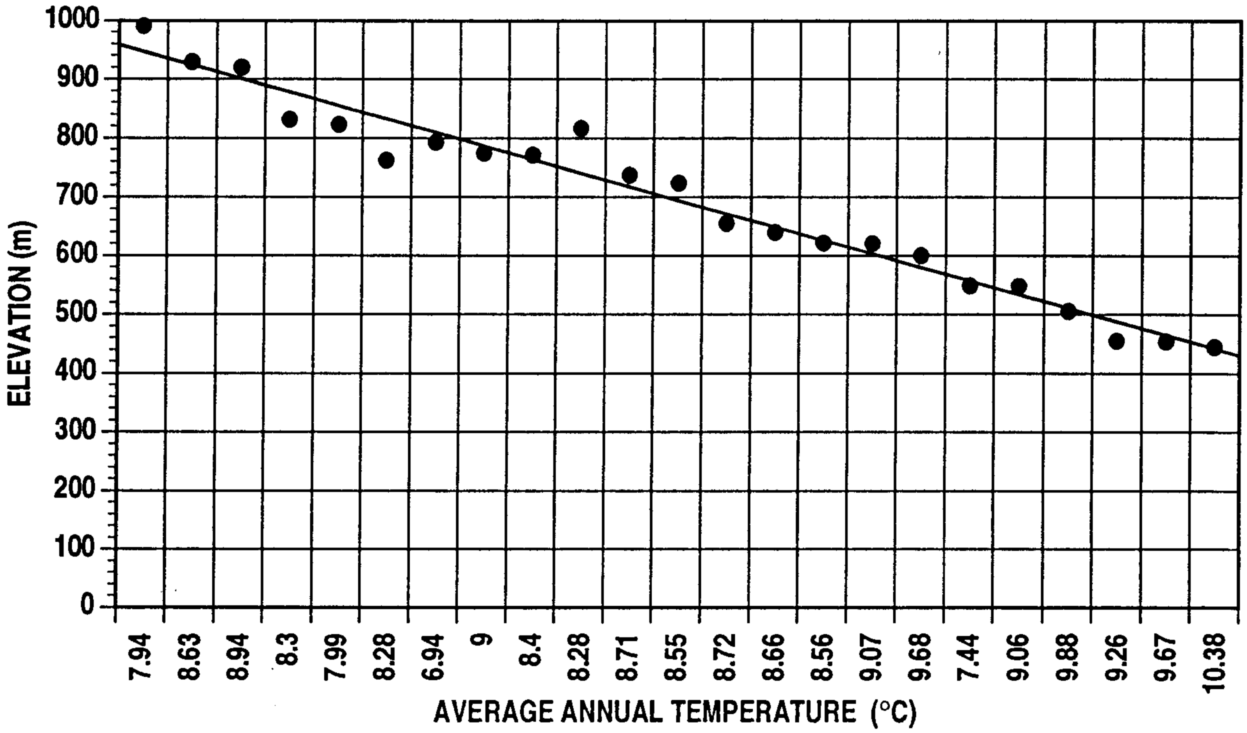

Figure 23. Numerical plot (along x axis) of average annual air temperature values (^{o}C) for stations versus altitude for weather stations in non-urbanized areas between 38^{o} 26' and 40^{o} 11' N in the Allegheny Mountain section (dots are indicative of elevation only). Note that recording stations are quite evenly distributed in terms of range of elevation. However, temperature values vary, indicating the effects of other factors such as air drainage and exposure. For station locations see Figure 21.

Quality and quantity of weather data for the field conference area vary greatly. A tabulation of records from two stations situated in the wide-valley topography northwest of Allegheny Mountain in Somerset County is given in Tables 3 and 4. In other areas, some examples averaged on a county basis can help illustrate present-day climates in the field conference area, although they may not be representative of a particular geomorphic region as a whole. For example, in Somerset County, mean annual air temperatures at four stations range from 8.3 to 9.5^{o}C. Nine stations recorded precipitation ranging from 945 mm to 1362 mm.

Other examples are drawn for individual weather stations to illustrate either good records

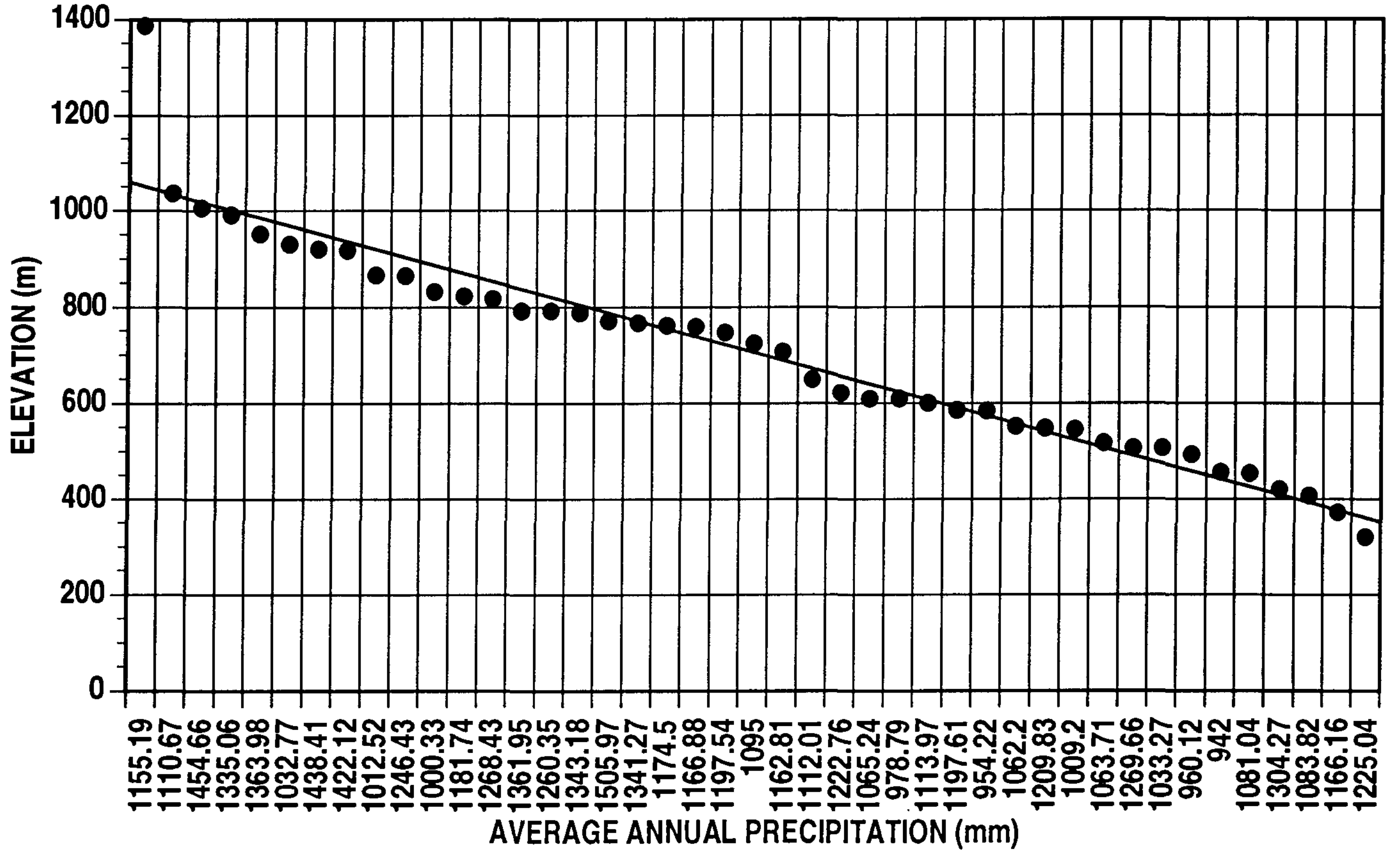

Figure 24. Numerical plot (along x axis) of average annual total precipitation (mm) for stations versus altitude for weather stations in non-urbanized areas between 38^{o} 26' and 40^{o} 11' N in the Allegheny Mountain section. Note that precipitation values follow no obvious pattern with respect to elevation, suggesting that other effects——such as rain shadows——are indicated.

or climatic extremes that are of interest for soil and geomorphic purposes. The years of record vary widely, but most figures given are valid for the general time frame of 1931 through the early 1980s.

Garrett County is the only county in Maryland to lie entirely within the Appalachian Plateaus province, and is also completely within the Appalachian Mountain section. This county is noted for high yearly totals of precipitation, snowfall, and low temperatures; the station at Oakland recorded a record low of -40°C on 13 January 1912. Mean annual air temperatures at five recording stations range from 8.3 to 9.6°C. Ten stations reported precipitation records; yearly totals ranged from a mean annual low of 980 mm to a high of 1325 mm. Robinette (1964) measured air temperature extremes in the Cranesville Swamp area and vicinity (Preston County, West Virginia, and Garrett County, Maryland) from July 1963 through June 1964. During this time interval, she demonstrated a strong frost-pocket effect that was enhanced by lack of an arboreal forest cover. The station in the Open Shrub community commonly had the lowest average minimum temperatures which were 8°F lower than any of the other maximum-minimum temperature stations.

The eastern part of the Allegheny Mountain section in West Virginia reaches extreme elevations and experiences severe weather. Spruce Knob, Pendleton County, West Virginia, is the highest elevation on the Appalachian Plateaus (1482 m) but has no weather station. The current station by that name is west of Spruce Knob at 1387 m, has a mean annual temperature of 8.7°C and mean annual precipitation of 1155 mm (including 1836 mm of snowfall). The station in Canaan Valley at 991 m recorded a mean annual air temperature of 7.94°C, and precipitation of 1335 mm (including 2327 mm of snowfall) for those years between 1931 and 1952, when records were kept. Another example, Bayard (724 m), in western Grant County, has a mean annual air temperature of 8.55°C, a growing season range of only 83 to 140 days, and average annual precipitation of 1095 mm.

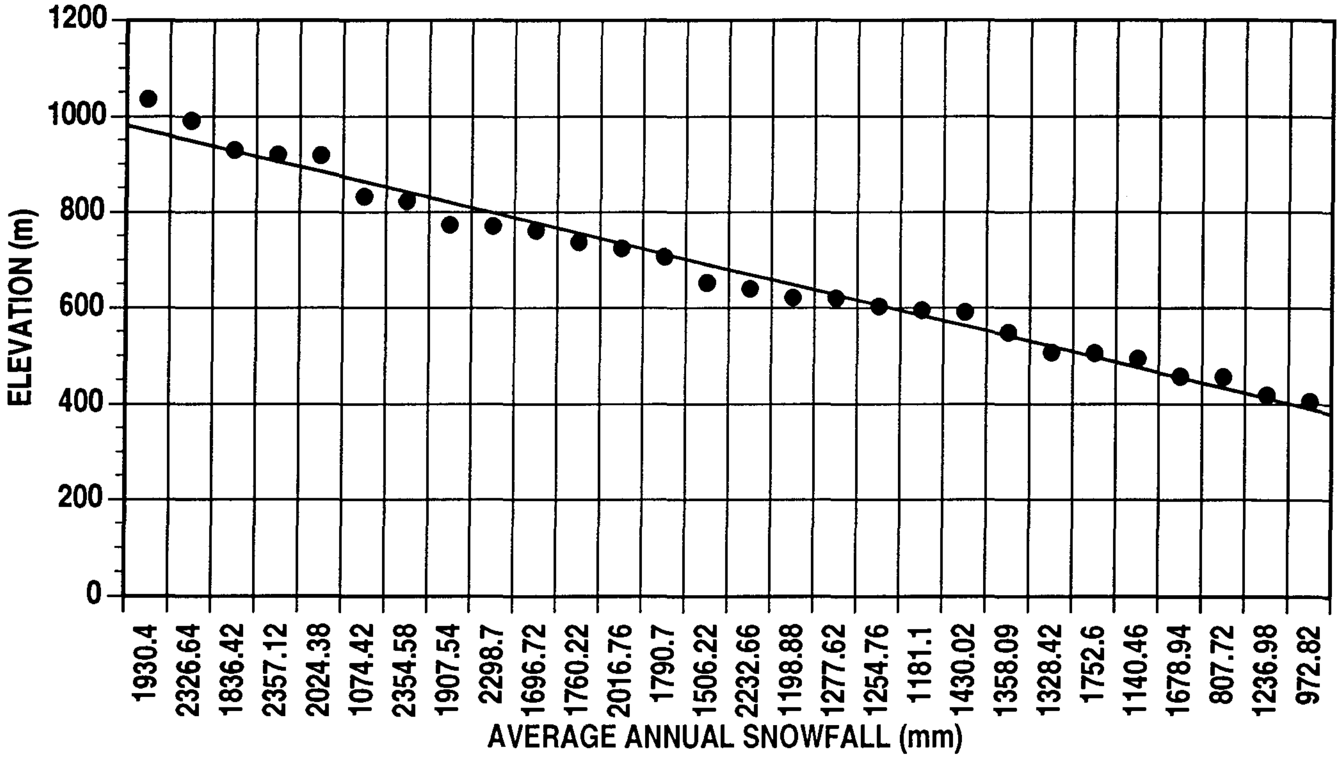

Figure 25. Numerical plot (along x axis) of average annual total snowfall (mm) for stations versus altitude for weather stations in non-urbanized areas between 38° 26' and 40° 09' N in the Allegheny Mountain section.

In several mountainous areas in the Central Appalachians, including the Allegheny Mountain section, there is actually more generally-valid information about mountain soil temperatures than about air temperatures. Carter and Ciolkosz (1980) found that soil temperature regimes are mesic on the lower ridge crests and frigid at the higher elevations. Cryic soils are not known in the field conference area, although frost pockets do occur in areas with excessive internal drainage of cold winter air. Under natural forest conditions with snow cover, however, representative Central Appalachian mountain soils are frozen in winter to depths of less than 25 cm (Carter and Ciolkosz, 1980). Exposed land without the protection of vegetation or snow cover, however, can freeze to depths of several feet especially in exposed sites and at the higher elevations.

In addition to the standard climatic data collected at most weather stations, there are other data which are of interest to geomorphologists and soil scientists. These include: rainfall intensity, extent and magnitude of severe storms that cause landslides and floods, humidity, cloud cover, length and severity of droughts and wet periods, and microclimatic variations. When adequate data exist, some calculations of certain variations in weather and climate can be made. For other purposes few to no such data are available at the present time for the field conference area.

VEGETATION AND LAND USE

Introduction

Reconstruction of the pre-settlement forest cover has important ramifications for many related fields of earth science. The composition and distribution of plant communities have powerful interactions with fauna, landscape stability, and soil genesis. Influential workers in the Appalachians included Braun (1950, 1951), who wrote that Pleistocene vegetational assemblages and their distributions beyond the ice sheets in Eastern North America were probably not much different than those found by the immigrants from Europe. Despite this misconception, Braun contributed much to our understanding of both the pre-settlement forest composition and its makeup during her active field research in the first half of the twentieth

Table 3. Comparison of precipitation data from two valley stations northwest of Allegheny Mountain in Somerset County, Somerset (655 m) and Springs (762 m). Years of record vary both between stations and among types of data recorded. Note that, although the station at Springs might be expected to receive greater precipitation effects related to its higher elevation, this station is in the lee of high elevations on Negro Mountain to the northwest and is thus in a rain-shadow locality. Data compiled by W. D. Sevon.

MONTNH	PRECIPITATION RAINFALL (mm)						SNOWFALL (mm)	
	MONTHLY MEAN		DAY≥2.54		DAY≥12.7		MONTHLY MEAN	
	So	Sp	So	Sp	So	Sp	So	Sp
J	105.41	93.22	10	7	1	1	353.06	365.76
F	88.39	76.71	9	9	2	2	299.72	353.06
M	107.19	102.11	10	9	2	3	281.94	358.14
A	111.76	98.04	9	9	2	2	83.82	71.12
M	121.92	110.49	11	9	3	3	T	2.54
J	128.02	129.79	10	10	4	3	0	0
J	117.35	119.38	8	9	3	3	0	0
A	112.52	114.81	9	9	3	3	0	0
S	86.61	84.07	9	6	2	2	0	0
O	76.45	86.61	7	8	2	1	2.54	20.32
N	80.26	75.69	5	5	1	1	175.26	182.88
D	91.19	83.57	9	8	1	2	309.88	342.90
A	1227.1	1174.5	106	98	26	26	1506.22	1696.72

Table 4. Comparison of temperature data from two valley stations northwest of Allegheny Mountain in Somerset County, Somerset (655 m) and Springs (762 m). Years of record vary both between stations and among types of data recorded. Note the lower temperatures recorded at Springs related to its higher elevation. Data compiled by W. D. Sevon.

MONTNH	TEMPERATURE IN DEGREES CELSIUS											
	MONTHLY MEAN		DAILY MAXIMUM		DAILY MINIMUM		RECORD HIGH		RECORD LOW		DAYS ≥32.2	≤0.0
	So	Sp	So	Sp	So	Sp	So	Sp	So	Sp	So	So
J	-2.78	-2.06	2.33	2.83	-7.78	-7.00	23.89	21.67	-27.78	-28.89	0	29
F	-2.50	-2.67	2.72	2.67	-8.11	-8.06	23.33	20.00	-28.33	-27.78	0	25
M	2.17	1.44	8.44	7.20	-3.50	-4.28	29.44	24.44	-27.22	-20.56	0	25
A	8.00	7.28	14.94	13.89	1.28	0.61	32.22	30.00	-19.44	-12.22	0	12
M	13.78	13.11	21.11	19.72	6.44	6.44	33.88	31.11	8.89	-7.78	0	3
J	18.44	17.72	25.17	24.16	11.11	11.22	37.22	33.89	6.67	-1.67	1	0
J	20.33	19.39	27.33	25.72	13.39	13.06	37.77	35.00	0.56	1.11	2	0
A	19.44	18.56	26.56	24.78	12.44	12.28	39.44	35.55	-1.67	1.11	1	0
S	15.89	14.94	23.56	21.56	8.67	8.33	36.67	32.22	-5.56	-5.56	1	2
O	9.78	9.83	17.44	16.44	3.06	3.22	33.33	28.33	-12.78	-11.11	0	9
N	3.78	3.56	9.44	8.83	-1.83	-1.72	25.55	23.89	-26.11	-20.56	0	20
D	-1.61	-1.56	3.17	3.39	-6.61	-6.50	22.22	22.78	-31.67	-26.67	0	25
A	8.72	8.28	15.17	14.28	2.38	2.29					5	150

century. With respect to the composition of the Late Holocene pre-settlement forest, Braun (1950) defined an "Allegheny Mountains" section of the Mixed Mesophytic Forest region. In the Somerset County area, the boundaries of this natural forest entity roughly coincide with those of the Allegheny Mountain geomorphic section, and thus provide a convenient geographic framework of reference for discussion.

Late-Quaternary Vegetational History

Selected Site Studies

Modern research on vegetational history has provided a wealth of information on fossil plant assemblages and, by extension, palaeoclimatic history through the study of pollen and plant macrofossils extracted from core samples. Despite the widespread appearance of wetland areas on topographic maps in the Allegheny Mountain section, there are few modern published works on Quaternary vegetational history in this geomorphic section, and none in the Somerset County area. Although not on the field conference route, there are several important localities which give some notions about the great vegetational changes that have occurred in the region during Late Quaternary time, and that illustrate the impact that such studies have had on our concepts of Quaternary palaeoenvironmental history.

Maxwell and Davis (1972) studied pollen from a sediment core taken from Buckle's Bog (814 m) in the McHenry quadrangle, Garrett County, Maryland (39° 34' N; 79° 16' W). They found that, from 19,000-12,700 yr BP, non-arboreal pollen (NAP) exceeded 50% of that in the core. Most of the NAP was Cyperaceae (sedge, 40%). Picea (spruce) (10-22%) and Pinus (pine, probably jack or red, at 5-17%) comprised the only significant arboreal (AP) pollen in the core. Deciduous tree pollen was always less than 5%. This pollen assemblage is similar to modern pollen rains in arctic regions, but with some differences. For example, although any significant stands of deciduous trees must have been far removed from the site during this time interval, the high ratio of spruce pollen to pine pollen indicates that boreal coniferous stands were perhaps within 10-25 km of the site. Otherwise, easily-transported pine pollen from this prolific producer would dominate the AP spectra as it does in modern high arctic tundra regions. Spruce may have grown in low, protected valleys in the Ridge and Valley province to the east, or in low river valleys on the Appalachian Plateaus. Maxwell and Davis suggest regional tree-line altitudes of 300 m and 450 m as possibilities. In such cases the Allegheny Mountain section would have been entirely devoid of trees. Alternatively, some trees may have existed along the axes of the deeper valleys. In the time interval between ca. 13,000-12,000 yr BP, the local vegetation around Buckle's Bog changed from tundra to boreal woodland and shrubs. Spruce, jack and/or red pine, and possibly fir grew in close proximity to the bog, beginning at 12,700 yr BP. The Holocene began at 10,500 yr BP at Buckle's bog when spruce woodland was replaced by a mixed-coniferous-deciduous forest. White pine pollen increased dramatically reaching a maximum of 45%, and was accompanied by a synchronous increase in birch pollen to a maximum of 18%. The overlying portion of the core contains an oak-chestnut pollen assemblage zone which began some time before 5,000 yr BP and lasted until 150 yr BP. Oak pollen maintained a value greater than 25% in this interval, and at first beech (14%), then chestnut (20%), and then hickory (7%) reached their maximum values in the core (Maxwell and Davis, 1972).

Larabee (1986) extracted a 2.3 m core from Big Run Bog (980 m) in the Mozark Mountain quadrangle, Tucker County, West Virginia (39° 07' N; 79° 35' W), about 25 km WNW of Allegheny Front. He found that, between 17,040 and 13,860 yr BP, the core contained high NAP and low AP percentages combined with low pollen accumulation rates. He concluded that the Picea and Pinus pollen in the core during this interval probably arrived by upslope wind transport from elevations as much as 500 m lower than the bog. The plant communities surrounding the site were interpreted to be a mosaic of alpine tundra dominated by sedges and grasses. Between 13,860 and 11,760 yr BP, there was a marked decrease in Pinus percentages and an increased representation of arboreal and shrub taxa in the pollen. NAP values remained high, and the taxa indicate that wet meadow and disturbed ground conditions were prevalent until 11,760 yr BP, indicating the dominance of colluvial activity over slope stability in the area providing pollen rain. Between 11,760 and 10,825 yr BP, the pollen rain reflects a complex transition period for the vegetation. Spruce, fir and pine were able to partially or perhaps completely close the boreal forest canopy, yet NAP from disturbance-favored taxa indicate that exposed areas were still undergoing active turbation. The next higher pollen zone, dated between 10,825 and 8,190 yr BP, records the local collapse of the boreal forest ecosystem, and its replacement by a closed, mixed, conifer-northern hardwood forest. The remaining upper portion of the core at Big Run Bog indicates that the Middle and Late Holocene was a time of continuing minor adjustments in the composition of the deciduous forest component.

Cox (1968) studied a 3.5 m long peat core from Cranesville Swamp (about 777 m) in the Sang Run quadrangle, Preston County, West Virginia, and Garrett County, Maryland (39° 32' N; 79° 29' W). Cox performed pollen analyses at a number of intervals, but obtained no radiocarbon dates. He concluded that pollen from the basal 1.5 m of the core represented two zones which indicate a subarctic vegetational assemblage with high percentages of NAP accompanied by AP from spruce, fir, and pine. Above a depth of 2 m, and to the sediment surface, Cox identified three deciduous forest pollen zones. Although Cox's study cannot be used for quantitative vegetational reconstructions because of the lack of numerical age dates, it is important because it shows a similar overall pattern of vegetational history, and because it draws attention to the presence of additional areas where vegetational records may remain for study.

Synopsis

Overall summaries of the responses of vegetation to changing palaeoenvironmental conditions during Late Quaternary time are in Delcourt and Delcourt (1984) and Jacobson and others (1987). For a number of sites during the last 40 Ka, Delcourt and Delcourt (1981) prepared vegetation maps that surround and include the Allegheny Mountain section. Later, they detailed tree population dynamics for eastern North America during the last 20 Ka to provide patterns for: vegetational stability during late-glacial cold-phase maximum conditions; late-glacial conditions of disequilibrium, instability and migrations and invasions of species; and a tendency to return to equilibrium vegetational assemblage conditions during Holocene time (Delcourt and Delcourt, 1987).

For the time interval of the last glacial cold-phase maximum (23 to 16.5 Ka), we are drawn to the ineluctable conclusion that——unless small refugia existed——the Allegheny Mountain section was a barren periglacial desert, to judge from the extremely small amounts of pollen in cores. The Late Wisconsinan, Late Glacial Interval (16.5 to 12.5 Ka), was little milder. Closed tundra cover may have become more extensive during this time interval, especially at lower elevations and in protected areas. If any forests existed in the section, it is almost certain that they were confined to the lowest and most protected floors of the major river valleys. During the first part of Holocene time (12.5 to 0 Ka), tundra was finally replaced by boreal woodland and shrubs. The transition to a mixed-coniferous-deciduous forest at intermediate elevational zones was delayed until about 10.5 Ka. At the higher elevations in the Allegheny Mountain section in West Virginia, spruce forests have persisted during Holocene time (Delcourt and Delcourt, 1986). Today, however, even the highest summits are well below estimated climatic timberlines. For example, Leffler (1981a) infers that Spruce Knob, West Virginia is about 610 to 914 m below, and Mt. Davis is about 1036 m below the climatically determined forest limit.

Much more research on the vegetational history of the Allegheny Mountain section will be necessary before precise altitudinal-exposure belts can be drawn for relatively narrow time slices. Direct evidence is lacking about the specific composition of vegetation assemblages which occupied the many different slope classes and aspects that comprise the complex topography of this geomorphic section. And when did Native Americans begin to exert significant impacts upon the vegetation? In other areas of the Appalachians, for example, the effects of Native American Indian activity during Holocene time, especially on floodplains and terraces, are increasingly being recognized from palaeovegetation studies.

Historic Vegetation and Land Use

Vegetation

The pre-European settlement forests in the Allegheny Mountain section were probably quite diverse because of the large ranges in climate, topography, parent materials and the soils developed from them. If one entertains the notion of climax forest development, then the time factor also enters into the equation. Braun (1950) summarized much of what was known from historical accounts of the "original" forest patterns that were found by the first settlers of European descent, and described the composition of present stands. Braun (1950) included all of these forest associations in a highly diverse forest region that she termed the Mixed Mesophytic Forest region. The following descriptions are from Braun (1950) except where otherwise noted.

At lower elevations, dominance was shared by a wide variety of arboreal species. Chestnut, red oak, white oak, chestnut oak, sugar maple, red maple, tuliptree, beech, basswood, buckeye, walnut, shagbark hickory, sour gum, and black cherry were typical components. On open valley floors along the major streams, there were areas with white oak stands, perhaps with beech. These were the White Oak Communities of Braun (1950). Hemlock stands were common in wet and/or shaded areas such as stream-head hollows, water gaps, and in the narrow northeastern extension of the section into central Pennsylvania.

On convex ridges, higher sideslopes, and ridge crests, the dominant association was chestnut-oak with associated pitch pine, and lesser amounts of red maple, black birch, sour gum, tuliptree, sassafrass, white oak, and basswood. Pitch pine was locally abundant, to judge from the presence of circular tar kiln trenches in some upland areas such as on Mt. Davis.

At the higher elevations in southern Somerset County and in Maryland, a higher-elevation deciduous forest existed, with beech, sugar maple, and birch as common dominants. At still higher elevations in Maryland and in West Virginia, red spruce was very abundant before the logging era. It either grew in pure stands or was mixed with yellow birch, beech, mountain ash, or balsam fir, and was common at elevations above 975 m and sometimes down to as low as 762 m. The largest and best developed original spruce stands in West Virginia were in Canaan Valley and in nearby areas in Tucker County (Core, 1966). Beneath the spruce areas, but above the Mixed Mesophytic Forests, was a belt of beech, sugar maple, and birch.

Today, little remains of forest areas which could suggest pre-settlement conditions, and even very small stands of virgin forest are rare. Of course, chestnut is gone as a forest tree, although sprouts from still-living root systems occur. Common forest trees in the Somerset County area include: northern red, black, and pin oak, hickory, yellow poplar, white ash, red and sugar maple, black cherry, black walnut, and eastern white, virginia, pitch, and shortleaf pine.

Land Use

Yaworski (1983) briefly recounted the early stages in settlement and development of the Somerset County area from 1755 to the middle of the nineteenth century. During and after this time interval, areas in the valleys were cleared for settlement and agriculture. Land that was unsuited or marginal for agriculture has largely been abandoned for that purpose and has reverted to forest land. Yaworski noted that production of lumber for the commerical trade in Somerset County began at Southampton Mills in 1848. By the end of the heyday era of logging in the Central Appalachians (ca. 1890-1920) the original forests had been logged and burned.

Much of the land area in the Allegheny Mountain section is in woodland. For example, Losche and Beverage (1967) noted that more than three-fourths of Tucker County and northern Randolph County, West Virginia, were forested. Stone and Matthews (1974) estimated that 69% of the land area in Garrett County, Maryland was in woodland in 1969. Yaworski (1983) estimated that woodland comprised about 64% of the total land area in Somerset County. In some woodland areas stoniness and steep slopes are major limitations for land use. Stands of second- and third-growth trees comprise the vegetation of the woodland areas. There is an increasing trend for woodland management of large tracts of land by corporations. Sugar maple stands are tapped yearly for sap in February and March for the production of maple syrup.

Farming is also a major land use in the Somerset County area. Farm land is predominantly in cropland and pasture, although fruits, vegetables, and nursery plants are also grown. Soil erosion is the main problem in soil management. Other management problems are soil drainage, and the low natural fertility and low organic matter content of many soils.

The first coal lands were optioned in the county in 1853 (Yaworski, 1983). Strip mining for coal is an ongoing activity and acid mine drainage continues to be a major problem. Clay mining has also been an activity in the county, mainly for flint clays of the Allegheny and Pottsville Groups (Harper, 1989), but also for a much younger sedimentary deposit of surficial clay in the southern part of the county (Flint, 1965). Much smaller areas are mined for building and construction materials such as limestone, sandstone, and shale. Peat deposits in the Allegheny Mountain section occur at a number of sites in Maryland and West Virginia, and have been mined in the Castleman Basin, Maryland according to Cameron (1970).

Other land uses include urbanization and recreation. The potential for increased land use for recreational purposes is high, both because of natural land attributes and the ease of access of the area by tourists from major population centers. An annual Maple Festival is held in Meyersdale every spring, for example.

WEATHERING AND EROSION

Weathering

The Somerset County area receives an abundant supply of precipitation sufficient to foster effective rates of chemical and biochemical weathering, even in areas where rain shadow effects occur. Even at the higher elevations, soil temperatures are sufficient for active chemical and biochemical reactions to occur throughout much of the year (Carter and Ciolkosz, 1980). Evidence of such weathering can even be found on exposed bedrock ledges composed of orthoquartzite, where solution pits (Opferkessel, see Hedges, 1969) have developed (Figure 26). These features are presumably active under present-day conditions, but neither the solutional mechanisms nor the rates of development are known. The low solubility of silica in natural waters suggests that biota are involved. A study by Bennett and Siegel (1987), for example, identified a direct link between the presence of dissolved organic carbon and high rates of dissolution of silica.

Norman K. Flint had extensive experience in field work in the southern Somerset County area, and noted the sparsity and poor quality of bedrock exposures (1962, p. 12; 1965, p. 113). Only a cursory look at low road cuts, especially those at the higher elevations, is necessary to agree with Flint's observations. Why are the rocks near the present toposurface so shattered, and when did this pervasive fracturing take place? Is it going on today? A number of physical, chemical, and biochemical processes shatter rocks, including tectonic forces, sheeting due to unloading, root growth, hydration shattering, and frost cracking. Given what is known about present and past climates, cold-climate weathering processes are likely candidates. From his extensive polar region research, Büdel (1982) developed the concept of the *Eisrinde* (ice rind)——a continuous layer of shattered rock fragments in an ice matrix which forms between firm bedrock and soil parent material. The fragmentation of former bedrock in this ice-rich layer is pervasive; even the individual clasts are shot through with ice-filled hairline cracks. Büdel notes that the ice rind is the lowest zone reached annually by the deepest and coldest frost penetration. It is a general characteristic of the upper boundary of permafrost, and, where observed by Büdel in Svalbard, the mean January air temperatures were about -18 to -20^{o}C, and temperatures in the coldest winters may drop below -40^{o}C. Some detailed research will be necessary to evaluate hypotheses on rock shattering in the Somerset County area.

Expanded joints (see Hedges, 1972) are excellent illustrations of the effects of processes which are considered primarily as weathering phenomena, but which link weathering to erosion. Expanded joints can be produced by a number of processes. Baughman Rocks (Figure 27) and Vought Rocks, both in the Markleton quadrangle, are excellent illustrations of small rock cities produced by the expansion of joints essentially parallel to bedding (Geyer and Bolles, 1987). Hedges (1972) concluded that the expanded joints he studied along the Niagara escarpment were produced by the growth of ice wedges in joint openings, and the subsequent displacement of dolostone blocks out over the underlying shale. Given the high elevations and exposed site conditions at Baughman Rocks and Vought Rocks, a similar set of mechanisms may have been responsible for expanding the joints at these two localities. The presence of Opferkessel in undisturbed growth positions on the bedding-plane surfaces at these sites indicates that little to no tilting of the rock blocks has occurred during the time span in which the Opferkessel have evolved.

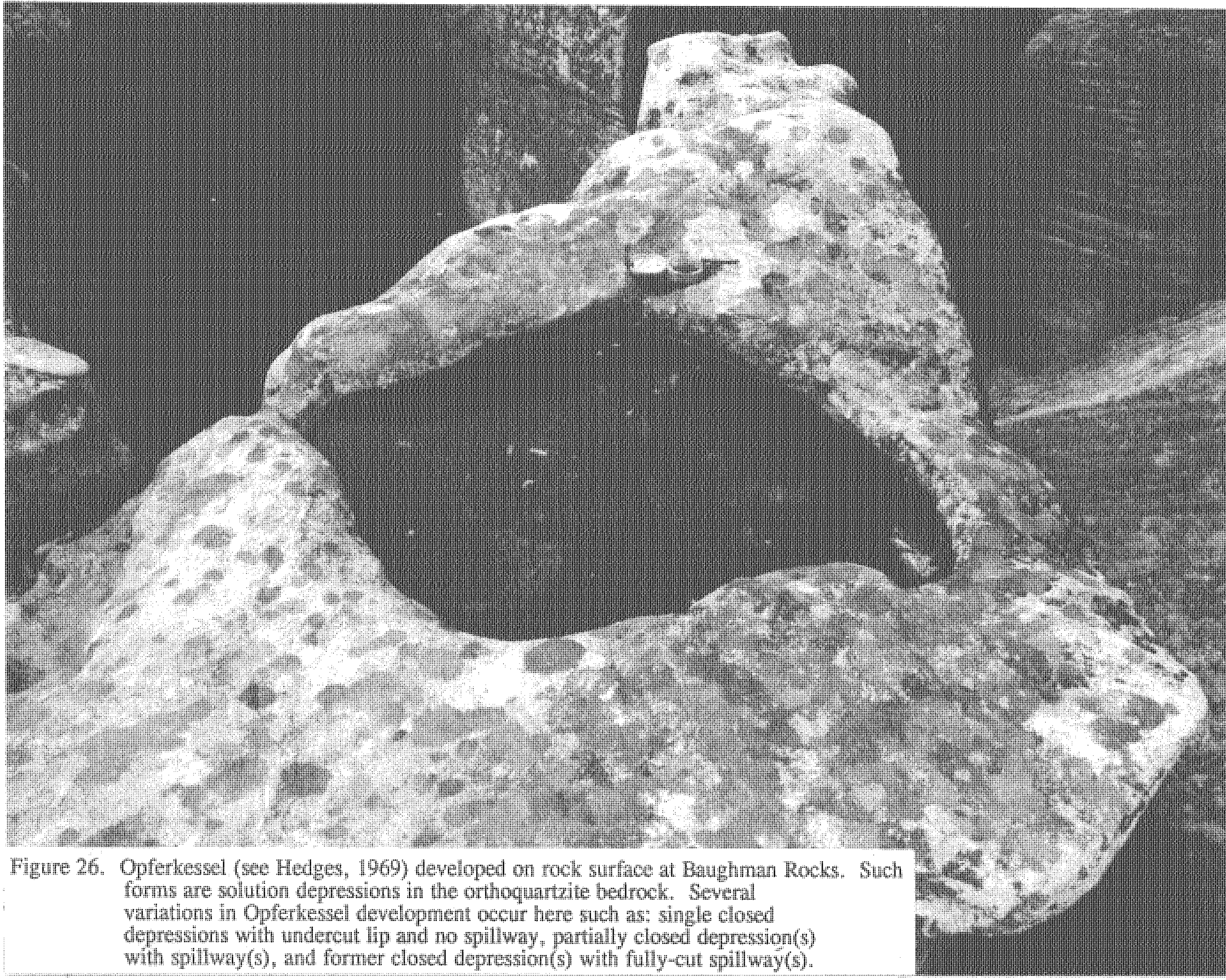

Figure 26. Opferkessel (see Hedges, 1969) developed on rock surface at Baughman Rocks. Such forms are solution depressions in the orthoquartzite bedrock. Several variations in Opferkessel development occur here such as: single closed depressions with undercut lip and no spillway, partially closed depression(s) with spillway(s), and former closed depression(s) with fully-cut spillway(s).

Figure 27. Baughman Rocks, Markleton quadrangle, developed in the Homewood Sandstone of the Pottsville Group (Geyer and Bolles, 1987). Note expanded joints. Length of 5 m tape with handle is 33 cm.

Erosion

Except along drainageways, there is little visible evidence of soil erosion in areas under undisturbed forest cover. The effects of logging undoubtedly increase erosion rates temporarily somewhat, but with careful road building and logging practices such effects can be held to a minimum. In areas where land is used for agriculture, however, authors of county soil surveys in the Allegheny Mountain section are in agreement that soil erosion is the main problem in the use and management of the soils used for cropland and pasture (cf. Yaworski, 1983, p. 51).

SOILS

Distribution

The soils of southern Somerset County are developed from sandstones, red shales, and grayish-brown shales (Yaworski, 1983). The sandstone soils are Dystrochrepts (Hazelton) and Fragiudults (Cookport) and are found primarily on the higher elevation areas such as Negro Mountain and Laurel Hill. The majority of the remaining area has grayish-brown shale soils except an area in the southeast where red shale soils are found. The grayish-brown shale soils range from Dystrochrepts to Hapludults (Weikert, Berks, Rayne, Gilpin, Wharton, and Cavode). The red shale soils are dominantly Hapludults (Leck Kill). Associated with these residual soils on lower backslope and footslope landscape positions are colluvial associates of these residual soils (grayish-brown shale-Ernest and Blairton; red shale-Albrights; sandstone-Cookport).

Fragipans

The residual soils generally do not have a fragipan while all the colluvial soils have a fragipan. These features are very significant to soil-use because they restrict the downward movement of both water and roots. Fragipans are thought to be associated with transported parent material of medium texture (not too sandy or clayey) in relatively youthful soils (see below). For a more complete discussion of the genesis of fragipans in Pennsylvania soils, see Ciolkosz and others (1992).

Sandstone Soils

Although the soils developed in sandstone are primarily skeletal (high content of rock fragments) Inceptisols (Hazelton), at higher elevations, there is a tendency for Spodosols to form, particularly if the original vegetation of the area was coniferous forest (Ciolkosz and others, 1990). Data from a Spodosol pedon (Leetonia) sampled within a sorted stone net on top of Mt. Davis are given in Table 5. This Spodosol is unique because in addition to having a spodic horizon (Bh and Bs), it also has a fragipan (Bx). In the past most Appalachian Spodosols were described as not having a fragipan. Limited observations indicate that many of the Spodosols at higher elevations have fragipans, but they are weakly developed. A possible reason for the occurrence of the fragipan is that these soil materials have been moved down-slope somewhat or they have been frost churned in place by periglacial process during Wisconsinan time (18,000 to 20,000 years ago). Although moved during the Wisconsinan, the surface of these landscapes appears to be stable today. This conclusion is based on the time required to form the Spodosol morphology noted in the Mt. Davis soil of 5,000 to 10,000 yrs (Ciolkosz and others, 1989) as well as the time needed to form a fragipan (6,000 to 18,000 yrs; Ciolkosz and others, 1992).

Shale Soils

Although the soils developed in the red and grayish-brown shales in the southeastern part of the county are of similar age (relatively young) they have different degrees of development. The soils developed from red-rock parent material tend to be deep, nonskeletal, and with argillic horizons (Hapludults), while the grayish-brown rock soils tend to be shallow to

Table 5. Characterization data for Leetonia pedon S71 PA-56-4 (1-11) from soil pit at site **b**, Figure 12. Additional data for this pedon are available in Ciolkosz and Thurman (1993).

				Percent				
Horizon	Depth	pH	Bulk density	Sand	Silt	Clay	Fe_2O_3	Organic Carbon
	cm		g/cc					
Oi	6- 5	4.5					1.2	34.18
Oa	5- 0	3.7		63.0	28.7	8.3	1.1	39.68
A	0- 5	3.6		74.5	22.6	2.9	0.2	12.62
E	5- 20	4.1	1.54	63.9	34.4	1.7	0.2	0.77
Bh	20- 25	3.7	1.33	55.3	34.2	10.5	1.0	3.76
Bhs	25- 46	4.4	1.31	39.9	44.8	15.3	3.0	1.28
Bw	46- 53	4.7	1.60	41.7	43.2	15.1	1.3	0.57
Bx1	53- 79	5.0	1.69	49.6	40.2	10.2	1.0	0.56
Bx2	79-104	5.0	1.75	55.4	33.6	11.0	0.8	0.54
Bx3	104-132	5.0	1.50	44.5	39.1	16.4	0.9	0.70
Bx4	132-160	5.1		61.0	27.1	11.9	0.7	0.63

moderately deep, skeletal, and without argillic horizons (Dystrochrepts) (Table 6). The reason for these differences is undoubtedly a reflection of the cement and/or matrix holding the clastic rock particles together, because these soils are found in juxtaposition on the same landscape. In addition to forming deeper soils with fewer rock fragments, the red rock parent material also weathers to clay size material more rapidly. Some of this clay has moved from the A into the B horizon forming an argillic horizon (Bt) in the same time that only cambic horizons (Bw) have formed in the soils developed from grayish-brown rock materials.

Table 6. Relative percentage of shallow (<50 cm) moderately deep (50 to 100 cm) and deep (>100 cm) to bedrock soils on red and grayish brown siltstones and shales in four Pennsylvania counties that encompass the Allegheny Front (from Clark, Editor, 1992/1993).

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

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

In the southcentral and southwestern parts of the county, the bulk of the soils are developed from grayish-brown shales and are Gilpin or its slightly deeper equivalent, the Rayne soil. The Gilpin is classified as an Ultisol and is a relatively weakly developed soil that is only moderately deep, has a high rock fragment content, and a thin B horizon (Table 7). These features indicate that it is not a typical Ultisol soil. Typical Ultisols are deep, highly weathered, well developed soils found extensively in the southeastern United States. Thus the Gilpin is not a genetic Ultisol but would better be called a parent material Ultisol. Therefore, we have two types of Ultisols, the parent material Ultisols of the Central Appalachian Mountains and the genetic Ultisols of the southeastern United States.

Table 7. Characterization data for Gilpin soil pedon S65 PA 2-8(1-6). Data from Ciolkosz and Thurman (1993).

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

*On a weight basis.

Conclusions

In general the soils of southern Somerset County show weak to moderate development. One of the main reasons that there are no strongly developed soils is that these landscapes have undergone significant landscape truncation and mobilization during the Wisconsinan, particularly on the steeper slopes. Thus, pedogenesis has had only a limited amount of time to express itself in the soils on these landscapes (Ciolkosz and others, 1989).

STRUCTURAL GEOMORPHOLOGY

Introduction

The Allegheny Mountain section borders the Ridge and Valley province along the entire southeastern edge of the section. Davis and Engelder (1985) related the location of the Allegheny Front to the southeastern limit of thick (> 75 m) salt of Silurian age. Along this boundary, décollement faulting ramped up from shale units of Cambrian age into the salt beds, and the structural style changed from duplex structures in the Ridge and Valley province to layer parallel shortening in the Appalachian Plateaus province. Davis and Engelder related the long wavelength, broad synclines, the much sharper anticlines, and the symmetry of folds to the weakness of the salt horizons at depth.

Folding

The first-order anticlines and synclines in the Allegheny Mountain section have profound effects on the topography. The anticlines are sharp-topped and are characteristically much narrower that the intervening broad, flat-bottomed synclines (Davis and Engelder, 1985). Where the resistant sandstones in the stratigraphic sequence have been breached, classical "inversion of relief" has occurred, producing broad, canoe-shaped anticlinal valleys, as in West Virginia, or elongate valleys as in the area of the Deer Park Anticline in southeastern Somerset County. At the present depth of erosion in the Allegheny Mountain section in Pennsylvania, both anticlinal and synclinal valleys occur, as well as anticlinal and homoclinal ridges.

In the Somerset County area, structural amplitude of the major folds is about 610-762 m. The dip amounts on the limbs of the major folds range from about 20^{o} in the east to about 5^{o} in the west. An example of topography developed on the limb of a major fold about midway between the eastern edge of the province and the Laurel Mountain anticline is shown in Figure 28.

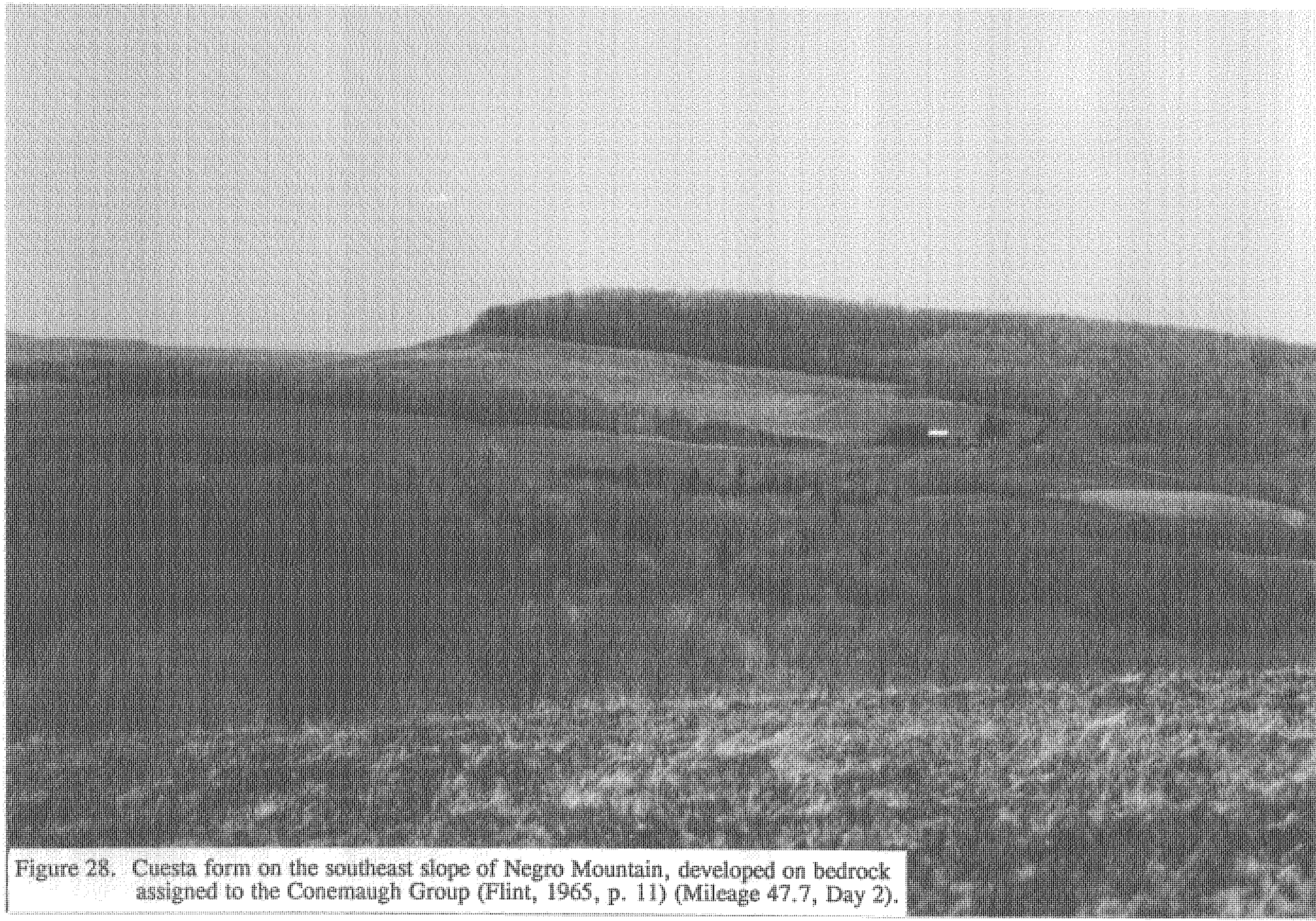

Figure 28. Cuesta form on the southeast slope of Negro Mountain, developed on bedrock assigned to the Conemaugh Group (Flint, 1965, p. 11) (Mileage 47.7, Day 2).

Fracturing

At depth, layer parallel shortening occurs along the décollement beneath the entire Allegheny Mountain section (Davis and Engelder, 1985). Other types of faults are known to occur in the subsurface, but only a few surface faults of small displacement have been reported (Iranpanah and Wonsettler, 1989). Flint (1962, 1965) reported a number of minor faults present in the area.

Shuman (1992) measured lineaments, fracture traces, and straight stream tips and trunk segments in two traverses from the Appalachian Plateaus province to the Piedmont province. One of Shuman's six-quadrangle study areas included part of the Allegheny Mountain section in west-central Pennsylvania. He found that the degree of expression of linear features on remote sending imagery of several scales was greatest on the Plateaus and least on the Piedmont. Iranpanah and Wonsettler (1989) mapped lineaments in Cambria County and vicinity from a topoimage produced from digital elevation data at a scale of 1:500,000, and from SLAR imagery. They found that the majority of the principal linear features they mapped trend westnorthwest, approximately at right angles to Allegheny Front.

On the outcrop level, however, joints are the most evident type of fracture systems in the Allegheny Mountain section. Nickelsen and Hough (1967) measured joints in the Confluence and Windber 15-minute quadrangles in the Allegheny Mountain section. In these quadrangles, they mapped northwest-southeast trending joints in shales and coals. In shales, two prominent joint sets ranged from between N30-45^{o}W and N45-60^{o}E. Iranpanah and Wonsettler (1989) mapped joints in exposures along the Conemaugh Gorge and Paint Creek in southern Cambria and Northern Somerset counties. One N45^{o}W set of joints is commonly predominant in both frequency and expression in these two areas, and were classified as cross-fold joints. Other joint orientations clustered about N10-20^{o}W and between about N40-60^{o}E. Other studies of jointing have concentrated on coal cleats and systematic and nonsystematic rock joints in Cambria County (McCulloch and Deul, 1973) and coal cleat and rock joints in Fayette County (Steidl, 1977).

Several interesting examples of expanded joints occur in the Markleton quadrangle. At Vought Rocks, there are two master joint sets; one trending N48-53^{o}W and one trending N30-42^{o}E. Dips of both sets are near 90^{o}. At Baughman Rocks (Figure 27) there are prominent joint orientations at N58^{o}W and N01^{o}E; a secondary joint orientation of N37-42^{o}E also occurs. Dips of joints at Baughman Rocks are near 90^{o}. Within the Mt. Davis road loop, the most pronounced joint orientation is N53^{o}W, dips are near 90^{o}, and joint spacing averages 1.7 m. Another joint orientation is N28^{o}E, dip is 83^{o}SE, and joint spacing is about 5 m.

Summary

Engelder (1993) summarized the use of joint patterns for the mapping of stress trajectories in the Appalachian Plateaus. He inferred clockwise rotation of joint propagation in response to changing directions of compression during phases of the Alleghanian Orogeny.

Another topic of interest to geomorphologists is the area of neotectonics. What adjustments is the Earth's crust making today, and can the effects of these movements be seen in the topography and the drainage? Engelder (1993) mapped the contemporary orientation of the maximum horizontal stress in northeastern United States using neotectonic fractures and joints. Such fracture systems are inferred to form within the upper 0.5 km of the Earth's crust as a result of denudation and lateral relief that follow uplift (Engelder, 1993). It will be interesting to see if such features can be related to regional uplift patterns (Dennison and Johnson, 1971) or to other features in the Allegheny Mountain section.

SOMERSET COUNTY AREA TOPOGRAPHY AND DRAINAGE

Introduction

Early overall treatises on the Central Appalachians that included the Allegheny Mountain section dealt largely with physiographic description and the fluvial and erosional surface history (cf. Davis 1889; Fenneman, 1928; Fenneman, 1938). Most of these early works assumed some type of cyclical erosional history which could be deduced from the study of physiographic features on topographic maps and which are visible in the field. It was assumed that the "evenness of skyline" and the commonalty of certain elevation ranges over broad areas were by products of episodes of rapid uplift, standstill, and regional landscape planation. The aspects of geologic structure (which included lithology) and geomorphic process were ignored by many workers, especially those who followed the classical masters of Appalachian geomorphology.

Topography

The overall topography in the Somerset County area is dominated by northeast-southwest trending broad ridges and valleys, except in some areas near the Ridge and Valley province. Hammond's land surface form classification (Hammond, 1963) included most of the Somerset County area within the category of open low mountains; the area near Conemaugh River drainage was categorized as open high hills. Hammond defined both of these slope categories as having 20-50% of the land gently sloping. In Hammond's classification, local relief in the areas of open low mountains is 305-914 m, and in the open high hills 152-305 m. In the field conference area, the local relief in these land surface form categories is on the low side of these two ranges. In both of these land surface form categories 50-75% of the gentle slope is in upland areas.

The highest topography of the unglaciated Allegheny Plateau section in Pennsylvania reaches 979 m on Mount Davis in the Markleton quadrangle, and several other high upland flats in the quadrangle also exceed 900 m in elevation. The presence of summit-level flats is puzzling, especially in areas such as Mount Davis where folding in the crestal part of the Negro Mountain Anticline is sharp-topped (Flint, 1965, Plate 1). Local relief reaches a maximum of about 500 m in the vicinity of transverse water gaps through Negro Mountain and Laurel Hill. The ridges tend to be well defined and so are named on 7.5-minute maps. A number of them are located in Figure 29. The local relief surrounding these ridges is about 300 m, and the absolute relief in the Somerset County area is about 600 m.

Valleys appear much more diffuse in their topographic expression, and are rarely named as such on topographic maps. Exceptions include the Brothers Valley-Glades Valley area in the high valley divide country around Berlin. In most valleys, however, informal usages refer to the valleys by either names of local communities or by the name of the local master valley stream. The valley areas contain a wide variety of topographies on the subdistrict scale (Table 2). Some highly dissected areas with average relief of about 150 m occur in close proximity to the larger streams such as Paint Creek, Shade Creek, and Stony Creek; and rivers such as Casselman River, Conemaugh River, Stony Creek River, and Youghiogheny River. Valley relief generally decreases away from incised drainage lines, and is at a minimum in the high valley longitudinal divide areas such as those around Berlin.

Drainage

Major drainage lines in the Allegheny Mountain section follow fold and lithologic trends and, quite probably, fracture zones in both straight-stream segments in both stream tips and in trunk stream segments (Shuman, 1992). Deep transverse gorges with rapids and waterfalls are common in this part of the Plateaus province. Headwater reaches often exhibit dendritic patterns, although some unusual patterns occur locally and will be discussed below. The wellspring areas of first-order tributaries in the uplands are often broad, diffuse, low-gradient areas which are poorly drained. Many such wetland areas are so indicated on large-scale topographic maps. A number of such wetland areas have been drained, surface mined for peat (see Cameron, 1970), or otherwise eliminated.

Along major water courses, Flint (1965, Plate 1) mapped areas of alluvium in southern Somerset County. Several such patches of alluvium are along Casselman River northeast of the Salisbury-West Salisbury area, at and upstream from Confluence, and on Laurel Hill Creek between King(s) Bridge and Barronvale. Flint (1965, p. 98) also noted that some stream terraces also occur in southern Somerset County.

Most drainage in the Somerset County area is westward to the Gulf of Mexico through the Casselman, Youghiogheny, Conemaugh, Monongahela, Ohio, and Mississippi Rivers. Many of the overall lengths of drainage courses are in the wide synclinal valleys which are underlain by

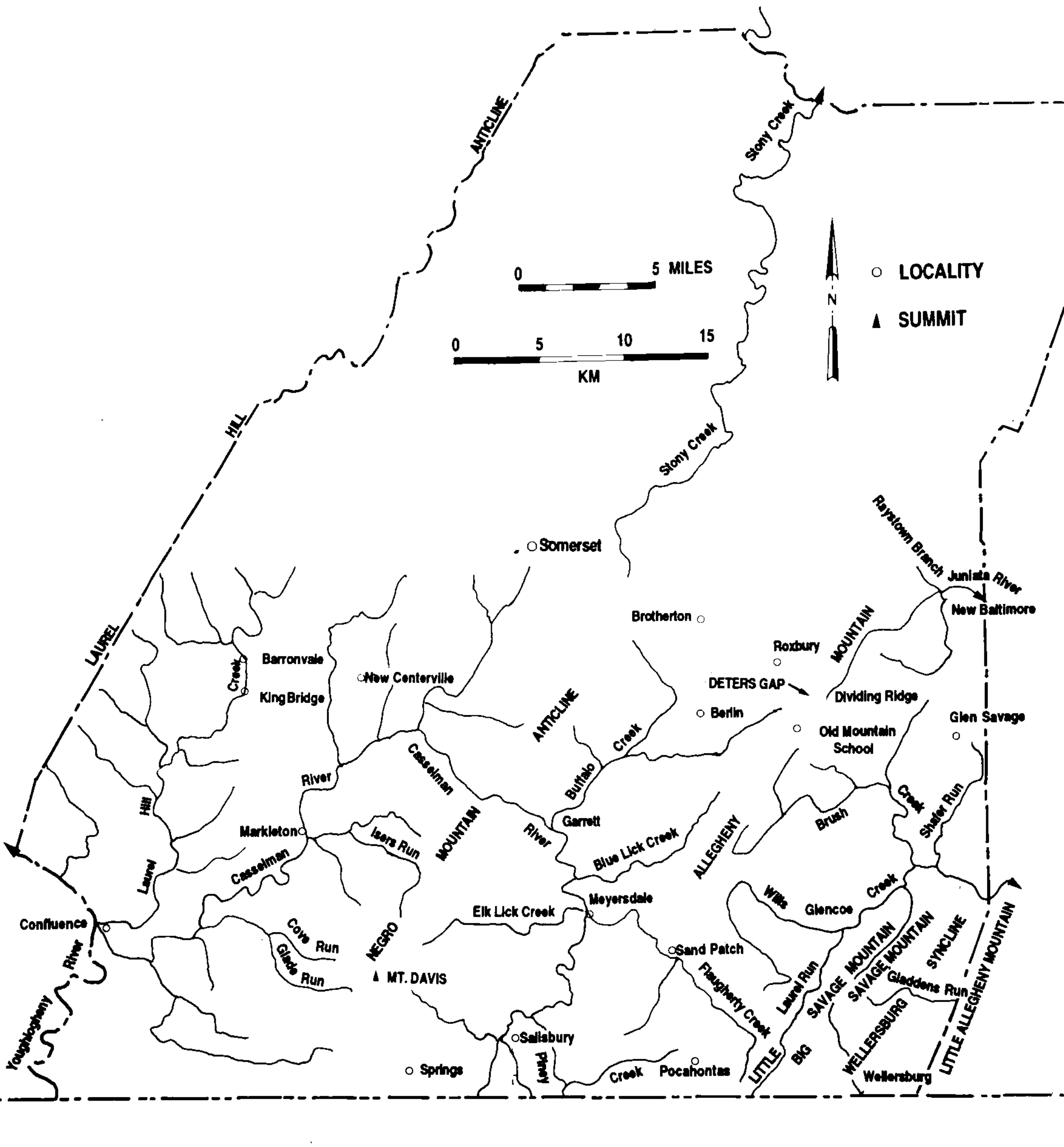

Figure 29. Location of prominent topographic and drainage features in southern Somerset County. From Flint (1965, Figure 4, p. 9).

less resistant rocks. Flint (1965) remarked on the course of Casselman River which rises in Maryland, flows northeast to Meyersdale, turns northwest and passes through Negro Mountain in a spectacular water gap, and then turns southwest to Confluence (Figure 29). Two tributaries of Casselman River still head east of Allegheny Mountain and flow westward through water gaps in the mountain. Flaugherty Creek drains westward into the Casselman River at Meyersdale through a gap in Allegheny Mountain at Keystone and Glade City, and Piney Creek which also drains westward through another gap into the Casselman River by Salisbury.

Areas east of Allegheny Mountain and north of the site of the old Mountain School, Deeters Gap, and Dividing Ridge flow into Raystown Branch of the Juniata River and hence to Susquehanna River drainage. In this area, the headwaters reach nearly to the crest of Allegheny Mountain which is the local western divide of contest. To the southeast of these headwaters of Raystown Branch, are several small drainage basins which drain to Wills Creek and thence to Potomac River drainage. These include Brush Creek, Shaffer Run, and Laurel Run. In terms of drainage divides, there is no sharply defined triple point as such. There is, however, a diffuse area centered on Allegheny Mountain in the vicinity of the wind gap 2.8 km east of Macdonaldton in the Berlin quadrangle, which receives precipitation which could variously go to Mississippi, Susquehanna, or Potomac River drainage. Sevon (1989b) notes the propensity for Atlantic Slope rivers to continue to nibble away at headwater drainage in the Appalachian Plateaus which flows to the Gulf of Mexico. The area east of Allegheny Mountain is one of active drainage reorganization, and is an excellent area in which to observe effects of probable stream piracy. Of course the primary drainage abstractions pit the more efficient Atlantic Slope rivers against the drainage to the Gulf of Mexico. A secondary contest occurs east of Allegheny Mountain between Susquehanna drainage to the northeast and Potomac drainage to the south. Two examples of these competitions are given below.

In the case of Atlantic-Gulf drainage, stream piracy is suggested by the prominent wind gap in Allegheny Mountain 2 km east of Hays Mill in the Wittenberg quadrangle and by barbed tributary drainage. The saddle in this wind gap, at 780-786 m is about 140 m higher than the water gap of Flaugherty Creek (640-671) m between Sand Patch and Glade City between 5.5 and 6 km to the southwest. Using a present-day estimate of the erosion rate in the Juniata River drainage basin of 27 m Ma (Sevon, 1989a), a hypothesized former water gap at this site could have become abandoned between 4 and 5 million years ago. This estimate could be either too high or too low. A longer time interval could be suggested because gaps through ridges underlain by resistant rocks tend to be lowered more slowly than the rest of their drainages upstream, and so form local base levels. On the other hand, erosion rates during the Quaternary are estimated to have been much higher than today, especially at the higher elevations (Godfrey, 1975; Braun, 1989). Regardless of the timing and rate of westerly divide shift, the headwaters of Wills Creek will eventually abstract the drainage of Flaugherty Creek, producing another wind gap through Allegheny Mountain. Near the Maryland border, Piney Creek will suffer a similar fate.

Some of the headwaters of Raystown Branch Juniata River now extend to crestal areas of Allegheny Mountain in the Central City and New Baltimore quadrangles. The future extensions of these stream tips will eventually tap headwaters of Stony Creek, tributary to Conemaugh River, unless such drainage is earlier abstracted by other Susquehanna tributary streams to the northeast.

When studying ongoing stream piracy, two questions need to be posed. First, what are the mechanisms of abstraction at work, and second, what are the factors involved in localization of piracy? Because we are dealing with erosional geomorphology, such questions are difficult to address, let alone answer. In the Logan Plateau, however, Outerbridge (1987) was able to interpret the history of drainage development since Late Tertiary time. He also calculated the age of residual upland surface areas from rates of erosion. He found that almost all of the surface of the Logan Plateau must be younger than 1.5 Ma, so that no erosional remnants of Cretaceous or Tertiary age can exist there.

The Allegheny Mountain section is reknown for impressive transverse water gaps which cut across resistant rocks in the major anticlines. In Pennsylvania are Casselman Gorge through Negro Mountain (Figure 30), Conemaugh Gorge through Laurel Hill, and Loyalhanna Creek Gorge and Conemaugh Water Gap through Chestnut Ridge (Geyer and Bolles, 1979). An example of a smaller transverse stream is Paint Creek on and near the Cambria-Somerset county line. The overall transverse, but sinuous, courses of these streams across major anticlinal structures no doubt gave comfort to adherents of various versions of the peneplain concept. Is this curvaceous nature due to the superimposition of older meanders, and if so, are the meanders intrenched or ingrown (Rich, 1914)?

Until the publication of recent studies, reasons for the orientations of individual stream reaches was somewhat of a mystery. The advent of remote-sensing imagery, coupled with field measurement of fracture systems, however, has rendered hypotheses which require complicated drainage development schemes unnecessary in at least some cases. A number of studies can be cited, for example, work by Nickelsen and Hough (1967) and Orkan and Voight (1985) on regional joint patterns. Often, joint measurements can be correlated with stream orientations. For example, Iranpanah and Wonsettler (1989) mapped joints in the Johnstown area in Conemaugh Gorge and along Paint Creek. In the Conemaugh gorge, which trends approximately N30^{o}W, they found that the maximum strike frequency distribution of the systematic joints ranged between N40^{o}-50^{o}W, a directional range parallel to some of the river bends. In the Paint Creek area, the strike frequency distribution maximum was N50^{o}-60^{o}W, roughly parallel to the average direction of the transverse drainage.

On a much larger scale, certain fracture systems have been shown to be coincident with river orientations. Such structural features include: cross-strike and strike-parallel

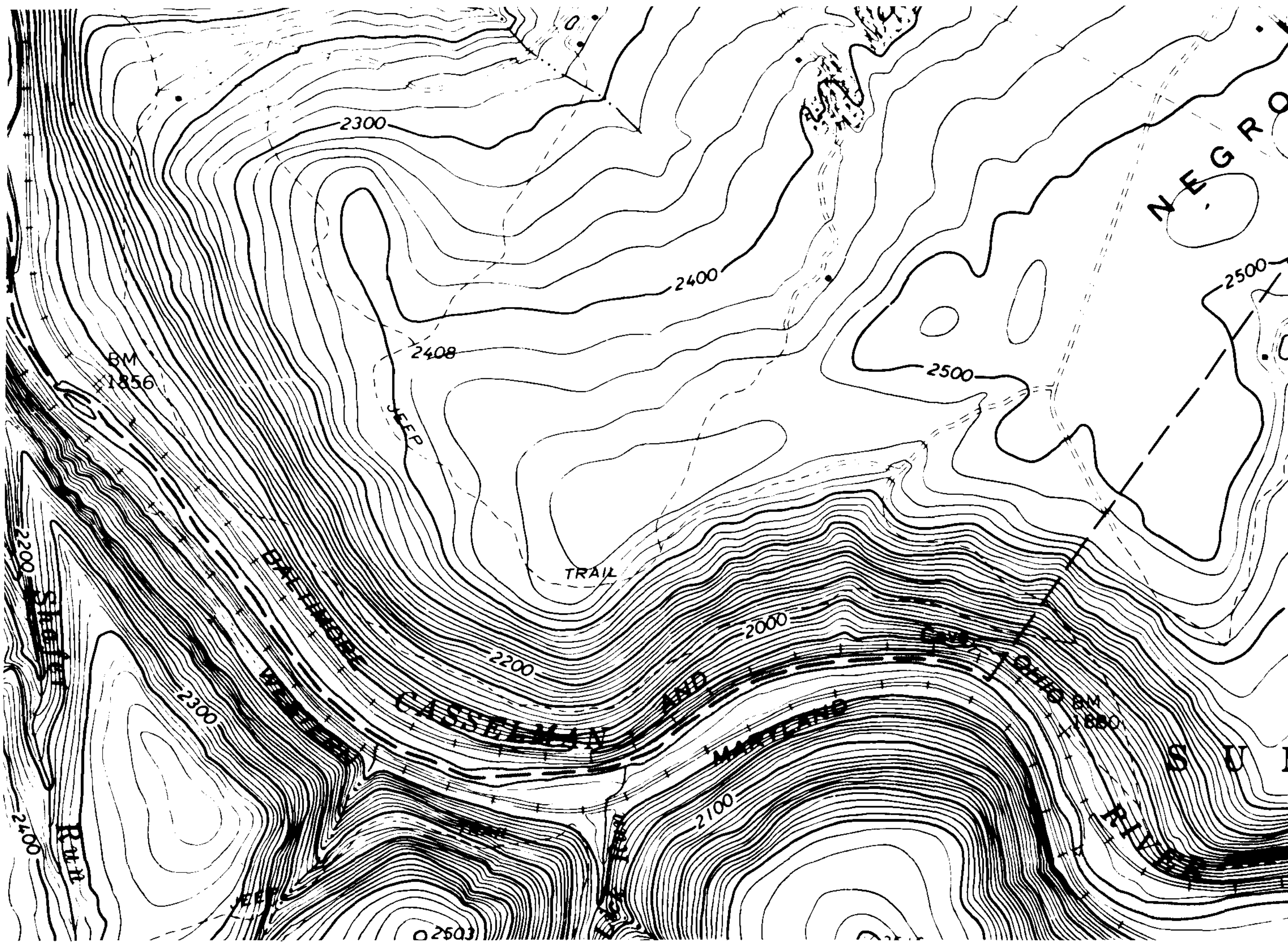

Figure 30. Casselman Gorge, exposing clastic sedimentary rocks from the Burgoon Sandstone of Mississippian age to the Pottsville Group of Pennsylvanian age (Geyer and Bolles, 1979). Map portion is from southwest corner of Murdock quadrangle.

structures (Gold and Pohn, 1985), and cross-strike discontinuities, or CSD's (Southworth, 1986).

We suggest that some of the controls on drainage evolution in the Allegheny Mountain section are rooted in epeirogenic effects such as regional upwarping (Wright, 1925; Dennison and Johnson, 1971) and rock fracturing (Shuman, 1992; Engelder, 1993) which have been demonstrated to exist elsewhere on the Appalachian Plateaus. Some of the controls on drainage evolution may be exogenic ones related to past climates. However, the dominant influence on drainage development in Somerset County has been the long range changes wrought by Late Mezozoic beheading of streams that originally flowed from Alleghanian-Orogeny-generated highlands to the east. More about that later.

Another possible complication is that drainage in headwater areas might still be adjusting to changes wrought by indirect effects of climatic change related to Quaternary continental glaciations to the northwest. The area is within the drainage of the old pre-glacial Pittsburg River of Tight (1903, Plate 1) which drained northward to the Canadian Shield. Many changes in base level would have resulted from the progressive rearrangement of the pre-Quaternary drainage basins into the post-glacial drainage of today.

Finally, process-response-feedback loop mechanisms must be considered when discussing causes of drainage evolution. Due to internal changes in matter and energy budgets, geomorphic thresholds can be exceeded, and massive responses can occur which are not directly related in time to the initial climatic or tectonic inputs.

The specific location of water gaps is interpreted to reflect structural control, possibly aided by lithologic control in areas where resistant rock units were thin or absent due to nondeposition and/or erosion. Structural elements which can localize transverse drainage can be divided into vertically-pervasive structures that allow rivers to remain in vertical place through time, strictly local (crestal) weaknesses that are found by down-plunge sliding of streams on structural highs of resistant rock units (structural ensnarement), and dynamic influences such as warping, tilting, and faulting. Deep-seated fundamental weaknesses apropos for the Allegheny Mountain section include: CSD's, DZ's, and other vertically-pervasive structures, as well as lineaments, fracture traces, and cross-fold joints (cf. Iranpanah and Wonsettler, 1989; Shuman, 1992; Southworth, 1986).

COLD-CLIMATE GEOMORPHOLOGY

Introduction

Both the Quaternary palaeoclimatic and palaeovegetational evidence amassed above indicate that the cold-phase environments of the last 2.4 Ma have been extremely severe in the Central Appalachians south of the glacial borders. The Allegheny Mountain section contains some of the highest and most exposed topography in the region, and its topographic lineation is parallel to subparallel with the known glacial borders in northwestern Pennsylvania (Figure 21). It should come as no surprise that this geomorphic section experienced cold-climatic environments which fostered geomorphic processes that had extreme geomorphic effectiveness on landscapes.

Palaeoglaciation: Did Glaciers Scour Allegheny Mountain Section's Peaks?

Introduction

Observers of the Markleton topographic quadrangle may be struck by the visual appearance of several features in certain valley areas. These include: (1) the hemiamphitheater shapes of the valley heads of Isers Run (Figure 31), Cove Run, Glade Run, and Cranberry Run; (2) The deep(?) basinlike areas in Cove Run and Glade Run immediately downslope from their half-bowl shaped valley heads; and (3) The "U"-, or more correctly, parabola-shaped cross-form of the north-facing valley of Isers Run.

Another interesting curiosity is Flint's description of a surficial clay mined by the Otto Brick and Tile Works at Springs, southern Somerset County (Flint, 1965, p. 194-196). This deposit was described as a light-bluish-gray plastic clay which weathers to a buff color. At some exposures, Flint described the clay as calcareous. Abundant pebbles, cobbles, and occasional boulders (to 15 cm diameter) in the clay had no observed textural or structural patterns. Flint suggested ice rafting to account for the larger clasts in the deposit. Ice rafting is a plausible mechanism, but what was the origin of the ice?

Proposal of a glacial origin for the above landforms and materials would certainly attract attention. Alternative hypotheses, however, may be able to explain the known field relationships.

Nonglacial Hypotheses

A non-glacial origin is possible for the several valleys that have morphologic similarity to glaciated valleys, particularly Isers Run which, with its north orientation, is probably the most likely candidate. In each of these valleys, as well as similar valleys to the northwest on the east flank of Laurel Ridge, the structure is an anticline with resistant Pottsville Group rocks forming the crest and slopes of the topographic form. Streams have breached the Pottsville rocks and cut deeply into the underlying softer, less resistant rocks of the Mauch Chunk Formation. It is thus possible that the glacial-form-similarity of these valleys results not from glaciation within already existing valleys, but rather from structural form and differential resistance to erosion of the rocks involved.

Another alternative non-glacial origin is possible from a geomorphic process standpoint.

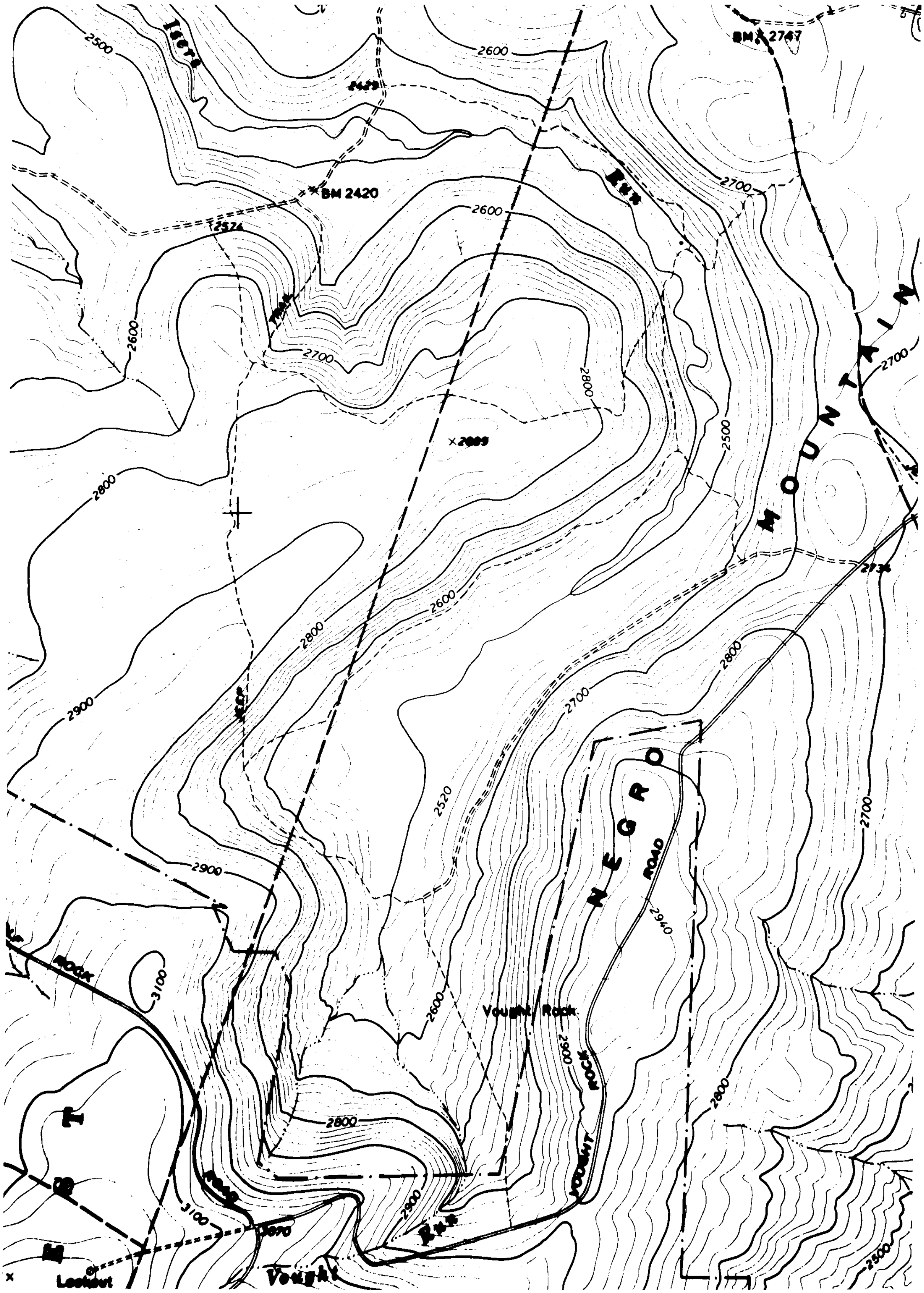

Figure 31. Valley of Isers Run. Map portion is from Markleton quadrangle.

Wentworth (1928) described hemiamphitheater-shaped valley heads and trough-shaped valleys in Hawaii that mimic cirques and glacial troughs. These landforms occur at low elevations where palaeoglaciation is unreasonable, and far below elevations where frost occurs today. Wentworth attributed these valley surface features to high permeability of the basaltic rocks, high mean annual precipitation and temperature, and intense chemical weathering in the zones of water table fluctuation. Because of the high permeability of the volcanic rocks, water tables are very low and near the valley floors, so that the attack of weathering and erosion is concentrated low on the sides and on the floors of the valleys.

Although the rocks on Mt. Davis are clastic sedimentary rocks and not volcanics, a parallel can be made with Wentworth's (1928) conclusion that water-table-zone chemical and biochemical attack can form hemiamphitheater- and trough-shaped valley features. In the case of Mt. Davis, highly-resistant, but fractured rocks of the Pottsville Group overlie fine-grained and relatively poorly permeable rocks of the Mauch Chunk Formation. Ground water that infiltrated through the Pottsville Group would have encountered the Mauch Chunk contact, and presumably then would have moved laterally to the nearest stream valley(s) that breached the formational contact. There, active seep and spring sapping, coupled with frost action during cold phases could have acted to expand joints (Hedges, 1972), remove sandstone blocks, and produce non-glacial, hemiamphitheater-shaped hollows and parabola-shaped troughs.

Palaeoglaciation Hypothesis

Nelson (1989) used large datasets on cryoplanation terraces (discussed below) from four areas in Alaska to establish definitive relationships among altitudinal range, and temperature and precipitation gradients. He found that, in a particular area, the altitudinal levels of cryoplanation terraces coincide with levels of empty glacial cirques. Nelson concluded that active cryoplanation terraces and cirque glaciers can co-exist in a region in the same altitudinal level when conditions are relatively marginal for glaciation. Active terrace formation is favored under slightly drier and less cold conditions.

If one were to speculate that part to all of the Negro Mountain area centered roughly around Mt. Davis underwent one or more episodes of palaeoglaciation, how could this speculation be bridled? Several approaches are available which have some potential to indicate whether or not it is a reasonable speculation to invoke palaeoglaciation to explain these relationships at this time.

Morphometric approaches are useful in the study of certain types of features of suspected glacial origin. Two such features are cirques and troughs. Glacial cirques are large hemiamphitheater-shaped hollows, open downstream and having a floor shaped by glacial erosion and a drainage divide-headwall which evolved at least partially by subaerial frost action. Several methods are available to determine the morphometry of large bowl-shaped hollows, and to compare them to features of known glacial origin (Linton, 1963; Evans and Cox, 1974). These techniques quantify aspects of cliffed headwalls, bedrock-floored basins, and the typical L-shaped break between these two features to produce specific indicators which have been used to infer a glacial origin.

Troughs are gutter shaped geomorphic forms that may or may not have been created by glacial ice that flowed in channels. Glacial troughs are bedrock channels eroded by the effects of moving ice when all or a major part of the discharge was confined. Four types of glacial troughs have been recognized by Linton (1963). Two of these four types of troughs can be considered as models for the Negro Mountain area. The "alpine type" of glacial trough is cut by valley glaciers whose zone of accumulation is overlooked by higher terrain. The "Icelandic type" of glacial trough is cut by ice cap or ice sheet subglacial ice which spilled in over the trough head. Such troughs are common around small local ice caps in Iceland and Norway. The glacially-suspect valley morphology seen in the Markleton quadrangle could be of either the "alpine type" or of the "Icelandic type." In the former case, small valley glaciers would have been confined to the valleys, and the upland surface might have been under a permanent snowfield or icefield, or windswept free of deep snow and veneered by a barren Felsenmeer. In this case, the valley glacier of present-day Isers Run would have been cirque-fed. In the latter case, the Mt. Davis area would have been buried by a small mountain ice cap, and radiating outlet glacier tongues would have accomplished the geomorphic work. In this scenario, the Isers Run valley glacier would have been outlet-fed from the ice cap. In either case, the ice would have been both moving and geomorphically effective. The possiblity that Ural-type glaciers once existed in the Mt. Davis area will not be considered here, because——if the present is a clue to the past——Ural-type glaciers do little geomorphic work. (Ural-type glaciers form slightly below the regional climatic snowline, and exist only because of the pervasive and cumulative effects of leeward snow drifting. They could not have, for example, excavated deep rock basins or produced long parabola-shaped valleys.)

Several methods are available to determine the morphometry of long topographic troughs, and to compare them to those of known glacial origin. For example, Linton (1963) emphasized that the floors of glacial troughs have distinctively deeper excavation in their headward areas when contrasted with stream valleys, and that such differences can be shown on long profiles. With respect to cross profiles, both Svensson (1959) and Graf (1970) agree that the cross-sectional forms of glacially-sculpted valleys are parabolic, with the general equation

$$y = axb$$

being the most adequate simple mathematical expression. In use, each half of the valley width is treated separately, with x measured as being positive from the valley midwidth. "Good" glacial troughs usually have exponents of about 2.

At the present time nothing would be gained by doing this in the Mt. Davis area of Negro Mountain because we do not know the form of the bedrock topography which is buried by a complex mantle of regolith. It is still well worth knowing that such techniques exist, however, because modern portable geophysical equipment and new sophisticated data-analysis techniques are now capable of resolving the bedrock topography.

Unconsolidated, surface material examined in several places along the lower slopes of Isers, Cove, and Glade Runs would be called colluvium by most geologists. Nothing in these materials suggests glacial debris. In addition, aerial photographs reveal no morphologic suggestion of moraines, valley-side kames, or other ice-contact deposits that might be expected along the margins of a glaciated valley. This is not surprising if, as argued below, any palaeoglaciation was pre-Wisconsinan in age.

In regions where sufficient palaeoclimatic data exist, an analysis of such information can be used to determine if ancient glaciation might have occurred. For example, Kutzbach and Wright (1985), in simulating the climate of 18 Ka BP, estimated that July average temperatures may have been 5-15^{o}C colder than now, and that annual precipitation was decreased 10-30%. Braun (1989) identified five episodes during the last 2.4 Ma when glaciation on a global scale exceeded that of the Late Wisconsinan; several of these had 0.25% $\delta^{18}O$ greater than that of the Late Wisconsinan! Clearly, if the Late Wisconsinan, Late Glacial Interval was sufficiently severe to promote the development of cryoplanation terraces (discussed later) which are periglacial cirque analogs, then there were five cold-phase episodes in Pre-Wisconsinan time when glacial climates in the Mt. Davis area can be inferred, providing that either snowfall was adequate and/or that accumulation by wind drifting was effective.

But specifically when could such palaeoglaciation have occurred? Several lines of evidence suggest that any postulated palaeoglaciation was ancient; it definitely could not have been during the Late Wisconsinan: (1) the dissected morphometry such as that seen in the headwaters of Cove Run and Glade Run; (2) the ubiquitous presence of colluvium, alluvium, paludal, and lacustrine sediments in these features, (3) the lack of any known glacigenic constructional topography; and (4) the weathered nature of the glaciolacustrine(?) clay reported by Flint (1965). As no Pre-Wisconsinan terrestrial record of palaeoclimate is known for the Allegheny Mountain section, recourse must be made to the marine record. Braun (1989) referred to North Atlantic DSDP Site 552A for the $\delta^{18}O$ record as a proxy for glacial advance and retreat. Large-scale, variable $\delta^{18}O$ maxima which are clearly greater than the Late Wisconsinan stage 2 maximum occurred during $\delta^{18}O$ stages 6, 12, 16, and 22 (Braun, 1989, Figure 2A, p. 237). Going even farther back in time, the Late Wisconsinan stage 2 maximum was also exceeded between 2.33 and 2.4 Ma BP (Braun, 1989, Figure 2B, p. 237).

Summary

In conclusion, we are left with no proof and no denial of palaeoglaciation. Although the landscape morphology, the cryoplanation-cirque analog, the severity of cold-phase palaeoclimates before Wisconsinan time, and a suggestive diamicton deposit are positive indicators, no diagnostic evidence is available at present. Subsurface investigation, both drilling and geophysical would provide additional data on the nature of sediments at depth and critical aspects of the bedrock morphology.

Palaeoperiglaciation

Introduction

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

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

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

It will also be productive at the present time, when Central Appalachian periglacial geomorphology is in a nascent state, to focus on objectives. Here, Thorn (1992) lists five primary objectives, as follows: (1) identification of the chemistry, physics and/or mechanics of processes; (2) identification of periglacial landforms; (3) identification of permafrost and its distribution; (4) investigation of the nature and behaviour of permafrost and active layers and their processes; and (5) reconstruction of palaeoperiglacial geomorphological realms.

Colluvium

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

Colluvial deposits are widespread on the Appalachian Plateaus, not only in close proximity to the Late Wisconsinan glacial border (Denny, 1956; Denny and Lyford, 1963; Kocsis-Szücs, 1971; Sevon, 1992) but also away from the margins. Pomeroy (1983) reported large, prehistoric, relict debris flows composed of diamicton deposits that occupy drainageways in the unglaciated Appalachian Plateaus province in Cameron, Elk, Forest, McKean, Potter, and Warren counties, Pennsylvania. Pomeroy (1983) attributed the genesis of the debris flows to colluvium generation and subsequent mass movements under periglacial environments that probably continued into early Holocene time. Aguilar and Arnold (1985) ascribed the development of asymmetrical valleys in the High Plateau section to solifluction that differentially truncated south-facing slopes more so than north-facing slopes.

Large areas of old colluvium also exist on the unglaciated Appalachian Plateaus at some distance from the ice margins. Pomeroy (1986) mapped extensive areas of old colluvium in Greene County, southwestern Pennsylvania in the Pittsburgh Low Plateau section. Gray and others (1979) concluded that ancient landslides on the Appalachian Plateaus occurred under former periglacial conditions. There are few numerical age dates, however, to constrain movement times. D'Appolonia and others (1967) reported that ^{14}C dating of slide surfaces at Weirton, West Virginia yielded minimum ages of > 40 Ka. Philbrick (1962) obtained ^{14}C dates of $9{,}750 \pm 200$ and $8{,}940 \pm 350$ yr on slide surfaces north of Wheeling and southwest of Morgantown, West Virginia, respectively. Limited exposures of colluvium indicate that, on the basis of color and texture, there are at least two ages of colluvium in Somerset County.

Colluvium is abundant in Somerset County. Most of the steep slopes in the county have a morphologically-definable zone of colluvium near the base of the slope. Slopes with hard, erosion-resistant rocks present at the top of the slope are generally littered with blocks and boulders of such rocks (e.g., Pottsville rocks on the slopes of Negro Mountain near Mt. Davis). Colluvium on low to moderate slopes is generally less obvious than that on steep slopes. Morphologically, definition of these deposits is either absent or subtle.

Sorted Patterned Ground

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

Large scale (> 2 m diameter in plan view) sorted stripes and sorted nets occur in the Allegheny Mountain section. Only a very limited amount of prospecting for sorted pattern ground sites has been accomplished in this geomorphic section. This sad state of affairs should be borne in mind when contemplating use of the finds to date for palaeoclimatic reconstruction. Most patterns either occur in areas underlain by resistant rock units and/or the blocks and boulders in their stone borders have been derived from upslope subcrops or outcrops of these rocks. Almost all of the finds to date (1993) have been on gently-sloping upland areas. Finds of well-developed and well-preserved sorted nets are less common; the observed nets tend to occupy nearly horizontal upland flats. Of course, many more sorted net localities probably occur on isolated high flat areas that lack road or trail access. The nets occur either immediately downslope from rock breakdown only a few meters below summit levels or on high flats without surface evidence of former outcrop. Downslope, some of the sorted nets are transitional to sorted stripes on slightly steeper slopes. Many of the sorted nets once may have been well-shaped sorted polygons, as suggested by slightly angular corners in the stone mesh intersections.

Clark and Ciolkosz (unpublished data) studied the sorted forms on Mount Davis (Figures 32, 33, and 34). These include sorted polygons, sorted nets, and sorted stripes. The polygons occur on high, essentially flat to very gently sloping (about 1^{o}) areas, and grade into stretched-out nets on slope gradients of about 1 to 7^{o}. Nets tend to become elongate downslope and to grade into sorted stripes as slope gradients increase. The soil in the sorted net area which was sampled on Mt. Davis (see Figure 32, sorted patterned ground site b) is described in detail by Ciolkosz and Thurman (1993).

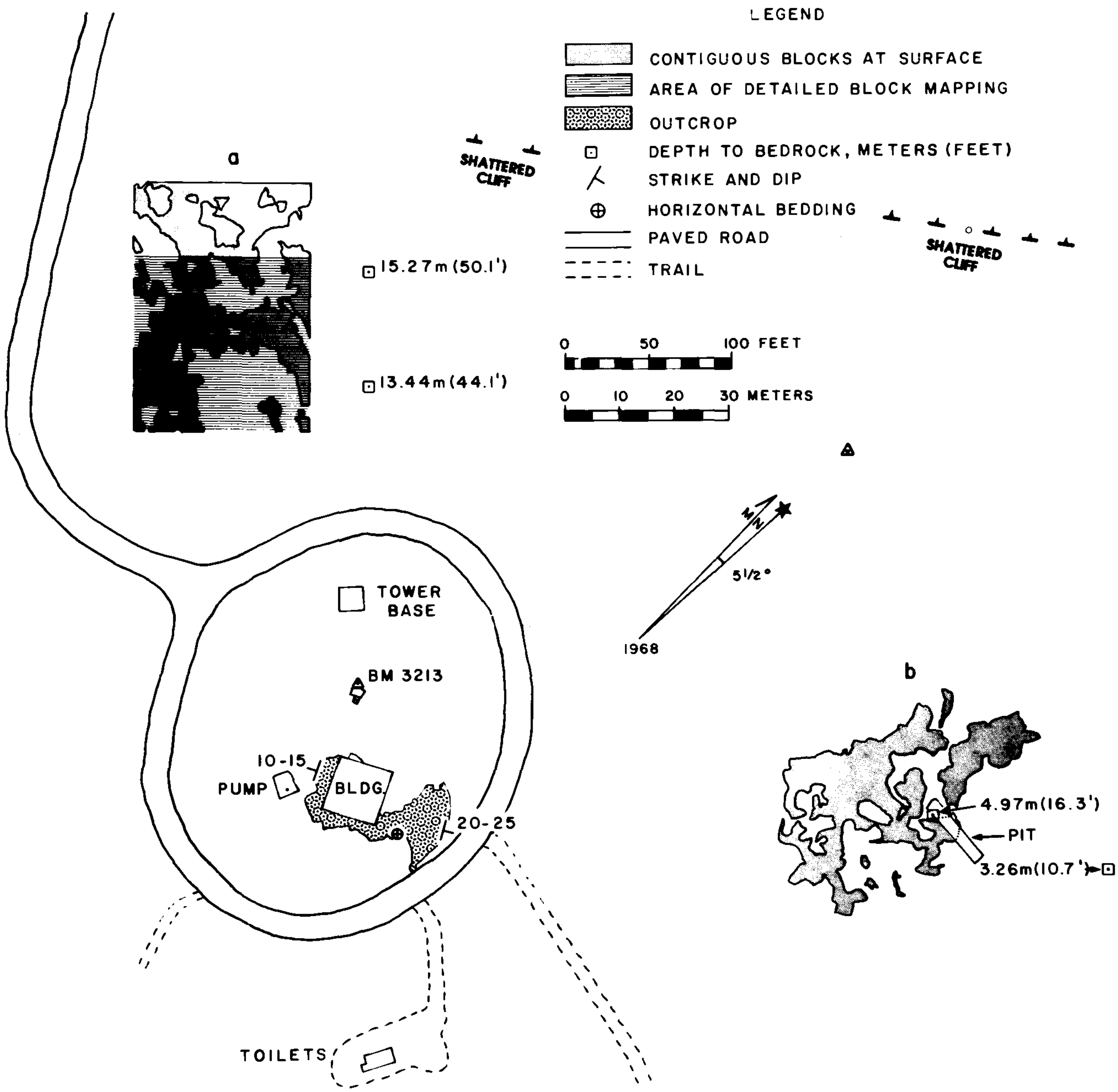

Figure 32. Map of the Mt. Davis observation tower circle area. Markleton quadrangle.

Good examples of large-scale sorted stripes occur in several areas of Somerset County. For example, several long individual sorted stripes, averaging about 65 m long and 4 to 6 m wide occur on slopes of 7.5 to 9^{o} about 45 m northwest of the Hays Mill Fire Tower in the Wittenberg quadrangle.

Sorted stripes occur in association with a valley-bottom block field and its associated stream headwaters 2 km east of the intersection in Roxbury in the Berlin quadrangle. The site is on the northeast (downslope) side of Route 31 below BM 2397 (730 m). Individual feeder

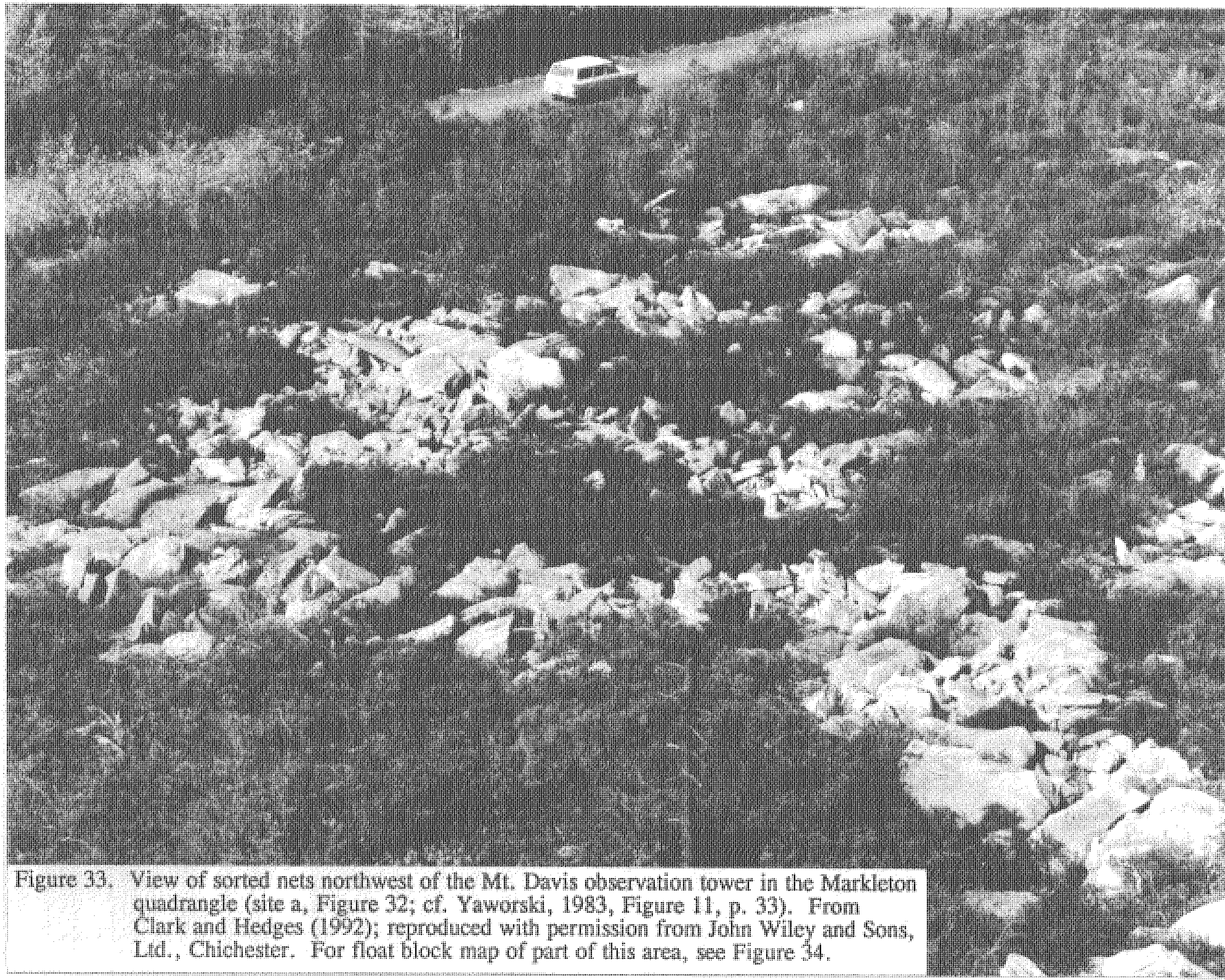

Figure 33. View of sorted nets northwest of the Mt. Davis observation tower in the Markleton quadrangle (site a, Figure 32; cf. Yaworski, 1983, Figure 11, p. 33). From Clark and Hedges (1992); reproduced with permission from John Wiley and Sons, Ltd., Chichester. For float block map of part of this area, see Figure 34.

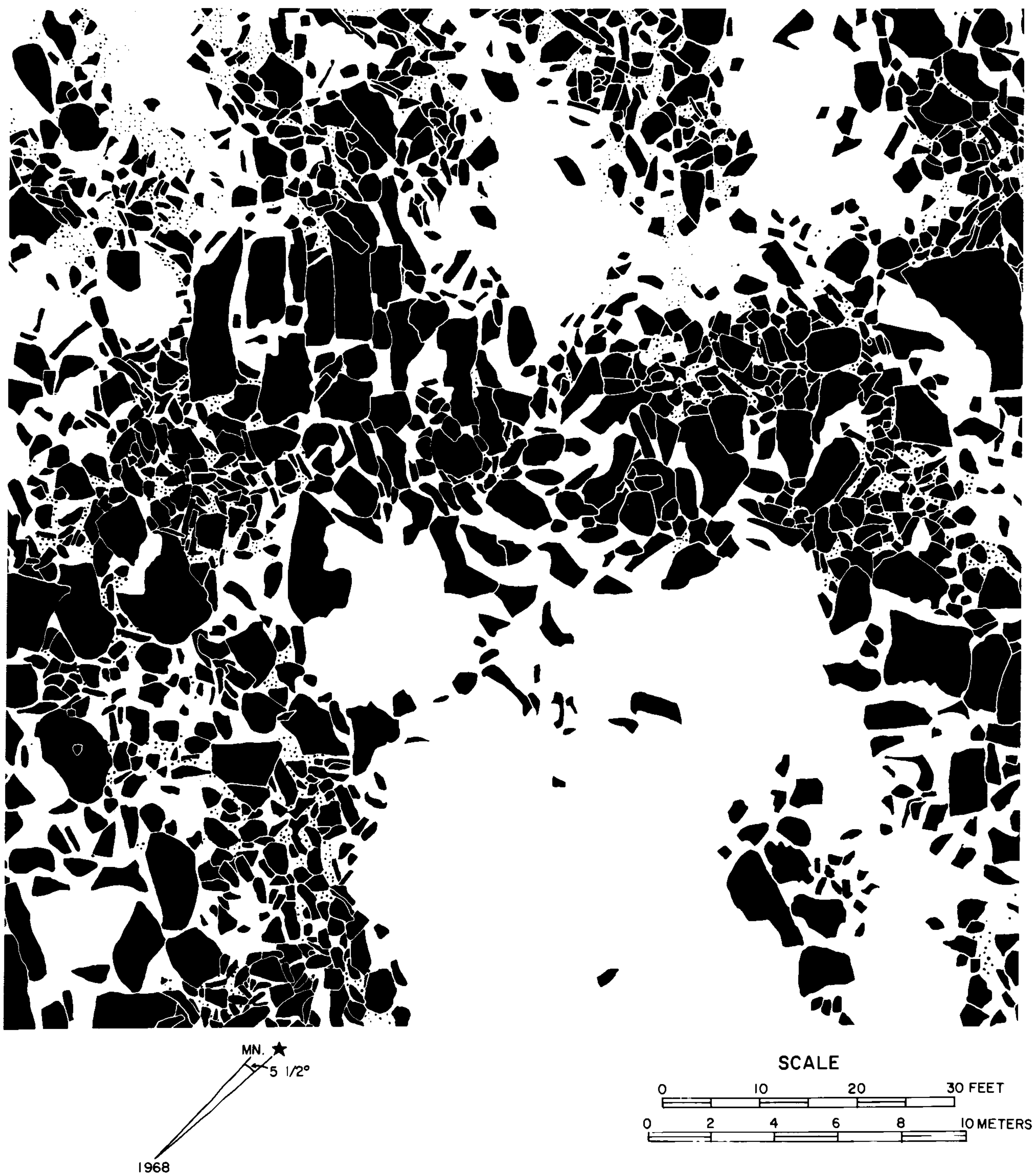

Figure 34. Map of sandstone float blocks within a 30.48x30.48 m square northwest of the Mt. Davis observation tower in the Markleton quadrangle (site a, Figure 32). Patterns are on 1 to 7^{O} slopes; slope direction is to the northwest. Note effects of late-state deformation in upper-central portion of map (wide, sinuous swath of contiguous blocks) which distorts symmetry of sorted nets. For location map and photograph which include this area see Figures 32 and 33, respectively.

stripes are 3 to 4 m wide and are typically about 30 m long. Many other small-scale features can also be seen at this locality, including stone free "islands" of soil about 6x8 m in plan dimension, small closed topographic depressions in the block field, and ongoing dissection of this block accumulation by the associated stream network.

In the Markleton quadrangle, along North Wolf Rock Road 1000 m from the intersection with the paved road by Baughman Spring, is an excellent sorted stripe complex which crossed the road at the location of the BM 3147 (959 m) marker. This compound feature illustrates both upslope source area conditions and a downslope gradation into lobate- to spatulate-shaped block-armored microrelief areas that, in turn, merge and grade downslope into blocky colluvium. Upslope from the road is a wet area with small, 30-100 cm-wide gullies that contain streamlets in wet weather and during snowmelt. The channels disappear at the upslope ends of sorted stripes. Slope gradients in this area range between 1.5 and 2°. The sorted stripes merge downslope to the road to form a stripe complex 18 to 24 m wide on a slope of about 4°. Downslope from the road, a clearly-defined sorted stripe occurs 7 to 13 m wide on slopes ranging from 4 to 9.5°. The stripes diffuse and spread out into spoon- to spatulate-shaped block accumulations, which, in turn, are continuous with stony soils on slopes which average 12°. The surface stream appears at the lower end of the sorted stripe complex, and has incised the diamicton apron complex in a large gully where the depth of incision ranges from about 2 to 4 m.

In upland areas underlain by or downslope from suitable sandstone source rocks in West Virginia, there are numerous occurrences of sorted stripes. Areas just west of the crest of Allegheny Front, the Cabin Mountain area, and the Mozark Mountain area all contain excellent occurrences of large sorted stripes. At Big Run Bog in the Mozark Mountain area, Larabee (1986, p. 65-66) reported:

"A periglacial block stream, apparently incised during the Holocene, borders the eastern edge of Big Run Bog, provides geomorphic evidence for local solifluction activity that probably occurred during the full- and late-glacial interval.'

No remains of vegetation were recovered from a soil pit on Mt. Davis. At the headwaters of Red Run (39° 04' N; 79° 29' W; 792 m), in the Blackwater Falls quadrangle, Tucker County, West Virginia, however, samples from a soil pit through part of a sorted polygon field were studied by Watts (1979). He found Picea (spruce) and Pinus (pine) needles. The arboreal pollen spectra were dominated by Picea and Pinus, but Tsuga (hemlock) was absent and pollen from deciduous trees was extremely rare. This indicates that these pollen spectra do not derive from modern flora, but from the early expansion of conifers into the region. This indicates that sorted patterned ground in this part of the Allegheny Mountain section remained active until at least about 12,500 yr BP.

Rock Cities

The term "rock city" has been used to describe a number of occurrences of joint-bounded, tower-like, masses of rock. Indeed, the proper noun Rock City refers to one occurrence that is a tourist attraction in the Southern Appalachians near Chattanooga, Tennessee (Wilson, 1983). What, then, is meant by the term "rock city?" Ashley (1933, p. 88) stated:

"At many places in the State large blocks of massive rock have been displaced from the parent ledge and lie strewn over the surface. Huge blocks of stone separated by narrow passages or joints, invite exploration and give the appearance of the masonry of a city in ruins. These have been called rock cities."

Smith (1953) gave the overall term of "rock cities" (Ashley, 1933) to these features and proposed them as a new kind of periglacial phenomenon in the Appalachians. Smith ascribed the origin of the expanded joints to periglacial frost wedging, he stated that would have been optimal during Wisconsinan time. The type areas are near Olean and Salamanca, New York, in the High Plateau section south of the Late Wisconsinan glacial border.

Examples of rock cities in the Allegheny Mountain section are Bear Rocks, Westmoreland County (Geyer and Bolles, 1979, p.137); and Baughman Rocks (Geyer and Bolles, 1987, p. 61-62) and Vought Rocks (Geyer and Bolles, 1987, p. 74-75), both in Somerset County. At the latter two sites, width of the expanded joint openings average about 0.3 m or less and the blocks are up to about 6 m high.

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

Aeolian Sediments

A number of authorities do not include aeolian processes and their effects in defining and delimiting periglacial processes and regions. This is understandable from both the standpoint that aeolian activity and deposits are widespread in many climatic and geomorphic regions worldwide and from the perspective that some periglacial areas lack obvious aeolian feature or deposits. There is no paucity of aeolian sediments in Pennsylvania; indeed there is much evidence that wind action had strong direct and indirect effects during more than one Quaternary cold phase. The direct evidence includes: the presence of fossil loess sheets, the anomalously high silt content of certain soil horizons, and the presence of large quantities of extremely fine-grained sediments often referred to as "aerosolic dusts" (or "desert dusts," because of their probable origin) in certain soils. Indirect evidence rests on the presence of fossil periglacial landforms that are interpreted to have required strong wind action for their development. Such features include cryoplanation terraces and some types of sorted patterned ground in the Allegheny Mountain section in Pennsylvania and West Virginia.

There are few data about loess in the Allegheny Mountain section. The map "Pleistocene eolian deposits of the United States" (Thorp and Smith, 1952) is the only known published work on the overall areal distribution of loess in the field conference region. Field observations indicate that loess occurs in many areas of western Pennsylvania, but there is little documentation of its distribution or character. In a north-south belt along the Allegheny, Beaver, and Monongahela rivers, Thorp and Smith (1952) mapped loess less than 1.22 m thick and covering less than 33% of the land surface in Cattaraugas and Chatauqua counties, New York; in Warren, Crawford, Forest, Venango, Mercer, Clarion, Butler, Lawrence, Beaver, Armstrong, Allegheny, Westmoreland, Washington, Greene, and Fayette counties, Pennsylvania; and in Monongahela and Marion counties, West Virginia. However, there are no published research results on the characteristics, origin, or ages of loess sheets in western Pennsylvania or in northern West Virginia.

Cryoplanation Summits and Terraces

The term "cryoplanation" (Demek, 1969; Priesnitz, 1988) encompasses a broad spectrum of periglacial landforms, materials, and interpreted climatic environments and processes of formation. There is evidence that such features may be products of more than one cold-phase event (Lauriol, 1990). A number of criteria for the recognition of cryoplanation summits and terraces have been amassed (Demek, 1969; Priesnitz, 1988), and a detailed protocol for mapping these landforms has been developed (Demek, 1972).

Clark and Hedges (1992) studied local broad upland sites in the Allegheny Mountain section in Pennsylvania and West Virginia, where relatively flat uplands locally truncate lithology and structure, and break abruptly at their edges——commonly as shattered cliffs——into blocky slopes. The Mt. Davis area has excellent examples of shattered cliffs, a number of which were mapped by Yaworski (1983, Sheet Number 50). Short horizontal and vertical distances downslope from these risers are one or more terraces. Several of the sites used in this study are in the Allegheny Mountain section; one of these sites is Mt. Davis.

Weathering and soil horizon characteristics at all the sites provide qualitative evidence of relatively prolonged slope stability. When broken open, both bedrock ledges and float blocks show differential weathering effects on top versus bottom surfaces. Large blocks are weathered and broken up in place, with little separation of the constituent fragments. Horizontal to gently-inclined surfaces of some large quartzite blocks and bedrock tors show well-developed Opferkessel that usually show no morphological evidence of block disturbance during the time over which they have developed. Two terrace localities in West Virginia reported by Clark and Hedges (1992) are on the eastern edge of the Allegheny Mountain section overlooking the Allegheny Front.

Clark and Hedges (1985, 1992) conclude that the upland forms and materials they studied are fossil end products of complex processes that worked to produce cryoplanation terraces (treads), and frost-riven cliffs and frost-riven, block-mantled scarps (risers). In their interpretation, the merging of cryoplanation terraces on opposite upland slopes created summit cryoplains such as the surface developed on Mt. Davis. Demek (1972, p. 171) states:

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

The work of Nelson (1989) provides strong incentive for further study of fossil cryoplanation features, because of the close altitudinal frequency distribution of these features with that of cirques and snowlines in central and western Alaska. The close spatial association of large-scale sorted patterned ground, block slopes, and "frostriven cliffs" with cryoplanation terraces argues that they all belong to some species of frost-rubble periglacial zone. In terms of their geomorphic effectiveness, frost-rubble periglacial zones are among the most severe of all periglacial realms, and occur in both continental "Siberian" and oceanic "Icelandic" regions. Specific inferences about palaeoenvironmental conditions may be possible in the future when environmental conditions of formation for different kinds of cryoplanation terraces become better known. Such inferences will be especially valuable if the times of formation of relict features can be dated. The time factors in cryoplanation terrace development are poorly known, but are slow. Priesnitz (1988) estimates that full development of cryoplanation terraces requires > 10,000 yr. In the Mt. Davis area, the stratigraphic section contains intervals of highly resistant rock, which would have had to have been broken up, and then transported over very low slope gradients to the edges of the upland area. If the interpretation of Clark and Hedges (1985, 1992) stands correct, then the complex processes that constitute cryoplanation must have operated over significantly long intervals of geomorphic time, and must have had extremely great geomorphic effectiveness. Many generations of coalescing terraces might be required in order to flatten the crest of a major fold such as the Negro Mountain Anticline. Such major landscape-making activity raises the ante when discussing the relative importance of palaeoperiglacial processes in shaping Appalachian landscapes. It imbues such processes with the power to create large elements of the landscape and provides a conceptual linkage between palaeoperiglacial research and the large-scale morphology of mountain slopes. This connection needs to be borne in mind when discussing the origins of Central Appalachian Mountain summits.

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

Thus, if the interpretations and conclusions of Clark (1989a) and Clark and Hedges (1985, 1992) are correct, then the level character of strike ridge crests and the flatness of the local broad uplands are truly fossil features. Given a periglacial scenario, whatever the pre-Quaternary landscapes in the highlands were like, their topographic forms have been destroyed by multiple episodes of altiplanation during cold phases of the Quaternary. Therefore, a demonstrated periglacial origin for the uplands we see today cannot disprove that a former climatogenic planation surface of some other genesis (cf. Baulig, 1952; Büdel, 1982) existed, but it certainly renders it unnecessary. One probably should not pay too much attention to the High Point peneplain mentioned on the plaque at Mt. Davis.

LONG-TERM GEOMORPHIC EVOLUTION (ALLEGHANIAN OROGENY TO THE HOLOCENE)

Topography

As noted earlier, the Allegheny Mountain section is renowned for its high elevations and large variations in local relief. Dennison and Johnson (1971) attributed the high elevations to uplift during the Cenozoic which they in turn concluded was fueled by thermal and mechanical effects of igneous intrusions of Eocene age. The uplift may have initiated in Eocene time, or later.

In many areas of the Allegheny Mountain section the upland summits appear to have both an accordant nature and an evenness of skyline. Always a faithful disciple of Douglas Wilson Johnson, Frank J. Wright ascribed these attributes to peneplanation and at first termed the supposed remnants the Upland Peneplain (Wright, 1925) and later the Schooley Peneplain (Wright, 1934). Current calculations of deflection of an elastic lithosphere, however, discount the likelihood of episodic uplift of regional areas of continental crust typical of that of the Central Appalachians (Gilchrist and Summerfield, 1991). These authors conclude that passive plate margins respond to progressive denudational unloading during their postrift history by continuous flexuring. If correct, this concept of continuous marginal upwarp along elevated passive margins has important implications for overarching theories of landscape evolution in such regions, because there would be no tectonic basis upon which to assume an episodic nature for epeirogenic uplift. Rather, uplift could be modeled to develop progressively from the initiation of continental margins. Long wavelength (longer than about 420 km) flexural isostasy of cooling and increasingly rigid lithosphere is hypothesized to be the mechanism capable of generating and propagating such uplift inboard of the rifting (Summerfield, 1985), and upwarp does not attain its maximum amplitude amplitude until perhaps about 100 Ma after the initiation of rifting (Gilchrist and Summerfield, 1991). Individual subregional upwarps could be later superimpositions upon parts of the rifted margin, perhaps by centers of igneous intrusion as envisioned by Dennison and Johnson (1971).

If indeed uplift was continuous, why then are the upland summits so visually accordant, why is there evenness of skyline, and why are so many of the mountain summits flat-topped? In the hardy triumvirate of structure, process, and stage, if structure and stage have been rendered untenable as causes, could it be that the answer lies in the field of that long-neglected area of research——geomorphic process?

Drainage Development

The Allegheny Mountain section is noteworthy for the spectacular development of transverse drainage in deep water gaps which incise major anticlinal folds (cf. Geyer and Bolles, 1979). Earlier opinions treated these occurrences as anomalous occurrences, and invoked mechanisms such as antecedence and regional superposition from supposed overlying peneplain surfaces in order to explain such apparent drainage curiosities. Later workers have proposed other hypotheses for the mechanisms of transverse drainage incision. Clark (1989b) proposed local superposition from shale covermasses down onto their contact with the underlying resistant sandstones, and then down-plunge shifting of the stream course until structural weaknesses were encountered at the crest of the fold. He termed this latter mechanism "structural ensnarement." Sevon (1989b) provided a mechanism that could account for widespread superposition on a regional basis. During Permian time, regional uplift and widespread denudation under arid climatic conditions would have produced great volumes of sediment over vast areas of the Appalachians inboard of the suture zone. In the absence of a forest cover, vast alluvial and mudflow fans and aprons would have coalesced westward, burying the bedrock geology under sediment thicknesses nearly 4 km thick at the Allegheny Front, thinning to 2 km in distal areas such as present-day Ohio and West Virginia (Zhang and Davis, 1993).

The initiation, persistence, and migration through time of marginal upwarps inland along the lengths of elevated passive margins also have implications for hinterland drainage system initiation and evolution (Summerfield, 1991). Summerfield's model (Figure 16.27, p. 428) assumes that the axis of uplift will propagate inland as the lithosphere cools, becomes more rigid, and therefore becomes capable of transmitting the effects of sediment loading on the shelf and unloading due to denudation in inland areas. The net result on drainage is for the coastal plain and piedmont rivers to increase their domains toward the hinterland by headward erosion and stream piracy of the headwaters of inland drainage.

Carried to a logical conclusion then, the Allegheny Mountain section contains elements of these processes (Sevon, 1993). The initial post-Alleghanian drainage was west and northwest (modern compass orientations) across an alluvial plain. Following Mesozoic rifting and development of east-flowing drainage, the Susquehanna and Potomac Rivers beheaded the west-flowing drainages and eroded westward into the hinterland. Once beheaded, the west-flowing streams changed from depositional to erosional, but lacked adequate drainage area and gradient to equal the down-cutting vigor of the east-flowing streams. Eventually, the west-flowing streams eroded through the west-dipping sediment and encountered older, harder and, in places folded, rocks. The west-flowing streams incised these rocks across fold axes while their tributaries began to change course orientation in gradual adjustment to structure. Thus, the Conemaugh and Youghiogheny Rivers probably represent descendants of earlier west-flowing streams and tributaries such as Laurel Hill Creek and Casselman River represent tributaries now adjusted to structure. Raystown Branch Juniata River and Wills Creek represent east-flowing drainages that continue to nibble at the hinterland.

Quaternary Landscape Evolution

Because of a number of factors discussed above, including lithology, structure, elevation, relief, and exposure, the overall effects of Quaternary cold-phase environments on landscape evolution in the Allegheny Mountain section are interpreted to have been severe. Results of pollen and macrofossil study indicate that, during the Late Wisconsinan cold-phase maxima, forest cover, if present, was probably limited to protected sites at the lowest valley elevations, and that most to all of the section was either in tundra vegetation or was a barren periglacial desert. A number of major Pre-Wisconsinan cold phases were even more severe. The pervasive flattening of upland summits by cryoplanation processes indicates that the highest elevations were in the "belt of nivation" which perhaps extended somewhat above the "climatic firnline" (Nelson, 1989). Even the possibility of Early to Middle Pleistocene glaciation cannot be discounted, especially in the Negro Mountain area!

Holocene environments appear to have had few morphogenetic effects in the Allegheny Mountain section. Re-establishment of a forest cover, weathering, and soil formation are interpreted to have been the major types of activity. Local areas have probably experienced "slope floods" and attendant landslide activity, and "channel floods" with accompanying floodplain morphogenesis (Newson, 1980). The effects of such cataclysmic events during the Holocene have not impacted most landscapes in the Central Appalachians to any great degree, however (Jacobson and others, 1989b). Thus, the landscapes in the Allegheny Mountain section can be thought of as very complex mosaicked assemblages of multigenetic landforms and materials the vast majority of which are of Plio-Pleistocene age (D. D. Braun, in Clark, G. M., ed., 1992/1993).

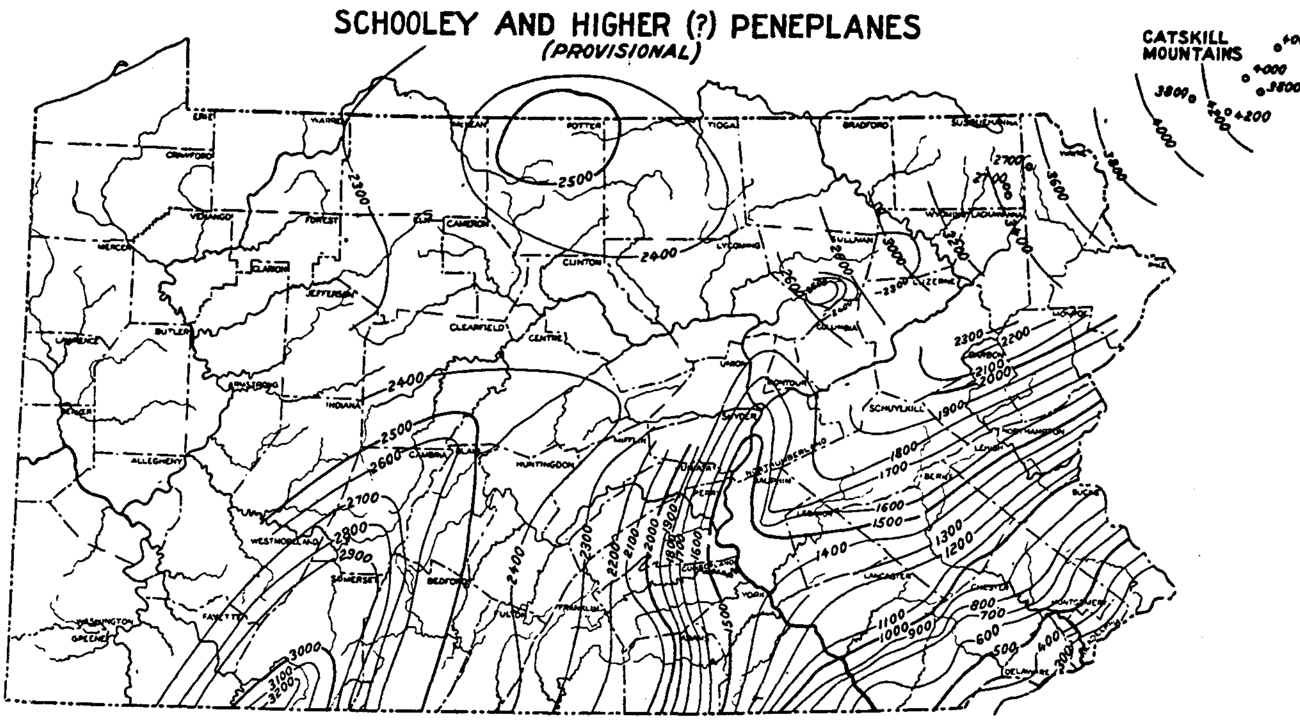

Figure 26. Chart showing by hypothetic contours present position of the deformed Schooley peneplane and possibly an older peneplane from North Mountain to the Catskills. The contours are those of the present "hilltop surface," not a higher hypothetical surface.

from: Ashley, 1933, PGS Bulletin G-6, p. 19.

Editor's insert

HYDROGEOLOGY OF SOMERSET COUNTY, PENNSYLVANIA

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INTRODUCTION

The Pennsylvania Geological Survey began to define the groundwater resources of Somerset County in 1991. The study is designed to determine the water-bearing characteristics of the rocks of Somerset County and the hydrologic budget of streams draining southern Laurel Hill. A new geologic map of the county is being compiled concurrently, and will be published at 1:50,000 scale as part of the groundwater resources report. Because the project is still underway, with very little data analysis completed, the groundwater resources can be discussed only in general terms. Lohman's 1938 study of groundwater in south-central Pennsylvania is the sole prior study of groundwater resources for the area.

DESCRIPTION OF STUDY AREA

Somerset County is bounded on the south by the Mason-Dixon line, on the west by the Youghiogheny River and the crest of Laurel Hill (Fayette and Westmoreland Counties), on the north by Cambria County, and on the east by Bedford County. Groundwater discharges locally to streams and small springs. Surface water flows into the Youghiogheny, Casselman, Stony Creek and Juniata Rivers, and Wills Creek. Just west of Mcdonaldtown there is a triple divide for the Ohio, Susquehanna, and Potomac river basins.

PHYSIOGRAPHIC SETTING

All of Somerset County is within the Allegheny Mountain section of the Appalachian Plateaus physiographic province, which is characterized by wide ridges separated by broad valleys with moderate to high relief. The highest elevation in the county is the peak of Mt. Davis, 3213 feet above mean sea level, the highest point in Pennsylvania. The lowest elevation is approximately 1040 feet, where Gladdens Run, a tributary of Wills Creek, exits the county 4.5 miles northeast of Wellersburg.

GEOLOGIC SETTING

Devonian-, Mississippian-, and, predominantly, Pennsylvanian-age rocks crop out in Somerset County. Exposures of Devonian- and Mississippian-age rocks are along the axes and on the flanks of the Laurel Hill, Negro Mountain, and Deer Park anticlines.

Structure is characterized by simple, open folds with an axial trend between N30°E and N35°E and dips of less than 1 to 8 degrees. Dips in the Deer Park anticline and Wellersburg syncline, in southeastern Somerset County, are in the 10- to 30-degree range.

OCCURRENCE AND MOVEMENT OF GROUNDWATER

Most of the springs are seepage springs, with flows of 1 to 100 gallons per minute. Many, especially in the coal measures, are contact springs, where groundwater flows to the surface at the crop of low-permeability rock. Many coals are underlain by clay, and it is common to find springs emerging at the base of a coal seam. In the early days of coal mining, a coal seam was often located by finding an associated spring.

Almost all porosity in the indurated rocks of Somerset County is secondary. Joints and bedding plane separations are thought to be the principal fractures contributing to rock porosity. Spacing, size, and extent of these fractures are irregular and partially controlled by lithology and topography. Consequently, there is a wide variance in yield of the rocks, even within formations. For example, 30 domestic wells drilled in the Catskill Formation have yields ranging from 0.5 to 80 gal/min.

Water-yielding fractures (which are reported by drillers as water-bearing zones, or WBZs) are uncommon more than 300 feet below the surface. Of the 325 wells currently inventoried in Somerset County, 39 are greater than 300 feet deep and have reported water bearing zones. Only 11 of these wells penetrated a WBZ below 300 feet, and 7 of the 11 wells have yields of 5 gal/min or less.

For decades, it has been thought that the weight of the overlying rocks squeezes shut any fractures, or prevents fractures from opening up. It may not be that simple. The KTB project hole, in southeastern Germany, produces "abundant" fluids (brine) from depths as great as 6 km. Core samples from 3.4 km deep had cracks more than a centimeter wide (Kerr, 1993).

WATER-BEARING CHARACTERISTICS OF THE ROCKS

Devonian-age rocks outcropping in Somerset County are the Scherr Formation, the Foreknobs Formation, the Catskill Formation, and the lower part of the Rockwell Formation. Thomas R. Wyland, an intern at the Pennsylvania Geological Survey, has compiled driller-supplied, well-yield data for the Scherr, Foreknobs, and Catskill Formations where they are exposed by the breeching of the Deer Park anticline. Yields of the formations are statistically indistinguishable, with median yields of 9 gal/min for the Scherr and Foreknobs Formations and 10 gal/min for the Catskill Formation. These figures are not representative of the water-yielding capabilities of the formations. All of the wells are for domestic supplies, which are drilled only deep enough to obtain a supply adequate for a home (5-10 gal/min). Non-domestic wells drilled in the Catskill Formation in the Juniata River Basin have a median yield of 30 gal/min (Taylor and others, 1982).

Mississippian-age rocks outcropping in the county are the upper part of the Rockwell Formation, the Burgoon Sandstone, the Loyalhanna Formation, and the Mauch Chunk Formation. Data on these units have not yet been compiled. The best aquifers in Somerset County should be in these rocks. State-wide data on the Rockwell Formation are very limited. Geyer and Wilshusen (1982) suggest that it may be an excellent aquifer, with yields in excess of 300 gal/min reported. Elsewhere in Pennsylvania the Burgoon Sandstone is a very productive aquifer (Taylor and others, 1982). The well with the highest reported yield in the county (2000 gal/min) is in the Burgoon Sandstone. No known data exist for the Loyalhanna Formation. It is known to be cavernous, so the potential for very large yields exists. The Mauch Chunk Formation is being exploited elsewhere in Pennsylvania as a source for high volume and quality groundwater. The Borough of Berlin obtains its water supply from wells drilled into the Mauch Chunk Formation.

Pennsylvanian-age rocks in Somerset County are the Pottsville Group, the Allegheny Group, the Conemaugh Group, which contains the Glenshaw and Casselman Formations, and the Monongahela Group. The Pottsville Group, which is predominantly sandstone, can yield large volumes of groundwater, but the water very commonly has iron and manganese concentrations in excess of the USEPA secondary maximum contaminant levels of 300 μg/L and 50 μg/L, respectively (Taylor and others, 1983, McElroy, 1988). There has been extensive coal mining in the Allegheny and Monongahela Groups, which can cause severe contamination problems and groundwater interception. There has also been local coal mining in the Glenshaw and Casselman Formations. In unmined areas in the units above the Pottsville Group wells will usually yield a sufficient volume of water for small to moderate supplies.

BLUE HOLE CREEK STUDY

Increasing development on Laurel Hill has raised concerns about potential overuse of water resources. Users include ski areas, golf courses, fish hatcheries, parks, homes, and cabins. Somerset Borough has drilled wells it plans to use for its municipal supply. Streams from the southern portion of Laurel Hill in Somerset County are tributaries of Laurel Hill Creek. All of Laurel Hill Creek and its tributaries have been designated as an exceptional-value, cold-water fishery.

Blue Hole Creek, which is south of Seven Springs Borough on the east flank of Laurel Hill (Figure 35), is being studied to determine the water resources of Laurel Hill. The undeveloped basin is almost entirely within Forbes State Forest, and drains 5.78 mi^2. The rock units underlying the basin are the Mauch Chunk Formation, the Pottsville Group, and the Allegheny Group. An estimated 20 to 40 feet of colluvium lies along the stream bottom of the

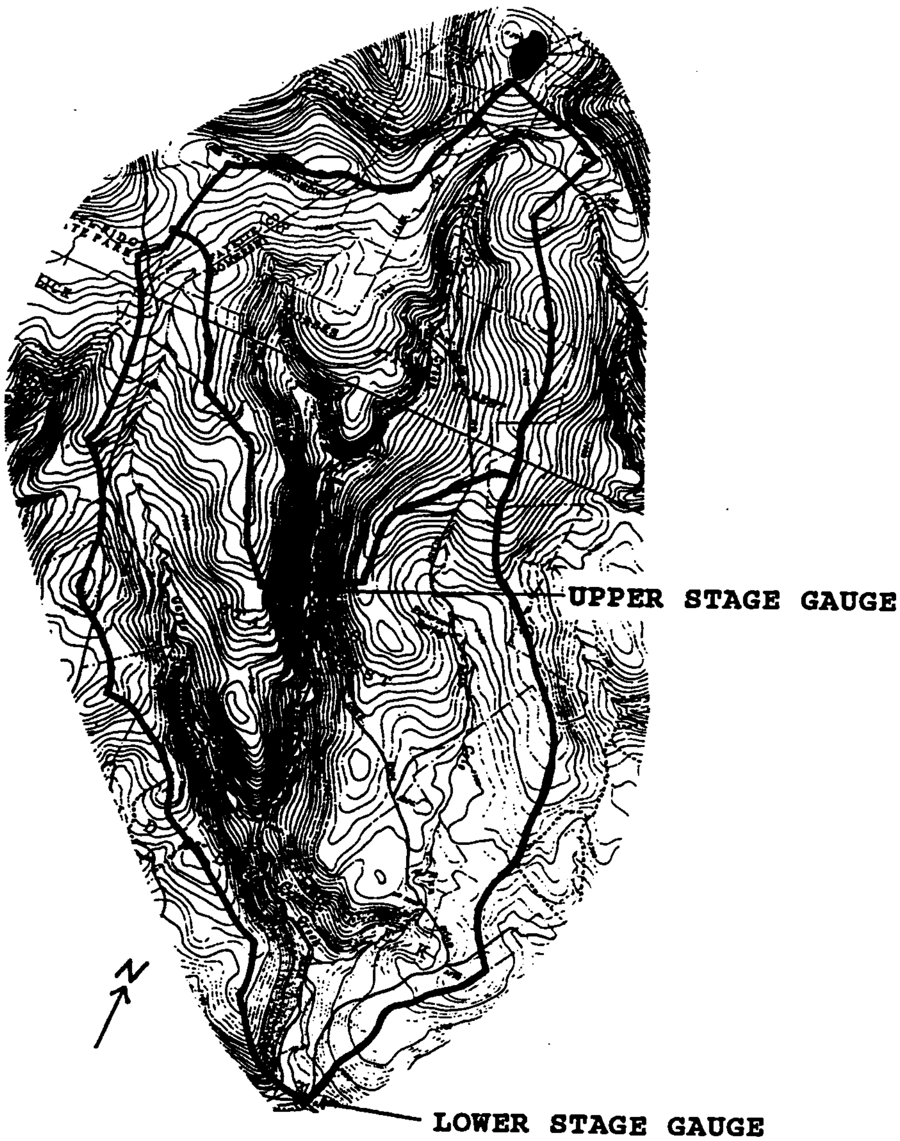


Figure 35. Topographic map of the Blue Hole Creek basin. Map from Kingwood and Seven Springs 7.5-minute quadrangles, reduced to 1:50,000 scale.

main stem. Maximum elevation of the basin is 2960 feet, near the crest of Laurel Hill. The mouth of the stream is at 1825 feet.

Two stream-stage gauges have been installed on Blue Hole Creek to determine the hydrologic budget. One gauge is 100 feet from the mouth. The other is approximately half way up the main stem, at an elevation of 2220 feet. Drainage area above the upper gauge is 2.19 mi^2. Two gauges were installed to account for Laurel Hill's expected orographic effect. At the time of this writing, two precipitation gauges are also being installed to determine precipitation variation with elevation.

Base flow separations have not been done, so the hydrologic budget cannot be discussed. An interesting phenomenon can be seen on the July, 1993 graph of the stage at the upper gauge (Figure 36). On July 7, water level in the stream began to fluctuate daily by as much as 0.2 feet. The fluctuation appears to be caused by vegetation intercepting base flow during dry periods. A shallow water table in colluvium allows plants access to the saturated zone. Low flow occurs at about midnight. The timing of low flow is probably delayed by the slow rate of groundwater flow. Stomates of most plants, except in arid areas, open at sunrise and close in darkness (Salisbury and Ross, 1992). Interruptions in the cyclicity were probably caused by precipitation. When soil moisture was depleted, the pattern began again.

The daily fluctuation of stage is also seen at the lower gauge, but is only about one-hundredth of a foot. Two tributaries, Garys Run and Coal Run, enter Blue Hole Creek below the upper gauge. Colluvium along these streams is not as thick as it along the main stem, limiting the groundwater available to vegetation.

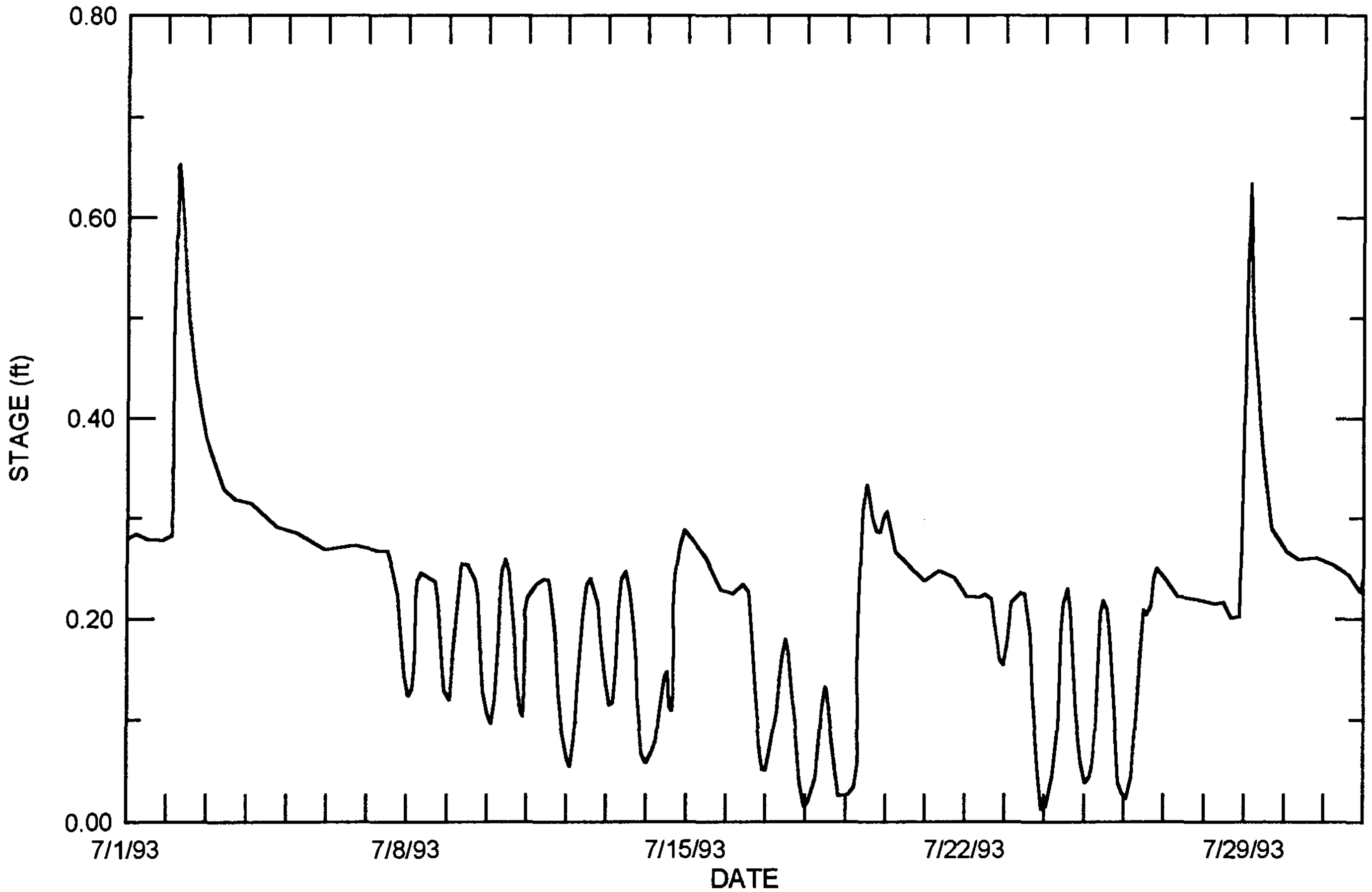


Figure 36. Water stage at upper Blue Hole Creek gauge, July, 1993.

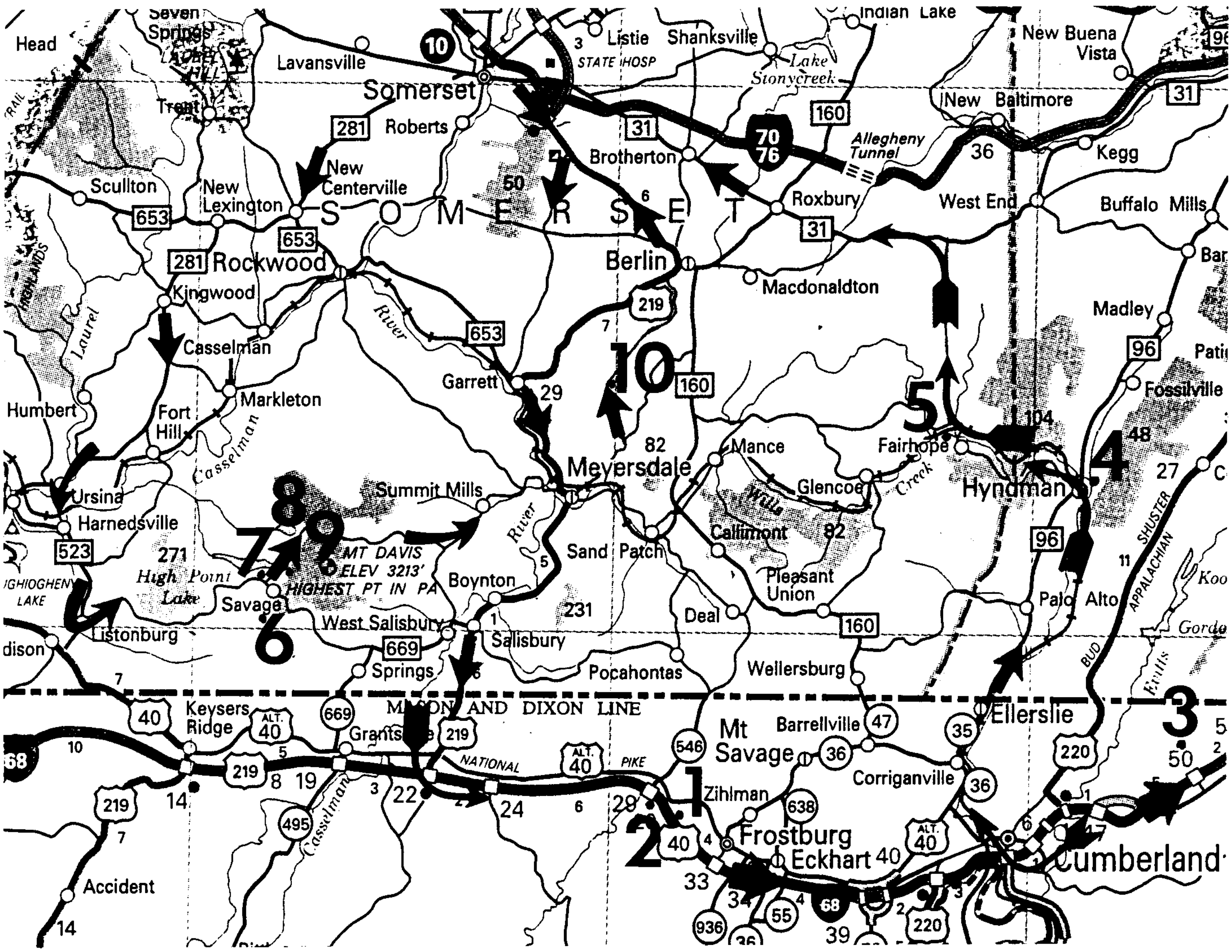


Figure 37. Map of field trip routes and stop locations. Scale: 1.9 inches = 10 miles.

Mileage Inc	Cum	DESCRIPTION
0.0	0.0	Leave parking lot of Ramada Inn. **TURN RIGHT.**
0.2	0.2	**TRAFFIC LIGHT. GO STRAIGHT AHEAD.** Cross Center Ave.
0.4	0.6	**TRAFFIC LIGHT. GO STRAIGHT AHEAD.**
0.3	0.9	**TRAFFIC LIGHT. TURN LEFT** onto PA Route 31 East.
0.3	1.2	**TRAFFIC LIGHT. BEAR RIGHT** onto SR 3041.
2.1	3.3	Cross over US Route 219. SR 3041 becomes US Route 219 South.
1.2	4.5	**TURN RIGHT** onto SR 2031.
0.7	5.2	Somerset State Correctional Institution on right.
2.3	7.5	Views ahead on left of landscape developed on rocks in the Berlin syncline.
2.6	10.1	Golf course on left. View of reclaimed strip mine on right.
1.6	11.7	Descend into the Casselman River valley. Reclaimed strip mine visible on right.
0.3	12.0	Enter Garrett Borough.
0.1	12.1	Casselman River valley on right. There are excellent exposures of Mississippian-age rocks along the river, but not visible from the highway.
0.2	12.3	**STOP SIGN. TURN LEFT** onto PA Route 653.

0.4	12.7	**STOP SIGN. TURN RIGHT** onto US Route 219 South. Just past the curve to the left are exposures of Johnstown limestone, uppermost member Johnstown limestone, uppermost member of the Kittanning Formation.
0.3	13.0	Exposure of Glenshaw sandstone on left.
0.1	13.1	Casselman River on right. Note color.
1.7	14.8	Exposure on left of Ames Limestone.
1.2	16.0	Large bodies of water on right are part of the sewage treatment facilities.
0.1	16.1	Narrow railway underpass.
0.5	16.6	Enter borough of Meyersdale. **CONTINUE** on US Route 219 South.
0.6	17.2	Cross Flaugherty Creek (channelized).
1.3	18.5	Meyersdale High School on right. Hills in distance on right were mined for Pittsburgh coal around the turn of the last century.
1.2	19.7	Good view on right.
2.5	22.2	Boynton post office on right.
0.2	22.4	Cross Piney Creek.
0.9	23.3	Enter borough of Salisbury.
0.2	23.5	Cross PA Route 669.
1.0	24.5	Outcrop of Casselman Formation on right.
1.2	25.7	Cross Mason and Dixon line into Maryland. A strip mine in Brush Creek is ahead on the left.
2.0	27.7	Cross Alternate US Route 40.
0.5	28.2	**TURN LEFT** onto Interstate 68 East (old MD Route 48).
0.8	29.0	Outcrops of Pennsylvanian Pottsville Formation.
0.2	29.2	Crest of Meadow Mountain.
0.8	30.0	Cross over Lower New Germany Road. At this interchange the Rockwell and Purslane (Burgoon) are exposed.
0.1	30.1	Crest of Red Ridge.
1.1	31.2	Exposure of Hampshire (Catskill) Formation on the left.
0.6	31.8	Cross under Green Lantern Road. This is the eastern continental divide in Maryland. From here waters drain to the Gulf of Mexico through the Youghiogheny, Monongahela, Ohio, and Mississippi Rivers. To the east, water flows to the Atlantic through the Savage and Potomac Rivers and Chesapeake Bay.
2.0	33.8	Cross under Old Frostburg Road. This is the axis of the Deer Park anticline. The rocks are the Devonian Foreknobs Formation.
1.9	35.7	Site of Stop 2 on right.
0.6	36.3	Site of Stop 1 on left.
0.3	36.9	Outcrops of Upper Freeport coal on both sides. Now entering the Georges Creek syncline which has Pennsylvanian-age strata.
0.4	37.3	Enter Allegany County.
0.6	37.9	Pittsburgh coal bed on right.
0.9	38.8	**EXIT RIGHT** at Exit 33 - Midlothian Road, Frostburg. Reclaimed strip mine on left. To south (right) one looks down the axis of the Georges Creek syncline.
0.3	39.1	**BEAR LEFT** to Stop Sign. **TURN LEFT.**
0.1	39.2	**TURN LEFT** to Interstate 68 West.
2.7	41.9	**PARK ON RIGHT BERM.**

STOP 1. UNCONFORMABLE MISSISSIPPIAN-PENNSYLVANIAN CONTACT (MAUCH CHUNK, POTTSVILLE, AND ALLEGHENY FORMATIONS).

Discussants: William E. Edmunds and Jane R. Eggleston.

INTRODUCTION

The roadcut for Interstate Route 68 at the top of Big Savage Mountain exposes 183 feet (56 m of the uppermost remaining Mississippian Mauch Chunk Formation disconformably overlain by the 105-foot (31 m) Pennsylvanian Pottsville Formation (Figures 38 and 39). Also present is the lower 87 feet (27 m) of the Allegheny Formation conformably overlying the Pottsville

Formation.

The Mauch Chunk Formation, as used in Maryland (Brezinski, 1989), extends from the top of the Wymps Gap (Alderson) Limestone Member of the Greenbrier Formation to the base of the Pottsville Formation and should be approximately 560 feet (170 m) thick at this point. The Mauch Chunk, as defined in adjacent Pennsylvania, extends from the base of the Loyalhanna Member or any subjacent redbeds to the base of the Pottsville and, thus, includes not only the Mauch Chunk of Maryland, but also the facies equivalent of the Maryland Greenbrier. As such, it should be about 800 feet (240 m) thick here.

THE EARLY PENNSYLVANIAN UNCONFORMITY

The nature of the Mississippian-Pennsylvanian boundary in southwest Pennsylvania, Maryland, and northern West Virginia is essentially as originally suggested by I. C. White (1891) and elaborated upon by C. D. White (1904) in which the Chesterian age Mauch Chunk Formation (or Greenbrier Limestone farther west) is disconformably overlain by the late Morrowan to late Atokan base of the Pottsville Formation. This unconformity is part of the vast erosion surface extending from the Appalachians to the Rockies which was produced by a major eustatic sea-level drop in early Morrowan time. Section equivalent to late Chesterian and early Morrowan and from early Morrowan to late Atokan is missing here within the disconformity because of erosion and non-deposition respectively. At this stop the disconformity is at the thin clay (Unit 15) of Figures 38 and 39.

MAUCH CHUNK STRATIGRAPHY

The amount of additional Mauch Chunk (and, perhaps, the pre-disconformity Pottsville equivalent to the Pocohontas Formation of southern West Virginia) that has been lost to erosion in this area is difficult to reconstruct. It is a little easier to speculate upon the original geographic extent of late Chesterian Mauch Chunk sediments or equivalents prior to their being cut back to the present limits.

The Loyalhanna through Wymps Gap interval is a facies of the Upper Greenbrier Limestone sequence to the south and west and the upper part of the Maxville Limestone of Ohio. The Loyalhanna and some post-Loyalhanna Mauch Chunk wedges out to the north in onlap fashion against the regional Meramecian unconformity surface that appears to slowly rise topographically in that direction. Unless, however, the topographic relief on the erosion surface rose much more abruptly across northern Pennsylvania than it seems to have elsewhere, it is likely that a significant part of the post-Loyalhanna Mauch Chunk originally extended well beyond its present northern limit.

If the complete post-Wymps Gap Mauch Chunk Formation were restored it would correlate with the marginal marine Bluefield thorough Bluestone Formations of southern West Virginia and western Virginia and the Bangor Limestone and Pennington Formation of Georgia, eastern Tennessee, and eastern Kentucky. The Pennington (Paragon)-Bangor sequence is cut out below the early Pennsylvanian unconformity near the Kentucky-Ohio line, but it seems possible that it originally extended across eastern Ohio above the Maxville and, perhaps, on across Lake Erie and western and central New York as the more distal, marginal marine facies of the late Chesterian part of the Mauch Chunk.

The age of the uppermost preserved Mauch Chunk at this stop cannot be determined directly. Correlations are too complex to pursue here, but a late Hombergian or early Elviran age seems most likely (Regar, 1931; Weller and others, 1948; Uhley, 1974; de Witt and McGrew, 1974; Brezinski, 1989; Sable and Dever, 1990; Henry and Gordon, 1992).

POTTSVILLE STRATIGRAPHY

The Pottsville Formation at this site is somewhat atypical. Although the Pottsville usually contains a large proportion of sandstone, it is unusual to have it entirely so, especially in the upper part. The olive gray coloration of the lower part of the sandstone is also uncommon for the Pottsville which is usually in the medium gray to very light gray range.

At 105 feet (32 m), the Pottsville here is relatively thin. Waagé (1950) remarked upon the thinness of the Pottsville in this area and noted that it ranged from as little as 60 feet

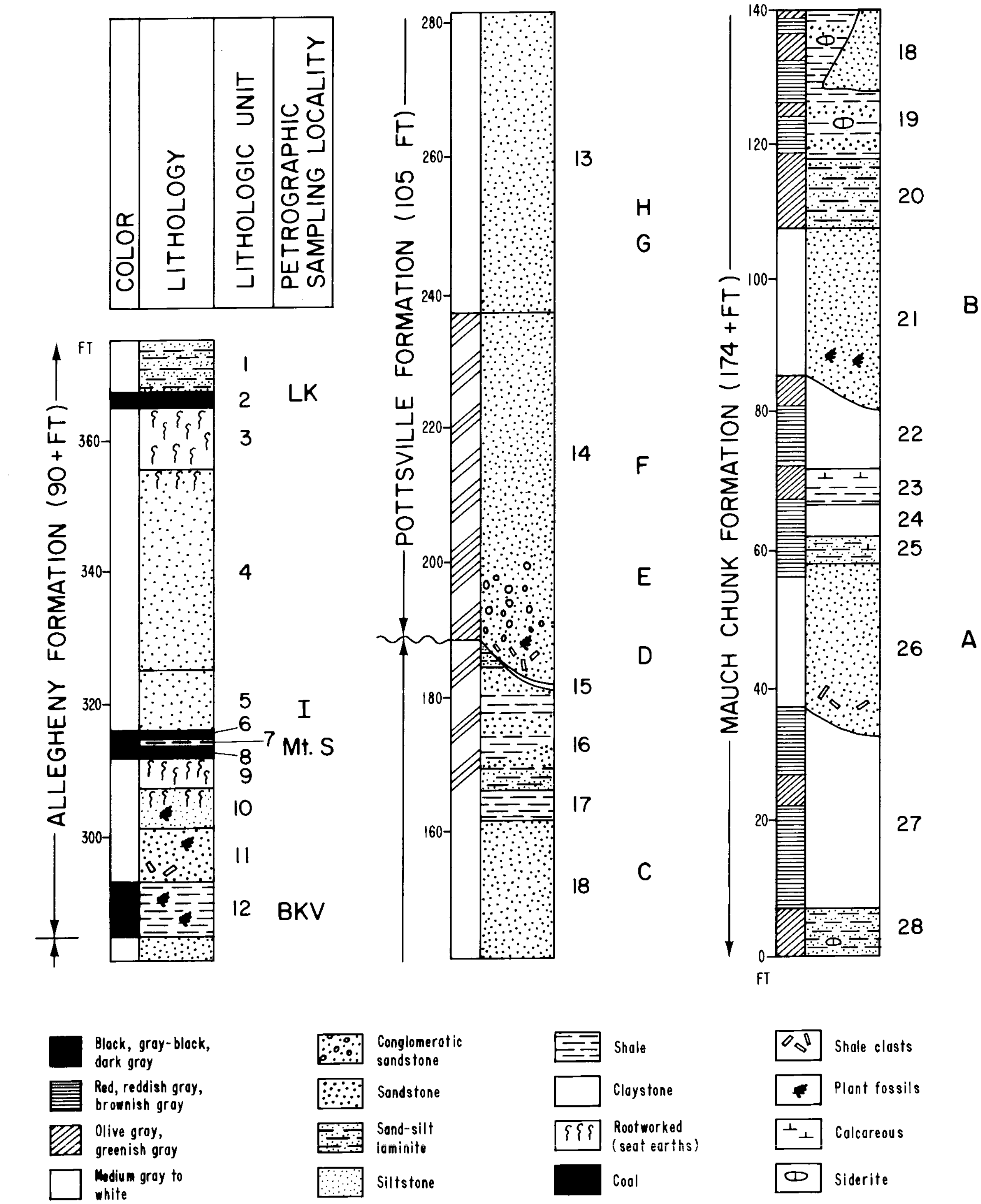


Figure 38. Interstate Route 68 roadcut on Big Savage Mountain, Maryland. Mississippian Mauch Chunk Formation (west end of outcrop) through Pennsylvanian Allegheny Formation (east end of outcrop). Units 1-10 are from south side of the highway. Units 11-28 are from north side of the highway.

1. Sand-silt laminite, medium gray, platy.
2. Coal, Lower Kittanning*.
3. Claystone (underclay), medium light gray.
4. Sandstone, medium grained, medium gray, top root-worked.
5. Sandstone, medium to coarse grained, very light gray, quartzose.
6. Shaly coal.
7. Shale, dark gray.
8. Coal and shale, Mt. Savage* (Clarion)
9. Clay shale grading up to claystone (underclay), medium light gray, rootworked.
10. Siltstone, light gray, top rootworked, plant fragments
11. Sandstone, coarse grained, very light gray to white, shale clasts, siderite nodules, plant fragments.
12. Carbonaceous shale, silty to clayey, gray black, plant fragments, Brookville* coal equivalent.
13. Sandstone, fine to medium grained, light gray to white, minor grayish pink, well sorted, hard, siliceous, thick bedded, planar bedding with some low-angle crossbeds, some shale clasts and dark mineral zones.
14. Sandstone, medium grained with lower 10 feet coarse to very coarse grained, some small quartz pebble conglomerate in lower 20 feet, abundant large shale clasts and carbonized tree fragments in lower 10 feet, thin shale beds and some shale clasts elsewhere, olive-gray to light olive gray and medium light gray, weathers light olive gray, planar bedded with some wedging, cut and fill, low-angle and festoon crossbeds (most common in lower 20 feet), dark mineral zones, incised base.
15. Clay, light greenish gray, erosion surface.
16. Interbedded sandstone, fine grained, olive gray to medium gray, clay matrix, micaceous, planar bedded, 0 to 4 feet, and clayshale, medium gray, hackly, siderite nodules.
17. Silt shale, medium gray, hackly, some siderite nodules, some reddish sandy zones, grades to clay shale, olive gray, hackly at base.
18. Sandstone, fine grained, medium light gray with some pinkish gray and grayish yellow, weathers reddish orange, 0.5 to 3 foot beds, hard, dark minerals, small festoon crossbeds, large-scale lensing, interfingers with unit below, incised base.
19. Shale, hackly and claystone, olive gray, some reddish-gray, some fine-grained sandstone, siderite nodule zones.
20. Sand-silt laminate, medium to dark greenish gray, flaser bedded, some dark-gray silt shale beds.
21. Sandstone, fine grained, medium gray, massive, hard, zone of carbonized fragments and yellow clay 8 feet above base.
22. Claystone, silty, hackly, olive gray to greenish gray interfingering with reddish gray, soft claystone in lower half.
23. Silt shale grading up to hackly silty claystone, greenish gray caliche nodules in upper 1.5 feet.
24. Silty claystone, hackly, moderate red.
25. Silt shale and hackly siltstone, grayish brown to grayish red calcareous nodules.
26. Sandstone, fine grained, grades upward to siltstone, medium gray, some light olive gray, some reddish gray, medium to thin bedded upward, shale clasts and caliche pebbles in lower 5 feet, incised base.
27. Silty claystone, brownish gray to grayish red, some light green, hackly.
28. Interbedded silt shale, siltstone, and sandstone, very fine grained, light greenish gray, hackly, nodular sideritic (?) masses.

*Coal Identifications based upon Waagé (1950) and particularly upon drill hole 21 of Waagé (1949, p. 80-84) located a few kilometers to the north.

Figure 39. Descriptions of rocks shown in Figure 38.

(18 m) near the Maryland-Pennsylvania border 7 miles (11 km) to the northeast to as much as 320 feet (100 m) near Kitzmiller, 22 miles (35 km) to the southwest.

The limited thickness of the Pottsville here suggests that it is equivalent to the Homewood sandstone, Mercer coal complex (which is absent), and, possibly, the upper part of the Connequenessing sandstones of Pennsylvania and the upper part of the Kanawha Formation of southern West Virginia. As such, it would be late Atokan and early Desmoinesian age.

ALLEGHENY FORMATION

Identification of the Allegheny Formation coal beds and, therefore, the Pottsville-Allegheny boundary is based upon correlation with the useage of Waagé (1949, drill hole 21, and 1950). Coal-bed nomenclature was developed by Waagé using numerous long drill holes extending from the Conemaugh Formation to the Mauch Chunk Formation and the nomenclature appears sound.

SEPARATING MAUCH CHUNK AND POTTSVILLE

This stop also points up the persistent problem encountered in separating the Mauch Chunk and Pottsville Formations in western Pennsylvania, Maryland, and northern West Virginia. Although relatively clear in this extensive exposure, in smaller outcrops and many drill holes it is often difficult to distinguish non-red Mauch Chunk sandstones from those of the Pottsville Formation. The last occurrence of red coloration is not a consistently reliable criterion for separation of the two units.

DEPOSITIONAL ENVIRONMENTS

The Mauch Chunk Formation exposed at Stop 1 consists of four, upper-delta-plain, fining-upward, fluvial cycles (units 28-16) (Figures 38 and 39). Only the top of the lowest cycle (units 28 and 27) is exposed. The second cycle (units 26-22) consists of a medium gray, fine-grained sandstone with a scoured base and a basal lag gravel of shale chips and caliche nodules. This is succeeded by reddish- and greenish-gray silt shales and hackly siltstone and claystone. The third fluvial cycle (units 21-19) is similar, grading up from a medium gray, fine-grained sandstone with incised base and an unusual zone containing preserved plant fragments (unit 21) into reddish- and greenish-gray sand-silt laminate and hackly silt shale and claystone (units 20 and 19). The fourth fluvial cycle (units 18-15) is medium light gray to pinkish-gray fine-grained sandstone with a scoured base. The lower part of the sandstone also grades laterally into the upper part of the hackly shales and siltstone of the underlying cycle (unit 19). This suggests that, initially at least, it developed as a distributary building across and into the terminal fine clastics of the previous cycle. The sandstone passes upward into medium gray and olive gray interbedded hackly shales and fine-grained sandstones of units 17 and 16. The upper part of the cycle has been removed by the sub-Pottsville erosion surface.

The Mauch Chunk was deposited in a subtropical to tropical, semiarid, wet-dry climate. This sequence of fluvial cycles is not typical, but still not especially unusual. Most Mauch Chunk fluvial cycles tend to be red throughout indicating that oxidizing conditions tended to prevail even during wetter conditions. The dominance of gray coloration and preservation of carbonized plant fragments in the sandstone of unit 21, suggest that this sequence represents a wetter than usual period with arid conditions prevailing only during the finer, upper part of each cycle, although this may represent more actual time. It could be expected that the proportion of gray-to-red cycles, such as these, would increase toward the top of the Mauch Chunk approaching the onset of wet tropical climatic conditions at the beginning of the Pennsylvanian Period. However, since it is not unlikely that at least several hundred feet of upper Mauch Chunk is unconformably missing at this point, most of the arid-to-wet transition is missing with it.

The light greenish-gray clay of unit 15 represents the sub-Pottsville erosion surface. The late Chesterian and earliest Morrowan section is missing by erosion and the rest of the Morrowan and most Atokan is missing by non-deposition. The presence of an erosional regolith of sorts seems to be relatively unusual. In most cases the unconformity is obscure and can be determined locally only by lithogic contrast. Channel scouring, although always present, is usually no more striking than many other temporally less-profound erosional channels throughout the sequence above and below. Experience shows that the erosion surface can display considerable relief (several tens of feet or more) on a relatively local basis (a few miles or less). The relatively thin (105 feet) overlying Pottsville suggests that this is a topographic high.

The Pottsville Formation here represents a very high energy fluvial-alluvial deposit (units 14 and 13). O'Conner reports (below) that the apparent grain-size of the sandstones is deceptively small and that microscopic examination shows they are actually parts of quartzose pebbles three to ten times the apparent grain-size. O'Conner also notes that crossbedding here indicates a southeast source and that petrographic examination suggests the source terrain was lower Paleozoic sedimentary rocks. The unusual olive color tone of most of the lower part of the Pottsville sandstone (unit 14) may reflect the high content of clay altered from rock fragments noted by O'Conner in sample "B".

The Allegheny Formation clastics and coal are delta plain deposits. The apparent lack of marine or brackish fossils and the general coarseness of the clastics suggest an upper delta plain setting rather than the lower delta plain environment common to the lower Allegheny Formation in central western Pennsylvania.

O'Conner (1989) produced the following detailed petrographic analysis of the sandstones at this stop.

"BIG SAVAGE MOUNTAIN SECTION PETROGRAPHY

The Mauch Chunk Formation in this area is a sequence of litharenite and sublitharenite sandstones (McBride, 1963) intercalated with mudstones and shale. Illite, mixed-layer clay minerals and kaolinite are ubiquitous and moderately quite abundant. Calcite and siderite occur as common secondary minerals. Relict metamorphic and igneous fabrics are common in the rock fragments and both potash feldspars and plagioclase are common, if minor and often altered, constituents of the clastics (Table 8). Although weathering and diagenetic alteration of the sandstones has modified the original clastic fabric of these rocks, the grains appear to be angular, poorly-sorted and generally immature.

TABLE 8. Petrographic analyses[1] of sandstones from the Savage Mountain section.

	Mauch Chunk Fm.			Pottsville Fm.					Allegheny Fm.
Mineral Species	A[2]	B	C	D	E	F	G	H	I
Monocrystalline quartz	54.2	55.0	46.8	79.4	82.2	66.6	58.8	67.8	76.0
Polycrystalline quartz	1.2	3.4	2.6	15.2	10.4	9.8	40.0	30.2	5.2
Recycled quartz (quartzite)	0.4	0.6	1.4	0.2	0.8	0.2	-	-	1.2
Chert	-	0.2	-	1.2	1.8	3.4	0.8	1.4	0.8
K-feldspar	3.8	-	1.2	-	-	-	-	-	tr
Plagioclase feldspar	1.0	0.1	0.6	-	-	-	-	-	-
Clay minerals after feldspar	1.6	4.6	1.0	-	-	-	-	-	-
Fine-grained rock fragments[3]	7.2	5.9	10.4	1.0	0.8	3.0	-	-	5.2
Coarse-grained rock fragments[4]	7.6	2.1	5.8	1.0	0.2	1.2	0.4	0.6	0.4
Clay minerals after rock	14.0	27.7	26.2	1.8	3.4	15.2	-	-	8.8
Muscovite	1.0	1.0	1.2	tr	tr	0.2	-	-	0.4
Biotite	0.2	0.1	tr	-	-	-	-	-	-
Undifferentiated opaques	0.2	0.9	0.2	0.2	0.4	0.4	-	-	-
Calcite & Siderite	0.2	tr	2.2	-	-	-	-	-	1.6

1 Petrographic modes based on 500 or 1000 point counts. Zircon, tourmaline, rutile, and anatase observed but not reported.
2 Location of samples (A-H) shown on Figure xx.
3 Sedimentary and low-grade metamorphic rocks.
4 Igneous and high-grade metamorphic rocks.

The Pottsville Formation here consists of coarse-grained quartz-arenites and sublitharenites to granule conglomerates and paraconglomerates. The sandstones consist of quartz grains and minor sedimentary and low-grade metamorphic rock fragments. Clay minerals are generally less abundant than in the Mauch Chunk, feldspars are generally absent, as is calcite. The grain size is not well represented by the appearance in hand sample; relict grain boundaries of aggregate grains cemented by clay minerals indicate that the original grain size was three to ten times the size of the average quartz fragments and close to that of the maximum size of the pebbles in the paraconglomerates. Overgrowths on grains are common but generally broken, and were of presedimentation origin.

Paleocurrent directions indicate a source to the southeast (O'Connor and Maberry, in preparation); the petrographic evidence suggests that this source was the lower part of the Paleozoic section and that this source may have been relatively nearby. Except for lesser thickness, the features of the Savage Mountain section are representative of those observed by the author at the Mississippian-Pennsylvanian boundary along the Allegheny Front from this area south to the Davis, WV area."

LEAVE STOP 1. PROCEED STRAIGHT AHEAD.

0.5 42.4 **EXIT RIGHT** at Exit 29 - MD Route 546, Finzel.
0.3 42.7 **STOP SIGN. TURN LEFT** onto MD Route 546.
0.2 42.9 **TURN LEFT** onto Interstate 68 East entrance ramp.
0.1 43.0 **PARK ON RIGHT BERM.**

STOP 2. HAMPSHIRE-ROCKWELL ROADCUT ALONG INTERSTATE ROUTE 68 THROUGH LITTLE SAVAGE MOUNTAIN, FINZEL, MARYLAND

Discussants: Jack D. Beuthin and David K. Brezinski

INTRODUCTION

The stratigraphic sequence that is magnificently exposed in the highway cut through Little Savage Mountain comprises the upper Hampshire and lower Rockwell Formations (Upper Devonian-Lower Mississippian). The Rockwell succession here is part of a regional, paralic lithosome that records the ultimate foundering of the Catskill delta during latest Devonian (Famennian) time, and the subsequent evolution of an early Mississippian (Tournaisian) coastal plain that was alternately submergent and emergent (Beuthin, 1986a,b,c; Bjerstedt and Kammer, 1988.) Our discussion focuses on sedimentologic and stratigraphic evidence for late Devonian-early Mississippian shoreline shifts in this area, the implications of these shifts for placement of the Devonian-Mississippian boundary, and the relationship of the Rockwell marine zones to Famennian-Tournaisian eustatic events.

GENERAL DESCRIPTION

Data for the Finzel outcrop presented herein are compiled mostly from measured sections of the Hampshire-Rockwell sequence made by Dennison and Jolley (1979), Beuthin (1986a), Bjerstedt (1986a), and Brezinski (1989a). Regionally, the Hampshire-Rockwell contact is placed at the horizon where the predominantly red strata of the Hampshire pass upward into dominantly green and gray strata of the lower Rockwell. At Finzel, the color change is very abrupt, making the formational contact easy to pick.

The uppermost Hampshire consists of thin- to thickly-interbedded, grayish-red mudstone, siltstone, shale, and fine-grained sandstone with a few thin beds of green sandstone and siltstone. Many of the redbeds have abundant root impressions, and pedogenic slickensides appear to be weakly developed in some of the mudstones. These strata were deposited on the Catskill deltaic-alluvial plain, mostly by aggradational overbank processes.

The Rockwell is 220 feet (67 m) thick here, but it ranges from 0-400+ feet (0-120+ m) in the Maryland-Pennsylvania-West Virginia tristate area (Figure 40). The basal 70 feet (21 m) of the Rockwell at Finzel constitutes a marine zone that records the final transgression over the Catskill coastal plain (Figure 41). Dennison and others (1986) informally termed the marine zone the "Finzel marine tongue" and correlated it with the marine Oswayo Formation of western Pennsylvania, and the black Cleveland Shale of Ohio. Bjerstedt and Kammer (1988) and Brezinski (1989a,b) also have equated the basal Rockwell marine zone with the Oswayo Formation of northwestern Pennsylvania. The Finzel tongue also correlates with the "upper sandy zone" of the Venango Formation that crops out in the Conemaugh Gorge through Laurel Mountain, Pennsylvania. The Venango upper sandy zone in the Conemaugh Gorge was reported and described by Harper and Laughrey (1989) and Laughrey and others (1989). Although various names have been used for the basal Rockwell marine zone, this body of strata is a lithologically distinctive and mappable lithostratigraphic unit throughout western Maryland and Somerset

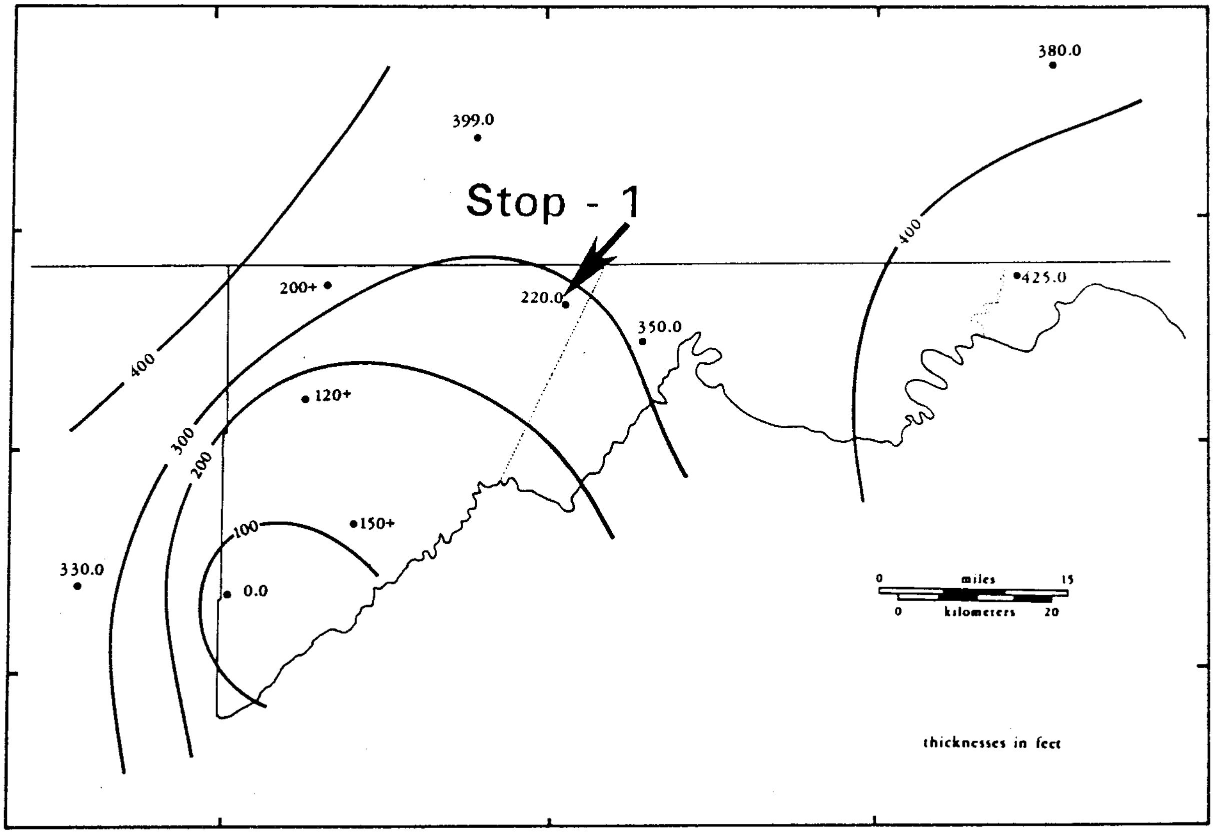


Figure 40. Isopach map of the Rockwell Formation of western Maryland and adjacent Pennsylvania. Taken from Brezinski (1989a).

County, Pennsylvania (Beuthin, 1986a). In western Maryland, the basal beds of the Oswayo transgression are intercalated with red alluvial-plain strata of the Hampshire (Figure 41). Along the Allegheny Front, the Oswayo marine zone grades into coeval Hampshire red strata, so that at Sideling Hill (location 1 of Figure 41) no Oswayo facies is evident.

The Oswayo marine facies at Finzel is a coarsening-upward (shoaling) sequence of intensely burrowed, green and gray shale, siltstone, and sandstone (Figures 42 and 43). The lower 30 feet (9 m) of the sequence consists mostly of gray to black silty shale interstratified with thin to medium beds of gray fine-grained sandstone. Wave-ripples and ball-and-pillow structures are common in the sandstones. Fossils from throughout the basal 30 feet of the marine zone include a *Planolites*-dominated assemblage of bedding-plane traces, and a low diversity shelly fauna of *Lingula*, *Camarotoechia*, and unspecified bivalves. Several distinctive, thick beds of *Skolithus*-burrowed, fine-grained, greenish-gray sandstone are interbedded with gray and green shale in the upper 40 feet (12 m) of the marine zone. Body fossils are unknown from the upper part of the marine zone. Brezinski (1989b) inferred a shallow shelf environment for deposition of the Finzel marine tongue. Beuthin (1986a,b) and Bjerstedt and Kammer (1988) favored a restricted bay environment, and interpreted the *Skolithus*-burrowed sandstones as the sand-bar complex of a prograding tidal or bayhead delta.

A 115-foot-(35 m)-thick interval of lenticular, greenish-gray sandstone and reddish-brown and greenish-gray siltstone and shale overlies the Oswayo facies at Finzel. The sandstones exhibit erosional bases, shale-pebble basal conglomerates, crossbedding, and fining-upward texture. These beds probably were deposited on a prograding alluvial plain concomitantly with Oswayo regression (Brezinski, 1989b). Just west of Finzel, the nonmarine Rockwell sequence is punctuated with a thin marine unit that Dennison and others (1986) equated with the Bedford marine shale of eastern Ohio (Figure 43). The "Cussewago equivalent" (lower Murrysville sandstone) exposed in the Conemaugh Gorge through Laurel Mountain (Harper and Laughrey, 1989; Laughrey and others, 1989) is probably equivalent to the middle Rockwell nonmarine unit at Finzel.

A second Rockwell marine unit overlies the nonmarine Rockwell facies at Finzel. Although it is not well-exposed, this upper marine zone is represented by a tan, fine-grained, medium-

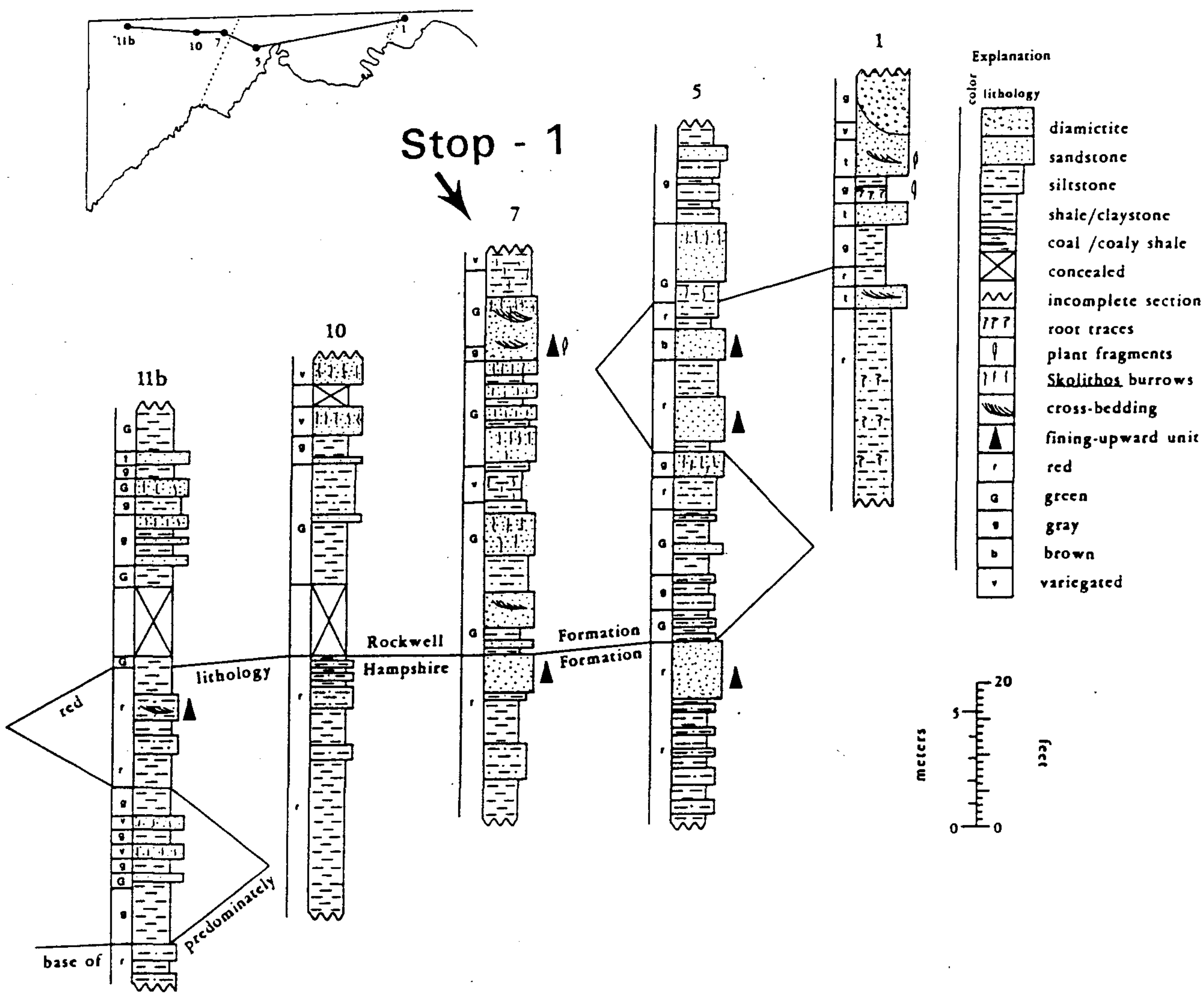


Figure 41. Intertonguing relationship between the Devonian Hampshire and Rockwell Formations in western Maryland. Locality 7 in the figure is same as STOP 2. Taken from Brezinski (1989a).

bedded, bioturbated sandstone. This sandstone is lithologically recognizable at other Rockwell exposures in western Maryland and adjacent Pennsylvania (Figure 44). This marine sandstone correlates with the Riddlesburg Shale of the Broadtop synclinorium of Pennsylvania (Bjerstedt and Kammer, 1988; Brezinski, 1989a,b) and of the Conemaugh Gorge through Laurel Mountain (Harper and Laughrey, 1989; Laughrey and others, 1989). Throughout most of western Maryland, the Riddlesburg transgression is represented by littoral sandstones rather than black silty, lagoonal shales, as in the Broadtop region of Pennsylvania. However, a black-shale facies of the Riddlesburg marine zone has been reported at Altamont, Maryland, about 24 miles southeast of Finzel (Beuthin, 1986a).

The Riddlesburg Sandstone is exposed on the north side of the Interstate Route 68 at Finzel. The remaining Rockwell and overlying Purslane Formation are not exposed at this stop.

DEVONIAN-MISSISSIPPIAN CONTACT

As concerns the Devonian-Mississippian boundary in the central Appalachians, Harper and Laughrey (1989) stated that "[t]he exact placement of this boundary is still up for grabs and should provide some interesting discussion during this Field Conference." Their words are no less true for the present Field Conference.

Using brachiopod species considered to be index fossils, Kammer and Bjerstedt (1986) correlated the Oswayo Member of northern West Virginia with the type-Oswayo of northwestern

Pennsylvania. Those workers assigned an Upper Devonian age to the Oswayo of northern West Virginia (except for the uppermost portion) on the basis of fossil content. Biostratigraphically significant fossils from the Riddlesburg Shale generally support a Mississippian age for that unit (Kammer and Bjerstedt, 1986). Furthermore, several recent studies (Dennison and others, 1986; Beuthin, 1986c; Bjerstedt, 1986b; Kammer and Bjerstedt, 1986; Bjerstedt and Kammer, 1988) have interpreted the Riddlesburg marine zone as an eastern facies equivalent of the Sunbury Shale of Ohio which conventionally is assigned to the lower Mississippian System (Pepper and others, 1954; DeWitt, 1970; Eames, 1974). On the basis of the foregoing age-determinations, the Devonian-Mississippian contact in western Maryland apparently falls within the interval comprising the uppermost Oswayo beds and the middle Rockwell nonmarine zone.

Bjerstedt (1986b) and Bjerstedt and Kammer (1988) placed the base of the Mississippian System in West Virginia and Maryland at what they interpreted to be a regional unconformity that is equivalent to the interval of the Berea Sandstone of Ohio and the West Virginia subsurface. This unconformity occurs at the base of the Riddlesburg Member of the Rockwell Formation at Sideling Hill, Town Hill, and La Vale, Maryland. At those locations the lower Riddlesburg consists of interbedded diamictite and cross-bedded, light-gray sandstone. Lower Riddlesburg beds apparently were deposited in shallow marine or shoreline settings. These environments were quite likely highly erosive in nature. As a result, one would expect unconformable contacts at the base of such units. Where these beds are absent, physical evidence of a "Berea-age" sub-Riddlesburg unconformity is lacking. At Keyser's Ridge, the Riddlesburg grades into the underlying Rockwell strata, indicating apparent conformity. Consequently, deposition during the Devonian-Mississippian transition probably was continuous throughout much of western Maryland, and Berea equivalents are likely present, even though they may be represented by a more terrestrial facies than the type-Berea. Harper and Laughrey (1989) and Laughrey and others (1989) have reported a Berea equivalent (upper Murrysville sandstone) from the section exposed in the Conemaugh Gorge through Laurel Mountain. At Finzel, the top of the Finzel marine tongue approximates the Devonian-Mississippian contact, although it probably occurs slightly higher in the overlying nonmarine interval. At Sideling Hill, the Devonian-Mississippian boundary is relatively closer to the Hampshire-Rockwell contact because the diamictite and the overlying Riddlesburg Member occur very near the base of the Rockwell.

The intertonguing nature of the Hampshire-Rockwell contact, the eastward pinchout of the Oswayo tongue, and apparent upsection migration of the contact from west to east (Figure 45) indicate that the Hampshire-Rockwell transition is diachronous; therefore, this lithostratigraphic boundary cannot be equated with the Devonian-Mississippian systemic boundary across the region.

ROCKWELL TRANSGRESSIONS AND FAMENNIAN-TOURNAISIAN EUSTACY

Figure 46 charts the relative sea-level changes in western Maryland and vicinity during Rockwell deposition. Shaly beds of the basal Finzel tongue record the culmination of a late Famennian sea-level rise. The *Skolithus*-burrowed sandstones of the upper Finzel tongue and the cross-bedded channel sandstones of the overlying nonmarine Rockwell interval indicate progradation of coarse clastics and shoreline regression during highstand. In Maryland, the sea-level drop associated with the Berea Sandstone of Ohio and West Virginia locally caused emergence above base level, sedimentary bypassing, and fluvial incision. Shortly thereafter, sea level rose again, causing the Riddlesburg transgression. Because the Riddlesburg extends farther east than the Oswayo transgression a larger rise in sea level is inferred for the former. Rockwell nonmarine beds overlying the Riddlesburg probably represent post-Riddlesburg highstand.

Using microspore zonation of strata enclosing the Devonian-Mississippian boundary, Streel (1986) demonstrated the presence of two interregional transgressions on the Old Red continent (Euramerica). The earlier of these two events was initiated during the late Famennian and is represented in Pennsylvania and Maryland by the Oswayo marine zone. The later transgression occurred during the early Tournaisian and corresponds to the Sunbury black shale of Ohio. Interregional correlations therefore strongly indicate that the Oswayo sea-level rise was eustatic. If, as inferred by Dennison and others (1986), Beuthin (1986c), and Bjerstedt and

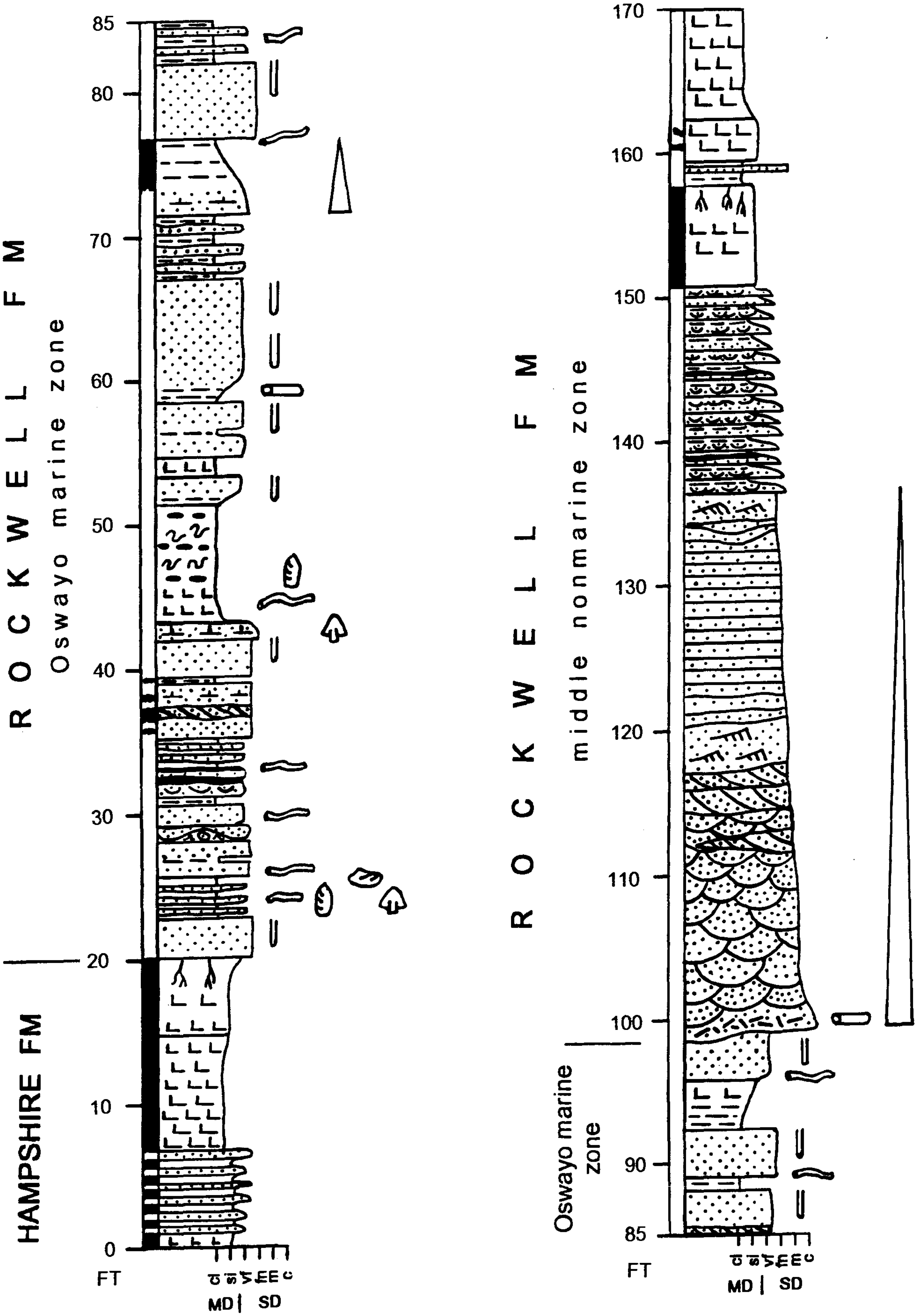


Figure 42. Measured section of upper Hampshire-lower Rockwell Formations along Interstate 68 at Finzel Road interchange, Garrett County, Maryland. Section is based on exposure along eastbound entry-ramp.

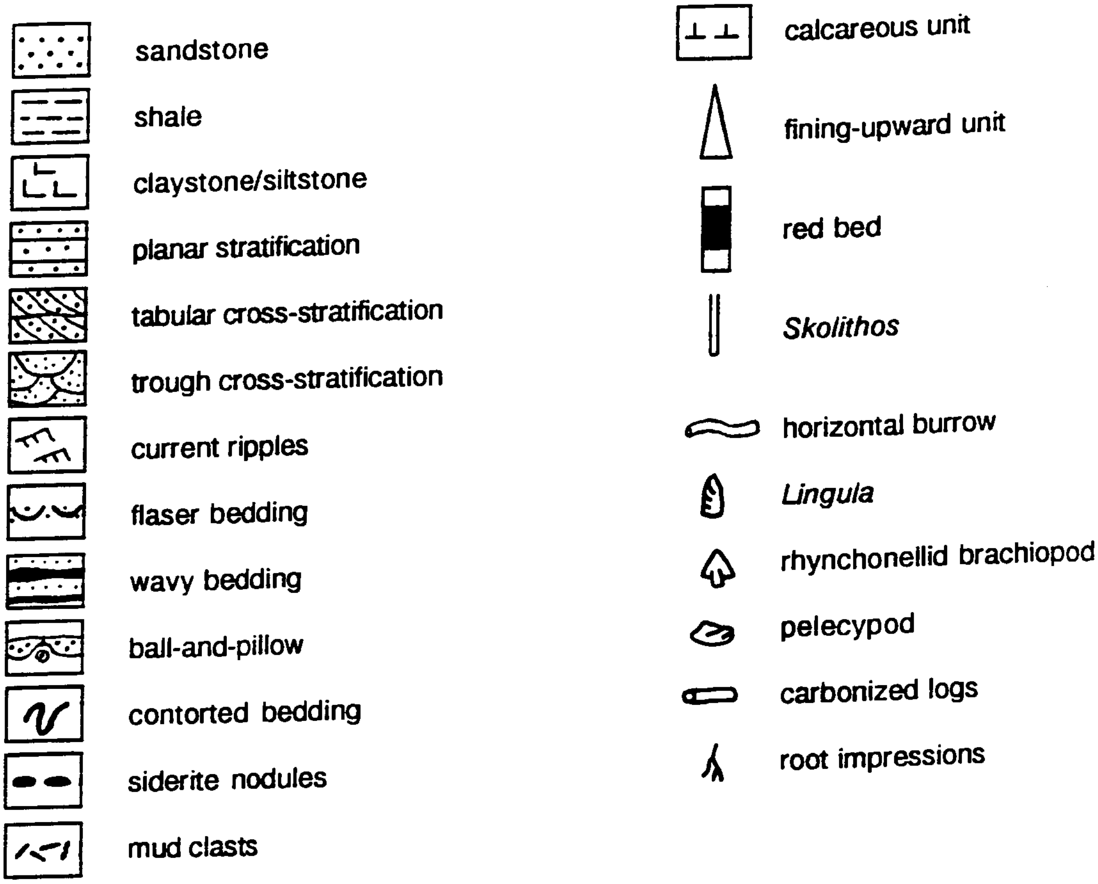


Figure 43. Explanation of symbols used in Figure 42.

Kammer (1988), the Riddlesburg marine zone is an eastern facies equivalent of the Sunbury Shale (or a portion of it), then it was probably eustatically controlled, also. Streel (1986) further suggested that the interregional late Famennian transgression was a glacio-eustatic event. Caputo and Crowell (1985) and Veevers and Powell (1987) documented evidence for a mid-Famennian glacial episode in Brazil and adjacent (then) northwest Africa. Late Famennian waning of the Gondwana ice sheet perhaps was the major control on the Oswayo transgression. A glacio-eustatic mechanism for the early Tournaisian (Sunbury) sea-level rise remains totally speculative because early Mississippian glaciation on Gondwanaland is unresolved (Caputo and Crowell, 1985).

LEAVE STOP 2. PROCEED STRAIGHT AHEAD.
1.4 44.4 Enter Allegany County.
2.9 47.3 Noah's Ark being rebuilt on left.
0.2 47.5 Limestones and coals of the Washington Formation, Dunkard Group.
1.5 49.0 Pass between Dan Mountain (right) and Piney Mountain (left).
2.0 51.0 Haystack Mountain can be seen ahead.
12.6 63.6 **EXIT RIGHT** at Exit 50 - Pleasant Valley Road, Rocky Gap State Park.
0.4 64.0 **STOP SIGN. TURN LEFT.**
0.2 64.2 **ENTRANCE** to Rocky Gap State Park.

STOP 3. LUNCH.

LEAVE ENTRANCE to Rocky Gap State Park.
0.2 64.4 **TURN RIGHT** onto Interstate 68 West.
7.0 71.4 **EXIT RIGHT** at Exit 43C - MD Route 51, Downtown.
0.2 71.6 **STOP SIGN. TURN RIGHT.**
0.1 71.7 **STOP LIGHT. TURN LEFT** onto Queen City Drive.

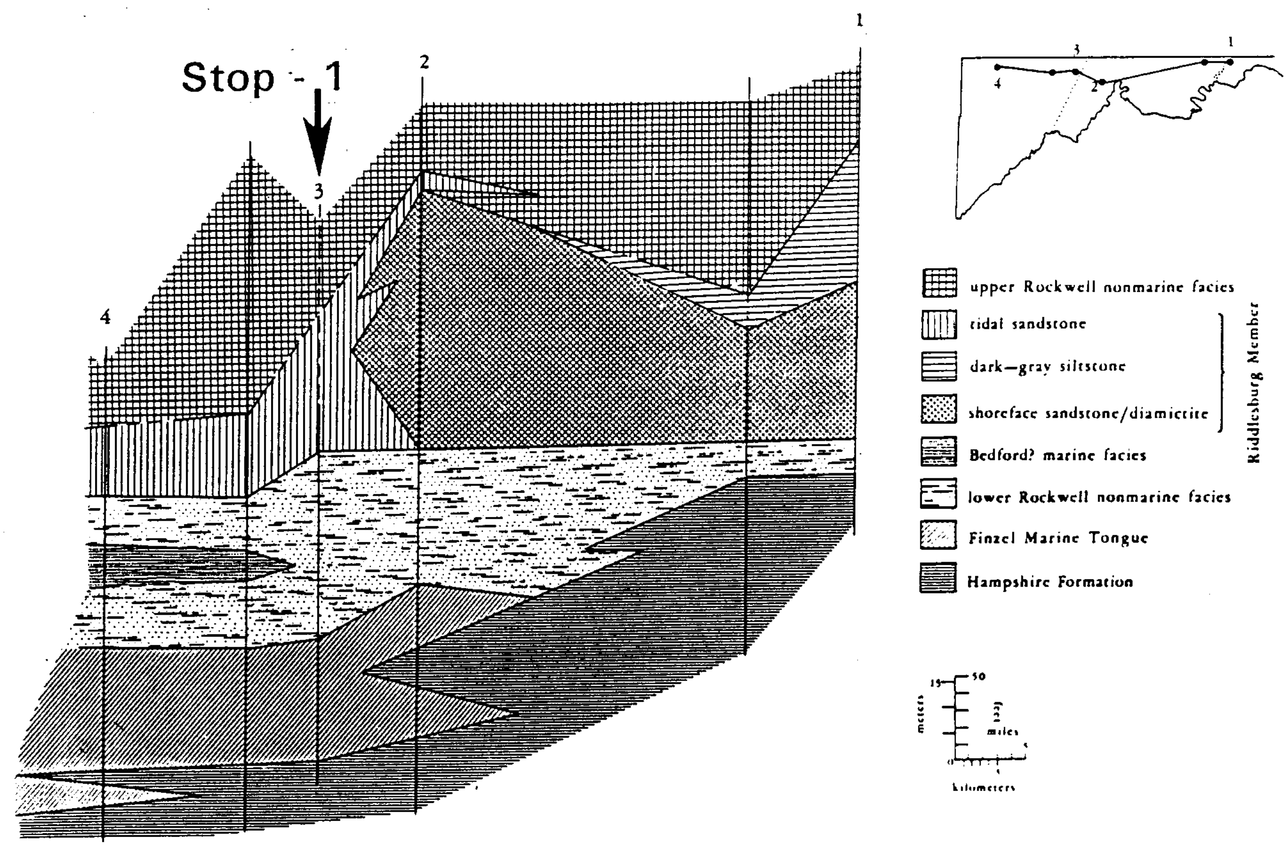


Figure 44. Facies relations within the lower Rockwell Formation of western Maryland. Locality 3 is the same as STOP 2. Taken from Brezinski (1989a).

0.6 72.3 **TURN RIGHT** onto North Centre Street.

0.6 72.9 **STOP LIGHT. PROCEED AHEAD** on Alternate US Route 40.

0.1 73.0 Outcrop of Tuscarora Formation sandstones on left.

0.2 73.2 Cross Wills Creek. Red shale and sandstone of the Juniata Formation is exposed along the Baltimore and Ohio Railroad on the right. The beds strike N28^{o}E and dip 20^{o}SE. Route is now in the Cumberland Narrows cut by Wills Creek through the Wills Mountain anticline. Quartzitic sandstones of the Tuscarora Formation form the flanks and crest of the anticline and are exposed beautifully in this gorge.

0.2 73.4 This is the approximate site of a well drilled between US Route 40 and Wills Creek to a depth greater than 500 feet terminating in the Juniata Formation which is about 1500 feet thick here. The well made a small showing of natural gas whose source may be the Late Ordovician Antes Shale Member of the Reedsville Formation.

0.5 73.9 Quartzites of the Tuscarora Formation exposed at track level on the right strike N26^{o}E and dip 78^{o}NW.

0.1 74.0 **STOP LIGHT.** US Route 40 goes left. **BEAR RIGHT** on MD Route 36 North. Wills Creek is on the right. The route from here to Hyndman roughly parallels the Wills Mountain anticline and traverses a sequence of Middle and Upper Silurian and Lower and Middle Devonian rocks in the valley of Wills Creek. Wills Mountain is to the right; Little Allegheny Mountain to the left.

0.9 74.9 On the right is a large abandoned quarry in the Tuscarora Quartzite extending upward along the west flank of Wills Mountain. The quartzite dips steeply to the west. In a shallow valley north of the quarry, rocks of the Juniata Formation are exposed in an old rock slide scar. A large landslide occurred sometime in the past (Pleistocene ?) and a large quantity of Tuscarora and Juniata rocks slid into Wills Creek. The volume was

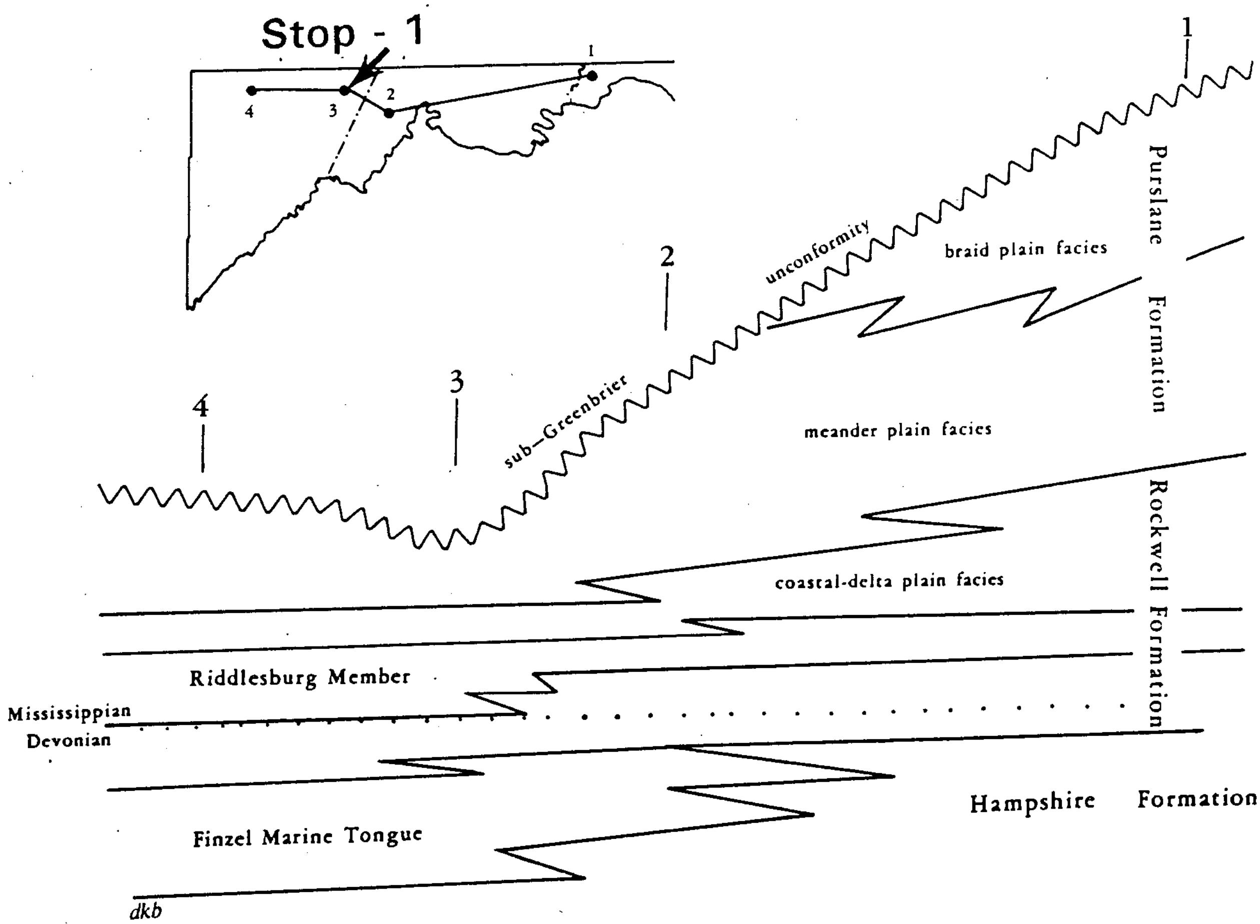


Figure 45. Environments of deposition within the Rockwell Formation of western Maryland. Taken from Brezinski (1989b).

apparently sufficient to deflect the creek westward where it cut a cliff in the face of Averys Ridge. On the left is an old quarry in the Tonoloway Limestone.

1.0 75.9 East boundary of Corriganville, MD. About 0.2 mile to the left is the Cumberland bone cave. The cave is in a deep cut through the Keyser Limestone along the old Western Maryland Railroad grade on Averys Ridge at an elevation of 837 feet at 39°41'30"N/78°47'15"W. A large collection of Pleistocene vertebrate bones was recovered from the cave between 1912 and 1915 (Gidley and Gazin, 1938). The collection included many extinct species. On the right, quarries of the Cumberland Cement and Supply Company are cut in a folded and faulted sequence of Silurian and Lower Devonian rocks in a ridge about 800 feet high. The western flank of the ridge, which includes the Keyser Limestone, Helderberg Group, Shriver Formation, and Ridgely Sandstone, once formed a conspicuous vertical rib, the Devils Backbone (O'Harra, 1900) which has been largely removed by quarrying. The type section of the Corriganville Limestone (Head, 1972) is in the western part of the lower quarry. This Helderbergian unit had previously been called the New Scotland Limestone because of its faunal similarities to the New Scotland in eastern New York, but it is lithologically different and warrants a local stratigraphic name.

0.2 76.1 **TURN RIGHT** onto MD Route 35, known locally as Schellsburg Road.

1.5 77.6 Middle Devonian Marcellus Shale is exposed on the left in cuts and borrow pits. Slickensided chips of the black, folded Marcellus greatly resemble bright coal and many in the past have excavated test pits looking for mineable coal. Such pits are an aid to mapping.

0.1 77.7 Enter Ellerslie, MD.

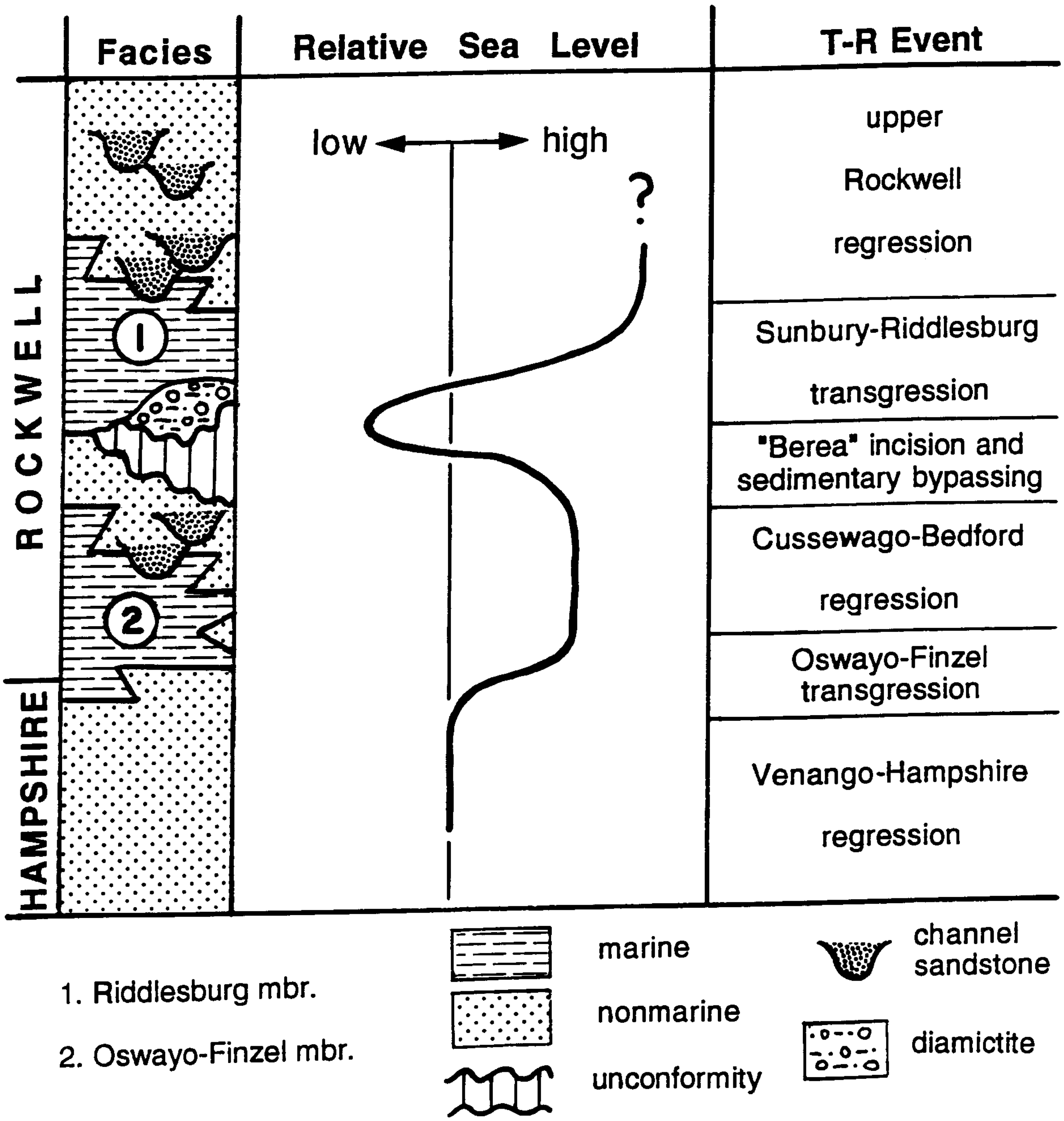


Figure 46. Relative sea-level curve for the upper Devonian-lower Mississippian (upper Famennian-lower Tournaisian) Rockwell Formation of western Maryland (based on Beuthin (1986a) with minor modifications). Curve does not indicate absolute magnitude, nor absolute duration of any sea-level event. Devonian-Mississippian transition probably occurred during the time-interval encompassing Cussewago-Bedford regression or "Berea" incision and sedimentary bypassing.

0.4 78.1 Tram Road on the left. Many years ago, a gravity plane and a two-mile long tram road brought flint clay and soft clay from the lower Pennsylvanian strata along Little Allegheny Mountain near the MD-PA state line to Ellerslie where the clays were used to manufacture brick and sanitary ware. The operation is long deceased.

0.3 78.4 Cross the Mason-Dixon line. MD Route 35 becomes PA Route 96.

0.7 79.1 On the left is the southern plunge-out of a narrow elongate anticline in the Ridgely Sandstone herein named the Stringtown anticline. PA Route 96 lies along the eastern flank of the anticline for about 2.3 miles to the structures termination about 0.5 mile north of Palo Alto. Massive east-

dipping Ridgely Sandstone crops out in many places.
1.0 80.1 On the left is an old stone farm house built of locally quarried Ridgely Sandstone.
0.6 80.7 Cross roads at the center of Stringtown. To the west along Hosselroade Run, both flanks of the Stringtown anticline are well defined by outcrops of Ridgeley Sandstone.
1.1 81.8 Village of Palo Alto. To the right much of the cleared and cultivated land west of Wills Creek is underlain by a folded and faulted sequence of Lower and Middle Devonian rocks. The wooded ridge to the east of the cleared land is underlain mainly by Upper Silurian rocks. About 1.77 miles to the west (left), Pennsylvanian-age rocks dipping 70°W-90° form the crest of Little Allegheny Mountain, the eastern face of the Allegheny Front.
2.5 84.3 Little Brook Farm on right.
0.1 84.4 Fossiliferous Needmore Shale exposed on right.
1.1 85.5 Borrow pit in steeply dipping Marcellus Shale. Bedding ranges from vertical to 85° overturned eastward.
0.2 85.7 On right is an old lime kiln once used to calcine Keyser and Tonoloway limestones.
0.1 85.8 On left is an old lime kiln built of Ridgeley sandstone and lined with locally produced fire brick.
0.2 86.0 **STOP SIGN. TURN RIGHT** following PA Route 96. **TURN LEFT** onto Clarence Street within 0.05 mile.
0.3 86.3 **PARK** along curb just before curve to left. Follow footpath to right, cross bridge, and proceed to railway cut and quarry on right.

STOP 4. HYNDMAN: RAILROAD EXPOSURE AND CLITES QUARRY.
Discussants: Wallace de Witt, Jr., Robert C. Smith, II, and Samuel W. Berkheiser, Jr.

At this stop, a faulted portion of the Ridgeley Formation is exposed in the B. & O. Railroad cut (39°49'30"N, 78°43'16"W) about 150 meters north of Wills Creek. Also exposed, in descending order are the relatively undeformed, but vertical, Shriver, Mandata, New Scotland (Corriganville Limestone), Coeymans undeformed (New Creek Limestone), Keyser, and possibly portions of the Tonoloway in the now-abandoned Clites Quarry (39°49'28"N, 78°43'14"W) just southeast of the railroad cut.

Discussion will proceed southeastward, i.e., down section from the railroad cut where Wallace de Witt, Jr., will give an overview of the structure in the Hyndman area and the railroad exposure in particular.

Wallace de Witt, Jr.

The village of Hyndman and the abandoned Clites quarry to the north are underlain mainly by vertically bedded Silurian and Devonian sedimentary rocks. The rocks are cut by a series of thrust faults with associated small drag folds. These faults make up the Hyndman fault zone (de Witt, 1974). The zone roughly parallels the trend of the Wills Mountain anticline to the east and the Allegheny Front to the west along the east flank of the Wellersburg basin.

FAULTS

The master fault, a synthetic thrust at the west edge of the zone, splays upward from a decollment at about -5000 feet subsea. At the surface, it cuts the Upper Devonian Brallier-Scherr sequence (Figure 19, p. 33). Because this 4,000-foot-thick sequence of interbedded mudrock, shale, siltstone, and sandstone lacks good key beds, determining the amount of rock removed by faulting is difficult. North of Hyndman and west of the Clites quarry, about 2,000 feet of the stratigraphic section appears to have been faulted out of the Hyndman fault zone.

As a result of increased vertical stresses developed by the growing amplitude and westward increasing asymmetry of the Wills Mountain anticline north of Hyndman during Alleghanian folding, several up limb antithetic thrust faults formed in the Hyndman fault zone. The most spectacular of these faults, here named the Reservoir Hollow fault, cuts the

Tuscarora Quartzite along the west side of Wills Mountain north of Hyndman and underlies the full 1.2-mile length of Reservoir Hollow. The fault itself is concealed beneath talus in the hollow. To the east in the foot wall, the Tuscarora dips about 30^{o} to the west, whereas in the western hanging wall the Tuscarora stands vertically in a wall about 100 feet above the floor of the hollow. The quartzite shows considerable crushing and brecciation in the hanging wall block. The Reservoir Hollow fault cuts down section to the northeast and is lost in a complex of small structures in the Juniata Formation and Reedsville Shale at the south end of Milligans Cove within Wills Mountain.

A less conspicuous antithetic thrust is present along the Baltimore and Ohio railroad about 300 feet west of the Clites quarry. There, the basal more calcareous part of the Ridgeley Sandstone in the western hanging wall is in contact with poorly exposed, chippy-weathering, medium-gray mudrock of the Needmore Shale in the eastern foot wall. The Ridgeley is exposed in normal stratigraphic position eastward to the west wall of the Clites quarry. The fault cuts down section to the north across the Ridgeley Sandstone-Keyser Limestone sequence and is lost in a complex of small faults and folds in the Keyser and Tonoloway limestones about a mile north east of Hyndman.

FOLDS

One of the most interesting folds in the Hyndman fault zone is well exposed in the basal part of the Ridgeley Sandstone along the Baltimore and Ohio railroad just west of the Clites quarry. There, an anticline-syncline couple is exposed for about 60 feet at track level. The base of the syncline lies close to the top of the more resistant Shriver Formation in the quarry. Proximity to the hard cherty Shriver may have been a factor in locating the fold in the more calcareous basal part of the Ridgeley. West of the fold, the dip of the Ridgeley is nearly vertical for much of the distance to the previously described antithetic fault 300 feet west of the quarry.

I believe this fold formed late in the generation of the Wills Mountain anticline when strong vertical stresses produced up limb antithetic faults in the Hyndman fault zone. The position of the fold in relation to the surrounding near-vertical beds suggests a late genesis. Possibly the stresses that produced the fold were in part reduced by the antithetic fault about 240 feet to the west. Consequently, a fault did not propagate from the fold at the west end of the Clites quarry. I think the fold may represent an aborted antithetic thrust that failed to break from the west limb of the fold as the generating stresses were released by faulting near by. I am sure that there are other explanations for the genesis of this intriguing fold. Undoubtedly it merits additional study.

SUMMARY

Structures at Hyndman are part of a fault-zone complex that was generated during the Alleghanian orogeny between the Wills Mountain anticline to the east and the Allegheny Front to the west. Compressive stresses during the growth of the Wills Mountain anticline produced both synthetic and antithetic faults and a number of small folds within the Hyndman fault zone.

Robert C. Smith, II

After discussion in the railroad cut, follow the blazed trail on your own past the Shriver Formation, a 180-220-foot-thick sequence of siliceous siltstone and dark bedded chert (de Witt, 1974) and the Mandata Formation, a 10-15-foot-thick sequence of dark slate and chert (de Witt, 1974). As noted by de Witt, the Ridgeley-Shriver and Shriver-Mandata contacts are both gradational.

Discussion will resume at the lower contact of the Mandata Formation (with the New Scotland), where the leaders will offer comments on the Bald Hill Bentonite zone (Smith and others, 1988) and the host depositional environment. Here, 26 ± 3 feet of New Scotland (Corriganville) Limestone characterized by light-colored chert and 15 ± 1 feet of crystalline Coeymans (New Creek) Limestone occur in the unquarried rib.

The Bald Hill Bentonite Beds (Smith and others, 1988) mark the end of carbonate production in an inland basin that began with the Tonoloway and continued through the Keyser, Coeymans, and New Scotland Formations. Following the carbonates, a period of non-deposition ensued, as suggested here by the glauconite-bearing phosphate nodule zone at the top of the New Scotland. Deposition eventually resumed with the organic-rich muds of the Mandata.

Interspersed within this transition are three volcanic ash beds called Bald Hill Bentonite A, B, and C from oldest to youngest. These bentonites have been traced from Cherry Valley, New York, to Monterey, Virginia. All three bentonites are best exposed at the principal reference section at Black Oak Ridge (40°06'43"N, 78°31'29"W), Bedford County, PA (Smith and Berkheiser, 1992).

With practice the individual Bald Hill Bentonites can be typically recognized as follows: A (Equivalent to the bentonite reported by D. W. Fisher and W. E. Brownell in the Kalkberg Formation of Cherry Valley, New York) occurs as 2 to 3 cm of buff, soapy-feeling, mixed-layer illite-smectite containing rare, pale-green, glauconite ooids near the base; B occurs as a 1-cm-thick, waxy mudstone containing sparse, red-brown biotite and abundant, dark-green, rounded, glauconite grains; and C occurs as a few millimeters of shaly clay containing common, 1-mm-size, euhedral, brown, biotite flakes. At the Clites Quarry, C is bioturbated by worm burrows and contains slickenlines.

In the lab, C yields abundant acicular, euhedral, zircon crystals with fine, tubular inclusions along the C axis. B and A yield lesser quantities of euhedral zircon. When mathematically corrected to constant 1% Ca, A typically contains $0.37 \pm 0.01\%$ TiO_2; B (with the reddish-brown biotite), 0.81 ± 0.03 TiO_2; and C, 0.62 ± 0.14 TiO_2.

Following discussion at the rib, resume observation of the 240-270-foot-thick Keyser Limestone (de Witt, 1974) by following the blazed trail around the rib. Discussion will resume for the third and last time at this stop near a face of massive bedded Keyser Limestone.

Samuel W. Berkheiser

Water, agricultural lime and limestone, construction materials, natural gas, glass sand, and trees have been the principal and potential resources at and near this stop (Table 9). In the future, water will be the significant resource. Perhaps the carbonates will again also prove useful, especially with respect to cleaning up man's dirty nest and mitigating our impact on the planet.

This abandoned quarry may date back to the late 1800's and might be the Ruschabarger & Co. quarry. Stevenson (1882) noted a quarry at Hyndman that ground limestone for the farmers use but charged an outlandish price for the product. By the early part of the 20th century, this quarry was the largest active operation in Bedford County. At that time, it was operated by Enterprise Lime and Ballast Company and was principally worked to obtain stone for burning (lime). Later it produced crushed stone for railroad ballast, highway construction, and concrete work. In 1929, the plant had the capacity to crush 200 tons of stone per day (Miller, 1934). By 1965, there is no record of active production (O'Neill, 1965).

Miller (1934) reports that three bands of limestone were worked near the eastern edge of the quarry (lower part of the section) for lime production. The last of these beds to be mined for lime was in the eastern 1/3 of the quarry where a 15-foot-thick zone was drift mined. This unit reportedly yielded limestone having 95 to 98% $CaCO_3$.

LEAVE STOP 4. PROCEED AHEAD around curve to left.

1.0 87.3 **TURN RIGHT** onto Shellsburg Street and **IMMEDIATELY BEAR LEFT** onto Gooseberry Avenue.
0.4 87.7 **STOP SIGN. TURN RIGHT** onto SR 3004.
1.2 88.9 Cross Wills Creek.
0.2 89.1 Small park on left.
0.8 89.9 Enter Somerset County. Now on SR 2019.
0.1 90.0 Cross Wills Creek. Route parallels Wills Creek to next stop. Note the clast size transported by the creek. Pottsville float occurs on the left.
0.5 90.5 Contact between the Mississippian Mauch Chunk Formation and the Pennsylvanian Pottsville Group. Note large boulders in Wills Creek.
1.6 92.1 Village of Fairhope. Named because the village had a "fair hope" of having the

Table 9. Some potential resources to think about at Hyndman, Pennsylvania.

Formation	Industrial Minerals	Hydrocarbons	Water	Comments
Ridgeley Sandstone	Glass, construction (fine aggregate), and refractory (dusting agent) sand. During the 1920's, cumulative annual glass sand production of 4 million tons was not uncommon in Pa (Schanz, 1957). Numerous abandoned pits occur between Everett and Tatesville. Ridgeley sand is still produced in Huntingdon Co. for glass, sandblasting, enamel, abrasives, fillers, filtration, pottery, fire, engine, foundry and molding sand uses (Berkheiser and others, 1985)	The most significant cumulative producing natural gas reservoir in Pa representing approximately 80% of all gas produced in the state. Nearly 9 billion Mcf produced in 1991 and >1.3 trillion Mcf cumulative historic production (Cozart and Harper, in press). Gas storage fields occur about 15 miles due east (Harper and others, 1982).	Where thick and below drainage level, productive water-bearer. Some large yield municipal wells. Domestic wells are very common. Some large springs (Spring Meadow produces 1800 gpm). Water of good quality, generally soft and iron free (Lohman, 1938). Occasional problems with completing wells due to friable nature of sandstone. Median casing depth is twice that of the Helderberg Group (Taylor and others, 1982).	Sandstone ridges produce luxuriant oaks used mainly for RR ties while the bark is used in tanneries. A large tannery consumed up to 17,000 cords / yr (Stevenson, 1882).
Shiver Formation	Cherts may have provided aborigines with tools. Blocky residual gravel from weatherd material used for light-duty roads and lanes (de Witt, 1974).	Generally lumped with Ridgeley production.	Relatively unimportant , supplies a few domestic wells.	Locally, when carbonate facies well developed, has potential as coarse aggregate source.
Mandata Shale	Unctuous black clays may have had aboriginal uses as body paints. Early part of this century used as paint pigment and black filler for iron work (Miller, 1911).	Very minor gas production and/ or potential source beds. Production generally lumped with Helderberg Group and Bass Islands Dolomite.	May locally act as an aquitard. The Mandata through Coeymans formations are generally lumped together as Helderberg Group or the Ridgeley through Coeymans formations are generally lumped together as the Old Port Formation or Group in hydrologic discussions.	Similar material was recommended "as filler or rough stuff for automobiles, carriages, buggies, passenger cars, safes, and all similar work on which a filler is used to make a surface, including machinery, machine tools, farming implements and all kinds of iron work" (Miller, 1911).

Table 9.

New Scotland Formation (Corriganville Limestone)	Cherts lower aggregate potential substantially due to equipment abrasion and potential reactivity with concrete applications.	Very minor gas production. Lumped with Helderberg Group and Bass Islands Dolomite production.	Large number of the springs in Bedford Co. issue from the Helderberg Group including the semi-famous Bedford Springs. Limestones yield large supplies to wells that encounter solution channels. Most waters are very hard and some have high concentrations of calcium sulfate (Lohman, 1938).	Bedford Springs discovered by mechanic in 1804 while fishing. After drinking, it proved purgative (shits) and sudorific (sweats). Strangely, this comfort (?) led him to drink and bath daily! His afflictions included rheumatic pain and severe ulcers on the legs (Stevenson, 1882).
Coeymans Formation (New Creek Limestone)	Agricultural limestone and lime, aggregate and RR ballast, and flux stone. Chemical analyses of probable Coeymans range from approximately 82% to 94% $CaCO_3$ (Miller, 1934).	do.	do.	Nearby Magnesia Spring (Bedford, Pa) is diuretic (makes you pee) and is cathartic (more shits) to boot (Stevenson, 1882)! Obviously, the custom of drinking this stuff is akin to eating unwashed sauerkraut on New Year's Day!
Keyser Formation	Agricultural limestone and lime, aggregate and RR ballast, flux stone, fillers, and poultry grit. Locally developed near the base, is "calico rock" which generally is >95% $CaCO_3$ and less than 30 ft. thick. 98% $CaCO_3$ was reported probably from this unit in the Hyndman area (Stevenson, 1882 and Miller, 1934).	do. (although technically not part of Helderberg Group)	Median well depths for domestic wells is 106 ft., non domestic is 175 ft. Median yields for domestic wells is 10 gpm versus 33 gpm for non domestic. The water is very hard and moderately high in dissolved solids (Taylor and others, 1982)	Before the blight, luxuriant stands of Chestnuts were common on limestone ridges (Stevenson, 1882). "Calico rock" is distinguished by millimeter size calcite "eyes" occurring in a dark grayish-brown colored mudstone matrix having conchoidal fracture.
Tonoloway Formation	Generally not mined due to flaggy beds in upper portion or lumped with the Keyser Fm. Becomes more $MgCO_3$ - rich.	do.	do.	Listed as source of Black Spring producing 40 gpm and the main supply to the Bedford Hotel (Lohman, 1938).

Acknowledgments: Chris Laughrey for hydrocarbons, Robert C. Smith, II for minerals, and Dawna Yannacci for hydrogeology.

railroad put through the town.

0.2 92.3 Cross Wills Creek. Note the solar panel used to power the stream gauge on the right.

0.3 92.6 **CROSS RAILWAY TRACKS AND PARK** on left side of roadway.

Catskill Formation exposure along Wills Creek about 2,000 feet (610 m) northwest of Fairhope, PA and 100 feet (30.5 m) upstream from the confluence of Shaffer Run and Wills Creek (Figure 47). ***PLEASE STAY OFF THE RAILROAD TRACKS!*** Pusher engines routinely travel down grade toward Cumberland on the tracks closest to Wills Creek at relatively high speeds and make little noise in the process. At the outcrops: Copperhead snakes are perfectly camouflaged for lying on the brownish-gray sandstone and have been noted in the area. Pigeons (rock doves) that roost high on the rock ledges and in crevasses present here may dislodge loose material.

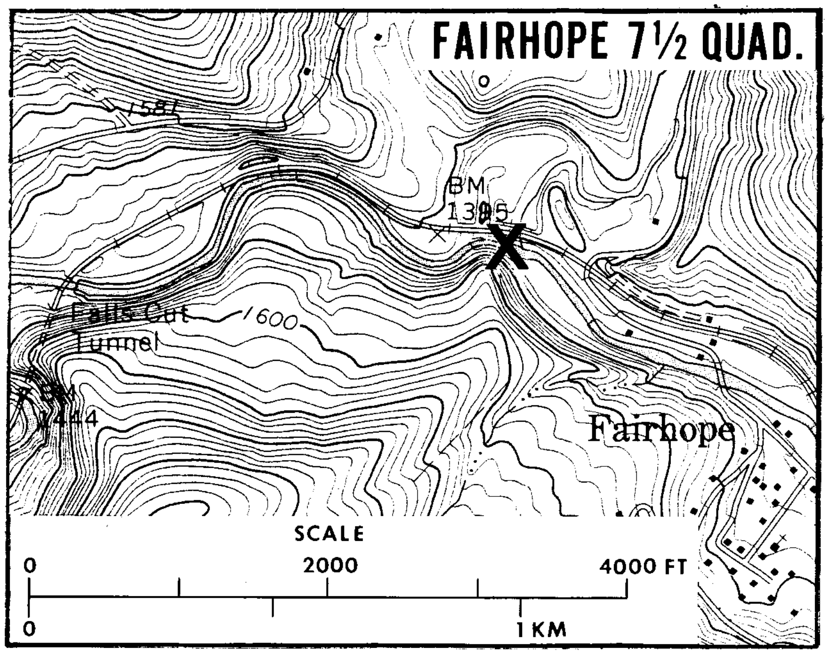


Figure 47. Map showing location of the Catskill exposure containing the "Fish Bone Pavements."

STOP 5. FOSSIL FISH, ICHNOFOSSILS, AND SEDIMENTARY STRUCTURES OF THE SHAFFER RUN-WILLS CREEK CONFLUENCE SECTION, SOUTHEASTERN SOMERSET COUNTY, PENNSYLVANIA

Discussants: Marilyn D. Kressel (The Ohio State University), James R. Shalis (Pennsylvania Geological Survey), and Arthur E. Wegweiser (Edinboro University of Pennsylvania).

INTRODUCTION

Severe flooding in 1984 in Wills Creek washed away much of the CXS System railbed in this area. Shortly after the flooding, the railroad company quarried back this outcrop to obtain new railbed material. Since 1984, talus has effectively separated the highwall from the quarry floor. A 75-100-foot-thick interval of rock along strike is presently covered by talus. Therefore, in a sense, two separate exposures exist, referred to as the "creek level section" and the "highwall section".

Both sections offer unique vantage points from which to view the rocks. Creek level section bedding planes dip in the same direction as the local stream gradient, albeit at a slightly greater inclination. Numerous beds have been eroded along their bedding planes during high flow velocities or catastrophic episodes, yielding a "stair stepped" or benched look (note the concave gouges in the basal sandstone if you doubt it!). Thus it is possible to view sedimentological and paleontological features in 3-D. Approximately 50 feet of vertical section is exposed. The 175-foot highwall section displays a lithologic sequence exemplifying the cyclicity and lensoidal nature of the beds at this outcrop. Undersides of bedding plane surfaces in the highwall section are easily examined.

VERTEBRATE LOCALITIES

Occurrences of Devonian fish remains are known worldwide (Long, 1989; Young, 1988; Dineley, 1990; Forey and others, 1992). Initial Old Red Sandstone descriptions were supplemented by descriptions from the northeastern United States. These were soon followed by reports of Devonian fish from elsewhere in the United States, and discoveries in Australia, Greenland, Yunnan Province of China, Saudi Arabia, and more, including a major discovery in Antarctica (Young, 1988).

The "bone pavement" of articulated placoderms, rhipidistians, and possibly acanthodians exposed here occurs in a horizon approximately 3 feet thick in the Middle Catskill Formation (Figure 47) along Wills Creek. Devonian fish remains from the Catskill Formation in Somerset County are generally parautochthonous and remarkably numerous. The "bone pavement" of placoderm plates and rhipidistian teeth is an extremely unusual occurrence and perhaps has no known equal, in the number of individuals occurring, other than the "bone pavement" localities in Antarctica (Young, 1988). H-P. Schultze (personal communication, 1992) confirmed the identification of both placoderm and rhipidistian fish, and the additional possibility of arthrodires. Dipnoans, commonly referred to as lungfish, may also be present (L. Babcock, personal communication, 1993).

This is the first reported occurrence of Devonian Placodermi and Rhipidistia (Figure 48) in southwestern Pennsylvania. They are known previously from localities in northeastern and central parts of the state (Butts, 1945; Thomson, 1976; Robb and Cuffey, 1989).

STRATIGRAPHIC OCCURRENCE

Rocks at the confluence of the Shaffer Run and Wills Creek have been mapped as Catskill Formation by Flint (1965) and Shaulis (in progress). No attempt has been made to subdivide the Catskill Formation of Somerset County into smaller units. The basal rock of the section exposed along Wills Creek is 600 feet above the top of the Foreknobs Formation (Shaulis and Kressel, 1993). The top of the highwall section is 775 feet below the base of the Rockwell Formation (Shaulis, 1993). The total thickness of the Catskill Formation in this area is 1,550 feet (Shaulis, in progress), and averages 1,600 feet throughout the county (Flint, 1965).

THE CYCLES

Ten complete, fining-upward cycles occur in the highwall section (Figure 49). Each cycle begins abruptly with a light-colored sandstone that usually has a basal lag. The sandstone grades upward into darker, reddish or red-green clay-siltstone or silty-clayshale. Due to limited accessibility, only the lower 7 cycles will be examined and discussed during this stop.

Cycle 1.

The first cycle is dominated by a 14-foot-thick, fine-grained sandstone, with a thin basal lag deposit, that forms a continuous outcrop between the base of the two exposures. The lower 10 feet of this sandstone contains well-developed planar crossbedding. Measurements of the crossbed slope directions average N25^{o}W and several bedding surfaces have parting lineations with N20^{o}W directional averages (Figure 49). The upper 4 feet of this sandstone contains thin planar beds with abundant calcareous nodules, Chondrites facies, and large Planolites facies ichnofossils. This bed is a local key stratigraphic marker horizon and is traceable for several hundred feet along strike in either direction. Overlying this sandstone is a 4-foot-thick, red, coarse-grained to clayey siltstone with interbedded green layers. It contains lungfish burrows, Planolites facies, and a cuspate rippled surface.

Cycle 2.

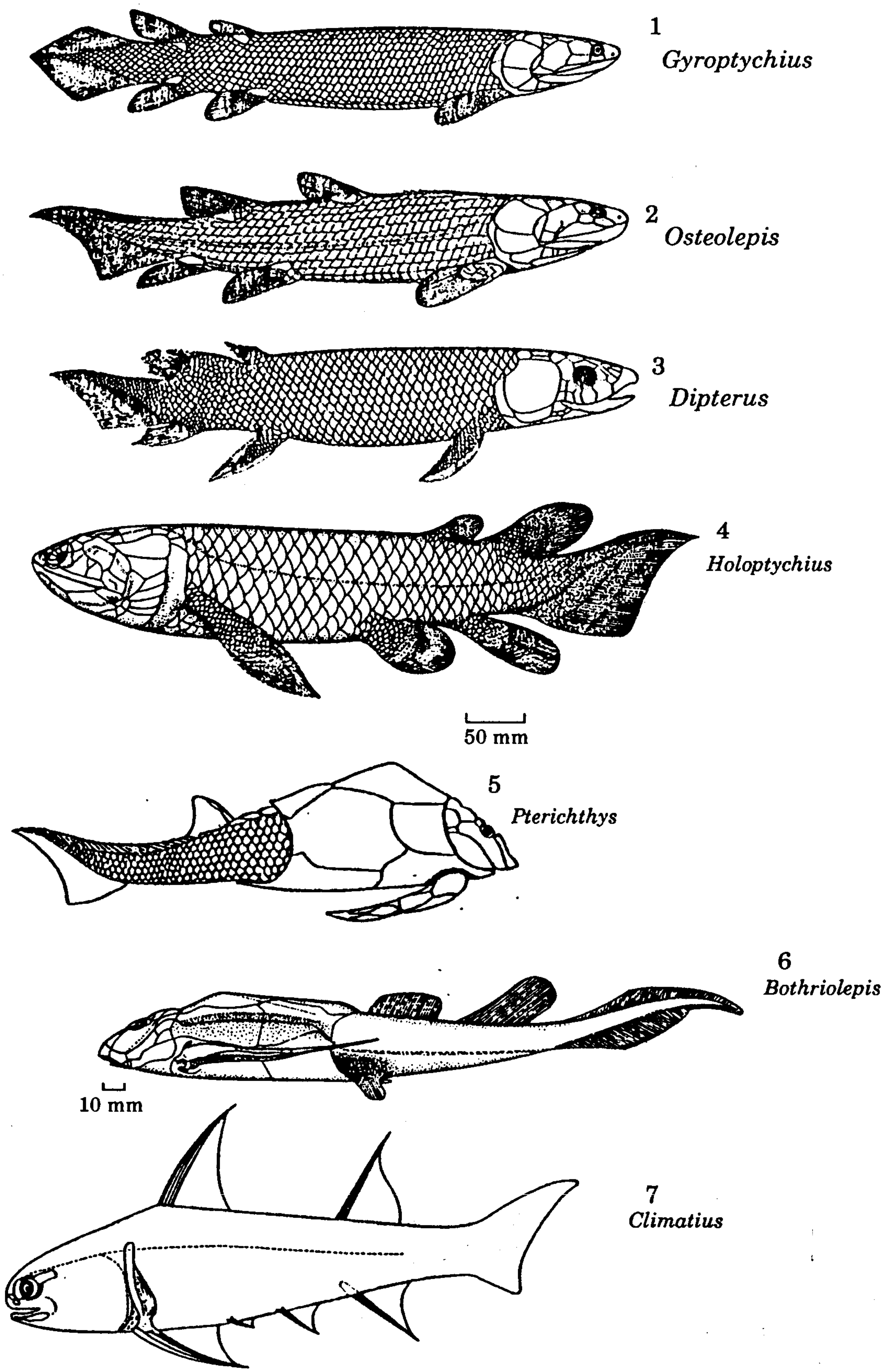


Figure 48. Examples of Devonian Placoderm, Rhipidistian, and Dipnoan fishes.

This cycle is approximately 10 feet thick and exhibits the same fining upward sequences as Cycle 1 but has an overall finer grain size. The lithology consists of a coarse siltstone with a few, thin, isolated beds of very fine-grained sandstone. Lag deposits occur in the troughs of a possible mega-rippled, coarse-grained siltstone at its base. No crossbedded laminae are present. The Chondrites facies reappears in the lower half of the cycle. An asymmetrical mega-ripple feature with trough axis striking N60°W is located near the middle of the cycle in the creek level section. Could this mega-ripple feature be a tidal scour? The numerous slump pocket structures present could represent a paleosol (W. D. Sevon, personal communication, 1993).

Cycle 3.

The basal unit of this cycle comprises 1.2 feet of very fine- to fine-grained sandstone, with a mud-draped, ripple-bedded surface. One bedding plane has asymmetrical current ripples with trough axis directions of N40°E. These ripples are truncated by features interpreted to be "crawl-ways" or "swim-ways" that are 1 foot wide and 0.1 foot deep. Ovoid and circular depressions 1-1.5 feet in diameter connect the trails. Approximately 0.2 feet under this unit is a bed containing fish plate fragments. Overlying this unit is approximately 3 feet of reddish, clayey siltstone, interbedded with green layers, containing abundant, infilled, desiccation cracks. This is overlain by a thin, mega-rippled, fine-grained sandstone with troughs infilled by a lag deposit of intraformational clasts, plant debris, fish plates and fragments, and calcareous nodules that are 5-20 mm in diameter. The trough-axis directions are approximately N30°E. Several fossil tree branches, possibly lycopods, approximately 1 foot in length, lie nearly parallel to the trough axes. Overlying the unit containing the tree fragments is a 3 foot bed of green, silty-clay shale to clayey-silt shale which grades into 3 feet of red, silt shale containing two fish bone pavements 0.1 to 0.5 feet in thickness. The bone pavements extend on strike, disappearing into Wills Creek to the north and into the talus to the south.

Fish plates found in the highwall section are on the top bedding plane of a fine-grained trough-crossbedded sandstone in mega-ripple troughs. The plates appear to be laterally correlative to the bone pavement in the bedding plane of the creek level section. The silt shale containing the bone pavements and the green, silt shale below grade laterally along strike to the SW into a sandstone with lag deposits. This section correlates to the basal 10 feet of this cycle in the highwall section. In the highwall section it has graded into a fine-grained, trough-crossbedded sandstone with lags at the top and bottom. Well-developed groove casts striking N30°W can be seen in the base of this sandstone. The top of this cycle in the highwall section consists of 3.5 feet of red, silt-clay shale interbedded with green layers and blebs containing no megafossils. Paleontologically, the rocks from this cycle may be among the most remarkable in the Catskill Formation of Pennsylvania.

Cycles 4 and 5.

The important features to note in these cycles are the lag deposits in each basal sandstone. These lags contain abundant, parautochthonous, fish-plate fragments and complete disarticulated plates are not uncommon. Groove casts striking N10°E appear in the highwall section on the bottom of bedding planes of the basal sandstone of Cycle 5.

Cycles 6 through 10.

Disarticulated fish plates and plate fragments are abundant in the basal unit of Cycles 6 and 7. Chondrites facies ichnofossils are abundant in the sandstone and siltstone of Cycles 6 and 7. The large overhanging ledge (with the drill hole in the center of it) located high up in the eastern corner of the highwall section has well-preserved load casts and tool marks on the underside. Cycles 6 through 8 are generally thicker, up to 46 feet, and are more uniform in grain size, ranging from coarse-grained silt to fine-grained sandstone. The upper 20 feet of the highwall section may contain additional cycles but have not been described due to inaccessibility.

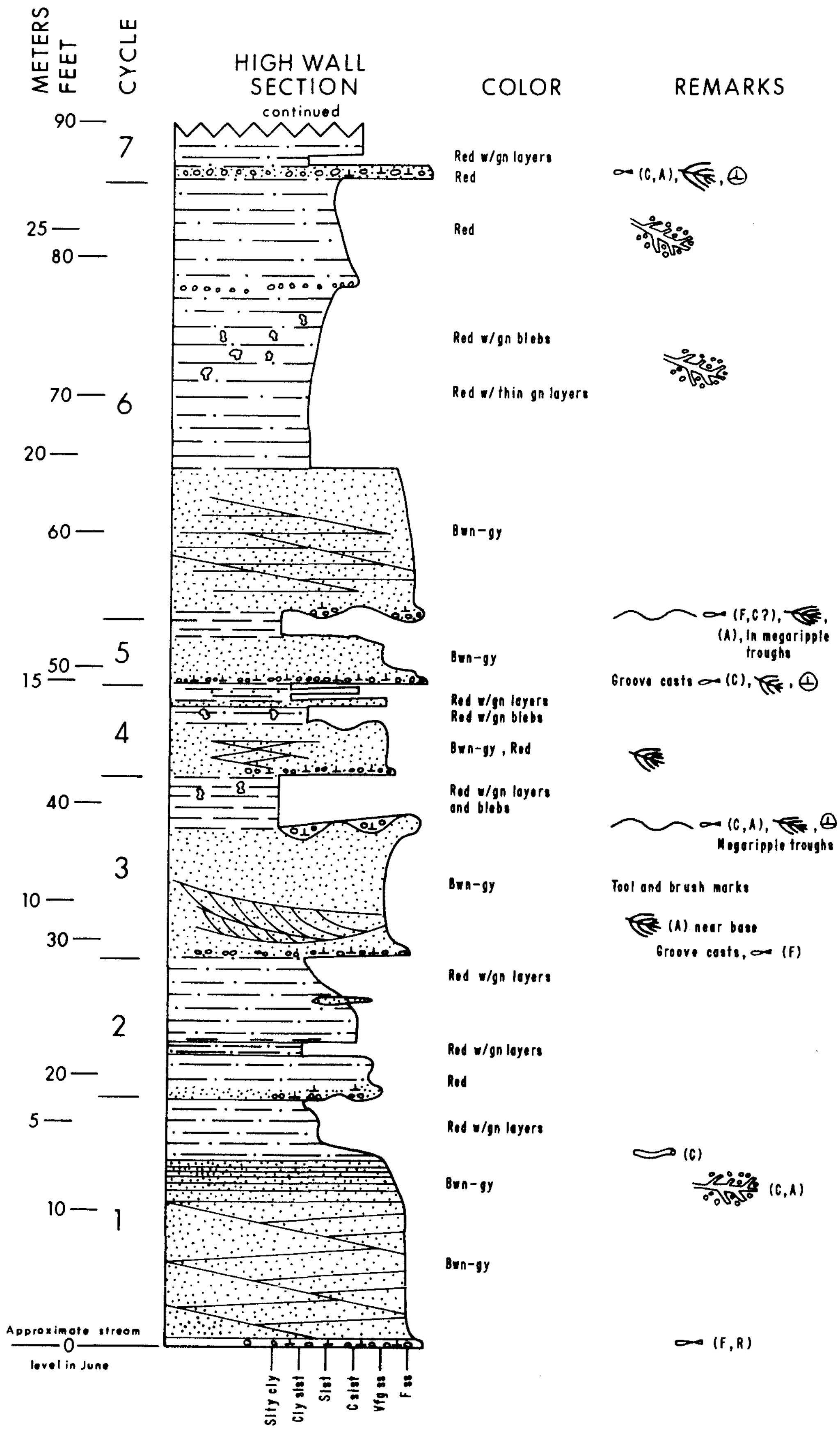


Figure 49. Columnar sections measured and described at exposures near the intersection of Shaffers Run and Wills Creek along with a diagram showing averages of paleocurrent indicators.

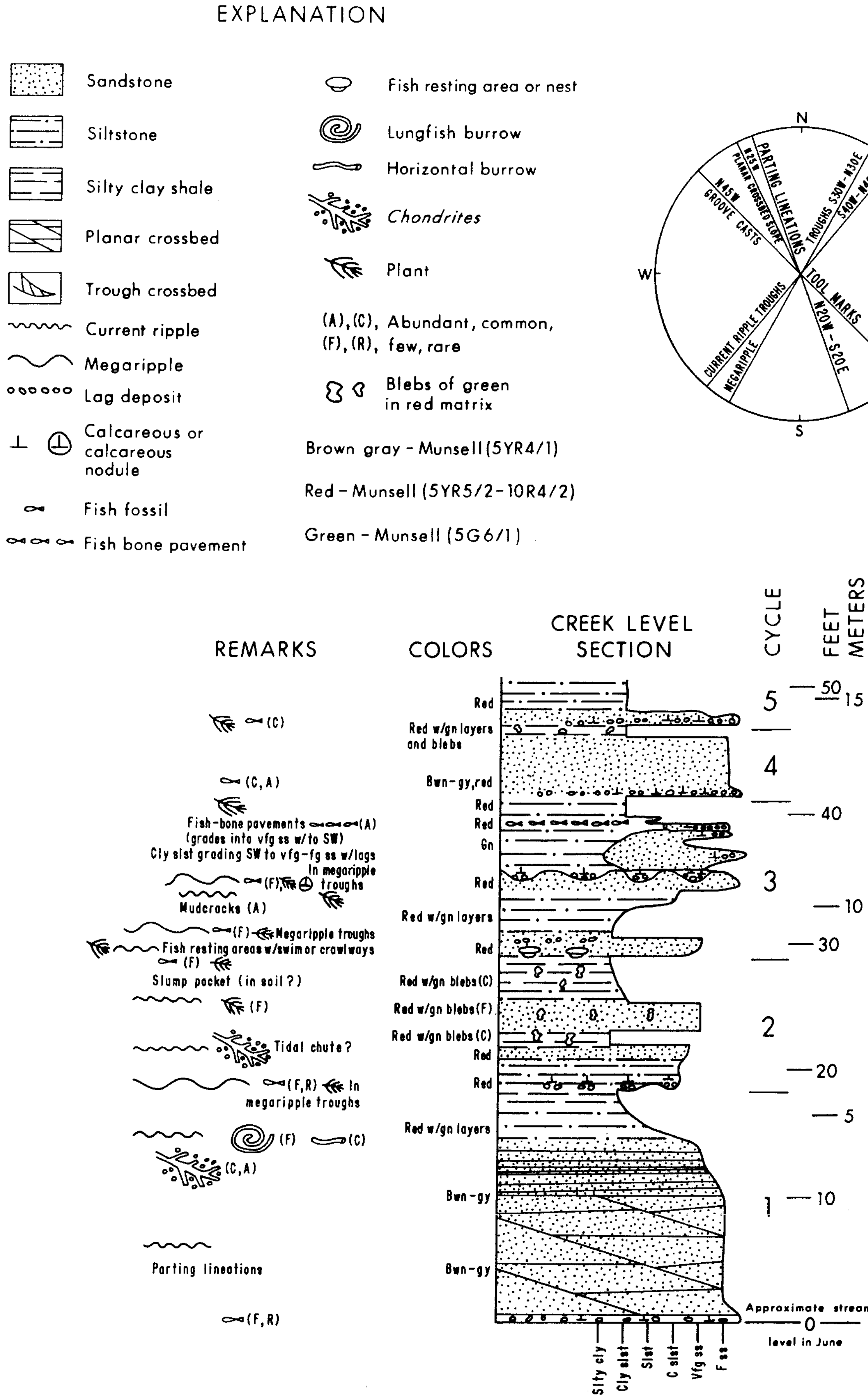


Figure 49. Continued.

FOSSILS AT THE CONFLUENCE OF SHAFFER RUN AND WILLS CREEK SECTION

The Vertebrate Fossils

Specimens of both Crossopterygii and Placodermi occur at this outcrop in Cycle 3. This outcrop exposes an unusual depositional occurrence of placoderm trunk shields, rhipidistian teeth (H-P. Schultze, personal communication, 1992), and lungfish burrows. The assemblage of fish fossils is unusual because of its diversity and the mode of deposition, which apparently occurred in a low energy environment. The usual occurrence of fish fossils is in lag deposits of high energy environments. In addition, this is the first reported occurrence of a fossil fish assemblage in the Catskill Formation of southwestern Pennsylvania.

The prominent placoderm is the Antiarch *Bothriolepis*. It is probable that some of the plates are Crossopterygii, of the Order Rhipidistia, with plates and teeth that are likely holoptychids, probably *Holoptychius*. Some teeth may be from rhizodontids.

During the Devonian, placoderms were the dominant fishes. In most placoderms, the exoskeleton of the trunk is composed of dermal bone. The dipnoans and crossopterygians also had plates and scales commonly composed of cosmine. Cosmine is a tissue of dermal denticle that has fused to form a continuous sheet composed of a layer of dentine and a superficial layer of an enamaloid substance. These layers have a pore canal system that may have served as part of an acustico-lateral system. Cosmine is periodically resorbed, allowing growth in the bony regions of the fish (Moy-Thomas, 1971).

The numerous trunk shields seen in Cycle 3 are primarily those of *Bothriolepis*. The general morphology of the typical *Bothriolepis* is shown in Figure 50 and in Figure 48, fish 6. The specimens are preserved as a bone pavement on separate bedding planes and encompasses an interval approximately 3 feet thick. Measurements of *Bothriolepis* anterior median dorsal plates and overall trunk shield lengths (Table 10) reveal that many specimens in this exposure are morphologically similar to those of *Bothriolepis* sp. ind. 4 in Antarctica (Young, 1988). If this is proven to be the same taxon, it would be the first reported occurrence in North America.

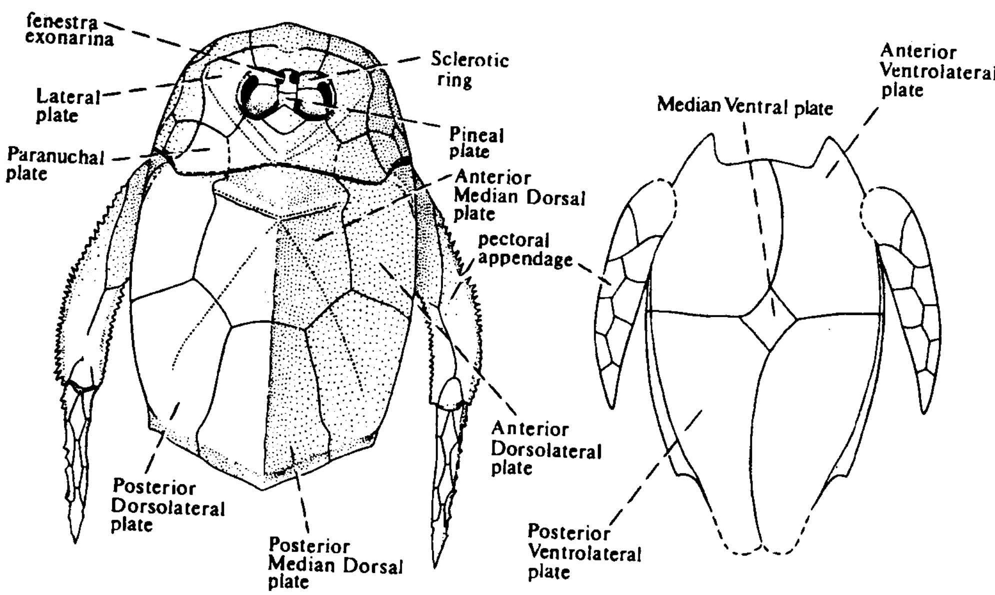


Figure 50. Diagram of *Bothriolepsis*, modified from Jarvik, 1980.

Bothriolepis is commonly considered to be a fresh-water fish, although it has been speculated that there may have been marine occurrences. There are plates at this outcrop that have an anterior median dorsal plate similar in shape to that of the placoderm *Asterolepis*, which resembled *Pterichthys*, (Figure 48, fish 5). This may however be a diagenetic effect and they may be *Bothriolepis* specimens. The placoderms found in this section probably ranged in length from 20 cm to slightly greater than 1 m.

The bed of placoderms next to Wills Creek is approximately 1-5 cm thick. Other occurrences of placoderm fragments occur stratigraphically higher throughout the section. The

Table 10. Measurements of anterior median dorsal plates.

AMD	Width in mm	Length in mm
1	60	62
2	64	72
3	56	59
4	58	60
5	60	63

most spectacular *Bothriolepis* specimen is an articulated trunk shield, (Plate 1C), exposed near the water's edge. It measures approximately 185 mm wide by 210 mm long. The pectoral fins are approximately 24 mm wide at their widest point and are 120 mm long. The entire fish was approximately 1 m in length. The articulation of these *Bothriolepis* specimens indicates a quiet environment of deposition. This is anomalous, as most plates usually occur in lag deposits. Notice that most specimens found along Wills Creek are articulated and in visceral view of the dorsal plates ("belly-up"). Some specimens are imbricated (Plate 2A), which could indicate final deposition on a shoreline or in a stream channel.

There is an average of 1 anterior median dorsal plate per 39 cm^2, most of which display the visceral view of the dorsal plate (Plates 1C,D and 2A). Given the exposed portion of the bedding plane, it is possible there may be over 3500 *Bothriolepis* specimens in this particular bed. Among the more easily identified "pieces and parts" are several pairs of pectoral fins.

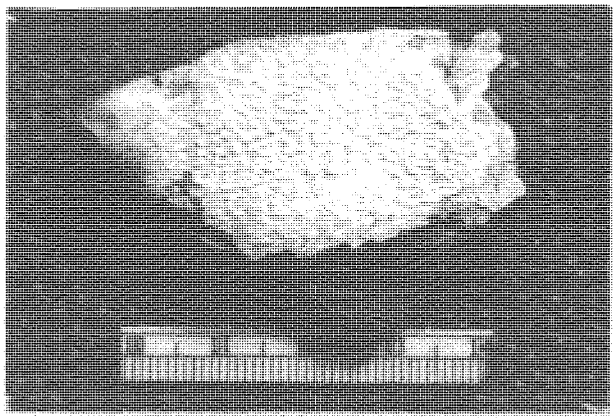
Bothriolepis and *Asterolepis* are known to be benthic genera as indicated by their heavy armor and generally flattened ventral surfaces. These benthic dwellers were not strong, powerful swimmers and were probably mud-grubbing deposit feeders. *Bothriolepis* possessed a paired sac of organs that presumably functioned as lungs (Moy-Thomas, 1971). It is possible that these fish could have survived in an environment occasionally devoid of water, such as a tidal flat, stream, or area that became dry due to the anastomosing nature of streams at the distal portions of deltas.

Close inspection reveals an infrequent occurrence of large and small striated and labyrinthic teeth (Plate 1A), possibly that of the Crossopterygian *Holoptychius*, (Figure 48, fish 4) or of a rhizodontid. These fishes had a pike- or muskellunge-type profile and ranged in size from 1 to 4 m or more in length (Moy-Thomas, 1971). These voracious predator fish are suggested to be the direct ancestors of tetrapods (Long, 1989, 1990; Thomson, 1976; Schultze, 1984), and could foray out of the water. They had long, labyrinthic and striated teeth. Perhaps the association of the predatory fish with *Bothriolepis* is indicative of selection of the smaller placoderms as a preferred "meal". It is possible these fishes rested on the bottom, lurking in the shadows waiting for their next meal to come "mud grubbing" along.

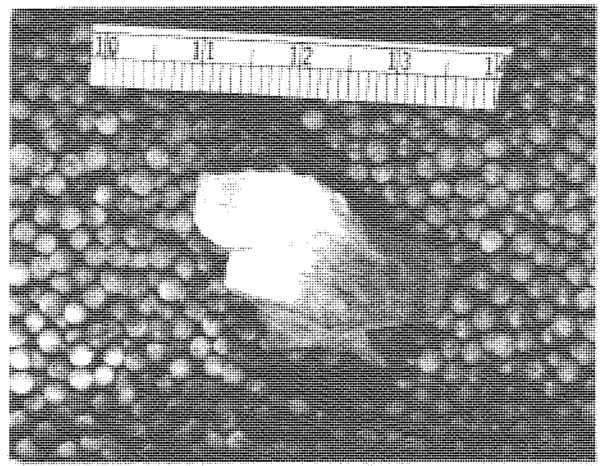
In addition, a specimen of a "lobe fin" (Plate 1A), possibly that of a dipnoan (Figure 48, fish 3) has been collected here (Shaulis and others, in progress). Dipnoan fishes are known to have been Devonian "lungfish".

At the base of the highwall section between Shaffer Run and Wills Creek, near the talus pile, is a well-preserved, unusual specimen of what resembles *Acanthaspis armatus* (Plate 1E). This fish is known from only a few cranial armor plates. The unique "pleural spine" shape is most similar to that of *A. armatus*. described by Newberry (1875) from the Devonian Corniferous Limestone of Sandusky and Delaware Ohio. The occurrence of an *A. armatus* would be the first reported of this rare armored specimen in Pennsylvania. Few specimens of these plates have been collected. However, the plate found in the outcrop is not quite the same as *A. armatus*. It is exposed with the visceral side of the dorsal plate. Where it is slightly worn, a tuberculated exterior is suggested from impressions in the rock. It is possible that this specimen represents an unknown taxon of placoderm.

The numerous spines observed in the creek level section, Cycle 3, are "straight" (Plate 1E, F). This is quite different from the descriptions of "spiny fishes", most of which are Acanthodians. Most described Acanthodian spines are slightly curved. The spines found in Cycle 3 most resemble those belonging to *Uraniacanthus spinosus*, as described from the Lower

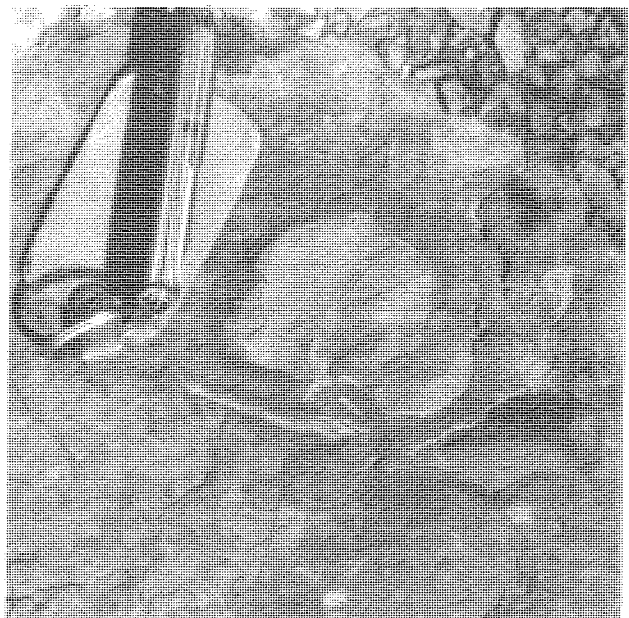


A

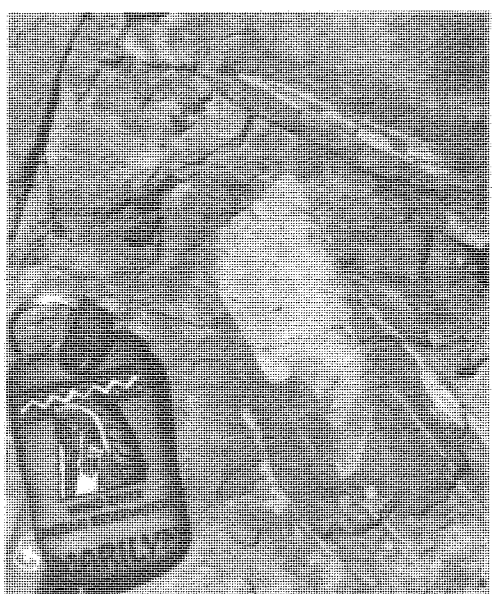


B

C



D



E

F

Devonian of Saudi Arabia (Forey and others, 1992) or *Devonochus* of the Lower Devonian of Latvia (Schultze, 1978). This may therefore be the first reported North American and Upper Devonian occurrence of these specimens. If these spines prove to be from the same taxon as those described by Forey and others (1992) it would extend both the geographic and stratigraphic ranges of these fish.

Bedding planes containing silty shale or lags in Cycles 2 and 3 commonly contain microscopic fish fragments and teeth, with pockets of disarticulated larger plates. In particular, the micaceous bedding plane in Cycle 2 containing vertical burrows also contains delicate micro plates, which can be observed in detail at 100X magnification. Examination under lower magnification might result in "pieces and parts" completely missed. Inspection of the bedding plane exposed in Cycle 3 reveals that, although there are a variety of sizes and parts, most specimens occur as articulated trunk shields. The prevailing position is of the visceral view of the dorsal plate. Apparently, some Devonian fish went "belly-up" with death also. Note that the posterior dorso laterals and posterior laterals (Figure 50) are fused, forming mixilateral plates. Numerous pectoral fins are often near the trunk shield of an individual specimen. The ornamentation in juvenile specimens is reticular, and may remain reticular in adult specimens or become tubercles or short ridges (Schultze, 1978). Many specimens exposed in Cycle 3 along the bank of Wills Creek are tubercular or ridged and, therefore, are likely to be adults.

The Ichnofossils

Numerous ichnofossils occur in several distinct horizons. The lowest noticeable occurrence is in a highly micaceous quartz arenite unit. The trace maker left a Chondrites facies trail (Plate 2F). In addition, the darker, circular "spots" appearing on the micaceous bedding planes in Cycle 2 are left by vertical burrowing. Some burrows appear in the centers of the green blebs on the bedding-plane surfaces. No thin sections have been made of the vertical traces. It is therefore unknown whether these traces truncate the grains and are borings that were made in lithified sediments or are simply escape burrows made in rapidly depositing sediments.

There are large, circular burrows visible on a bedding plane near the top of Cycle 1. We suggest that these burrows may be those of dipnoans (lungfishes) (Figure 48, fish 3; Plate 2D). The burrows are similar to reported dipnoan burrows (Anderson, 1983; Dubiel and others, 1987; Lund, 1973; Voorhies, 1983) (Plate-). Whatever the trace maker was, there are several of these circular burrows, all in or near to the same stratigraphic horizon. The burrows are generally circular in design, winding around and inward. Diagenesis has compressed them into "cow-pies". Individual burrows may range from 9 to 12 cm in width.

At the base of Cycle 3 are large circular, elliptical, and ovoid depressions 1-1.5 feet in diameter (Plate 2C). We suggest that these could be traces made by fish resting on the bottom, or in low areas of remaining water where possibly the rhipidistian or rhizodontid types traveled to wet themselves. Similar "resting beds" made and used by domestic Koi (a Japanese Carp) have been observed by the authors. Other fishes have been observed to employ this behavior. Why not Devonian fishes also?

Other structures (biogenic?) on the bedding plane include gently curving "grooved trails" (Plate 3). The trails connect the "rest areas" and are somewhat evenly spaced between the depressions that are 7.5-8 feet apart. These furrowed "crawl-ways" or "swim-ways" truncate the ripples and are 1 foot wide and 0.1 foot deep. It is possible that these trails were made by dipnoan fishes resting in small remaining pools of water because the trough traces in Cycle 3 approximate the circular burrow diameter. This may be the first reported discovery of this type of trail.

Plate 1. (Opposite page) Photographs of specimens found in "bone pavements" of Cycle 3.
A. Tuberculated surface on a lobe in *Holoptychius* or Dipnoan. Approximately 4 cm long.
B. Striated Rhipidistian tooth fragments. Approximately 20 mm long.
C. Articulated trunk shield of *Bothriolepis*. Approximately 210 X 180 mm.
D. Visceral view of anterior median dorsal plate form *Bothriolepis*.
E. Cranial pleural spine of *A. armatus* and anterior median dorsal plate of *Bothriolepis*.
F. Fin spine of Devonochus. 100 cm long.

PALEOENVIRONMENTAL INTERPRETATION

Depositional Environment

The rocks are nonmarine Catskill facies that were deposited by rivers flowing to the northwest from a southeastern source area. The rocks mainly (1) decrease in grain size from the bottom to the top of each cycle, (2) are predominantly red in color, (3) vary laterally and vertically, and (4) were deposited by meandering or braided river systems (Sevon, 1988) at the distal portion of the delta comprising the Fulton Lobe. Delta-plain deposition at this locality was accomplished by meandering streams with (1) high sinuosity, (2) low gradient, (3) shallow water depth, and (4) low erosional capability (Sevon, 1988). Groove cast lineation directions done by Shaulis (1993) (Figure 49) supports analysis done on cross-bedding dip azimuths by Leeper (1962) indicating a general northwest paleocurrent direction.

Facies

The outcrop has a general strike of 27^{o}NE and a dip of 21^{o}SE. Analyses done at the portion of the exposure of this section existing in 1960 indicate the sediments here are not "clean" and contain an average of 74% quartz, 9% feldspar, and 4% rock fragments (Leeper, 1962). The fish specimens are best preserved in the quartz-arenite horizons. Those fish specimens occurring in the lithic arenite weather and fragment quickly.

Sedimentologic Structures

Bedding planes vary from planar to trough crossbedded and those containing mudcracks are infrequent throughout the outcrop. Those that do contain mudcracks are generally silty sands with no other apparent associated fossils or sedimentary structures, and the mudcracks are well developed. Ripple structures, both cuspate and current ripples, are noticeable on several bedding planes. Calcareous nodules in Cycle 1 are associated with the *Chondrites* facies. Shale clasts occur in several lags. Fish fragments, shale clasts, and carbonaceous debris are present in the lags of Cycles 2-10. Calcareous nodules and slump features indicate soil development. Lungfish aestivation tubes, desiccation cracks, burrows, and plant fragments occur throughout the outcrop.

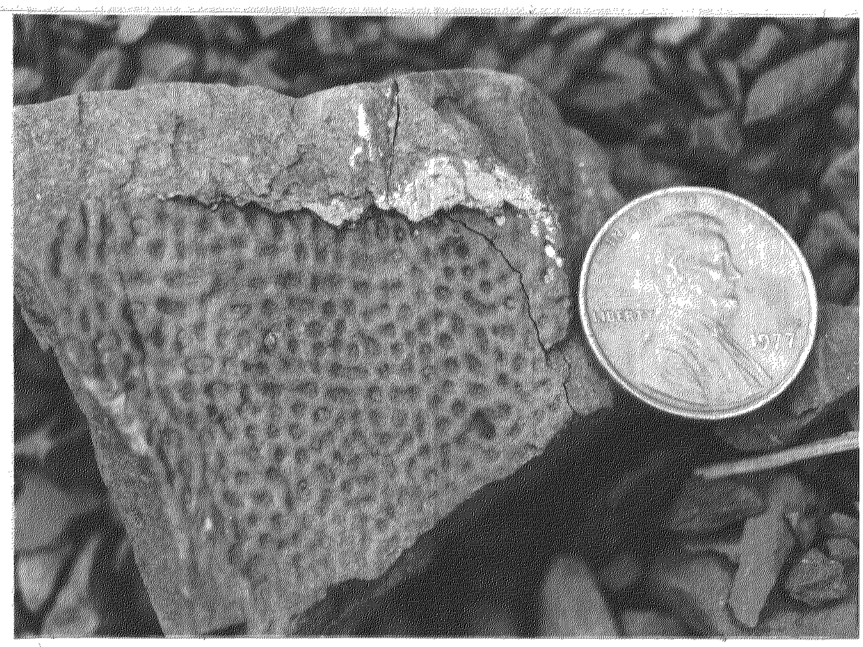
PALEOECOLOGY OF CYCLE THREE

The basal unit of Cycle 3 is a sandstone that contains mud-draped current ripples truncated by equally spaced ovoid depressions, 7.5-8 feet apart. The depressions connect to each other by a network of concave furrows (Plate 3). We interpret the spacing of the ovoid depressions to indicate territoriality. The trails connecting the depressions may indicate that the depressions are resting traces. Perhaps the network of trails means the depressions were used by more than one individual. The truncation of the ripples indicates an inundation of water with higher energy, perhaps bank-full discharge, followed by quiescence, and a return to lower water levels with low hydraulic velocity. The size of the furrows probably indicates that these structures were created by rhipidistian or rhizodontid fishes. Perhaps we see here indications of the transition from fish to tetrapod. The furrows were likely created by the fish (or tetrapod) dragging its body through the mud of abandoned channels, small pools, or flood plains. The spacing between them might indicate territoriality. These are indeed unique burrows, worthy of further study.

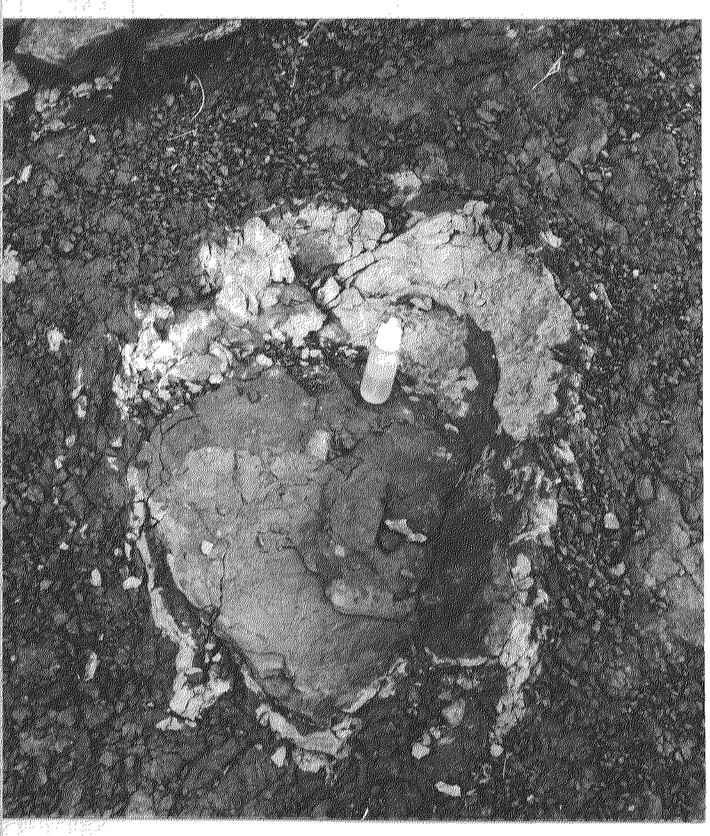
Overlying this bedding plane is silty shale interbedded with bright green blebs and

Plate 2. (Opposite page) Photographs of specimens and features associated with Cycles 1 and 3.
A. Fish-bone pavement in Cycle 3.
B. Visceral view of *Bothriolepis* dorsal plate showing reticulated surface.
C. resting trace of fusiform fish (?) or amphibian (?) in Cycle 3.
D. Inwardly spiraling lungfish burrows in the top of Cycle 1.
E. Large planolite-type burrow system in top of Cycle 1.
F. Branching horizontal and linear vertical burrows of *Chondrites*

A



B



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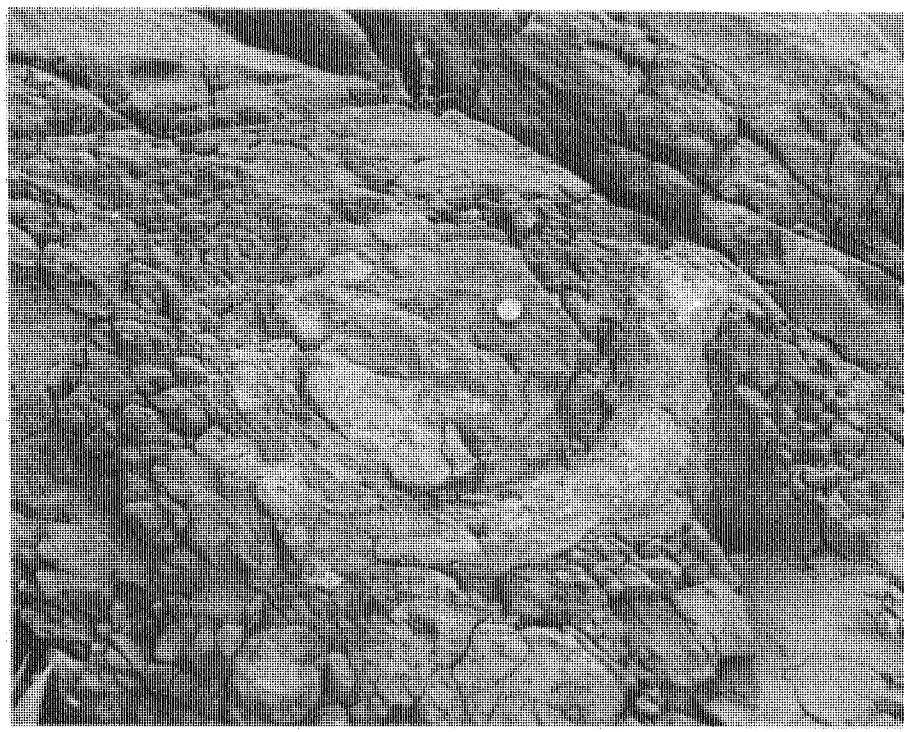

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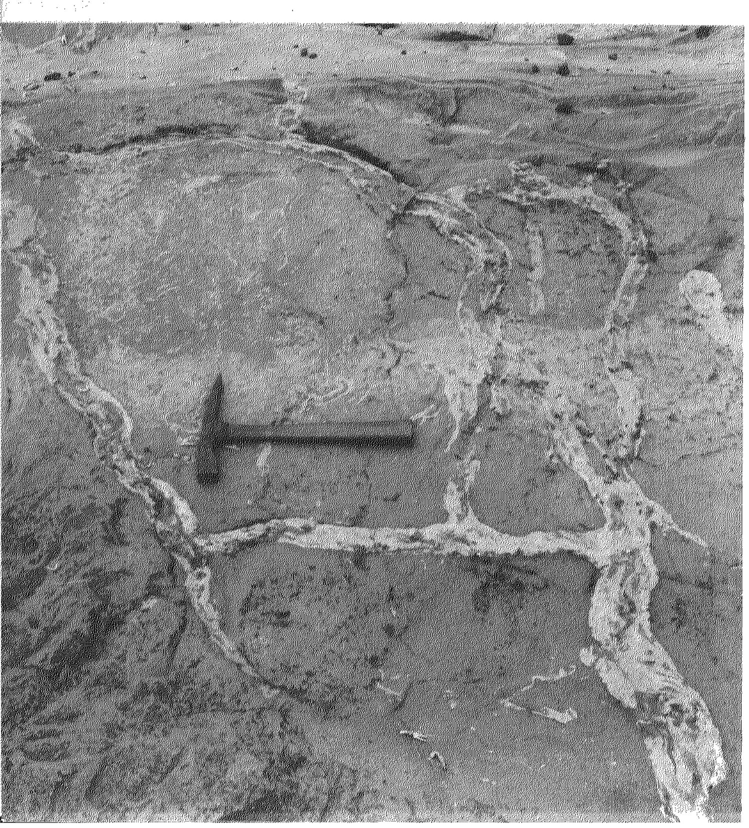

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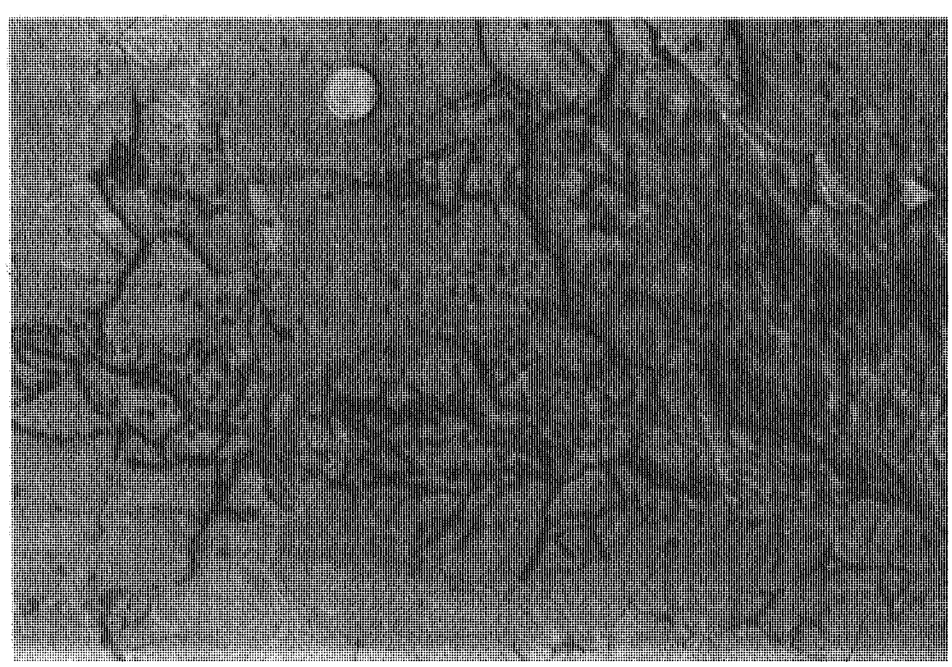


F

layers. The silty shale contains plant debris, probably lycopods, and desiccation cracks. The desiccation cracks indicate a period of drying. The sandstone unit overlying this layer is mega-rippled and contains fish fragments, plant debris, and calcareous nodules. Therefore, the period of drying and soil development was followed by another inundation of water. This is followed by 3 feet of greenish, silt shale overlain by several feet of reddish, clay siltstone containing two separate fish-bone pavements.

Bothriolepis was a bottom dwelling fish, adapted to resting on the bottom using their pectoral fins as props. Their eyes and nasal passages were dorsally located. They were mud-grubbers eking out a living in the sediments at the bottoms of fresh water rivers, lakes, and ponds. Behind the trunk shield was a long, muscular body with an unrestricted notochord, indicating an eel-like motion while swimming (Moy-Thomas, 1971).

Rhipidistians were fusiform fishes and were well adapted for free swimming in shallow water. Their pike-like shape easily lent itself to quick lunges after prey. The similarity of the structure and movement of their pectoral fins to tetrapod appendages results in general agreement that they were capable of "walking" in shallow water and short distances over muddy banks. In addition, the general assumption that they possessed an airbladder leads to the conclusion that they could gulp air for a short time to survive terrestrial excursions. Rhipidistians were predators with sharp teeth and jaws capable of opening wide enough to swallow their prey whole (Moy-Thomas, 1971).

Dipnoan biology was apparently the same in the Paleozoic as it is today. They were and are adapted for bottom dwelling in shallow water. These early lung-fish were capable of excursions onto the land (Moy-Thomas, 1971).

What caused this death assemblage?

Observe the apparent imbrication of some of the trunk shields. Could a phenomenon similar to that which causes the abundant dead fish on the shores of Lake Erie each spring have occurred? Considering that the geographic position of this portion of North America during the Devonian was equatorial, the probability of a freeze-thaw cycle is very low. Could there have been a "red tide"? Because this portion of the Catskill Formation is close to the Fulton Lobe of the Catskill deltaic complex, were these fish in a river? Is it possible that a catastrophic storm event produced an extra high tide, with a resulting salinity intolerable to *Bothriolepis*? Note that this bone pavement does not appear to be in a lag deposit. Did *Bothriolepis* return to this locality to spawn like Pacific Salmon, only to die by the hundreds in the tributary they chose? The thickness of this horizon and its repetition throughout the outcrop indicates that *Bothriolepis* were in this locality frequently. Did they have both an open ocean and freshwater stage of their life cycle? Does the occurrence of the predatory fish indicate this was a well-established community? All questions worth pondering.

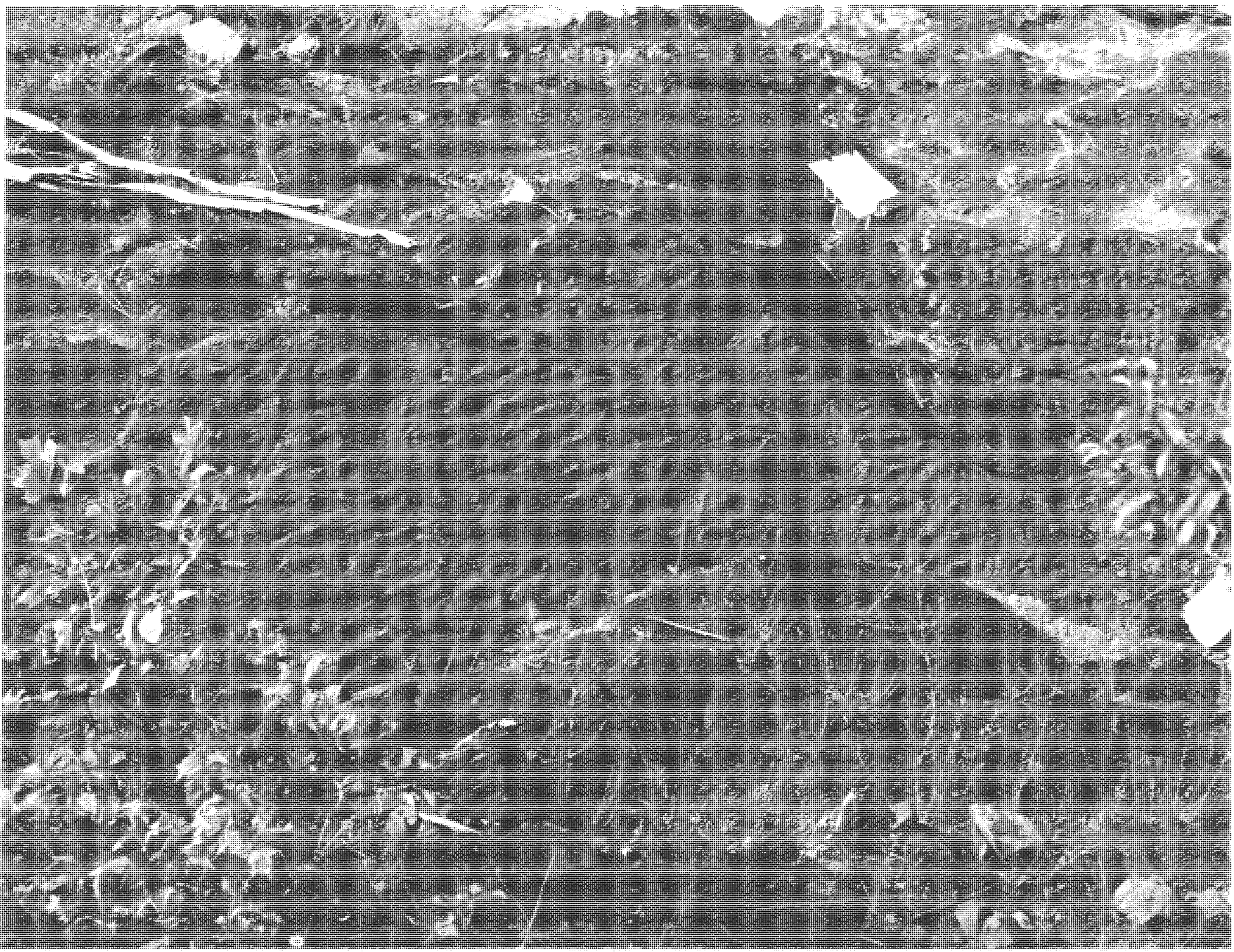
CONCLUSION

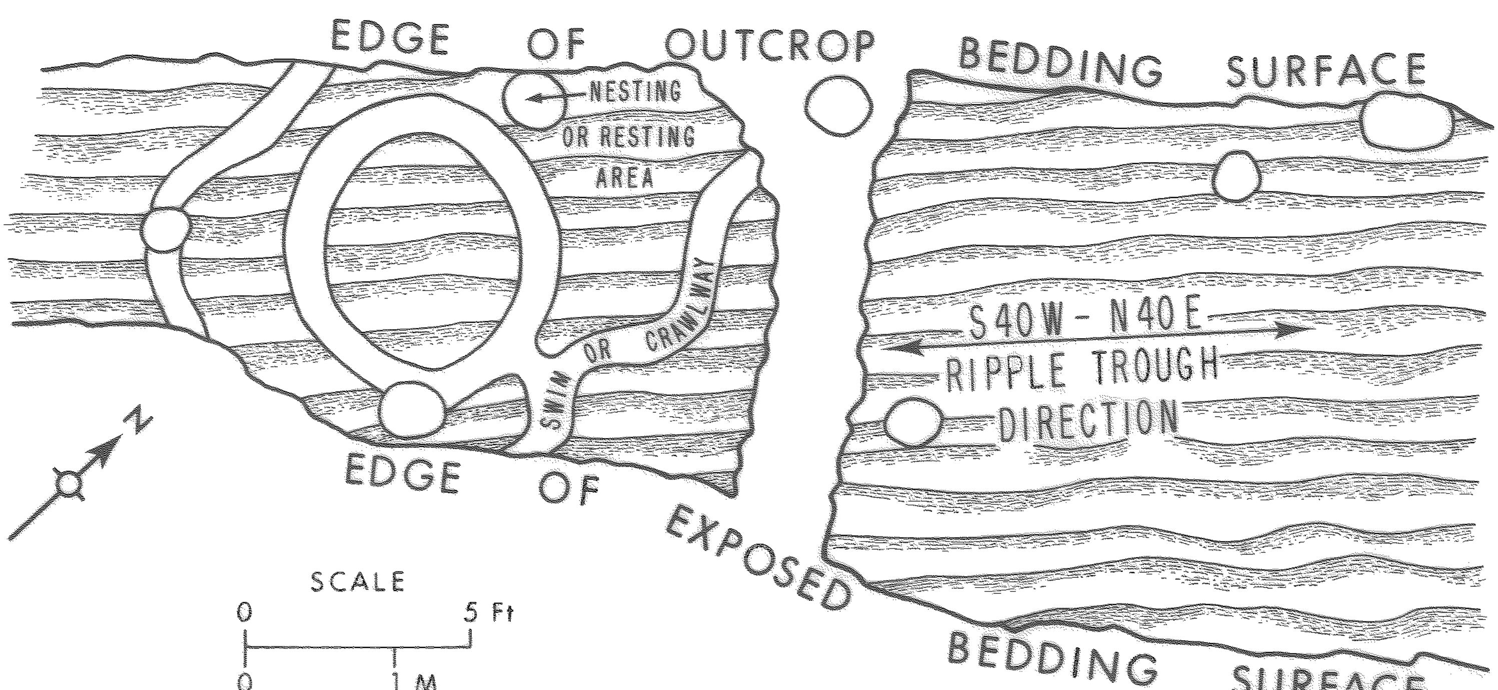
Let us imagine the Upper Devonian......

A meadering stream channel in the distal portion of a deltaic wedge (Fulton Lobe, Sevon, 1985) abandons its channel. Some lungfish and rhipidistian fishes escape back to the main channel (basal sandstone of Cycle 3, highwall section) before the evaporation of the oxbow lake moves the paleoshoreline too distant for them to crawl to the moving water of the stream. Like the modern "walking catfish" they preceded, the dipnoans traverse from depressions to other lakes, ponds, and stream channels. Some burrow into aestivation tubes during low water stands, others are not so lucky. Other rhipidistians, including *Holoptychius*, live along the banks of the oxbow lake, occasionally slithering into deeper water for a *Bothriolepis*, a la càrte, or snapping up an unwary dipnoan. The rhipidistians create territorial crawlways connected by resting traces in the soft mud, where they curl their tails and digest the latest unfortunate (base of Cycle 3). The *Bothriolepis* trapped in the oxbow swim about unaware that their days are numbered. The lake then formed a stratified water column with anoxic bottom waters (greenish, silt shale below Cycle 3 bone pavements, creek-level section, interpreted by W. D. Sevon, personal communication, 1993).

The lake may have survived for a few years or many years before completely drying up. As

Plate 3. Photo and sketch of resting or burrowing traces with associated swimways or crawl-ways of Dipnoan (?)- or Rhipidistian (?)-type fish found near the base of Cycle 3 (geologic hammer in resting trace at center of photo).




EDGE OF OUTCROP
BEDDING SURFACE
NESTING OR RESTING AREA
SWIM OR CRAWLWAY
S40W - N40E
RIPPLE TROUGH DIRECTION
N
EDGE OF EXPOSED BEDDING SURFACE
SCALE
0
5 Ft
0
1 M

the oxygen level of the lake decreased to levels intolerable for the fish living in it, death rate increased. As the bottom of the food chain diminished in numbers, the predatory fishes at the top suffered a decrease as well. Catastrophic death of the fishes occured, resulting in a thanatocoenose of generally parautochthonous fishes. The articulated state of the *Bothriolepis* fossils indicates anoxic bottom conditions intolerable even to scavengers. Many are preserved in visceral view of the dorsal plates indicating that at least these fish died "belly-up", just as many do today.

Subsequent streams eroded the layers of fossilized fish reworking the plates. The lag deposits overlying the bone-pavement of fish fossils contain the disarticulated dermal plates of numerous Devonian fishes. The thanatocoenose assemblages were reworked during periods of higher water and greater hydraulic energy. Eventually, the sediments were buried by the swamps of the Carboniferous, and remained buried until the CRX Railroad blasted the rock in 1984 to obtain bedfill. The fossils remained undiscovered until the 1992 Devonian mapping project of Somerset County. Once again, the luck of the draw.

		LEAVE STOP 5. TURN LEFT onto SR 2019.
0.4	93.0	**BEAR LEFT** following SR 2019. Note conflicting message given by signs on right.
1.2	94.2	Exposures on right of Foreknobs Formation.
0.7	99.9	Enter village of Glen Savage. Site of early 1900's sandstone quarries in ridges to left.
0.3	100.2	Outcrop of basal conglomerate of Foreknobs Formation on right. Thickness of the conglomerate ranges from 3 to at least 86 feet.
1.6	101.8	Enter Mount Zion. **STOP SIGN. TURN LEFT** onto PA 31 West. Route is traversing the upper Scherr Formation nearly on the axis of the Deer Park anticline.
0.7	102.5	Conformable contact of Scherr and Foreknobs Formations exposed on left. The Scherr contains *Ambocaelia umbonata* and other brachiopods, ichnofossils, and fenestrate bryozoa. The Foreknobs contains *Tylotherus* and other brachiopods, trilobite (?) fragments, and pelmatazoan stems. The next outcrop to the west is in the middle of the upper Foreknobs and contains: brachiopods, *Nervostrophia nervosa*, *Platyrachella* sp., pelmatozoan fragments, ichnofossils, and small vertebrate fragments. The next roadcut to the west is upper Foreknobs with *Mucrospirifer* (?) and other *Spirifer* species, pelecypods, and small vertebrate fragments.
1.4	103.9	Note ridge to west. It is the western flank of the Deer park anticline which is supported by the Mississippian Burgoon Sandstone.
0.8	104.7	Village of Dividing Ridge on the left. It is so-named because the east-west ridge separates drainage basins of the Potomac and Juniata Rivers.
0.7	105.4	Nice view to the left of intricate dissection of the Deer Park anticline.
1.2	106.6	Enter Dieters Gap.
0.9	107.5	Enter Stony Creek township. A triple divide occurs 1.5 miles south of here.
0.3	107.8	Barbara No. 1 deep coal mine in Upper Kittaning on right.
0.9	108.7	Cross PA Route 160 in village of Roxbury.
1.3	110.0	Cross approximate axis of the Berlin syncline.
1.7	111.7	Enter village of Brotherton.
1.5	113.2	Enter village of Burksville.
0.5	113.7	Strip mine in Upper Freeport.
0.6	114.3	Enter village of Wills.
0.3	114.9	Cross PA Turnpike.
1.3	116.2	Laurel Hills form horizon ahead.
0.4	116.6	Cross US Route 219.
0.3	116.9	Somerset State Hospital on right.
0.5	117.4	Cross PA Turnpike.
0.1	117.5	Enter Somerset Borough.
1.2	118.7	**STOP LIGHT. TURN RIGHT** onto PA 281 North.
0.2	118.9	**TRAFFIC LIGHT. PROCEED STRAIGHT AHEAD.**
0.4	119.3	**TRAFFIC LIGHT. PROCEED STRAIGHT AHEAD.**
0.3	119.6	**TURN LEFT** into parking lot of Ramada Inn.
		END OF DAY 1. SEE YOU AT THE BANQUET!

ROADLOG AND STOP DESCRIPTIONS - DAY 2

Mileage Inc	Cum	DESCRIPTION
0.0	0.0	**LEAVE PARKING LOT OF RAMADA INN. TURN RIGHT.**
0.2	0.2	**TRAFFIC LIGHT. TURN RIGHT** onto Center Avenue.
0.5	0.7	Somerset County court house is at 2190 feet, the highest court house in Pennsylvania.
0.1	0.8	**TRAFFIC LIGHT. TURN RIGHT** onto PA Routes 281 South and 31 West and Main Street.
0.7	1.5	**TURN LEFT** onto Harrison Avenue, following PA 281 South.
0.1	1.6	**TURN RIGHT** onto Tamen Avenue, following PA 281 South.
0.7	2.3	Good view to the right of landscape eroded into rocks of the Conemaugh Formation. Distant wooded hilltops are cuestas upheld by harder rocks. The rocks dip towards the viewer and into the Lexington syncline.
0.7	3.0	Cross west branch of Coxes Creek. Note the width of the floodplain. Two interpretations are possible. Either the stream has attained a temporary base level on a resistant rock unit and has widened its valley considerably, or a lot of alluvium and colluvium from higher on the slopes has filled in a deeper valley. Truth of interpretation requires subsurface information that is lacking here. Many similar valleys occur on the Conemaugh rocks and, where subsurface information is available, both interpretations are verified.
1.7	4.7	Laurel Hills visible to the right. Note between here and Centerville the terrain and the prosperous-looking farms. Farming on the Conemaugh is good in contrast to farming on the other rock units of the area. Note also the numerous heads of drainages rimmed by rounded hills with similar crest elevations and the drop of 10-20 feet within the drainage basin to a lower level of similar elevations. The levels of similar elevations are eroded on harder rock than the slopes. The smoothness of the slopes masks the benching effect that occurs during erosion of these rocks.
0.4	5.1	Enter Milford Township.
3.7	8.8	Enter Centerville.
0.2	9.0	Junction with PA Route 653. **CONTINUE ON** PA 281 South.
1.4	10.4	Cross Middle Creek and enter Middle Creek Township.
1.1	11.5	Enter community of New Lexington. Note sign to Scolten——location of most recent "Bigfoot" sighting in the county.
0.3	11.8	PA Routes 653 and 281 diverge. **BEAR LEFT** following PA Route 281 South.
1.4	13.2	Enter Upper Turkeyfoot Township.
0.9	14.1	Enter Kingwood Borough. **CONTINUE** on PA Route 281 South.
1.1	15.2	Laurel Hills are visible to the right.
1.9	17.1	Views ahead on left of Negro Mountain.
1.6	18.7	Chicken Bone Road on right named for chicken thieves.
1.6	20.3	Enter Lower Turkeyfoot Township. Fort Hill is briefly visible across the valley to the left. Archeological study of the flat-topped hill revealed palisaded Indian villages with extensive house and burial grounds all dating from the discovery period. Question: Is the flat-topped hill natural or man made? Investigation has led to the speculation that the flat-topped hill is an Ibberian Celtic hill fort leveled by pre-Columbian immigrants from Portugal or Spain during the first millennium BC. See comments by Shaulis on page 10. Note ahead the changing topography. Steeper slopes and deeper valleys reflect erosion by major streams. Similar erosion has not yet occurred on the uplands just traversed.
1.9	22.2	Cross Laurel Hill Creek.
0.1	22.3	Enter Ursina.
0.1	22.8	**TURN LEFT** onto SR 3047.
0.1	22.9	Cross Laurel Creek.
1.5	24.4	**STOP SIGN. TURN LEFT** onto PA Route 523 South.

0.2	24.6	Cross Casselman River.
2.2	26.8	Outcrop of Upper Kittanning coal on left.
1.0	27.8	**TURN LEFT** onto SR 2004 in Listonbaurg.
0.5	28.3	Large float blocks on left.
0.8	29.1	Good view to left rear of Laurel Hills.
0.7	30.4	Ridge on right is supported by basal Pennsylvanian Pottsville Group sandstones. Now passing into rocks of Mississippian age. Colluviated blocks of Pottsville occur on valley bottom.
0.3	30.7	Scenic view to the right.
0.1	30.8	Float blocks of Pottsville on left.
1.0	31.8	St. Paul's Lutheran Church on right.
0.7	32.5	Outcrop of Mississippian Loyalhanna Formation on left. Notice Highpoint Lake to left at elevation 2480 feet.
2.5	35.0	Quarry on left was originally quarried for the Deer Valley and Loyalhanna limestones, but is now quarried for the Burgoon Sandstone.
0.3	35.3	Enter Savage. **TURN RIGHT** onto T 378.
2.7	38.0	**TURN LEFT** into quarry.

STOP 6. LOYALHANNA-MAUCH CHUNK KEYSTONE LIME QUARRY AT SPRINGS.
Discussant: David K. Brezinski.

At this stop we will examine an active quarry in the Loyalhanna Formation. Also exposed is the lower Mauch Chunk Formation, including the Deer Valley Limestone Member.

LOYALHANNA LIMESTONE

At this location the Mississippian Loyalhanna Formation is approximately 40 feet thick (Figure 51). It consists of festoon crossbedded, arenaceous grainstone (Figure 52). Unlike

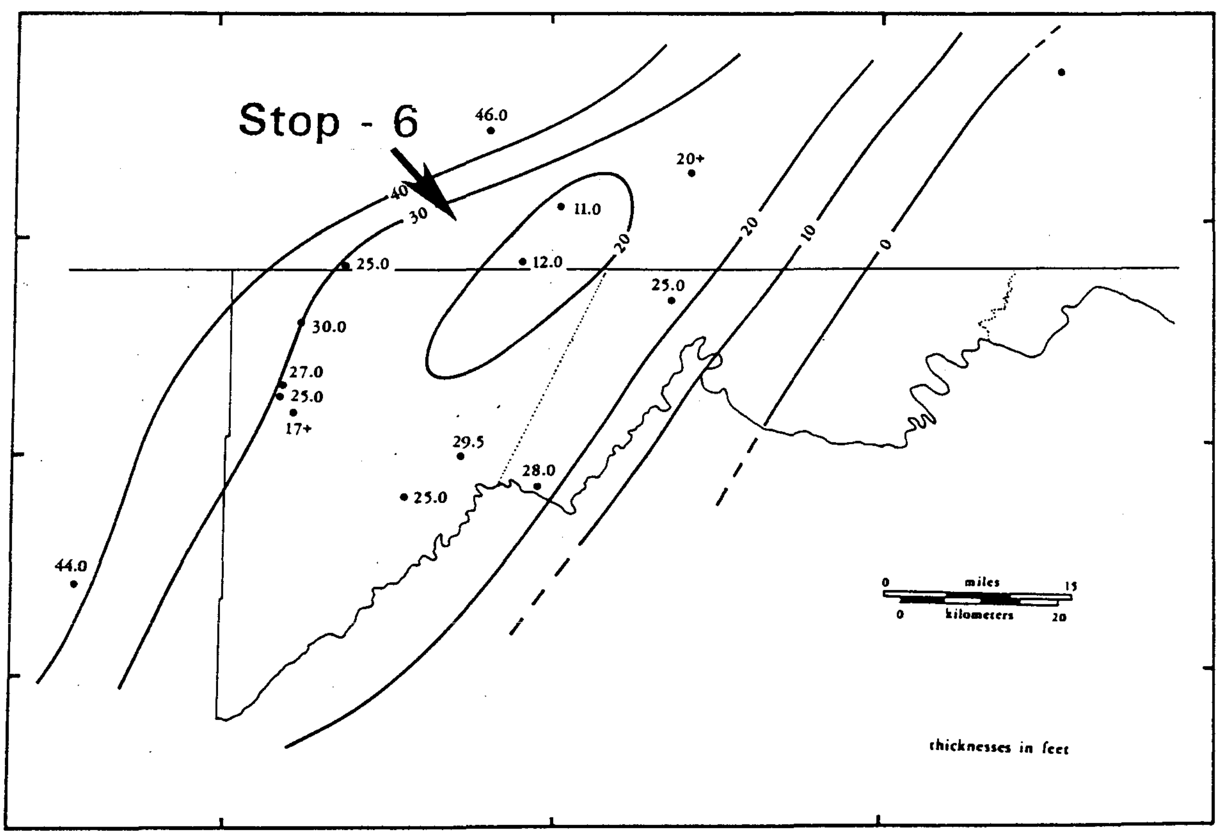


Figure 51. Isopach map of the Loyalhanna Limestone in western Maryland. Taken from Brezinski, 1989a.

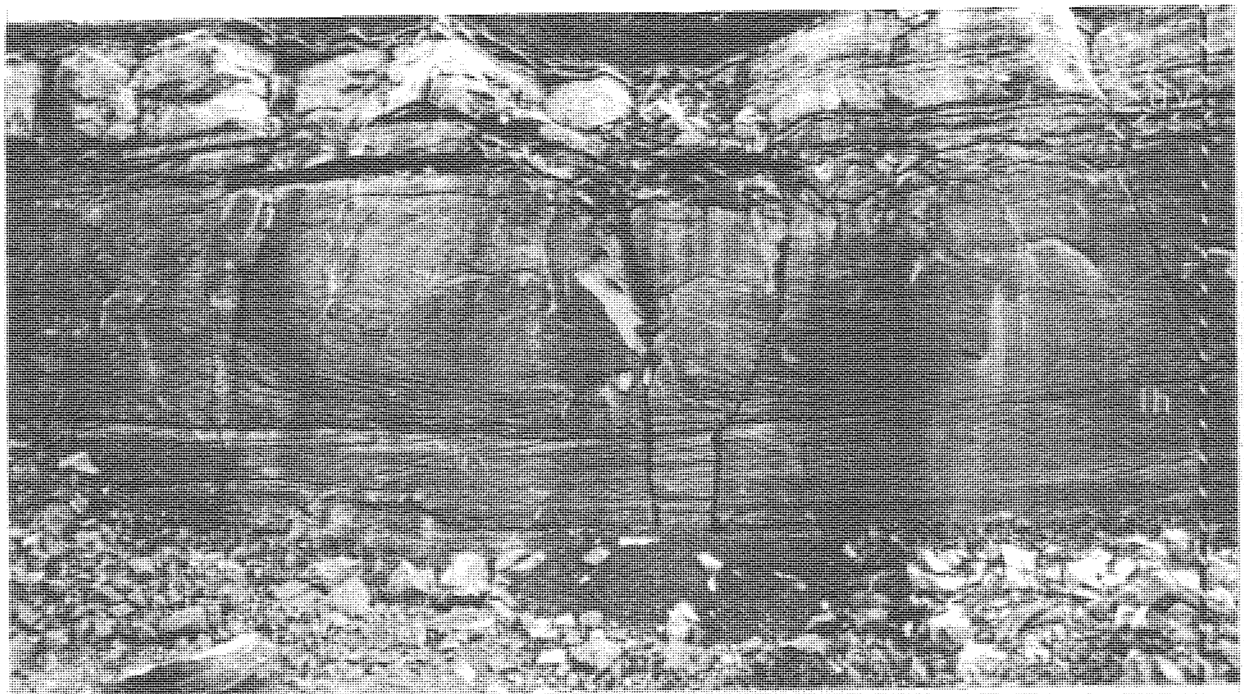


Figure 52. Loyalhanna and Deer Valley Limestones in the Keystone Lime quarry at STOP 6.

the typical Loyalhanna which is grayish-green, in this area and adjacent Maryland the formation has a reddish tint. This is caused by a small admixture of red clays that appear to be syndepositional.

The large-scale crossbeds are accentuated on weathered joint faces along the entrance into the main working face. Here, clastic-rich layers weather less rapidly, and stand out in relief on the exposed faces. The crossbedding is less evident on a fresh, worked face. The crossbeds are mainly directed to the east and northeast, apparently normal to the paleoshoreline (Adams, 1970; Hoque, 1975).

Thin (< 1 foot), tan, siltstone lenses usually occur at numerous locations on the worked face. These lenses pinch out laterally, are convex downward, and are truncated on the upper surface. Brezinski (1989b) interpreted these lenses to represent remnants of shallowing episodes or slack water deposits preserved in swales between submarine dunes, that were scoured and largely removed by subsequent dune migration.

MAUCH CHUNK FORMATION

Dear Valley Limestone Member

Ten feet of white limestone overlie the Loyalhanna. Flint (1965) named this unit the Deer Valley Limestone Member of the Mauch Chunk Formation. The Deer Valley is separated from the subjacent Loyalhanna by a 6-inch-thick, red siltstone that probably represents final shallowing and shoaling of the Loyalhanna sea. The Deer Valley differs from the underlying Loyalhanna in that the former is medium-bedded, rather than crossbedded, and lacks the quartz sand that characterizes the Loyalhanna. Furthermore, the Deer Valley Limestone contains a sparse brachiopod fauna. In thin section, the Deer Valley is composed of a well-cemented carbonate sand. The sand contains large numbers of coated grains and ooids.

The Deer Valley extends only slightly into Pennsylvania (Figure 53) but thickens to the southwest. In the southern corner of Garrett County, Maryland, the Deer Valley Member interfingers with dark-gray limestone lithologies of the Loyalhanna Member of the Greenbrier Formation of Maryland.

The Deer Valley Limestone represents a submarine sand shoal environment that submerged a

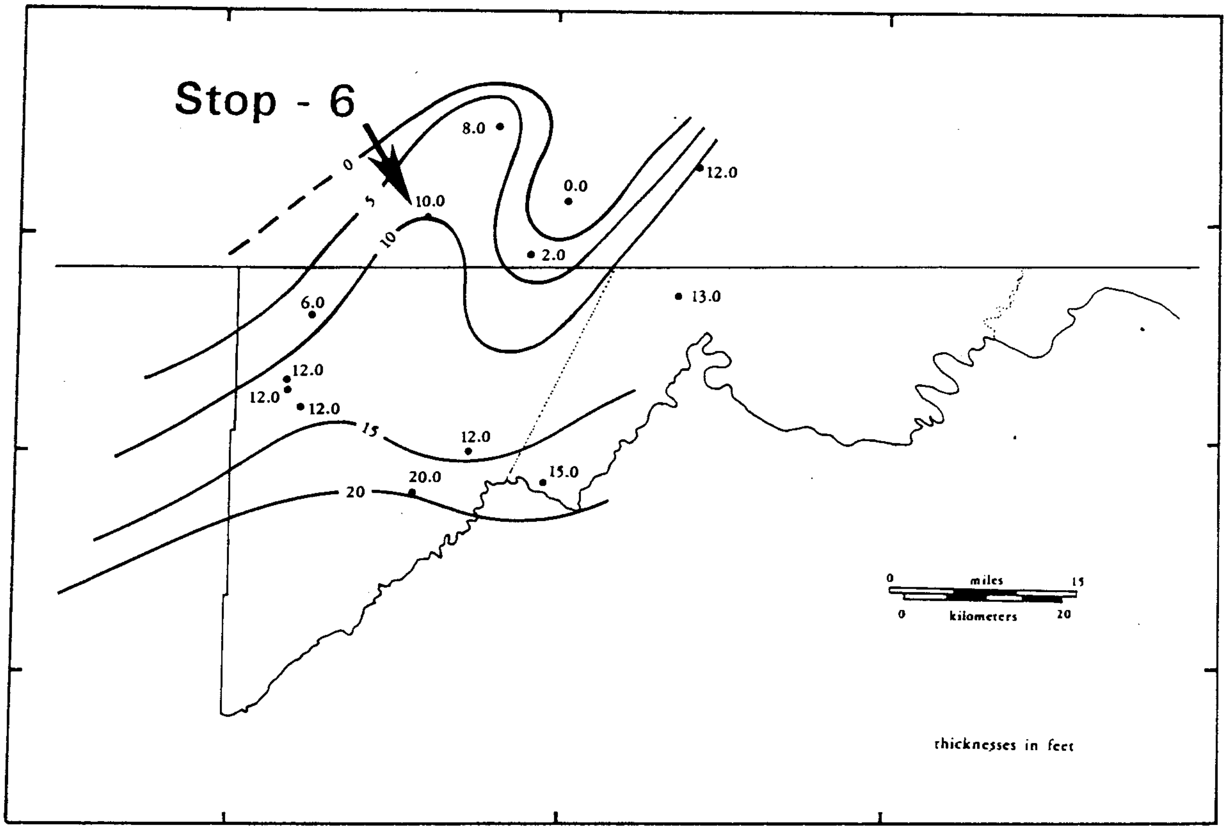


Figure 53. Isopach map of the Deer Valley Limestone Member in Western Maryland. Taken from Brezinski, 1989a.

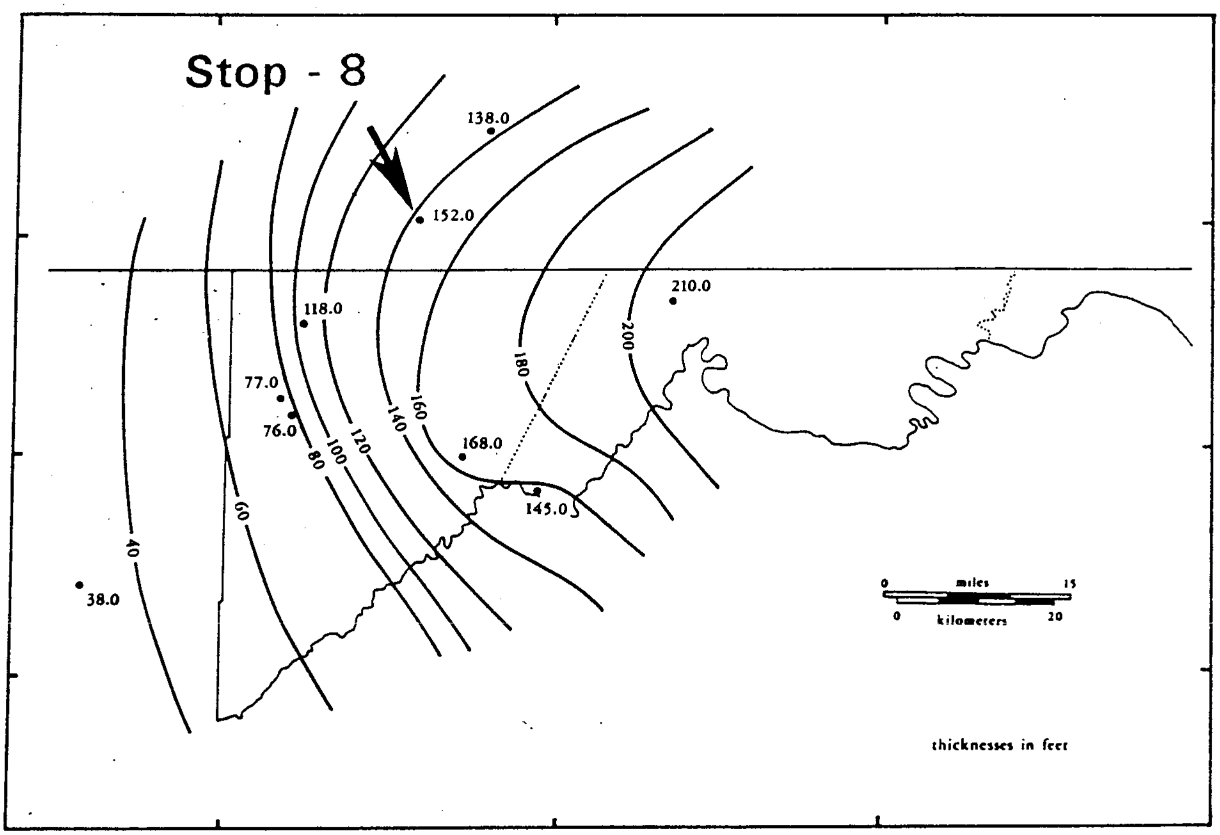


Figure 54. Isopach map of Savage Dam Member of the Greenbrier Formation of Maryland (Mauch Chunk of Pennsylvania). Taken from Brezinski, 1989a, Figure 9.

small area of southern Somerset County, Pennsylvania and Garrett County, Maryland. It represents a depositional episode distinct from the Loyalhanna as indicated by the red siltstone that invariably separates the Deer Valley from the Loyalhanna.

Savage Dam Member

Overlying the Deer Valley Limestone and separating it from the Wymps Gap Limestone is an interval of red and green clastics 40-200 feet thick. Brezinski (1989a) named this unit the Savage Dam Member of the Greenbrier of Maryland, but it is considered part of the Mauch Chunk Formation in Pennsylvania (Figure 54). The Savage Dam Member is characterized by interbedded white sandstones; red and green, fossiliferous, calcareous shale; redbrown, mudcracked siltstone and shale; and several thin (<3 feet), gray and variegated limestones. The white sandstones and fossiliferous shales represent littoral sands and shallow marine deposits, respectively. These marine deposits are interbedded with the mudcracked siltstone lithologies, suggesting cyclic marine and nonmarine conditions (Brezinski, 1989c). As many as 6 marine/nonmarine cycles can be recognized (Brezinski, 1989c) (Figure 55).

The Savage Dam Member thickens from west to east, concurrently with thinning of the overlying Wymps Gap Limestone.

		LEAVE STOP 6. TURN RIGHT onto T 378.
2.7	40.7	**STOP SIGN. BEAR RIGHT** onto SR 2004.
0.2	40.9	**TURN LEFT** into Keystone Lime Quarry.

STOP 7. KEYSTONE LIME COMPANY SAVAGE QUARRY ELK LICK TOWNSHIP, SOMERSET COUNTY, PENNSYLVANIA

Discussant: William Edmunds.

THE SUB-LOYALHANNA UNCONFORMITY AND REGIONAL ASPECTS OF MIDDLE AND UPPER MISSISSIPPIAN STRATIGRAPHY

Introduction

As is frequently the case in southwest Pennsylvania, aggregate produced at Savage Quarry comes from the arenaceous limestone of the Loyalhanna Member of the Mauch Chunk Formation. Here at Savage Quarry, however, quarrying has continued below the Loyalhanna into a sequence of variegated, non-calcareous sandstones. In doing so they have crossed a physically obscure, but stratigraphically profound regional unconformity which extends throughout most of the central Appalachians.

The unconformity underlies the Greenbrier Limestone Group in southern and central West Virginia and the equivalent Maxville in Ohio. In Pennsylvania, Maryland, and northern West Virginia it occurs at or shortly below the base of the Loyalhanna Member of the Mauch Chunk Formation. The Loyalhanna is a far-reaching tongue of the Greenbrier. Despite its apparent physical obscurity, the unconformity is generally recognized to represent a large amount of missing time. What seems to be less well recognized is that the unconformity very likely represents the disposal of a considerable sequence of rock and that such loss has greatly affected the perception of the age, areal extent, and correlations of the Mauch Chunk delta.

Butts' (1924) original interpretation of the age of the Loyalhanna as late Meramecian (St. Genevieve) is still accepted. Throughout southwest Pennsylvania and adjacent Maryland and West Virginia the Loyalhanna usually rests unconformably upon the late Osagian-age upper surface of the Burgoon Sandstone Member of the Pocono Formation or equivalent. In north-central and northeastern Pennsylvania and occasionally in limited areas elsewhere, the Loyalhanna rests unconformably on a thin remnant of the basal Mauch Chunk Formation which is conformably transitional with the underlying Pocono. This basal Mauch Chunk is scarcely younger than the top of the Pocono and much older than the overly Loyalhanna Member. Southern Somerset County is interpreted as one of those other "limited areas" where a remnant of the base of the original Mauch Chunk is preserved. The lower variegated sandstone in the following description of the Savage Quarry exposure is interpreted as basal Mauch Chunk Formation:

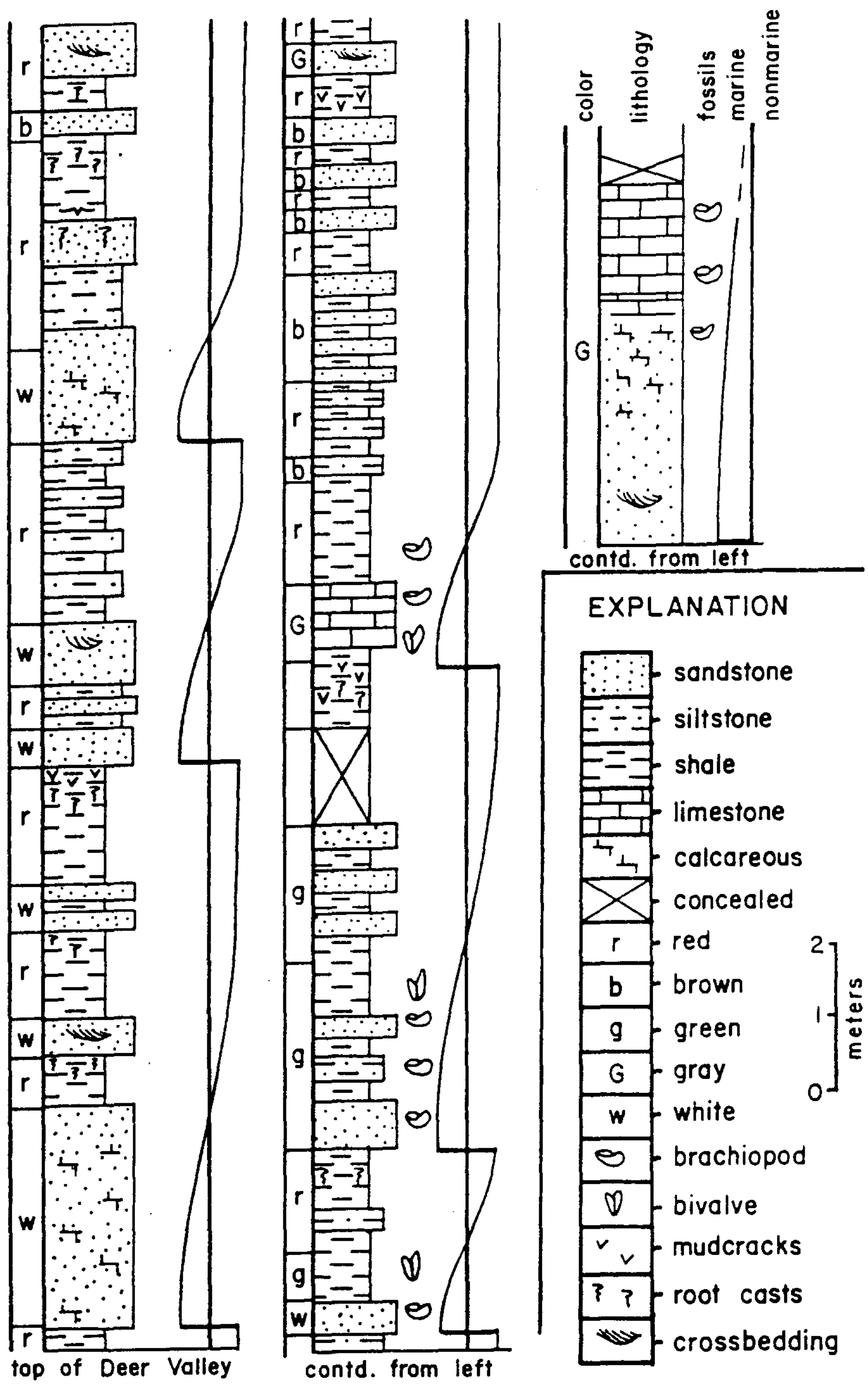


Figure 55. Shallowing-upward cycles of the Savage Dam Member at its type locality, Garrett County, Maryland. Taken from Brezinski, 1989c.

1. **Loyalhanna Member arenaceous limestone** (35 feet +), grayish red (5R4/2-10R4/2), some medium gray (N5); very fine- to medium-grained sand fraction; high-angle pi or omikron crossbeds (broad festoons) in 2- to 5-foot sets, pronounced fluted weathering. Classified as arenaceous calcarenite by Adams (1970), pelloidal (?) grain-stone by Brezinski (1984), and protoquartzitic sparry intraclastic calcarenite by Hoque (1965). Basal contact sharp.
2. **Calcareous sandstone** (0.6 to 1.0 foot), color banded medium dark gray (N4), medium light gray (N6), grayish brown (5YR3/2), olive gray (5Y4/1), and dark yellowish orange (10YR6/6); fine to medium grained; few thin shale stringers, single bed. Lower contact gradational but irregular.
3. **Sandstone** (0.4 to 1.1 feet), medium gray (N5), grayish brown (5YR3/2), and dark

greenish gray (5GY4/1); fine to medium grained; numerous grayish-red, dusky red, pale red, moderate pink, pale yellowish-orange, and light greenish-gray shale clasts; contorted bedding; slightly calcareous in spots; single bed. Basal contact sharp and ragged.

4. **Sandstone** (4.0 to 4.5 feet), dark gray to gray black (N3 to N2), fine to medium grained; rounded quartz grains set in matrix of black Fe/Mn minerals and mica; upper part contorted with possible carbonized roots; few small shale chips; minor calcareous spots. Basal contact sharp. Regional unconformity assumed to be associated with this unit.
5. **Sandstone** (45 feet +), medium light gray (N7), medium light bluish gray (5YR6/1), light brownish gray (5YR6/1), light olive gray (5Y6/1), grayish red (5R4/2 and 10R4/2), and grayish red purple (5RP4/2); colors in beds, zones, and bands; fine to medium grained; sub-round grains; scattered mica; 1- to 4-foot-thick, planar, lenticular, and wedge bedding; crossbedding; wavy bedding; cut and fill; contorted bedding and slump structures; local grayish-red, greenish-gray, and gray-black shale clasts. Tends to weather into flaggy beds. Local 5-foot-thick zone of silt shale near top, light olive gray (5Y6/1) and pale red (5R6/2) with very fine-grained sandstone lenses up to 0.5 foot thick (west end of quarry).

Here and throughout southern Somerset County, the sandstones found below the Loyalhanna can be distinguished from normal Burgoon Sandstone by their striking variegated colors (see Flint, 1965). The red, brown, purple, and bluish shades contrast sharply with the almost universal medium light gray to very light gray or very light greenish gray of unweathered Burgoon. Some other characteristics, such as the fine grain size, bedding and cross-bedding style, and flaggy weathering, while not outside the range known to occur in the Burgoon, are not quite typical of that unit.

Assuming that the variegated coloration of these sandstones is primary, rather than secondary mineralization associated with ancient groundwater activity associated with the overlying erosion surface, it is reasonable to consider the possibility that they are basal Mauch Chunk. It might also be noted that in the type area of the Mauch Chunk Formation in eastern Pennsylvania, the conformably transitional beds between Pocono and Mauch Chunk are included in the Mauch Chunk. In that area, a sequence of variegated sandstones, such are seen here, would normally be included in the Mauch Chunk.

A complete measurement of the variegated sandstones is given in the record of the Marker No. 1 gas well between footage 529 and 589, 7.2 miles (11.6 km) northeast of the Savage Quarry (Flint, 1965, p. 235). The 60-foot (18 m) interval is described as a sandstone which "...at 529 is predominantly various shades of red with a minor amount of green. The green sandstone increases in amount downward as the various shades of green decrease so that at 589 the sample consists entirely of light greenish-gray sandstone". Although the contact between the Burgoon and variegated sandstone has not been observed directly, the sequence described in the Marker well seems to be gradational, suggesting a conformable contact.

LEAVE STOP 7. TURN LEFT onto SR 2004.

1.1 42.0 **PARK IN PULL-OFF AREA ON LEFT.** Walk across road to deep mine.

STOP 8. WYMPS GAP LIMESTONE MINE, MT. DAVIS.

Discussant: David K. Brezinski.

At this stop we will examine an exposure of the Wymps Gap Limestone Member of the Mauch Chunk Formation.

GENERAL DISCUSSION

The Wymps Gap Limestone (formerly called the Greenbrier Limestone of Pennsylvania) was named by Flint (1965) for exposures near the Pennsylvania/West Virginia border south of Uniontown, Pennsylvania. In adjacent Maryland the Wymps Gap Limestone is considered the uppermost member of the Greenbrier Formation (Figure 56). To the south the Wymps Gap Limestone thickens rapidly (Figures 57, 58). Along with the thickening of the Wymps Gap is a thinning of the

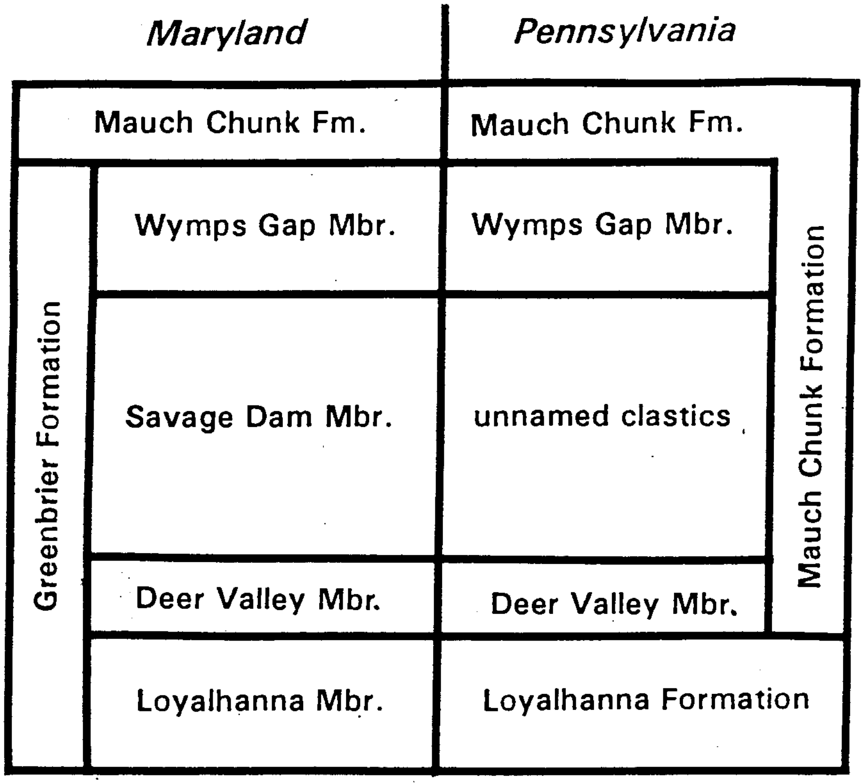


Figure 56. Comparison of nomenclatural differences for Upper Mississippian strata of western Pennsylvania and western Maryland.

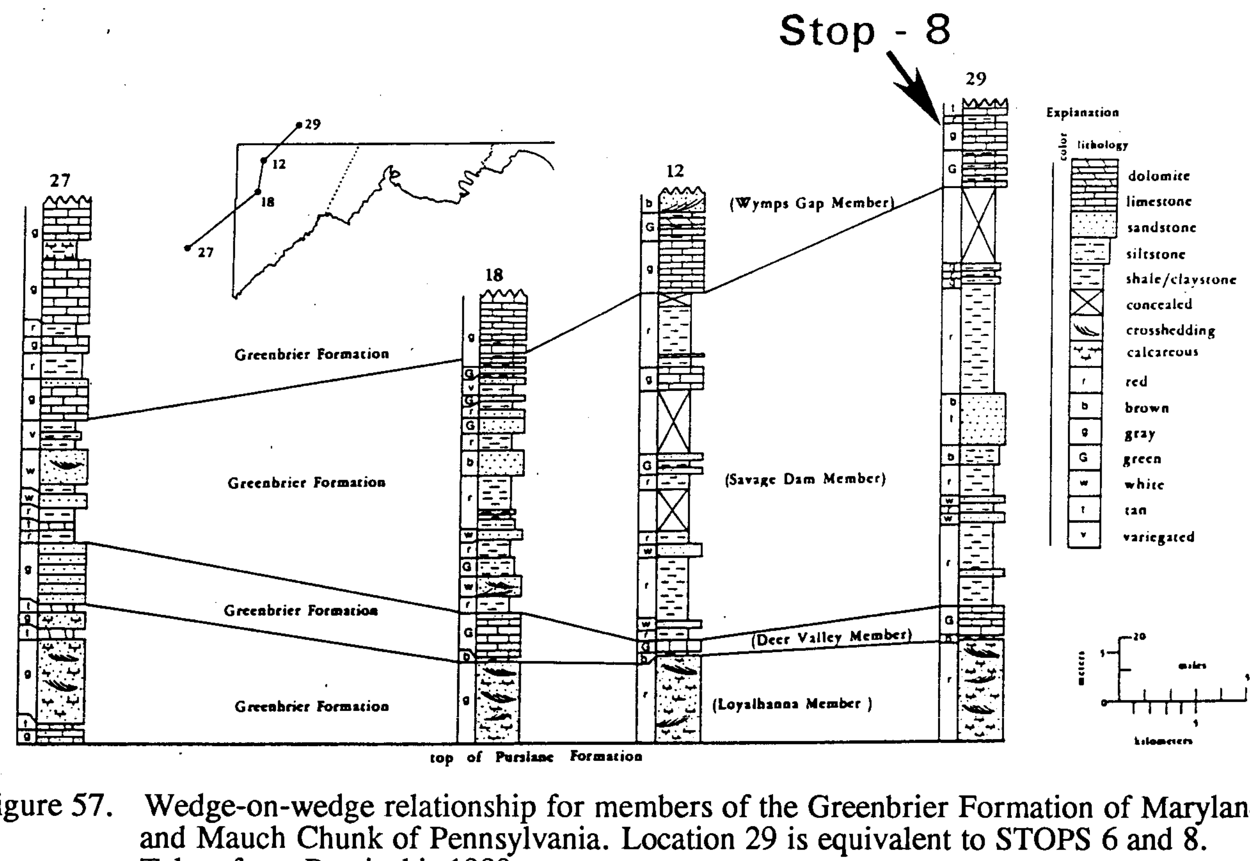


Figure 57. Wedge-on-wedge relationship for members of the Greenbrier Formation of Maryland and Mauch Chunk of Pennsylvania. Location 29 is equivalent to STOPS 6 and 8. Taken from Brezinski, 1989a.

underlying clastics of the Savage Dam Member.

At this stop the Wymps Gap consists of a light-gray, peloidal and oolitic grainstone. Figure 59 shows that much more of the underlying Wymps Gap is present than is currently

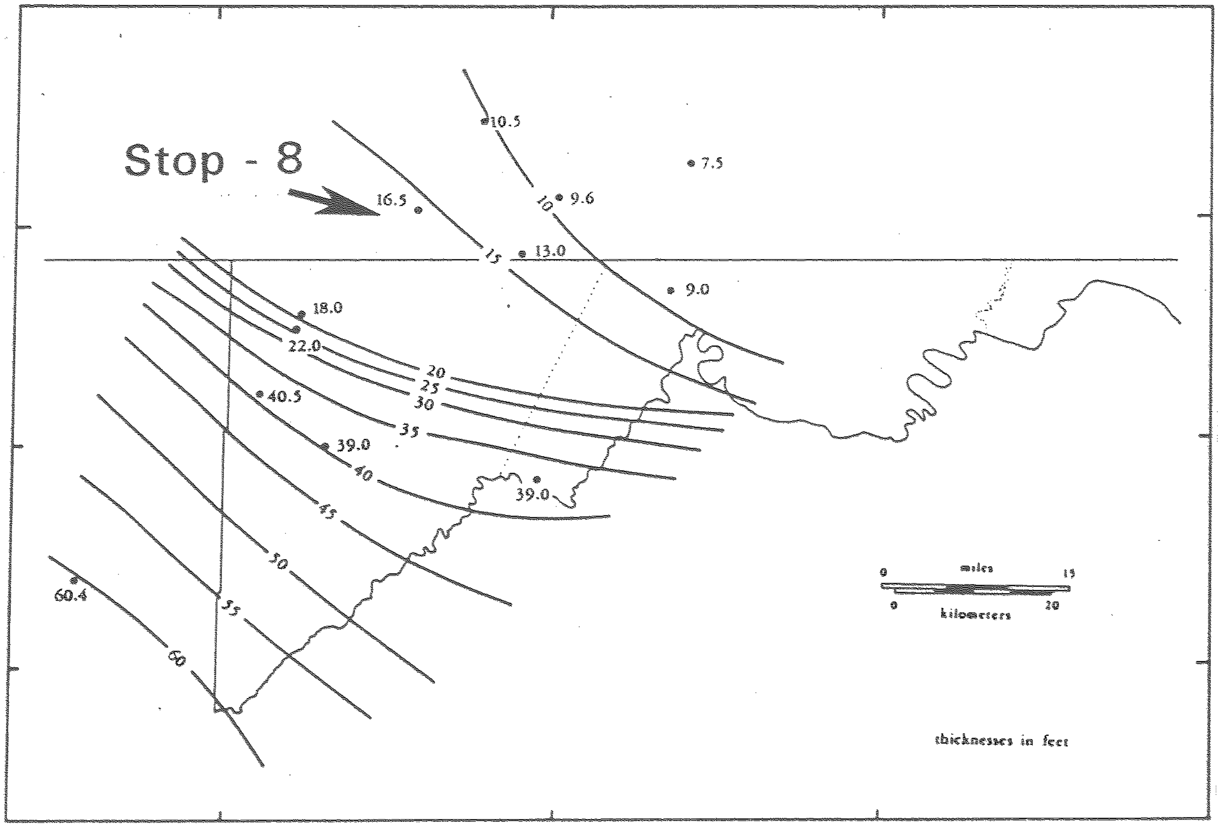


Figure 58. Isopach map of the Wymps Gap Limestone Member. Taken from Brezinski, 1989a.

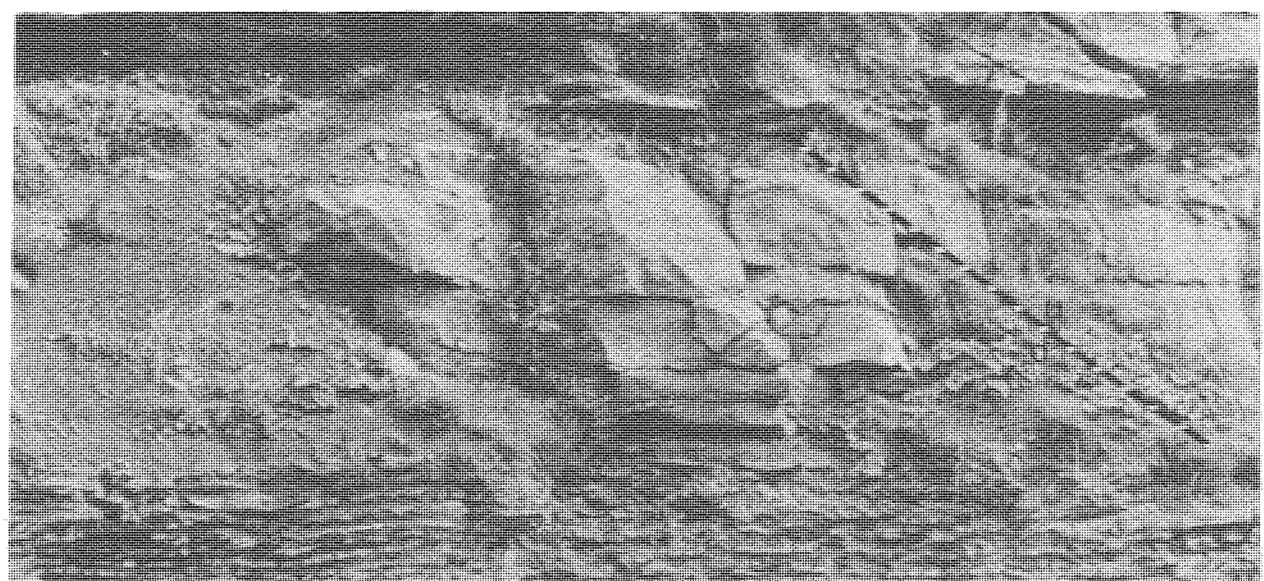


Figure 59. Wymps Gap Limestone at STOP 8 as exposed in 1982.

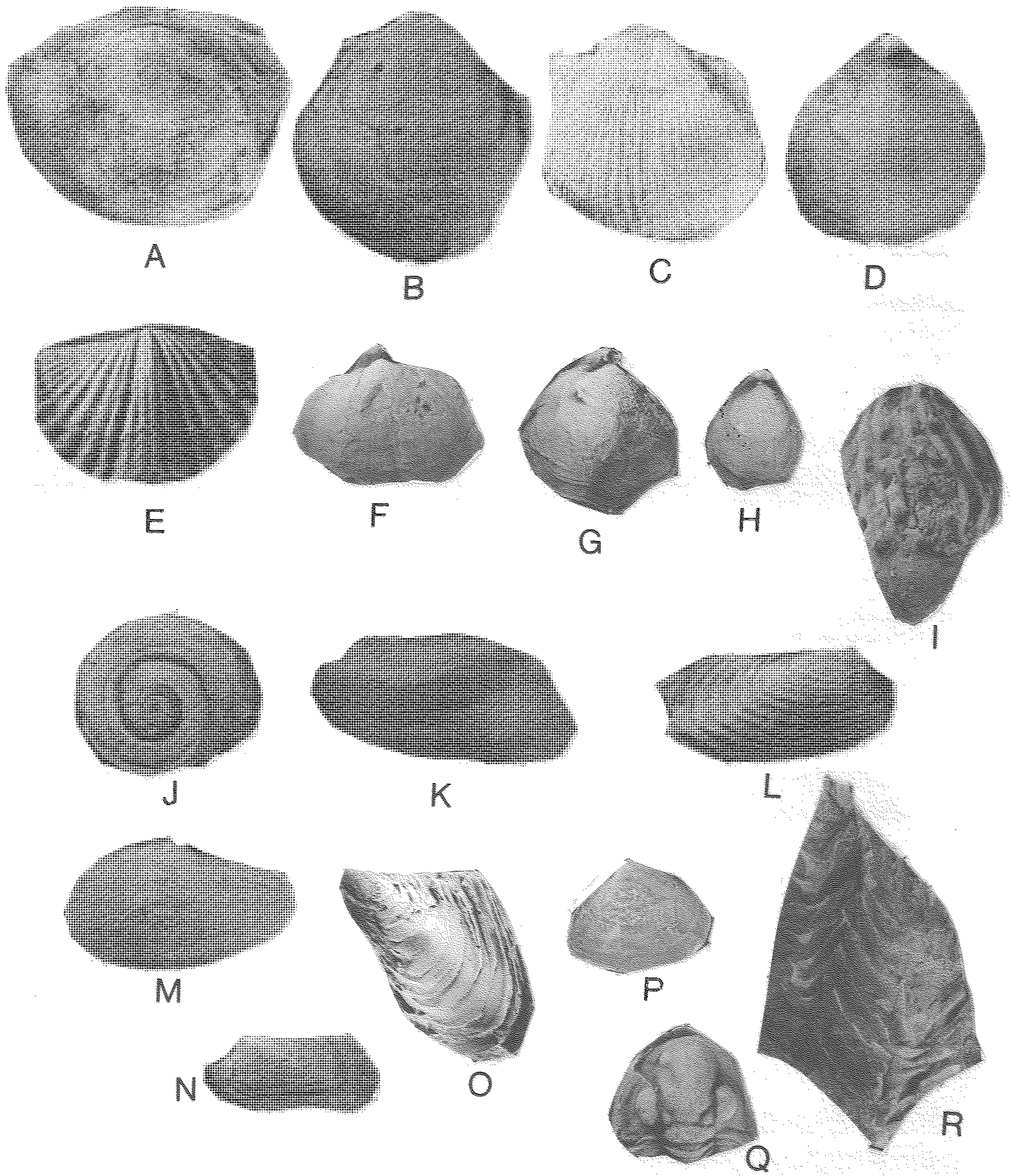


Figure 60. Common fossils of the Wymps Gap Limestone. A. *Orthotetes*, x1.0; B. *Ovatia*, x2.5; C. *Diaphragmus*, x2.0; D. *Martinia*, x0.75. E. *Arthracospirifer*, x1.5; F. *Phrycodothyris*, x1.0; G. *Composita*, x1.0; H. *Girtyella*, x1.5; I. *Platycrinites*, x2.5; J. *Straparollus*, x1.5; K. bivalve, x1.0; L. *Wilkingia*, x0.75; M. *Paleoyoldia*, x2.5; N. *Goniophera*, x2.0; O. *Septimyalina*, x1.5; P. nuculid bivalve, x1.5; Q. *Paladin*, x2.5; R. *Archimedes*, x0.5.

exposed. These concealed strata consist of thinly interbedded fossiliferous limestones and calcareous shales. The fossils are characteristic of the Upper Mississippian (Figure 60). This part of the Wymps Gap probably represents transgressive beds. The thin limestones represent storm deposits formed in a peritidal environment.

The main limestone ledge represents shallow tidal shoal deposits. These carbonate sands are extremely pure because they are so well winnowed. To the southwest the Wymps Gap becomes dark gray and shaly. There the Wymps Gap was deposited in a deeper subtidal environment, well below wave base. To the north and east the Wymps Gap is very thin and consists of variegated, nodular-bedded, shaly limestone and was probably formed in a restricted circulation lagoon formed landward of the sand shoal of the current stop (Figure 61) (Brezinski, 1989c).

Overlying the main limestone ledge are several thin limestone wedges interbedded with calcareous shale. These strata are only sparingly fossiliferous and contain mudcracks. These interbedded strata represent regressive deposits.

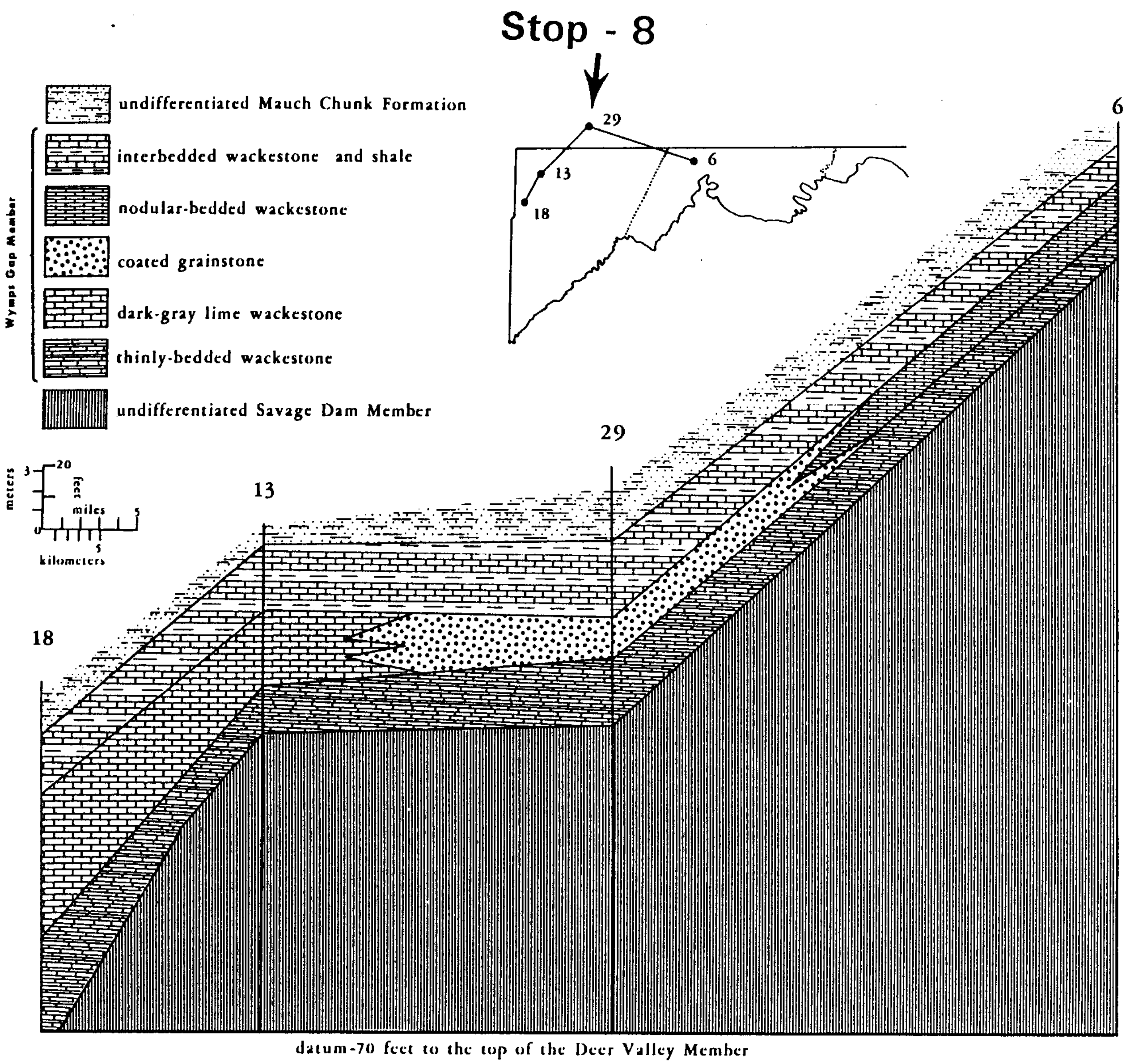


Figure 61. Lithofacies variation within the Wymps Gap Limestone. From Brezinski, 1989a.

LEAVE STOP 8. PROCEED AHEAD on SR 2004.

0.2 42.2 View of Deer Valley Lake at elevation 2653 feet on left. Note in particular the the irregular topography of the foreground slope leading to the lake. Is it erosional? Is it constructional? If the latter, what does it represent?

0.8 43.0 Deer Valley YMCA camp on left. Note the variable abundance of Pottsville float blocks on the left slope ahead.

0.7 43.7 Approximate Mississippian-Pennsylvanian contact.

0.1 43.8 Road on right leads to Mt. Davis Natural Area.

0.1 43.9 Baughman Rocks on left.

0.2 44.1 **TURN RIGHT** into Mt. Davis State Forest Picnic Area.

STOP 9A. MT. DAVIS PICNIC AREA, BAUGHMAN ROCKS, AND LUNCH.
Discussants: G. Michael Clark and Edward J. Ciolkosz.

The procedure for this stop will be as follows: After disembarking from the buses, attendees will assemble for comments about the area from Michael Clark and Edward Ciolkosz.

When discussion is completed, lunch will be served. After attendees have finished eating, they are encouraged to walk to Baughman Rocks to see the excellent rock city and some of the best Opferkessel present in Pennsylvania. Following that, attendees may either wait for bus transport or walk the trail (0.6 mile) to the Mt. Davis observation tower. The buses will remain at the lunch site for about 1 hour (departure time will be announced). They will then proceed to Mt. Davis and remain there for about 3/4 hour. The buses will depart from the Mt. Davis parking lot to proceed on the remainder of the trip.

Attendees who wish to view the area from atop the observation tower should be aware that the tower has a limited capacity and that it will take some time for all to visit the tower. Clark and Ciolkosz will show the patterned ground features near the tower to those who are interested.

There is no formal stop description for this stop. Mt. Davis has numerous plaques that provide information (some are a little dated——note reference to the Appalachian Revolution—— and some items come from unknown sources——the High Point peneplain). There are several pages in the chapter by Clark and Ciolkosz that are relevent or directly related to Mt. Davis: Present-Day Climate, p. 42-45; Vegetation, Synopsis, p. 48; Weathering, p. 50; Soils, p. 53-55; Fracturing, p. 57; Cold-Climate Geomorphology, p. 62-74 with emphasis on Sorted Patterned Ground, p. 67-71 and Cryoplanation Summits and Terraces, p. 72-74.

		LEAVE STOP 9. TURN LEFT onto SR 2004.
0.3	44.4	**TURN RIGHT** into the Mt. Davis Natural Area.
0.6	45.0	**TURN LEFT** at sign for "Mt. Davis highest point in Pennsylvania elevation 3213 feet". Proceed to parking area.

STOP 9B. MT. DAVIS.

		LEAVE STOP 9B. TURN RIGHT and return to SR 2004.
0.6	45.6	**STOP SIGN. TURN RIGHT** onto SR 2004.
0.1	45.7	Baughman Rocks on left.
0.2	45.9	Mt. Davis State Forest Picnic Area on right.
0.7	46.6	Leave Forbes State Forest as route crosses pipeline.
0.8	47.4	View ahead of topography eroded on the Berlin syncline.
0.4	47.8	On the left is a head of drainage with abundant colluvial fill.
0.2	48.8	On left ahead is an excellent view of the Berlin syncline valley. Note the cuesta with slope dipping east into the syncline (see Figure 28, p. 56).
0.3	49.1	**TURN LEFT** at T-intersection staying on SR 2004.
0.8	49.9	**TURN LEFT** onto SR 2005 at the satellite dish.
0.9	50.8	Note deep dissection in small filled valley on left.
0.3	51.1	Enter Summit Township. Cross Elk Lick Creek.
0.4	51.5	Cross Elk Lick Creek.
1.5	53.0	**STOP SIGN. TURN LEFT** onto SR 2004, towards Meyersdale.
1.1	54.1	Sugar shack on left.
1.4	55.5	Somerset County fairgrounds on left.
0.1	55.6	Cross Elk Lick Creek.
0.2	55.8	Cross railway tracks.
0.1	55.9	Cross Casselman River.
0.2	56.1	**STOP SIGN. TURN RIGHT** onto US 219 South.
0.2	56.3	**TURN LEFT** onto Main Street at the school. Follow Main Street through downtown Meyersdale.
0.3	56.6	Cross active railroad tracks.
0.1	56.7	Cross inactive railroad tracks. Street bears right and becomes SR 2025.
0.4	57.1	West flank of the Deer Park anticline on the right.
0.3	57.4	Flaugherty Creek water gap on right.
1.3	58.7	**T-INTERESECTION. TURN LEFT** following SR 2025.
0.3	59.0	**TURN LEFT** onto SR 2026 at Y-intersection.
0.2	59.2	Maple Valley Park, Meyersdale Lions Club on right.
0.4	59.6	Cross Blue Lick Creek.
0.5	60.1	Valley on right clogged with colluvium.

0.3 60.4 **TURN RIGHT** onto SR 2027 at Y-intersection.
0.1 60.5 Reclaimed strip mines on Pittsburgh, Blue Lick, and Redstone coal seams on right.
0.8 61.3 Cemetery on right.
1.4 62.7 SR 2027 bears left. **TURN RIGHT** onto Cumberland Road (T 415).

STOP 10. CRONER STRIP MINE: POINT BARS, CREVASSE SPLAYS, AND LIMESTONE

Discussants: James R. Shaulis, Viktoras W. Skema, and Jane R. Eggleston.

Surface coal mines
are very ephemeral,
they are likely to change
just like the weather will.
One day they're here,
the next day they're gone,
you have to look fast,
they don't last too long.
But hopefully for us,
we'll get here in time,
if not, not to worry,
we'll just use a strip mime.

James R. Shaulis and Viktoras W. Skema

INTRODUCTION

The Croner Mine is a multiple-seam strip-mining operation that mines the Blue Lick and Redstone coals in the Berlin syncline south of Pine Hill (Figure 62). The mine has uncovered several unique sedimentological features that provide an unusually detailed look at the nature of deposition occurring in this area of the Appalachian Basin during the late Pennsylvanian. The Croner highwall contains the alternating sequence of coals and fresh water limestones separated by siliciclastics ordinarily found in this part of the geologic section (Figure 63B). However, both the Blue Lick and the Redstone coals are split by extraordinary deposits of fluvially transported sediments. A migrating point bar associated with a single-story, channel deposit splits the Blue Lick coal. This has over 100 well-preserved individual point-bar deposits of lenticular sandstone and silt shale. Each is highlighted by a thin mantle of coal and carbonaceous clay shale (Figure 64). Higher in this same highwall, the Redstone coal is split by a thick crevass splay deposit of sandstone and silt shale. The highwall cuts perpendicularly through the entire width of the deposit. In a distance of 1300 feet along the cut, the split expands from a several-inch-thick claystone parting to a 20-foot-thick deposit of sandstone and silt shale and then back again to a thin parting. Both of these sedimentary features are exceptional in their level of detailed preservation and exposure.

POINT-BAR DEPOSIT IN THE BLUE LICK COAL

The Blue Lick coal in the Croner highwall is split uniformly along the entire length of the cut by 8 feet of siliciclastics. Internally this split consists of 110 sandstone and silt-shale lenses dipping 15°-25° to the south and east. They are sigmoidally shaped and have coarsening upward grain size. Each of these lenses, termed scroll bars, is 2.5 to 3.5 feet thick. At the south end of the cut, the dip angle decreases rapidly and the unit consists primarily of trough crossbedded sandstone lenses. Slumping occurs to the right of these trough-shaped beds at the extreme south end of the highwall (Figure 65). With few exceptions, these features correspond well to the internal geometry that would be expected of the point bars, the channel fill, and the cutbank that would develop in a small, highly sinuous, meandering river system that transports most of its sediment load by suspension. Such rivers flow along an extremely low gradient and have a depth to width ratio of less than 10. They deposit excess sediment load along the channel banks and erode the material in the streambed (Schumm, 1963).

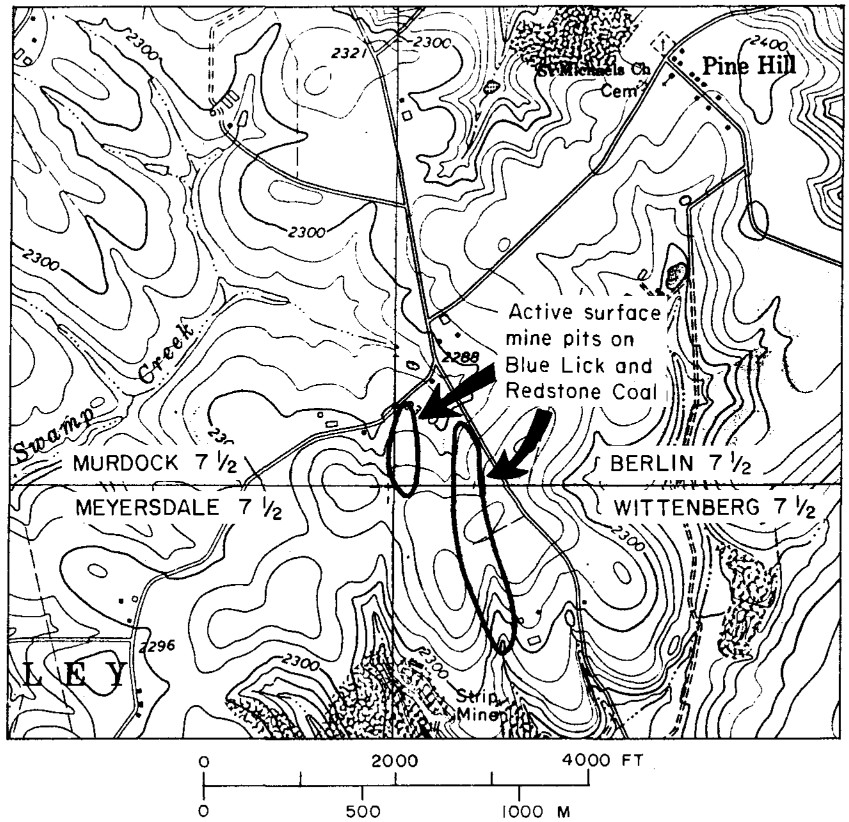


Figure 62. Location of active surface mine pits in the Croner Blue Lick mine-permit area.

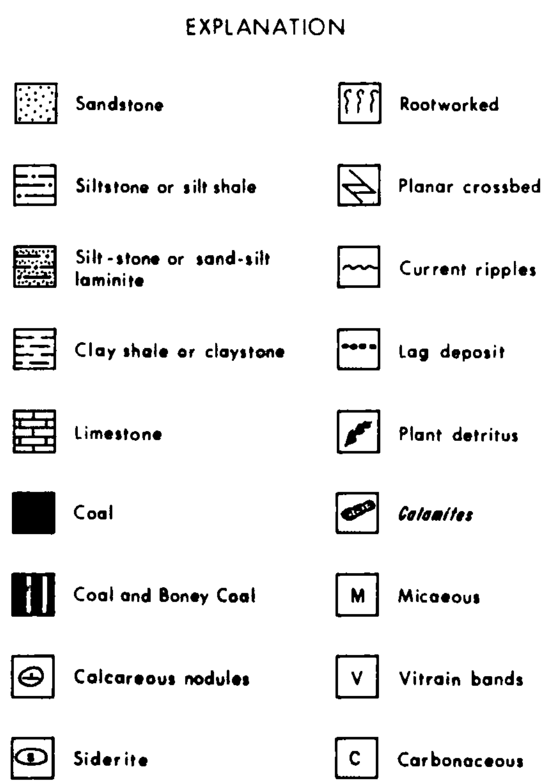
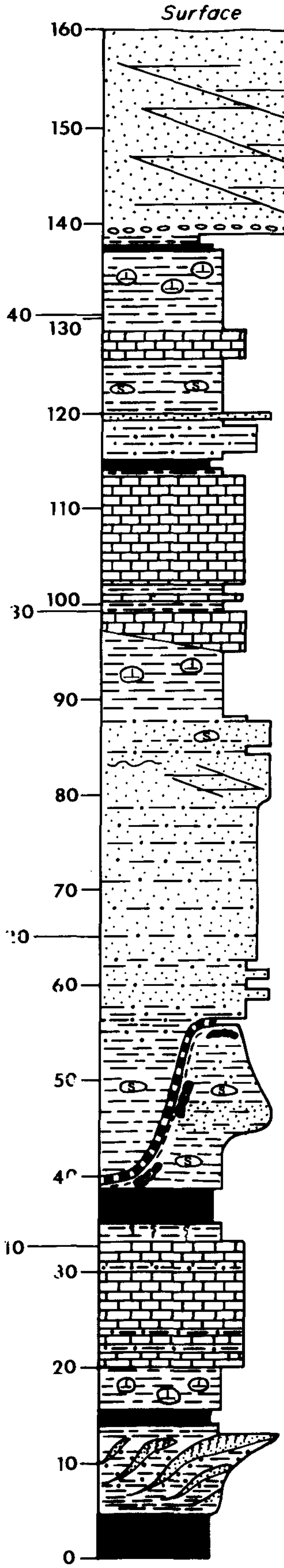


Figure 63A. Explanation of symbols used in Figures 63B, 67, and 68.



UNIT NUMBER	STRATIGRAPHIC NAME OF UNIT	DESCRIPTION	DEPOSITIONAL ENVIRONMENT
19	Sewickley Ss.	Medium- to coarse-grained sandstone, lag at base	Fluvial channel
18		Carbonaceous shale	Overbank, backswamp
17	Upper Sewickley coal	Bony claystone	Periodically flooded peat swamp
16		Clay shale w/ limey nodules	Interdistributary pond
15	Benwood L.S.?	Silty limestone w/ shale clasts	Freshwater lake
14		Clay shale w/ siderite	Backswamp or overbank
13		Siltstone capped by thin sand	Levee or crevasse splay?
12	Sewickley coal	Coal	Periodically flooded peat swamp
11	Fishpot L.S.	Dolomitic limestone	Freshwater lake
10		Claystone w/ calcareous veins (calcite-filled desiccation cracks) and nodules	Interdistributary pond, ephemeral
9		Coarsening-upward sequence of clay and silt shale containing siderite, overlain by interbedded siltstone and sandstone, plants throughout	Overbank levee deposits overlain by channel deposits
8	Redstone coal ub	Coal and bony coal	Periodically flooded peat swamp
7		Coarsening-upward sequence of clay, silt, and sand, and a generally fining-upward sequence of similar material within the coal split, both contain siderite and plants	Crevasse splay
6	Redstone coal lb	Coal and rootworked underclay	Sediment-starved peat swamp Seat earth
5	Redstone L.S.	Dolomitic limestone w/ few thin silt-shale interbeds	Freshwater lake deposits interrupted by splays
4		Claystone w/ limestone nodules	Interdistributary pond
3	Blue Lick coal ub	Coal and bony coal	Periodically flooded peat swamp
2		Uniform coarsening-upward sequences of clay, silt, and sand capped by thin coaly to carbonaceous layers	Cyclic point bar/channel bank deposit
1	Blue Lick coal lb	Coal	Inactive peat swamp

Figure 63B. Composite columnar section of Upper Pennsylvanian rocks (lower Monongahela Group) exposed in the Croner surface mine (395234/785950-395217/785944).

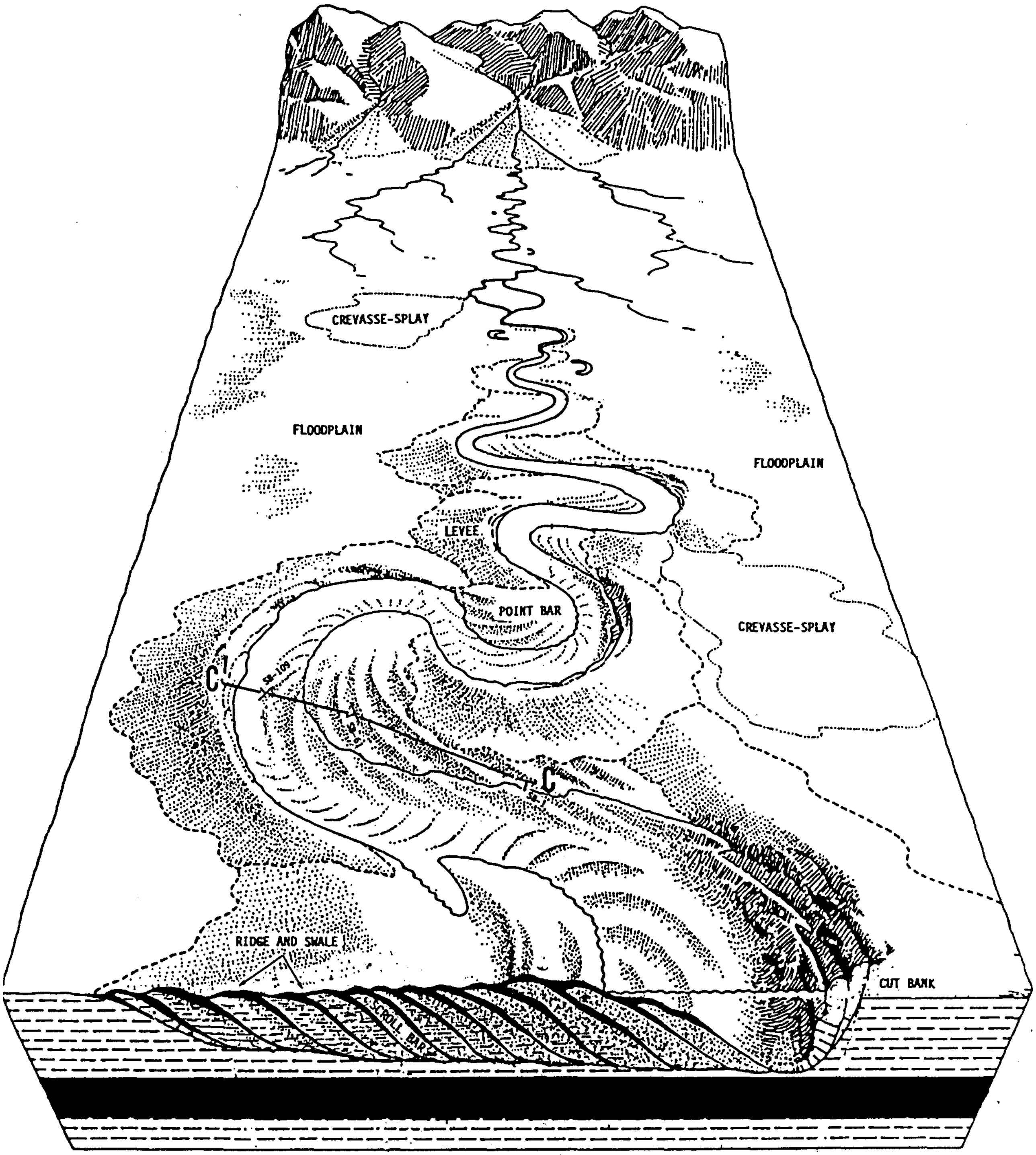


Figure 64. A skematic diagram of a point-bar deposit showing the location of the Croner Blue Lick highwall, represented by C-C' (modified from Smith, 1987).

Areally, point bars along a meandering river are crescent shaped bodies of sand and silt deposited in the slower flowing water along the inner side of the bends (Allen, 1984; Smith, 1987). They are often asymmetrically longer on the downstream side of the bend where flow velocity is slowest and more sediment is deposited. Grain size is usually finer in this downstream area and increases in an up-stream direction toward the point. The upper surface of the point bar is covered with a concentric pattern of slightly elevated ridges separated by small swales (Figure 64). The ridges form at the highest points of individual scroll bars. Internally, each of these scroll bars dips perpendicularly from its curved axis toward the adjacent channel. A linear cross section, such as the Croner highwall, cut through the long

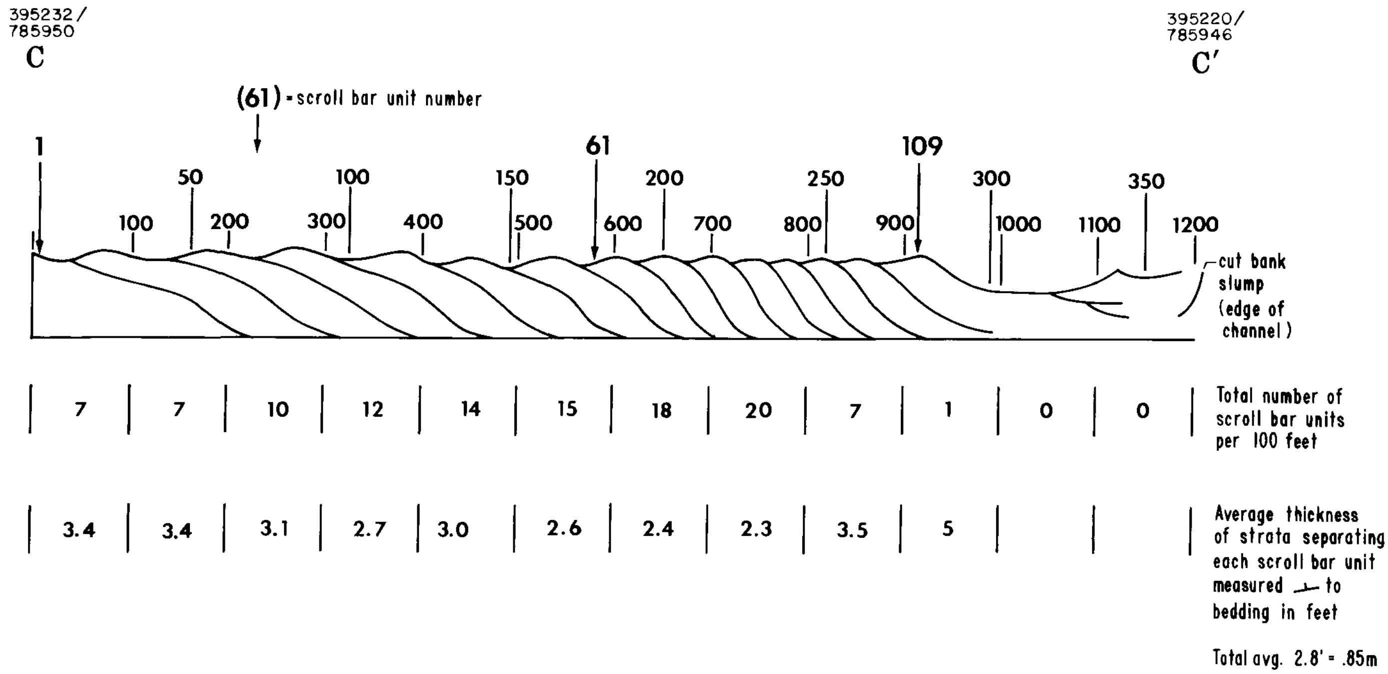


Figure 65. Skematic drawing of a point bar deposit occurring in the Croner Blue Lick mine. Corresponding tables indicate the frequency and thickness of scroll-bar units. See Figure 64 for location of cross section relevent to stream position.

axis of the point bar deposit would intersect each of these concentrically arranged scroll bars at a progressively different angle and would result in an ever changing apparent dip. The relative position of the Croner highwall approximates line C-C' (Figure 65) shown on Figure 64. As expected, apparent dip of the scroll bars increases from left to right to just beyond scroll bar 63, at which point the cut is perpendicular to the bars, and the dip seen in the highwall is the actual dip (Figure 66). Beyond this point, dip angles decrease again slightly, and the highwall cuts obliquely through the channel. Grain size generally increases from left to right in the highwall (Figures 67 and 68). This would also be expected in a typical point bar, because it would be the up-stream direction toward the point.

These features are all typically associated with point bar deposition along a slow, meandering river. However, several other features displayed in this cut are not. The one truly unique characteristic of this deposit is the thin mantle of coal and carbonaceous shale draped over each individual point bar deposit. These coals cover the top of the scroll bars and extend 1/4 to 1/3 of the way down the sloping upper surfaces of each bar. They are typically less than 0.75 inch thick with approximately 0.25 inch of non-banded coal at the bottom overlain by bone coal which contains increasingly more clay upward. Laterally, the coals thin down the bar slope. The lower 3/4 to 2/3 of the sloping upper surface of each scroll bar is covered with a thin layer of carbonaceous clay shale. The carbon content of 5 samples of the basal, non-banded coal ranged from 73.9% to 75.6%. This places these coals in the medium-volatile bituminous rank. Ash content ranged from 16.9% to 42.0% and averaged 33.2% (Table 11). The values indicate that, though the coals contain clay, an appreciable thickness of the basal portion of the coals blanketing the point bars falls into the category of coal and not bone coal. Portions of the sandstone directly beneath the coals are rootworked. This suggests that the coal was formed, at least in part, from plants growing in place. The roots appear to be exclusively from *Calamites* plants. Large, tree-like *Calamites* were over 30 m tall and grew in coal swamps along with giant lycopods. Smaller varieties commonly grew in thick stands along rivers (Gillespe and others, 1978), the setting believed to have been present during deposition of the point-bar coals present in the Croner highwall. These plants had a main root that resembled their stems and grew horizontally, close to the surface. Small, short, secondary rootlets grew at right angles to the main root (Figure 69). These plants quickly colonized each successive scroll-bar deposit and protected the bars from erosion during subsequent floods. The end result was the unique preservation of a normally

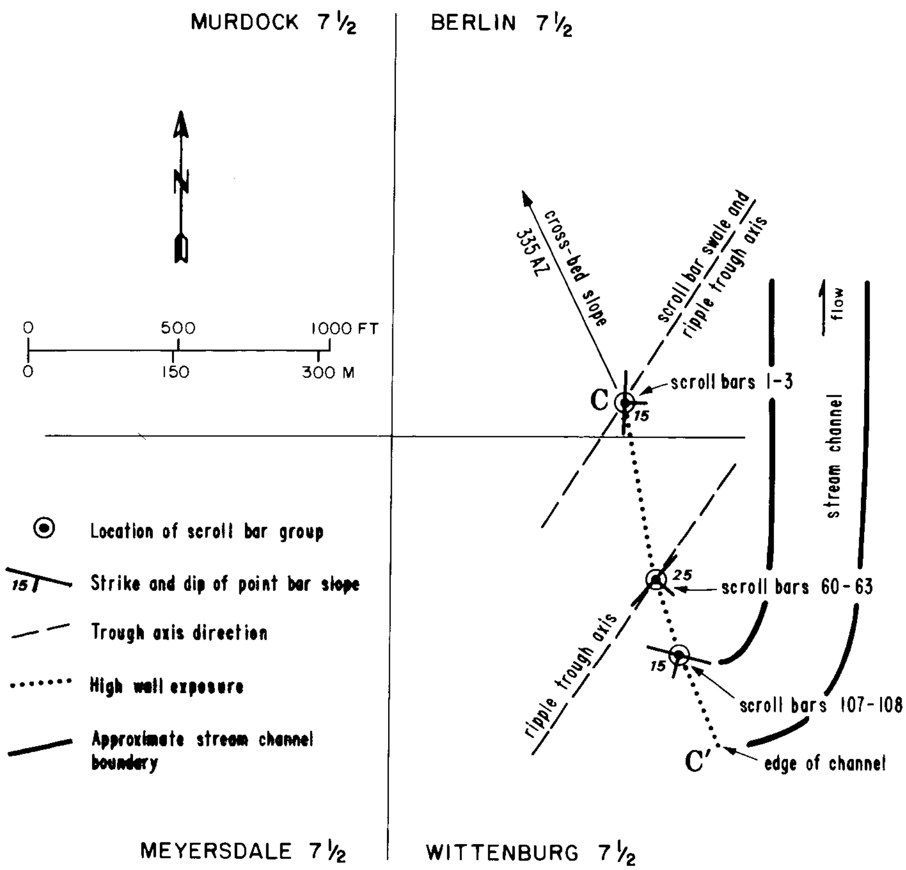


Figure 66. Location and average orientation of scroll bar slopes and associated current structures in Croner's Blue Lick mine.

Table 11. Thickness and chemical-analysis data of coal deposits in the Croner Blue Lick mine.

UNIT	Thick-ness (feet)	Dry Base Ash	Dry Base Sulfur	Dry Ash-Free Fixed Carbon	Dry Ash-Free BTU
Sewickley Coal	1.1	11.8	2.6	68.5	15565
Redstone (upper bench)	1.1	15.9	1.0	70.0	15303
Redstone (lower bench)	3.6-3.9	10.0	1.2	69.5	15403
Blue Lick (upper bench)	3.5	16.2	3.5	72.0	14969
Scroll Bar No. 1	0.05	42.0	3.5	74.2	14276
Scroll Bar No. 61	0.05	40.0	2.0	75.6	14657
Scroll Bar No. 79	0.05	16.9	3.8	73.8	14576
Scroll Bar No. 86	0.05	32.8	3.5	75.1	14881
Scroll Bar No. 104	0.05	34.5	3.0	73.9	14674
Blue Lick (lower bench)	3.2	23.5	2.7	69.4	15118

UNIT	Thickness (feet)	$CaCO_3$ (%)	$MgCO_3$ (%)	Total $CaCO_3$ & $MgCO_3$ (%)
Fishpot Limestone	12.3	66.2	12.3	78.5
Redstone Limestone	10.8	67.3	11.5	78.8

very unstable deposit.

Another unusual feature of this exposure is the coarsening upward trend of grain size in each point bar deposit. A fining upward trend is usually reported as a characteristic of these deposits. A rare exception to this is the deposition occuring along the banks of westward flowing rivers in southeastern Australia where they cross the Riverine Plain, a broad flat alluvial plain. Reverse grading, or upward coarsening, has been observed in places along the Barwon River in this area (Taylor and Woodyer, 1978). These rivers are very sinuous and narrow with a low width to depth ratio. They generally carry extremely fine-grained sediment, mostly in suspension and in low concentrations much of the time. Deposition occurs mainly along the banks with the points and the lower portions of the bank receiving more sand than other areas. The rivers of southeastern Australia are probably some of the best examples of suspended load systems and, therefore, a good analog for the depositional setting of the point bars seen in the Croner Mine highwall. Taylor and Woodyer speculate that the reverse grading may be partly due to the source of the water and sediment mix at times of flooding. The supply of sediment deposited on the point bar has geographically different sources and varies in composition and concentration accordingly. Consequently, the arrival time of each type of sediment varies. In parts of the study area on the Barwon River, mud was deposited at the arrival of the river's sediment-load peak which preceeded by 14 days the arrival of the flood peak carrying sand. At the Croner point bar, the first sediment to arrive would have been the material eroded from the channel bottom and the cut-banks nearby. This would have been the clay and silt from the overbank deposits through which the river meandered. The sand would have come from a more distant source and arrived later.

The sequence of events thought to be responsible for the deposition and preservation of the remarkable point bar exposure seen at this stop are as follows (see Figure 70):

1. A major change in the direction of flow occured along a normally slow flowing, highly sinuous river meandering over a broad, relatively flat alluvial plain. A new permanent course was established through very fine-grained, over-bank deposits overlying a large thick peat deposit (Blue Lick). Similar to the rivers in southeastern Australia, coarser sediment, sand and silt, were deposited along the points of curves.
2. Flood conditions did not last long, and the river returned to its normal state of very low flow velocity and low sediment load. This condition lasted long enough for a a dense growth of *Calamites* to establish on the upper portions of the point bar which was subaerially exposed to submerged in shallow quiet water. The lower portion of the bar was in deeper and slightly faster water and was not vegetated. Only small amounts of clay and fine plant debris were deposited on that part of the bar.
3. The dense stand of rooted trees and the organic rich mud coating the lower portions of the bar protected the unconsolidated sand from being washed away during the next flood. Smith (1976) found that a 5-cm-thick root mat made a stream bank 20,000 times more resistant to erosion. In the early stages of this next flood the dense *Calamites* vegetation lining the concave cutbanks of bends and the straight stretches of river bank, was torn apart and floated downstream. Much of it was trapped by the vegetation growing on the quiet downstream part of the point bar thus creating an exceptionally thick tangle of vegetation. This vegetation was then buried by flood-born sediment. The first sediment to be deposited on top of the vegetated point was the mud from nearby banks. This was soon followed by sand from more distant parts of the river basin. This remarkably consistent cycle of low flow that allowed growth of dense vegetation followed by rapid sedimentation repeated itself more than 100 times as the point bar migrated laterally over 1000 feet.

CREVASSE-SPLAY DEPOSIT IN THE REDSTONE COAL

A crevasse-splay deposit is formed when a stream's natural levee is breached during a period of flooding and sediment is deposited in the area beyond the breach. At the site of the breach or "crevasse", sediment laden water "fans" or "splays" out in a delta-shaped pattern across the adjacent floodplain, perpendicular to the main channel. The coarser sediments are deposited closest to the breach in smaller newly formed channels while the finer

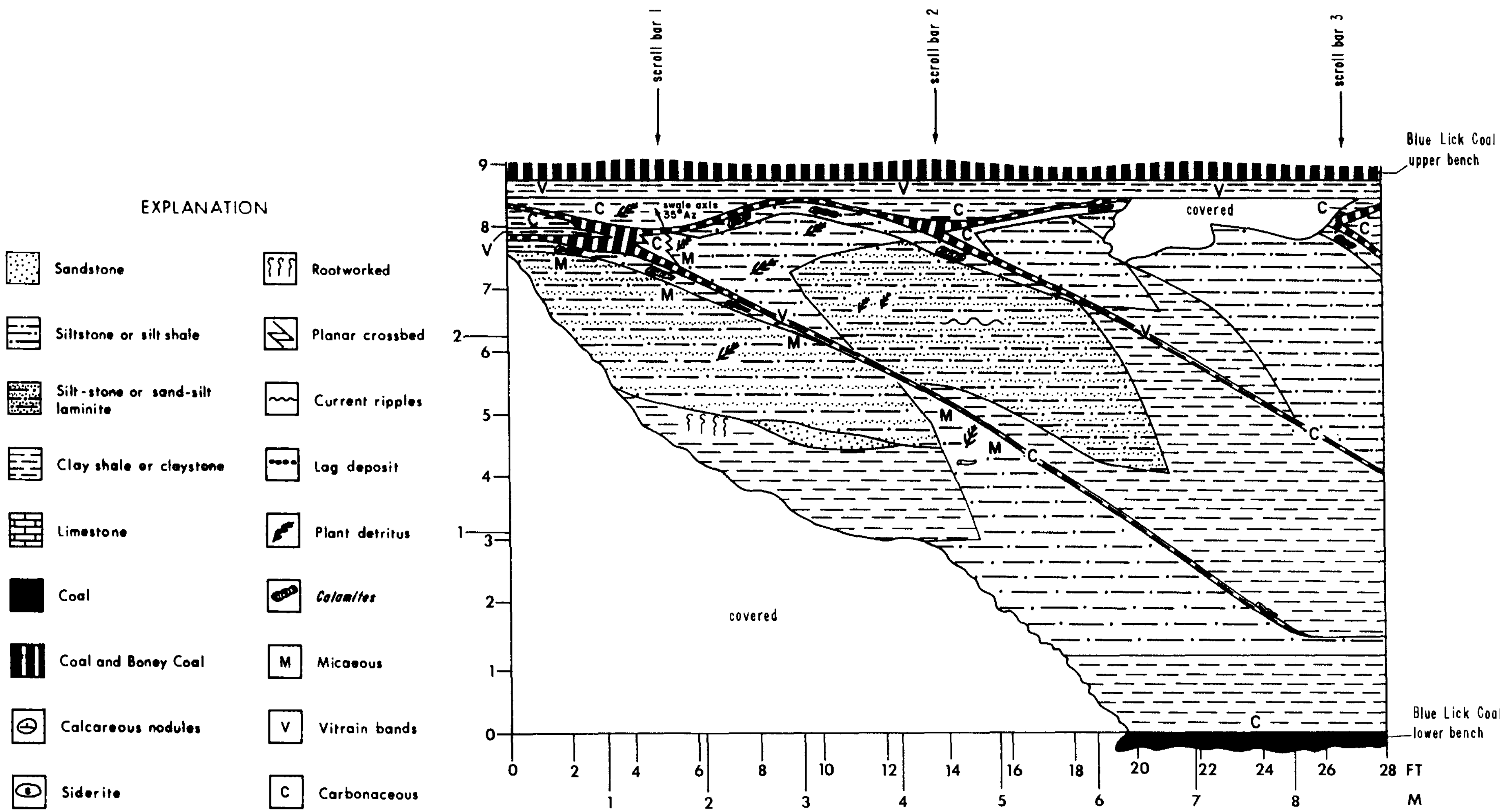


Figure 67. Sketch of a highwall section in Croner's Blue Lick mine showing relationships of lithologic units found in scroll bars 1, 2, and 3.

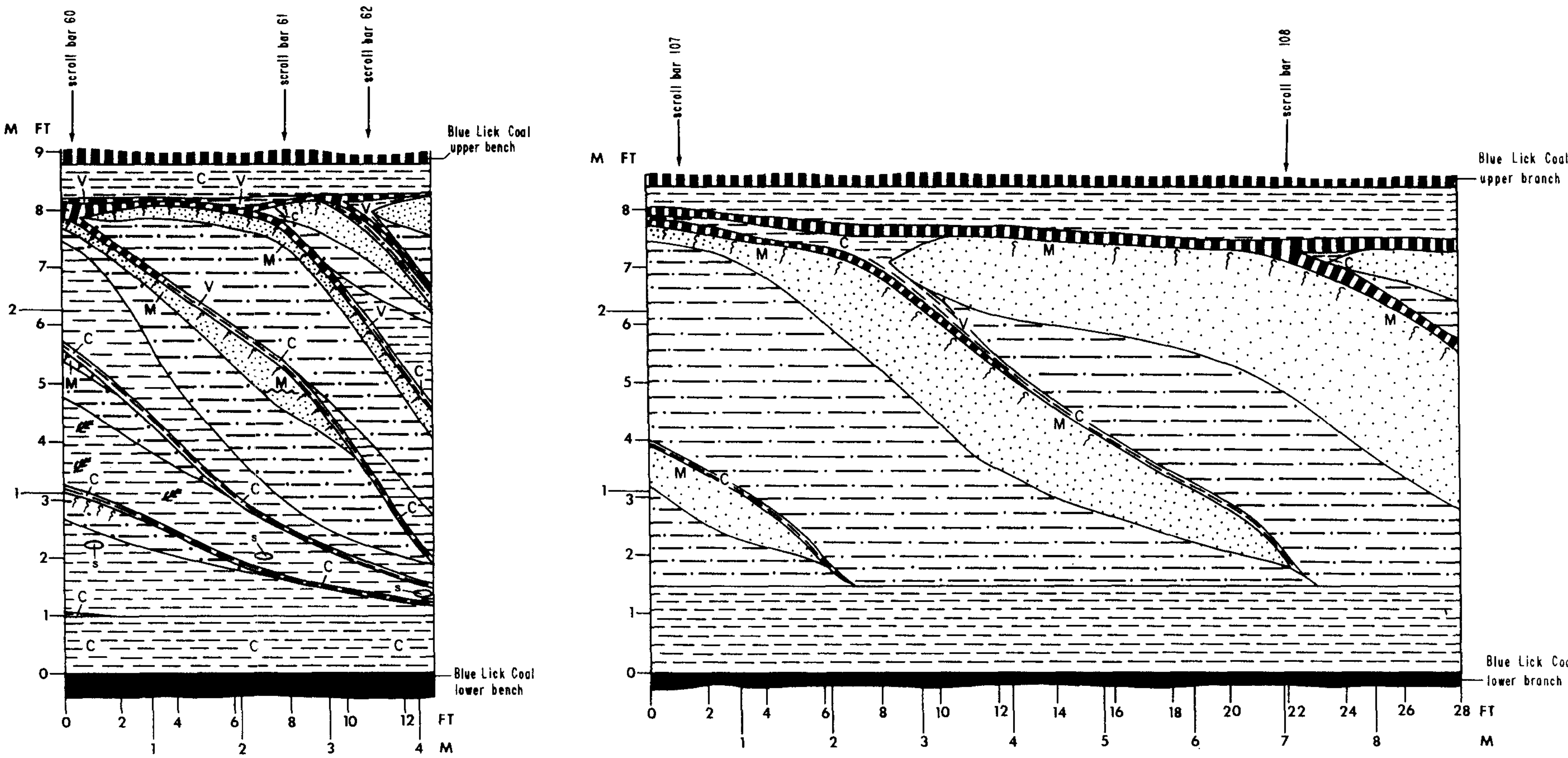


Figure 68. Sketch of a highwall section in Croner's Blue Lick mine showing relationships of lithologic units found in scroll bars 60, 61, 62, 107, and 108.

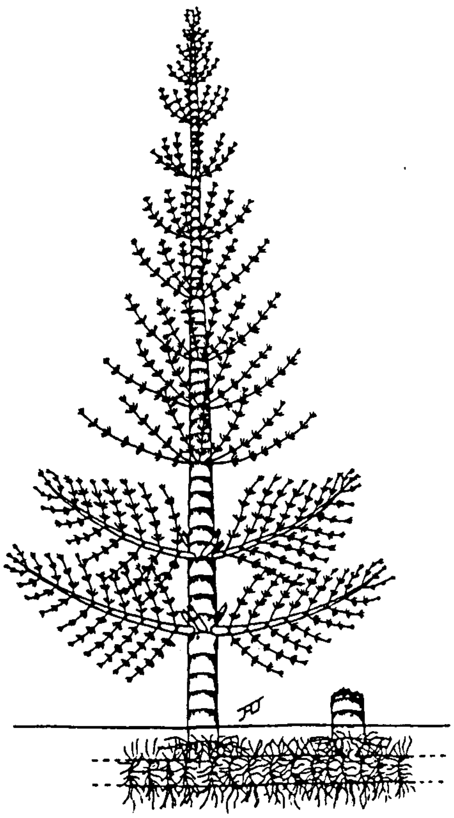


Figure 69. Reconstruction of *Calamites* after Himer and others (Gillespie, 1978).

grained deposits are carried farther out blanketing the surrounding floodplain. In general, a fining upward and outward pattern is developed.

At the Croner mine site, the same relationship can be seen in a crevasse splay which is now preserved as a parting in the Redstone Coal (Figure 71). Cross sections A-A' and B-B' (Figure 72) show three-dimensionally the internal morphology of the splay. They were constructed from detailed geologic descriptions made along two parallel north-south trending highwalls separated 1,000 feet longitudinally at the Croner Inc. mine site. Figure 61 also shows the location of these cross sections and the thickness boundary lines of the crevasse splay deposit. These thickness boundary lines appear to converge to a point just west of section A-A' where the channel breach should be located. Assuming that section A-A' is located nearest to the breach, then a fining outward and upward pattern should occur in the direction of B-B'. This is exactly what occurs. From these cross sections and regional depositional models, an interpretation of 5 stages of deposition was made and is illustrated in Figure 73.

STAGE 1

In stage 1, a suspended-load stream flanked by a peat swamp (lower bench Redstone coal) is carrying sediments derived from a southeastern highland source while it meanders northward (Donaldson, 1979) across a deltaic plain.

STAGE 2

In Stage 2 flooding takes place that causes the levee on the outside of an easterly concave meander to fail causing a gap or crevasse to form. Initially, this crevasse allows water, laden with fine-grained sediment, derived from the erosion of overbank and levee deposits, to spill out over the (Redstone lower bench) peat swamp. The peat is very fibrous and unconsolidated and it readily compacts under this sediment load. The areas where the sediments concentrate become lows in the peat that can act as channels where more sediment can

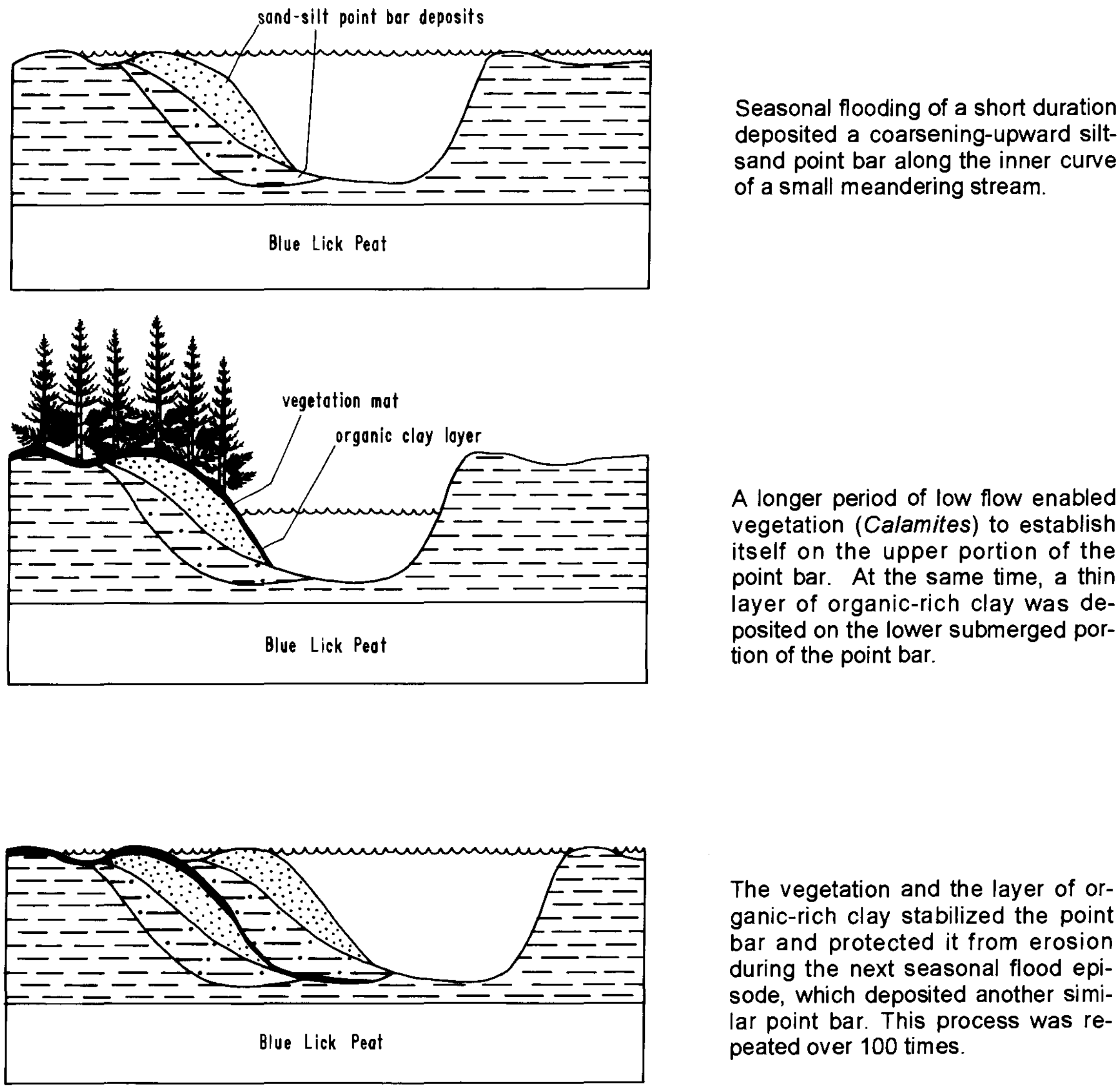


Figure 70. Depositional history of scroll-bar units between the upper and lower benches of the Blue Lick coal in the Croner Blue Lick mine.

accumulate. In a crevasse splay, these channel-like deposits are usually oriented perpendicular to the main channel at the point of the breach. In cross section B-B' (Figure 72), the initial slug of fine sediment is represented by a clay shale that immediately overlies the lower bench of the Redstone coal. In highwall sections 13-15 (B-B', Figure 72), the clay shale is thickest with its "thalweg" centered at section 14. Unfortunately, not enough of the splay deposit was exposed in cross section A-A' (Figure 72) to observe this relationship, but a southward thickening trend of the clay shale could indicate a thalweg in that direction. Following the deposition of the clay shale, coarser sediments that formed fine- to very fine-grained sandstone were deposited in the same peat trough with the thickest deposits centered again at section 14, indicating a preestablished low area for sediment to accumulate. A fining outward trend shown by the fine-grained sandstone in sections 6 to 8 (A-A', Figure 72) grades easterly into siltstones and silt-sand laminites found in sections 11 to 14 of B-B' (Figure 72). After the sandstone and silt-sand laminites were deposited, representing the maximum flood stage, silt shale and clay shale were laid down in a fining-upward sequence as flooding subsided. At its maximum thickness, the splay sediments total nearly 20 feet at section 14 and average 14-16 feet thick along a 1,300-foot-long section, as shown in B-B' (Figure 72). Ferm and Horne (1979) report finding splays with similar dimensions in the Pennsylvanian coal fields of Kentucky.

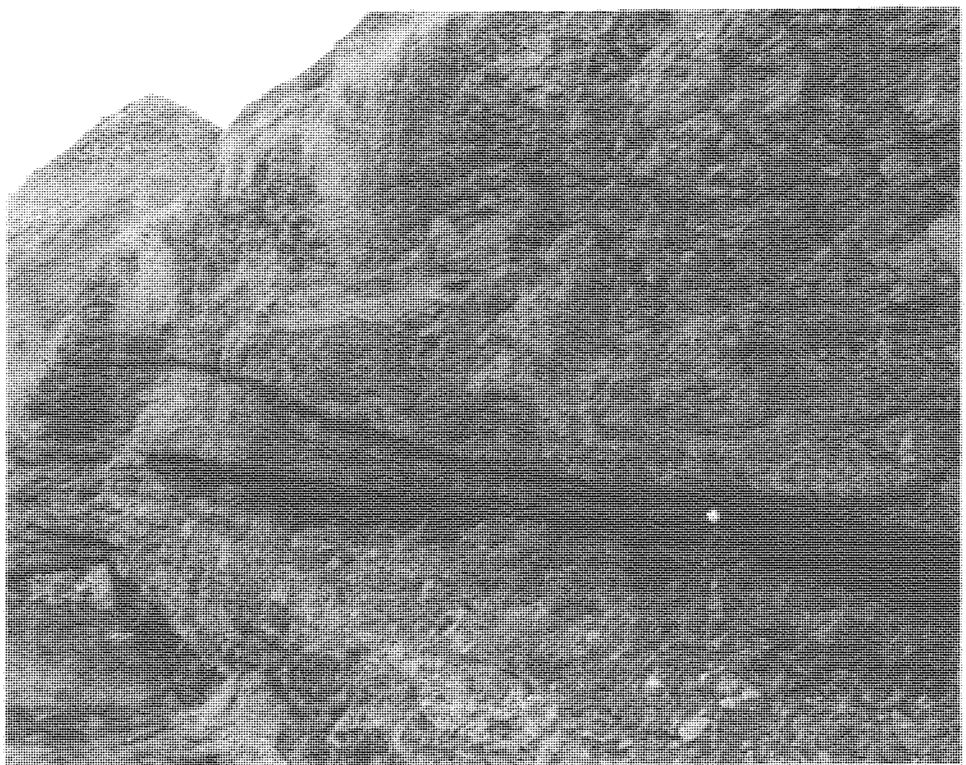


Figure 71. Photo of crevasse splay in highwall exposure of Croner Blue Lick mine at B-B'. Hard hat in right side of photo for scale.

STAGE 3

When water levels in the main stream channel were returning to normal, the water levels were apparently still slightly higher in the flood basin over the swamp. Previously established plants were drowned and a new pioneer plant began to take over the whole region. This plant was *Calamites*. *Calamites* liked shallow water and formed dense thickets along streams and shores of lakes where other plant were unable to compete (Gillespie and others, 1978). The upper 0.3 to 0.5 feet of crevasse splay sediments reflect this dominance over the entire Croner mine site and for several square miles in the surrounding area. This interval is made up entirely of flattened *Calamites* roots and stems that are preserved in a pyritic, carbonaceous clay shale. Where weathered in the highwall, it appears as a whitish layer just under the upper bench of the Redstone coal.

STAGE 4

By Stage 4, the levee was completely rehealed and sediment input into the swamp was restricted. Lower water levels allowed for increased plant growth and thick peat formation in areas not overlying the thick crevasse splay sediments. Where the splay sediments are a few feet or more thick, the coal occurring above, as a rule, is thinner and bonier than coal found above thinner (1 foot or less) crevasse splay sediments (see Figure 72). This is probably because of the continued compaction of the peat (lower bench Redstone) below the thicker splay sediments. This created a lower area in the swamp that had deeper water, grew fewer plants, and received more sediment than areas over thin splay sediments. This condition produced a thinner, more sediment-enriched peat than otherwise occured across the rest of the swamp.

STAGE 5

Stage 5 is represented by the elongated dome or mound-shaped crevasse splay deposit that can be observed today in the Croner highwall. The upper bench of the Redstone coal drapes over the curved top surface of the deposit and the lower bench of the Redstone coal marks its

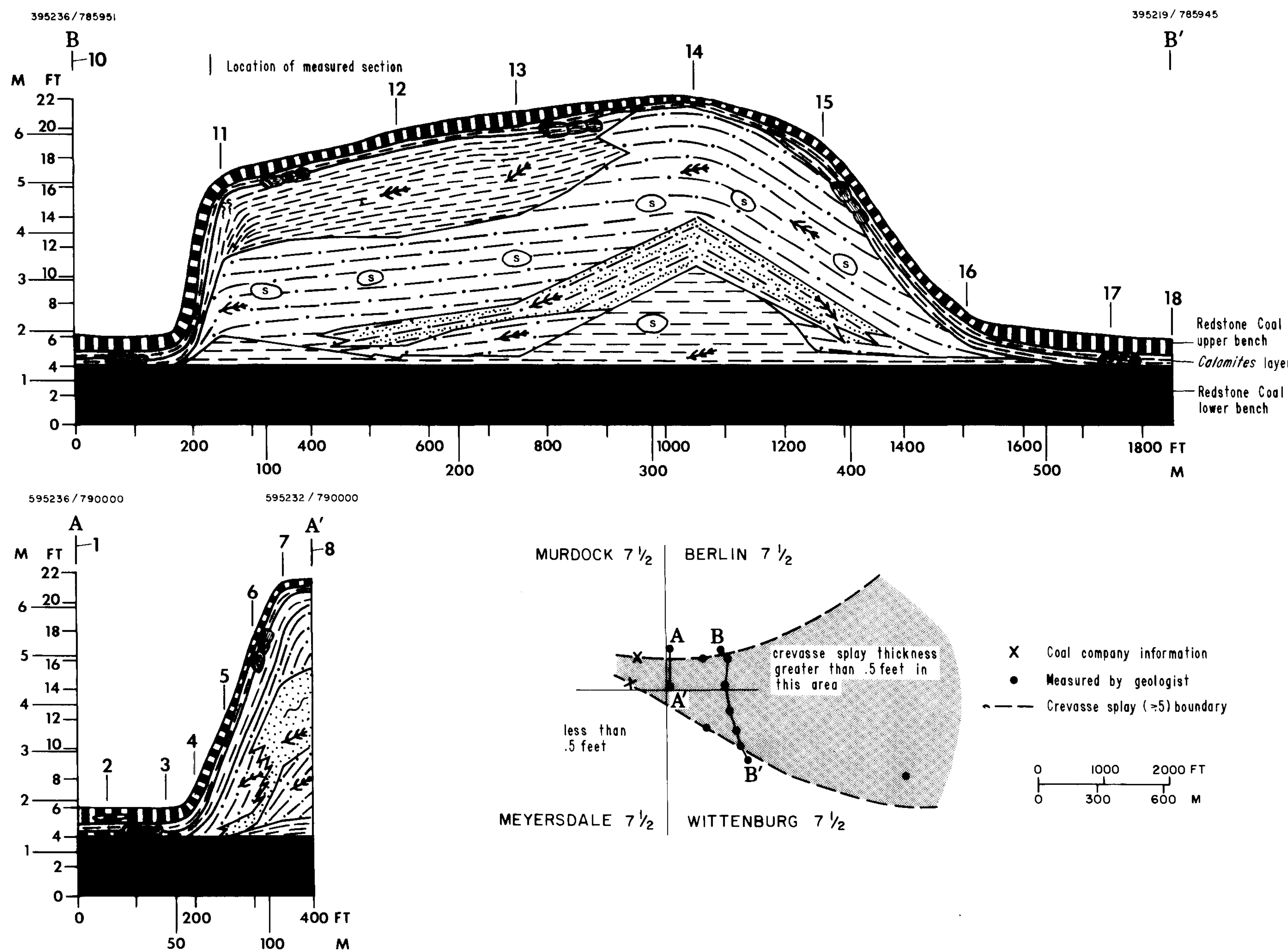


Figure 72. Cross sections showing internal morphology and location of crevasse-splay deposit found at Croner Blue Lick No. 2 mine site.

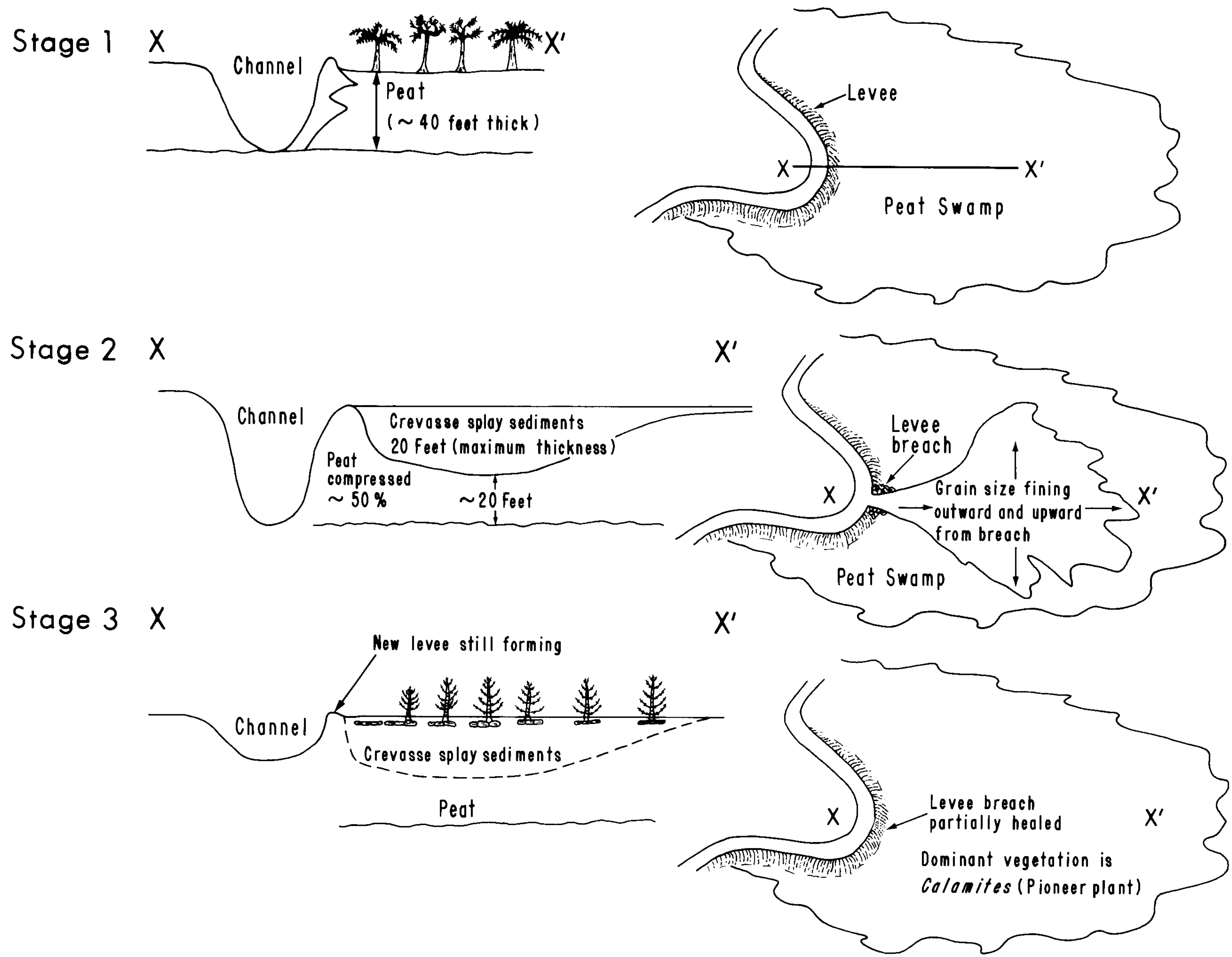
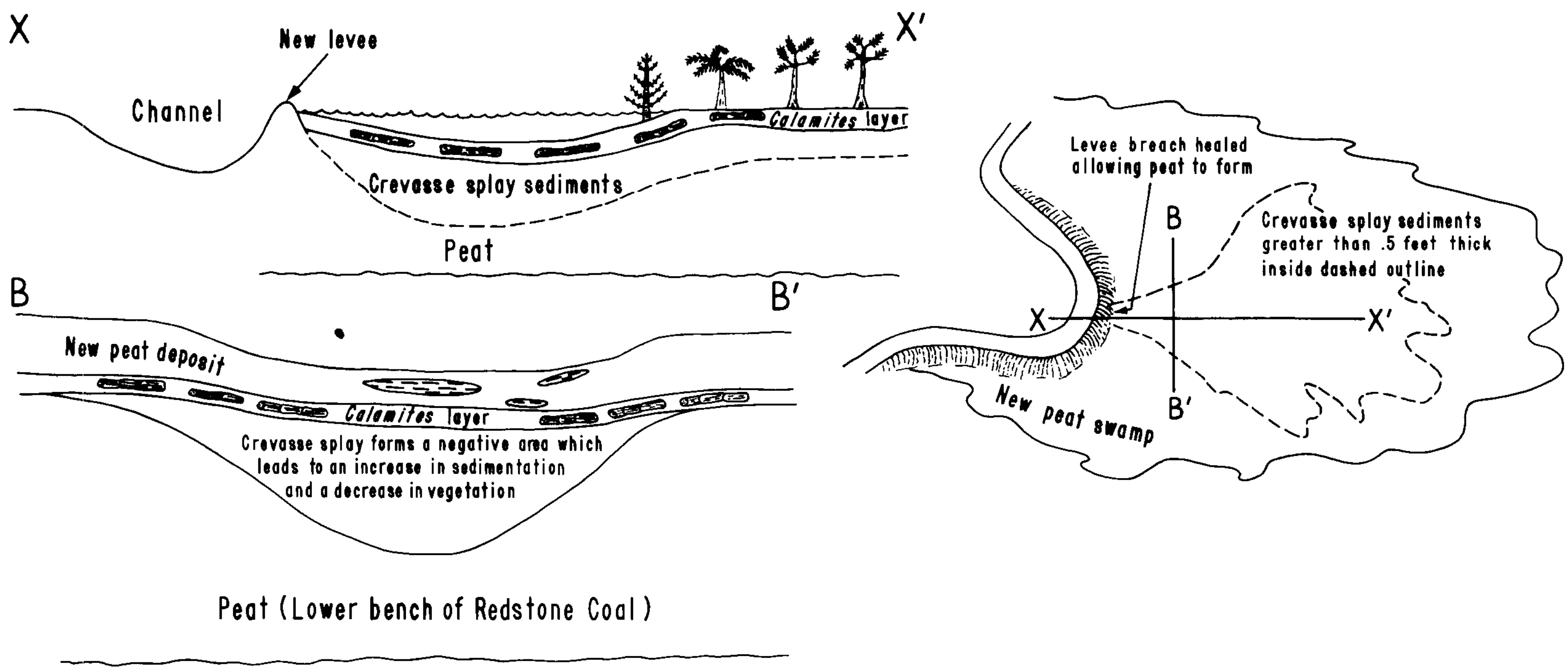


Figure 73. The depositional and diagenetic history of the crevasse-splay deposit in the Redstone coal in the Croner Blue Lick mine.

Stage 4



Stage 5 Coalification and Differential Compaction

(Cross section of the present day Croner Inc. highwall)
Refer also too cross section B-B' in Figure

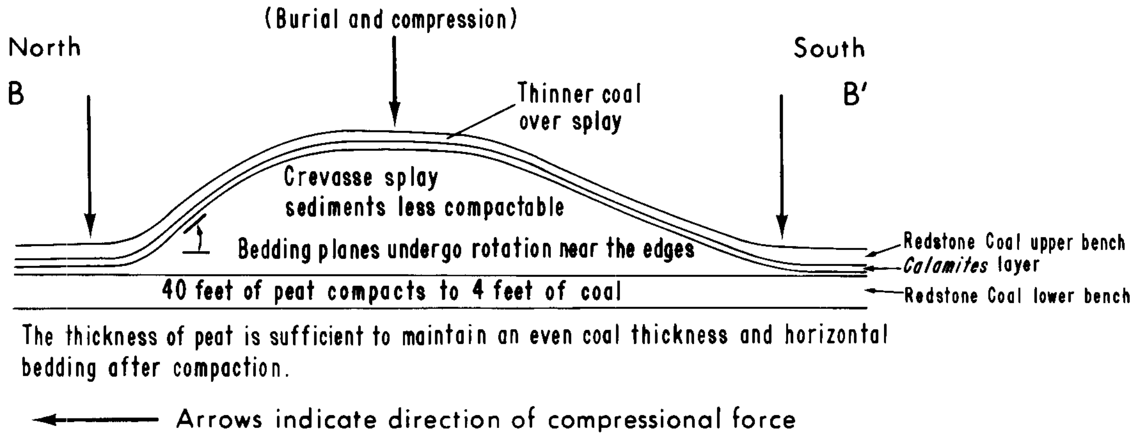


Figure 73. Continued.

flat horizontal base. This mound shape is just the reverse of what it would have looked like if it had been preserved before diagenesis and differential compaction occurred. During diagenesis, the peat compacts and is reduced in volume by 80-90% (mostly through dewatering) while the crevasse-splay sediments are changed very little volumetrically. The net result is analogus to what would happen if you placed a rock on a big, thick, flat sponge and applied equal pressure to both from above. Initially the rock's weight causes it to sink down into the sponge, but as the applied pressure increases, it becomes a positive feature. If another big, flat sponge is placed on top of the rock and pressure is applied, the result is the current configuration of the crevasse splay deposit in the Croner highwall as shown in cross-section A-A' (Figure 72). Table 12 gives a summary of peat to coal compaction ratios that range from 1.4:1 to 30:1 (Ryer and Langer, 1980) and average approximately 10:1. If an average value of 10:1 is used, the lower 4-foot-thick bench of the Redstone coal would equate to 40 feet of peat. The crevasse splay sediments at their maximum thickness of nearly 20 feet would have had to initially compact the Redstone (lower bench) peat 50%. The lower bench of the Redstone coal shows no change in thickness under the 20 feet of crevasse splay sediment so a minimum of 6 to 1 ratio for peat to coal had to be present for this to occur.

CONCLUSIONS

The point bar and crevasse-splay deposits at the Croner mine site are geologically significant not only because they are unique sedimentologically, but also because of their spectacular preservation.

The crevasse-splay deposit is outstanding because it is rare to find one in the form of a coal parting that can be viewed in a three-dimensional highwall setting. This 3-D perspective made it possible to observe in detail the internal morphology of the deposit, making comparisons with modern day crevasse splays more certain. Also, the fact that this deposit was bounded by coal layers made it possible to observe depositional and diagenetic relationships involving differential compaction. For example, it was found that a thinner bonier coal occurred above the thick, domed-shaped portion of the crevasse splay and that the lower bench of the Redstone coal, immediately below it, was formed from a peat layer that was compacted by a minimum factor of 6:1 before coalification.

The point bar is significant for two reasons. First, it is very unusual to have a thin, coaly layer preserved on the upper surface of each scroll bar. Smith (1987) and Puigdefabregas and Van Vliet (1978) have noted presence of mud drapes on the top surfaces of scroll bars associated with single-story, stream-channel deposits, but this may be the first time anyone has documented coal preserved in this position.

Secondly, it is important because it provides insight into how much time is required to deposit a specific volume of sediment on a point bar of a meandering stream during Upper Pennsylvanian time in this region. The remarkable uniformity of each individual point-bar deposit and, especially, the large number of point-bar deposits strongly suggests a definite cyclicity of the flooding events responsible for their deposition. The only cycle so uniformily alternating between wet, high-water conditions and relatively drier, low-water conditions needed for vegetation to establish itself on each scroll bar is a seasonal change of climate. This seems to be a reasonable amount of time to deposit each 2.5-3.5-foot-thick bar. The Barwon River in southeastern Australia lays down a comparable 0.8 m of sediment each year (Smith, 1987). The problem is the seemingly insufficient time to grow the vegetation necessary to produce the thickness of coal found on each bar if a peat swamp model is employed to calculate coal formation rates.

McCabe (1984) suggests a high average of 2.5 mm of peat accumulation per year for the upper Carboniferous swamps in the northern hemisphere. If this value is used along with an average 10:1 compaction ratio (Table 12), nearly 50 years would be required to accumulate the 5 inches of peat necessary to produce a 0.5-inch-thick, scroll-bar coal. This time discrepancy may be explained by considering how forming a coal on a scroll bar is different from forming a coal in a peat swamp. Firstly, the peat swamp depends entirely on in-place vegetation to form its peat. The scroll-bar does not. During periods of flooding, vegetation growing on banks of the river that are more vulnerable to erosion, is eroded and transported down stream. This organic debris is washed onto the upper portion of the scroll bar where it becomes lodged in the vegetative cover on top of the bar. In this way more vegetation can be

Table 12. Summary of peat to coal compaction ratios (from Ryer and Langer, 1980).

Author	Peat:Coal Thickness Ratio	Method	Comments
Renault, B., 1899	12:1 to 30:1	petrographic?	observations regarding "shrinkage of stems of trees in passing from wood to (bituminous) coal"; French literature cited by Moore
Ashley, G. H., 1907	3.5:1	density	for "well-compressed" peat to bituminous coal
	4:1 to 7:1	stratigraphic	reconstructed original peat thickness in small coal basin compared to present coal thickness; for bituminous? coal
	4:1 to 20:1	stratigraphic	thickness variations of coal bed relative to topography of surface underlying coal; for butuminous? coal
	1.4:1 to 2:1	stratigraphic	reduction of coal thickness beneath sandstone "rock rolls" (erosional channels); for bituminous? coal
Glockner, F., 1912	2.5:1	inclusions	"draping of coal over tree stump at base of seam; for brown coal; German literature cited by Stutzer (1940)
Thiessen, R., 1920	(5:1 to 40:1)	petrographic	not directly applicable to peat:coal ratio; observations on compression of plant cells recognizable in coal
Lewis, J. V., 1934	10:1	density	for bituminous coal
	13:1	density	for anthracite coal; values 50% greater for uncompacted vegetal matter:coal
Raistrick, A., and Marshall, C. E., 1939	15:1	—	for "uncompacted" peat; no specific data cited
Stutzer, O., 1940	2.2:1	inclusions	increase in thickness of coal bed where coal balls are present; for bituminous? coal
Mott, R. A., 1943	12.5:1	density	for anthracite coal
Kolotukhina, S. E., 1949	4:1 to 5:1	—	Russian literature cited by Zaritsky (1975)
Rukhin, L. B., 1953	20:1 to 30:1	—	Russian literature cited by Zaritsky (1975)
Kosanke, R. M., Simon, J. A., and Smith, W. H., 1958	3:1	inclusions	increase in thickness of coal bed where coal balls are present; for bituminous coal
Weller, J. M., 1959	20:1	density	calculation based on decrease of volatile matter in coals of increasing rank with fixed carbon considered as a constant; value cited here is for bituminous coal
Bobrovnik, D. P., 1960	30:1	—	Russian literature cited by Zaritsky (1975)
Prikhodko, Y. N., 1963	5.9:1	stratigraphic	Russian literature cited by Zaritsky (1975)
Bloom, A. L., 1964	5:1 to 10:1	stratigraphic	reconstructed original vs compacted thicknesses for sedge peats 1,000 to 7,000 yrs old
Volkov, V. N., 1964	2.5:1	—	for brown coal
	5:1	—	for bituminous? coal
	7:1	—	for anthracite coal; Russian literature cited by Zaritsky (1975)
Falini, F., 1965	10:1	density	for brown coal
	20:1	density	for bituminous coal
Williamson, I. A., 1967	7.5:1	—	a modification of the 15:1 value cited by Raistrick and Marshall (1939) taking into account the "compression" of peat with depth of burial
Stach and others, 1975	7:1 to 20:1	inclusions	for bituminous coal
Zaritsky, P. V., 1975	5:1	inclusions	compaction around carbonaceous coal balls (sulfide and siliceous concretions, formed later, give lower ratios)
Stanton, Ron, U.S.G.S., 1979 (written comm.)	3:5:1 to 4:1	inclusions	compaction around pyrite framboids contained in vitrinite; for bituminous coal
	(7:1)	petrographic	not directly applicable to peat:coal ratio; for compaction of woody tissue
	(20:1)	petrographic	not directly applicable to peat:coal ratio; for compaction of spores
Ryer, Phillips, Bohor, and Pollastro, in press	10.6:1	stratigraphic	reconstructed original peat thickness in basin compared to present coal thickness; a minimum value; for bituminous coal

accumulated on the scroll bar surface than can be grown there in one year.

Secondly, the plant material on the scroll bar surface is rapidly covered by sediment instead of water, as would be the case in a peat swamp. This quick burial with sediment would minimize loses due to decomposition that normally occur during the peat formation process. These two factors may help to explain how a deposit with a normal development time of 50 years can be formed in a single year. It would not be hard to imagine a 5-inch-thick layer of trunks or limbs of trees (probably *Calamites*) collecting on the surface of a scroll bar on the down current side of a meander bend at the onset of each spring flooding event, then being rapidly buried before water levels return to normal, and for this same scenario to be repeated year after year for more than a century during the Pennsylvanian in Somerset County.

Jane R. Eggleston

REDSTONE AND FISHPOT LIMESTONES

The Redstone and Fishpot limestones are two of five persistent and widespread nonmarine limestones within the Pittsburgh Formation in the northern Appalachian basin. Together, these five limestones locally can constitute up to 80% of the lithologic section. The limestones are interbedded with coal beds and thin claystone units, and the apparent cyclicity between these lithologies has long been of interest to researchers. In some areas, siliciclastic rocks are present within this interval, and are interpreted to have formed in a generally northward flowing fluvial system (Roen and Kreimeyer, 1973, and Donaldson, 1969).

A detailed stratigraphic and sedimentological study of the Redstone limestone is currently underway. Several cores and numerous outcrops (including the Cromer Mine) have been sampled for study. The Redstone limestone was first named by Platt and Platt (1877, p.62, 88-91) at a locality in southwestern Somerset County where the 3.1-m-thick limestone was being quarried. The Redstone limestone reaches a thickness of 12 m in Monongalia County, WV and occurs as far south as Cabell County, WV and as far west as Morgan County, OH. An average of 2 m of claystone and shale occur between the top of the Pittsburgh coal bed and the base of the limestone, although at the Cromer Mine the claystone is 1.3 m thick (and the coal bed is the Blue Lick, which is believed to be an upper split of the Pittsburgh). The claystone commonly contains calcareous nodules. Less than 1.3 m of shale and claystone (0.7 m at the Cromer Mine) occur above the limestone, followed by the Redstone coal bed.

X-ray diffraction analyses of the Fishpot and Redstone limestones by the Pennsylvania Geological Survey indicate that these limestones contain calcite, ankerite (or ferroan dolomite), quartz, and some chlorite. In addition, analyses at other sites show minor amounts of chert, pyrite, feldspar, and clay minerals in the limestone. Petrographic examination revealed that calcite and ankerite are commonly in the form of micrite. However calcite, ferroan calcite, and ankerite occur as rhombohedra 3-15 mm in size within voids created by shells and cracks. Chert also fills some voids. Pyrite occurs as cubes, blebs, and large patches up to 5 mm in the limestone, sometimes replacing portions of invertebrate fossils and often associated with plant material. Phosphate is present in the form of bone fragments. The predominant fossils are ostracods, although bivalves, small gastropods, spirorbis, bone fragments, and plant debris are also present.

Megascopic and microscopic examination indicate that the Redstone limestone probably formed in a very shallow lake that was subject to periodic subaerial exposure during drier periods. Dessication breccia, in which cracks, root traces, and lack of original bedding predominate, is very common in most limestone outcrops/cores examined. In addition, rounded intraclasts, broken and nested shells, and bioturbated limestone are all indicators of shallow water sedimentation. Lamination is rare, and usually represents a brief influx of clay and sand into the lake. However, SEM analysis of one sample showed that laminae were created by higher concentrations of rhombohedral ankerite in particular beds of calcite. These laminae may indicate seasonal changes in the climate or lake conditions, and/or could be algal in origin. A third type of lamination was found at the top of the Redstone limestone in a mine just a few miles south of the Cromer Mine. There, the laminae are created by carbonate and abundant diagenetic kaolinite. Although this suggests the possibility of a volcanic ash layer, further investigation to identify zircon and beta quartz will be necessary before any interpretations can be made.

Stratigraphic data indicates that the lake environment was widespread and probably occurred as a series of lakes. The fact that the Redstone limestone reaches 12 m in thickness indicates that the lake was probably stable, at least in some areas, for a long time. The absence of evaporitic minerals such as gypsum and halite, the scarcity of clay minerals, and the apparent sparsity of stromatolitic structures suggest that the lake was not a playa or brine lake, but, in fact, a freshwater lake, in which fresh water influx exceeded evaporation. Rainfall varied, probably seasonally, as suggested by the predominance of subaerial exposure features.

Initial investigations of the other four limestones, including the Fishpot at the Cromer Mine, indicate very similar depositional histories to that of the Redstone limestone.

		LEAVE STOP 10. TURN RIGHT onto SR 2027.
0.1	62.8	**STOP SIGN. TURN RIGHT.**
0.6	63.4	Community of Pine Hill. On left, cemetary and Redstone and Blue Lick surface mines.
0.5	63.9	Coal breaker on right.
0.9	64.8	Cross abandoned railroad tracks and then Buffalo Creek.

0.9	65.7	**STOP SIGN. TURN RIGHT** onto US Route 219 North.
1.4	67.1	Enter town of Berlin.
0.2	67.3	Intersection of PA Route 160 and US Route 219. **CONTINUE AHEAD.**
4.6	71.9	Enter Somerset Township.
0.3	72.2	Water tower of Somerset State Prison on left.
1.2	73.4	US Route 219 North turns left. **CONTINUE STRAIGHT AHEAD** on SR 3041.
1.8	75.2	Enter Borough of Somerset.
0.5	75.7	**STOP LIGHT. TURN LEFT** onto US Route 31 West.
0.3	76.0	**STOP LIGHT. TURN RIGHT** onto PA Route 281 North.
0.2	76.2	Be in left lane. **STOP LIGHT. STRAIGHT AHEAD.**
0.4	76.6	Be in left lane. **STOP LIGHT. STRAIGHT AHEAD.**
0.3	76.9	**TURN LEFT** into parking lot of Ramada Inn.

END OF TRIP! HAVE A SAFE JOURNEY HOME!!

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