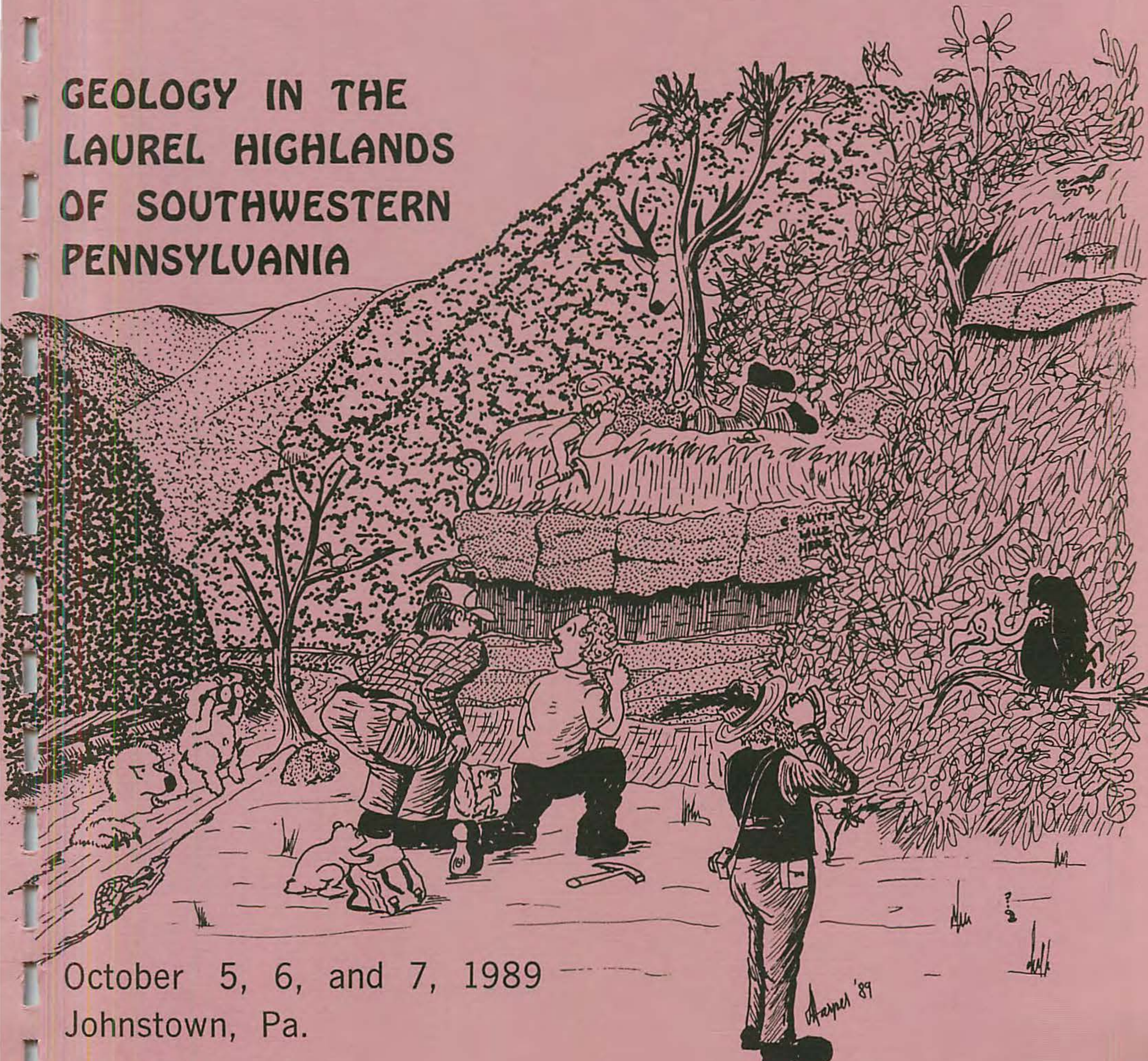
GUIDEBOOK

54th Annual Field Conference Of Pennsylvania Geologists

GEOLOGY IN THE LAUREL HIGHLANDS OF SOUTHWESTERN PENNSYLVANIA



October 5, 6, and 7, 1989
Johnstown, Pa.

Hosts: University of Pittsburgh at Johnstown
Pennsylvania Geological Survey

Guidebook for the

54th ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

GEOLOGY IN THE LAUREL HIGHLANDS, SOUTHWESTERN PENNSYLVANIA

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Cover: Geological field work in the Conemaugh Gorge (how many critters can you find?) by John A. Harper.

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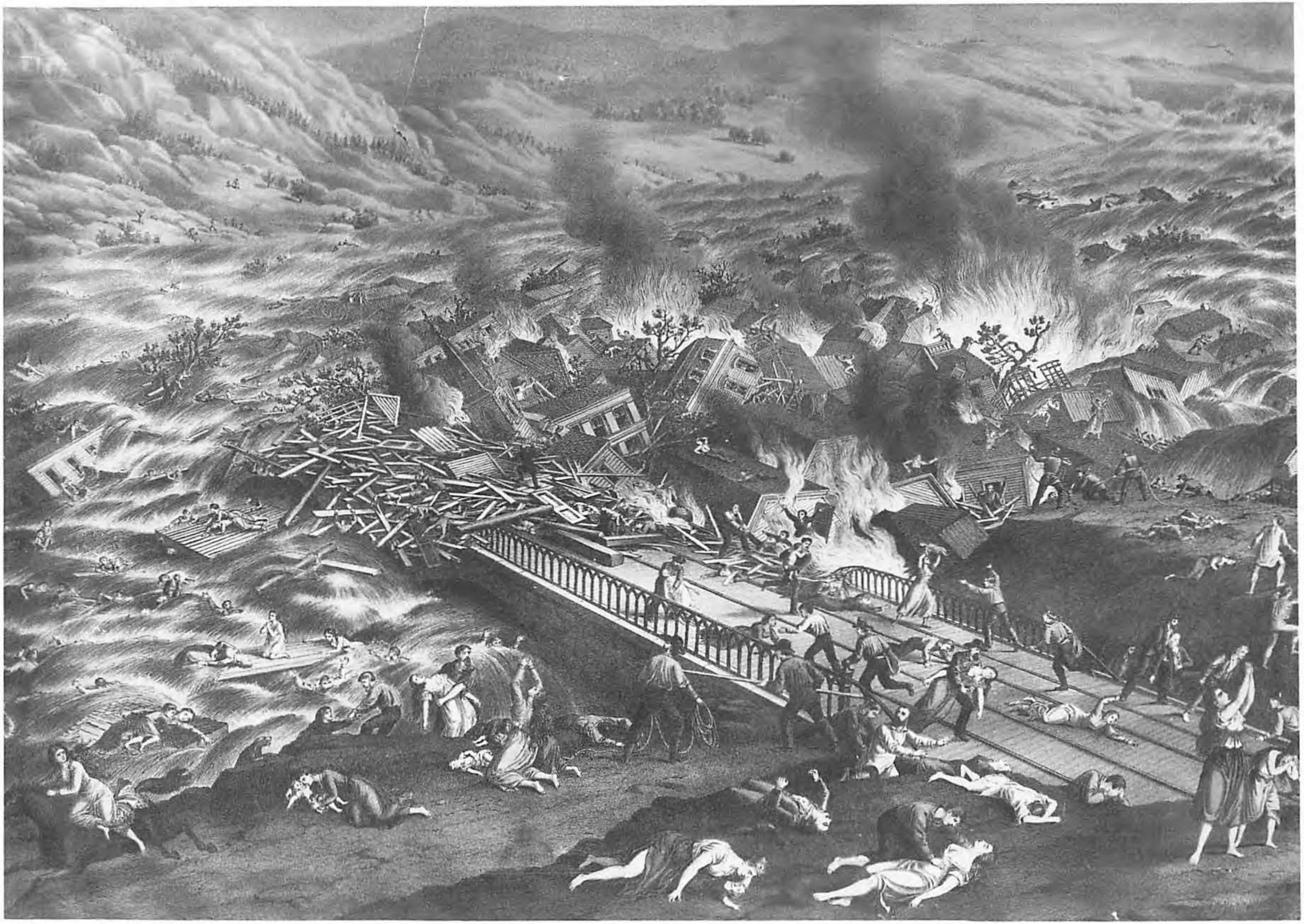

Frontispiece: Artist's conception of the events at the Old Stone Bridge.
Photo courtesy of the Johnstown Flood Museum.

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GEOLOGY IN THE LAUREL HIGHLANDS, SOUTHWESTERN PENNSYLVANIA

INTRODUCTION

Welcome to Johnstown and the 54th Annual Field Conference of Pennsylvania Geologists. This year's field conference could easily be subtitled "A Plateau Potpourri" because of the diverse nature of the field stops. On this conference we will be examining: 1) the stratigraphy, petrography, and depositional environments of the Late Devonian and Early Mississippian formations that crop out in the deeper gorges in the Laurel Highlands; 2) the relationships of the carbonate and clastic depositional systems of the Mississippian Mauch Chunk, Loyalhanna, and Burgoon Formations; 3) the character and origins of the nonmarine limestones and flint clays of the Pennsylvanian Allegheny Group; 4) the carbonate geochemistry of the fossiliferous Brush Creek limestone and shale of the Pennsylvanian Conemaugh Group; 5) environmental problems associated with coal mining in the Johnstown area; and 6) the history and engineering problems associated with the disastrous Johnstown floods of 1889 and 1977.

ACKNOWLEDGEMENTS

The authors and field trip leaders thank the following personnel without whose efforts this field conference and guidebook would not have come about: Lajos Balogh, John Petro, and Janet Wotring, Pennsylvania Geological Survey; Harold C. Fry, University of Pittsburgh at Johnstown; Geospectra Corporation; Johnstown Flood National Memorial; Johnstown Flood Museum; Teresa L. Kaktins; and Rebecca A. Kilbert, University of Pittsburgh (main campus).

GENERAL GEOLOGY

Physiography and Drainage

The field conference area lies mainly in the Allegheny Mountains Section of the Appalachian Plateaus Province (Figure 1). The Allegheny Mountains of southwestern Pennsylvania are commonly known by the more popular name of "Laurel Highlands", thus the title of this field conference. This area is characterized by low, open folds with flank dips ranging from 5 to 20 degrees. The anticlines tend to form prominent, dissected, topographic ridges such as Chestnut Ridge, Laurel Hill, and Negro Mountain, and the synclines form broad, relatively flat valleys between them. To the east folds with dips greater than 30 degrees dominate the Ridge and Valley Province, whereas to the west and north the Pittsburgh Plateaus Section of the Appalachian Plateaus Province consists of broad, low, open folds with dips generally less than 5 degrees. These folds have little noticeable effect on topography.

Local relief in and around the ridges in the Laurel Highlands ranges from a few hundred to more than 1200 feet. The greatest relief occurs where the major streams cross the ridges. Total relief is considerably greater than local relief, however, because the highest elevation in Pennsylvania, Mt. Davis on Negro Mountain in Somerset County, occurs in this physiographic section. Mt. Davis is 3,213 feet above mean sea level, whereas the Youghiogheny River where it flows through the gorge in Laurel Hill (southern Fayette and Somerset Counties) stands at about 975 feet.

With the exception of a few creeks along the Allegheny Front, all of the

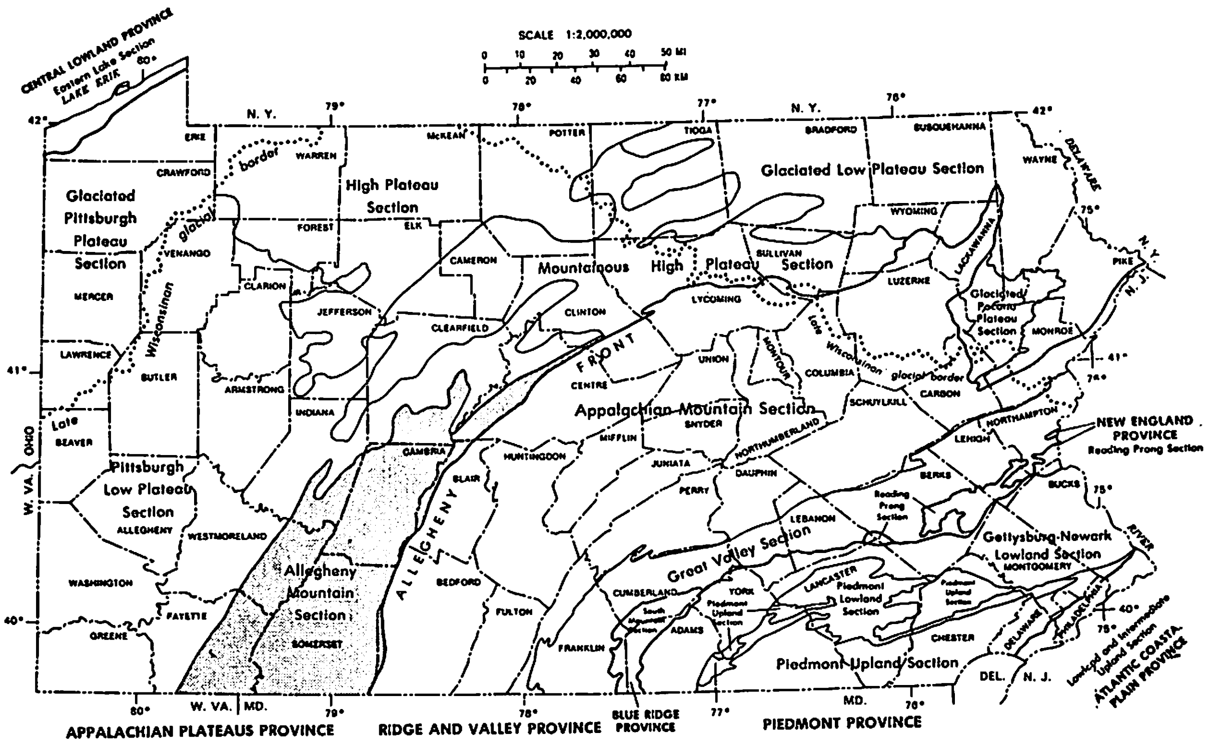

Figure 1. Map of the physiographic provinces of western Pennsylvania, showing the location of the Laurel Highlands (modified from Berg and others, 1989).

streams in the Laurel Highlands drain westward to the Ohio River drainage system, and thence to the Gulf of Mexico. Major streams draining the Laurel Highlands include the Youghiogheny River and its tributaries in Somerset and Fayette Counties and the Conemaugh River and its tributaries in Cambria, Westmoreland, and Indiana Counties. North of the Laurel Highlands, streams drain eastward to the Atlantic Ocean via the Susquehanna River drainage system.

Bedrock Geology

Most of southwestern Pennsylvania is underlain by rocks of Pennsylvanian or Permian age. Permian rocks lie entirely outside of the Laurel Highlands; their easternmost exposures occur along the axis of the Uniontown syncline south of the Conemaugh River, in Westmoreland and Fayette Counties. Rocks older than Pennsylvanian crop out generally where the prominent ridges in the Laurel Highlands are dissected by streams. Rocks younger than Permian are very rare, and lie mostly outside of the Laurel Highlands. Jurassic-age kimberlite dikes occur in outcrop across the Greene-Fayette County boundary and in a deep mine in Indiana County. Unconsolidated to semi-lithified alluvial deposits of Pleistocene age occur along terraces above some of the major streams in southwestern Pennsylvania, including streams in the Laurel Highlands. Although they cannot technically be considered "bedrock", they are important geologically because they help us unravel the post-Paleozoic history of the Appalachians. Formations exposed in the Laurel Highlands of southwestern Pennsylvania are listed in Figure 2.

SYSTEM	GROUP OR FORMATION
Quaternary	Carmichaels Formation
Pennsylvanian	Monongahela Group Conemaugh Group Allegheny Group Pottsville Group
Mississippian	Mauch Chunk Formation Loyalhanna Formation Burgoon Sandstone "Rockwell tongue" "Weir sand" Riddlesburg Shale "Murrysville sand"
Devonian	Venango Group

Figure 2. Generalized stratigraphic section of the Pennsylvanian and Mississippian formations of the Laurel Highlands area.

Devonian and Mississippian

The oldest rocks exposed in southwestern Pennsylvania crop out in the centers of the gorges that were carved by streams flowing through the linear ridges. These rocks are of Late Devonian (Famennian) and Early Mississippian (Tournaisian) age and correlate in part to the thick sequences of red beds of the Catskill Formation in central and eastern Pennsylvania. These rocks, consisting mostly of sandstone, siltstone, and shale. Many of these rocks can be separated into valid lithostratigraphic units and mapped between the surface and subsurface, but the work has not been done in a formal manner for the most part. The recognized and formally named Mississippian formations include, from top to bottom, the Mauch Chunk Formation, Loyalhanna Formation, and Burgoon Formation. Mississippian rocks older than Burgoon, and all of the Upper Devonian rocks, that crop out have not been described previously in any satisfactory manner, and for the most part they have not been named formally. Berg and others (1980, 1986) used the wholy unsatisfactory names Shenango Formation through Oswayo Formation, undifferentiated, Rockwell Formation, Catskill Formation, and Foreknobs Formation for the rocks older than Burgoon in the Laurel Highlands. We will attempt to show on this field conference that these designations are unacceptable. The field work done for this conference, and the work done previously by Kelley and Wagner (1970) and Harper and Laughrey

(1987) are first steps toward understanding the section and proposing a final nomenclature.

Mississippian-Pennsylvanian Boundary

White (1891) originally proposed the idea of a Mississippian-Pennsylvanian disconformity in Pennsylvania, Ohio, and West Virginia based on the absence of fossil plant assemblages present in the southern anthracite field of east-central Pennsylvania. Even without paleontological data the rock record suggests the presence of a disconformity representing a considerable period of time of erosion or non-deposition. Subsurface studies (for example, Kelley and Wagner, 1970 and Harper and Laughrey, 1987) indicate that the contact between the basal Pottsville and the top of the Mississippian is uneven, and that the subcrop of the Pottsville grows progressively older to the north and northwest. The rocks of the Pottsville Group formed by alluvial deposition (Meckel, 1967) as river systems brought coarse terrigenous clastics into southwestern Pennsylvania from the tectonically unstable Alleghanian highlands to the southeast and east. Rivers carrying gravelly and sandy sediments initially cut channels into the Mississippian bedrock, leaving relatively high interfluve areas of the Mississippian in an otherwise Pottsville fluvial system.

The Mississippian-Pennsylvanian boundary can be seen along the Conrail tracks near Bolivar, Westmoreland County. The right-of-way for the tracks was excavated through a promentory in the Conemaugh gorge through Chestnut Ridge, exposing a continuous section from the Homewood Sandstone of the Pottsville Group down to the Loyalhanna Formation. We will be visiting this locality on this trip, so that we will have the opportunity to examine the boundary and note its irregular shape.

Pennsylvanian

The exposed Pennsylvanian rocks in the area of the Laurel Highlands consist of about 1,500 ft of interbedded sandstones, siltstones, shales and claystones, coals, and limestones of the Pottsville, Allegheny, Conemaugh, and Monongahela Groups. Most of the rocks at the surface in this area, belong to the Conemaugh Group. Monongahela Group rocks generally are restricted to a few occurrences along the axes of synclines, whereas the Allegheny and Pottsville Groups crop out in the deeper stream cuts and on the flanks of the anticlines.

Because of erosion or non-deposition the Pottsville Group in southwestern Pennsylvania contains only a fraction of the strata deposited elsewhere at the beginning of the Pennsylvanian System. Up to 1,500 ft (457.2 m) of rock occurs in the Pottsville Group in the anthracite coal basin of northeastern Pennsylvania, and up to 1,700 ft (515 m) of rocks considered to be older than Pottsville occurs in the proposed Pennsylvanian stratotype area of southern West Virginia (Englund, 1979). Yet in southwestern Pennsylvania the thickness of the group rarely exceeds 200 ft (60.9 m). The Pottsville consists predominantly of sandstone and conglomerate, but also contains significant amounts of coal, claystone, shale, and limestone. The base of the group is very irregular, and the subcrop ranges from the Burgoon Formation ("Big Injun sand" of drillers) near the Ohio border, to the Mauch Chunk Formation, which may be over 200 ft (60.9 m) thick.

The Allegheny Group is typically described as comprising all the strata between the top of the Upper Freeport coal and the base of the Brookville coal. Inasmuch as these coalbeds are not laterally persistent the exact limits of the group vary somewhat from investigator to investigator. Where the more persistent coalbeds can be identified, the Allegheny Group is divided into three formations, from top to bottom the Freeport Formation, Kittanning Formation, and Clarion Formation.

The Conemaugh Group consists of all the rocks between the base of the Pittsburgh coal and the top of the Upper Freeport coal. It comprises two typically discrete and recognizable formations, the wholly non-marine (in Pennsylvania) Casselman Formation above, and the Glenshaw Formation below. The Glenshaw Formation is distinguished by at least six units of marine rocks (Busch and Rollins, 1984). The top of the youngest of these marine units, the Ames Limestone, forms the Casselman-Glenshaw boundary. The group consists of highly variable facies of non-marine or marginal marine sandstone, siltstone, shale, claystone, coal, and limestone that, except for the major marine units, can rarely be traced over distances of greater than 1 or 2 miles. The upper and lower group boundaries, however, are often remarkably recognizable so that the group as a whole may be persistently correlated even when its component formations and members cannot.

The rocks of the Monongahela Group crop out only on the higher hilltops near the axes of some of the Laurel Highlands synclines. Monongahela limestones and dolomites, claystones and shales, minor sandstones, and coals representing the lower portion of the group occur in the Ligonier syncline around Ligonier, Westmoreland County, in the Johnstown syncline near Boswell, Somerset County, and in the Berlin syncline between Berlin, Somerset County and the Maryland border. The group has been divided into a lower Pittsburgh Formation and an upper Uniontown Formation in the Pittsburgh area, but in the Laurel Highlands there is not enough rock remaining on the topographic remnants to justify dividing the group.

<u>Quaternary</u>

Unconsolidated alluvial deposits occur in the floodplains and on terraces above many of the streams of the Laurel Highlands. These deposits are mostly Recent in age, but the terrace deposits represent floodplain deposits laid down when the streams were at a higher elevation, probably during the Pleistocene. Flint (1956) noted that the terrace deposits in southern Somerset County occur only a few feet above the streams, whereas both Phelan (1910) and Schaffner (1958) mentioned the occurrence of terrace deposits at elevations of 100 feet or more above the level of the larger streams. Phelan tentatively regarded the Johnstown area terrace deposits as belonging to the Carmichaels Formation, the terrace deposits of the Monongahela drainage system.

STRUCTURAL GEOLOGY

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University of Pittsburgh at Bradford

INTRODUCTION

The study area, part of the Allegheny Mountain Section of the Appalachian Plateau, is characterized by northeast-southwest trending open folds that plunge 1° to 2° northeast. From southeast to northwest the following folds are present in the area: Ebensburg anticline, Johnstown syncline, and Laurel Hill anticline.

The Conemaugh River cuts through the Laurel Hill anticline on a northwesterly course and forms the Conemaugh Gorge. Although most of the area is underlain by Upper Mississippian and Pennsylvanian strata, the Conemaugh Gorge gives us the opportunity to study joints and others structures in the Upper Devonian and Lower Mississippian as well. The Conemaugh Gorge trends approximately N30°W, with an approximate relief of 1,500 ft (460 m). It is an erosional window across the Laurel Hill anticline (Figure 3). The gorge is located approximately 25 mi (40 km) west of the front of the "Eastern Overthrust

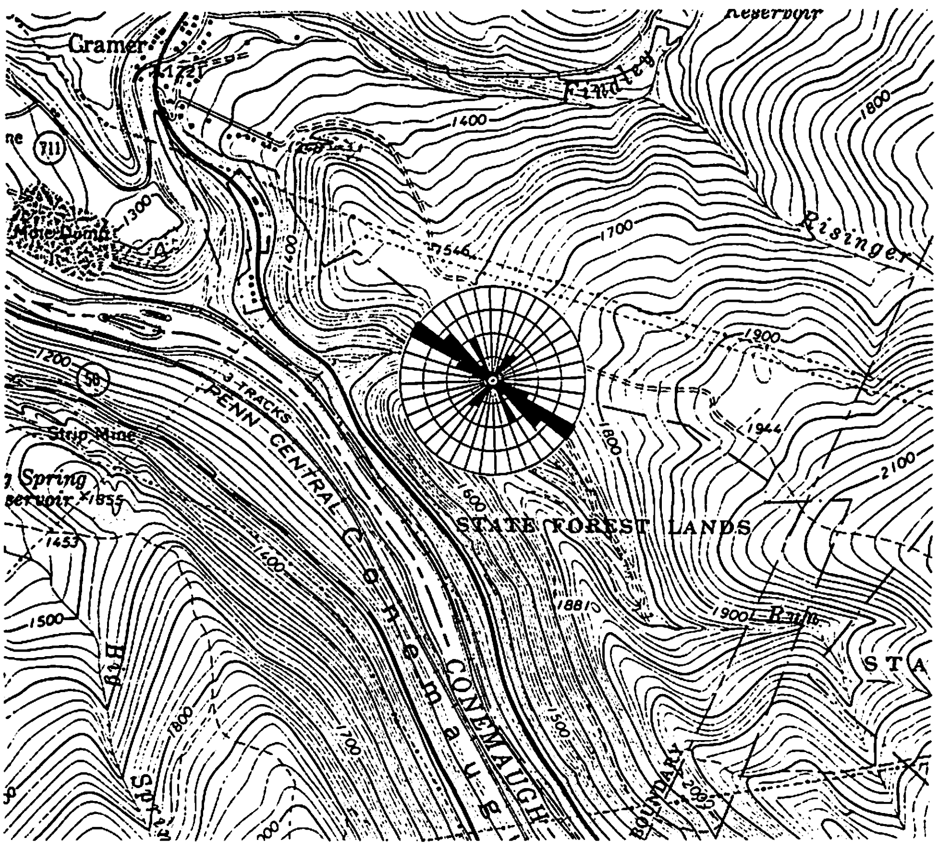


Figure 3. Topographic map of the Conemaugh Gorge in Laurel Hill near Cramer. Note the maximum strike frequency distribution (N40°-50°W) of the systematic joints measured in a traverse line trending N30°W.

Belt". The Conemaugh River is considered by some to be an antecedent river that existed before the surface expression of the Laurel Hill anticline occurred. The river kept pace downcutting while uplift progressed in the Appalachian Plateau. The Laurel Hill anticline is an open, slightly asymmetric fold, with the dip on the southeastern limb ranging from 10° to 15° and from 8° to 10° on the northwestern limb.

The compression that caused the folds is considered to have been non-rotational in the horizontal plane. Hubbert (1928) showed that non-rotational compression causes folds that are parallel to the trend of the deformed belt, as in the Appalachian system, whereas the rotational stress produces en echelon folding lying at about 45°. Laurel Hill and Ebensburg anticlines are definitely of the former type, being roughly parallel to the Allegheny Front.

Also studied in the Johnstown area were joints along Paint Creek (see Stop #7) approximately 2 mi (3.2 km) west-northwest of Windber, Somerset County (Figure 4). In this area, the river flows southwest into Stony Creek and the study area is located approximately on the axis of the Ebensburg anticline. Paint Creek cuts through the upper sandstone portion of the Mauch Chunk Formation. Joints are readily available for study in this sandstone member.

Minor mesoscopic folds were observed at two locations in the Conemaugh Gorge: along PA Route 403 about 0.75 mi (1.2 km) southeast of Clark Run, and along the

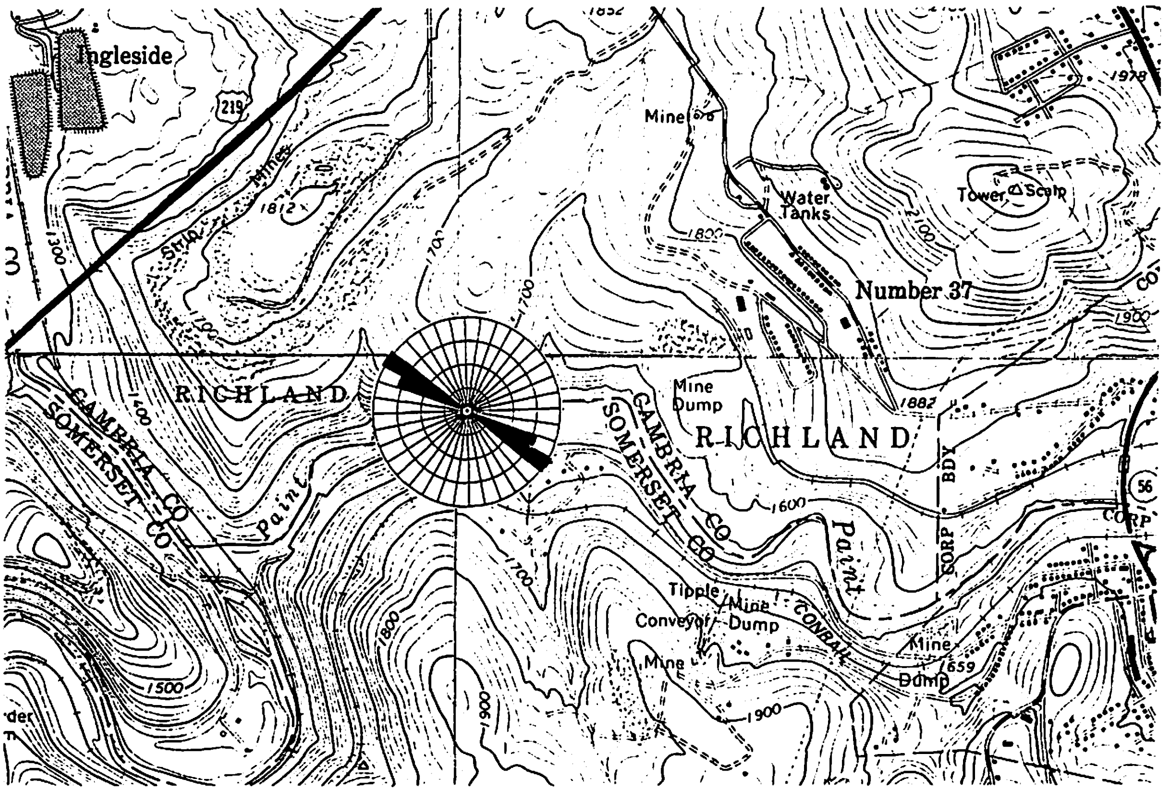


Figure 4. Topographic map of the Paint Creek section in the Ebensburg anticline. Note the strike frequency distribution maximum (N50°-60°W) of the systematic joints measured along the creek.

Conrail railroad tracks below PA Route 403. The minor fold in the gorge, occurring in the Burgoon Formation, reflects a second-order disharmonic fold with the first-order Laurel Hill anticline. The minor fold trends northeast, and plunges gently to the southeast. This part of the outcrop is a distinct structural domain, separated from the rest of the outcrop by a low angle northwest-trending wedge fault and several smaller faults that are associated with the nose of the minor fold (Figure 5A). The wedge fault is subparallel to the bedding, and makes an angle of 18° with the bedding. This fault is part of the folding process, interpreted as developing during the early stages of folding. The poorly developed cleavages on the minor fold of alternating sandstone (compentent), and mud-shale (incompetent) beds are controlled by "cleavage refraction". This is similar to cleavages that are generally formed in folded low-grade metamorphic rocks and in which the clay-rich rocks tend to develop axial-plane cleavages, whereas cleavage in clay-poor rocks tend to fan around the fold.

The mesoscopic folds that occur in the Weir sand on the north side of PA Route 403 are interpreted as local "drags" that appear to be of tectonic origin (Figure 5B). They are developed in alternating layers of sandtones (competent beds) and mud-shales (incompetent beds). The crests of these folds show stretch gashes in which the openings decrease toward the cores of the folds. The mud-shales have probably provided room for the ductile deformation of the sandstones (under a relatively high static pressure) by plastic flowage along the maximum local strain direction (fold axis). Compressional slip movement is indicated by a local wedge fault on the top of the second-order fold in the Conemaugh Gorge.

No large mappable faults are present in the Conemaugh Gorge and Paint Creek areas, yet a small bedding fault was observed in the Burgoon Formation along the Conrail tracks on the north side of the gorge (Figure 5C).

Joints are prolific in both the Conemaugh Gorge and the Paint Creek areas. Preferred orientation in the Johnstown area seems to be along a northwest strike. This would coincide with the axis of compression from the nearby "Eastern Overthrust Belt". Host lithology is an important parameter in influencing the development of regional joint sets as well as their surface morphology. Sheldon (1912) recognized that certain joint sets favored certain lithologies. Strike joints were common in shales but less well developed in interfingered sandstones.

Figure 5. Photographs of structural features in the Conemaugh Gorge near Cramer. (A) Disharmonic second-order fold in the Burgoon Sandstone along the Conrail tracks. The fold axis trends northwest and plunges southeast. The wedge fault on the top of the core of the fold makes an approximate angle of 18° with the bedding planes. Note the plastic flow of the ductile mud-shale along the several small, local faults. Also note the crenulation cleavages that are parallel to the fold axis; (B) Drag folds in the Weir sand along PA Route 403. Note the megaripples at the base of the folds that may have controlled the development of the drags in this outcrop; (C) Bedding-plane fault breccia in the Burgoon Sandstone along the Conrail tracks near Clark Run.

A

B

C

Landsat and subsurface data indicate the presence of a basement-controlled strike-slip fault in the area; the trend of the Conemaugh River gorge is probably the surface manifestation of a deeply buried (basement?) fault (Kaktins and Brice, 1985). The Johnstown syncline takes a jag to the northwest and appears to be offset laterally to the left. If a line is drawn northwestward, connecting the two ends of the axial trace of the Johnstown syncline, this line will approximately parallel and coincide with the northwestward trend of Conemaugh Gorge.

METHODOLOGY

The megascopic structural features of the study area were investigated using: 1) four 1:24,000-scale 7.5-minute topographic quadrangles; 2) the 1:250,000-scale Geologic Map of Pennsylvania (Berg and others, 1980); 3) three 1:500,000-scale photoimages provided by Geospectra Corporation, including a topoimage, a second derivative of a Bouguer gravity map, and a second derivative of magnetic intensity map; and 4) a 1:400,000-scale near and far range radar image.

At each structural domain, strike and dip, spacing, surface markings, persistence, planarity, and host rock lithology were recorded for all systematic joints.

A stereographic projection program for the Macintosh PC (McEachran, 1986-1988) was utilized to calculate the eigenvalues (E_1, E_2, and E_3) and eigenvectors for the data set that was run for Pi and Beta. The eigenvalues were used to examine the uniformity of the distribution of the data sets.

To determine the true measurement of joint frequency in the Conemaugh Gorge, a traverse correction for strike and dip was made using the following relation (LaPointe and Judson, 1985; Marshak and Mitra, 1988):

$$N = n/\sin \phi \cdot \sin \beta$$

where N represents the corrected number of joints in a 10 degree class interval, n is the number of individual intervals measured in the field, ϕ is the acute angle between the strike and the direction of traverse (N30°W), and β represents the arithmatic mean dip of the joint set.

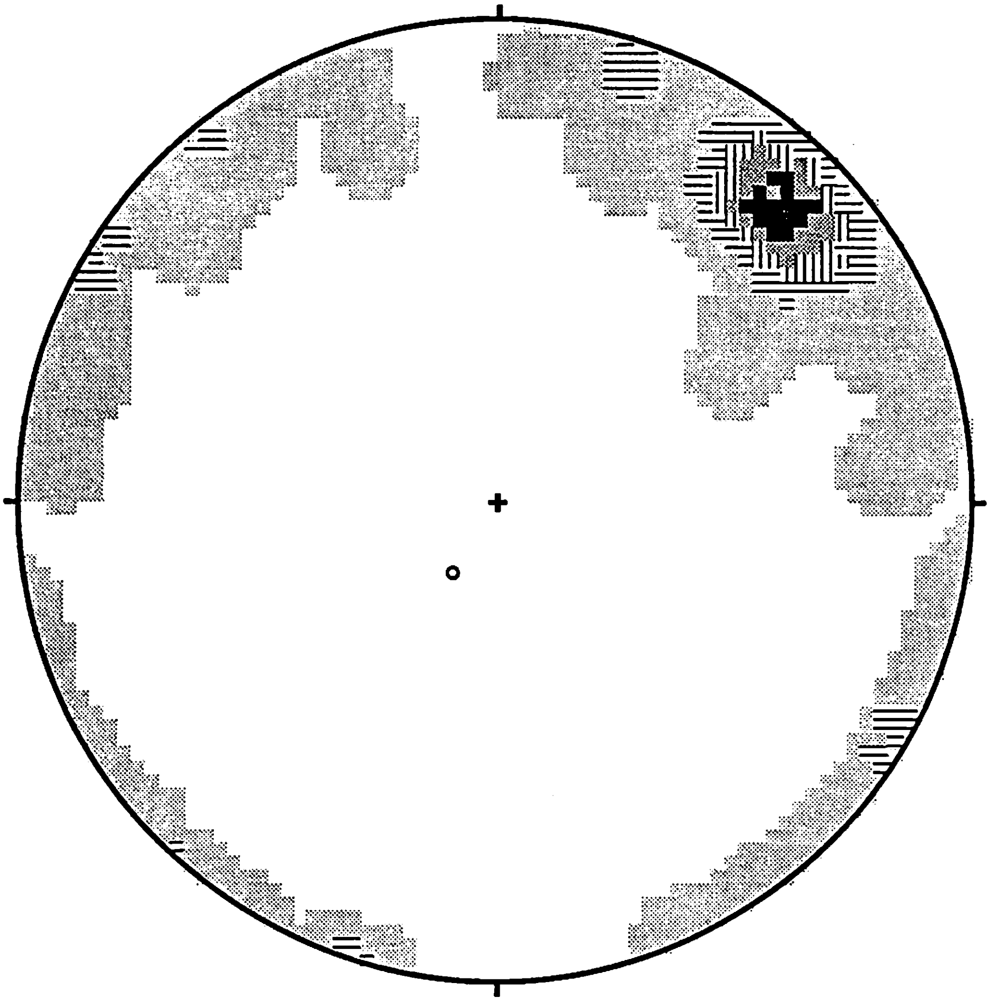
Mean orientation of joints were determined graphically from the histograms, the strike frequency diagrams, and/or computer contoured Pi and Beta sterograms (Figures 6 through 11). The poles of the best-fit great circles were plotted as open circles in the Pi and Beta diagrams and the results were summarized in the legend boxes.

Three additional eigenvalues, r_1, r_2, and k were also estimated from the following relations:

$$r_1 = LN\ (E_1/E_2)$$

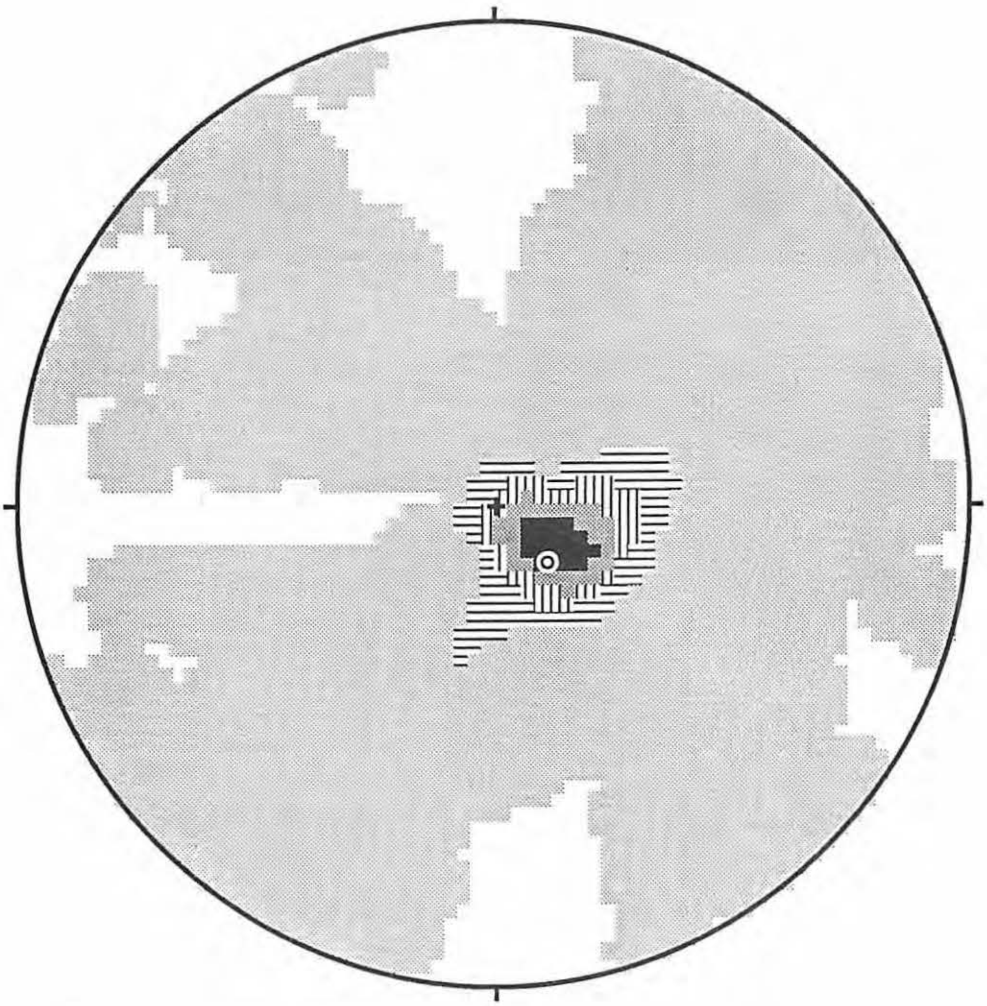
$$r_2 = LN\ (E_2/E_3)$$

$$k = r_1/r_2$$



Data	Schmidt Equal Area Projection	Statistics
Conemaugh Gorge, Joints 0.7-5.8% 21.0-26.1% 5.8-10.9% 10.9-15.10% 15.10-21.0% N = 134		o Pole to bestfit great circle 210.7 75.4 E1 = 92.77 E2 = 38.90 E3 = 2.33 r1 = 0.87 r2 = 2.82 K = 0.31 s. var. = 0.285 Rbar = 0.715

Figure 6. Pi stereogram of all measured joints in the Conemaugh Gorge. A single maximum defines a set trending 135°, and subordinate sets are 108°, 210°, and 230° azimuth. The set with maximum frequency is a cross-fold joint trending perpendicular to the trend of the fold axis of the Laurel Hill anticline. The set 210° represent joints that are subparallel to the bedding strike (strike joints).



Data	Schmidt Equal Area Projection	Statistics
Conemaugh Beta Diagram		o Mean Beta Vector
0.0-5.2%	20.9-26.1%	137.1 76.3
5.2-10.4%		E1 = 6887.17
10.4-15.7%		E2 = 1745.54
15.7-20.9%		E3 = 268.29
		r1 = 1.37 r2 = 1.87 K = 0.73
	N = 8901	s. var. = 0.154 Rbar = 0.846

Figure 7. Beta stereogram of all measured joints in the Conemaugh Gorge. Note a single maximum that defines a set trending 135° azimuth. N represents the number of the intersections for 134 joints measured in the field.

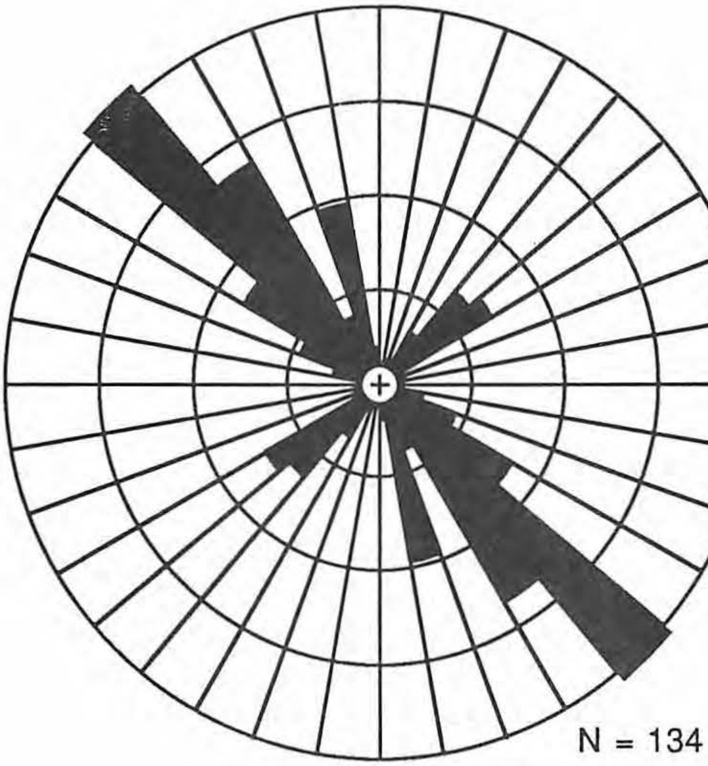


Figure 8. Rose diagram of all measured joints in the Conemaugh Gorge.

To study the general distribution of the uniformity, the values of r_1, r_2, and k were plotted in the distribution diagram (Davis, 1986 and adapted from Woodcock, 1977), where r_1 values were plotted on the y-axis and r_2 values on the x-axis (Figure 12). R_{bar} (normalized value of R), and the spherical variance (sv) were estimated from the relations:

$$R = [(\sum l)^2 + (\sum m)^2 + (\sum n)^2]^{\frac{1}{2}}$$

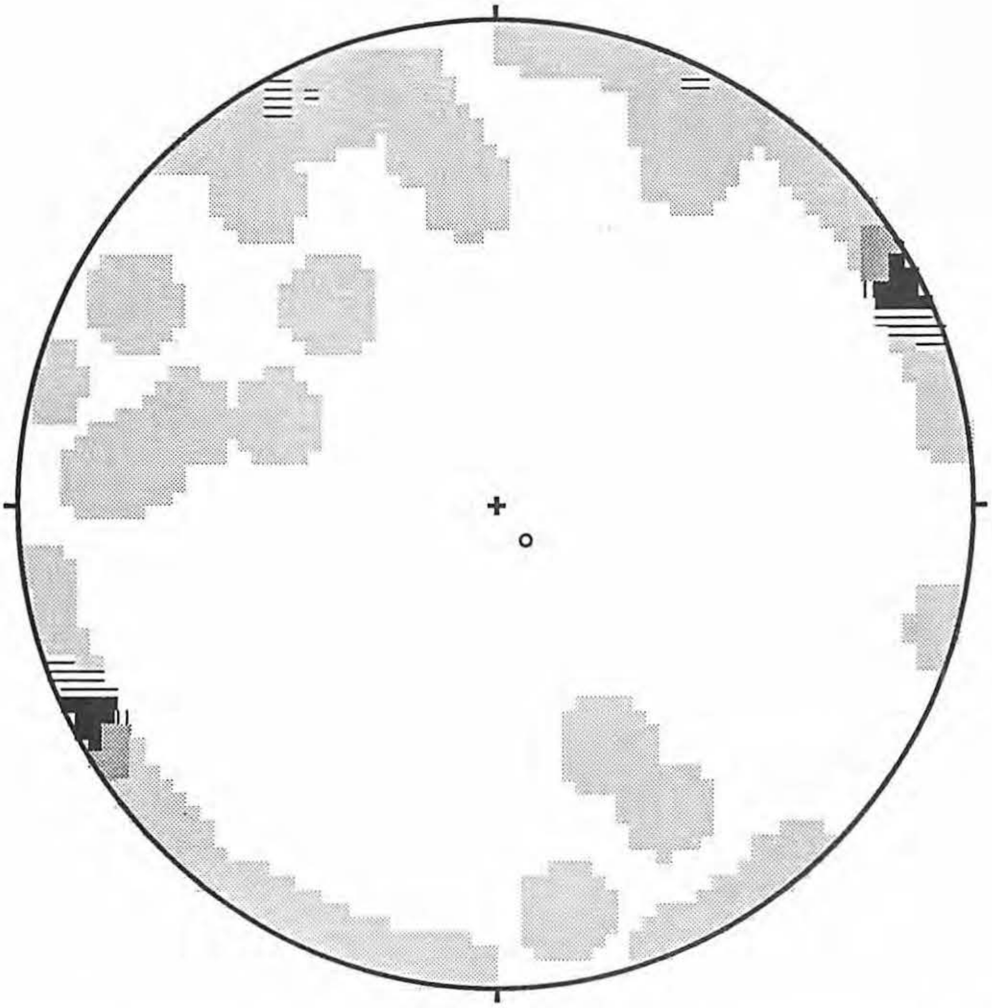
$$R_{bar} = R/n$$

$$sv = (n - R)/n \text{ or } sv = 1 - R_{bar}$$

FRACTURES

Joints are the most ubiquitous structural features in the detrital sediments of Mississippian and Devonian age in the study area. Nickelsen and Hough (1967) and Engelder and Geiser (1980) examined joints in the Allegheny Plateau, and they have summarized the sparse literature on joint in that area.

Station selection priority was given to locations suitable for inclusion in the Field Conference stops. The result of analysis of regional jointing in the



Data	Schmidt Equal Area Projection	Statistics
Paint Creek Joints, Pi Diagram 0.8-9.5% 9.5-18.2% 18.2-26.9% 26.9-35.6%	35.6-44.3% N = 122	o Pole to bestfit great circle 138.6 81.9 E1 = 85.31 E2 = 33.35 E3 = 3.34 r1 = 0.94 r2 = 2.30 K = 0.41 s. var. = 0.334 Rbar = 0.666

Figure 9. Pi stereogram of all measured joints in the Paint Creek section. A single maximum point defines a set trending 125°.

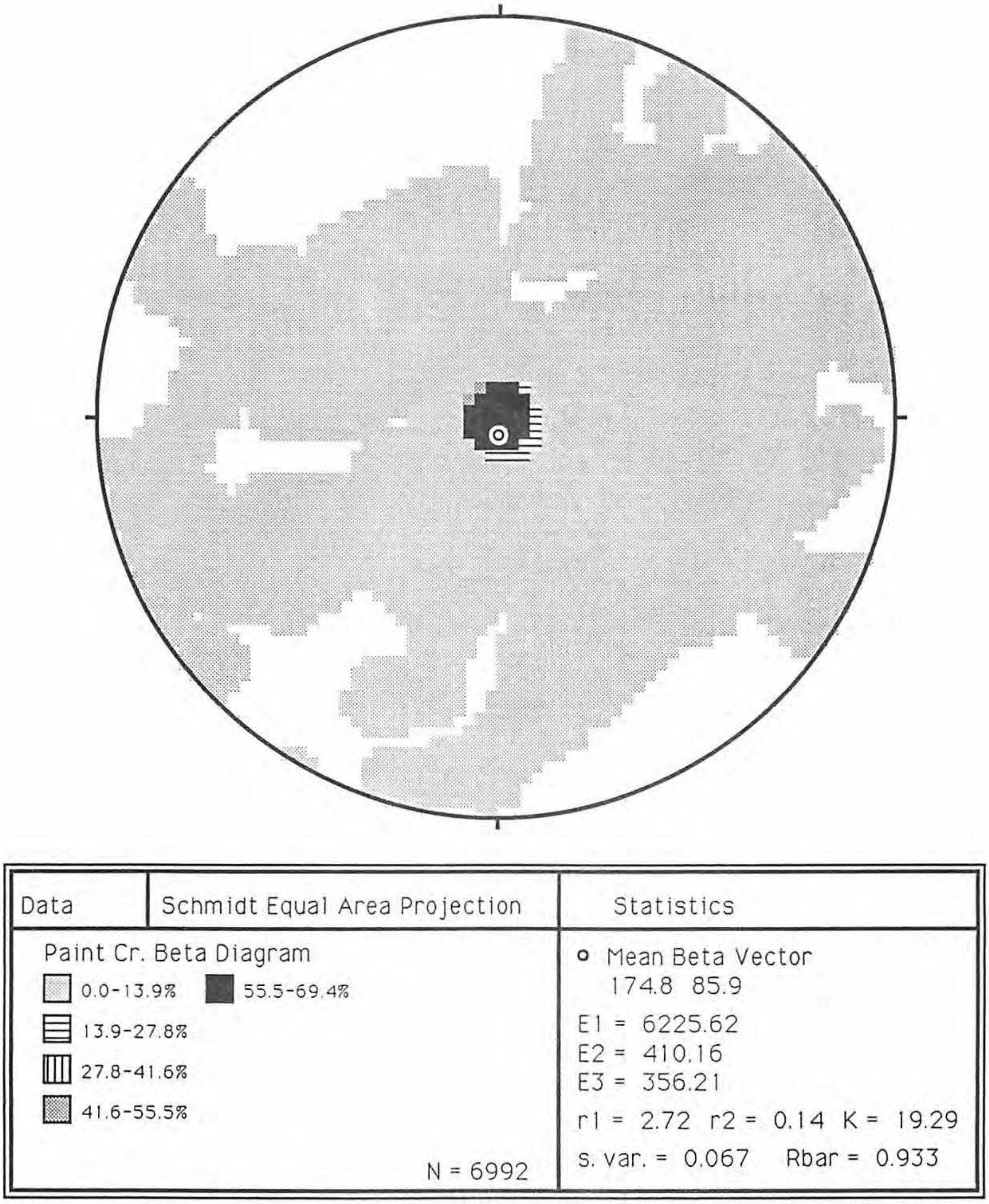


Figure 10. Beta stereogram of all measured joints in the Paint Creek section. A single maximum of 125° defines the azimuth of the dominant joint set. N represents the number of the intersections for 122 systematic joints.

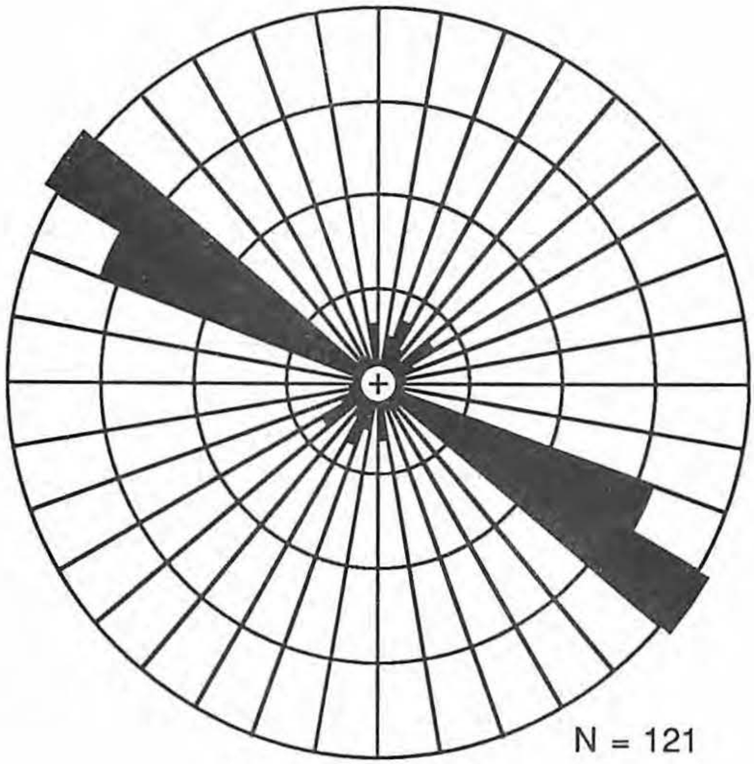


Figure 11. Rose diagram of all measured joints in the Paint Creek section.

study area are presented here from the following structural domains: the Conemaugh Gorge through Laurel Hill anticline (Stop #4); and the Paint Creek section through Ebensburg anticline (Stop #7). To determine the geometric relationships between the joint sets and the local folds, the geometry, physical features, and sequence of joint development within the joints sets were examined.

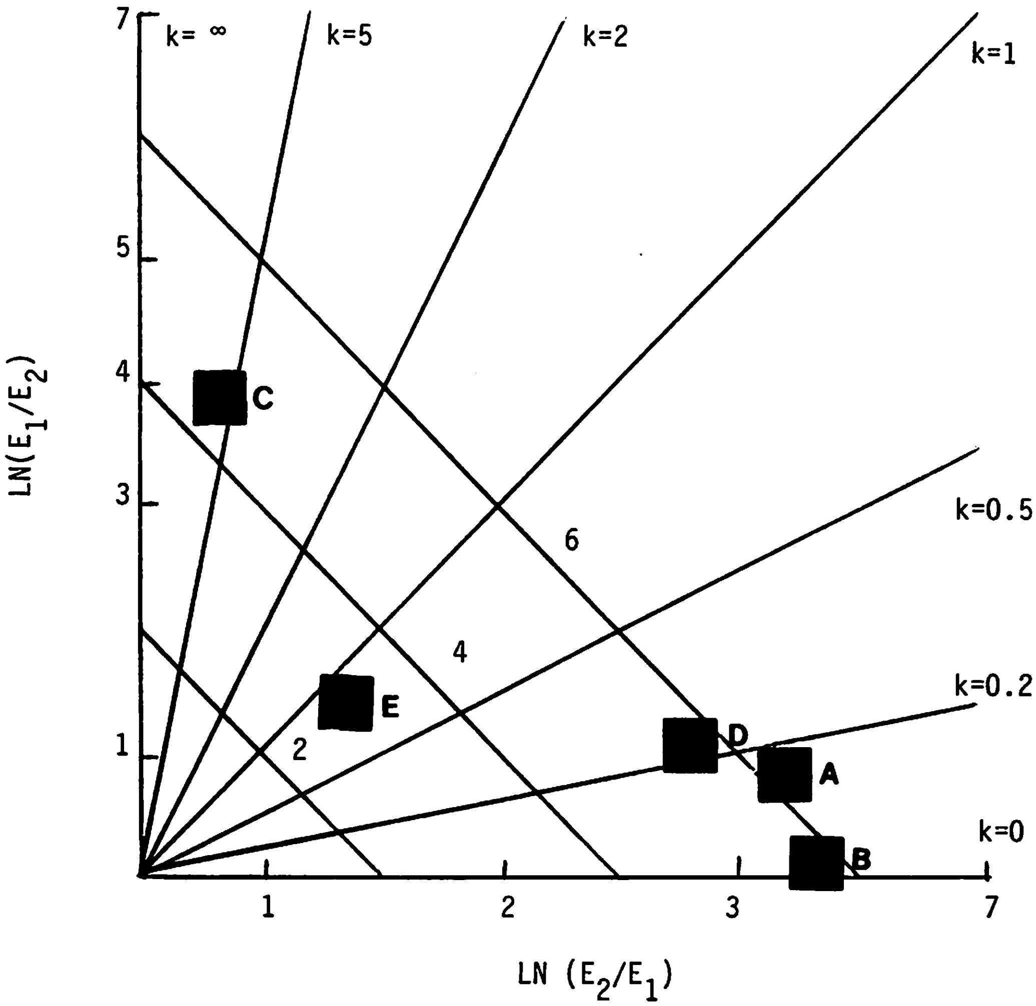
In Conemaugh Gorge, joints were measured in several stratigraphic rock units in order to examine the role of the regional lithology in the orientation and spacing of the systematic joints. Every principal joint was measured in the gorge on a traverse line oriented N30°W. The mean strike was calculated for 10 degree interval of group data from the relation (Sharmak and Mitra, 1988; also Table 1):

$$a_m = \text{arc cos } (G/T)$$

or:

$$a_m = \text{arc sin } (H/T)$$

where $G = (\sum \cos a_i)/n$; $H = (\sum \sin a_i)/n$; and $T = (G^2 + H^2)^{\frac{1}{2}}$.



A = Loyalhanna Formation

B = Burgoon Sandstone

C = Rockwell tongue sandstone #1

D = Rockwell tongue sandstone #2

E = Venango Group, Middle red shale zone

Figure 12. Distribution diagram showing the position of the stereograms from Conemaugh Gorge and Paint Creek with regard to the eigenvalues (taken from Davis, 1986, adapted from Woodcock, 1977).

Table 1. Statistical analysis of the joint measurements collected from the Conemaugh Gorge through the Laurel Hill anticline.

STRUCTURAL DOMAIN	ROCK FORMATION TYPE	E_1	E_2	E_3	r_1	r_2	k	$s_{varience}$	R_{bar}	ln E_1/E_2	ln E_2/E_3
LAUREL HILL ANTICLINE	Loyalhanna Limestone	8.26	3.68	0.06	0.81	4.15	0.19	0.40	0.63	0.81	4.12
	Burgoon Sandstone	4.99	3.97	0.04	0.23	4.67	0.05	0.30	0.71	0.23	4.60
	Rockwell Sandstone #1	27.24	0.51	0.25	3.97	0.71	5.57	0.01	0.99	3.98	0.71
	Rockwell Sandstone #2	20.10	10.42	0.58	0.70	2.88	0.24	0.40	0.62	0.66	2.90
	Catskill Formation	6887.17	1745.54	268.29	1.37	1.87	0.73	0.15	0.85	1.31	1.81

Subvertical systematic joints are common in both the Conemaugh Gorge and Paint Creek areas. The largest concentration of the joints in the gorge trends N40°-50°W, which is approximately perpendicular to the general strike of the bedding planes (N43°E). These joints are classified as cross-fold joints in this area. A subordinate joint set, trending N40°-50°E, exist orthogonal to the dominant joint direction (Figure 6 to 8). The systematic joints measured in Paint Creek area, approximately along the axis of the Ebensburg anticline show approximately similar maxima (N60°W) as in the Conemaugh Gorge. Several subordinate joint sets were measured in the Paint Creek area (Figures 9 to 11). Two orthogonal cuts of dihedral systematic joints are present in the Loyalhanna quarry at Clark Run between PA Route 403 and the Conrail tracks (Stop #4).

Joint density varies with bedding thickness and the lithology of the strata. For accurate comparison of the data collected from the field, the data from similar lithologies were plotted together; all data were then plotted together and statistically analyzed (Figures 6 through 11; Table 1).

Arrest features are common on the joint surfaces of both thin- and thick-bedded sandstones and thin-bedded mud-shales in the Conemaugh Gorge and the Paint Creek area.

The megascopic linear features were traced on the topoimage (Figures 13 and 14), and far- and near-range Side Looking Radar (SLAR) images. The majority of the principal linear features trend west-northwest, approximately perpendicular to the Allegheny Front. As discussed above, the Conemaugh Gorge is a transverse antecedent valley that has been interpreted as the surface expression of a cross-strike structural discontinuity (CSD), a deeply buried basement fault (Figures 13 and 14). Another CSD, trending northwest-southeast, offsets the axis of the Johnstown syncline laterally to the left. Several smaller linear features were traced on the topoimage trending north-northeast. We conclude that the presence of the dominant pervasive joint sets subparallel to the linear feature along the Conemaugh Gorge infers a continuation of the CSD until at least the termination of the Alleghanian orogeny (approximately 320 to 280 Ma).

Stylotized joint surfaces are common in the thick to massive-bedded quartzitic sandstone of the Pottsville Group (Homewood Formation) in the Paint Creek area (U. Kaktins, 1988, personal comm.). Stylolites are essentially parallel to bedding, and some are perpendicular to it. The layer-parallel stylolites are believed to be related to diagenetic processes - compaction, pressure solution, and recrystalliztion due to the load of the overburden. The bed-normal stylolites are of tectonic origin in that pressure solution developed under the influence of the principal horizontal stress (PHS), trending southeast-northwest, approximately perpendicular to the Appalachian Front. The bed-normal stylolites are layer-parallel shortening fabrics (LPS), congruent to the Ebensburg anticline and probably developed during or after the folding.

Thin sections were made in the directions parallel and perpendicular to the bedding plane. Petrographic analysis of the surface of the stylolites reveals that the stylotized joints are partially coated with finely granulated metamorphosed quartz and open spaces, suggesting that the stylolite surfaces have probably developed by the mechanism of granulation and pressure solution. These stylotized sandstones appear to have been metamorphosed dynamically into slightly calcareous, but highly siliceous quartzite along the fold axis of the

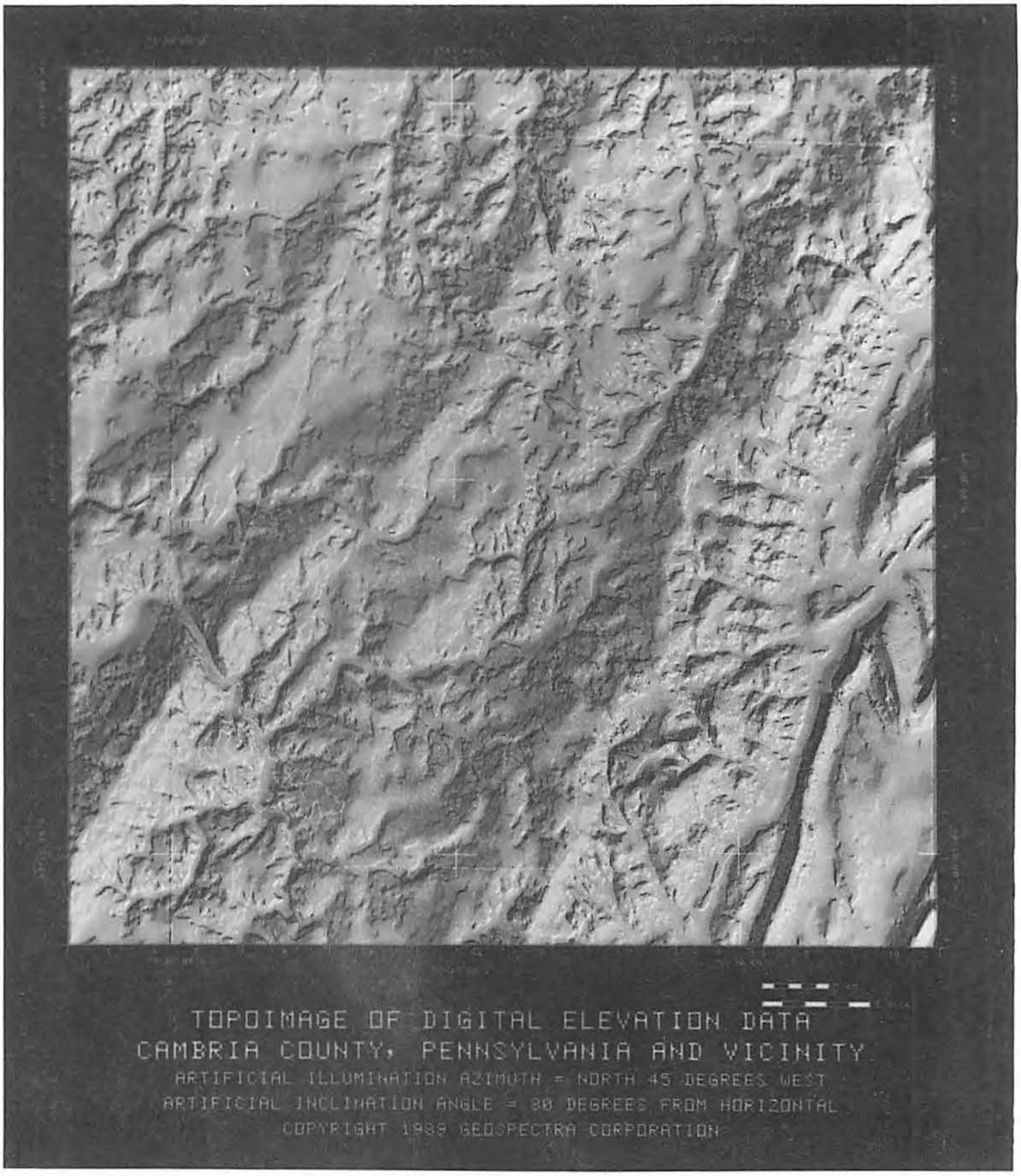


Figure 13. Topoimage of digital elevation data of Cambria County and vicinity at a scale of 1:500,000 (courtesy of Geospectra Corporation). The artificial illumination azimuth is N45°W and the artificial inclination angle is 30° from horizontal.

Ebensburg anticline, probably during the Alleghanian orogeny. The individual composite metamorphosed quartz grains are highly strained, showing distinct undulose extinction, under the directed load. The majority of the composite metamorphosed quartz grains have crenulated, granulated, and straight boundaries. The strained quartz grains are cemented by in situ quartz that probably resulted from pressure solution, which in turn strained during the deformation.

Figure 14. Lineament map of Cambria County and vicinity showing the traces of the interpreted linear features from a topoimage (Figure 13), second derivative Bouguer gravity, and second derivative magnetic intensity maps, all at 1:500,000 scale.

The granulated quartz grains occur as matrix along the stylolites and in the pore spaces.

Data from Nickelsen (1966), Faill (1977), and Engelder and Engelder (1977) suggest that layer parallel shortening probably extended approximately mi (150 km) to the west-northwest into the entire width of the Appalachian Plateau from Lodi anticline to the Allegheny Front.

DISCUSSION

The Pi and Beta stereograms (Figures 6, 7, 9, and 10) show the orientation of the joints measured in the Conemaugh Gorge through the Laurel Hill anticline and in the Paint Creek section. They demonstrate a point maximum of 45° and two subordinate peaked clusters at 18°, 60°, and 40° (Figures 6 and 7). The maxima correspond to the subvertical systematic joints trending 135°, 108°, 210°, and

230° respectively. The first set of joints (N45°W) is commonly predominant in both expression and frequency in the outcrop. Apparent variations are observed in the individually contoured stereograms from different lithologies and formations. Variations in the joint density appears to be related to the lithology and the thickness of the individual layer in the outcrop. The distance in joint spacing decreases with the increase of the thickness of the individual bed. Joint surfaces are irregular and curviplanar in the mud-shales, which are associated with abundant arrest points. Arrest points are scarce in thick-bedded sandstones. It was also revealed that host lithology plays an important role in determining the strike of joints.

Considering that the majority of the systematic joints are subvertical, we can conclude that the maximum horizontal stress (σ_1) is striking approximately N45°W, the intermediate principal stress (σ_2) is vertical, and the minimum horizontal stress trends approximately N45°E, paralleling the orientation of the fold axis in the study area.

Strain developed during the folding of the Appalachian Plateau, producing open folds and systematic joints. The orientation of the joints is closely related to the structural elements of the folds. Minor joint sets appear to be limited to local scale and are not common for both the Laurel Hill and the Ebensburg anticlines.

In both outcrops discussed here the major joint set parallels the direction of the maximum compressive stress. Most of the systematic joints measured in the study area lack plume features, which probably indicates a rapid rate of fracturing.

The most common systematic joints (N45°W) are approximately orthogonal to the strike (N43°E) in the Laurel Hill anticline and Ebensburg anticlines. They are classified as cross-fold joints in this area.

Examination of a topoimage for Cambria County and vicinity, prepared by Geospectra Corporation from digital elevation data with an artificial illumination angle of N45°W, shows that the majority of the lineaments strike northwest and east-west (Figure 13). They are approximately normal to the trend of the Allegheny Front. A second deriviative of Bouguer gravity filtered to enhance northeast trending gravity anomalies, and a second derivative of magnetic intensity, filtered to enhance northeast trending magnetic anomalies revealed that the principal linear features identified from the topoimage are consistant with the geophysical data. Some of the northwest-trending lineaments in Cambria County were also observed in a far-range radar image.

The illumination of the topoimage, Bouger gravity anomalies, and magnetic intensities variation do not allow us to depict the CSD's that may be present subparallel to the trend of the strike of the maximum joint density (N40°-50°W in the Conemaugh Gorge). An artificial illumination with a 45° azimuth and a 30° inclination from the horizontal may be required to enhance the CSD's effectively in this area.

SUBSURFACE STRATIGRAPHY

John A. Harper
PA Geological Survey

INTRODUCTION

The deepest well drilled to date in the Appalachian Basin is the Amoco Production #1 Leonard Svetz in Middle Creek Township, Somerset County. The well was drilled on Laurel Hill anticline to a depth of 21,460 ft (6,541 m), penetrating the most complete section of Paleozoic rocks of any well south of northern Armstrong County. Records, descriptions of drill cuttings, and geophysical logs from the #1 Svetz and other, shallower, wells form the basis of our knowledge of the sub-Mississippian rocks in the Appalachian Plateau. The present nomenclature used for the subsurface stratigraphy of western Pennsylvania is illustrated in general by Figure 15. The following is a summary of Precambrian through Devonian rocks in the Laurel Highlands.

PRECAMBRIAN

The Precambrian rocks in most of western Pennsylvania are unknown. Only in Erie, Crawford, and Mercer Counties in the northwestern part of the state have oil and gas operators drilled wells deep enough to penetrate the basement (Saylor, 1968). Well cores and drill cuttings in this area have been described as schistose biotite gneiss and leucocratic granitic rock (Lapham, 1975), and indicate a Late Precambrian age (between 908 and 633 ma - Lapham and Root, 1971). Depth to basement near Lake Erie is about 5,000 ft (1,525 m) below sea level and increases rapidly to the southeast, reaching an estimated 30,000 to 40,000 ft (9,000 to 12,000 m) below sea level in Somerset County. This estimate is based on a combination of geophysical data (seismic, gravity, and magnetic information) and an educated guess as to the amount of Paleozoic section not penetrated in the Svetz well.

CAMBRIAN

Inasmuch as the uppermost Cambrian was barely penetrated in any well southeast of Mercer County, we know very little about the Cambrian section in southwestern Pennsylvania. The Svetz well penetrated only 600 feet into the Cambrian, reaching perhaps to the level of the Ore Hill Member of the Gatesburg Formation. The Peoples Natural Gas #1 Nellie Martin well in Armstrong County penetrated 2,600 ft (790 m) of Cambrian, to the level of the Olin Sandstone of Wagner (1976). The Martin well, however, was drilled in the Rome Trough, a Late Precambrian-Early Ordovician basement graben complex that stretches from Kentucky into western Pennsylvania (Figure 16). Thousands of feet of sediment filled the graben during the Cambrian, creating a much thickened geologic record that is difficult to correlate across the trough (Figure 17). Wagner (1976) thought that the thick Cambrian sandstone found near the bottom of the Martin well was a new member in the middle of the Gatesburg Formation. He named the member the "Olin Sandstone" and mapped it within the limits of the "Olin basin" (his name for the Rome Trough). In actuality the "Olin Sandstone" is merely the Upper Sandy Member, thickened and offset downward within the trough.

The Gatesburg Formation consists predominantly of medium gray dolomites

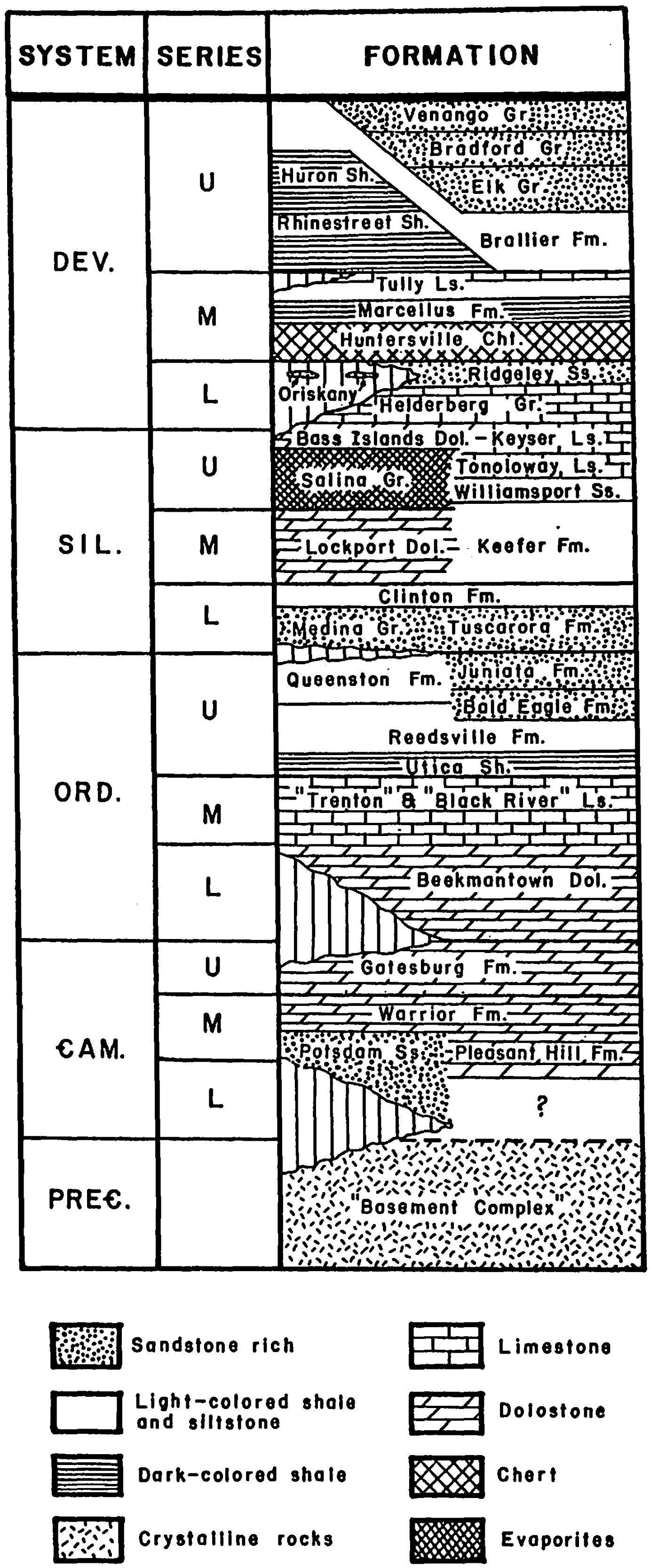


Figure 15. Generalized diagram of the sub-Mississippian formations occurring in the subsurface of western Pennsylvania (modified from Laughrey and Harper, 1986).

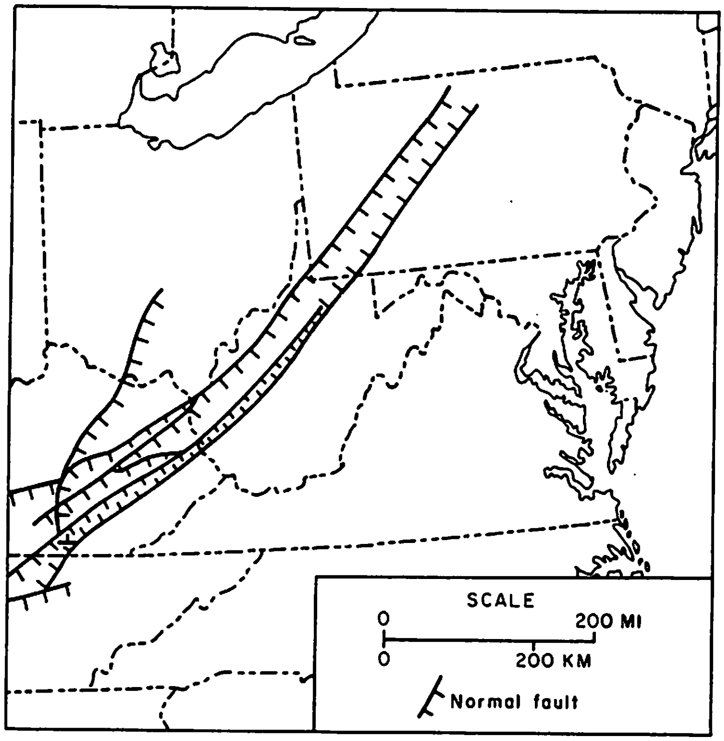


Figure 16. Speculated trend and extent of the Rome Trough in the central Appalachians (from Harper and Laughrey, 1987).

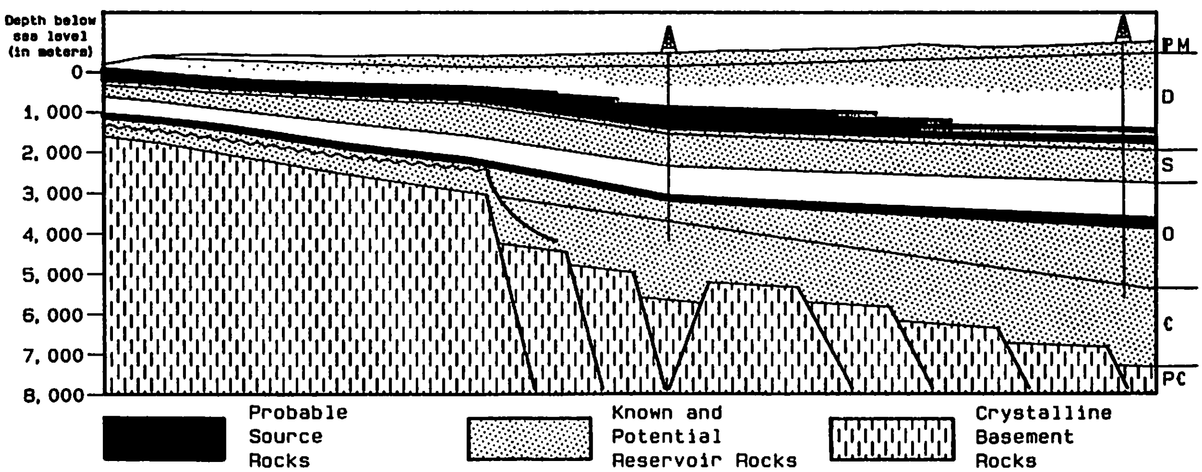


Figure 17. Generalized cross section of western Pennsylvania showing the relationship of hypothesized basement extension faults to development of the Paleozoic basin and the deposition of petroleum source and reservoir rocks.

containing pellets, oolites, pseudo-oolites, light and dark colored cherts, and some pyrite scattered thoughout the section. Sandstones and arenaceous dolomites occur in two major zones within the formation. These are the upper and lower sandy members of Wagner (1966 and 1976). The uppermost member of the Gatesburg, the Mines Member, contains abundant chert. This constituent is relatively less abundant in the overlying Lower Ordovician dolomites, and the presence or absence of chert can be used as a tool for establishing the systemic boundary where fossils are rare to absent (Wagner, 1966).

ORDOVICIAN

Based on correlation between the Martin well in Armstrong County, which has a total depth of 15,574 ft (4,747 m) in the Upper Cambrian Gatesburg Formation, and the Svetz well, there should be approximately 8,000 ft (2,400 m) of Ordovician rock beneath the Laurel Highlands. Dolomites and limestones comprise most of the Lower and Middle Ordovician rocks in this area, whereas the Upper Ordovician is almost equally divided between carbonates and clastics.

Wagner (1966) used drill cuttings to correlate the Ordovician carbonates between the outcrop in central Pennsylvania and the deeper drill holes in the Appalachian Plateau of New York, Ohio, Pennsylvania, and West Virginia. Using subtle changes in texture, carbonate composition, and specific constituents such as fossils, chert, and volcanic ash particles, Wagner carried many of the names from central Pennsylvania formations into the subsurface. It is very difficult to detect the subtle nuances of carbonate facies changes in geophysical logs, however, so that Wagner's stratigraphic nomenclature is rarely used in the subsurface.

Approximately 5,500 ft (1,670 m) of Ordovician dolomites and limestones occur in the Svetz well. The Martin well, however, contains only about 1,500 ft (450 m) of carbonate rocks. This is due to a major unconformity (the well-known Knox unconformity) at the base of the Middle Ordovician (Wagner, 1976) that truncated the underlying Beekmantown Group dolomites west of the eastern edge of the Rome Trough. Abundant volcanic ash beds occur within zones in the section. These ash bed zones are excellent stratigraphic markers for correlating within the Ordovician carbonate section.

The dark colored limestones at the top of the Ordovician carbonate sequence are laterally equivalent to, and commonly interfinger with, the organic-rich black shales of the Utica Shale in western Pennsylvania. Where this happens, east of the Rome Trough, Berg and others (1986) applied the name Antes Shale in place of Utica. The Utica in the Martin well consists of about 300 ft (90 m) of black, slightly calcareous shale containing pyrite. In the Svetz well the Antes consists of about 750 ft (230 m) of medium to dark gray, brown, or black, platy, micaceous shale becoming increasingly interbedded with medium gray to brown limestones and light gray siltstones in the lower 250 ft (75 m).

Between 2,300 and 3,000 ft (700 and 915 m) of clastic rocks, including light to medium gray silty of the Reedsville Formation, and red and green sandstones, siltstones, and shales of the Juniata Formation, lie above the Utica-Antes interval. The Juniata Formation forms the top of the Ordovician. North and west of the Rome Trough the Juniata becomes thinner and changes character to the red shales and siltstones of the Queenston Formation (Figure 18). The Juniata grades upward into the Lower Silurian Tuscarora Sandstone through 150 to 300 ft

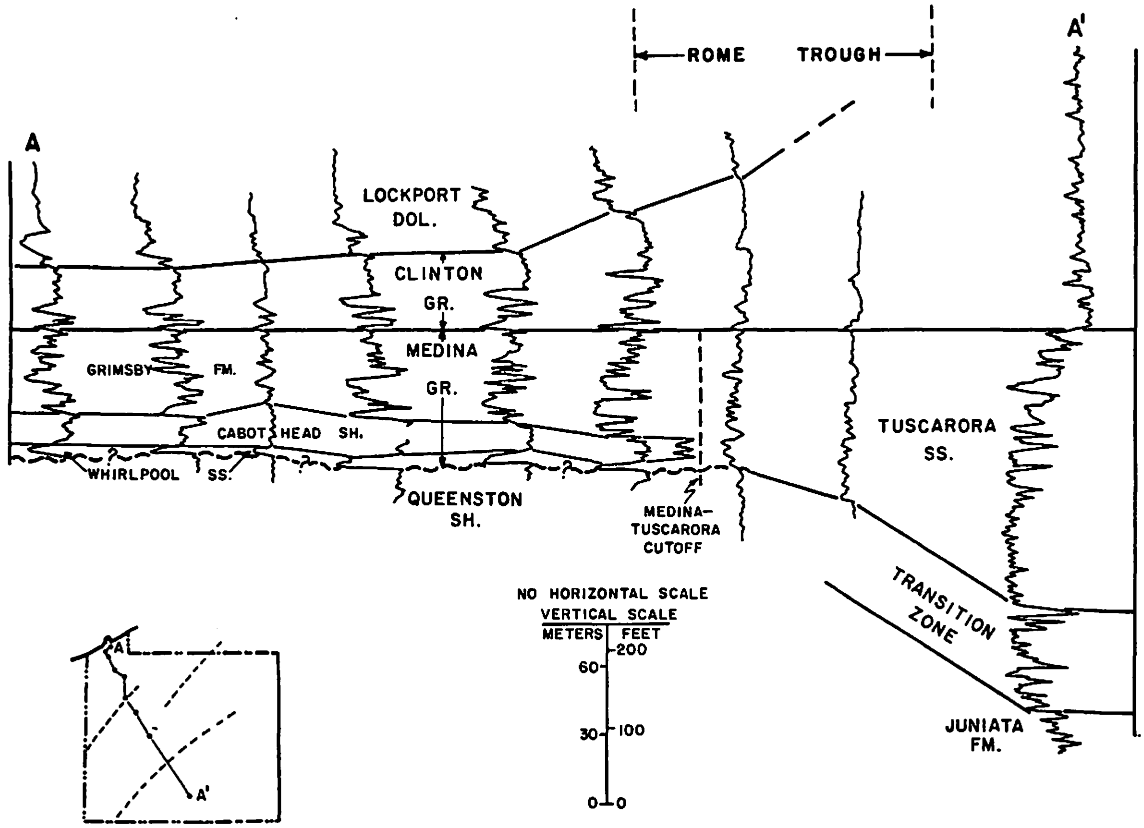


Figure 18. Regional subsurface cross section of the latest Ordovician and Early Silurian rocks in the subsurface of western Pennsylvania (modified from Laughrey and Harper, 1986).

(45 to 90 m) of section that may be assigned to either of those formations (the Juniata-Tuscarora transition of Piotrowski, 1981, and others).

SILURIAN

Approximately 2,600 ft (790 m) of Silurian rocks lie beneath the Laurel Highlands. Silurian rocks in western Pennsylvania consist of discrete zones of sandstones, shales, dolomites, limestones, and evaporites. Major facies changes take place from east to west, generally over the Rome Trough. This structure must have been reactivated, at least subtly, in the Late Silurian because the greatest thickness of Salina Group evaporites and carbonates (based on Fergusson and Prather, 1968) occurs within the suspected limits of the trough.

The basal Silurian formation in the Laurel Highlands, the Tuscarora Sandstone, consists of about 250 ft (75 m) of yellow, light gray, to white, fine- to very fine-grained sandstone capped by about 150 ft (45 m) of interbedded sandstone, siltstone, and shale. The Tuscarora grades westward, across the Rome Trough, into the Medina Group of northwestern Pennsylvania (Laughrey and Harper, 1986). Above the Tuscarora lie approximately 500 ft (150 m) of (in ascending order) dusty red shale and light greenish-gray dolomite, light greenish-gray shale, and interbedded medium gray shale, siltstone, and limestone of the Rose Hill Formation. The siltstone beds in the upper portion of the Formation may represent the western equivalent of the Keefer Sandstone (Heyman, 1977). Only 50 ft (15 m) of medium to dark gray shale above the Rose Hill can be assigned to the Rochester Shale. Over 450 ft (135 m) of brown to black limestone, medium to light gray dolomite, and dark gray shale comprise the McKenzie Formation. This formation grades westward into the Lockport Dolomite.

About 1,300 ft (395 m) of limestones, dolomites, and evaporites referable to the Salina Group lie above the McKenzie. Fergusson and Prather (1968) followed the work of Michigan Basin workers in dividing the Salina into seven informal units, labeled A to G, based on the correlation of salt beds. Heyman (1977) was able to subdivide the seven units even further, and correlated many of them to established outcrop units. For example, units A to D correlate to the Wills Creek Formation of central Pennsylvania, whereas units E to G correlate to the Tonoloway Formation. Because of facies changes within and across the Rome Trough, parts of the Salina Group in the Laurel Highlands might be more easily referred to one or the other formation rather than to the group. In the Svetz well the basal 200 ft consists of brown dolomites, limestones, and shales that could be labeled either Wills Creek or units A2, B, and C of the Salina Group. Salt beds occur in the 400 ft (120 m) above this basal unit, overlain in turn by about 700 ft (215 m) of dark-colored dolomite containing some anhydrite.

The Keyser Formation represents a transition between the Silurian and Devonian. Inasmuch as the systemic boundary is based on fossil evidence (Bowen, 1968), it is impossible to determine the boundary on geophysical logs, and close to impossible in drill cuttings. In the Svetz well the Keyser Formation consists of about 300 ft (90 m) of medium gray dolomites and dark olive gray limestones.

DEVONIAN

The Devonian in the Laurel Highlands (not counting the Devonian portion of the Keyser Formation) consists of 7,000 to 8,000 ft (2,130 to 2,430 m) of mudstones, siltstones, sandstones, and limestones. These rocks are among the most important hydrocarbon source and reservoir rocks in the Appalachian Basin and, therefore, are among the better known of the subsurface formations. Over 200,000 wells have been drilled into Upper Devonian rocks since Drake's famous well in 1859. About 8,000 wells have been drilled into or through the Lower Devonian carbonates (the Helderberg Group of drillers). Most of the information pertaining to rocks younger than Silurian come from wells such as these. Figure 19 illustrates the nomenclature used in the subsurface of western Pennsylvania.

Although the Helderbergian Stage includes all of the rocks between the base of the Keyser Formation and the base of the Ridgeley Sandstone, the drillers' "Helderberg Group" does not include the Keyser. In general, the oil and gas industry does not try to divide the "Helderberg Group" into its constituent formations, and indeed in many places in western Pennsylvania it is impractical, if not impossible, to do so on the basis of geophysical logs and drill cuttings. For example, the Corriganville and New Creek Limestones are separated on the basis of subtle lithologic changes that connot be detected easily in the subsurface. In outcrop south of Pennsylvania the Corriganville can be separated from the New Creek based on the relative abundance of chert, but in most wells the entire interval contains abundant chert. The overlying Mandata Shale consists of about 25 to 50 ft (8 to 15 m) of black shale. Above that is about 100 to 200 ft (30 to 60 m) of olive, brown, or light gray Licking Creek

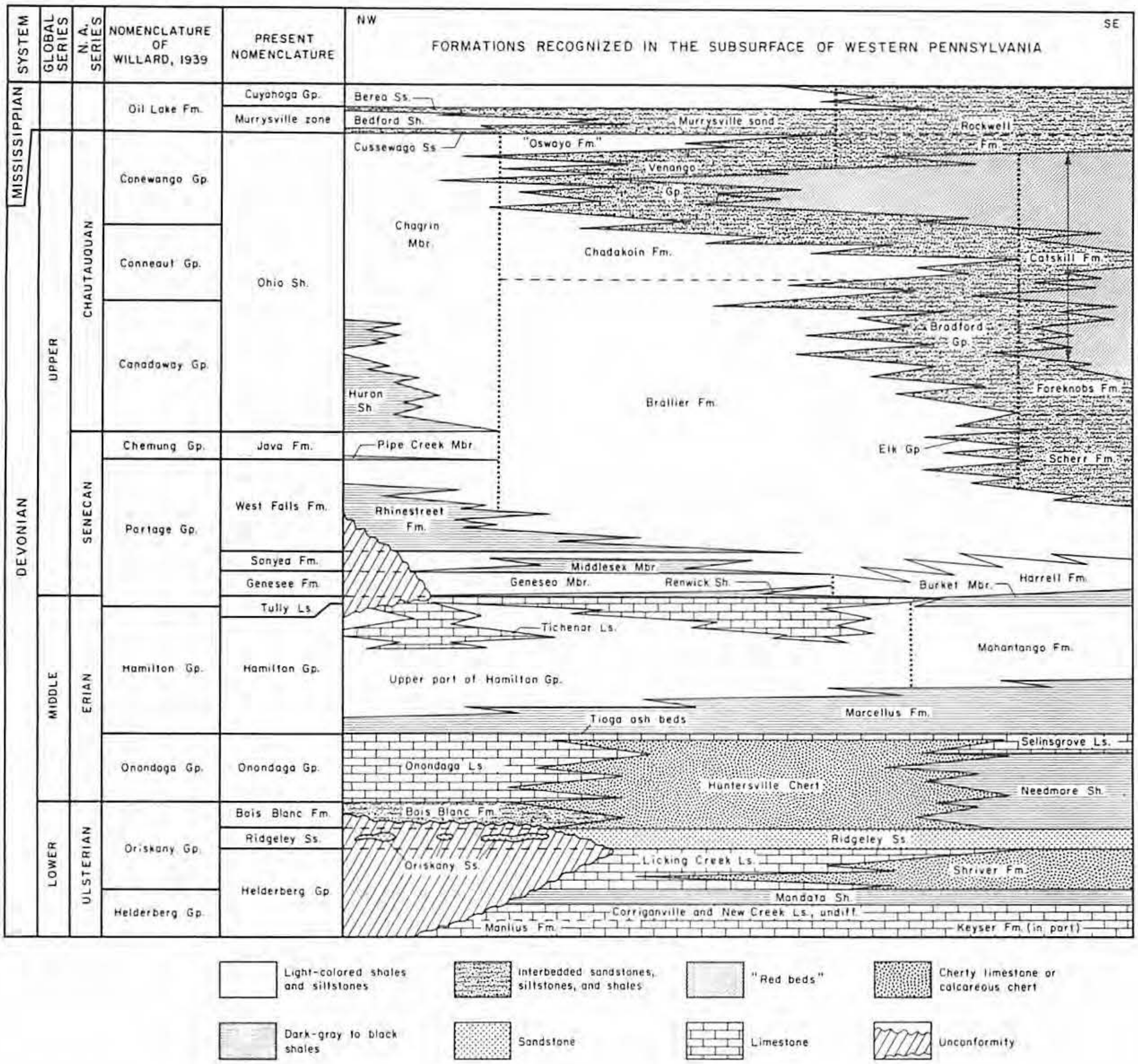


Figure 19. Schematic diagram of Devonian stratigraphic units in the subsurface of western Pennsylvania (modified from Harper and Laughrey, 1987).

Limestone. The Licking Creek grades laterally into the Shriver Chert.

The Ridgeley Sandstone ("Oriskany" of drillers) is highly variable in both composition and thickness in the Laurel Highlands. It typically consists of white, yellow, or light gray, fine grained, calcareous, quartz arenite that grades downward into the dark-colored limestones of the Helderberg. It may be as thick as 100 ft (30 m) or as thin as 15 ft (5 m); in the vicinity of Johnstown it is about 45 ft (13 m) thick (Abel and Heyman, 1981). This variation is due in part to structural disturbance and in part to lithologic changes.

Movement of salt in the Salina Group created a series of synthetic and antithetic imbricate thrust faults through the Lower and Middle Devonian rocks that translated upward into the low folds seen at the surface as Chestnut Ridge, Laurel Hill, etc. Tilting and repetition of the Ridgeley are common. In addition, the Ridgeley-Helderberg transtition may be gradual, and the boundary based entirely on the presence or absence of sandstone. Where the underlying limestone contains abundant quartz sand, the boundary is placed at the base of the arenaceous limestone. Where the limestone contains little or no quartz the boundary is placed in the traditional position at the base of the sandstone.

Above the Ridgeley, the rock complex of the Onesquethaw Stage includes the Needmore Shale, Huntersville Chert, and Selinsgrove Limestone. These formations comprise sets of intertonguing marine facies dominated by single lithologies. Inners (1979) found two distinct facies domains in these rocks: 1) mostly black, organic-rich, noncalcareous and calcareous shale with scattered limestone interbeds (Needmore) occurs east of the Allegheny Front; 2) mostly white to light gray, calcareous and argillaceous chert (Huntersville) occurs west of the Front. In both areas a thin layer of gray to black, argillaceous limestone and calcareous shale caps the assemblage. This limestone, the Selinsgrove (Onondaga of drillers), may contain several volcanic ash beds, part of the Tioga ash zone of Way and others (1986). Throughout much of southwestern Pennsylvania the Onesquethaw complex attains thicknesses in excess of 200 ft (60 m), with about 50 ft (15 m) of Needmore, 130 ft (39 m) of Huntersville, and 20 ft (6 m) of Selinsgrove. In the Johnstown area, however, the complex is unusually thin. In the Fairman Drilling #1 Robert McFadden well on Laurel Hill just north of Johnstown, for example, the entire complex is less than 150 ft (45 m) thick.

The Hamilton Group consists of more than 600 ft (180 m) of dark gray to black, platy, micaceous, slightly calcareous shales in the McFadden well. It thickens dramatically in various places in southwestern Pennsylvania because of tectonic disturbance; many of the thrust faults that originate in the Salina Group die out or become decollement faults in these shales. Repeated sections are not uncommon, particularly in wells on or near anticlinal axes. The lower portion of the Hamilton Group consists of the black, organic-rich shales of the Marcellus Formation. These are among the most important petroleum source beds in the Appalachian Basin. The rocks above the Marcellus have not been divided into formations throughout most of western Pennsylvania. In the northern part of the state the New York names Skaneateles, Ludlowville, and Moscow can be used with varying degrees of accuracy (see, for example, Rickard, 1986). In central Pennsylvania the upper Hamilton becomes increasingly silty and sandy and carries the name Mahantango Formation. As Harper and Piotrowski (1979) pointed out, however, the Mahantango loses its siltstones, and therefore its cohesive characters, just west of the Allegheny Front, near the western flank of Negro Mountain anticline.

The Tully Limestone, the unit immediately overlying the Hamilton Group, presents an interesting problem in the Laurel Highlands. An anomalously thickened zone of Tully occurs on Chestnut Ridge in Fayette and Westmoreland Counties where the limestone exceeds 100 ft (30 m) thick (Figure 20). To the east the limestone becomes thinner until it cannot be recognized in drill cuttings or geophysical logs. This boundary occurs on Laurel Hill anticline. Between Laurel Hill and Negro Mountain, and south of the Conemaugh River, shales and siltstones that may or may not contain calcareous nodules replace the dark gray limestones of the Tully. Harper and Piotrowski (1979) argued that the anticlines were already growing by the time the Marcellus Formation was being deposited. The Laurel Hill and Negro Mountain positive areas acted as sediment traps, filtering out mud invading the area from the east, and allowing the limestone to develop in a carbonate platform setting on the Chestnut Ridge positive area. Dennison (1982) countered that the siltstone facies of the Tully was actually a Mahantango siltstone, that about 50 ft (15 m) of the Hamilton Group had been uplifted and beveled off between the Rome Trough and the Lat 40°N fault zone of Root and Hoskins (1977). Although this explanation is possible, it is unlikely. In drill cuttings the Tully-equivalent siltstones and shales are dark colored, like the limestone, whereas the Mahantango siltstones beneath them are lighter colored. Also, the Mahantango siltstones can be recognized below the Tully clastics in some more easterly Plateau wells. More intensive work needs to be done in order to determine which concept has more validity.

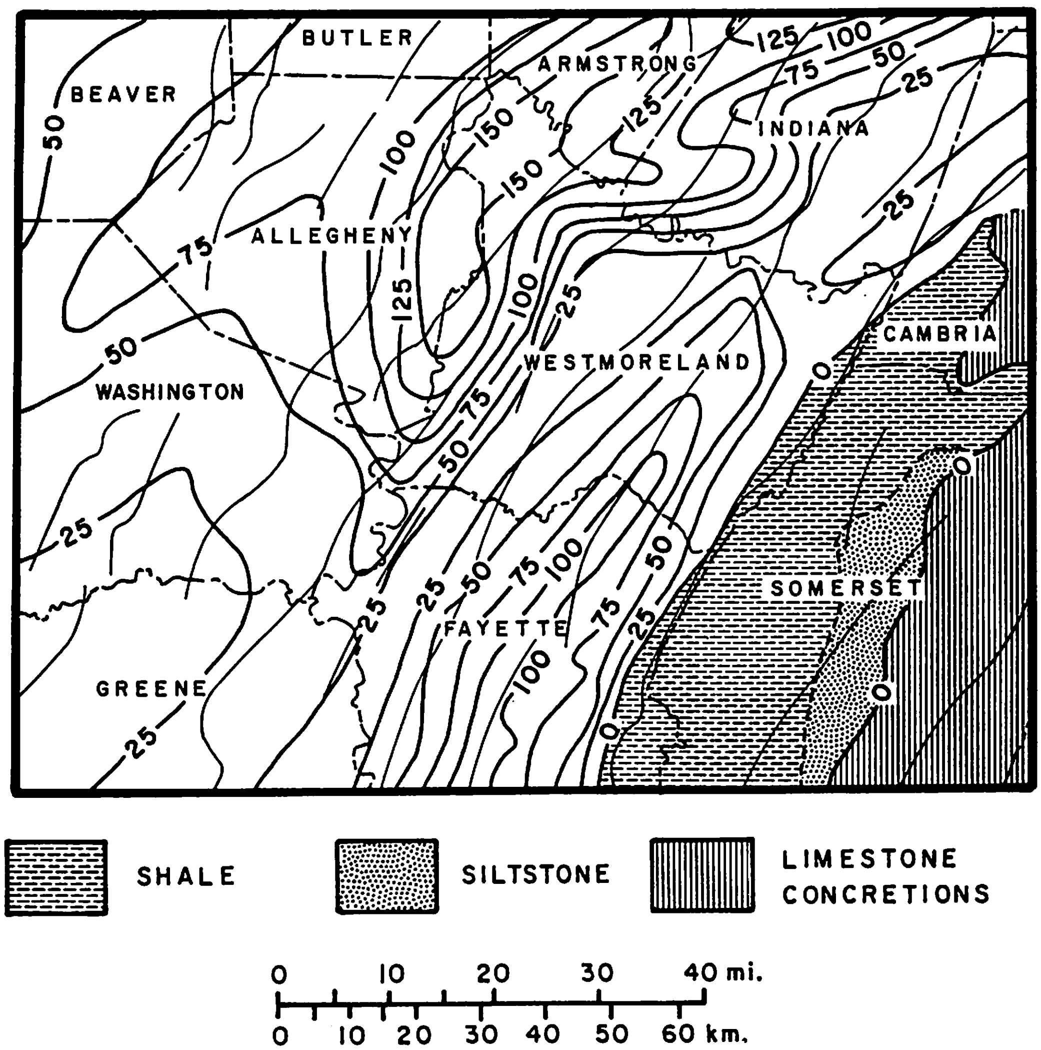


Figure 20. Isopach map of the Middle Devonian Tully Limestone in southwestern Pennsylvania, shown with structure axes (finer lines) based on surface data (modified from Harper and Piotrowski, 1979). Contour interval = 25 ft.

The Upper Devonian Series in the central Appalachians constitutes one of the most complex sequences of rock in North America. The laterally interfingering and upwardly coarsening rocks provide a classic example of the facies concept that is cited over and over again in the literature. Despite nearly 150 years of intense scrutiny, especially in outcrop, many of the stratigraphic relationships of this system are only now being satisfactorily defined. Because the largest areal extent of these rocks is in the subsurface many of them have been characterized only with the aid of hydrocarbon exploration tools.

The Upper Devonian succession in Pennsylvania is shaped like a large wedge having a thickness of approximately 2,550 ft (775 m) in Erie County and 7,700 ft (2,345 m) in southern Somerset County (Piotrowski and Harper, 1979). These rocks are the most important oil- and gas-related rocks in Pennsylvania. The sandstones of the Venango and Bradford groups (Figure 19) produce 90 percent of the Commonwealth's natural gas and almost 98 percent of the crude oil. In addition, the Upper Devonian includes thousands of ft (hundreds of meters) of dark, organic-rich shales that are probably the most important hydrocarbon source rocks in the Appalachian Basin.

Based on well data, the Upper Devonian Series in the Laurel Highlands ranges in thickness from about 5,500 ft (1,700 m) at the northwestern edge to about 7,700 ft (2,345 m) in Somerset County. It is a heterogeneous assemblage comprising marine, deltaic and continental shales, siltstones, and sandstones, with a few thin marine carbonates that can be used as marker beds in local areas, and perhaps regionally. Because many of these rocks represent facies which do not crop out anywhere in the Appalachian Basin, they have not been sufficiently described or defined. The Upper Devonian is divided into two stages, the Senecan and Chautauquan (Figure 19), equivalent to the Frasnian and Famennian global stages. The Senecan and Chautauquan comprise almost 85 percent of the total Devonian System in southwestern Pennsylvania. The boundary between these two stages, the base of the Huron Member of the Ohio Shale, is evident only in the subsurface of the northwestern counties where the Huron Member and its New York equivalent, the Dunkirk Shale, are encountered (Piotrowski and Harper, 1979). The lateral equivalence of the Huron is uncertain, but probably corresponds in part to the Bradford Group, and in outcrop, to the Pound Sandstone Member of the Foreknobs Formation (according to McGhee and Dennison, 1980). For the sake of simplicity, then, we use the global series term Upper Devonian in the Laurel Highlands in place of the two North American stage names.

As shown in Figure 21, the Upper Devonian of western Pennsylvania consists of five broadly defined lithosomes that remain relatively lithologically consistent throughout the geologic and geographic section, despite the differences in specific provenance, transport system, and depositional setting (Harper and Laughrey, 1987). These lithosomes include, from offshore to onshore (generally speaking, from west to east and from bottom to top): 1) dark-gray to black marine shales deposited under anoxic conditions (so-called deep-water black shales); 2) slope-spread turbidite sequences; 3) shallow-water, open shelf, sandy siltstones and mudstones; 4) deltaic, estuarine, and other coastal conglomerates, sandstones, siltstones and mudstones; and 5) fluvio-deltaic red and green claystones, mudstones and sandstones typically called "Catskill" wherever they are encountered. At almost any given time interval in the Late Devonian of the central Appalachians these five lithosomes can be traced as lateral equivalents.

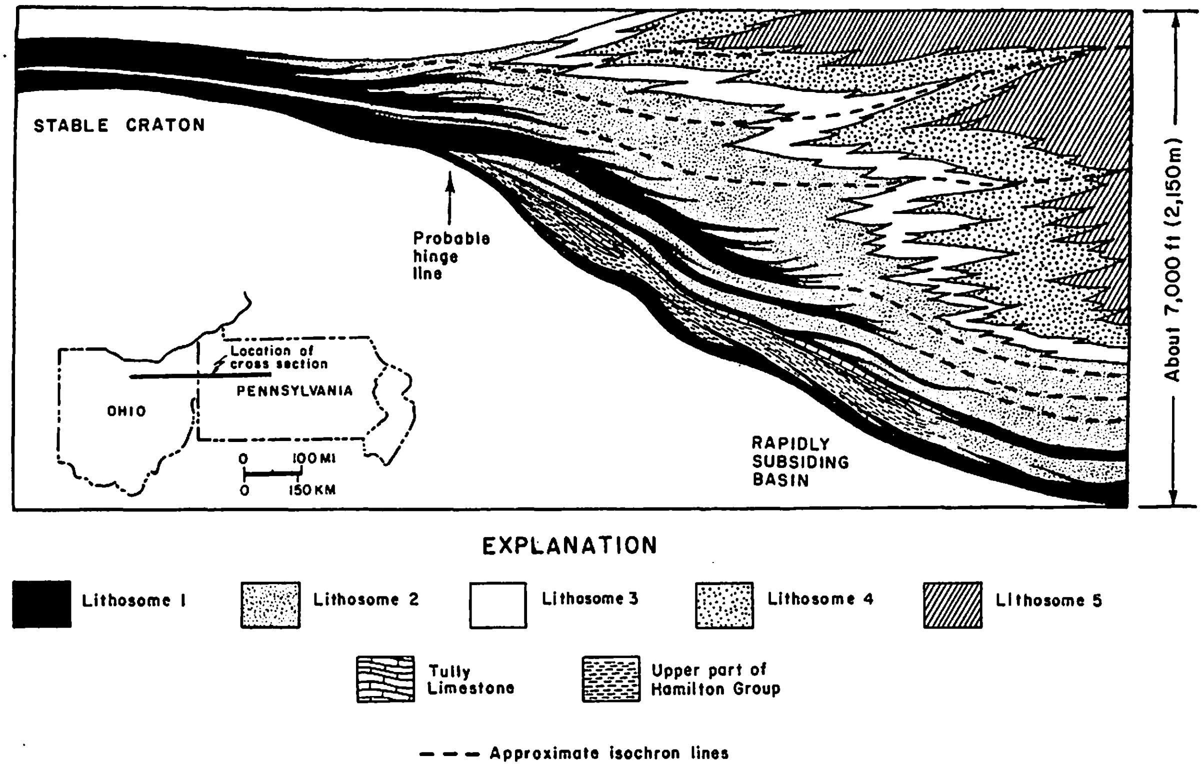


Figure 21. Schematic diagram of the Upper Devonian lithosomes across the Appalachian Basin (modified from Harper and Laughrey, 1987).

Lithosome 1 consists predominantly of dark-colored shales typically interbedded with some lighter colored shales and siltstones. These dark Devonian shales have been the subject of considerable study sponsored by the USDOE since 1976 in an effort to characterize and develop their potential for natural gas production. In the Laurel Highlands this lithosome includes the basal Burket Shale of the Harrell Formation and the Middlesex Member of the Sonyea Formation (Figure 19). The Burket and Middlesex rarely attain thicknesses of more than 25 ft (8 m).

Lithosome 2 consists of westwardly prograding, distal, siltstone turbidites interbedded with mudstones, claystones, and some minor sandstones. The Brallier Formation, the main unit within this lithosome, may be as thick as 3,300 ft (1,000 m) (Lundegard and others, 1980). In the Laurel Highlands it is about 1,600 ft (490 m) thick. The Brallier rises in the Upper Devonian section from east to west because of the overall progradational nature of the Catskill deltaic system in the Upper Devonian (Figure 19). Most modern turbidite models, based mainly on submarine fans, do not adequately describe the Brallier's depositional system. Lundegard and others (1980) concluded that the formation resulted from turbidites deposited on a series of ephemeral, low energy, coalescing lobes fed by deltas rather than submarine canyons or upper fan channels.

Lithosome 3 is typically thin and interfingers with lithosome 4 to the extent that in many places it becomes unrecognizable as a separate facies in the overall plan. The major exception to this in the Laurel Highlands is the Chadakoin Formation. Lithosome 3 formations, such as the Chadakoin, include shallow-marine, fossiliferous, fine-grained, shelf clastics. The Chadakoin loses its identity to the east as lithosome 4 and 5 become dominant.

Lithosome 4 in the Laurel Highlands includes the Venango and Bradford Groups, and the Foreknobs Formation which is partially equivalent to them. The underlying Elk Group and equivalent Scherr Formation consist of combined lithosomes 2 and 4, that is, of packages of marine sandstones separated by thick sequences of turbidites. The Bradford and Elk Groups are the dominant oil and gas producing formations east of the Allegheny and Monongahela Rivers (east of the center of the Rome Trough), whereas the Venango Group is dominant west of the rivers. The Foreknobs and Scherr have not yet been sufficiently explored to make formal statements about their potential for hydrocarbon production.

Lithosome 5, sometimes called the "Catskill facies", occurs in the Laurel Highlands in two units. The first of these, the Hampshire Formation, is simply the southern equivalent of the Catskill Formation. It has not been studied as intensely as the Catskill, and therefore has not been divided into discrete members. A thorough study of the unit may result in abandonment of the name if it can be shown that the Catskill and Hampshire are indistinguishable. The second unit, called "Sandstone B" by Laird (1941), occurs as a middle tongue of the Venango Group. In this guidebook we call it the "Middle red shale zone" (see the next chapter on Late Devonian and Early Mississippian stratigraphy).

UPPER DEVONIAN AND LOWER MISSISSIPPIAN STRATIGRAPHY AND DEPOSITIONAL SYSTEMS

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INTRODUCTION

With a few exceptions, notably in the northern tier of counties and in a few scattered watergaps in the highlands of the southern tier, Upper Devonian and Lower Mississippian rocks occur only in the subsurface in western Pennsylvania. Oil and natural gas have been produced from reservoir sandstones in these sequences for over 100 years, yet very little is known about their lithologic natures of the rocks aside from what has been gleaned from a few cores, and numerous well cuttings and geophysical logs. Some excellent studies exist, but for the most part they do not address all issues in a comprehensive manner. Field geologists, such as Bradford Willard, Kenneth Caster, and Wilson Laird, concentrated on a few outcrops, whereas subsurface geologists, such as Charles Fettke, Robert Bayles, and Robert Wolfe, concentrated on drill cuttings and geophysical log correlations. On occasion the two groups got together and cooperated (e.g. Fettke's report in Hickock and Moyers, 1940). Except for the petroliferous Upper Devonian Venango sands that crop out in northern Pennsylvania, and some Lower Mississippian reservoirs rocks that crop out in Ohio (e.g. Berea Sandstone), exposures of reservoir rocks within 50 to 100 mi (80 to 160 km) of production are rare in Pennsylvania. Perhaps the best and most complete such outcrop, aside from the aforementioned Venango sands, is the exposure of Lock Haven Formation rocks at the Allegheny Front, only three to five miles east of the prolific Council Run gas field in Centre County.

On this Field Conference we will be examining outcrops of some of the most productive Upper Devonian and Lower Mississippian reservoir rocks in southwestern Pennsylvania. These are also the oldest rocks exposed in southern Pennsylvania west of the Allegheny Front. They are equivalent to the productive sandstones of the Upper Devonian Venango Formation (or Venango Group), and the Lower Mississippian Murrysville, Weir, Squaw, and Big Injun drillers sands that produce oil and gas throughout southwestern Pennsylvania and northern West Virginia.

DEPOSITIONAL BASIN AND PROVENANCE

During much of the Late Devonian, the Appalachian Basin was rapidly filling with sediment shed from the tectonic source area to the southeast, the Acadian Mountains of Appalachia. Appalachia originated in the Late Ordovician when Precambrian(?)-through-Early Ordovician sediments, volcanics, and intrusives were uplifted and metamorphosed as a result of the Taconic orogeny. Sediment influx resulting from erosion of Appalachia in the Late Ordovician helped create an asymmetrical, trough-shaped basin, deeper on the side adjacent to the source area, due to differences in the subsidence and sedimentation rates. From Early Silurian until Middle Devonian the basin received minimal coarse, terrestrial sediment input and carbonate or muddy siliciclastic facies dominated (Faill, 1985). Renewed tectonic activity beginning in the Middle Devonian, the Acadian orogeny, rejuvenated the southeastern source area and created the Catskill delta complex. Large volumes of coarse-grained sediment poured into the eastern trough area, whereas in the west, adjacent to the relatively stable craton, the Devonian sediments were mostly fine-grained particles falling out of suspension. As erosion of the rejuvenated Appalachia continued, the Catskill delta complex prograded westward, filling in the basin. Progradation continued through the Late Devonian, moving the coarser sediments increasingly westward, and leaving a broad alluvial plain to the east (Sevon, 1985). When erosion of Appalachia ceased in the latest Devonian, erosion of the alluvial plain, especially near the eastern mountains, provided a new sediment source in the west. From the end of the Devonian through to the end of the Paleozoic the sediment brought into the basin from the southeast probably resulted from stream cannibalization of the proximal portions of the alluvial plain (Inners, 1987). Sediments consisted of fine- to coarse-grained clastics composed mostly of quartz, rock fragments, and mica deposited in settings ranging from estuaries to the upper delta plain. Only a few relatively minor transgressions occurred during this time, bringing dark-colored muds or light-colored carbonates into the western portion of the basin.

Available paleomagnetic data indicate the Appalachian Basin lay in the low latitudes of the southern hemisphere during the Devonian (Kent, 1985) and, probably, the Mississippian (Figure 22). Woodrow and others (1973) and Woodrow (1985) determined that the configuration of the Devonian land masses in relation to the earth's climate system probably resulted in a tropical-dry or savannah-like climate, hot and with seasonally restricted rainfall. The Late Devonian stratigraphic record, as much as 80% of the total thickness of Devonian sediments (Colton, 1970), may be the result of long-term cyclic storm patterns affecting deposition on Catskill coastal plains and continental shelves.

The position of Appalachia with respect to the central basin is uncertain. Sevon and Woodrow (1981) suggest, however, that a distance between 31 and 62 mi (50 to 100 km) east of the present outcrop is a reasonable estimate.

SEA LEVEL VARIATIONS

There has been considerable interest in the subject of cyclic sedimentation in the Paleozoic rocks of eastern North America for more than a decade. Discussions of eustatic sea level changes, punctuated aggredational cycles (PAC's), and hierarchical transgressive-regressive (T-R) units have often dominated professional meetings and publications, arousing comments from all sides as to the validity and applicability of the subjects. Some debate has centered around the causes of cyclic sedimentation with topics focusing on regional tectonics, global sea level changes, Milankovitch (astronomical) cycles, etc. Other discussion has dealt with whether cyclic sedimentation results from changes in sea level (allocyclicity) or from changes in coastal processes such as delta building and degradation (autocyclicity).

Most of the arguments centering around cyclic sedimentation have focused on outcrop formations such as the Helderbergian carbonates of eastern New York (Anderson and Goodwin, 1985), and the Pennsylvanian cyclothems of western Pennsylvania and the midcontinent area (Busch and Rollins, 1984; Heckel, 1986). Other than Harper and Laughrey (1987) and Boswell (1988) little has been done concerning cyclicity in the Late Devonian and Early Mississippian rocks in the Appalachian Basin.

Harper and Laughrey (1987) recognized at least five orders of cyclicity (transgression and regression) during the Late Devonian of western Pennsylvania. Besides the general first-order transgressive-regressive event of the Paleozoic

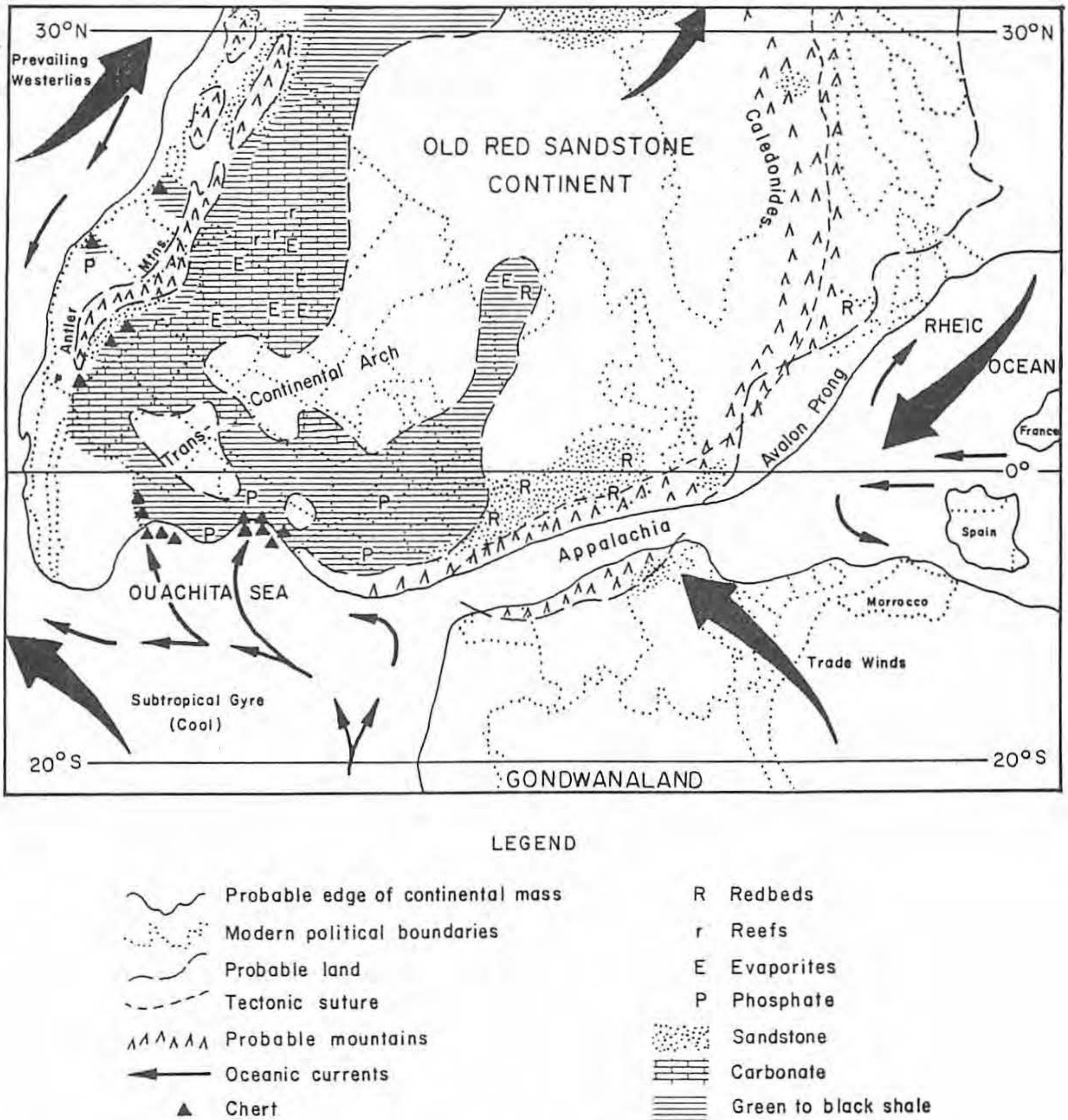

Figure 22. Reconstructed paleogeography of North America during the Late Devonian and Early Mississippian (modified from Ettensohn and Barron, 1980 by Sevon and Woodrow, 1981).

and the overall progradation throughout the Late Devonian and Early Mississippian (second order) documented on a worldwide scale by Vail and others (1977), the Catskill deltaic system seems to have undergone several large-scale (third order), and numerous relatively smaller-scale (fourth and fifth order), events in the Late Devonian. Dickey and others (1943) showed very clear evidence of the fifth-order events in the oil-producing sandstones of Venango County. They documented transgressiveregressive cycles of deposition from the Venango Third sand to the Venango First sand (Figure 23). Although these cycles could also have been caused by autocyclic events such as delta switching, the reservoir sandstones occur in packages or zones that can be correlated over much of

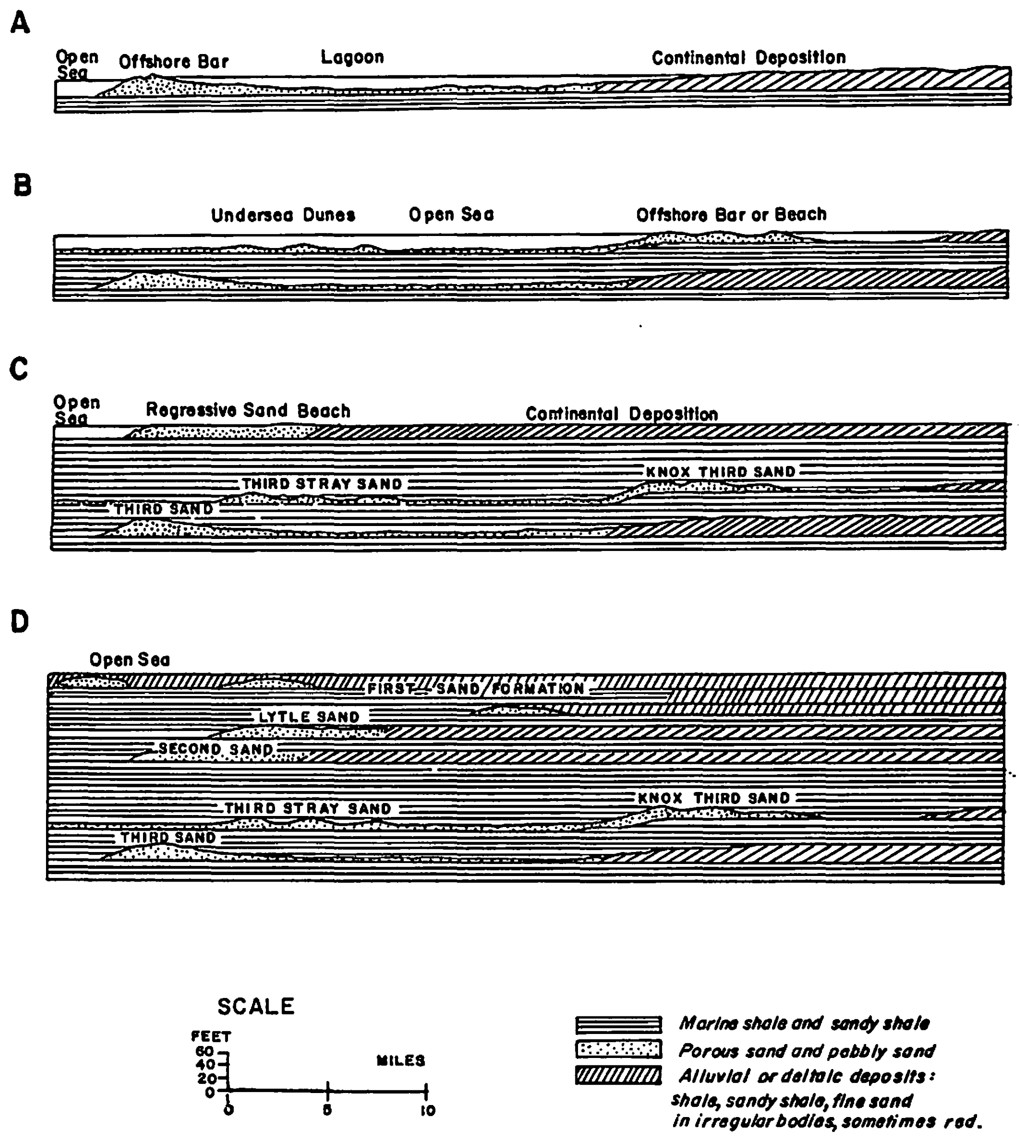

Figure 23. Probable origins of the Venango oil-producing sandstones of Venango County as beach and bar deposition during fifth-order eustatic sea level changes (modified from Dickey and others, 1943).

western Pennsylvania and into West Virginia, despite variations in depositional input centers. Such cycles are unlikely to be caused by simple depositional changes.

The reservoir sandstones apparently formed as repetitive series of offshore bars, subaqueous dunes, tidal and estuarine channel fills, and beaches that shifted back and forth with successive rises in sea level, interspersed with increases of terrigenous influx from the east.

In contrast to these small-scale events, the third-order cycles occur (in Figure 19) as the major sandstone groupings (Venango, Bradford, Elk). These are large-scale wedges of coarser clastics and intercalated shales. Slow, steady, westward progradation of the Catskill deltaic system through the Late Devonian, punctuated at irregular intervals by third-order pulses of regression and/or progradation, resulted in vertical and lateral facies changes of marine black shales (lithosome 1 as explained under Subsurface Stratigraphy) at the bottom and in the west to coarser clastics (lithosomes 4 and 5) at the top and in the east (Figure 19). A period of more rapid influx of terrigenous sediments near the postulated Senecan-Chautauquan boundary resulted in the overall large-scale event of the Bradford Group. There followed another marine transgression, somewhat larger than the previous one, that resulted in deposition of the Chadakoin Formation. Either a major drop in sea level or a large-scale erosional event in the eastern mountains caused a second rapid, massive influx of terrigenous sediment in the upper part of the Upper Devonian. Deposition of the Venango Formation, representing the most westward extent of the Catskill coarser clastics in the Devonian, resulted from this event. Toward the end of the Devonian another transgression occurred as the marine shales and thin siltstones and sandstones of the Riceville and Oswayo Formations were deposited over the Venango Formation. Boswell (1988) concluded that these Late Devonian transgressive-regressive cycles occurred as a result of both regional tectonic events (the Acadian orogeny) and eustatic sea-level variations. Tectonism dominated during the Senecan Stage whereas eustacy dominated during the Chautauquan Stage.

Mississippian sea level variations are more difficult to characterize in southwestern Pennsylvania. Ross and Ross (1985) and Veevers and Powell (1987) reviewed and synthesized the transgressive-regressive sequences and fossil zonations for the Late Paleozoic on a world-wide basis, but at this time it is difficult to correlate their data to southwestern Pennsylvania because much of the Appalachian Basin was thoroughly clogged with nonmarine sediments during this time. Transgressions are known to have occurred at the time of deposition of the Bedford Shale, the base of the Cuyahoga Formation, and the Loyalhanna Formation, but whether these correlate to the three third-order transgressions indicated by Veevers and Powell (1987) has yet to be determined.

EXPLANATION OF STRATIGRAPHIC NOMENCLATURE

Some of the Devonian and Mississippian nomeclature presently used in western ern Pennsylvania is based on the outmoded stratigraphic philosophy used in the late 1800's and early 1900's in which formations were based largely on biostratigraphic data, rather than strictly on lithostratigraphy. Laird (1941, 1942), for example, created his own classification scheme based on that recommended by Ashley and others (1933). His hierarchy included system, series, stage, member, and bed or lentil. Laird substituted the term "member" for formation in this classification.

To make matters worse, many geologists, engineers, and drillers who have been active in western Pennsylvania and adjacent states disregard the structured formality of stratigraphy in favor of a "whatever works" approach. Names such as Burgoon Sandstone, Pocono Series, and Big Injun sand have been used inter- interchangeably at professional meetings, and in published and unpublished reports. There exists a plethora of informal drillers' names that have been applied to subsurface formations in western Pennsylvania for more than 100 years (Figure 24). Unfortunately, many of these names are carried beyond the areas in which they were first used, giving rise to numerous problems of regional correlation.

The unacceptability of much of the historical subsurface nomenclature in western Pennsylvania led Kelley and Wagner (1970) and Piotrowski and Harper (1979) to adopt a system of informal zonation for the Upper Devonian in western Pennsylvania (Figure 24). There are some names that can be used for these zones, however (Harper and Laughrey, 1980). Carll (1880, 1890) and Ashburner (1880) coined the names Venango, Bradford and Elk groups for the Upper Devonian reservoir rock sequences of northwestern Pennsylvania. Harper (1979) and Harper and Laughrey (1980) reinstated this practice, extending the names throughout the subsurface of western Pennsylvania. These names are currently in use (Berg and others, 1986). However, they are broad-brush names in need of more extensive

SYSTEM	Piotrowski & Harper, 1979		Harper & Laughrey, 1987	This report		Drillers' nomenclature in southwestern Pennsylvania
PENNSYLVANIAN (in part)			Pottsville	Pottsville		Salt
MISSISSIPPIAN	Pocono		Mauch Chunk	Mauch Chunk		Maxton
			Loyalhanna	Loyalhanna		Big lime
			Burgoon	Burgoon		Big Injun
			Shenango	Rockwell		Squaw, Papoose
			Cuyahoga	Riddlesburg		Weir, Bitter rock
			Berea	Murrysville		Berea, Murrysville, Butler
			Bedford			
			Cussewago			
DEVONIAN (in part)	Riceville		Oswayo	Venango	Upper sandy zone	Gantz, Hundred-Foot Fifty-Foot Thirty-Foot, Upper Nineveh
	D	D3	Venango			
		D2			Middle red shale zone	Snee, Lower Nineveh Gordon Stray, Boulder Gordon, Third Fourth
		D1			Lower sandy zone	Fifth, Fifth Stray Bayard, Bayard Stray Elizabeth, Sweet Richard
	C		Chadakoin	Chadakoin		Pink rock
	B	B4	Bradford	Bradford		First Warren Second Warren Third Warren
		B3				Speechley Stray Speechley Tiona
		B2				First Balltown Second Balltown Third Balltown, Sheffield
		B1				First Bradford Second Bradford Third Bradford Kane
	BO		Elk	Elk		Riley, Elk Benson Alexander
	A		Brallier	Brallier		Devonian shales
			Rhinestreet			
			Sonyea	Harrell		
			Genesee			

Figure 24. Correlation of rock-stratigraphic nomenclature and commonly used drillers' sand names within the general area of the natural-gas producing belt in western Pennsylvania.

work, including subdivision into recognizable lithologic subunits. At this Field Conference only the Venango Group will be examined in any detail.

In contrast, the Lower Mississippian rocks have been ignored for the most part. Names such as "Shenango Formation through Oswayo Formation Undifferentiated" have been applied to these rocks (Berg and others, 1986) because, until recently, they were essentially unknown correlatives of formations that crop out in northwestern Pennsylvania. Drillers have given names to many of the Mississippian formations, but because Mississippian rocks are largely unproductive outside of westernmost Pennsylvania not much is known about them east of the Monongahela River.

It is beyond the scope of this guidebook to propose new formal nomeclature for the Upper Devonian and Lower Mississippian. The need for some kind of nomenclature is apparent, however. For this Field Conference we will be using a combination of formal and informal nomenclature that should enable us to get by with a minimum of misunderstanding. Each of these names will be discussed in turn in this section. Figure 25 illustrates the terminology that we use, as well as the historical development of the nomenclature applied in southwestern Pennsylvania since Rogers (1858). Figures 26 and 27 are northwest-southeast cross sections of the Lower Pennsylvanian Pottsville to Upper Devonian Elk sequence, based on geophysical logs and sample descriptions from wells. We will be referring to these figures extensively during discussion of the Upper Devonian and Lower Mississippian in this guidebook.

UPPER DEVONIAN

General

Most of the rocks of the Upper Devonian were deposited as marine, transitional, and non-marine sediments of the Catskill deltaic system, a series of "multiple contiguous deltas operating in the same sedimentary basin at approximately the same time" (Sevon and Woodrow, 1981, p. 11). The Catskill deltaic system is the type example of a *tectonic delta complex*, a delta system dominated by orogenic sediments built by erosion of an active tectonic complex in an adjacent marine basin (Friedman and Johnson, 1966). Based on the physical attributes of lithologic units in central and eastern Pennsylvania, Sevon and others (1978; also see Sevon, 1985) identified eight major drainage systems in the Catskill delta that acted as input centers in the state during the Late Devonian. Using net thickness of sandstone as an alternate criteria, Laughrey and Harper (1986) established a remarkably similar configuration of sediment input for the subsurface rocks of western Pennsylvania (Figure 28). As the Catskill deltaic system prograded westward across the basin in the Late Devonian, the shape of the shoreline, controlled by rate of sediment supply, position of different sediment-input systems, tectonic perturbations, and oceanic processes, must have been very irregular (Willard, 1934; Boswell, 1988). The gradual increase in distance from source area to shore during progradation was accompanied by a decrease in transport gradient, creating a decrease in grain size, and a concommitant increase in depositional complexity across the basin. Sediments ranged from muds, sands, and gravels deposited in alluvial fans, braided rivers, and other typical continental environments to clays and muds settling out of suspension onto thefloor of the shallow anoxic basin.

During the Late Devonian the Catskill Formation, a complex of mostly red-

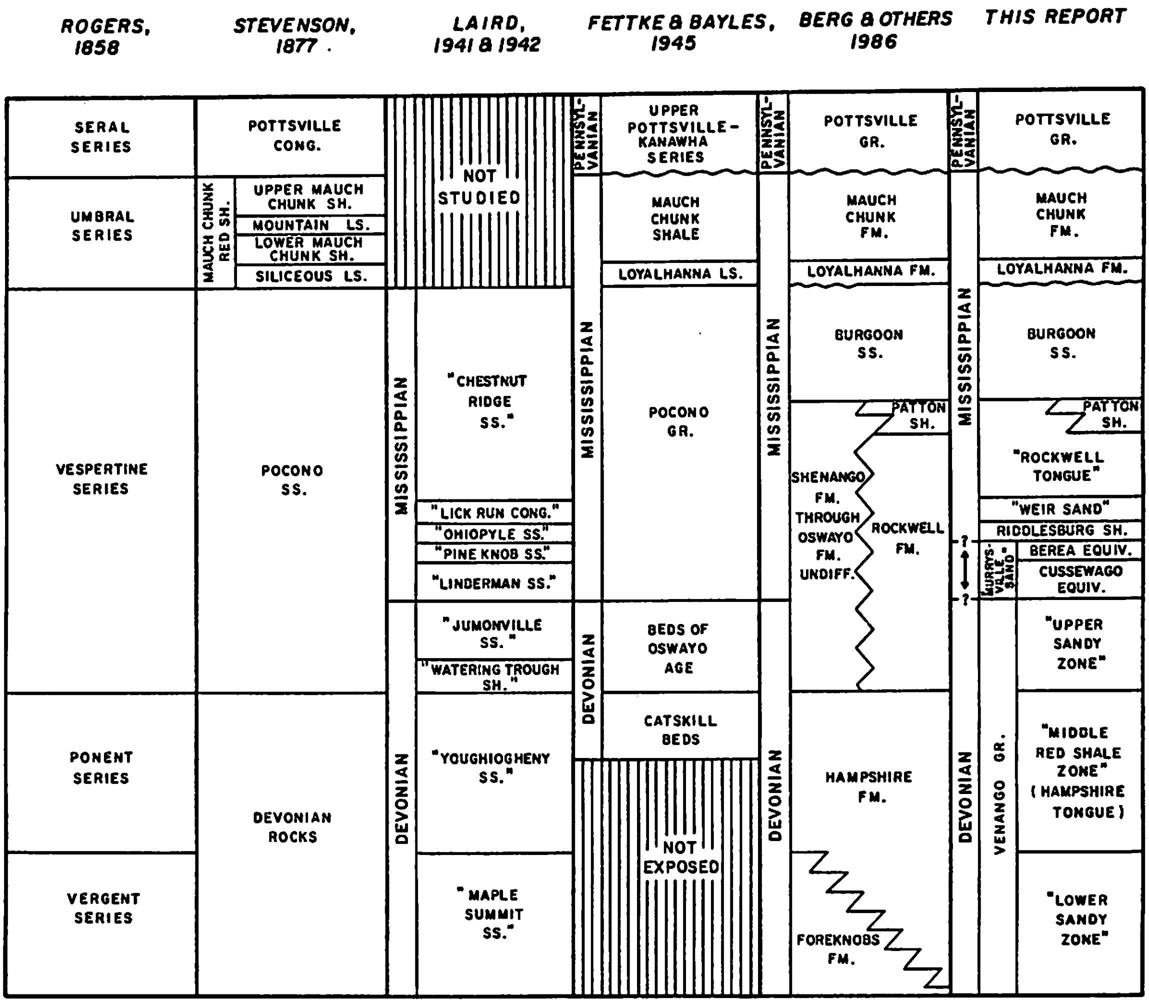

Figure 25. Historical development of stratigraphic names applied to the Upper Devonian through Lower Pennsylvanian rocks exposed in southwestern Pennsylvania.

colored delta-plain and alluvial-plain facies, dominated deposition in the eastern half of Pennsylvania. To the west, however, marine sedimentation dominated. It was here, in western Pennsylvania, that the oil- and gas-reservoir sandstones of the Elk, Bradford, and Venango Groups originated under conditions ranging from prodelta and delta-slope environments to on-delta paralic environments.

Venango Group

In the type area of Venango County, the Venango holds formation rank and consists of all the strata between the top of the Woodcock Sandstone and the base of the Panama Conglomerate (Venango First and Third sands of drillers). The formation is actually a thick facies sequence that expands downward at the expense of the underlying Chadakoin Formation to the south and east, acquiring sandstones with drillers' names such as Magee Hollow, Deemer, and White Gravel. In southwestern Pennsylvania, the Venango Formation includes drillers sands such as the Hundred-Foot, Nineveh, Snee, Boulder, Gordon, Fourth, Fifth, Bayard, and

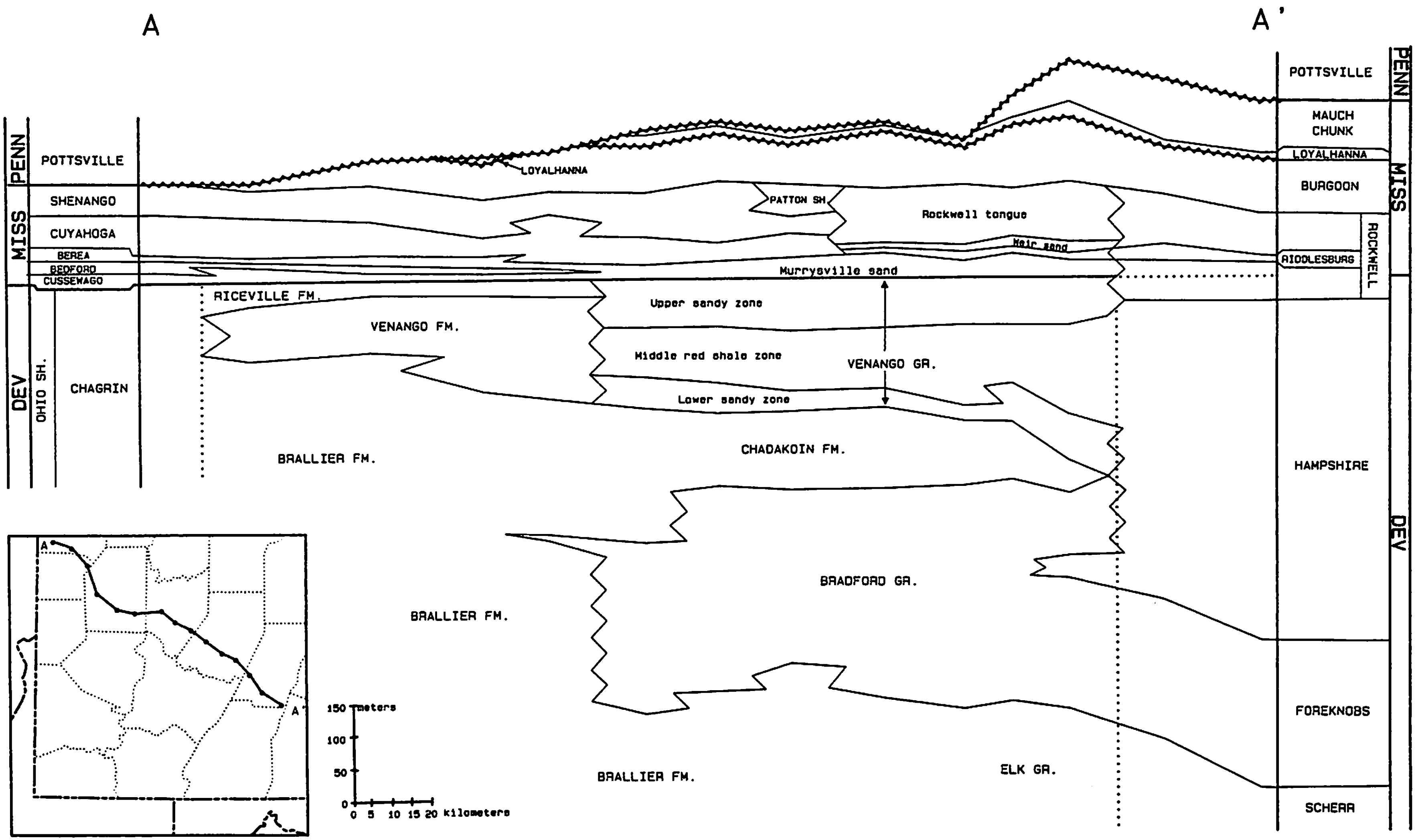

Figure 26. Interpreted cross section A-A' of Lower Pennsylvanian through Upper Devonian rocks between Mercer County and Cambria County, Pennsylvania, based on geophysical logs, sample descriptions, and drillers' records.

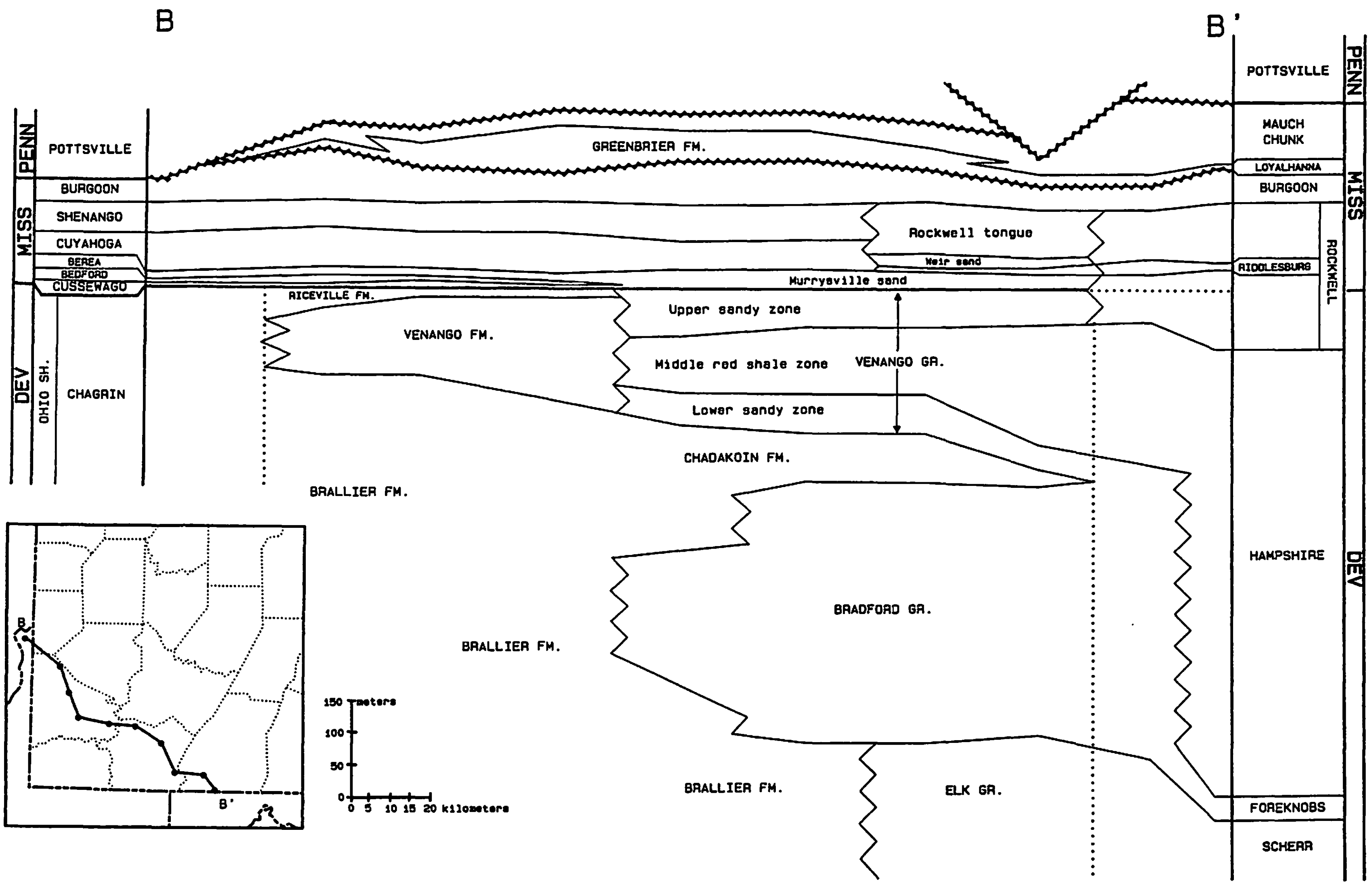

Figure 27. Interpreted cross section B-B' of Lower Pennsylvanian through Upper Devonian rocks between Hancock County, West Virginia and Somerset County, Pennsylvania, based on geophysical logs, sample descriptions, and drillers' records.

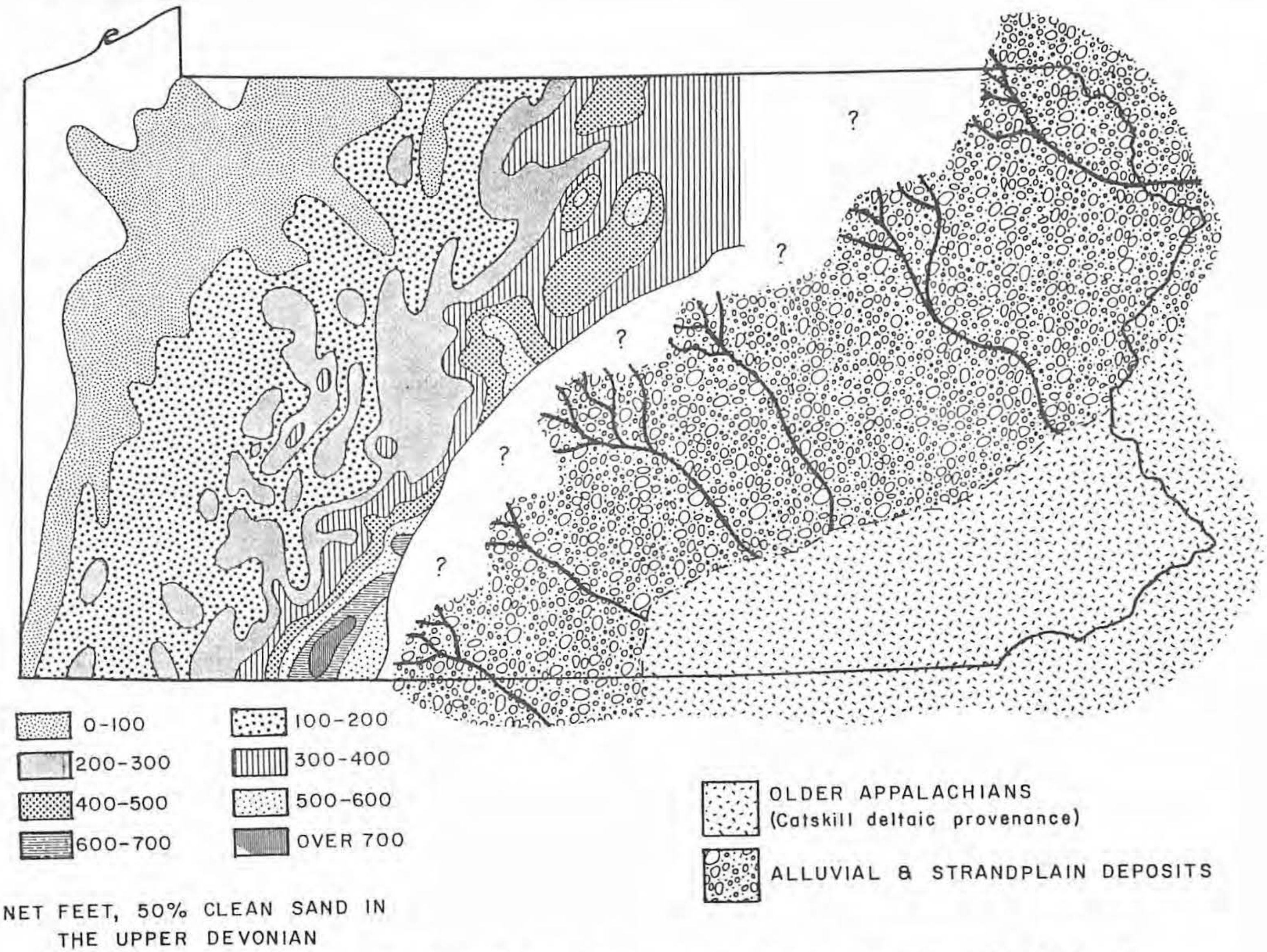

Figure 28. Thickness and distribution of Upper Devonian sandstones (based on 50% "clean" sand cutoff as measured on gamma-ray logs) and generalized depositional framework of the Catskill deltaic system (modified from Laughrey and Harper, 1986). Compare this depositional framework with the recognized input centers of Sevon and others (1978).

Elizabeth. Brick-red shales commonly occur between some of the sandstones in the middle of the formation. The most general definition of the Venango Formation, therefore, is all the strata between the top of the subjacent Chadakoin Formation (the "pink rock" of drillers) and the base of the superjacent Riceville Formation (sometimes called "Oswayo Formation" - see, for example, Harper and Laughrey, 1987). Figures 26 and 27 show the Venango Formation at the left (northwest) side of the diagrams.

There is a noticeable lithologic change in the Venango Formation across a zone about 5 to 10 miles wide that contains the paths of the Monongahela and Allegheny Rivers. Harper (1987) suggested that this zone, and the rivers, might be related to the basement extensional faulting of the Rome Trough (see Subsurface Stratigraphy). West of the rivers the Venango Formation maintains a fairly consistent lithologic pattern of sandstone layers separated by shale and siltstone layers. East of the rivers, however, the Venango becomes increasingly dominated by shales and fissile siltstones, and there is a general increase in the red beds of lithosome 5, the Catskill facies. On the east side of the rivers the Venango can be described as a group consisting of three discrete, though unnamed, formations. Harper and Laughrey (1987) used the descriptive terms "Upper sandy zone", "Middle red shale zone", and "Lower sandy zone" for these formations, and we follow that terminology here.

Lower Sandy Zone

The Lower sandy zone consists of the rocks drillers call Fifth, Bayard, and Elizabeth sands. These rocks are exposed at only one place in Pennsylvania, near Victoria in the Youghiogheny River gorge through Laurel Hill between Ohiopyle, Fayette County and Confluence, Somerset County. This outcrop will be examined during a pre-Conference field trip (Stop #A). West of the Monongahela River the Lower sandy zone becomes a part of the Venango Formation. East of Laurel Hill it is essentially replaced by the red beds of the Hampshire Formation.

Stevenson (1878) was the first to recognize that the lowest beds exposed in the Youghiogheny gorge were of Devonian age. Based on fossils collected during earlier work, he labeled some of these rocks, those east of Victoria, "lower Chemung". Butts (1908), however, determined that the Devonian faunas found in the inliers in southwestern Pennsylvania indicated that all exposed rocks were equivalent to the "Conewango Series" of the northwestern counties, i.e. to rocks considerably younger than "Chemung". Willard (1933) reasserted Stevenson's conclusions that the non-red Devonian rocks of the Chestnut Ridge and Laurel Hill inliers were of "lower Chemung" age. This prompted an exchange of views between Willard and Caster (1935) in which Caster stated that the fauna in the exposed Devonian rocks on Chestnut Ridge near Uniontown were definitely "Conewango". Chadwick (1935) muddle things even more by stating that these rocks, based on the fossils, were "Canadaway" in age. In his classic study of the Upper Devonian Willard (1939, p. 268) stated:

> "At Ohiopyle in northeastern [sic] Fayette County, marine Devonian and Catskill contiental beds are exposed along the Youghiogheny River, but the few poorly preserved fossils collected were inadequate as evidence of the precise age of these beds, although they are perhaps not younger than latest Chemung."

The only comprehensive report on the geology of the Lower sandy zone is the doctoral work of Wilson M. Laird in which Laird, as Caster's student, apparently set out to solve the controversy. Much of Laird's doctoral work was published by the Pennsylvania Geological Survey a year before he completed his dissertation. In these works Laird (1941, 1942) called the rocks at Victoria Sandstone A ("Maple Summit Member") and described them as probably being "Conneaut" in age, that is, younger than "Chemung" and "Canadaway" but older than "Conewango".

Berg and others (1980; also Berg and others, 1986) labeled these rocks Foreknobs Formation. However, the Foreknobs Formation lies east of Laurel Hill anticline (Figures 26, and 27).

Boswell and others, 1987 called rocks that are at least partially equivalent to the Lower sandy zone at Rowlesburg, West Virginia the Cannon Hill Formation of the Hampshire Group. We have serious reservations about using this name in Pennsylvania, however. The authors indicate that the formation rises through the section across the state, encompassing the Elizabeth and Warren sands (= Bayard and Elizabeth sands in Pennsylvania) to the east and the Fourth and Fifth sands in the west. Although the rocks at the type section are probably equivalent to the Lower sandy zone, the philosophy behind the formation definition and correlation of it to the west results in a very different mappable unit than the Lower sandy zone as defined by Harper and Laughrey (1987).

Petrographic characteristics of the Lower sandy zone sandstones are quite diverse. The sandstones are fine to coarse grained, often conglomeratic, and poorly to moderately well sorted. Compositionally, the rocks consist of feldspathic and lithic graywackes, sublitharenites, and quartz arenites. Monocrystalline and polycrystalline quartz grains are subangular to rounded and commonly form about 65 to 90 percent of the sandstone frameworks. Feldspar contents range from trace amounts to 10 percent. Lithics range from less than one percent to 15 percent.

In decreasing order of abundance, the feldspars consist of plagioclase, orthoclase, and microcline. Lithic grains include chert, shale, carbonate rock fragments, low-rank metamorphic rock fragments, and volcanic rock fragments. Mica, zircon, tourmaline, and magnetite are common accessory grains. Carbonate allochems, lithic intraclasts, and terrestrial plant debris are abundant. In the arenites, silica, calcite, and dolomite comprise the principal cements. Lesser amounts of smectite and chlorite also serve as binder. In the feldspathic and lithic graywackes, the binder consists of both epimatrix, derived from the diagenetic alteration of framework grains, and pseudomatrix that formed by the mechanical deformation of labile detrital grains.

Interpretations of the detrital modes of the Lower sandy zone sandstones, supplemented by regional mapping, indicates that the source area was an uplifted sedimentary and metasedimentary tectonic terrane that also provided at least modest amounts of recycled plutonic detritus (Harper and Laughrey, 1987). The sands were transported from the southeast by fluvial currents and reworked and deposited in a variety of on-delta paralic environments that shifted laterally in response to eustatic sea level changes during the Late Devonian. The vertical sequence of sandstone facies exposed in the Youghiogheny River gorge through Laurel Hill at Victoria resembles the vertical sequences of facies documented by Field (1980) on the inner continental shelf of Maryland. From bottom to top, both sequences consist of fluvial and/or estuarine facies overlain by lagoonal and tidal facies that are in turn overlain by littoral and inner shelf marine facies. This comparison is important because it suggests that transgressive models of Upper Devonian deposition are as significant and useful as the more commonly cited regressive models. The Lower sandy zone appears to have originated, in part, as a seaward-accreting, transgressive coastal sequence.

Middle Red Shale Zone

The predominantly shallow- or marginal-marine sandstones of the Gordon and Fourth sands (and, sometimes, portions of the Nineveh and Fifth sands) west of the Monongahela River disappear eastward, replaced primarily by red and gray, marginal-marine to nonmarine, fine-grained sandstones, siltstones and shales - the "Catskill" of drillers. East of the Laurel Hill anticline red beds become more numerous down section, replacing the Lower sandy zone, the Chadakoin Formation, and the upper portion of the Bradford Group. At this point, shown as an arbitrary cut-off in Figures 26 and 27, the name Hampshire Formation is used.

Darton (1892) named the Hampshire Formation for occurrences of Devonian red beds exposed in Hampshire County, West Virginia. Butts (1940) and Price and Woodward (1940) each revived the name because the Virginia and West Virginia red beds were clearly younger than those at Catskill Mountain in New York (the type Catskill is late Middle Devonian and early Late Devonian in age), and thus required a separate name according to the philosophy of the day. Despite of the use of chronostratigraphy in the revised formation definitions, the name Hampshire has continued to be used in Maryland, Virginia, and West Virginia.

Dennison and others (1972) extended the name Hampshire Formation into south-central Pennsylvania, but it has not exactly become a household word there. Harper (1979), Berg and others (1980), and Laughrey and Harper (1986) continued to call the red beds in south-central and southwestern Pennsylvania Catskill, but Berg and others (1986) restored the name Hampshire in south-central Pennsylvania, both in outcrop and in the subsurface in the Laurel Highlands. At this Field Conference we have followed Berg and others (1986) in using the name Hampshire Formation, but only with reservations. The Hampshire has not been as thoroughly studied as the Catskill, and no attempts have been made to divide the formation into the types of discrete members that characterize the Catskill Formation in central Pennsylvania. If it can be demonstrated that the two formations are not lithologically distinct, the name Hampshire should be abandoned.

Stevenson (1877) first recognized the existence of the Middle red shale zone. He noticed that the break between the Devonian and the overlying Pocono sandstone was distinct, that the sandstones of the Pocono graded downward through sandy shales into the well-defined reddish shales and sandstones of the Catskill Formation. In a later report (Stevenson, 1878) he suggested that the Catskill and part of the "Chemung" were probably missing in southwestern Pennsylvania. Willard (1935, 1939) regarded Stevenson's assertion as correct, based on evidence in the Conemaugh and Youghiogheny River gorges through Laurel Hill anticline. At the Johnstown and Cramer sections, Willard (1939, p. 268) noted:

> "On the east flank, characteristic Catskill red sandstone and shales underlie the Pocono. On the west flank the Pocono overlies marine Devonian beds without intervening red strata. It is probable that

these beds are very late Chemung, but there is a chance that they are younger."

To back up his premise, Willard stated that at Summit, on Chestnut Ridge near Uniontown, and again at the Youghiogheny River gorge through Chestnut Ridge south of Connellsville, he found no trace of red beds between the Pocono and Upper Devonian marine beds. This indicated to him that:

"...the transgression of the continental beds did not reach this point during the closing stages of the Devonian, unless they were subsequently done away with during the Devonian-Mississippian hiatus. I say 'closing stages of the Devonian' because of reported red beds at some depth in well borings in Fayette County. Considering the irregular nature of the western limit of the Catskill and the vacillating conditions under which it was laid down, temporary advances and retreats may be expected."

Willard's arguments about the great hiatus and the age of the Devonian marine beds exposed in southwestern Pennsylvania were a house of cards. There are red beds on the west (Cramer) side of Laurel Hill, exposed along the railroad tracks below PA Route 403. Their position along the road is not well exposed because the ground is not steep enough to form cliffs. The red beds are apparently more easily eroded here, but the soil is characteristically brick-red. There are red beds at Summit, exposed in the deeper ravines adjacent to US Route 40 (Berg and others, 1980). And there are red beds exposed in the gorge south of Connelsville. We do not understand how Willard could have missed or misinterpreted these, especially considering that the Fayette County report issued one year later (Hickock and Moyer, 1940) indicates that red beds occur about 250 ft (76 m) below the Pocono in the Connellsville gorge and 100 to 300 ft (30 to 91 m) of red shale and sandstone were well known from oil and gas wells drilled on and near Chestnut Ridge.

Laird (1941, 1942) referred to the rocks of the Middle red shale zone as Sandstone B ("Youghiogheny Member"), and characterized them as being "Conewangoan" in age, equivalent to the Venango Formation of northwestern Pennsylvania. Boswell and others (1987) coined the name Rowlesburg Formation of the Hampshire Group for a similar sequence of rocks in West Virginia. With some study it may be demonstrated that the Rowlesburg and the Middle red shale zone are equivalent.

The petrography and sedimentology of lithologies within the Middle red shale zone are poorly understood and require considerable attention. In preparation for the Field Conference, we joined Uldis Kaktins and William Brice of the University of Pittsburgh at Johnstown in conducting a cursory reconnaissance of the interval in the Conemaugh River gorge through Laurel Hill. This included measuring the exposed section along the railroad tracks on the west side (part of the Cramer section). The measured interval consists of a little more than 100 ft (31 m) of stacked, fining-upward cycles dominated by finer grained lithologies in the lower half and by sandstones and siltstones in the upper half (Figure 29). The sandstones are reddish gray, very fine to fine grained, moderately well sorted, micaceous, and sublithic to lithic (Figure 30A). Hematite cement is intercalated with argillaceous components. Sandstones display a number of sedimentary structures, including trough cross-bedding, tabular cross-stratification, low-angle to planar bedding and laminations, and current ripple laminations. Scour surfaces are common on the bases of individual fining upward sandstone sequences. Sandstones exhibit channel geometries (Figure 30B). Plant fossils are abundant. Sandstones from the Middle red shale zone on the Johnstown side of the gorge are similar with one significant exception. Sandstone bar-forms containing calcite cement and coarse carbonate grains resembling pisolites (Figures 30C and D) are interbedded with the more typical types of sandstones described above. Shales and siltstones are red, fissile, blocky, or hackly, very micaceous, and exhibit occassional burrow traces and green mottling.

Actual interpretations of these lithologies must await detailed facies analyses. The rocks of the Middle red shale zone, however, appear to resemble delta plain and alluvial plain non-marine facies of the Catskill coastal plain described by Sevon (1985).

Upper Sandy Zone

The Upper sandy zone consists of interbedded marine and nonmarine rocks equivalent to the Riceville Formation and the Hundred-Foot and upper Nineveh sands west of the Monongahela River. East of Laurel Hill anticline they are replaced by the nonmarine rocks of the Rockwell Formation (Inners, 1987). The lower portion of this zone may consist of dark-colored shales and thin, lightcolored siltstones and sandstones containing a distinctly marine fauna.

Stevenson (1877) placed the Upper sandy zone in the Pocono as a the lithologic transition between true Pocono and Catskill. Butts (1908) assigned these rocks to the Conewango Formation, but considered both the Conewango and Catskill to be part of the Carboniferous System. Phalen (1910) included the Upper sandy zone at Johnstown in the Pocono. As discussed previously, Bradford Willard and Kenneth Caster were greatly at odds over the correlation and age of these rocks; Willard agreed with Stevenson and Caster agreed with Butts. Laird (1941, 1942) eventually solved the disagreement.

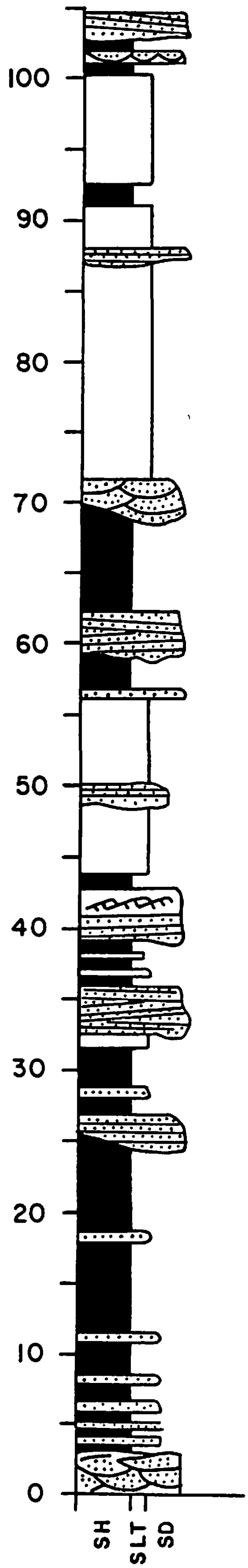

Figure 29. Measured stratigraphic section of the Middle red shale zone of the Venango Group exposed along the Conrail railroad tracks in the Conemaugh Gorge through Laurel Hill.

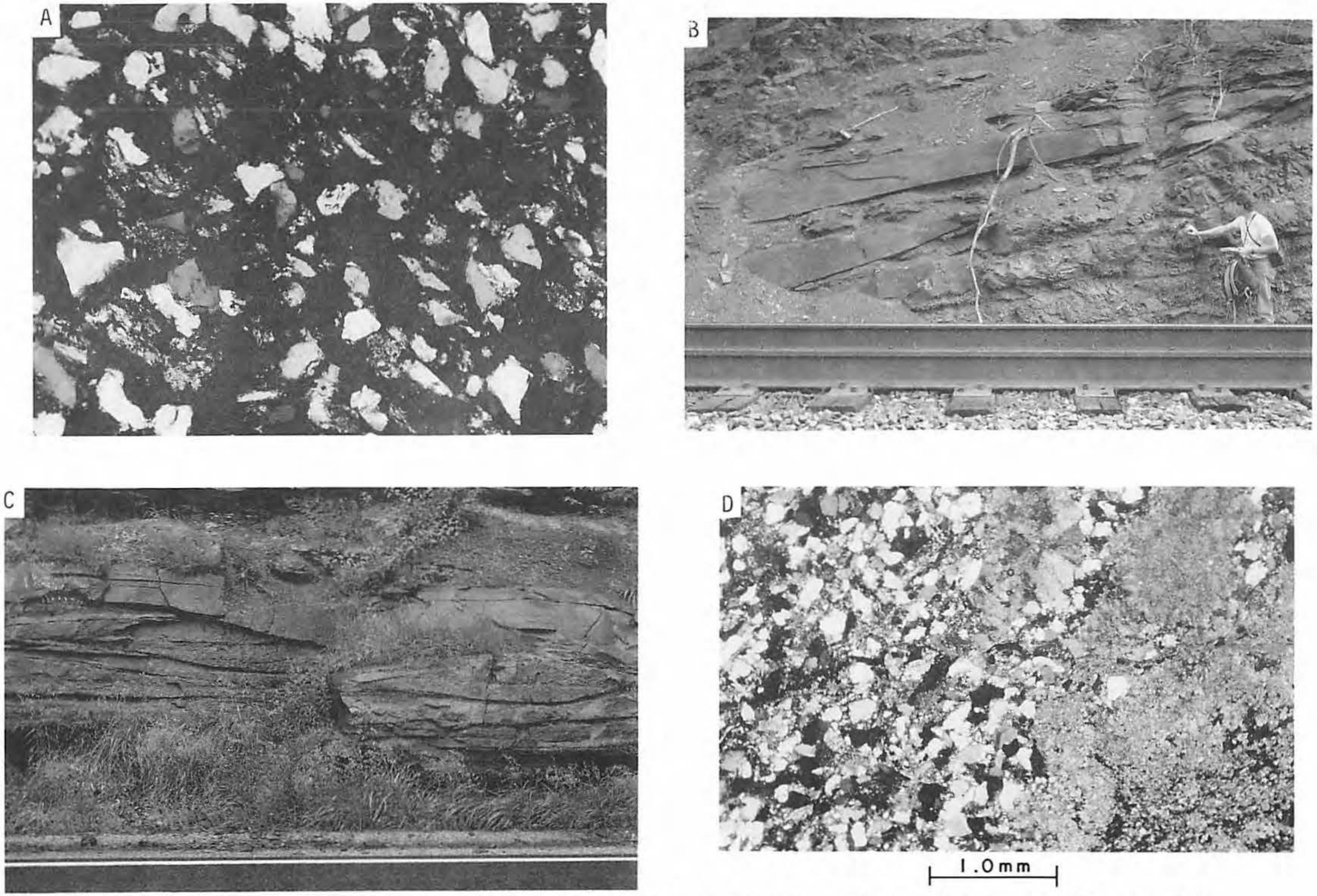

Figure 30. Photographs of the Middle red shale zone of the Venango Group in the Conemaugh Gorge. (A) Photomicrograph of argillaceous, hematitic sublitharenite; (B) Outcrop of the multiple, stacked, fining-upward sequences along the Conrail railroad tracks. Note the channel-fill geometry of the sandstone bodies; (C) Intercalated beds of channel sandstones and pisolite(?) bars along PA Route 403 on the Johnstown side of the gorge; (D) Photomicrograph showing carbonate clasts in sandstone from the pisolite(?) bar shown in C.

He separated these rocks into a lower, shale-rich unit called Shale C ("Watering Trough Shale") and an upper, sandstone-rich unit called Sandstone D ("Jumonville Sandstone"). Based on the rich fossil evidence from these rocks, he considered Shale C the upper part of the Venango Formation ("Conewangoan" of early usage) and Sandstone D equivalent to the Riceville Shale of northwestern Pennsylvania.

Fettke and Bayles (1945) referred to the Upper sandy zone rocks as "Beds of Oswayo Age". Harper and Laughrey (1987) restricted the name "Oswayo Formation" to the upper 10 to 30 ft (3 to 9 m) of shale and siltstone above the sandstones of the Hundred-Foot sand and its equivalents. West Virginia investigators continue to refer to the Upper sandy zone as the Oswayo Member of the Price Formation (Kammer and Bjerstedt, 1986; Boswell and others, 1987; Bjerstedt and Kammer, 1988). We feel that use of the term Oswayo when used in anything but an informal sense in southern Pennsylvania and West Virginia is unfortunate. Although there are gross lithologic similarities between the Upper sandy zone and the type Oswayo Formation of New York (they both contain sandstones, siltstones, and shales), and their fossils indicate that the two are the same age, there are many differences. The type Oswayo seems to be entirely marine and consists of olive-green to rusty-colored sandy shales with intermittent thin layers of sandstone (Glenn, 1903). The Upper sandy zone is dominated by interbedded gray, marine and nonmarine sandstones, siltstones, and shales. As we will see at the outcrop near Cramer in the Conemaugh gorge (Stop #4), there are distinct nonmarine channel sandstones between the marine zones.

Bayles (1949) thought a discrepancy existed in correlating the Upper sandy zone at the surface and in the subsurface. The thick Hundred-Foot sand of drillers on the west side of the Monongahela River grades eastward into the siltstone-rich sequence seen in outcrop at Cramer. The Hundred-Foot also correlates well with a sandstone sequence exposed at Victoria in the Youghiogheny gorge. What Bayles apparently failed to realize is that many of these Upper Devonian sandstones have lenticular channel-and bar-form geometries. The sandstone at one location may be shale at another and siltstone at a third. At Cramer the Upper sandy zone along PA 403 only vaguely resembles the same beds along the railroad tracks a few hundred feet down dip.

Sandstones and siltstone in the Upper sandy zone are notably lithic (Figure 31). Rock fragments constitute from 16 to 26 percent of the bulk composition of the rocks that, when recalculated to the relative amounts of quartz, feldspar, and lithic framework grains, becomes 18 to 31 percent lithic fragments. The rocks are sublitharenites and litharenites. About 3 percent of the total amount of quartz is polycrystalline.

The framework composition of the Upper sandy zone sandstones in the Laurel Highlands indicate a recycled orogen provenance and collision orogen/foreland uplift source of the sedimentary materials (see Dickinson and Suczek, 1979). The Upper sandy zone is particularly noteworthy because a strong case can be made for estuarine sedimentation during its deposition. Distinctly fluvial deposits are overlain by, and intercallated with, fossiliferous, marginal marine deposits. Upper sandy zone facies sequences exposed at Cramer are remarkably similar to the riverine estuary sequences of the Georgia coast described by Frey and Howard (1986). The argument for an estuarine interpretation of the Upper sandy zone is fully presented in the discussion for Stop #4. The lower 2/3 of the Upper sandy zone at Cramer reveal a tension between regressive fluvial sedimentation induced by erosion of tectonic highlands to the east and eustatic sea

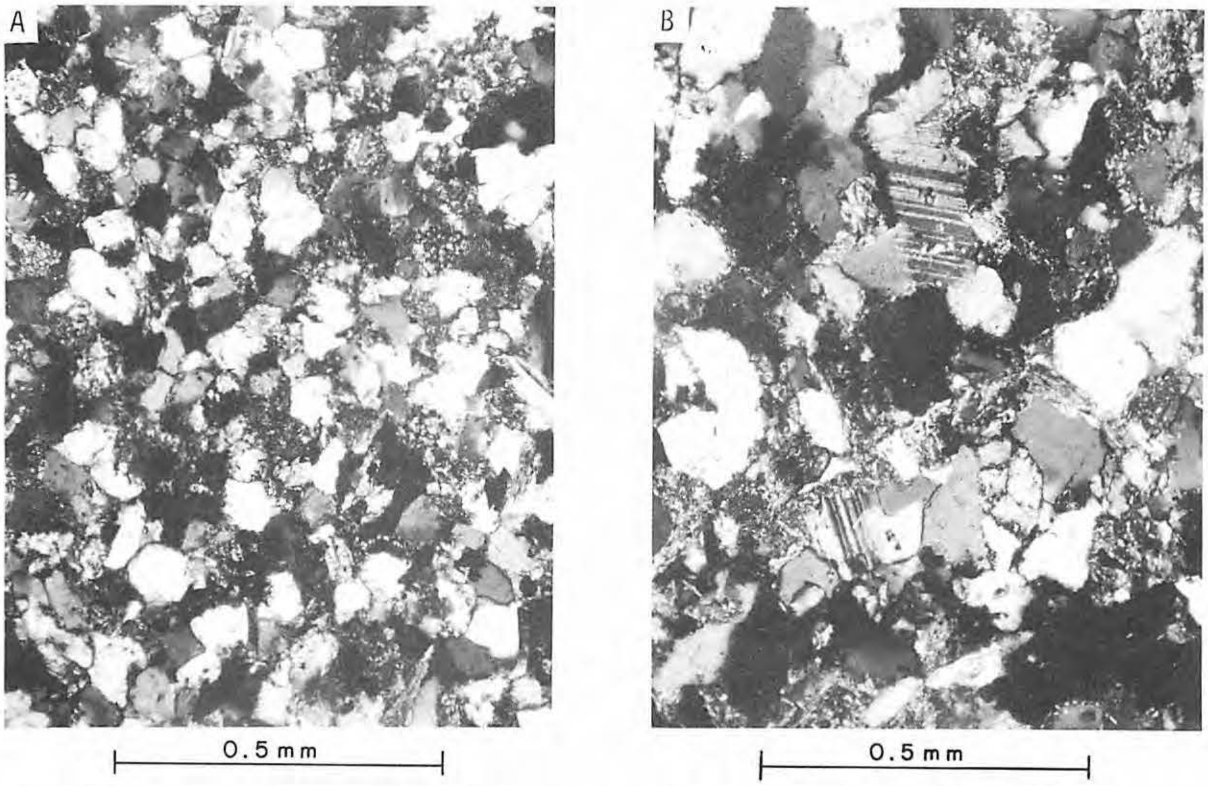

Figure 31. Photomicrographs of the fluvial facies sandstone from the Upper sandy zone of the Venango Group. (A) Low magnification; (B) High magnification.

level rise that flooded the basin margin from the west. Distal river valleys were gradually filled by estuarine accretionary sediments and topped by tidal flats and shoals. Rising sea level prevailed over deposition of the sediments represented in the upper 1/3 of the Upper sandy zone (the "Oswayo Formation" of Harper and Laughrey, 1987). These deposits are strictly marine. Muddy marine shelf and/or bay deposits grade upwards into mixed fine clastic and marine carbonate deposits.

DEVONIAN-MISSISSIPPIAN BOUNDARY

In Figure 25 the systemic boundary is shown as a queried zone ranging from the base of the Riddlesburg Shale to near the base of the Murrysville sand. During the past 115 years the stratigraphic position of the boundary has changed up and down though about 300 ft (91 m) of section in western Pennsylvania and eastern Ohio (Bayles, 1949; Eames, 1974; deWitt and McGrew, 1979; J. L. Carter, 1989, personal comm.). The exact placement of this boundary is still up for grabs and should provide some interesting discussion during this Field Conference.

MISSISSIPPIAN

General

Deposition of Lower Mississippian (Kinderhookian and Osagian) rocks in

Pennsylvania resulted from the continued effects of the Acadian orogeny, although at a much reduced intensity (Edmunds and others, 1979). Some westward progradation of sediments occurred, but for the most part the stable alluvial plain built during the latest Devonian continued to dominate in central and western Pennsylvania. Demarest (1946; also Pepper and others, 1954) recognized the development of deltas at the western edge of the plain during the earliest phase of deposition (Murrysville sand and western equivalents). Following this phase, the sea transgressed into the basin. The marine rocks deposited on the Murrysville complex are often black, organic-rich shales containing restricted faunas of inarticulate brachiopods, infaunal bivalves, and nektonic forms such as conodonts and cephalopods. In Ohio, western Pennsylvania, and western West Virginia these rocks are called Sunbury Shale, typically considered the basal member of the Cuyahoga Formation (Figures 26 and 27). In central Pennsylvania they are called Riddlesburg Shale; in many places this Riddlesburg is considered a member of the otherwise nonmarine Rockwell Formation (see, for example, Inners, 1987).

The Appalachian Basin became relatively quiescent and deposition of mostly nonmarine sediments occurred across the broad alluvial plain developed during the Late Devonian. Progradation across this plain is clearly marked - in a vertical sequence, the meandering fluvial sequence of the Rockwell Formation give way to the anastomosing fluvial sandstones of the Burgoon Sandstone during the Osagean. The coarse clastic rocks of these formations dominated the lithologies of the Lower Mississippian in western Pennsylvania (Figure 32).

The Early Mississippian ended with the erosion of the upper Burgoon Sandstone thoughout much of its geographic extent. The superjacent Greenbrier and Loyalhanna Formations lie disconformably on this erosional surface (Adams, 1970; Brezinski, 1984; Harper and Laughrey, 1987).

Murrysville Sand

Butts (1904, p. 5) named the Murrysville sand for the prolific gas reservoir drilled near the town of Murrysville, Westmoreland County. In the Allegheny Valley drillers called this reservoir rock the Butler gas sand, and Butts coined the new name in order to avoid confusion with the Butler sandstone of the Allegheny Group (Pennsylvanian).

Murrysville sand is an informal term that, at present, has no formal counterparts. Several authors (e.g. Pepper and others, 1954; Kammer and Bjerstedt, 1986) have suggested that the name Cussewago Sandstone be used in place of Murrysville. Correlations made by Harper and Laughrey (1987), however, indicate that the Cussewago is equivalent only to the lower 1/3 to 1/2 of the thick Murrysville sand of western Westmoreland County.

We use the name Murrysville sand for the sequence of rocks between what has been accepted classically as the top of the Devonian System (the "Oswayo Formation" of Harper and Laughrey, 1987) and the base of the Sunbury Shale and its eastern equivalent, the Riddlesburg Shale. East of the Monongahela and Allegheny Rivers, the Murrysville consists of a more or less single, thick sandstone unit. West of the rivers, however, the sand splits into three separate formations that are persistent throughout westernmost Pennsylvania, Ohio, and West Virginia. These are the Cussewago Sandstone, Bedford Shale, and Berea Sandstone (Figures 26 and 27). Harper and Laughrey (1987) considered these

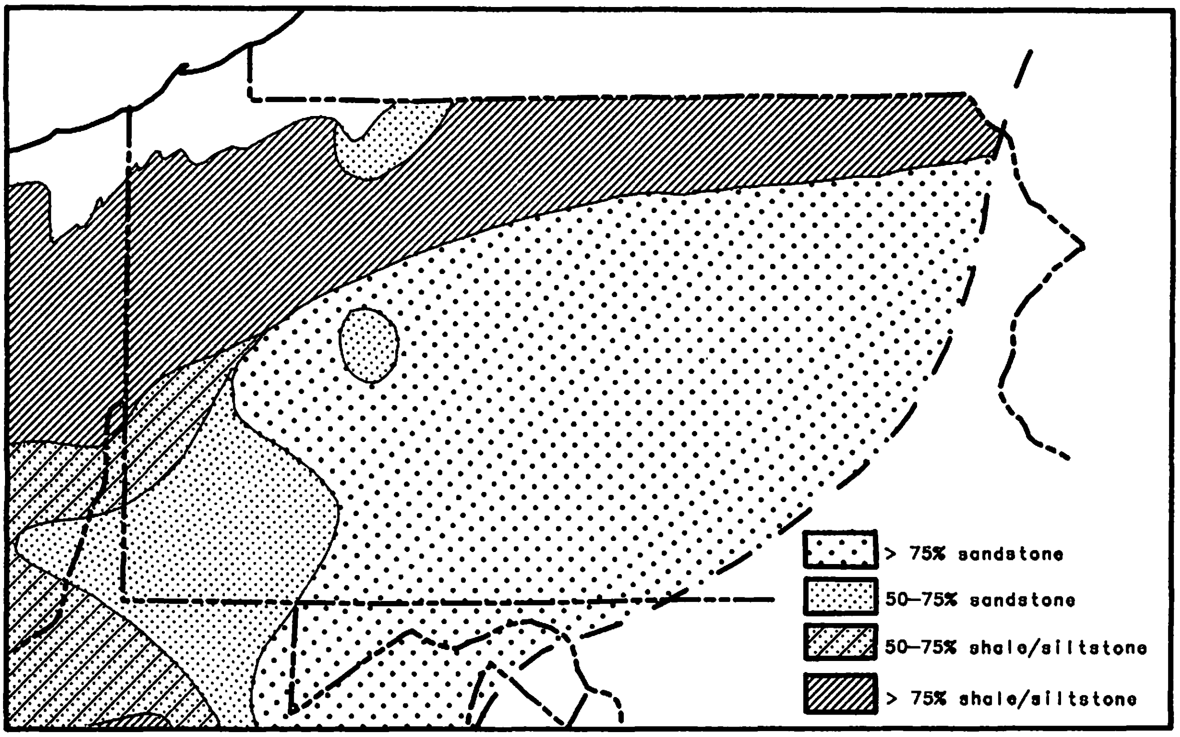

Figure 32. Generalized lithofacies map of Lower Mississippian rocks in Pennsylvania (modified from Walker, 1962). The dashed line indicates the eastern limit of Mississippian rocks.

formations to correspond to the seemingly single depositional system of the Murrysville. In the Laurel Highlands the Murrysville sand can still be considered a single unit, but lithologic changes within the Murrysville, corresponding approximately to the Cussewago and Berea, can be recognized as far east as Johnstown. Because of this we have divided the Murrysville into a lower Cussewago equivalent "member" and an upper Berea equivalent "member". These are discussed separately.

Cussewago Equivalent Member

The Cussewago equivalent member shares many of the common lithologic attributes of the type Murrysville sand in Westmoreland County, leading Pepper and others (1954) to conclude that the Murrysville and Cussewago were subsurface and surface counterparts. Both are composed of poorly cemented, white, gray, or greenish-yellow, very fine- to coarse-grained sandstone having scattered lenses and pods of very coarse sand and quartz pebbles. These characteristics of the rock make it easily identifiable over most of its surface and subsurface extent. The Cussewago equivalent in the Laurel Highlands is typically thicker, more thickly bedded, and more coarse grained than the Berea equivalent, but this is a generalization and many exceptions exist. In fact, west of the Monongahela River the Berea typically exhibits thicker beds of coarser grained sandstone than the Cussewago (Harper and Laughrey, 1987).

Laird (1941, 1942) called the Cussewago equivalent Sandstone E ("Linderman sandstone") and Conglomerate F ("Hopwood conglomerate"), depending on the specific lithology exposed at any particular locality. The unit seems to grow coarser westward. Laird (1942, p. 125) described the "Linderman" at Victoria in the Youghiogheny gorge through Laurel Hill a fine- to medium-grained, gray-brown, well sorted sandstone cemented with calcite. At Cramer, however, this sandstone is medium grained, gray-brown, and moderately well sorted (personal observation). Some exposures, such as those at Cramer, contain thin lenses or layers of quartz pebbles. At exposures along Chestnut Ridge the unit is replaced by Conglomerate F, a very coarse grained, conglomeratic sandstone or conglomerate. For example, at Summit near Uniontown, the Cussewago equivalent contains a lower sandstone and an upper lenticular conglomerate (Laird, 1942). We have observed a similar division in the Conemaugh gorge at Bolivar. Stevenson (1877) reported quartz pebbles larger than hen's eggs from this unit in the Youghiogheny gorge through Chestnut Ridge south of Connellsville.

Cussewago equivalent rocks exposed at the Cramer section, and penetrated in gas wells in the Laurel Highlands, are moderately sorted, medium-grained sublitharenites. Monocrystalline and polycrystalline quartz, respectively, comprise about 56 percent and 18 percent of the sandstones' bulk compositions. Quartz is rounded to subrounded. Minor amounts of quartz cement in the form of overgrowths and pore-bridging prisms impart slight angularity to some constituents. The lithic portion of the sandstones includes chert (eight percent), metamorphic rock fragments (five percent), and sedimentary rock fragments (one percent). Feldspar is a minor component, and mica, zircon, and pyrite make up the accessories in the rocks. Authigenic clays, calcite, and silica bind the framework grains together. The sandstones are poorly cemented, however, and can be easily disaggregated between two fingers. Porosity is secondary and mostly due to the dissolution of chemically labile rock fragments along with calcite cement.

Facies analyses of the Cussewago equivalent rocks near Cramer support a fluvial interpretation for the depositional origin of the sequence exposed in the Conemaugh gorge through Laurel Hill (see description of Stop #4). This interpretation is consistent with that of Pepper and others (1954), but in direct disagreement with the conclusions of Bjerstedt and Kammer (1988). These latter authors suggested that Cussewago equivalent rocks are basal transgressive sandstones deposited through shoreface retreat during a major marine transgression. A discussion of these conflicting interpretations is in the description of Stop #4 presented in this guidebook. We feel that a fluvial origin for the Cussewago equivalent at Cramer is rather obvious, but we are not familiar with the sequence in adjacent portions of West Virginia and Maryland; therefore, we do not wish to extrapolate our view out of the Field Conference area.

Berea Equivalent Member

The Berea equivalent member commonly consists of fine-to very fine-grained, well-indurated, white to light-gray sandstone, but pockets of coarse sand and small pebbles occur in porous zones scattered over its geographic extent. The Berea is a persistent sandstone in the southwesternmost counties of Pennsylvania, but it tends to lose its discreteness where it merges with the Cussewago to form the Murrysville sand (east of the Monongahela River).

Pepper and others (1954, p. 61 and fig. 35) indicated that the type Berea Sandstone had a northern source area, but showed that easternmost occurrences of the sandstone were shoreline and near-shore sand deposits having a southeastern source. This agrees with data showing the Berea as being an upper tongue of the

Murrysville sand (Harper and Laughrey, 1987).

Laird (1941, 1942) called the Berea equivalent Sandstone G ("Pine Knob member"). Laird (1942) found that, at Summit near Uniontown, sandy shales (fissile siltstones?) dominate the base of this unit, but they grade upward into thin-bedded, fine-grained, well-sorted sandstones. He indicated that it could be differentiated from the rest of the Mississippian only in Fayette County, but he did not examine all of the localities. For example, at Cramer he measured and described the section along the railroad tracks where the Berea equivalent is not exposed. Fettke and Bayles (1945) examined the section along what is now PA Route 403 above the railroad tracks and measured 23 ft (7 m) of fine-grained, greenish gray sandstone and a great deal of interbedded greenish gray sandy shale and dark gray shale in this interval. The section at Bolivar is covered. The fauna of Sandstone G suggested to Laird that this unit bears a relationship to the Tidioute shale of Caster (1934; = Bedford Shale in part).

Today, at Cramer along PA Route 403, approximately 30 ft (9.1 m) of Berea equivalent sandstone, siltstone, and shale crop out directly above the Cussewago equivalent. The lower three ft (0.9 m) indicate a radical departure from the depositional style of the subjacent fluvial sequence. This lower Berea interval consists of stacked, coarsening upward, parallel laminated sandstones with scour surfaces on their bases and wave ripples on their tops. The remaining 27 ft (8.2 m) of Berea equivalent consists of interbedded sandstone, siltstone, and shale. The sandstones contain numerous trace fossils and display cross lamination. Burrows are common in the siltstones and shales. Plant fossils occur throughout the entire interval. The Berea equivalent member at Cramer consists of paralic facies that are transitional between subjacent fluvial deposits and overlying marine sediments of the Riddlesburg Shale.

Riddlesburg Shale

The Riddlesburg Shale was named by Reger (1927) for 75 ft (22.9 m) of greenish-black siliceous shale exhibiting pencil cleavage and containing a marine fauna in the lower part. In central Pennsylvania the Riddlesburg is considered to be a member of the Rockwell Formation (Berg and others, 1986; Figures 26 and 27), and in West Virginia it is a member of the Price Formation (Kammer and Bjerstedt, 1986). The Riddlesburg crops out at numerous localities in the in the Broad Top synclinorium and along the Allegheny Front near Altoona. Inners (1987) found bivalves and rhynchonellid brachiopods in greenish gray silty shales interbedded with sandstones at Horseshoe Curve, but he did not use the name Riddlesburg for this occurrence.

Laird (1941, 1942) considered the Riddlesburg to be restricted to central Pennsylvania. In western Pennsylvania he considered equivalent rocks to be part of his Sandstone H ("Ohiopyle sandstone"), but indicated a distinct similarity in faunas between the two units.

At the type locality of Sandstone H near Victoria, the unit is sandstone rich, whereas at Summit on Chestnut Ridge it seems to be missing altogether. At Cramer the unit is apparently mostly dark-colored shale, but this is not known for certain because the Riddlesburg section is mostly covered by talus. Only the upper 29 ft (8.8 m) of Riddlesburg crops out along PA Route 403, and the section along the railroad is covered. In fact Laird, who studied only the railroad outcrop, did not recognize many of his units at this locality.

Laird (1942) found that the Riddlesburg fauna occurred in the lower 25 to 30 ft (7.6 to 9.1 m) of the unit in central Pennsylvania. The fact that only the upper part of the unit is completely exposed at Cramer may help explain why the fauna found there is so sparse.

Riddlesburg lithologies at the Cramer section in the Conemaugh gorge through Laurel Hill include clayshales, mudstones, limestones, and sandstones. Clay-shales and mudstones dominate most of the Riddlesburg interval. These shales are dark gray to greenish and grayish black. They are laminated, with flaggy, platy, and fissile partings. The shales are moderately to weakly bioturbated. Trace fossils, mostly horizontal and vertical burrows, are common. Fossils in the shales include lingulid and rhynchonellid brachiopods, bivalves, rare cephalopods, and plant debris. The limestones and sandstones occur near the top of the Riddlesburg exposure as thin beds with the dominant shale. The limestone is argillaceous and dolomitic; it exhibits distinctive cone-in-cone structure (Figure 33). The sandstones are fine and medium grained to conglomeratic, variably sorted, contain mudstone clasts, and display various sole marks and scour prods on their basal sides. Sedimentary structures include low-angle cross lamination with numerous reactivation surfaces, trough cross stratification, lenticular bedding, and wave-ripple laminations. The sandstone beds swell and pinch (hummocky cross stratification?). Vertical and horizontal burrows are common.

The lower 2/3 of the Riddlesburg Shale sequence exposed at Cramer represents a continuation of the transgression initiated during deposition of the subjacent Berea equivalent member of the Murrysville sand. We interpret this part of the sequence as restricted marine. The upper third of the Riddlesburg, however, is retrogradational. Thin sandstone beds, deposited during storm activity on the muddy, restricted marine basin-margin floor, represent the first advance of regressive sediments that prograded westward during Late Kinderhookian time.

Weir Sand

We are using the term "Weir sand" for want of a better name. Weir sand is a drillers' name that originated in eastern Kentucky for an oil producing sandstone in the New Providence Formation, named for Weir in Kanawha County, West Virginia. The name has also been used in West Virginia for gas-producing sandstones that occur within the equivalent Cuyahoga

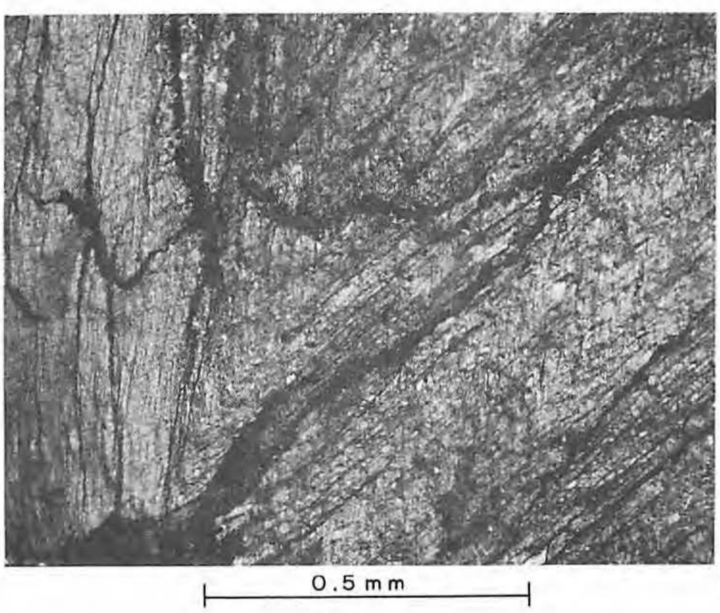

Figure 33. Photomicrograph showing cone-in-cone and stylolite structures in a carbonate layer at the top of the Riddlesburg Shale

Formation. In western Pennsylvania the shales of the Cuyahoga Formation at this level grade into silty shales, siltstones, and rare sandstones called the Second Gas sand, or "Bitter Rock". In general they are only of stratigraphic importance. Harper and Laughrey (1987) thought that these beds correlated in part with the Sharpsville Sandstone of northwestern Pennsylvania, but this has not been confirmed.

We have separated the Weir sand from the superjacent Rockwell tongue for this study because the two units are significantly different in outcrop, both lithologically and depositionally. We do not know at this time if these two units can be separated and mapped adequately in the subsurface.

Laird (1941, p. 16; 1942) called this unit Conglomerate I ("Lick Run conglomerate") describing it as "a massive conglomerate composed chiefly of rounded or oval, white quartz pebbles averaging pea size or somewhat larger imbedded in a matrix of coarse, grey sandstone." In some beds it is a conglomeratic sandstone, whereas in others it is a true conglomerate. He found the formation barren of fossils. Despite indicating that it was the most widespread and easily identifiable Lower Mississippian unit in southwestern Pennsylvania, Laird was unable to find it in the Conemaugh River gorges in Chestnut Ridge and Laurel Hill. However, Fettke and Bayles (1945) measured 67 ft (20.4 m) of conglomeratic sandstone at Cramer that could be attributed to Conglomerate I.

At Cramer, the Weir sand consists of fine- to coarse-grained sandstones and conglomerates. Sedimentary structures are abundant and include trough cross bedding, profuse wave ripple bedding and lamination, wavy, lenticular, and hummocky stratification, and current ripple laminations. Rip up clasts and scour surfaces are common. Contrary to Laird's (1941, 1942) contention, trace fossils are abundant and include vertical, horizontal, and U-shaped burrows. The sequence coarsens upwards.

DeWitt and others (1979) indicated that the Weir sand is part of a complex depositional system, ranging from open-sea marine sandstones of the Borden Formation in central Kentucky to the largely subaerial sandstones of the Price Formation in southern West Virginia. In their primary producing area the Weir sands may have accumulated as prodelta sheet sands, bars, or beaches. We tentatively interpret the Weir sand exposure at Cramer as a marine sandstone and conglomerate deposited in a setting dominated by fluvial output. The conspicuous upward coarsening is likely due to river/delta-mouth bar progradation. Our conclusion is provisional, however, because much more rigorous study is needed within this portion of the stratigraphic section.

Rockwell Tongue

As the name indicates, this unit is a tongue of the Rockwell Formation that extends into western Pennsylvania from its area of maximum development in south-central Pennsylvania, Maryland, and West Virginia. Kammer and Bjerstedt (1986) called this the Rockwell Member of the Price Formation in West Virginia, but we are not convinced that it should be considered a lithologic subdivision of an entity to which it is not related.

The Rockwell tongue appears to be lithologically and depositionally distinct from the subjacent Weir sand. The contact between the two units is placed at the last occurrence of conglomeratic sandstones and conglomerates. This is a sharp contact at Cramer, but we have not actually observed any form of contact at any other locality.

Laird (1941, 1942) combined the rocks in this interval with those of the superjacent Burgoon Sandstone, apparently because they were lithologically similar and contained no marine fossils. He called this combined interval Sandstone J ("Chestnut Ridge sandstone"), and characterized the rocks as massive, cross bedded sandstones containing plant fossils and basal rip-up clasts, with a few interbedded gray, micaceous, thin-bedded shales.

The Rockwell tongue is the surface equivalent of the Squaw sand of drillers, a well-known unit below (subservient to) the thicker and more famous Big Injun sand (thus the name). Harper and Laughrey (1987) confirmed earlier suspicions that the Squaw sand is equivalent to the Shenango Formation of northwestern Pennsylvania. Scattered reports of gas shows or production occur in southwestern Pennsylvania, and Griswold and Munn (1907) reported scattered occurrences of oil in the sand in the vicinity of Burgettstown, Washington County. Several areas of West Virginia report production from the Squaw sand, but it is probably only as subsidiary production to deeper reservoirs.

The Rockwell tongue is generally a fine-grained, light-gray, indurated sandstone that tends to be less than 40 ft (12 m) thick in the southwestern counties of Pennsylvania, but locally develops a thickness of greater than 115 ft (35 m). Where it thickens, it generally comprises multiple layers of sandstone and shale separated from the superjacent Burgoon Formation by as little as 20 or 30 ft (6 or 9 m) of dark-gray, red, or reddish-brown shale. Where they occur, the reddish colored rocks are called Patton Shale. At Cramer Fettke and Bayles (1945) measured 320 ft (97.5 m) of sandstone and "shale" (actually, fissile siltstones for the most part) in this interval. They observed that no red shales occurred in these rocks, indicating that the Patton was probably absent.

Along the railroad tracks below PA Route 403 at Cramer, the Rockwell tongue consists of multiple, stacked, fining-upward sandstone sequences. The sandstones are mostly trough cross bedded, but some current ripple bedding and laminations occur, also. Fossils include undifferentiated vertebrate material and abundant plant impressions and remains. Scour surfaces abound and mud rip-up clasts occur throughout the section. Subordinate amounts of shale and siltstone, characterized by substantial spheroidal weathering, top the numerous fining-upwards sequences. The Rockwell tongue at Cramer obviously originated within a fluvial depositional environment. This section deserves further attention addressed at determining the fluvial style of the Rockwell in western Pennsylvania, and the exact relationship of the Rockwell and the Squaw sand in the subsurface.

Burgoon Formation

Butts (1904) named the Burgoon Sandstone for exposures of thick bedded gray sandstones that crop out along the railroad tracks in the Sugar Run valley near Horseshoe Curve in Blair County, Pennsylvania (see Inners, 1987). The Burgoon is typically a thick sequence of sandstones with only minor occurrences of finer-grained detrital material. In the subsurface of southwestern Pennsylvania it almost always contains at least one shale member on the order of 30 to 100 ft (9 to 30 m) thick near the middle or top of the unit. For this reason, Harper and Laughrey (1987) felt the rank term "formation" more adequately described the

Burgoon in that area than does the descriptive term "sandstone" as used by Berg and others (1986).

At its type locality Butts (1904, p. 5) described the Burgoon as comprising approximately 300 ft (91.4 m) of:

> "...coarse and very thick-bedded gray sandstone, which, with the exception of a concealed interval of about 60 feet in a ravine east of Allegrippus, is continuously exposed along the tract for the 3,000 feet between the top of the red shale at its base and Allegrippus...on the southern side abundant boulders of coarse siliceous sandstone and soil that is almost pure sand indicate the presence of the stratum close beneath the surface."

The Burgoon Sandstone was deposited as a westward-extending, anastomosing, alluvial-deltaic sequence (Edmunds and others, 1979). Exposures of the rock in Fayette and Westmoreland Counties exhibit abundant cross bedding, basal lag deposits, clay galls, plant fossil debris, scour-and-fill sequences, sole markings, and other features typical of fluvial sandstones. Laird (1941) correlated the Burgoon to at least a portion of Sandstone J ("Chestnut Ridge sandstone") at the Youghiogheny River gorge in Laurel Hill near Ohiopyle, Fayette County. Fettke and Bayles (1945) measured 299 ft (91.1 m) of sandstone and shale in this section at Cramer.

The upper contact of the Burgoon is erosional in southwestern Pennsylvania, but it is not immediately apparent in either sample study or log analysis because of the lithologic and geophysical similarities of the Burgoon and the superjacent Loyalhanna Formation. The lower contact is typical of fluvial sandstone units - it is sharp where the sand-carrying rivers and streams cut channels into the underlying shales of the upper Shenango Formation/Rockwell tongue/Rockwell Formation.

Burgoon/Loyalhanna Contact

The Loyalhanna Formation lies disconformably on the subjacent Burgoon Sandstone thoughout much of southwestern Pennsylvania. Edmunds and others (1979, p. B13) queried the existence of the disconformity, stating:

> "The contact between the two is sharp but otherwise remarkably uniform. The age of the Loyalhanna is probably fairly reliable, but control on the terminal age of the Burgoon is very weak. We postulate...that the Burgoon Sandstone was deposited on a vast anastomosing alluvial sand plain, which by Meramecian time was depositionally static. If so, the relation between the Burgoon and Loyalhanna is simply that of a transgressive marine unit encroaching on a foundering alluvial plain."

Harper and Laughrey (1987) countered that the variable thickness of the Burgoon throughout southwestern Pennsylvania (see Figure 14), combined with the relatively consistant thickness of the Loyalhanna, suggested that the disconformity was, in fact, real. We basically agree with the conclusions of Edmunds and others (1979, p. B13, B19) that the Loyalhanna Formation of southwestern Pennsylvania was deposited in a narrow tongue of the sea transgressing over the previously uplifted and eroded Burgoon. Either continued influx of Burgoon-type detrital sediment from the north and east or the reworking of eroded Burgoon sandstones was responsible for the quartz content of the Loyalhanna.

FACIES RELATIONSHIPS AND CORRELATIONS BETWEEN THE GREENBRIER OF WEST VIRGINIA AND THE MAUCH CHUNK OF PENNSYLVANIA

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During the Late Mississippian two distinctly dissimilar depositional regimes were present in the Appalachian Basin. To the east and northeast, terrestrial red beds of the Mauch Chunk were deposited. However, to the southwest and west marine carbonates of the Greenbrier Formation accumulated. What is currently western Pennsylvania was situated where the marine carbonates intertongue with the nonmarine red clastics (Brezinski, 1984; Figure 34). As a result of this intertonguing relationship, correlation between the Mauch Chunk and the Greenbrier, and the stratigraphic nomenclature used within this interval, have long been unclear. It is the purpose of this report to discuss the nomenclatural differences between Pennsylvania and West Virginia and to illustrate the facies relationships within the zone of intertonguing.

Figure 35 illustrates the changes in stratigraphic nomenclature between the Mauch Chunk of central Pennsylvania and the Greenbrier of central West Virginia. There are two major changes one should note: 1) the Mauch Chunk of West Virginia and Maryland correlates only to the upper Mauch Chunk of western Pennsylvania (i.e. the Mauch Chunk which overlies the Wymps Gap Limestone Member); and 2) farther to the south marine units are present progressively higher in the section. This suggests that the marine embayment existed much longer and later to the south and that the entire Upper Mississippian is a progradational/regressional package. Although throughout the Upper Mississippian there is a net retrogradation of the shoreline to the southwest, water

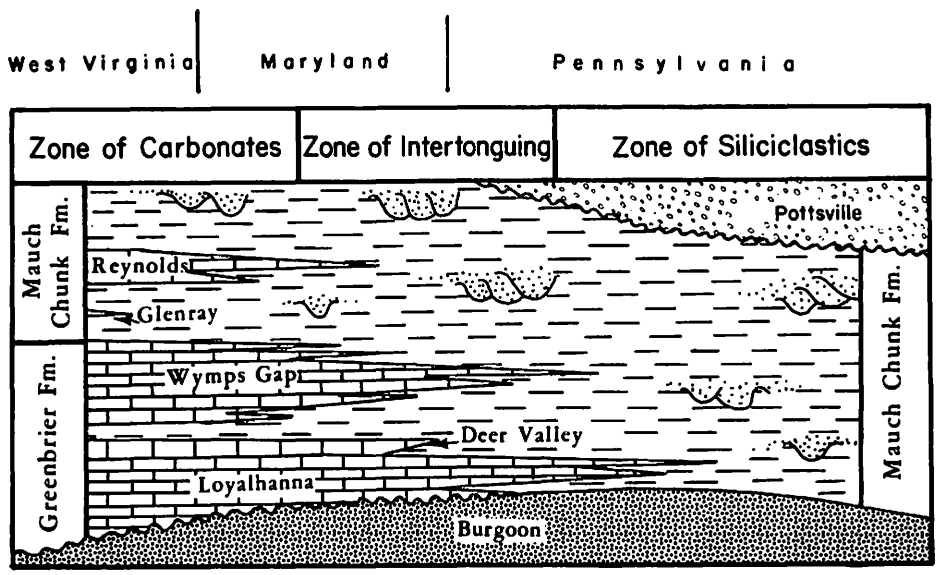

Figure 34. Generalized diagram illustrating the relationship between the Greenbrier/Mauch Chunk interval of central West Virginia and the Mauch Chunk of southwestern Pennsylvania.

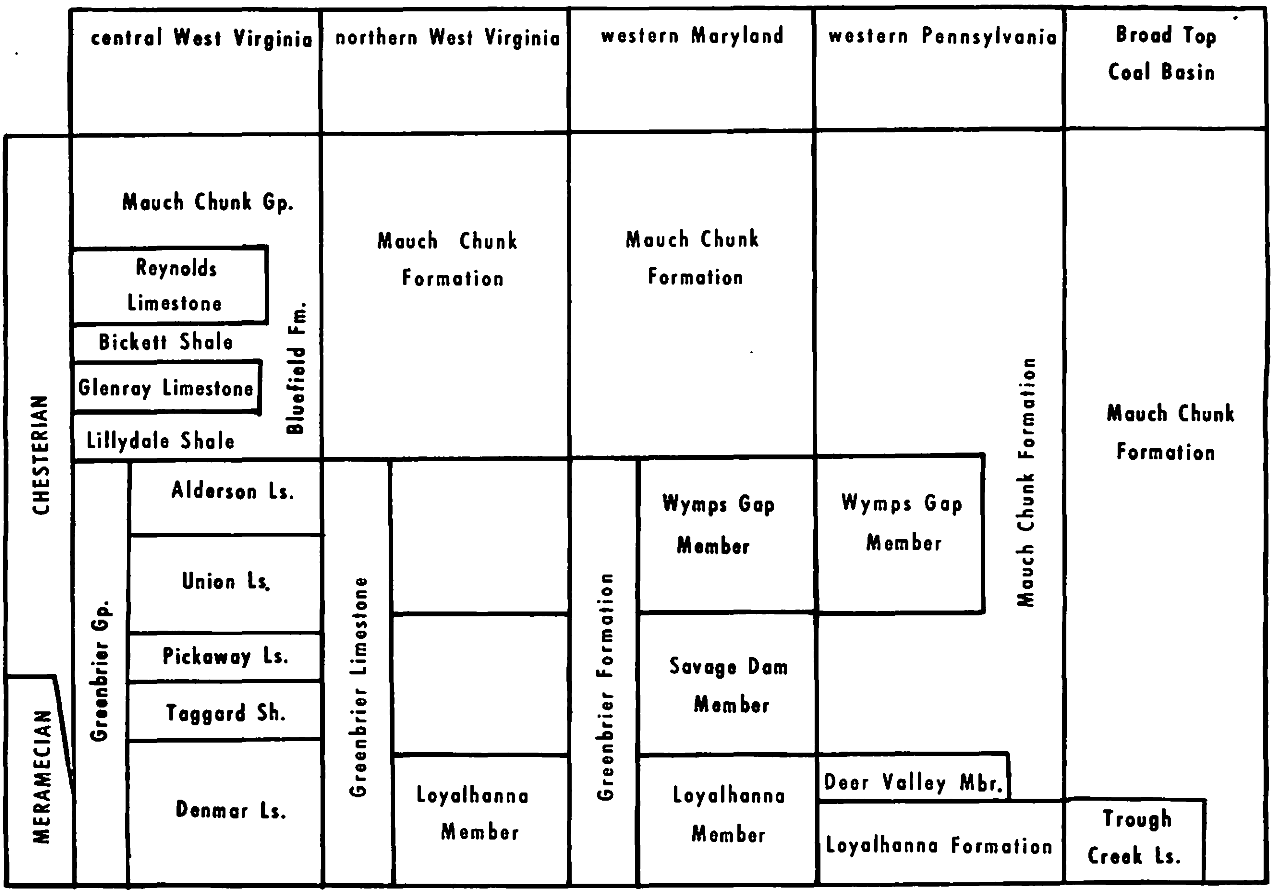

Figure 35. Correlation diagram illustrating changes in stratigraphic nomenclature of the Greenbrier and Mauch Chunk Formations between central West Virginia and central Pennsylvania.

depths and areal extent of individual marine units varied considerably. Consequently, the overall progradational Upper Mississippian package has superimposed upon it deepening and shallowing episodes of several different orders of magnitude.

CORRELATION OF GREENBRIER AND MAUCH CHUNK UNITS

The most lithologically consistent unit throughout northern West Virginia and Pennsylvania is the Loyalhanna Formation (Figure 36). Even though it is termed the Denmar Limestone in central and southern West Virginia, the lithologic character changes little from north to south. One of the more important changes is the progressive diminishing of the percentage of quartz sand and silt to the south. Additionally, the Denmar contains shaly interbeds and fossils. Owing to the continuity between the Loyalhanna and Denmar there is little question regarding their correlation. Overlying the Loyalhanna in northern West Virginia and extreme southern Fayette and Somerset Counties, Pennsylvania is a thin, but easily recognizable, marine limestone that Flint (1965) termed the Deer Valley Limestone. To the south, the Deer Valley merges into, and is indistinguishable from, the Denmar Limestone; however, to the north the Deer Valley grades into nonmarine detrital strata of the lower Mauch Chunk.

In southwestern Pennsylvania the interval between the top of the Loyalhanna Formation and the base of the Wymps Gap Limestone Member is informally termed the lower Mauch Chunk. This same interval is called the Savage Dam Tongue (Brezinski, 1989a) or Savage Dam Member in Maryland (Brezinski, 1989b). Although at Bolivar and Cramer (Stops #1 and #4) these strata are interbedded, detrital, marginal marine and nonmarine facies, farther to the south marine limestones become progressively more abundant and thicker. In central and southern West Virginia the names Taggard Shale and Pickaway Limestone are applied to this interval of interbedded marine and nonmarine strata (Arkle and others, 1979; Wray and Smosna, 1982).

The Wymps Gap Member of the Mauch Chunk is a limestone tongue extending northward into Pennsylvania from the Union and Alderson Limestones of central West Virginia. It is not possible at this time to determine which of the West Virginia formations precisely correlates with the Wymps Gap. Inasmuch as a greater water depth has been interpreted for the Alderson (Wray and Smosna, 1892; Yeilding and Dennison, 1986), it appears that maximum deepening of the Greenbrier sea occured during deposition of this formation. Consequently, the Alderson should be the most areally extensive of the Greenbrier units. Based on lateral facies relationships between the Wymps Gap Limestone and the lower Mauch Chunk, Brezinski (1984) estimated that south of Uniontown, Pennsylvania water depths within the Wymps Gap may have exceeded 130 ft (40 m). This is much greater than any depth estimates for other Loyalhanna or Mauch Chunk facies. Therefore, maximum deepening of the Greenbrier sea appears to have occurred within the Alderson Limestone of West Virginia and the Wymps Gap Limestone of Pennsylvania.

Overlying the Wymps Gap Limestone in southwestern Pennsylvania is the upper Mauch Chunk. This interval throughout most of southwestern Pennsylvania is non-marine alluvial deposits. However, in southern Fayette County two thin marine units are present. These marine limestones and shales are northern extensions of the Glenray and Reynolds Limestones of the Bluefield Formation of the Mauch Chunk Group in West Virginia. The Reynolds, in particular, is an important marker unit (Flowers, 1956) insofar as it can be traced throughout much of West Virginia and into eastern Kentucky. It is termed by drillers as the "Little Lime". Conodont biostratigraphy indicates that the Bluefield Formation is correlative to the Glen Dean Formation of the Illinois Basin (Rexroad and Clarke, 1960).

CAUSES OF THE INTERTONGUING

The intertonguing relationship between the Greenbrier of West Virginia and the Mauch Chunk of Pennsylvania appears to be largely the result of progradation of the Mauch Chunk alluvial plain and the waxing and waning of sea level. The oscillations of marine waters are interpreted to represent sea level rises and falls rather than fluctuations in subsidence. This is because the number of apparent sea level oscillations increases to the southwest, in the direction of the marine embayment. If subsidence were the main factor controlling these apparent sea level changes, one would expect the number of oscillations to increase to the east in the direction of greatest subsidence and sediment influx.

Brezinski (1989a) recognized four levels of transgressive and regressive episodes for the Greenbrier-Mauch Chunk interval of southwestern Pennsylvania

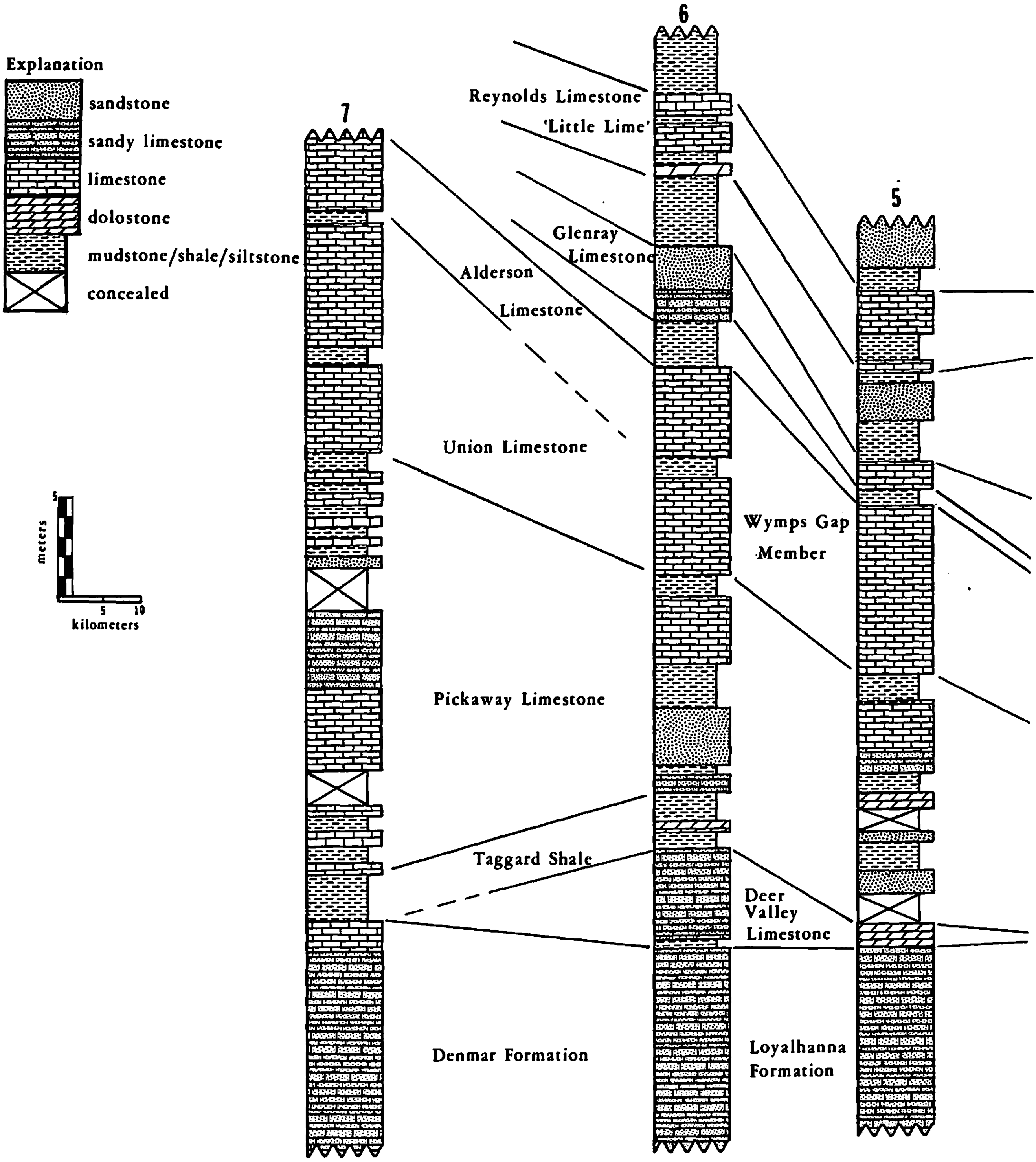

Figure 36. Interpreted correlation of individual units of the Greenbrier and Mauch Chunk between southwestern Pennsylvania and central West Virginia. Measured section locations: 1) Bolivar, Westmoreland County, Pennsylvania; 2) Loyalhanna Creek, Westmoreland County,

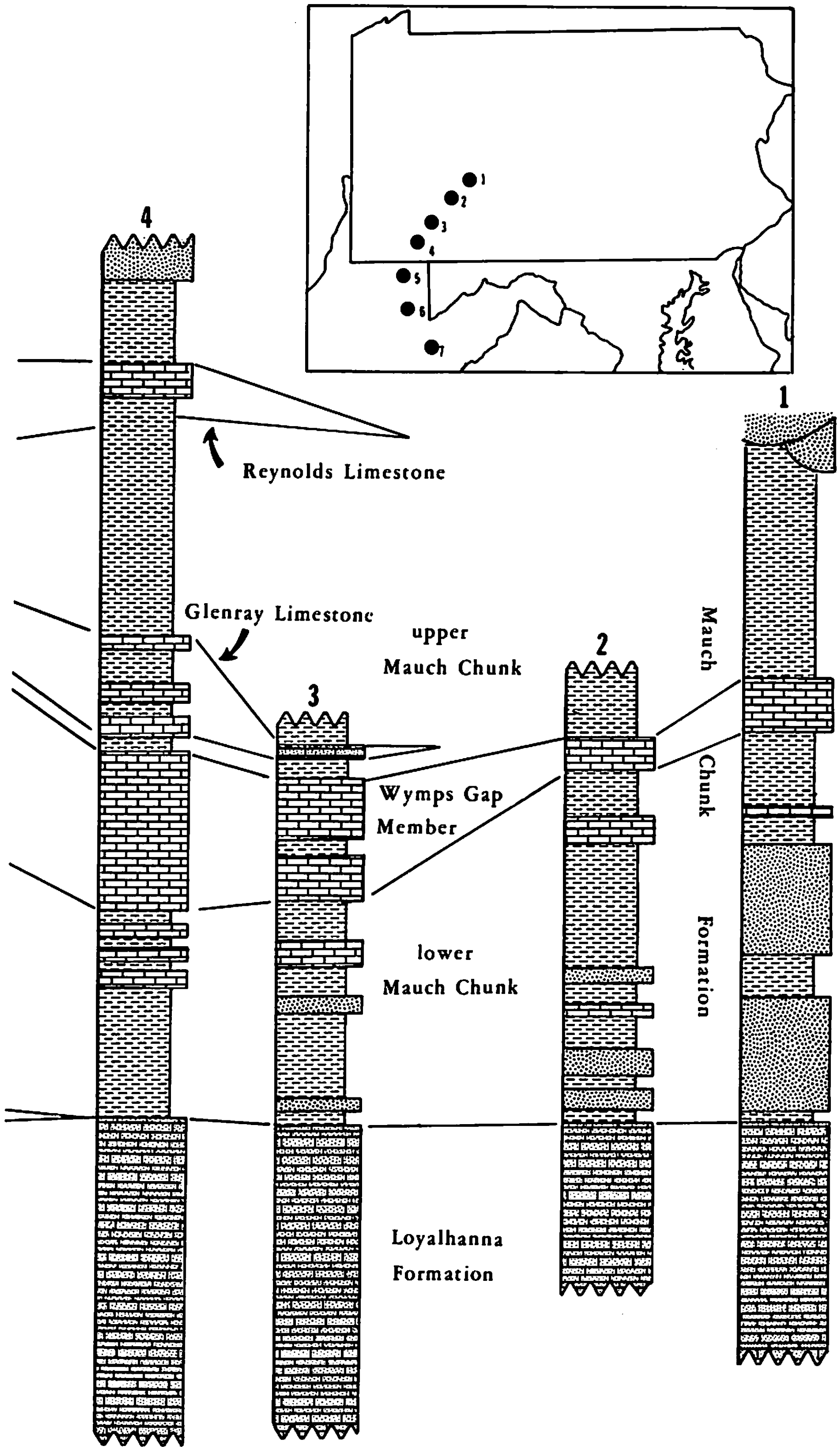

Figure 36 (cont.) Pennsylvania; 3) Connellsville, Fayette County, Pennsylvania; 4) Hopwood, Fayette County, Pennsylvania; 5) Greer, Monongalia County, West Virginia; 6) Rowlesburg, Preston County, West Virginia; 7) Buena, Tucker County, West Virginia.

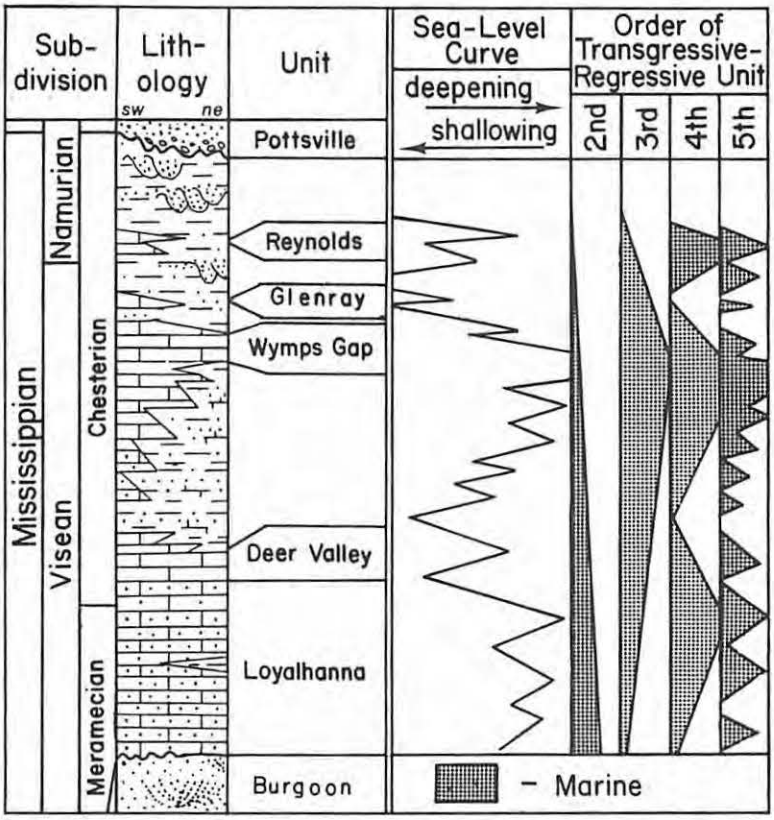

Figure 37. Interpretive orders of transgressive and regressive units within the Greenbrier-Mauch Chunk interval of northern West Virginia and southwestern Pennsylvania (from Brezinski, 1989a).

and northern West Virginia (Figure 37). As mentioned above, the entire Upper Mississippian section represents a regressional (i.e. progradational) episode. This correlates to the withdrawal of a 2nd-order sea level event according to Vail and others (1977). Superimposed on this regressional episode is a single transgressive-regressive episode of the 3rd order. This episode apparently reached its maximum depth during dpeosition of the Alderson-Wymps Gap interval. Fourth-order levels of transgression and regression are each illustrated by deposition of the Denmar-Loyalhanna, Union-Alderson-Wymps Gap, and Reynolds Limestones (Figure 37). The smallest level of transgressive-regressive unit (5th order) recognized in the Upper Mississippian is exemplified by the Deer Valley Limestone, and individual shallowing episodes in the Loyalhanna, lower Mauch Chunk, and Reynolds.

CONCLUSIONS

The intertonguing of marine and nonmarine strata of the Greenbrier and Mauch Chunk Formations is the result of sea level fluctuations superimposed upon a progradational episode. Although subsidence may have played a significant role in the local arrangement of facies patterns, regional development of marine and nonmarine facies indicates that eustatic sea level change was the major facies controller.

STRATIGRAPHY OF FLINT CLAYS OF THE ALLEGHENY AND POTTSVILLE GROUPS, WESTERN PENNSYLVANIA

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INTRODUCTION

Keller (1968, p. 113) defined flint clay as a dominantly kaolinitic underclay that breaks with a conchoidal fracture and resists slaking in water. Flint clays occur between, or are associated with, most coal horizons of the Allegheny and Pottsville Groups of western Pennsylvania. An understanding of the coal-flint clay relationship is important to the prediction of clay occurrence, and also to coal stratigraphy.

Flint clays are physically, mineralogically, and chemically intermediate between plastic clays and high alumina nodule clays. They are commonly of local extent, brecciated, multicolored, hard and contain an abundance of well-crystallized kaolinite. Considerable attention has been devoted to an understanding of the origin of flint clays and the subject has not been without controversy. Late nineteenth and early twentieth century investigators into the origin of various types of Carboniferous clays rapidly found themselves polarized over the question of a residual versus a transported origin. The evolutionary outcome of this controversy, with respect to flint clay, involves the role of differential colloidal flocculation versus the processes of in situ residual leaching. Pottsville and Allegheny flint clays exhibit evidence of both petrogenetic mechanisms.

The purpose here is to describe the physical characteristics, stratigraphic relationships and origin of flint clays in the Allegheny and Pottsville groups of western Pennsylvania. A discussion of the relationship between flint clays and other lower Pennsylvanian clay types is necessarily included.

PHYSICAL PROPERTIES

The definitive megascopic properties necessary for flint clays are conchoidal fracture and a resistance to slaking. Another common characteristic is hardness (3 to 5 on Mohs hardness scale) the degree of which is broadly attributed to the amount of kaolinitic recrystallization (Patterson and Hosterman, 1960).

Flint clays occur in a great variety of colors including medium to dark gray (rarely black), light greenish gray to olive to green, tan to dark brown to red. Individual deposits are usually varicolored, although one color often predominates. Lower Allegheny and Pottsville clays are neutral to dark gray or brownish gray whereas Upper Allegheny clays are typically, tan, olive, greenish gray and, rarely, red.

Ferm and Smith (1981) after examination of several hundred core samples, have subdivided flint clays into four categories based on physical appearance: massive, layered, brecciated and mosaic (see discussion, Figure 38). Oolitic flint clays occur in some Allegheny and Pottsville core samples. Patterson and Hosterman (1960, p. 186) note that "oolites are very abundant in some flint clay

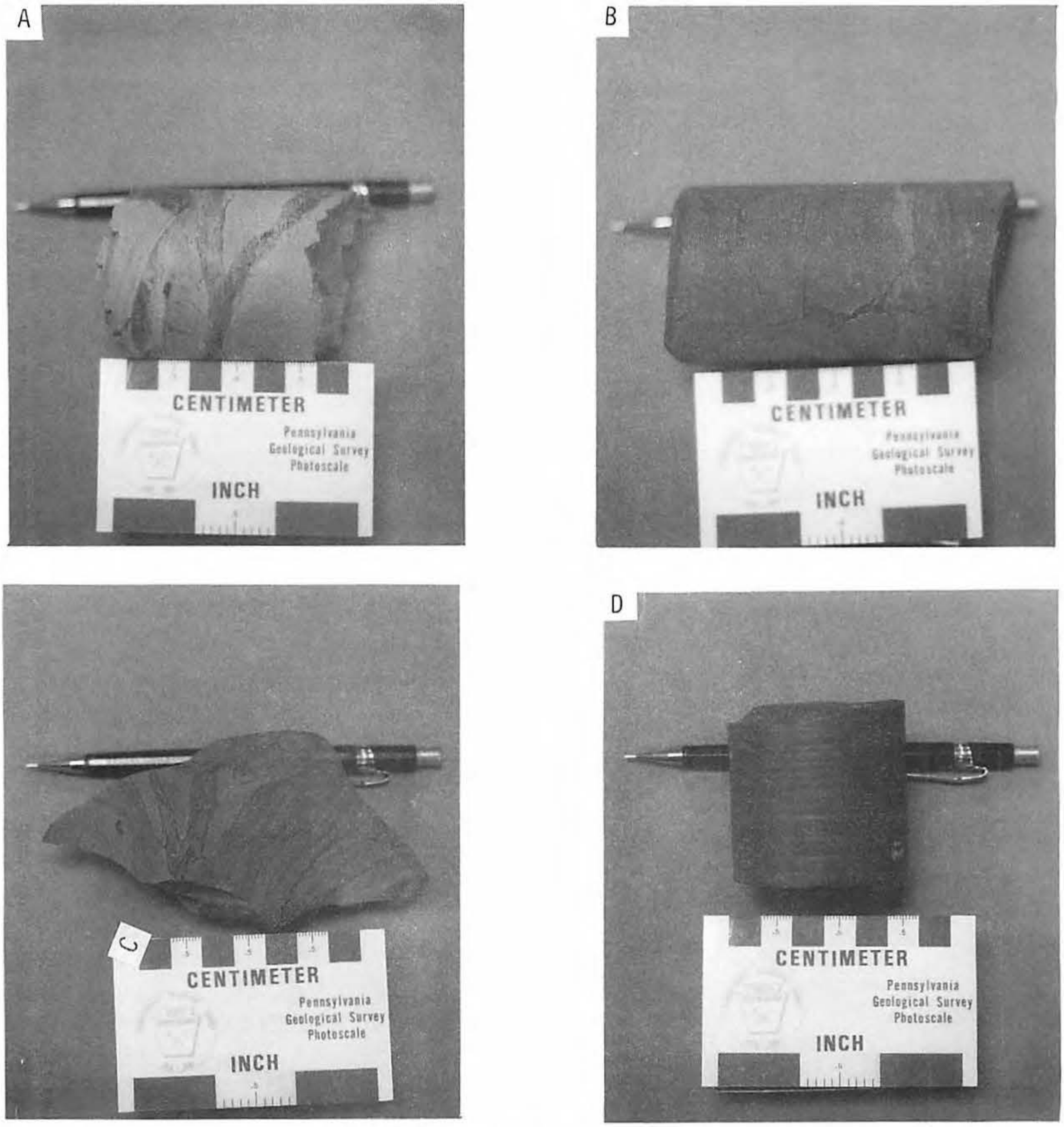


Figure 38. Photographs of various flint clays. (A) Brecciated semi-flint clay (Upper Freeport, Westmoreland Co.). Composed of angular clay fragments in a sandy or silty matrix; volumetrically, this type of clay is disproportionately abundant. (B) Mosaic flint clay (Upper Freeport, Indiana Co.). "Mosaic" refers to a type of brecciation where the individual clay fragments may be seen to fit together if the matrix were removed. (C) Layered flint clay (Lower Mercer, Centre Co.). Less common; usually occurs as color laminations in brecciated fragments. Fracture is independent of layering. (D) Massive flint clay (Lower Mercer, Clearfield Co.). Also occurs as brecciated fragments, but may be represented as continuous lengths of core.

but they are not present at all in others." Similarly, some flint clays are root penetrated and contain broken plant fragments whereas others are devoid of fossils. Slickensides are extremely rare in flint clay.

DEFINITIONS AND NOMENCLATURE

Flint clays are middle members of a physical, mineralogical, and chemical continuum ranging from illitic-rich plastic clays to aluminum-rich (boehmite, diaspore) nodule clays. Table 2 contains a summary of three generally recognized groups of clays.

Plastic clays are characterized by a soft, plastic or shaly texture, are often internally slickensided, may be silty or sandy, and break down when mixed with water. Much of the nomenclature for plastic clays has evolved through common usage. To clarify the inherent ambiguity Table 3 (definitions) is included.

Underclays and seat earths commonly coarsen and lighten in color downward in the stratigraphic section. They are typically rooted, but despite the above definitions, it is often speculative as to whether the roots were from the plants that formed the overlying coal seam or from plants that pre-dated the coal seam.

Mineralogically, illite predominates in plastic clays, but subordinate amounts of kaolinite, mixed layer clay minerals and chlorite are common. Non-clay minerals, which can be abundant, are quartz, feldspar, mica, siderite, and calcite. Chemically, SiO_2 predominates (60 to 80 percent by weight) and Al_2O_3 comprises between 10 and 20 percent by weight. Minor oxides include K_2O, MgO, Fe_2O_3, TiO_2 and CaO (Williams and others, 1968).

Semi-flint clays are a broad category of clays that contain properties intermediate between plastic and flint clays. Ideally, they are intermediate physically, mineralogically, and chemically. They are softer than flint clay (2 to 3 on Mohs hardness scale), possess a sub-conchoidal fracture, and are frequently slickensided. They may be strongly to weakly slaking or even non-slaking. The kaolinite range for semi-flint clay is between 60 and 85 percent (Smyth, 1980) with illite and mixed layer clay minerals comprising the bulk of the remainder. Chemically, semi-flint clays contain 35 to 37 percent Al_2O_3 (Weitz, 1954). SiO_2 and the minor oxides present in plastic clays constitute the complementary chemical components.

The distinction between flint clay and higher grades of semi-flint clays can be problematic. The definition of flint clay incorporates both microscopic (percent kaolinite) and megascopic (conchoidal fracture and slaking) properties. Yet many clay types will satisfy only two of the three criteria for the definition of flint clay (and the term "sub-conchoidal" is ambiguous).

Table 4 shows chemical analyses and X-ray diffraction data of clays from the Allegheny and Pottsville Groups. All of these clays possess some degree of conchoidal fracture, and some are non-slaking, yet chemically they contain less Al_2O_3 than Weitz's (1954) definition of semi-flint clay. Furthermore, Figure 39 illustrates X-ray diffraction data for four of twelve X-rayed samples of conchoidally fracturing clay from the Allegheny and Pottsville Groups. Note that the quartz (siderite in IND-D-3055) peaks are commonly more significant than the

Table 2. Properties of the Flint Clay Facies (from Smyth, 1980). Data compiled from Patterson and Hosterman (1960, p. F52-F58), Keller (1968, p. 113-115), Keller (1976, p. 262), Keller (1978a, p. 15, 19), Keller (1978b, p. 239, 241), and Keller (1982, p. 150-151).

CHARACTERISTICS	CLAY TYPE		
	FLINT	SEMI-FLINT	PLASTIC
FRACTURE	Conchoidal.	Rough, irregular, approaching conchoidal.	Rough, irregular.
HARDNESS	3.	2-3.	Softer than semi-flint.
GENERAL CLAY MINERALOGY	85% kaolinite 15% illite + mixed-layer clays.	60-85% kaolinite.	60% kaolinite 40% illite + mixed-layer clays.
NATURAL PLASTICITY	Almost no plasticity unless very finely ground with water.	Little plasticity unless finely ground with water.	Considerable plasticity when wet.
SLAKING CHARACTERISTICS	Resistant to slaking.	Intermediate between flint and plastic clays.	Breaks down rapidly into small particles in water.
SLICKENSIDES	Very few.	Abundant. Diversely oriented.	Abundant. Becoming sealed upon weathering and clay becomes homogeneous in appearance.
S.E.M. CHARACTERISTICS	Kaolinite plates or flakes can be seen to be well-developed, interlocking, intergrown, dense and randomly oriented.	Shows some swirl pattern composed of overlapping curved kaolinite flakes. Flakes are less curved than in plastic clays.	Shows platy, anhedral, bent, and twisted flakes with a swirl pattern.

Table 3. Definitions of plastic and related clay types.

CLAY TYPE	DEFINITION
Underclay	A layer of fine grained detrital material, usually clay, lying immediately beneath a coal bed or forming the floor of a coal seam. It represents the old soil in which the plants (from which the coal was formed) were rooted and it commonly contains fossils of roots (esp. of the genus Stigmaria) (AGI Glossary, p. 676).
Seat Rock or Seat Earth	A British term for a bed of rock underlying a coal seam representing an old soil that supported the vegetation from which the coal was formed (AGI Glossary, p. 564).
Fireclay	1) A siliceous clay rich in hydrous aluminum silicates capable of withstanding high temperatures without deforming (either disintegrating or becoming soft and pasty), and useful to the manufacture of refractory ceramic products (such as crucibles or fire-brick for lining furnaces). It is deficient in iron, calcium and alkalies, and approaches kaolin in composition, the better grades containing at least 35% alumina when fired (AGI Glossary, p. 230). 2) A clay that resists fusion or heat deformation below the arbitrarily defined pyrometric cone equivalent* 28 - customarily written PCE 28 (about 1615° C under specified conditions of heating). (Keller, 1975, p. 65-66). 3) A term formerly, but inaccurately, used for underclay. Although many fireclays commonly occur as underclays, not all fireclays carry a roof of coal and not all underclays are refractory (AGI Glossary, p. 230).
Ganister	In England, a highly siliceous seat earth (AGI Glossary, p. 252).
Tonstein	Originally meant an argillaceous rock, but has come to imply a number of additional characteristics including: association with coal seams, homogeneous mineral composition, usually kaolinite-rich, relatively thin (usually 2-3 inches), laterally persistent, and often considered a stratigraphic marker bed for correlation purposes (Moore, 1968, p. 108-109). Tonsteins are often of volcanic origin.

*Pyrometric cone equivalent is a measure of the firing or melting temperature of the clay.

Table 4. Chemical analyses and x-ray diffraction results of flint and semi-flint clay samples from the Allegheny and Pottsville Groups of western Pennsylvania.

	CHEMICAL ANALYSES				X-RAY DIFFRACTION RESULTS		
SAMPLE	SiO_2	Al_2O_3	FeO_2	PCE*	MAJOR MINERALS	CHARACTERISTIC PEAK	PEAK HEIGHT
Upper Freeport Westmoreland County	63.82	17.33	5.52	15-16			
Upper Freeport Westmoreland County	42.66	24.78	11.62	5			
Upper Freeport Westmoreland County	59.74	15.80	9.85	15			
Lower Freeport Westmoreland County	56.36	23.20	6.10	19	Quartz Kaolinite	4.26 A 7.17 A	65 24
Lower Freeport Westmoreland County	64.82	23.87	1.53	30			
Brookville Jefferson County	60.70	24.60	5.30	20-23			
Brookville Jefferson County	67.67	22.82	2.17	31½-32	Quartz Kaolinite	4.26 A 7.17 A	45 50
Brookville Jefferson County	62.73	27.81	1.78	30-31			
Mercer Clearfield County	42.90	40.45	1.45	33			

*Pyrometric cone equivalent - a measure of the firing or melting temperature of the clay.

kaolinite peaks. Although these data are not directly quantitative, the implication is that there is a substantial quantity of quartz in rocks that are megascopically termed flint clays. Stricter definitions and/or nomenclatural expansion of the plastic/semi-flint/flint clay continuum appear to be warranted.

Hard clays are broadly subdivided into two categories; flint clays and nodule clays. Flint clays contain greater than 85 percent kaolinite and less than 15 percent illite and mixed layer clays (Smyth, 1980). Halloysite and chlorite may exist in minor amounts. Quartz, siderite, and feldspar are the most common nonclay minerals, although heavy minerals (tourmaline, rutile, and zircon) may occur in the form of sand size grains (Bragonier, 1970). Al_2O_3 should be in the 38 to 40 percent-by-weight range (Weitz, 1954). The minor oxides occurring in plastic and semi-flint clays are also present in flint clay. Commercial quality flint clay must have a pyrometric cone equivalent (PCE) (see Table 3) of 32 (1700 ^{o}C in standard heating environment) or higher and a bulk density above 2, preferably 2.2 (Baumann and Keller, 1975).

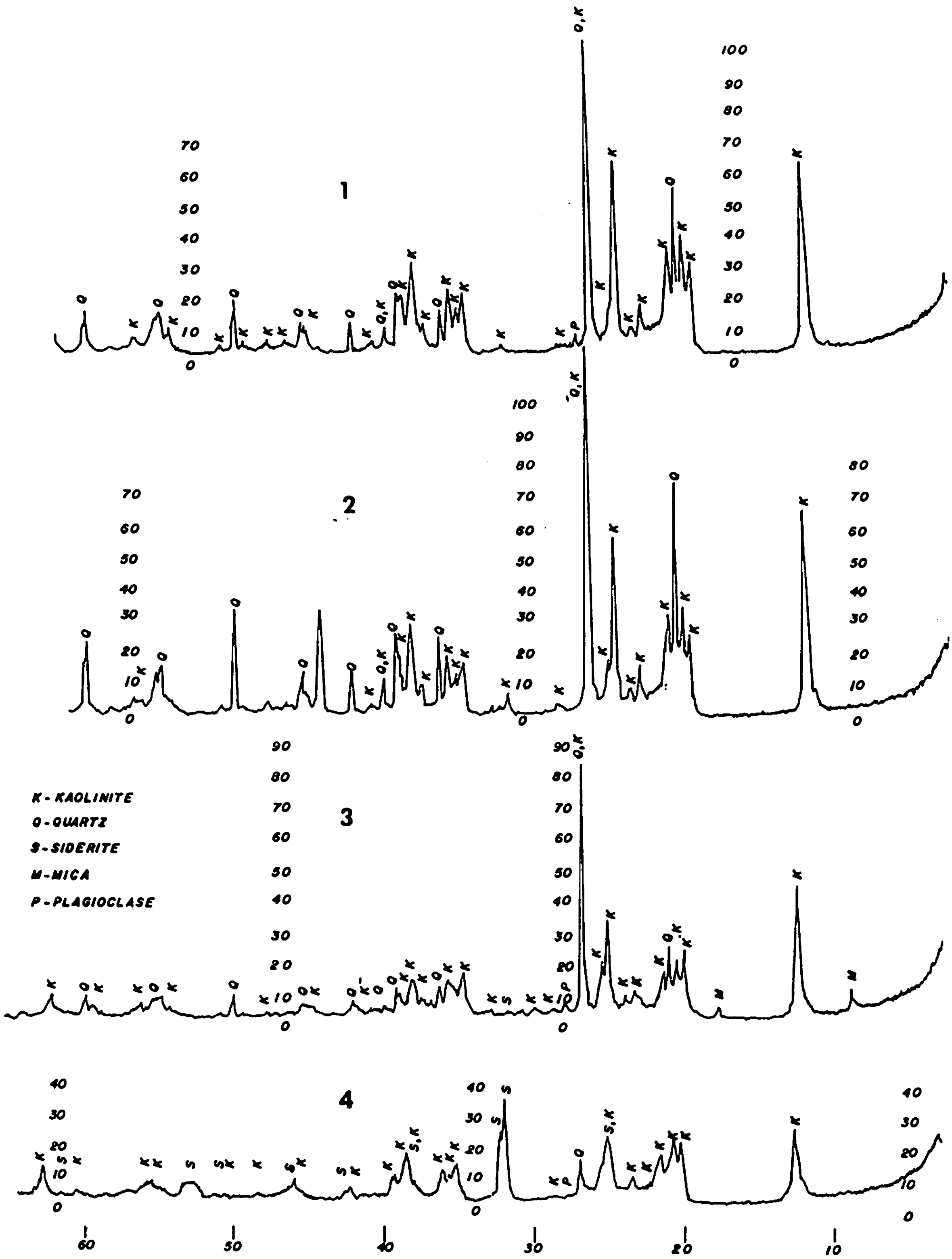
Nodule clays are hard clays that contain rounded nodules of the aluminum hydroxide minerals boehmite ($HAlO_2$) and diaspore (AlO OH). Nodule clays may contain only a few nodules in a kaolinite groundmass or be comprised almost entirely of aluminum hydroxide nodules. Gibbsite may be present in minor amounts. Nodule clays may be quite hard (greater than 5 on Mohs hardness scale) and contain up to 75 percent AL_2O_3 by weight. In western Pennsylvania nodule clays are stratigraphically restricted to the Mercer horizon and geographically restricted to Clearfield, Centre, and Clinton Counties.

Lithologic names and descriptions used in the mining industry (Table 5) have been summarized by Foose (1944) and modified slightly by Weitz (1954). The descriptive terminology in Foose's classification is advantageous, but it is based on physical properties and has no petrographic significance. Weitz and Bolger (1951) advanced an alternative classification of fireclay types (Table 6). They used Foose's descriptions as their framework, but subdivided the high-alumina clay types on the basis of mineralogical composition. Erickson (1963) combined apects of both previous classifications to produce a more systematic and moderately descriptive arrangement of fireclay types (Table 6).

The above classifications serve as workable instruments for the hard clay industry but all emphasize the more exotic but less common, nodule clay types. Furthermore, Weitz and Bolger (1951) and Erickson (1963) incorporate the problem of creating a field classification which is ultimately based on microscopic properties.

STRATIGRAPHIC RELATIONSHIPS

Flint clays occur at nearly all stratigraphic horizons in the (post-Connoquenessing) Pottsville and Allegheny Groups of western Pennsylvania. Smith and O'Brien (1965) have also reported flint clays as young as late Pennsylvanian, indicating that they formed throughout much of the Pennsylvanian. Nevertheless, they are much less common above the lowermost Conemaugh. Williams and others (1968) have demonstrated that there is an overall up-section increase in the illite:kaolinite ratios of underclays from the Mercer to Upper Freeport (consistent with data presented in Table 3. Keller (1975) also confirms that higher quality refractory clay are stratigraphically confined to the lower part of the Pennsylvanian system in the eastern United States. The Mt. Savage clay


1
2
3
4
K - KAOLINITE
Q - QUARTZ
S - SIDERITE
M - MICA
P - PLAGIOCLASE
60
50
40
30
20
10

of western Maryland, the Olive Hill clay of Kentucky, the Cheltenham clay of Missouri and the Mercer of central Pennsylvania are examples of high quality refractory clays that temporally represent the Lower and Middle Pennsylvanian. Keller suggests that they characterized "a particular geologic environment that was widely prevalent in the eastern United States during early Pennsylvanian time" (Keller, 1975, p. 65). The Cheltenham and Mercer are the only clay deposits in the United States that contain the high alumina Diaspore/Boehmite facies and both are believed to rest unconformably on Mississippian sediments (Keller, 1975).

Non-plastic clays of the middle and upper Allegheny range from semi-flint to flint clay. Although many possess characteristic conchoidal fracture and brecciation, they are slightly to strongly slaking and marginally kaolinitic. Nevertheless, some Upper Allegheny flint clays are of refractory quality (e.g., the Bolivar flint clay of southwestern Indiana County).

Flint clays in the Allegheny Group usually occur in association with other "chemical" rocks, specifically limestone and coal. Thin layers of flint clay have been found interbedded with the freshwater limestones beneath the Upper and Lower Freeport and Upper Kittanning coals, but are more characteristically found immediately beneath these limestones (Buswell, 1980). Williams and others (1968) demonstrated that flint clays are laterally equivalent to the Vanport Limestone in portions of Clarion County, Pennsylvania.

Figures 40A and 40B illustrate that flint clay is commonly the lateral equivalent of both coal and limestone. Coal equivalence with flint clay has been documented by Sturgeon (1958) for the Pittsburgh seam, by T. Miller (personal communication) for the Mahoning seam, by Smith and O'Brien (1965), Pedlow (1977), Clark (1979), and Hohos (1979) for the Upper Freeport, by Buswell (1980) for the Upper Kittanning, by Merrill (1952) for the Middle Kittanning and by Williams and others (1968) for the Scrubgrass (Clarion No. 3).

GENESIS

Introduction

Despite numerous geochemical and petrologic investigations of flint clays, controversy still exists concerning their origin. Smyth (1980) has summarized the existing published theories of the origin of flint clays and related clay

Figure 39. X-ray diffraction patterns of flint and semi-flint clays from the Allegheny and Pottsville groups of western Pennsylvania. (1) Lower Mercer, Centre Co. Hard, higher grade flint clay. Note sharp, symmetrical and well resolved nature of reflections. (2) Flint clay from Widman St. Exit, Johnstown, below Upper Kittanning coal. Well resolved peaks indicate fairly high grade flint clay, but quartz peaks more distinct than in (1). (3) Semi-flint clay from Lower Freeport horizon, drill hole in Conemaugh Twp., Indiana Co. Lower amounts of both kaolinite and quartz are present; peak heights and resolution not as well defined as in (2). Also note existence of mica, siderite, and plagioclase. (4) Siderite-rich semi-flint clay from above Upper Freeport coal, West Wheatfield Twp., Indiana Co. Note poor resolution.

Table 5. Nomenclature of fireclays as used in the mining industry (from Weitz, 1954, modified from Foose, 1944).

CLAY TYPE AND DESCRIPTION	APPROXIMATE % of Al_2O_3
"Burnt" nodule clay Gray to brown, porous, cindery appearance; usually nearly all diaspore; very rough fracture.	65-75
Fine-grained (or blue) nodule clay Homogeneous appearance; all small nodules; smaller nodules and harder than green nodule clay.	60-65
Green nodule clay Coarsely nodular; rough fracture; usually greenish cast.	50-60
Nodule block clay Gradational between green nodule and block clay; scattered nodules comprise less than half of the mass; rough, blocky fracture.	40-50
Nodule flint clay Gradational between green nodule and flint clay; scattered nodules comprise less than half of the mass; rough, conchoidal fracture.	40-50
Flint clay Very hard; smooth, conchoidal fracture with sharp edges and points; weathers into smaller jagged fragments; usually clear light or dark gray, but may contain dark spots or widely scattered nodules.	38-40
Block clay Hard; blocky fracture; weathers to rounder granules than flint clay; usually clear, light or dark gray, but may contain dark spots and widely scattered nodules.	38-40
Semi-flint clay Gradational from flint clay to soft plastic clay; rough, irregular fracture, approaching conchoidal.	35-37
Associated nonrefractory clays include: Slabby soft clay Fracture slabby and irregular; slickensides common. Soft (plastic) clay Soft; irregular fractures; plastic when wet. Shaly clay Bedding evident; shaly fracture.	

Table 6. Classification of high-alumina rock types (from Erickson, 1963).

Weitz and Bolger's Classification	Composition	Equivalent Miners' Term	Erickson's Classification
Diasporite	Over 90% aluminum hydroxides	"Burnt" Nodule	Diasporite
Argillaceous Diasporite	Over 50% aluminum hydroxides	Fine-grained Nodule Green Nodule	Argillaceous (over 50% nodules) Diasporite
Diaspore Claystone	Over 50% kaolinite	Nodule Flint Clay Nodule Block Clay	Nodule Claystone (25-50% nodules) Nodule Block Claystone
			Flinty Nodule Claystone (5-25% nodules)
			Nodular Flinty Claystone (5% Nodules)
Flinty Claystone Blocky Claystone	Apparently all kaolinite	Flint Clay Block Clay	Flinty Claystone Blocky Claystone
Shaly Claystone		Shaly Clay	Shaly Claystone
Soft (plastic) Clay		Soft (plastic) Clay	Soft (plastic) Clay

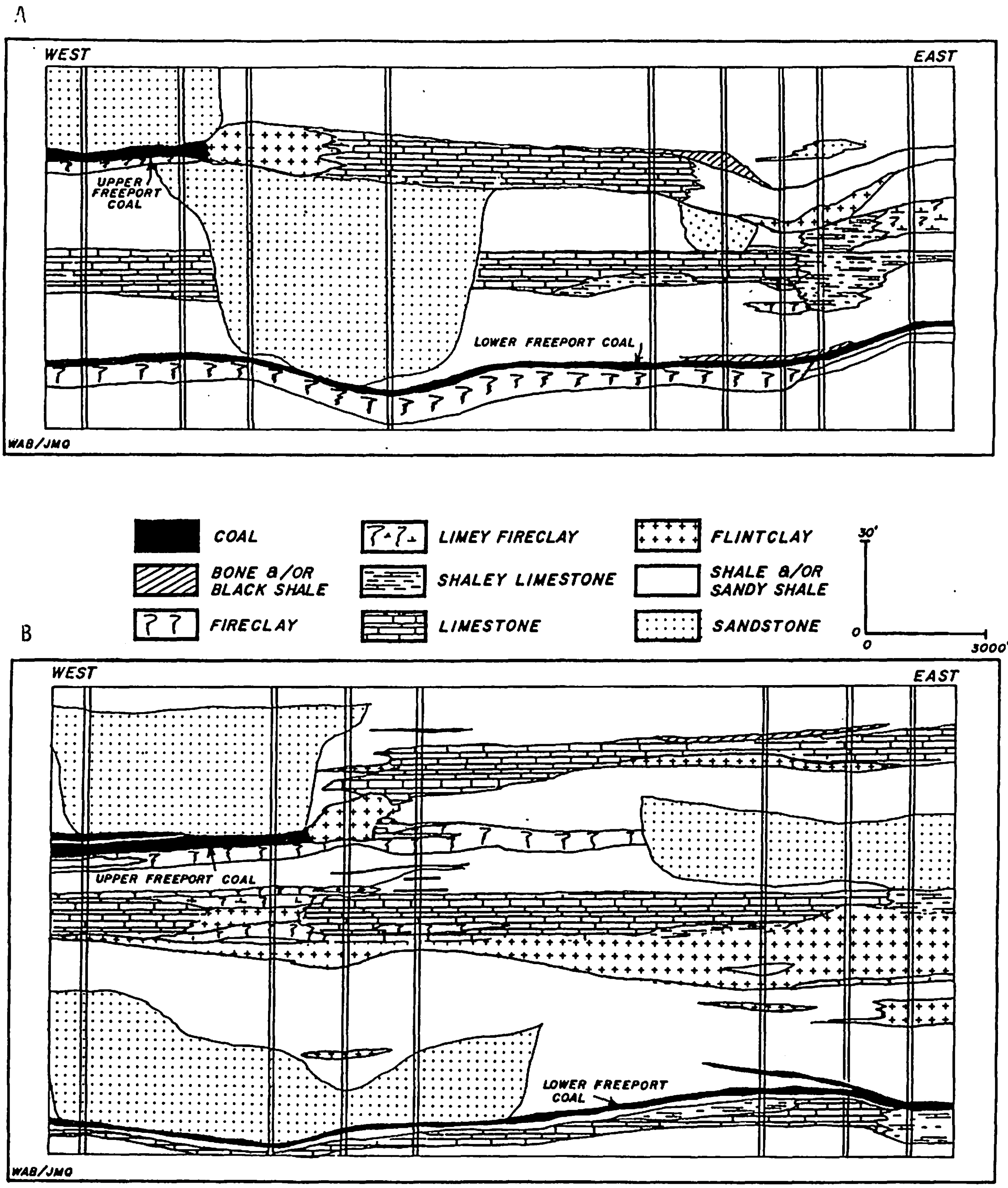


Figure 40. Cross-sections showing lateral facies changes from coal to flint clay to fresh water limestone in the Upper Freeport horizon near Brush Valley, Indiana County. The datum is the top of the Upper Freeport limestone.

types. Her overall subdivision of theories into allogenic, authigenic, and combined recognizes a fundamental problem of flint clay origin - were they formed in situ or transported?

Williams and others (1968) have demonstrated that although the illite/kaolinite ratios of underclays within the Pottsville and Allegheny Groups increase stratigraphically upward, the same is not true for shales immediately overlying the respective coal seams. Their conclusion is that "the composition of the sediments received from unknown source areas did not change in the stratigraphic interval examined" (Williams and others, 1968, p. 75). Their conclusion necessarily implies clay mineral alteration within the environment of deposition. This evidence stands in opposition to the theories proposed by Lovejoy (1925) Grim and Allen (1938) Greaves-Walker (1939), Schultz (1958) and Wilson (1965), all of whom invoke an external source area.

Formation of flint clays within the environment of deposition may be accomplished either by differential colloidal flocculation controlled by the chemistry of the depositional environment (Bolger and Weitz, 1952; Falla, 1967; and Williams and others, 1968) or by in situ leaching (Halm, 1952; Keller, 1952; Slatkine and Heller, 1960; Patterson and Hosterman, 1960; Smith and O'Brien, 1965; Goldberry, 1979; and Keller, 1981).

In-Situ Leaching

Keller (1981) provides one of the most complete accounts of in situ flint clay genesis. He interprets flint clay as a product of very early diagenetic alteration of a parent alumina-silicate material. During a period of crustal stability in non-marine paludal/fluviatile environments, colloidal to fine grained sediments accumulated in quieter, commonly plant-fringed, swamps. Removal of silica, iron, and alkaline and alkali earths presumably were the result of dialysis, hydrolysis, and the action of organic complexing compounds, organic acids, and silica accumulating plants. Keller (1968) suggests that acid swamp waters are the source of H^+ ions which replace K^+ ions in illite, producing H-rich illite and kaolinite by structural rearrangement of the remaining silica and alumina. These processes could have been initiated in the fringing soil to produce colloidal kaolin. This, in turn, led to the formation of "a colloidal-chemical phase, possibly gel-like, having a composition essentially that of kaolin, from which the mineral kaolinite crystallized or crystallized into packets of intergrown kaolinite crystals..." (Keller, 1981, p. 239). Other theories of in situ flint clay origin commonly incorporated the processes which Keller details, emphasizing various aspects for specific clay deposits.

Evidence which suggests in situ leaching is an important mechanism in flint clay genesis include the following:

Mineralogical

Vertical kaolinite enrichment within individual clay beds (both upward and downward kaolinite enrichment has been reported respectively by Smyth, 1980 and Keller, 1981).

Etching and complete dissolution of quartz grains (Patterson and Hosterman, 1960; Bragonier, 1970; Smyth, 1980).

Lack of feldspar (Patterson and Hosterman, 1960).

A change in kaolinite mineralogy from the outside of clay breccia fragments, where poorly crystalline kaolinite occurs in the cores of the breccia fragments surrounded by a well-crystallized kaolinite rim (Smith and O'Brien, 1965).

Kaolinite enrichment on paleotopographic highs (Holbrook and Williams, 1973).

Geochemical

Vertical alumina enrichment (Smyth, 1980; Keller, 1981).

Enrichment in titanium dioxide (Jaron, 1967; Williams and others, 1968).

Lack of Fe_2O_3 in the upper portions of some clays (Williams and others, 1968).

Iron and calcium concentrated in concretions or cracks in the lower portions of clays (Huddle and Patterson, 1961).

Upward loss of K_2O (Holbrook and Williams, 1973).

General

Soil-like features in some clay deposits including cutans, clay-filled pores, ooliths, aggregates, spherulitic siderite, and mottled zones, roots, and soil profiles (Smyth, 1980).

The Effects Of Organics

Keller's (1981) mention of organic complexing compounds, organic acids and silica-accumulating plants is important. Keller (1968, p. 122) notes:

> "The vegetation contributed to flint clay formation in several ways. Mechanically, it may have served as a filter that lined marshes and held out coarser clastics but allowed colloidal clay suspensions to pass. Plants growing in the clay extracted alkali and alkaline earth metals from the clay for growth and metabolism. These metal ions are easily leached out of leaves and stems after they fall from plants, thus mobilizing the flux ions for removal by solution. Silica likewise will be mobilized, thereby enriching the clay residue in alumina. Silica accumulating plants, such as reeds and bullrushes, live in this type of environment. If *Equisetum* was present, the aqueous solubility of silica could have been more than doubled relative to its value in freshwater as observed by Lovering (1959). Chelation by organic compounds and complexing by CO_2 from decaying organic matter could enhance the removal of fluxes and silica from the clay colloids and mud in the swamps. H^+ ions from organic acids would react with the silicates present to accelerate kaolinization."

The chemical effect of plants on the genesis of flint clays has been discussed by numerous authors including Hopkins (1898), Stout and others (1923), Hodson (1927), Chukhrov (1970), and Staub and Cohen (1978).

Furthermore, some tonsteins (see Table 3) associated with coal seams are believed to be volcanic ash deposits that owe their alteration to kaolinite almost entirely from the interaction with organic compounds and acids (Stach, 1950; Chalard, 1951; Bouroz and others, 1958; Bohor and Triplehorn, 1981). The influence of organic compounds on the recrystallization of kaolinite and the formation of diaspore and boehmite is also believed to be substantial (Bragonier, 1970; Keller, 1975).

Differential Colloidal Flocculation

Williams and others (1968) provide the most comprehensive argument for flint clay genesis via differential colloidal flocculation. They note that the Lower Kittanning flint clay in Clarion County is confined to an area laterally equivalent to the Vanport Limestone and an unnamed coal they also interpret as a lateral equivalent. They note that the distribution of illite/kaolinite ratios in the insoluble residue of the Vanport Limestone roughly correspond to the thickness distribution of the Vanport. They interpret this to suggest that the clay ratios parallel the Vanport shoreline. This reasoning is further supported by an overall agreement between the distribution of the illite/kaolinite ratios and the SiO_2:clay ratios and Fe_2O_3 distribution within the Vanport insoluble residue.

Noting that Millot (1942) has shown colloidal flocculation is strongly affected by pH and electrolyte concentration, Williams and others conclude that flint clays are most likely to occur in areas where pH changes range from acid to basic, such as paludal-lacustrine environments that fringe a shallow sea. In such environments, if cation concentrations are low, colloidal alumina would be more readily flocculated while silica would remain in solution to be flocculated in near-shore marine areas.

Williams and others (1968) propose a four-phase paragenesis for the flint clay as follows:

1) Flocculation of a colloidal gel in electrolytic solution forming interlocking kaolinite grains.

2) Recrystallization and shrinkage with water loss producing a brecciated appearance.

3) Resuspension of clay and quartz under more acid, swamp water conditions resulting in reprecipitation of the fine-grained groundmass, kaolinite books and quartz crystals.

4) Compaction and lithification.

Flint and semi-flint clays of the Allegheny Group illustrated in Figures 39 to 42 are believed to have originated from differential colloidal flocculation. Several stratigraphic relationships suggest this. Flint clay is commonly most abundant immediately adjacent to a coal seam, and appears to fringe the coal swamp. In the non-coal (basinward) direction flint clay is often laterally equivalent to freshwater limestone (a similar relationship observed by Williams and others, 1968 between the Vanport limestone and Kittanning flint clay).

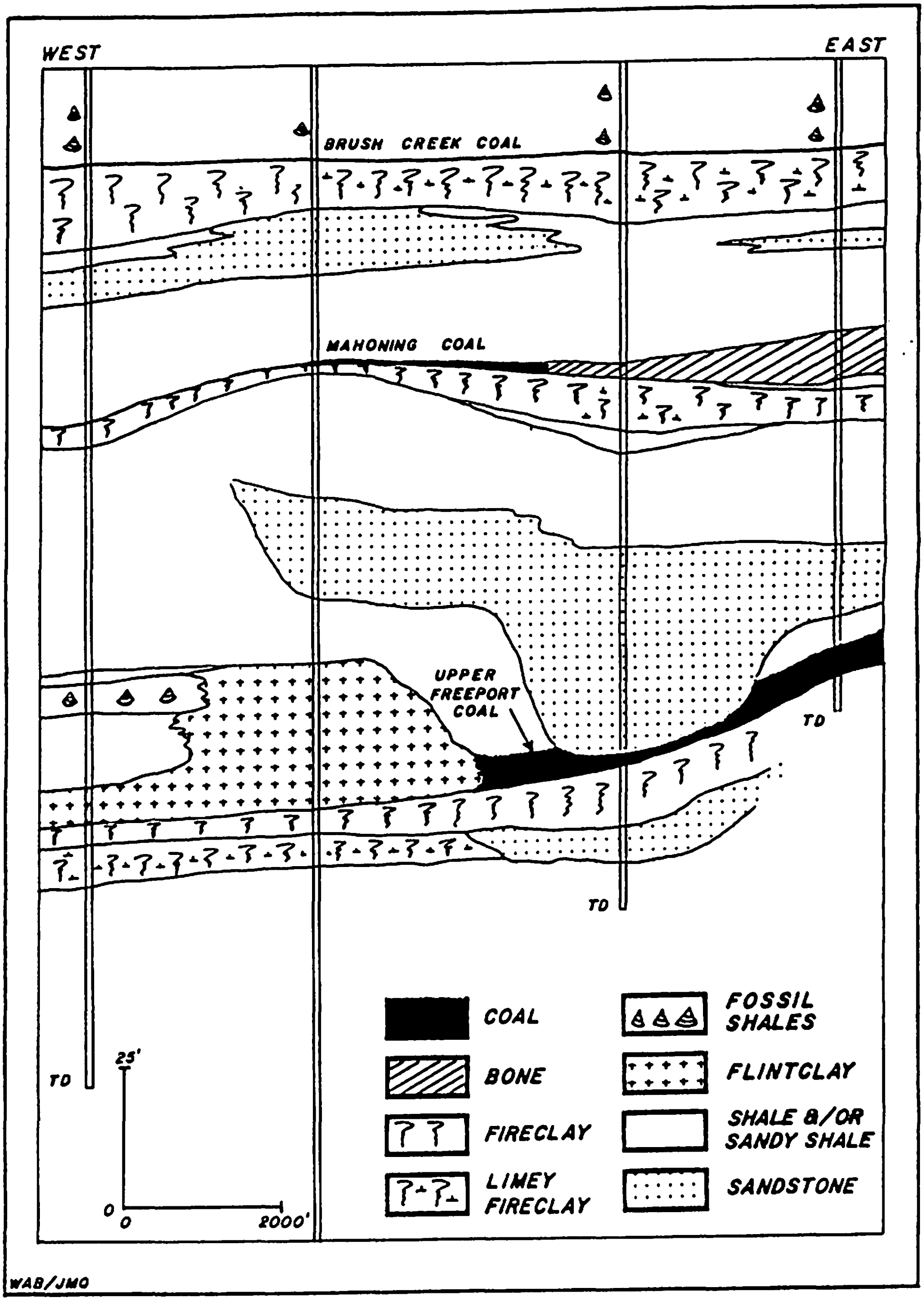


Figure 41. Cross-section showing lateral facies changes from coal to flint clay to black shale with freshwater fossils in the Upper Freeport horizon near Trees Mills, Westmoreland County. The datum is the overlying Brush Creek coal. Note position of coal relative to base of flint clay.

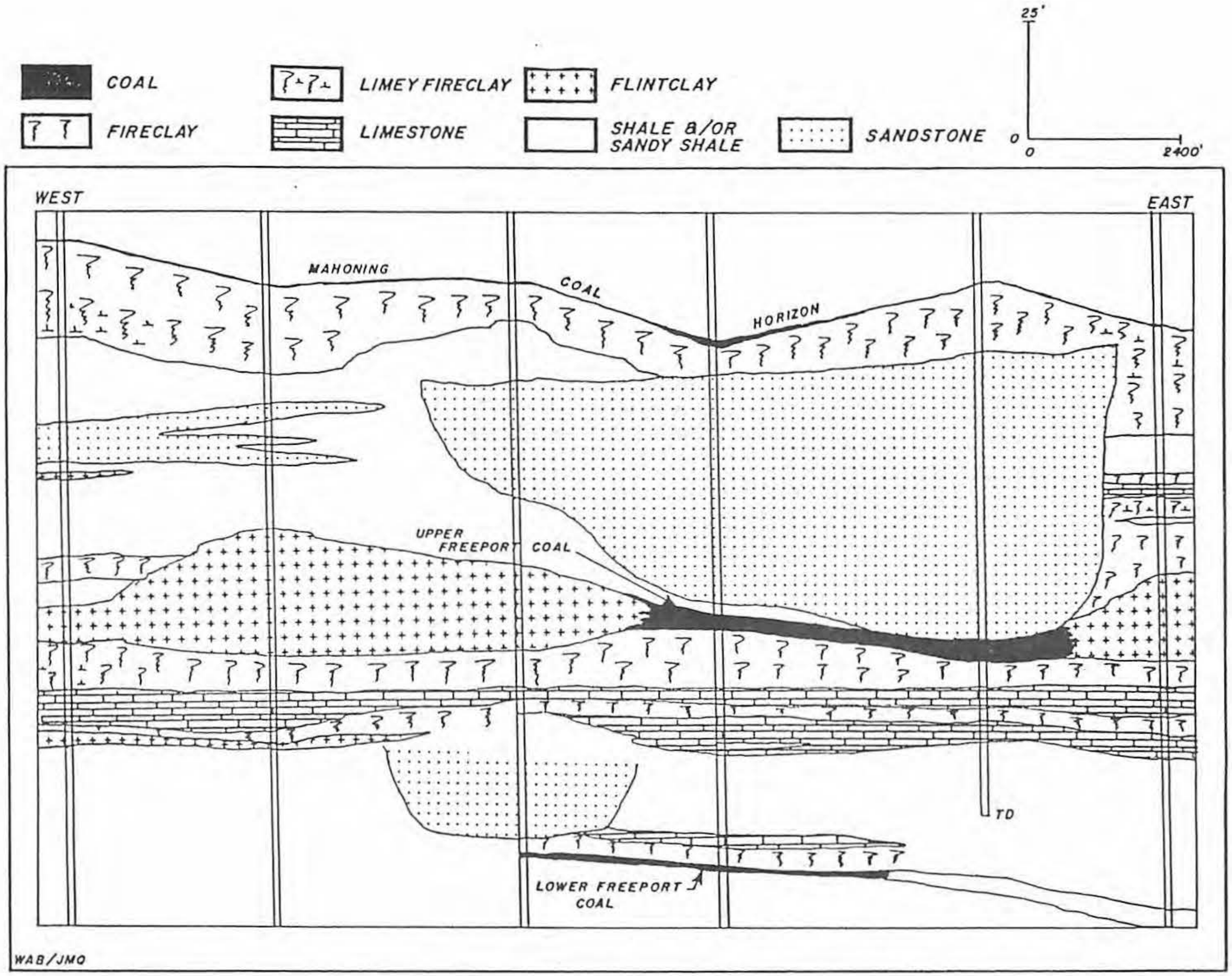


Figure 48. Cross-section of Upper Freeport coal and associated flint clay near Five Points, Westmoreland County. The datum is the top of the Upper Freeport limestone. Note vertical position of coal relative to the base of the flint clay.

Near Trees Mills, in northern Westmoreland County, a black shale containing freshwater fossils (conchostracans and ostracods) appears to be the lateral equivalent of the Upper Freeport flint clay (Figure 41).

The genetic implication is that Upper Allegheny coal swamps were commonly adjacent to freshwater lakes. As peat accumulated, colloidal clays coming into contact with the acid swamp waters were flocculated. Staub and Cohen (1979) have documented the rapid flocculation of clay particles entering an acid environment in the modern Snuggedy Swamp of South Carolina. Schofield and Sampson (1954) note that acidity and a low cation concentration will cause edge-to-face (non-layered) flocculation of clay particles. The overall acidity of the lake would determine whether clay flocculation would be continuous across the lake or confined to the more acidic near-shore environments. Acidity, in turn, is strongly influenced by the size and shape of the lake, which controls internal circulation.

A further argument for a lacustrine flint clay origin-deposition in a paleotopographic low may be directly observed in the roadcut at the Widman Street exit (see description of Stop #11). Figure 42 illustrates a similar circumstance with a thicker coal and flint clay sequence (Upper Freeport). When the underlying Upper Freeport limestone is used as a datum, the Upper Freeport coal corresponds to a position near, but not at, the base of the adjacent flint clay. If the peat and clay accumulated at roughly the same rate, but the peat compacted four to five times more than the clay, this is the relationship to be expected.

The very fine laminae observed in many flint clays (Figure 38C) is also suggestive of sedimentation in a low energy environment. Such laminae have been observed in flint clay deposits believed to be of authigenic origin and may represent sedimentation of previously formed clay particles in localized depressions. Nevertheless, the presence of delicate, thin laminae, indicative of quiet water sedimentation, certainly does not preclude a lacustrine origin, especially for semi-flint clays.

Brecciation

The brecciation associated with many flint clays (Figure 38A) may, in fact, be related more to loading rather than shrinkage and drying as suggested by Williams and others (1968). The matrix for many of the brecciated flint and semi-flint clays is commonly not clay, but much coarser grained sand- and silt-sized material, often similar to the immediately overlying lithology. At Cambridge, Ohio, a roadcut exposes a brecciated semi-flint clay that is laterally equivalent to the Upper Freeport coal. Here, the material between the brecciated clay fragments is the same composition, color, and texture as the overlying lithology. Several large scale slump blocks are also present, indicating that when the clay was loaded, it was structurally incompetent. The overlying material appears to have been oozed and slumped into the flint clay causing it to acquire a brecciated, fragmental appearance. The brecciation, of course, may be aided by the release of entrapped water. These conclusions are supported by evidence for early diagenetic slumping of flint clay at the Widman Street exit of Route 56 at Johnstown (see description of Stop #11). Figure 43 illustrate the hypothetical genetic model for deposition of the Upper Freeport flint clay and laterally equivalent facies prior to (43A) and after (43B) sediment loading.

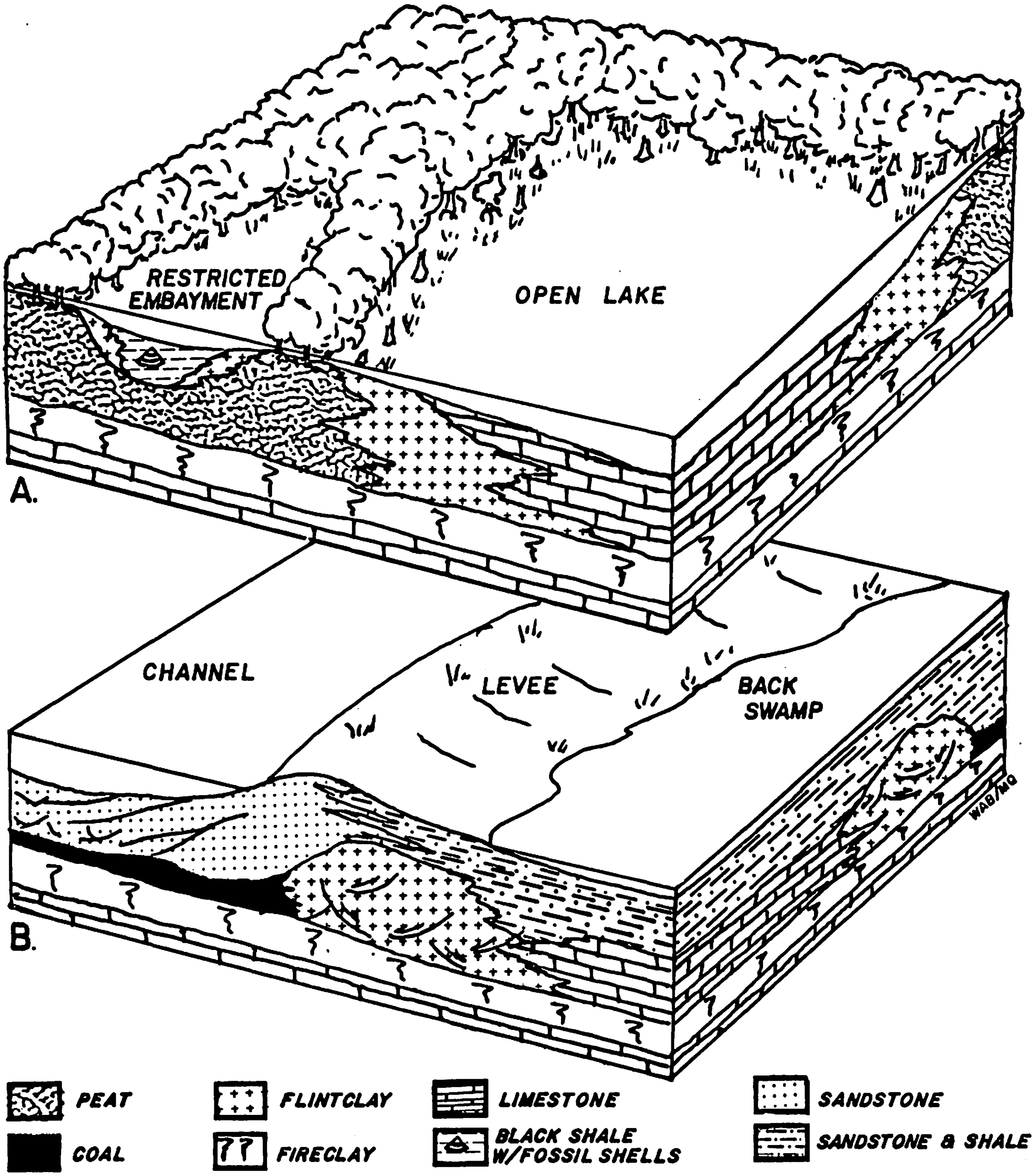


Figure 43. Depositional model and resultant compactional effects in the Upper Freeport sequence. (A) Depositional model for the Upper Freeport flint clay during deposition of the coal-flint clay-limestone sequence. (B) Resultant compactional effects of the Upper Freeport sequence after 10 to 20 ft (3.1 to 6.2 m) of loading by overlying sediments. Channel sandstones are commonly attracted to thick peat sequences (see Figures 40 to 42). Restricted embayment facies not shown in (B); presumed eroded by channel sandstone.

CONCLUSIONS

Geologic literature on the genesis of flint clay provides evidence that flint clays and related clay types may originate via three genetic mechanisms.

1) Leaching of an existing alumino-silicate deposit causing an alumina enrichment and the formation of kaolinite and/or aluminum hydroxide clay minerals.

2) Differential colloidal flocculation of kaolinite in shallow, low-energy, lacustrine or paludal environments.

3) The interaction of certain alumino-silicate deposits with organic compounds and acids. This mechanism is often supplementary but has been invoked exclusively to explain the genesis of tonstein deposits in coal seams.

In the Pottsville and Allegheny Groups, with few exceptions, higher grade flint clay (and nodule clay) occurs in the Pottsville and Lower Allegheny whereas less kaolinitic flint and semi-flint clay occurs in the Middle-to-Upper Allegheny (and Lowermost Conemaugh). Genetically, evidence such as dissolved and pitted quartz grains and boehmite enrichment on topographic highs strongly suggests that the Lower Mercer (Pottsville) flint and nodule clay was formed from intensive leaching over a long period of time, with the supplementary aid of organic compounds and acids. Other Lower Allegheny flint clays may have had a similar origin.

Upper Allegheny flint and semi-flint clays are thought to originate from differential colloidal flocculation in shallow paludal/lacustrine environments. This conclusion is supported by the following observations:

1) The association of flint clay with the perimeter of several coal seams.

2) The apparent distal equivalence of flint clay with limestone and/or other freshwater lacustrine rocks.

3) The paleotopographically lower position of flint clays relative to adjacent coal seams.

4) The occurrence of flint clay at the base of a coarsening upward sequence, laterally equivalent to a black shale with coal streaks.

5) Very fine laminae observed in many fragments of brecciated flint clays.

The brecciation observed in many flint clays and formerly attributed to shrinkage and drying is believed to be caused at least partially by loading of the flint clay prior to complete lithification and possibly aided by the release of entrapped water. Incorporation of the immediately overlying lithology as the matrix material between brecciated flint clay fragments has been observed in drill holes and surface exposures. In the surface exposures it may be seen that the overlying material has been squeezed and slumped into the flint clay. It may also be demonstrated from surface exposures that sedimentary slumping occurred early after 12 to 15 ft (3.7 to 4.6 m) of material had accumulated on top of the clay and that the flint clay was not sufficiently lithified at the time of slumping to incorporate underlying units in the slump.

A DEPOSITIONAL MODEL FOR THE UPPER FREEPORT LIMESTONE (UPPER ALLEGHENY GROUP), ARMSTRONG AND INDIANA COUNTIES, PENNSYLVANIA

by
Suzanne D. Weedman

INTRODUCTION

Freshwater limestones commonly occur as thin beds under the coals of the upper Allegheny Group of western Pennsylvania (Figure 44). The lack of modern analogues, as well as rarity of exposures, has plagued attempts at interpreting them. Pennsylvanian freshwater limestones appear for the first time in the late Middle Pennsylvanian under the Upper Kittanning coal, and are commonly encountered in all younger formations of the northern Appalachian Basin.

The upper Allegheny Group freshwater limestones -- the Johnstown, Lower Freeport, and Upper Freeport -- are virtually indistinguishable in the field or in core. However, the minor differences in the depositional environments of the limestones that occur over brackish water shales (much of the Johnstown) and those that occur over freshwater shales (much of the Upper Freeport) are unknown. For this study the Upper Freeport limestone was concentrated on because it has been reported in thicknesses greater than 30 feet in parts of the basin that have been extensively cored.

The depositional model present here is based on a Markov chain analysis of core logs through the upper Allegheny Group in Indiana and Armstrong Counties, and on isopach maps of sandstone and limestone within the limestone-bearing coal-to-coal interval.

Geologic Setting

The upper Allegheny Group of western Pennsylvania was deposited in late Middle Pennsylvanian time on an upper delta/alluvial plain (Williams and others, 1968; Ferm, 1970) of the eastern North American foreland basin. Sediments filling the basin were derived primarily from the mountains rising to the south (the Alleghanian orogeny), and are considered to be synorogenic (Donaldson and Schumaker, 1981; Quinland and Beaumont, 1984).

The Freeport Formation (from the top of the Upper Kittanning coal to the top of the Upper Freeport coal), specifically the origin of the Upper Freeport limestone, has received far less attention than the Clarion and Kittanning Formations. Williams and others (1968) interpreted this nonmarine cycle as a fluvial-lacustrine complex.

Study Area and Data Base

The study area is shown in Figure 45. The data base consists of 421 lithologic logs (rock type and thickness) of cores drilled through the upper Allegheny interval. The logs are based on the core logging system of Ferm and Smith (1981) and were provided by the Rochester and Pittsburgh Coal Co. of Indiana, Pennsylvania. Thirty-three cores of limestone were retained and examined in detail. For this study, the Ferm and Smith (1981) lithologic classification system was condensed into thirteen basic lithologies (Table 7).

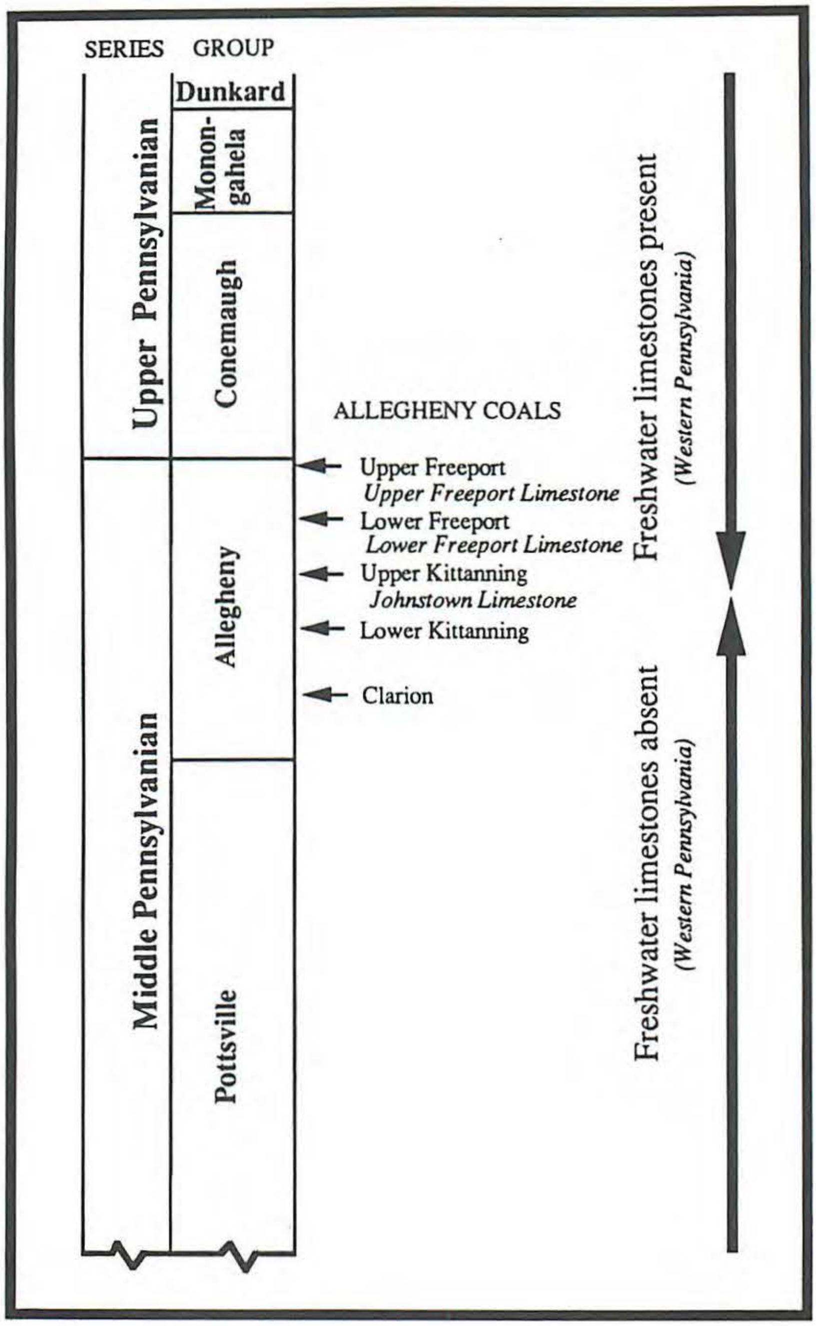


Figure 44. Stratigraphic column for the Pennsylvanian System in western Pennsylvania. the major commercial coals are shown for the Allegheny Group, with the associated freshwater limestones. The distribution of freshwater limestone-bearing coal cycles is shown by large vertical arrows.

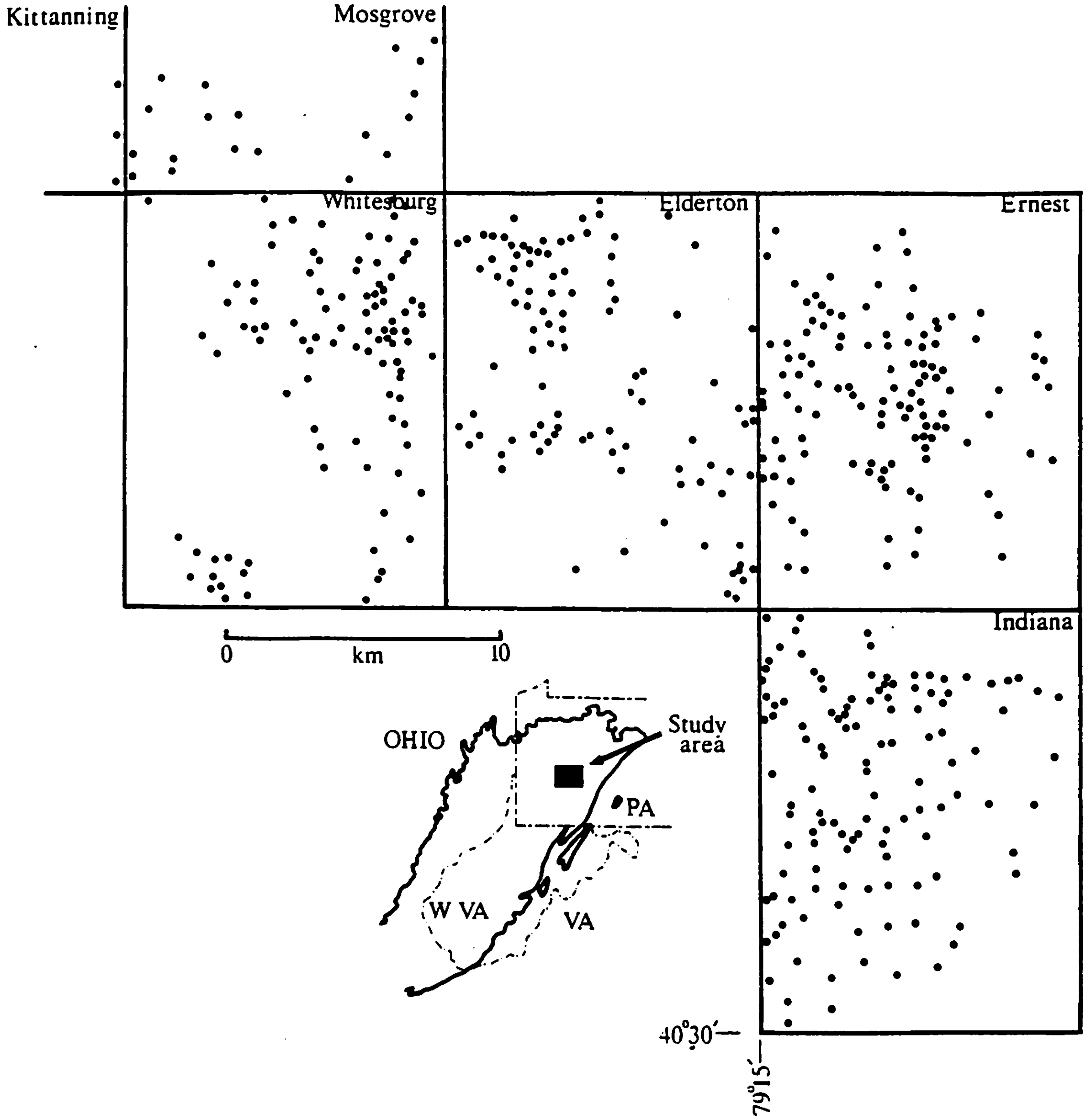


Figure 45. Location map of the study area in the Appalachian Basin (shown in bold outline in the inset map) in western Pennsylvania. Core logs through the upper Allegheny Group were examined from Mosgrove, Kittanning, Whitesburg, Elderton, Ernest, and Indiana quadrangles.

Sites with thick sandstones (greater than 6 m) between the Upper Freeport coal and the next lower coal are excluded from the analysis, on the assumption that the sand bodies are probably fluvial channel deposits (channels, point bars, and/or levees), and that deposition in and near channels is basically

Table 7. Lithofacies classification.

Detrital lithofacies	Chemical/organic lithofacies
conglomerate	limestone
sandstone	shaley limestone
sandy shale	coal
black and dark gray	
light gray/green	
silty claystone	
shale	
black and dark gray	
light gray/green	
with calcareous nodules	
claystone	
flint clay	

different from deposition on the floodplain. Because thick sandstones are relatively rare in the study area, few drill sites were excluded.

RESULTS

Markov Chain Analysis

The vertical lithofacies sequences are analyzed by a first order embedded Markov chain analysis described in Walker (1984), with the addition of Harper's significance test (C. W. Harper, 1984), using the Powers and Easterling (1982) method to construct the random transition matrix. The results of the analysis are in the form of transition probabilities. The most significant lithologic transitions are those whose probability of being random are very close to zero. Complete data tables are in Weedman (1988).

A summary lithofacies sequence diagram with transition probabilities is shown in Figure 46. While the diagrams from the six quadrangles are slightly different, the basic cycle common to each quadrangle is: coal -> dark shale -> dark sandy shale interbedded with sandstone -> light sandy shale -> silty fireclay -> fireclay -> coal. Where limestone is present, it is found overlying and interbedded with either a silty fireclay or a fireclay. Where calcite nodules are present, they are associated with the limestone and gray shale.

Sandstone and Limestone Isopach Maps

The thickness data obtained from the core logs for sandstone and limestone in the limestone-bearing interval were used to make isopach maps (Figures and 48). The objective of the maps is to highlignt the areas of greatest sandstone and limestone accumulations and contrast them to areas of zero accumulation.

Comparison of the two maps in Figures 47 and 48 shows that the sites of greatest limestone accumulation overlie areas of thin or absent sandstone, and

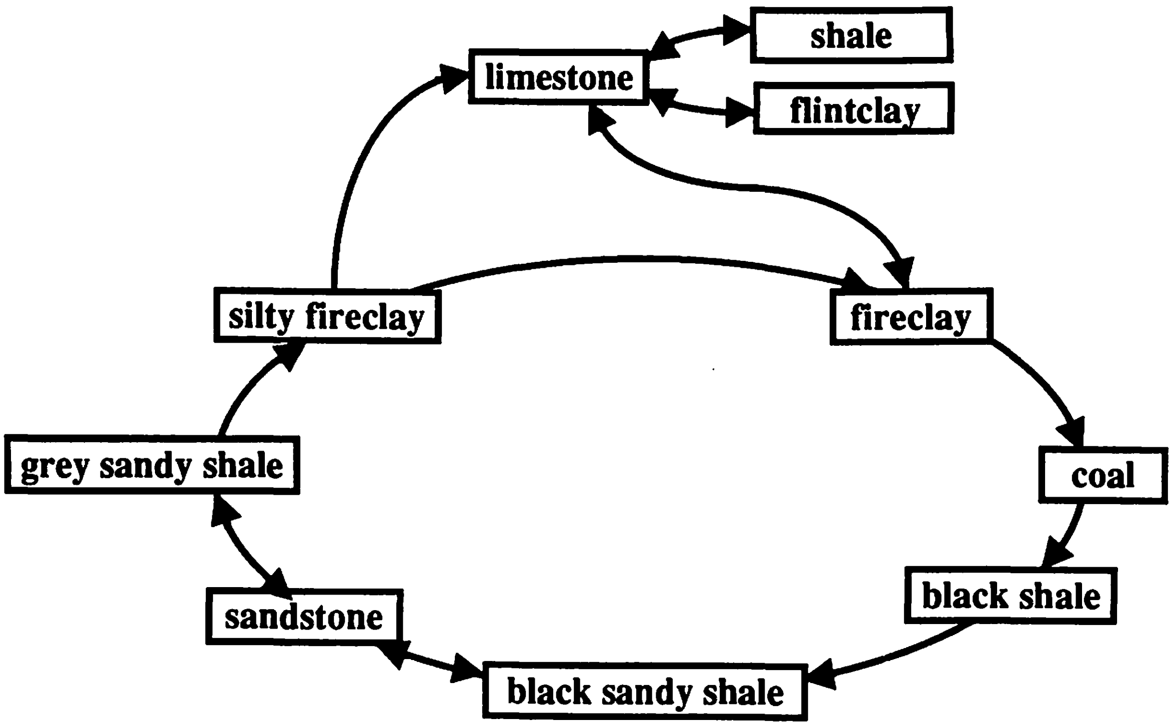


Figure 46. A general lithofacies sequence diagram for the significant lithofacies transitions in the coal-to-coal intervals that contain the Upper Freeport limestone, upper Allegheny Group in western Pennsylvania. The symbol --> means "is overlain by", and <--> means "is interbedded with."

conversely, the thickest sandstones are overlain by thin or absent limestone. The areas of greatest sandstone accumulation are in the Indiana and Whitesburg quadrangles, whereas the areas of greatest limestone accumulation are in the Elderton and Ernest quadrangles. The Mosgrove and Kittanning quadrangles have very few data points; however, the same relationship between sandstone and limestone thickness is observed there.

DISCUSSION

When the significant facies transitions are linked, two at a time, in each lithofacies sequence diagram, a closed cycle is formed. In grain size terms, the cycle can be described, beginning with the coal, as a coarsening-upward sequence followed by a fining-upward sequence. Because only sites without thick sandstones were used in the analysis (i.e. boreholes that did not intersect channel sand bodies), these vertical grain size changes are assumed to reflect floodplain aggradation.

The limestone and associated fine detrital sediments, where present, are found in the upper parts of the fining-upward sequence, and may contain small coarsening-upward packages of shale and silt, on the order of 0.5 m thick. Similar grain size trends in other floodplain associations of sediments have been observed by others (Doveton, 1971; Casshyap, 1975).

The cycle is interpreted as the following scenario:

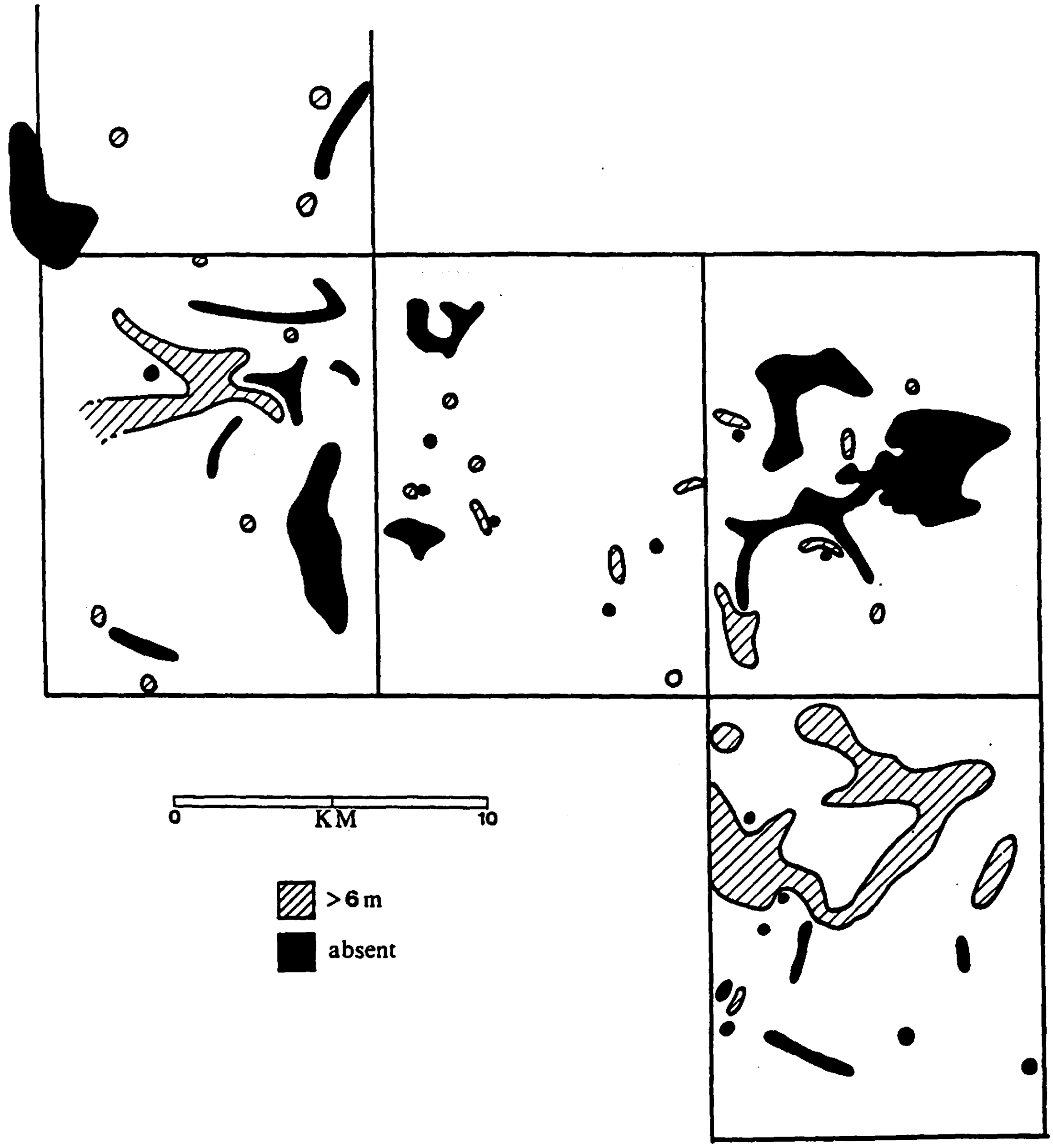


Figure 47. Isopach map of the sandstone that occurs between the Upper Freeport limestone and the next lower coal. Areas of zero occurrence and greater than six meters of the sandstone are contoured. Areas of greater than six meters are though to approximate channel sand body locations.

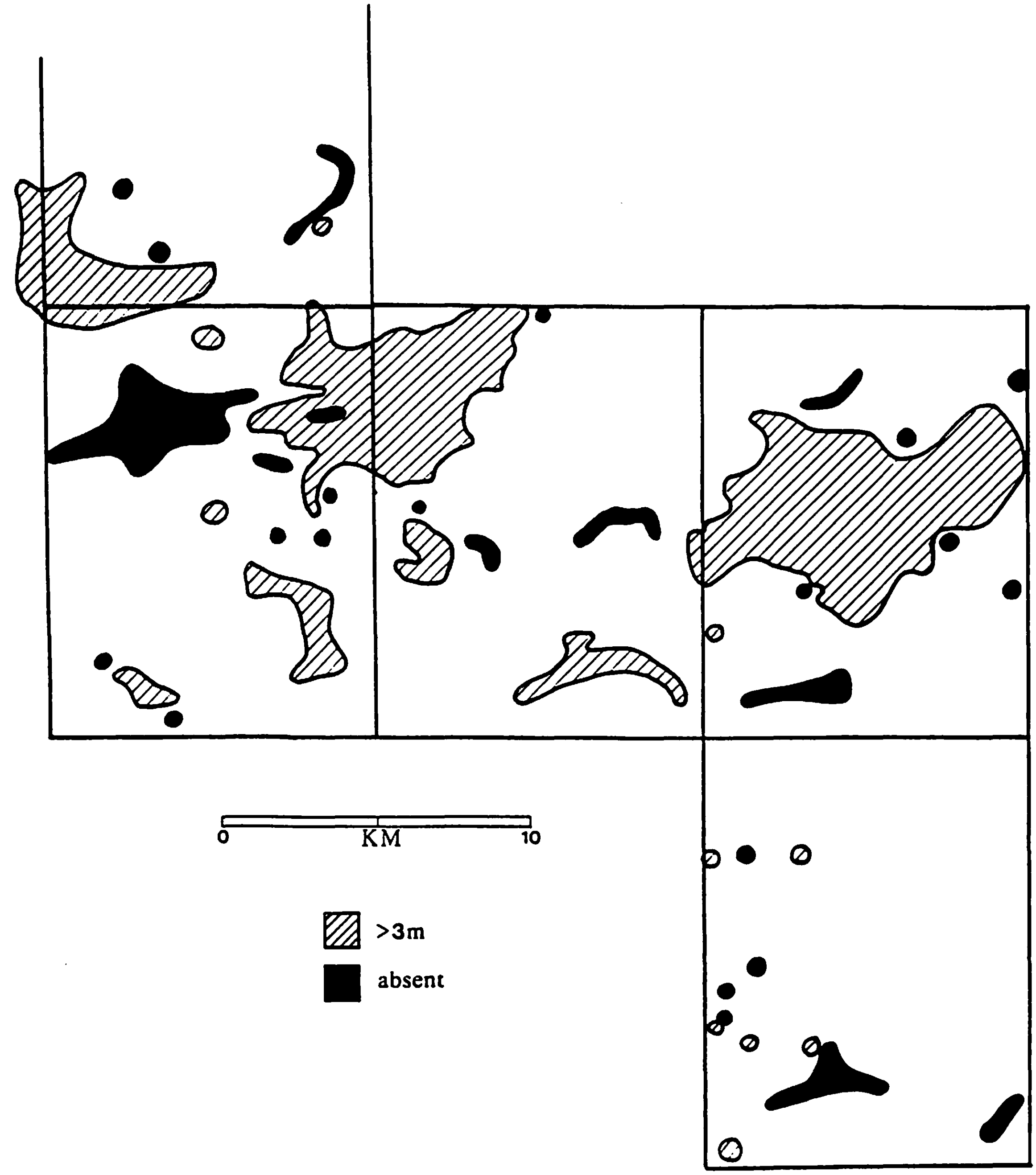


Figure 48. Isopach map of the limestone that occurs between the Upper Freeport coal and the next lower coal. Areas of zero occurrence and greater than three meters are contoured. Areas with three meters or more of limestone are assumed to be the sites of the deepest parts of the lakes.

1) The peat swamp (coal) is flooded with sediment-laden water, from a nearby, newly-avulsed channel. The introduction of muddy sediment into the peat swamp produces a fissile dark gray to black shale.

2) As progradation of overbank sedimentation continues (resulting in levee progradation), organic-rich clays, silt, and sand accumulate over the peat swamp.

3) Sand is deposited over the dark sandy mud as more proximal overbank, or perhaps crevasse splays, reach the distal areas of the floodplain; progradation is at a maximum.

4) The deposition of light sandy mud suggests that the progradation of crevasse splays is waning. The lighter color can be interpreted as either a decline in vegetation or an increase in subaerial exposure.

5) The appearance of a massive (non-bedded) silty mud (silty fireclay) over bedded sandy mud signifies that the source of coarse sediment -- the bedload-transporting channel -- has avulsed upstream, and the overbank sediments subsequently are bioturbated or rooted to obliterate bedding.

6) Levee build-up and progradation during active sediment transport by the channel has led to the formation of topographic highs over the sites of sand deposition (an assumption from modern environments). Continued subsidence combined with a marked decline in sedimentation rates after avulsion, results in perennial flooding of the floodplain. Freshwater lakes form in the low areas, colonized by cyanobacteria ("blue-green algae"), that infill with biogenic carbonate, flood-borne mud, and vegetation.

7) The peat swamp migrates over the lake from the margins as it fills in with sediment and vegetation; the cycle is complete.

The model is shown in block diagram in Figure 49 at a stage when the channel has been abandoned by bedload-transporting flow, but before the lakes have reached their maximum size. The location of the lakes is shown to be controlled by the location of the underlying abandoned channel sand body and levee. Stages one through four are repeated numerous times within the coal-to-coal cycle in the core logs examined. The depth of the lake basin, and eventually limestone thickness, according to this model, is controlled (theoretically) by the height of the levees, the width/depth ratio of the sand body, the lateral spacing of adjacent channel sand bodies, and the duration of abandonment.

Progradation versus Abandonment

The coarsening-upward and fining-upward packages of sediment are interpreted as the floodplain deposits that span a progradational phase and an abandonment phase of the adjacent channel. The progradation phase is similar to depositional models of other coal-bearing horizons (Ferm, 1970; Elliot, 1974). However, the abandonment phase of the upper Allegheny cycle is somewhat different in that there is a period of lacustrine carbonate deposition that precedes the establishment of the peat swamp, and that there are non-marine sediments, instead of marine, deposited over the peat. In other words, overbank sheet flooding and crevasse splays do not entirely fill in the interchannel lows before vegetation can take over, nor do marine waters eventually cover the peat swamp. Instead, after upstream avulsion, the interchannel area appears to remain a water-filled

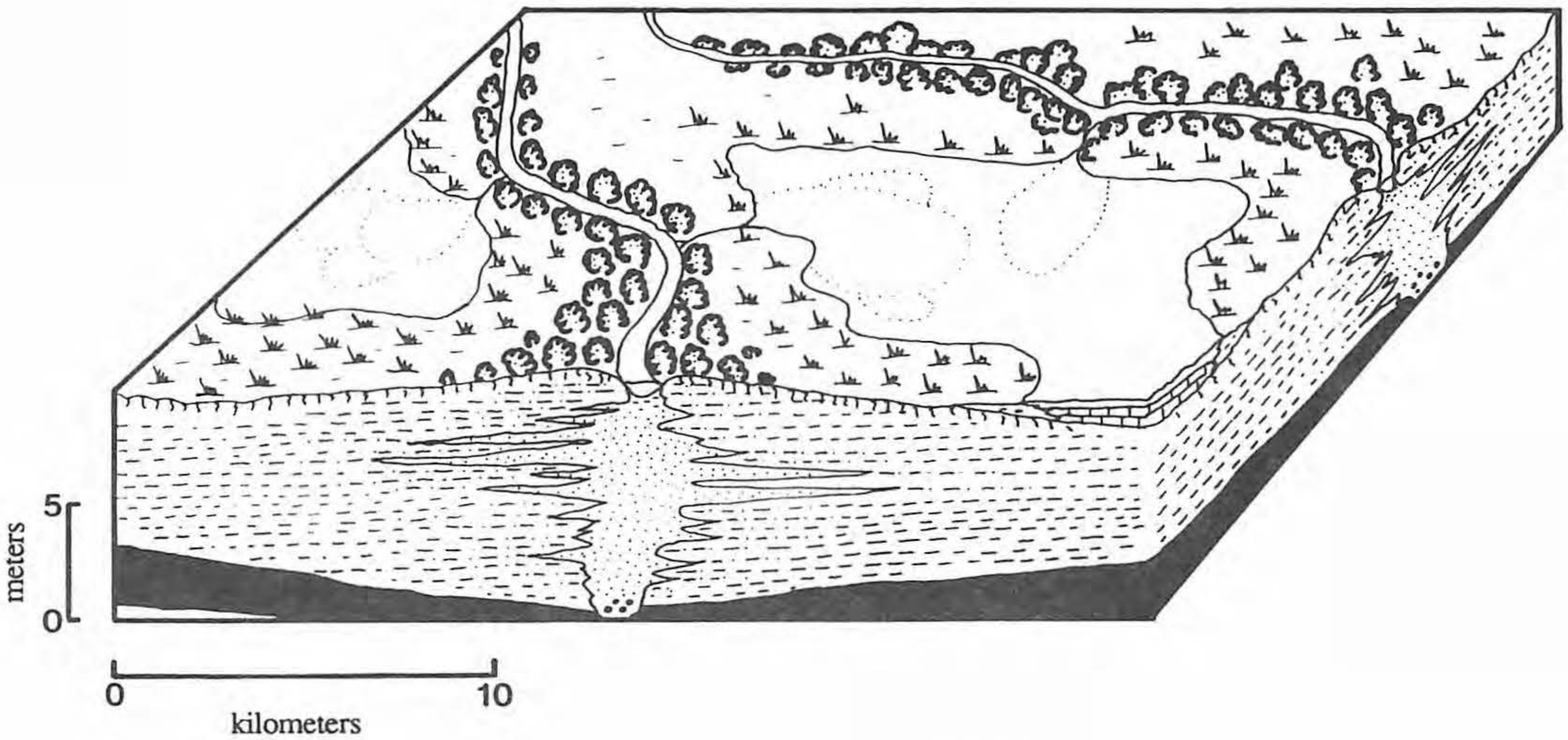


Figure 49. The depositional model for the Upper Freeport limestone and associated lithofacies. The paleogeography is depicted at a time just after the upstream avulsion of the channel, but before maximum lake expansion and peat swamp formation. Lithofacies shown are conglomerate (heavy dots), sandstone (fine dots), sandy shale (alternating dots and dashes), shale (dashes), fireclay (vertical lines), limestone (blocks), and coal (black). The form of muddy lacustrine deltas is indicated by dotted lines in lake areas. Though the channels are abandoned they can transport suspended load to the floodplain and lake during flooding.

topographic low, receiving little detritus, accumulating only carbonate sediment, silts, clays, and vegetation. Subsidence cannot be attributed to the sinking of sandy delta lobes into the fine muds of the marine basin as in the moern Mississippi Delta, or as in Ferm's (1970) model, but more appropriately to the foreland basin subsidence that has been attributed to the overloading of a viscoelastic crust by advancing thrust sheets (Quinland and Beaumont, 1984).

The depositional model, suggested here for the upper Allegheny Group, is very similar to an anastomosed river system in that the channel sandstones appear to have relatively low width-depth rations (are shoestring shaped rather than tabular), the deposits are dominated by floodplain sediments, and sediment-starved lakes are common in the floodplain and are overlain by peat.

Rivers anastomose in response to a relative rise in base level -- either a true rise in base level, the build-up of a downstream "obstacle", or an increase in net subsidence relative to base level (Smith and Putnam, 1980). A rise in sea level is rejected here as the primary cause of rising base level because the distribution of fresh and marine water fauna in the middle and upper Allegheny Group indicates that the upper Allegheny Group was deposited during a major regression (Edmunds and others, 1979; Busch and Rollins, 1984). Therefore, an increase in subsidence relative to sedimentation rates is favored.

In anastomosed rivers, the relative rise in base level results in a decrease in gradient that causes the rivers to increase vertical aggradation over lateral, to build up prominent levees, and to increase avulsion rates. The channel sand bodies become more "shoestring" in shape, with lower width/depth ratios than the sand bodies of meandering and braided streams, and the rivers in map view have an anastomosed pattern. Floodplain sediments comprise up to 90 percent of all of the sediment deposited by the anastomosed river system comprising crevasse splay sands and silts, and lacustrine and swamp sediments (Smith and Putnam, 1980).

Freshwater limestones are common in both the overlying Conemaugh and Monongahela Groups, becoming thicker and more laterally extensive with time. If the appearance of freshwater limestones is an indicator of an increase in basin subsidence, then the difference between foreland basin downwarping rates and infilling rates must have increased from late Allegheny time through the end of the Pennsylvanian Period. A similar relationship between subsidence rates and fluvial style has been proposed for the Tertiary of the Powder River Basin (Flores, 1981) and for the modern Magdalena Basin of Columbia (Smith, 1986).

Carbonate-producing lakes formed in Monongahela time were so large that they are referred to as "sea lakes" by Donaldson (1974). At the present, however, the relationship demonstrated between the limestones and sandstones of the upper Allegheny Group has not been established in these younger sediments.

CONCLUSIONS

1) Deposition of the upper Allegheny Group in Indiana and Armstrong Counties occurred on an upper delta plain/alluvial plain; the freshwater limestones were deposited in floodplain lakes, post-avulsion. The low detrital input (i.e. the sediment-starved condition) allowed maximum photosynthetic activity for the precipitation of biogenic calcite.

2) The depth and location of the floodplain lakes was controlled by the thickness and distribution of the sand bodies of the stratigraphically lower channel; that control is attributed here to the topographic relief created by prominent levees built up adjacent to the channels. Maximum lake depths would result with maximum levee build-up, minimum width/depth ratios of sand bodies, and decreased channel density in the floodplain fine-grained sediments; these conditions are the predicted responses to a decrease in the gradient of surface flow.

3) The depositional plain gradient would be reduced by either a relative or true rise in base level, an increase in the rate of basin subsidence, and/or a decrease in the sediment supply delivered to the basin.

4) This basin-wide change in subsidence and/or sedimentation appears to have begun in late Allegheny time and increased through the Late Pennsylvanian.

TAPHONOMY AND GEOCHEMISTRY OF THE BRUSH CREEK MARINE INTERVAL IN INDIANA, ARMSTRONG, AND CAMBRIA COUNTIES

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INTRODUCTION

Preservation of biogenic aragonite and high-magnesium calcite in ancient sediments is an unusual geochemical event. These minerals are metastable at near-surface pressures and temperatures, and will recrystallize to more stable low-magnesium calcite given sufficient time and the presence of circulating water. The Late Pennsylvanian (Missourian) Brush Creek marine interval of western Pennsylvania is one of a handful of places in the world where primary aragonite and high-magnesium calcite fossil components have been preserved in a Paleozoic rock unit. Such fossils are useful both 1) as a means of determining original shell mineralogy and skeletal ultrastructures of extinct organisms and 2) as records of the trace-element and isotopic composition of ancient sea-water.

Aragonitic molluscs and other preserved metastable bioclasts in the Brush Creek marine interval have been the subject of paleontological and biogeochemical studies for more than two decades (Rollins, 1967; Batten, 1972; Morrison and others, 1985; Brand and Morrison, 1987a, 1987b). Our own work began as part of a senior research project at Indiana University of Pennsylvania that focused on establishing the mineralogy of crinoid and trilobite skeletal material at the Shelocta outcrop of the Brush Creek interval (Durika, 1987). In follow-up work, cores taken from the Brush Creek interval by the Rochester and Pittsburgh Coal Company were used to map out areas of aragonite preservation in Armstrong, Indiana, and Cambria Counties (Durika and others, 1987).

This paper presents new data obtained from taphonomic, petrographic, and geochemical analysis of the Brush Creek marine interval, focusing particularly on the Shelocta and GeeBee localities to be visited by the 54th Annual Field Conference of Pennsylvania Geologists. We will propose a working hypothesis to account for the geographic and stratigraphic variations in metastable fossil preservation in the Brush Creek marine interval and discuss the geologic significance of these unusual fossils.

REGIONAL GEOLOGY

The Brush Creek is one of several marine intervals that occur in the Conemaugh Group of western Pennsylvania (Figure 50). These intervals record eastward transgressions of the North American epeiric sea over the fluvial-deltaic coastline of the Alleghanide uplands. In the study area, the Brush Creek consists of a core limestone that is overlain and sometimes underlain by fossiliferous dark shales. Immediately below the Brush Creek marine interval lies the thin and discontinuous Brush Creek coal. Above the marine interval, marine shales grade into the fluvio-deltaic siliciclastic deposits of the Buffalo sandstone.

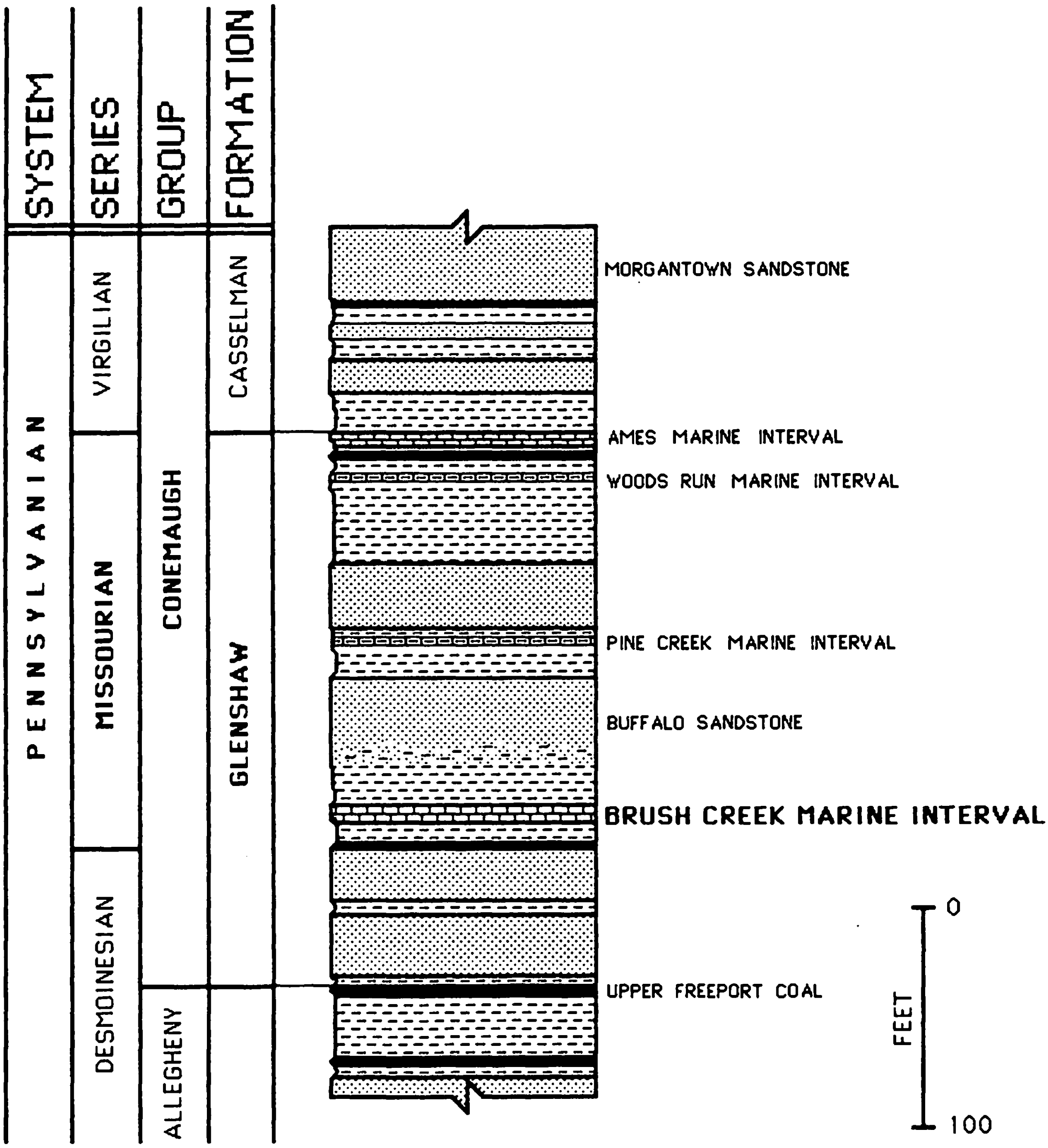

Figure 50. Partial stratigraphic column of the Upper Pennsylvanian in Armstrong, Indiana, and Cambria Counties, Pennsylvania.

FIELD DESCRIPTION

Across the study area (Figure 51), the core limestone of the Brush Creek interval is a bioclastic lime wackestone that contains an abundant brachiopod-dominated fauna. This unit is both underlain and overlain by black calcareous marine shales containing a high-diversity, mollusc-dominated fauna. Partial

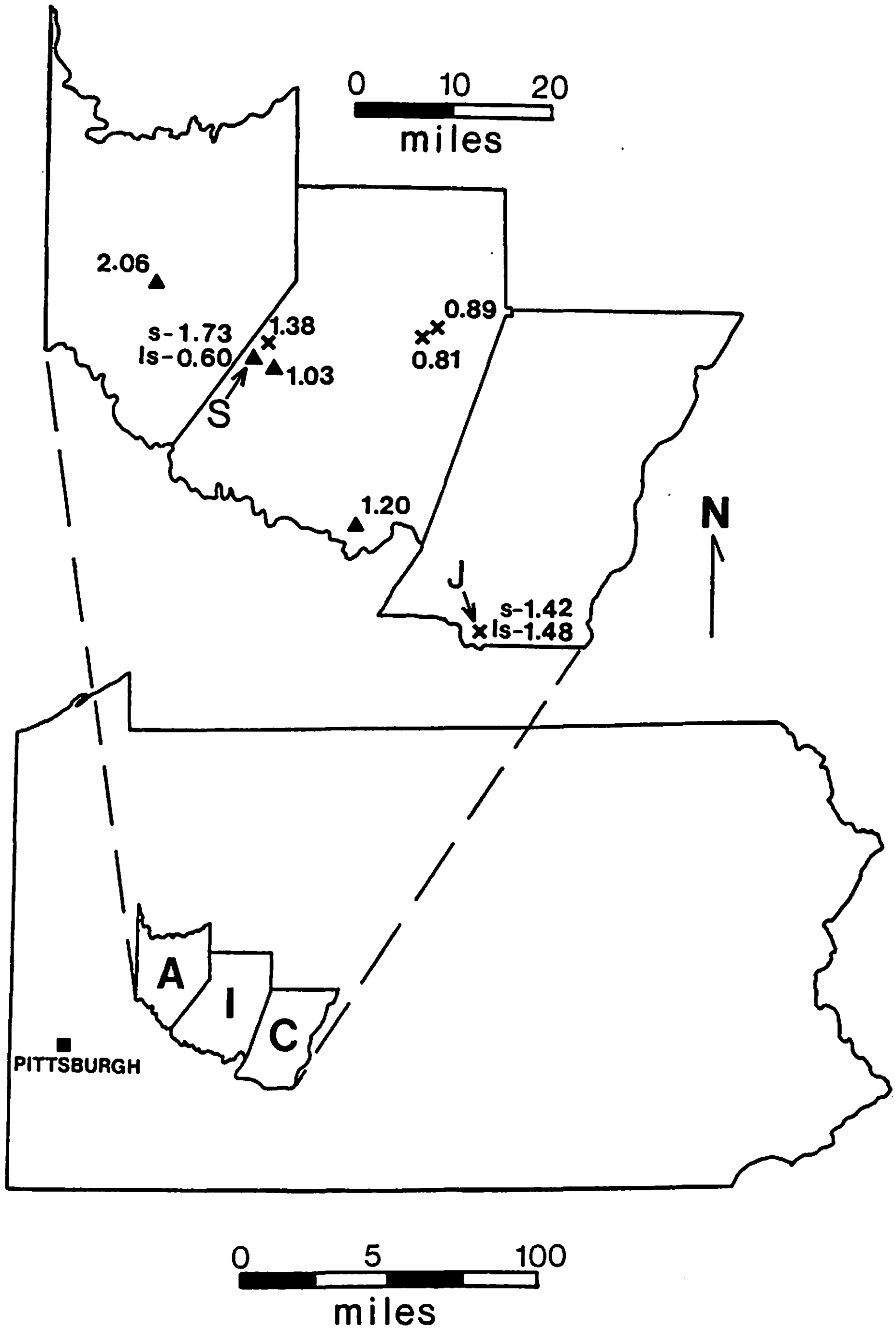

Figure 51. Distribution of preserved (▲) and stabilized (x) metastable carbonates in the Brush Creek marine interval in Armstrong (A), Indiana (I), and Cambria (C) Counties, Pennsylvania. Numbers represent the percentage of total organic carbon (TOC). TOC figures for enclosing shales are given for all localities; TOC values for both limestone (ls) and shale (s) are given for the outcrop localities at Shelocta (S) and Johnstown (J).

lists of the genera recovered from the Brush Creek interval in the study area can be found in Hoskins and others (1983) and the stop descriptions for Stop #2 and Stop #8 provided in this guidebook.

In all Brush Creek localities that have been examined so far (Figure 51), bioclasts from the core limestone are completely recrystallized to low-magnesium calcite (Durika and others, 1987). Primary aragonitic and high-magnesium calcite fossil components occur only in the fissile black marine shales that lie above and below the core limestone. Molluscs from these shale beds commonly display the chalky texture characteristic of slightly decomposed aragonite (Morrison and others, 1985). High-magnesium calcite crinoids, intermediate-magnesium calcite rugosan corals, and low-magnesium calcite trilobites and brachiopods all have a dirty gray appearace very similar to that of the shale matrix and are generally less fragile than the aragonitic molluscs.

FOSSIL PETROGRAPHY AND GEOCHEMISTRY

Thorough geochemical analysis of the Brush Creek bioclastic material (Morrison and others, 1985; Brand and Morrison, 1987a, 1987b) has shown that the least altered crinoids have a magnesium content of approximately 5 mole percent. This value falls only slightly below the range established for modern crinoids (Milliman, 1974), a discrepancy attributed to the presence of secondary calcite within the crinoid pore space (Morrison and others, 1985) and interaction with isotopically light meteoric water (Brand and Morrison, 1987a). The crinoids that we examined from the Shelocta outcrop may represent even less-altered material in that they lack microdolomite (discussed below), that was well-developed in the fossils analyzed by Brand and Morrison (1987a). Aragonitic molluscs analyzed by Morrison and others (1985) apparently also retained primary trace element concentrations. The strontium values within these bioclasts range from 4,000 to 16,000 ppm, values that are similar to those in modern species (Milliman, 1974).

Under the petrographic microscope, original textures of metastable carbonates are generally well preserved. Aragonitic molluscs are finer-grained than recrystallized molluscs and display a brighter and bluer fluorescence under ultraviolet excitation. This fluorescence is similar to that of modern unrecrystallized molluscs examined by Pedone and Cercone (1987), and distinctly different from the dull yellow fluorescence exhibited by recrystallized molluscs from other parts of the Brush Creek interval.

Crinoids and rugosan corals appear to have a murkier texture under the petrographic microscope, possibly reflecting the presence of the secondary calcite intergrowths observed by Morrison and others (1985). When etched and examined under reflected white light, crinoids from Shelocta do not appear to contain any evidence of microdolomites, the small dolomite inclusions that are formed when high-magnesium calcite is recrystallized. Scanning electron microscopy also confirms the absence of discrete microdolomites, although backscatter images show areas of slightly higher magnesium content that could represent the onset of recrystallization. The fluorescence of unrecrystallized crinoids and rugosan corals is bright blue, similar to that of unrecrystallized molluscs. This distinctive color appears to reflect the presence of intracrystalline organic matter rather than an intrinsic carbonate fluorescence (Pedone and others, 1989). The observation of bright blue fluorescence in Pennsylvanian age rocks was quite unexpected, and provides strong support for the primary nature of the metastable bioclasts in the Brush Creek marine interval.

Given the remarkable state of preservation observed in molluscan, crinoidal, and coralline material from the Brush Creek, a special effort was made to examine trilobite specimens from the same units. Trilobites are rare in the Brush CReek fossil assemblage, but they have been found occasionally both at Shelocta and elsewhere. Diligent searches by one author (NJD) resulted in the discovery of two small pygidia of the proetid trilobite *Ditomopyge scitula*, whose composition was then determined by chemical staining and energy-dispersive analysis under the scanning electron microscope (SEM). The trilobite cuticle tested negatively negatively in a staining procedure (Titan yellow) designed to detect the presence of magnesian calcite. Additionally, the SEM analysis revealed the magnesium/silicon ratio in trilobite cuticle did not exceed that in Brush Creek shale, with which both trilobite fragments were coated. In contrast, Brush Creek crinoids examined under the SEM had magnesium/silicon ratios more than six times as large as that of background shale. High levels of chlorine were also detected in the energy-dispersive analysis of trilobite cuticle. It probably is derived from the phosphatic material that trilobites used in addition to carbonate to construct their cuticle.

SHALE GEOCHEMISTRY

Shales of the Brush Creek interval were analyzed for the following parameters: total organic carbon (TOC), visual kerogen type, composition of extractable organics, and pristane-phytane ratios. Owing to limited funds, only a few samples were analyzed in detail, but the available data show several trends that still appear to be valid.

Three groups of samples were analyzed for total organic content: core limestones, shales containing recrystallized fossil components, and shales containing primary metastable carbonate components. In general, higher organic carbon contents in sediments indicate either higher rates of primary organic productivity or lower energy environmental settings, which in turn may result in oxygen deficiency of sediments and/or bottom waters. Brush Creek shales in which metastable carbonates are preserved have a high average content of total carbon - 1.47 percent. Although this value is not extraordinary for shales, it is high enough to classify these Brush Creek shales as petroleum source rocks. Shales in which metastable carbonates have been recrystallized have a significantly lower average TOC content of 1.12 percent.

When the TOC contents of limestones in the Brush Creek marine interval are examined, an interesting pattern emerges. At Shelocta, where metastable fossils are remarkably well-preserved, the core limestone has a TOC value of 0.60 percent, compared to a value of 1.73 percent in adjacent, metastable-bearing shales. At the GeeBee locality, where metastable carbonates have not been preserved, the core limestone has a TOC content of 1.48 percent, which is actually higher than that of adjacent shales (1.42 percent). It is not clear why the core limestone unit of the Brush Creek has such variable values of TOC, but it is clear that for the marine shales, high TOC values correlate with preservation of metastable carbonate.

Visual examination of kerogen type proved uninformative, as almost all Brush Creek samples showed similar distributions dominated by degraded herbaceous kerogen (33 to 50 percent), with smaller amounts of woody (18 to 25 percent), and amorphous (10 to 27 percent) organic matter. Maturation indices determined from sporopollen color were also fairly uniform across the study area (2.0 to 2.6 TAI). Extractable organics were dominated by aromatic compounds in the hydrocarbon fraction and by asphaltenes in the non-hydrocarbon fraction, which is not unusual for deltaic marine shales (Tissot and Welte, 1978).

Geochemical indicators of oxygenation state during Brush Creek deposition appear to be variable. Shales containing metastable carbonates in Indiana County have a pristane-phytane ratio of 1.30. Since pristane forms from chlorophyll only under reducing conditions, this suggests that sediments were oxygen-poor during sediment deposition. Another metastable-containing shale from Armstrong County, however, showed a pristane-phytane ratio of only 0.30. This seems to suggest that sediments there were well-oxygenated, since phytane is the breakdown product that forms when chlorophyll degrades in the presence of oxygen. Part of this discrepancy, however, may be accounted for by the fact that the Armstrong County shales appear to contain a more degraded type of organic matter, making it difficult to resolve the pristane and phytane peaks.

The inconsistencies in the geochemical data show that further work is needed to completely clarify the relationship between the organic content of the shales and the degree of preservation of the metastable carbonates. An important role for organics seems likely, however, considering the obvious potential of the organics for coating the bioclasts and reducing the permeability of the sediment, thus isolating the fossils from circulating pore fluids essential to the stabilization process. This conclusion is supported by the higher average organic content of metastable-bearing shales and the association of organic-rich sediments with other sites of preserved Paleozoic aragonite such as the asphaltic limestones of the Pennsylvanian Boggy Formation of Oklahoma (Brand, 1989).

TRACE FOSSIL EVIDENCE

Many taphonomic studies (Aller, 1982; Speyer and Brett, 1988) have placed appropriate emphasis on the activity of infaunal organisms, particularly intermediate and deep burrowers, as a contributing factor in the physical and chemical degradation of skeletal material in the sediment. In the specific example of the Brush Creek interval, the relationship between style of bioturbation and degree of preservation is well illustrated by the Shelocta outcrop. Discrete trace fossils are fairly common in the black shales containing preserved metastable bioclasts, but the trace makers did not effectively churn the sediment. The commonest components of the ichnofauna are 1) long, narrow, sinuous feeding/locomotory traces attributable to the abundant gastropod *Meekospira* (H. B. Rollins, personal communication) and 2) a much wider feeding trace that resembles *Zoophycus* in displaying a "rooster tail" appearance on the bedding surface. Significantly, however, the latter trace apparently represents only surficial and/or very shallow deposit feeding and lacks the three-dimensional aspect displayed by most forms of *Zoophycus*. It is the three-dimensional, sediment-churning aspect that led Speyer and Brett (1986, 1988) to specifically identify *Zoophycus*-type deep burrowing as a destructive influence in fossil preservation. The fissility of Brush Creek shales, preponderance of articulated bivalves, presence of largely articulated crinoid columns, and essentially *in situ* occurrence of rugosan corals (somewhat clustered and oriented calyx-up at an oblique angle to bedding) all indicate that disruption of the sediment by intermediate and deep burrowers was minimal to nonexistent. In contrast, the absence of stratification and random orientation of predominantly disarticulated brachiopod valves in the core limestone indicate extensive churning of the sediment by bioturbation; not surprisingly, the skeletal carbonates in the limestone are completely recrystallized. However, whether the infaunal activity controlled the preservation process by piping oxic bottom waters, and possibly microorganisms, into the sediment to destroy the organic films that protected the bioclasts from circulating pore waters, or is merely associated with the preserved bioclasts as another consequence of the reducing conditions created by the depositional setting, is difficult to say.

CONCLUSIONS

Previous biogeochemical studies of Brush Creek material (Morrison and others, 1985; Brand and Morrison, 1987a, 1987b) have demonstrated the value of preserved metastable skeletal carbonates in deriving data on the temperature, salinity, and oxygen content of Pennsylvanian oceans. The confirmation in our study of a stable low-magnesium calcite composition for trilobite cuticle provides encouragement that trace element and isotopic signatures within the skeletons of this faunal group may provide similarly useful paleo-oceanographic data from strata of all Paleozoic systems.

Our own taphonomic and geochemical study has shown that preserved metastable bioclast assemblages within the Brush Creek marine interval are not uniformly distributed, either stratigraphically or geographically. Preserved assemblages occur only in the dark calcareous shale facies; bioclasts in the core limestone facies are recrystallized. Also, may sections of the Brush Creek interval display complete stabilization of the metastable components even in the calcareous shale intervals. The geochemical data and trace fossil evidence indicate that exceptional preservation took place only where highly organic calcareous fine-grained siliciclastics accumulated in localized low energy areas (bathymetric lows?) of the flooded deltaic margin, in the absence of intermediate and deep burrowing by infaunal organisms. Additional work is needed to resolve the relative importance of infaunal activity and organic geochemistry of the enclosing shales in the preservation process.

THE OCCURENCE OF ACID MINE DRAINAGE IN THE JOHNSTOWN AREA AND THE IMPLICATIONS FOR THE FUTURE EXPLOITATION OF REMAINING COAL RESERVES

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INTRODUCTION

The geology of the Johnstown area strongly influenced the development and present day character of the local community. Exploitation of the coal reserves found in the hills surrounding Johnstown provided the basis for the area's economic growth, which in turn attracted people of cultural and ethnic diversity. The economic health of the Johnstown area continues to be influenced by diverse cultural heritage remains. Another persistent legacy of the area's coal mining history is that, while pristine mountain streams still do exist, many of the drainage basins of the area have been polluted by acid mine drainage (AMD). Whether any given stream in the Johnstown area is productive and populated by native brook trout, or is sterile and choked with iron hydroxide precipitates, is often a matter of geologic fate. The degrees to which the geologic factors that produce AMD are understood and controlled is one consideration that will determine the degree of influence coal mining has on the future development of the Johnstown area.

HISTORICAL INFLUENCE OF COAL MINING ON ECONOMIC DEVELOPMENT AND WATER QUALITY

The discovery of coal along the banks of the Stonycreek River in 1788 had little impact upon the initial development of the Johnstown area, but that changed in the middle and latter part of the 19th century. While coal was utilized for domestic purposes as early as the 1820's, the iron industry relied mainly upon wood as the primary resource for coke production. As the supply of readily available timber declined, coal gradually became the preferred fuel. The abundance and relative accessibility of the area's coal resources allowed the iron and steel industries to expand to meet increasing demand. By the turn of the century, the Cambria Iron & Steel Co. was using over 1.5 million tons of coal per year and by 1920 the Johnstown metropolitan area had grown to become the 9th largest city in the commonwealth (Levine, 1969).

Growth in the coal industry continued in conjunction with the expanding metals industry up through World War II. Coal production for Cambria County exceeded 20 million tons in 1942 with approximately 21,000 people employed by the industry (Department of Environmental Resources, 1988). Diversification of the area's economic base during the period of significant growth was minimal, and consequently, during the post-war decline of the metals industry, the area's economy suffered. Coal production in Cambria County, exclusive of the period from 1974 through 1982, has steadily declined to a present day figure of approximately 4 million tons per year and a total employment of less than 1300 individuals (Department of Environmental Resources, 1988).

In light of present day economic considerations, the future influence of coal on the local economy appears, at best, uncertain. The demand for metallurgical grade coals is minimal, and the local industry faces additional constraints including competition from domestic and foreign sources, increasing production costs associated with the depletion of the most accessible reserves, competition from other energy resources, etc.

Another constraint is the need to exploit the remaining coal reserves in a manner that limits the environmental impact.

While providing a base for economic growth and expansion, the early development and exploitation of the area's coal resources resulted in significant adverse environmental impacts. Approximately 43,000 acres (17,400 ha) of abandoned surface mine land and approximately 285,000 acres (115,340 ha) of abandoned deep mine workings exist within the Cambria and Indiana county area alone (Mentz and others, 1978). In terms of surface water degradation, these areas account for approximately 230 mi (368 km) of polluted streams. Acid loading in the regional drainage basin of the Conemaugh River has been estimated in excess of 690,000 lb (313,000 kg) per day. The cost of neutralizing this amount of acid with hydrated lime would be approximately $11,600 per day or $4.2 million per year just for the reagent and excluding the costs for construction, maintenance, and manpower for treatment facilities. In addition to chemical degradation of surface and groundwater resources, abandoned, unreclaimed, surface mines and deep-mine refuse piles are subject to accelerated erosion and increasing sediment load resulting in the physical disturbance and/or destruction of aquatic habitats.

On a smaller scale, the impacts of previous mining activities are readily visible in several subbasins within the Johnstown area. The Little Conemaugh River basin has been extensively mined and the mainstem of the Little Conemaugh River has been severely degraded by AMD. The Abandoned Mine Lands Survey Report (Mentz and others, 1978) indicates that "over 90% of the acid load discharged by all point sources identified in the basin are the result of abandoned deep mine operations and associated facilities". The Stonycreek River Basin exhibits similar conditions, however; where pollution from underground mines remain the primary source, the influence of surface mining activities is also both apparent and contributory.

The Paint Creek Basin, which will be visited during Field Conference Stops #6 and #7, is an example of the extent of the existing problem and illustrates the degree of effort required to obtain significant abatement and reclamation. Underground mines, mine-refuse sites, and surface operations contribute to the pollution load in Paint Creek. Large deep mine complexes and associated refuse piles, such as the Mine #37 site (Stop #6) are significant point sources. These large complexes also represent a most difficult scenario in terms of practical or cost effective abatement techniques. In many cases their large areal extent, in combination with geologic structure, complicate or inhibit mine-seal development (due to the excessive hydraulic head that would be created). Reclamation and abatement of AMD emanating from surface operations and refuse sites is also a very costly endeavor. The costs and complexities of trying to abate and/or treat the acid mine drainage at these sites are prohibitive.

While AMD pollution in the local area is extensive, not all streams have been affected. Watersheds on which the primary coal bearing strata have either been eroded away or remain too deeply buried for mining are often the watersheds that local residents now rely upon for water supplies and recreation. Streams whose valleys dissect the primary local coal bearing strata of the Allegheny

Group are generally degraded by AMD.

The South Fork Little Conemaugh River basin, located to the east of Johnstown, illustrates the relationship between the quality of local streams and the geology they dissect. The headwaters arise near the 2,700 ft (823 m) elevation along the Allegheny front and flow westward through the Mississippian Rockwell Formation, Burgoon Sandstone, and Mauch Chunk Formation (Berg and Dodge, 1981). The upper 7.0 mi (11.2 km) of the South Fork Little Conemaugh River supports a native brook trout population, is stocked by the Pa. Fish Commission, and serves as a public water supply source. Farther to the west, as the stream dissects younger strata preserved in the Wilmore Syncline, it begins to receive recharge from the Pottsville and Allegheny Group. The South Fork Little Conemaugh River dies near the town of Lloydell, shortly after it cuts through the cropline of the Lower Kittanning Coal, the most extensively mined seam in the Johnstown area. Table 8 presents analyses of samples taken from the South Fork Little Conemaugh River. Sample one was collected upstream from where the river receives recharge from Lower Kittanning mine complexes and sample number two was located downstream of the Lower Kittanning cropline.

While the accepted cost of past economic development has been serious AMD pollution, in recent decades environmental degradation has become a less acceptable price for economic growth. The tremendous costs associated with abatement of existing AMD dramatically underscores the importance of understanding the causative factors and of perfecting predictive/preventive techniques along with sound mine planning and development.

Much of the existing AMD problem in the Johnstown area is due to the old abandoned deep mine complexes, but most of the present mining is being conducted by surface mining methods. The following sections will explore some of the efforts that have been made toward understanding and preventing AMD, and will include specific examples from mine sites located in the Johnstown area. Most of the recent efforts have been directed toward surface mining rather than deep mining, although some of the general concepts apply to both methods.

FACTORS INFLUENCING THE OCCURRENCE OF AMD

The example of the South Fork Little Conemaugh River given above shows how the quality of local streams can change quickly as they dissect different rock units. However, it is not only the presence or absence of mineable coal reserves that determines whether or not any given local watershed has been impacted by AMD. Regarding their potential for generating AMD, not all coal

Table 8. Water quality from South Fork Little Conemaugh River.

SAMPLE	pH	ALKALINITY*	ACIDITY*	Fe*	SO_4*
1	6.2	24	0	0.18	15
2	3.4	0	120	5.76	330

* Values in mg/l

Table 2 . Water quality from Griffithtown Lower Freeport deep mine.

pH	ALKALINITY*	ACIDITY*	IRON*	MANGANESE*	SULFATES*
6.4	96	0	0.30	0.05	57

* Values in mg/l

seams and associated strata were deposited equally. There are locations in this region where drainage taken directly from abandoned mine openings provides a source of chemically good quality water. An example is the Griffithtown public water supply which obtains water from the discharge of an abandoned Lower Freeport seam deep mine located approximately twelve miles north northwest of Johnstown. Table 9 includes an example of a water sample analysis from this Lower Freeport deep mine discharge.

Clearly there are differences among the local coal-bearing strata which influence the quality of water produced by a mine site. Williams and others (1985) summarized the results of previous research by noting that the amount of sulfur, the amount of carbonates, and the presence of channel sandstone units are the three most important geologic factors influencing post-mining water quality.

The percent sulfur in a coal seam and its overlying strata is one important factor influencing AMD production, because the oxidation of iron disulfide minerals (FeS_2 - pyrite and marcasite) produce AMD. Laboratory tests have shown that the higher the percent sulfur in a rock sample, the higher the acidity in leachate from that sample (Williams and others, 1982). However, there appears to be more to the sulfur story than the percent present. It is commonly believed that finely disseminated iron disulfides are more reactive than large grained pyrite. Caruccio (1970) found that fine grained framboidal pyrite is more reactive than other forms. Hornberger's (1985) results did not confirm this finding, however. Marcasite weathers more readily than pyrite according to Tennissen (1974), which implies it may produce acidity more readily than pyrite. While it seems clear that the morphology, grain size, and purity of FeS_2 may affect the production of AMD, the details of how these factors affect AMD occurrence are not fully understood.

Because of its direct role in AMD chemistry, sulfur content has long been implicated as a culprit in AMD production. But in recent years increasing attention has been given to the influence of calcium carbonate on AMD production. Strata with relatively high calcium carbonate content and the associated high pH-alkaline groundwater can neutralize AMD and precipitate some metals, thus improving water quality. In addition, the presence of calcium carbonate may actually inhibit the oxidation of pyrite (Carrucio and others, 1981; Williams and others, 1982).

Surface mine sites which have a predominance of sandstone overburden, especially channel sandstones, tend to produce AMD, even when the percent sulfur present is relatively low. The relationship between the occurrence of AMD and the presence of sandstones has been noted by Williams and others (1982), diPretoro (1986), Brady and others (1988), and Brady and Hornberger (in preparation). Sandstones generally do not contain significant amounts of carbonates, and are lacking in ion-exchange capacity, which may account for the higher-than-expected acidities often generated by sites with predominantly sandstone overburden (Brady and Hornberger, in preparation). Another possibility is that blocky sandstone overburden does not compact as well as fine-grained overburden during backfilling. Blocky sandstone overburden produces more porous backfills that result in the availability of more oxygen and more rapid flushing of weathering products.

The environment of deposition of coals and their related strata influences the amount of sulfur, the amount of carbonates, and the occurrence of channel sandstones; this relationship links the depositional environment of strata and their AMD producing potential has been proposed by Williams and others (1982).

In the Johnstown area the primary coal-bearing strata occur in the Allegheny Group, composed of the Clarion, Kittanning, and Freeport Formations. Lower Pennsylvanian Pottsville Group coals also occur, as do some of the Conemaugh Group coals, but these other coals, while occasionally mined, are not generally economically or environmentally important in the local area.

Paleogeographic maps have been compiled for the Allegheny and Pottsville Groups on the basis of fossil fauna (Williams, 1960). The faunas were grouped into freshwater, restricted marine (brackish), and marine.

Williams and Keith (1963) found that coals overlain by deposits of marine origin were higher in sulfur content than coals of the same age overlain by freshwater beds. Guber (1972) found in studies of western Pennsylvania coal strata that shales deposited under brackish conditions contained sulfur in excess of 1.5 percent. The freshwater deposits of the upper Allegheny Group often include calcareous beds (Williams and others, 1968).

Hornberger and others (1981) compiled water quality data from deep mines in western Pennsylvania that showed freshwater deposits to be generally non-polluting, with brackish and marine deposits generally producing AMD. Hornberger's results also showed that acid production from deposits of marine origin can be reduced or eliminated if limestones are present.

AMD PREDICTION

Broad paleoenvironmental frameworks, along with historical water quality results, are useful tools in making preliminary assessments of AMD potential. Site specific data is essential, however, to more fully define the AMD potential of specific strata in a given locale. Two of the most important influences on AMD production, the presence of channel sandstones and the amount of carbonates present (especially in freshwater deposits), are rather erratic in occurrence due to their often abrupt lateral boundaries. Site specific exploratory data, including analysis of the sulfur and carbonate contents of coal-bearing strata can help define variables such as discontinuous limestone beds and irregular facies boundaries that influence the AMD potential of a mine. In addition, other site specific factors such as the quality of groundwater entering a site and mining plans (Brady and Hornberger, in preparation) and the weathering out of carbonates under relatively shallow cover (Brady and others, 1988), can have a significant influence on post-mining water quality.

Acid-base accounting overburden analysis, as described by Sobek and others (1978), provides useful site-specific data for evaluating the acid producing potential of surface mining sites and is used in the Johnstown area as well as in the rest of the bituminous coal fields of Pennsylvania. Information provided by acid-base accounting includes percent sulfur, the neutralization potential (NP), which is a measure of a stratum's ability to neutralize a strong acid (and which is assumed to represent calcium carbonate content), and a qualitative fizz rating (effervescence) noted when the samples are contacted with a 25 percent HCl solution. The NP is commonly expressed in terms of tons $CaCO_3$-equivalent per 1,000 tons of strata. The maximum potential acidity (MPA) of a stratum is sometimes calculated from the percent sulfur and includes the assumption that all sulfur present will react to form AMD. The MPA is expressed in terms of negative tons $CaCO_3$ equivalent/1000 tons of strata. While the information gained by acid-base accounting is useful in evaluating the AMD producing potential of mine sites, the method does have shortcomings. Brady and Hornberger (in preparation) have pointed out some of the shortcomings of the method, which will not be elaborated here.

Various approaches to interpreting acid-base acounting data exist. Currently, for the evaluation of surface mining permits in Pennsylvania, the minimum significant NP is considered to be 30 tons/1000 tons with a detectable fizz and the minimum significant percent sulfur is considered to be 0.5 percent; these numbers are based upon Department of Environmental Resources experience that values less than these seem to have limited impact on AMD production (Brady and Hornberger, 1989). These numbers are general guidelines only and should not be taken to imply that strata which fall outside these ranges will in all cases not influence AMD production. For comparison sake, it is useful to calculate volume-weighted calcium carbonate equivalents for each significant zone. The use of acid-base account-overburden-analysis data to predict the occurrence of AMD is complicated by the existence of a significant "gray area" composed of sites with both relatively low NP's and low percent sulfur (Brady and Hornberger, in preparation). Sites within the gray area may produce either alkaline or acidic water.

CASE STUDIES

Some examples of acid-base account-overburden-analysis data collected from mining operations around the Johnstown area and water quality produced by these mining operations are presented in the following paragraphs. The examples are presented to show some of the variations that can occur in the sulfur and carbonate content of local strata and how those variations may relate to post-mining water quality. To define site variability a minimum of two overburden-analysis holes are required for permitting purposes; the data from only one hole per site is presented here as examples.

Site A is located approximately 3 mi (4.8 km) west of Johnstown (see Figure 52 for site locations). Table 10 presents the acid-base account-overburden data for the Lower Kittanning coal seam, the underclay, and the 92 ft (28 m) of strata overlying the coal seam. Interbedded mudstones, siltstones, and sandstones predominate. A discontinuous rider coal seam occurs 30 ft (9.1 m) above the Lower Kittanning seam and the Upper Kittanning coal seam is logged in at 76

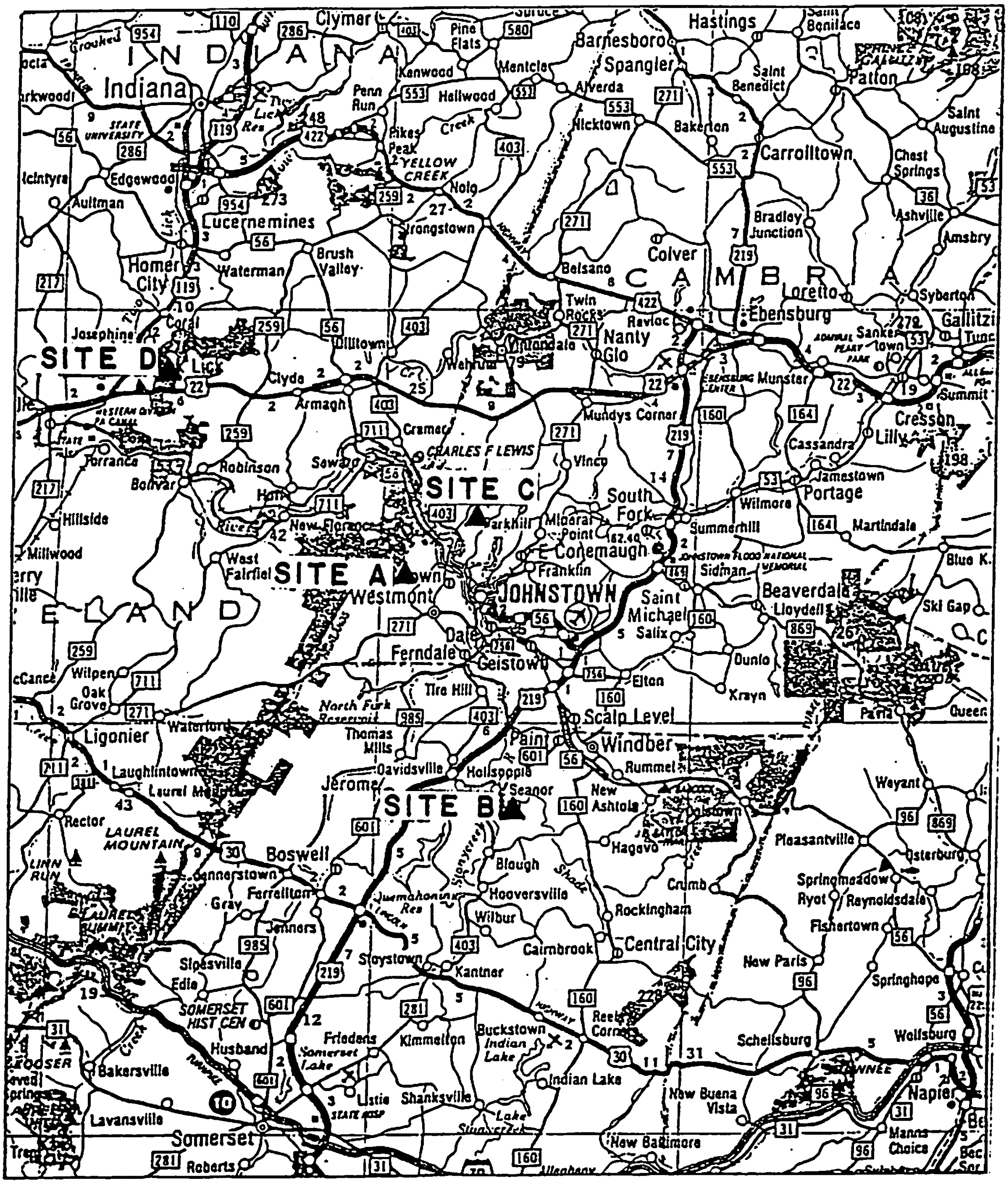

Figure 52. Site location map for AMD studies in the Johnstown area.

ft (23.2 m) above the Lower Kittanning seam. The analysis for these strata includes several intervals showing sulfur contents in excess of 0.5 percent. The low carbonate content as evidenced by the lack of a detectable fizz rating is significant. The sulfur content coupled with the absence of any significant amount of carbonates suggest that this site may be an acid producer. Water samples collected from seeps which have developed subsequent to the mining confirm this obserbation. The water quality of the discharges show pH of 3.0 to 3.5, high acidity, iron, manganese, aluminum, and sulfates. A summary of these

Table 10. Overburden analysis for mine Site A.

BOTTOM DEPTH (FT)	LITHOLOGY	FIZZ RATING[1]	% SULFUR[2]	NP[3]
6.0	Clay	0	0.05	-0.45
9.0	Clay	0	0.02	0.97
12.0	Clay	0	0.01	2.00
14.0	Shale	0	0.01	2.41
16.0	Coal (U.K.)	0	0.68	1.42
19.0	Shale	0	0.14	2.00
22.0	Shale	0	0.08	12.27
25.0	Shale	0	0.34	14.48
28.0	Sandstone	0	0.62	2.64
31.0	Sandstone	0	0.32	15.92
34.0	Shale	0	0.62	12.33
37.0	Sandstone	0	0.70	4.93
41.0	Shale	0	0.24	3.62
45.0	Shale	0	0.12	4.49
48.0	Shale	0	0.08	25.29
52.0	Shale	0	0.06	15.15
56.0	Shale	0	0.16	29.97
58.5	Shale	0	0.23	22.52
62.0	Coal (L.K. rider)	0	2.14	2.16
65.0	Shale	0	1.66	-0.63
68.0	Sandstone	0	0.44	1.23
71.0	Shale	0	0.18	1.64
75.0	Shale	0	0.68	6.68
78.0	Siltstone	0	1.43	12.29
82.0	Sandstone	0	0.24	23.88
86.0	Sandstone	0	0.23	21.90
90.0	Sandstone	0	0.30	53.67
92.0	Shale	0	0.34	18.03
97.0	Coal (L.K.)	0	8.02	2.01
98.0	Shale	0	0.66	0.08

1 Fizz rating: A qualitative test of observable effervesence using a 25 percent HCl solution (0 = none, 1 = slight, 2 = moderate, 3 = strong)(Noll and others, 1988).

2 Percent total sulfur: as determined by procedures outlined in Noll and others (1988).

3 NP: Neurtralization Potential expressed as tons of $CaCO_3$ equivalent per 1000 tons of material as determined by procedures in Noll and others (1988). Example: a sample having an NP = 500 would be equivalent to a sample composed of 50 percent $CaCO_3$.

Table 11. Water quality data from mine Site A.

SAMPLE POINT	pH	ALKALINITY*	ACIDITY*	IRON*	MANGANESE*	SULFATES*
Discharge	3.5	0.0	914	90.3	161.0	2136
Discharge	3.7	0.0	1068	99.0	230.8	2934
Discharge	3.7	0.0	1126	93.5	207.9	2772
Pitwater	2.5	0.0	1128	242.0	19.9	600

* Values in mg/l

samples is present in Table 11.

Mine Site B, located approximately 4 mi (6.4 km) southwest of Johnstown, is also on the Lower Kittanning coal. The overburden analysis (Table 12) represents the Lower Kittanning coal, the underclay, and 67 ft (20.4 m) of strata above the coal. A rider seam occurs 24 ft (7.3 m) above the Lower Kittanning seam and a one ft (0.3 m) thick coal logged as the Middle Kittanning occurs 50 ft (15.2 m) above the Lower Kittanning. The overburden analysis for Site B shows that only the coals and the stratum directly above the Middle Kittanning coal has sulfur contents greater than 0.5 percent, and there are zones with a positive fizz rating and NP's greater than 30. Samples collected from seeps on an unreclaimed Lower Kittanning strip cut and from an abandoned Lower Kittanning deep mine on Site B are presented in Table 13. These water samples are generally moderately acidic, with a pH in the 4's and with slightly elevated iron and moderate sulfur concentrations.

Mine sites A and B, while on the same coal seam, have different overburden analyses in terms of the sulfur and carbonate content and are associated with different water quality. Williams (1960) classified the shales overlying the Lower Kittanning coal in the Johnstown area as freshwater-brackish water interface for the Lower Kittanning depositional environment, and produced much more acidic water. The overburden-analysis data show higher sulfur and less carbonate on Site A than Site B, which may account for the differences in discharge quality.

Another factor possibly influencing the difference in discharge quality between sites A and B is the source of the water entering each site. Site A is located in a groundwater recharge area on a topographic high, and the primary source of water to it is from direct precipitation. Upper Allegheny strata occur upgradient from Site B, so ground water moving into the site may be influenced in quality by the overlying strata. The water samples in Table 13 suggest that AMD is being formed and subsequently partially neutralized as indicated by the disproportionate acidity and sulfate concentrations.

Mine Site C is located approximately 3 mi (4.8 km) north of Johnstown. It includes mining on the Upper Kittanning, Lower Freeport, and Upper Freeport coal seams. Overburden analysis for these seams and their associated strata is

Table 12. Overburden analysis for mine Site B.

BOTTOM DEPTH (FT)	LITHOLOGY	FIZZ RATING	% SULFUR	NP
3.0	Clay	0	0.00	0.08
6.0	Clay	0	0.01	1.70
9.0	Clay	0	0.01	2.80
12.0	Shale	0	0.01	2.58
13.5	Claystone	0	0.00	6.13
14.0	Shale	0	0.03	20.98
16.5	Shale	0	0.01	2.28
17.0	Shale	0	0.59	2.20
18.0	Coal (M.K.)	0	0.83	2.83
21.0	Shale	0	0.09	2.90
24.0	Shale	1	0.10	29.70
26.0	Shale	1	0.05	25.70
30.0	Shale	0	0.15	20.15
33.0	Shale	0	0.18	20.93
36.0	Shale	0	0.12	15.50
39.0	Shale	0	0.06	24.38
42.0	Shale	1	0.27	33.09
43.0	Coal (L.K. rider)	0	0.46	2.60
46.0	Clayshale	0	0.17	3.18
49.0	Sandstone	0	0.10	5.48
52.0	Sandstone	0	0.01	10.30
55.0	Sandstone	0	0.03	22.05
58.0	Shale	1	0.06	62.90
61.0	Shale	1	0.16	63.40
63.0	Shale	1	0.25	28.60
65.0	Shale	0	0.19	11.33
67.5	Shale	0	0.26	14.13
70.0	Coal (L.K.)	0	1.83	3.60
73.0	Claystone	0	0.04	1.85

presented in Table 14. As would be anticipated from the presence of freshwater limestones, this overburden includes strata with significant NP and fizz ratings. In general, the sulful contents of the sampled strata are low with the exception of some units occurring in association with the coals. Analysis of samples taken from the active Upper Kittanning pit and from a Lower Freeport deep mine discharge which occurs on this site show alkaline water with low metals and sulfates concentrations (Table 15).

Site C, which includes significant amounts of carbonate, is characteristic of the relatively high NP strata often associated with the upper section of the Allegheny Group. Even though the coals and strata immediately above and below the coals contain greater than 0.5 percent sulfur content, and are of the same general magnitude of those on Site B, the NP in this overburden is sufficiently high to inhibit AMD production.

Table 13. Water quality data from mine Site B.

SAMPLE POINT	pH	ALKALINITY*	ACIDITY*	IRON*	MANGANESE*	SULFATES*
Seep	4.4	0.0	48.6	2.76	5.60	464
Deep mine discharge	4.2	0.0	55.1	3.90	1.13	535

* Values in mg/l

Table 14. Overburden analysis for mine Site C.

BOTTOM DEPTH (FT)	LITHOLOGY	FIZZ RATING	% SULFUR	NP
5.0	Clay	0	0.00	5.33
10.0	Clay	0	0.00	4.93
13.0	Siltstone	0	0.00	5.25
16.0	Siltstone	0	0.00	7.40
19.0	Siltstone	0	0.00	7.08
22.0	Siltstone	0	0.00	7.98
25.0	Siltstone	0	0.00	9.08
28.0	Siltstone	0	0.00	4.80
31.0	Sandstone	0	0.50	1.98
33.5	Coal (L.F.)	0	2.49	0.08
37.0	Claystone	3	1.54	278.75
42.0	Siltstone	2	0.05	83.50
45.0	Sandstone	1	0.00	60.33
50.0	Sandstone	1	0.00	55.08
55.0	Sandstone	0	0.01	13.03
60.0	Sandstone	2	0.00	41.63
63.0	Siltstone	2	0.00	81.25
65.5	Shale	1	0.12	33.75
66.0	Coal (rider)	0	0.45	9.60
71.0	Siltstone	1	0.10	27.75
73.0	Siltstone	1	0.10	25.20
75.0	Shale	1	0.07	28.15
80.0	Siltstone	1	0.32	21.78
85.0	Shale	1	0.27	35.40
87.5	Coal (U.K.)	0	0.83	2.38
90.0	Shale	3	0.75	351.75
92.0	Limestone	3	0.01	697.13

Table 15. Water quality data from mine Site C.

SAMPLE POINT	pH	ALKALINITY*	ACIDITY*	IRON*	MANGANESE*	SULFATES*
Pitwater (U.K.)	6.9	38.4	Neg.	0.87	0.38	42
Deep mine (L.F.)	7.1	80.5	Neg.	0.10	0.03	63

* Values in mg/l

Mine Site D is located approximately 16 mi (25 km) northwest of Johnstown. The Upper Freeport coal has been mined on this site, with a very small area of Upper Kittanning and Lower Freeport strata also having been affected. Data from one of the overburden-analysis holes on Site D is presented in Table 16. The Upper Freeport overburden is primarily sandstone with no significant carbonate (NP and fizz) content. Only the coal and the strata directly overlying the coal have sulfur contents equal to or greater than 0.5 percent. Serious AMD problems are associated with Upper Freeport mining on several mine sites surrounding Site D. A post-mining discharge has developed downslope of the Upper Freeport mining area on Site D (Discharge D-1, Table 17). Discharge D-1 is acidic with elevated metals and sulfates. A discharge has also developed just below the area where the small Lower Freeport and Upper Kittanning pits were open (Discharge D-2, Table 17). Discharge D-2 is also located below the areas where the Upper Freeport seam was mined. While discharge D-2 shows elevated metals and sulfates, it is alkaline. Note that the overburden-analysis data for both the Lower Freeport and Upper Kittanning overburden on Site D include strata with NP greater than 30 and a detectable fizz and no strata (other than the coals) with percent sulfur greater than 0.5.

The Upper Freeport overburden on Site D is predominantly sandstone, the significance of which has been alluded to earlier. Where the carbonate-bearing strata were disturbed on Site D, the discharge was alkaline although high metals and sulfates also occurred. Site D illustrates the importance of considering the site specific mining plan. The original mining plan for Site D included multiple seam mining of the Upper Kittanning, Lower Freeport, and Upper Freeport coal seams across much of the site with some of the higher NP strata from the lower seams to be mixed with the overburden of the Upper Freeport seam. However, soon after mining began, the lower seams were dropped, and most of the carbonate-bearing strata never became part of the reclaimed spoil. An acidic discharge occurred in the area where only the Upper Freeport coal and its associated sandstone overburden were affected.

The above examples of overburden-analysis data were presented to show some examples of sulfur and carbonate contents in local strata along with the related mine discharge quality. A full evaluation of acid-base account data should include comparison of calculated volume-weighted $CaCO_3$ equivalents for all significat zones. The overburden analysis data also must be carefully con-

Table 16. Overburden analysis for mine Site D.

BOTTOM DEPTH (FT)	LITHOLOGY	FIZZ RATING	% SULFUR	NP
1.0	Soil	0	0.01	2.83
4.0	Clay	0	0.01	1.17
9.0	Sandstone	0	0.01	2.83
14.0	Sandstone	0	0.01	3.97
19.0	Sandstone	0	0.00	1.17
24.0	Sandstone	0	0.01	1.55
29.0	Sandstone	0	0.03	4.10
34.0	Sandstone	0	0.07	3.34
39.0	Sandstone	0	0.20	5.89
43.0	Sandstone	0	0.29	2.06
47.0	Clay	0	0.50	5.12
50.0	Coal (U.F.)	0	5.58	-3.55
53.0	Clay	0	0.40	6.65
56.0	Clay	0	0.30	14.17
59.0	Shale	1	0.13	31.32
62.0	Shale	3	0.09	175.49
65.0	Shale	2	0.01	76.85
68.0	Shale	2	0.18	37.91
71.0	Shale	1	0.12	23.24
74.0	Shale	1	0.07	42.05
77.0	Shale	1	0.06	27.91
80.0	Shale	1	0.10	32.08
83.0	Shale	1	0.09	29.55
86.0	Shale	0	0.09	9.20
89.0	Shale	0	0.16	9.46
90.0	Coal (L.F.)	0	1.12	4.61
93.0	Clay	0	0.11	13.03
96.0	Shale	2	0.11	66.34
99.0	Shale	1	0.01	19.20
102.0	Shale	1	0.01	21.34
105.0	Shale	1	0.05	20.71
108.0	Shale	1	0.07	18.19
111.0	Shale	0	0.02	7.16
114.0	Shale	0	0.04	10.99
118.0	Shale	0	0.08	12.26
121.0	Shale	0	0.18	9.20
123.0	Coal (U.K.)	0	2.60	3.59
126.0	Clay	0	0.31	0.40

sidered in light of other factors such as premining groundwater quality and the proposed mining plan. The conclusions reached from the above examples may seem straightforward, but were obtained, for the most part, with the benefit of hindsight.

Table 17. Water quality data from mine Site D.

SAMPLE POINT	pH	ALKALINITY*	ACIDITY*	IRON*	MANGANESE*	SULFATES*
D-1	4.3	6	78	4.15	14.10	558
D-2	6.4	174	0	56.70	11.70	660

~~* Values in mg/l~~

On the basis of overburden analysis and other predictive data, mining may be restricted on certain sites or portions of sites. Another use of overburden analysis is to identify the relationship of high sulfur strata to high NP strata and to devise mining plans that will place the strata in relative positions likely to inhibit the production of AMD. Some other methods of AMD prevention that are being explored, but which remain far from perfected are the importation of carbonates onto mine sites, the control of mine site hydrology (Carrucio and others, 1983), and the inhibition of AMD catalyzing bacteria such as Thiobacillus ferrooxidens (Kleinman, 1981).

CONCLUSIONS

Further refinements in the prediction of AMD occurrence and the development of preventive and abatement techniques which can be economically applied are necessary. Earlier in this paper the significance of caol mining to the early development of the Johnstown area was noted, as with the cost of that development in terms of AMD pollution. Current law and regulations prohibit the issuance of mining permits in cases where the available data indicate that AMD will be the result, and mining companys are liable for treating in perpetuity discharges which do not meet required effluent standards. In today's age of environmental awareness, the degree to which the remaining coal reserves can be exploited without significant negative impacts on groundwater and surface water quality will help determine the role of coal mining in the future of the Johnstown area.

EARLY GEOLOGICAL EXPLORATIONS OF THE JOHNSTOWN AREA

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No one knows when the first person noticed that the black material found along the hillsides would burn, but that individual created the reason for geologic exploration of the Johnstown area. If the black rock could be found at one location, then, perhaps, it could be found elsewhere as well. As the inhabitants of the region changed, so did the need for more geologic exploration.

THE EARLY YEARS

Members of the Delaware and Shawonese tribes were the first people in this region where two rivers meet. The Shawonese came to the area between 1678 and 1698. The Delaware were there already (Stokey, 1907), predating the Colonial records that describe the Shawonese as "...treacherous and ferocious..." (Stokey, 1907, I, p. 46). Not especially liked by the tribes of the Six Nations, the Shawonese were gone from the region by 1755.

For years there was an Indian village at the site where Johnstown now stands for it was the crossing of one of the main east-west trails and a major north-south route leading to where Bedford is today. Jonah Davenport and James LeTort came into the area in 1731 to trade with the Delawares and Shawonese. In a trade document filed in Philadelphia October 29, 1731, they referred to an Indian town called "CONNUMAH" (Stokey, 1907), a name meaning "Otter Creek". There are several methods of spelling the name, including "Can-na-maugh", "Caugh-naugh-maugh", "Con-nu-mach" (as it appears on the City Seal for Johnstown), and the present spelling "Conemaugh". At that time over 600 Indians were living along the rivers and in the town of Connumah, but as more Europeans moved into the region, the Indian population declined, and according to the notes of Peter Goughnour (Stokey, 1907), almost all of the Indians were gone by 1798. The first permanent European settlers were Solomon and Samuel Adams who ran a grist mill on Solomon's Run prior to 1770. The first reference to the discovery or at least mention of a coal exposure is found in an endorsement on a land warrant (Stokey, 1907, I, p. 572):

> Date of Warrant, April 3, 1769; Name of Warrantee, William Barr; Number of acres, 300. Remarks: On the South side of Stone Creek [Stony Creek], opposite to the Stone Cole [coal] bank. Returned, &c. 31st October, 1788.

Later this land was owned by Louis Von Lunen and is now part of the Moxham section of Johnstown.

This endorsement was made about five years before Joseph Johns purchased what was known then as the Campbell Tract in 1793 and made a settlement on it. By 1800, Johns formed an official town and called it "Conemaugh"; the name Johnstown was not formally adopted until 1834. According to an article by James M. Swank in 1869 (quoted in Stokey, 1907), the first flood was recorded in 1808, only eight years after the founding, and another flood occurred in 1816. Having the new city flood twice in the first 16 years of its existence should have caused the city officials to think twice about the location.

GILPIN'S JOURNAL

The European settlers soon exploited the local coal and iron ore and much of the early geologic work centered around the search for them. Among the earliest published descriptions of the region are those found in the travel journal of Joshua Gilpin of Philadelphia who passed through the area in 1809 while inspecting family properties scattered throughout Pennsylvania (Walker, 1975). On October 8th, 1809 he left Indiana, Pennsylvania and went south, describing lands along Yellow Creek and "Chesnut" Ridge:

> "...the country here as well as on our Crooked Creek lands abound in coal tho [sic] the veins near the surface are thinner than to the southward being generally not more than from 2 to 3 feet thick ... the tenants say that there is iron on these lands but have not investigated it, I apprehend however that it will be found on those parts of the lands which are upon the Chesnut [sic] ridge which almost every where abounds with it [coal]..." (Walker, 1975, p. 123-124).

Gilpin goes on to indicate that a local blacksmith was mining coal from lands near Yellow Creek to use in his shop. Gilpin and his party became lost for a while that day, but arrived eventually at Armagh which he describes as "...a miserable place consisting of a few houses..." (Walker, 1975, p. 125). From Armagh the group travelled over Laurel Hill and into the Johnstown area along:

> "...the banks of the Conemaugh[,] a beautiful stream navigable from hence to the Allegany [sic] - after fording it we rode along its banks to its junction with the Quemahoning, where we found a neat little town formerly an Indian settlement-& now called Jones's town [Johnstown?]...surrounded on all sides by mountains...[with] a good mill & 20 or 30 very decent houses;..." (Walker, 1975, p. 127).

From Gilpin's description, I assume that he confused the Stony Creek with its tributary, the Quemahoning, which joins the Stony Creek near Davidsville. Gilpin speaks of John Halliday who was, "...the Proprietor of the town who owns the mill & lives in it..." and according to Walker (1975, footnote on p. 128), Halliday did live in what is now known as Johnstown and operated the Cambria Forge. Halliday came to the town from the Juniata Valley where he had been in the iron industry. No doubt his decision to relocate to Johnstown was based, to some extent, upon the presence of coal, limestone, and iron ore. Although these resources must have been exposed along the river banks, Gilpin did not mention them. Perhaps as he did not own land there, he was not interested.

The only other geologic information about the region Gilpin mentions come after decending "Alleganey" Mountain where he came across deposits of "...alumins, that loose crumbling slate...", and "Allum" deposits that he saw near what is now Pleasantville. Near Dunning Creek he saw "...veins of limestone..." (Walker, 1975, p. 131).

By now the various spellings of the name of the river and the mountain, "Alleganey", "Allegany", etc. are apparent. this is not a Nineteenth Century problem (see Rand 1980; Lyons, 1988 and 1989; and J. Rogers, 1989). Given the numerous variations, I shall give the spelling as it appeared in the original reference, regardless of whether or not it conforms to the Pennsylvania spelling, without adding "[sic]".

MORE EARLY HISTORY

Stokey (1907) mentions that a Mrs. Ann Linton used coal for domestic purposes in 1822. By 1890, the Berwind-White Coal Mining Company was one of the largest producers of bituminous coal in the country. Production in 1902 was 10,561,835 tons; by 1905, 12,600,891 tons averaging 3.24 tons per man per day on an 8-hour shift.

During the late 1830's, the iron ore was extensively mined by the "Cambria Iron works" (H. D. Rogers, 1858). The major exploitation of the iron ore came as a result of the Panic of 1837, one year after Henry D. Rogers and his co-workers began the first geological survey of the state. As a result of the economic chaos, actual paper money as a medium of exchange was in short supply, and people had to rely on the barter system. The problem was that Johnstown, aside from coal, had little with which to barter. George Shryock King, who came to Johnstown from Mercersburg in 1833, concluded that if the natural products of the area were taken to Pittsburgh, then exchange could be made for food, dry goods, etc., and, at the same time, provide employment for the local work force. He believed the local iron ore was the key to this venture.

David Stewart and Samuel Kennedy were operating a small foundry on an island in the Conemaugh River before 1837, but the business dissolved during the 1837 Panic. King then joined with Stewart in 1838 to prospect in the region for iron ore (Stokey, 1907). By 1840 they discovered a nice vein of the ore on John Seigh's farm on Laurel Run. Out of a 37 ft (11.3 m) deep shaft they prepared, several tons of nodular ore were removed from a 15 in (38.1 cm) vein. King and Stewart took the ore to the Ross Furnace in Westmoreland County to be smelted, and they hauled the pig metal to a forge on the Juniata River. The finished metal was good, but very hard and rather brittle.

The two men were sufficiently encourage to acquire land from Mr. Seigh in March of 1841 and they set up their own furnace on Ben's Creek. In the agreement with Seigh, King and Stewart were able to get not only the iron ore, but limestone as well. Shortly afterward they formed a partnership, "George S. King and Company" (Stokey, 1907), and by 1842 the company had started their "Cambria Furnace" on the Seigh property. Iron was a commodity to exchange for goods in Pittsburgh, although the hard and brittle nature of the metal made it hard to sell or exchange at times. This hardness proved a blessing in disguise, for later it was discovered that the hard steel made ideal rails for street cars and railroads (Stokey, 1907). Thus by the 1840's, the connection between Johnstown and the steel industry was off to a flying start.

Not ones to rest on their success, King and Stewart found more veins of iron ore on the upper and lower sides of Hinckston's Run that was of even better quality and quantity than what they had on Laurel Run. Other mines opened on Mill Creek around 1843-44, and by 1847 David Prosser had the Prosser Mine producing iron ore from Prospect Hill. Peter Schenberger of Pittsburgh bought Stewart's share of the company for $6,000 on March 24th, 1844, and King and Company opened four new iron ore drifts in 1845. So rich for its day was the area, that a section known as "Round Mound" was considered to be among the richest pieces of real estate in the country; on a par with the gold fields of California (Stokey, 1907). King and Company had purchased the land for $800 and refused $80,000 a few years later. The Cambria Steel Company was formed November 14, 1898, and in 1907 it used 71,000,000 gal (268,806,000 l) of water, 1,600,000 tons of coal, and 1,237,724 tons of ore to produce a net profit of $4,964,003.15 (Stokey, 1907).

Eventually richer ore from Michigan, where the Lake Superior mines had been opened in the 1830's, and other places replaced the local iron ore and that aspect ceased operations, but coal mining and the steel industry continue in the region today.

THE PORTAGE RAILROAD

The building of the Portage Railroad and the accompanying canal system stimulated interest in western Pennsylvania, and the various excavations made along the tracks offered an opportunity to look at fresh material. Edward Miller, a civil engineer who, according to Lesley (1876, p. 37), went on to become "...one of the most distinguished civil engineers of the United States..." did a geologic description of a measured section along a portion of the Allegheny Mountain, starting at Hollidaysburg, following the Portage Railroad. His section went over the top and into part of Cambria County, stopping at Ben's Creek near Cassandra (not to be confused with the other Ben's Creek at Johnstown). Miller's motivation for doing the work was not economic as was the case in most of the early work, but rather, "As recreation from duties of a more arduous character..." (Miller, 1835, p. 251).

In Miller's report is a nicely colored foldout cross section approximately 10 X 5.5 in (26 x 13.5 cm) that includes such detailed information as the angle of dip, bed thickness, and total thicknesses. Lesley (1876, p. 49) praises Miller's work on the section, but he said that because of the scale used, the section was of little value:

> "Had he [Miller] not, in obedience to the taste of the eastern geologists, and from habit as a constructing engineer, exaggerated the vertical scale to eight times that of the horizontal scale, so as to distort all the dips, this section would not be only of the highest interest as a classic in the science, but would stand us in capital stead in our annual report this year (1874-'5);...but the section as Mr. Miller published it is worthless; and, alas, the suite of specimens which he sent with it to the museum of the society [Geological Society of Pennsylvania] in 1833, cannot now, perhaps, be recovered." (Parentheses and emphasis in the original).

Among Miller's missing specimens were several fossils, both plants and shells, coal, and iron ore samples. Richard Harlan (1835, p. 256) described the plant fossils and gave their location as, "Vicinity of Johnstown, western base of the Alleghany mountains." One of these, Pecopteris milleri, Harlan named in honor of Edward Miller. According to Harlan (1835, p. 258), Miller told him that the plant fossils came from the "...top of the Alleghany mountains, lying immediately on the surface of a bed of bituminous coal, and that marine shells were found both above and below them." Timothy Conrad, who, later, was to work with the New York Geological Survey, described the shells (Conrad, 1835), but there is no indication in Conrad's paper as to where the shells were collected. He lists five new specimens, Stylifer primogenia, Turbo tabulatus, T. insectus, Productus confragosus, and Pecten armigerus, plus nine other specimens found with these five new ones. Thomas G. Clemson, formerly of the Royal School of Mines in Paris, France, and later to be the Superintendent of the Flemington

Mines in New Jersey (Lesley, 1876), analyzed the coal and iron ore samples that were keyed to Miller's cross section and paper. The coal was taken near the top of Incline Number 7. I could not ascertain the location of the iron ore, but I assume it came from near Incline Number 6. Clemson's (1835) analyses are rather simple, e.g. for the coal he lists only volatile matter 15, ashes 8, and carbon 77 [weight percent]. Apparently in 1835 there was no interest in the sulfur content or any other elements. The iron ore seems to be typical of what is found around Johnstown, for Clemson (1835, p. 274) listed:

"Carbonate of protxide of iron (protoxide of iron 49.42, carbonic acid 30.94	80.36
Sand and argile	12.60
Carbonate of lime	1.00
Carbonate of manganese, carbonate of magnesia, bitumen, and water	6.04
	100.00

One hundred parts of this ore, then, yield 38.2 of metallic iron."

These few short descriptions serve to illustrate that there was geologic exploration taking place before the official geological survey, and some of it touched upon Johnstown.

FIRST PENNSYLVANIA GEOLOGICAL SURVEY

The very next year, 1836, the Pennsylvania Legislature appropriated funds for the first geologic survey of the state under the direction of Henry Darwin Rogers (Figure 53). North Carolina started its survey in 1823 (Lesley, 1876) and was the first state to create an official geological survey. The original intent of the Pennsylvania Legislature was for a ten-year project, but the funds were stopped in the sixth year, and publication of the work did not occur until 1858 (H. D. Rogers, 1858).

Johnstown was in Rogers' Third District and part of the "South-Eastern Belt of the Bituminous Coal Region" (H. D. Rogers, 1858, p. 32-33). In terms of the Paleozoic region, Johnstown was part of his "Ninth, or Bituminous Coal District" (p. 110). During the third year of the survey, 1838, Mr. Charles B. Trego and Mr. Townsend Ward "...wandered through the wilderness south of the Clearfield turnpike, as far as the Maryland line, (keeping east of Chestnut Ridge)..." (Lesley, 1876, p. 69). Johnstown and Laurel Hill lie in that "wilderness." The field season of 1840 found Ward working with John T. Hodge of Plymouth, Massachusetts while they extended the study of the bituminous region south from Centre County. In his Fifth Annual Report Rogers (1841, p. 10), indicates that the leader of the work in this coal district, Mr. Joseph T. Hodge, was chosen because of his:

> "...familiarity with the methods of research requisite in a wooded country-acquired during former seasons, in some of our northern counties, and, previously to this, during two years in the wilderness of the State of Maine qualified him with the species of skill particularly wanted in this department of the survey."

The party consisted of Hodge, Ward, and:

"...two tents, a wagon and three horses, with three brothers [of Hodge's] for his hands, two of whom he [Hodge] had trained the previous year, and a cook, who hunted and could occasionally dig." (Lesley, 1876, p. 103).

In addition, Rogers (1841, p. 10) said that there were:

"...three skillful miners [Hodge's brothers?], whose business it was to expose, by judiciously conducted diggings, the outcrop of all beds of coal, limestone, iron ore, or other materials, either obscurely indicated on the surface, or merely inferred to exist by previous measurements of the adjoining rocks."

The group were in the field for seven months, and by August they had reached Loretto, Cambria County, where J. Peter Lesley joined them. From there they and Lesley worked down the Conemaugh, doing precise work in the Johnstown region where they worked out the details of the iron ore and the coal beds as these represented a major economic resource. Later, by the 1870's, the Cambria Iron Works had become the largest iron mill in America (Lesley, 1876) using the local iron ore (see earlier description).

No doubt the groups collected many samples during their fieldwork, but, as with many collections, the housing and cataloguing did not match the skill of the geological field work. Lesley (1876, p. 177-180) described in detail what happened to some of the samples, e.g.:

"The law compelled him [Rogers] to place a part of the collections at Pittsburg [sic]; where they were burnt up. The law obliged him to place duplicates at Harrisburg; there they were stolen, and finally sent to the Insane Asylum." (p. 179).

Not many of us have our samples put in an institution for the mentally ill, although we may occasionally think so! However, the samples of the First Survey work were of little help to later geologists.

During the first year of the survey, Rogers simply used Roman numerals for each unit, starting with the Limestone of the Lebanon Valley as I and continuing to the coal measures as XII (H. D. Rogers, 1838; Lesley, 1876); later he modified and added new numbers to the system as new formations were described. The numbers served Rogers well as a flexible system to use until he had ascertained all of the major groups and whether or not what he found in Pennsylvania conformed to the rocks elsewhere, namely New York, Virginia, and Europe. In the final report Rogers did not use Roman numerals or any of the existing European or New York formational names:

"It was found that these Appalachian Rocks were far from being sufficiently co-ordinate with the European Palaeozoic strata, under their British types, to bear their names; while, on the other hand, the special titles assigned to them in New York were deemed too local and too

Figure 53. Left: Henry Darwin Rogers, first State Geologist of Pennsylvania (from Merrill, 1920, pl. 29). Right: John Fulton, A.M.E.M. (photo courtesy of the Johnstown Flood Museum).

inexpressive, either of their position in the scale of Formations, or of their ruling characters, to be usefully applicable." (H. D. Rogers, 1858, I, p. vi).

He did use the European name "Paleozoic", and in the legend on the geologic map, he included the equivalent New York and European names, but he created his own nomenclature for the 15 Paleozoic formations he described. The formations were based upon the fossils and stratigraphic position, and the names given to the formation was reflective of its relative position. As Rogers (1858, I, p. vii) put it, he was:

"...suggesting metaphorically the different natural periods of the day...These names are--Primal, Auroral, Matinal, Lavant, Surgent, Scalent, Premeridian, Meridian, Post-Meridian, Cadent, Vergent, Ponent, Vespertine, Umbral, and Seral, meaning respectively the Formations of the Dawn, Daybreak, Morning, Sunrise, Mounting Day, Climbing Day, Forenoon, Noon, Afternoon, Declining Day, Descending Day, Sunset, Evening, Dusk, and Nightfall. Some such nomenclature, based on time, is, for many reasons, preferable to the inexpressive ones which rest for the most part on geographical terms, only locally correct, or on narrow and inconstant palaeontological characters."

Although these names worked well for Rogers, as the European names gained stature and acceptance, it was not always easy to correlate between the two name systems. Claypole (1883, p. 668) had an interesting comment concerning the Rogers nomenclature: "The transcendental nomenclature of Rogers is doomed to deserved extinction..." The Second Geological Survey abandoned the transcendental names in favor of the older and, by that time, more generally accepted names from New York and/or the system of Roman numerals (Lesley, 1883).

The Paleozoic strata of the Johnstown area Rogers put into four groups: 1) Ponent, that he said was the equivalent of the Catskill/Old Red Sandstone elsewhere (Lesley, 1876, p. 176, indicates that Rogers had the Ponent for the Lower Catskill only); 2) Vespertine, that according to Lesley (1876, p. 176) was the very upper part of the Catskill, and he reiterated when he said the Ponent was "...for the gray sandstone strata forming the peaks of the Catskill." Based on Rogers' description (see below) and what Platt and Platt (1877a, p. xxvi) said, I feel that although the Ponent may have included the very top of the Catskill, it must have extended up the section and into the Lower Carboniferous beds - up through the Burgoon (Pocono position); 3) Umbral which is in the Carboniferous, but above the Vespertine, with only red shales and sandstones - Mauch Chunk today; and (4) Seral, the rocks that include the coal seams (Pennsylvanian strata). Within the Seral, Rogers and his staff had a working subdivision of the coal measures. During the field season of 1838 the teams were able to see that the coal strata were divided into two groups separated by a series of beds with little or no coal. Rogers used this broad designation in his report (H. D. Rogers, 1858, II, Pt. 2, p. 956-957). The coal bearing strata were known, respectively from oldest to youngest, as the Seral Conglomerates, with a few workable beds (Pottsville Group); the Lower Coal Measures, also known as the Lower Productive beds (today the Allegheny Group), a middle series of beds without much mineable coal, the Barren series (the Conemaugh Group), and the Upper Productive beds (the Monongahela Group).

It is interesting to note that while Rogers marks the existence of Ponent

(Catskill) rocks within the Conemaugh River gorge through Laurel Hill on the large geologic map (Figure 54) and on the cross section of Laurel Hill, he does not mention it in his general description of Ponent rocks (H. D. Rogers, 1858, I, p. 142, and Map - western sheet). On top of the Ponent Rogers had his Vespertine Series that he found on the southeast base of Laurel Hill, a "...grey sandstone with beds of shale, terminating upwards in a grey calcareous sandstone; its thickness is 400 to 500 ft." (p. 143). The Umbral rocks were also found on the southeast flank of Laurel Hill, "...red shale, including, near its base, beds of light-blue sandy limestone, and near its superior limit grey and white argillaceous sandstone and iron ore. Its thickness is 370 ft." (p. 146). This is a good description of the Burgoon, Loyalhanna, and Mauch Chunk formations. The Seral rocks were exposed on the flanks of Laurel Hill and in the synclinal valleys.

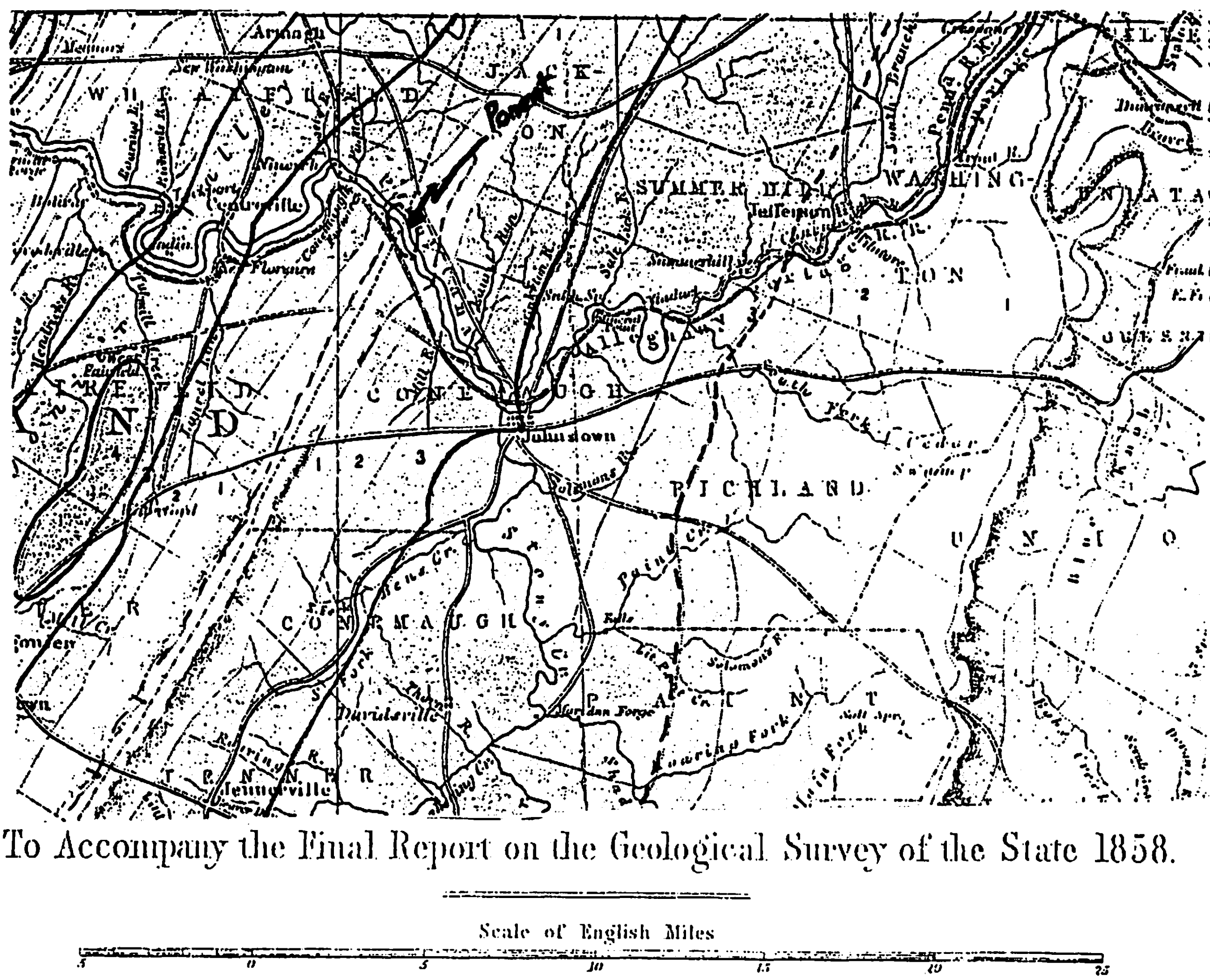


Figure 54. A portion of the western sheet of the state map prepared for the 1858 report of Henry D. Rogers. Key: Coal Measures; no. 1, 2, and 3 (oldest to youngest); Center of Laurel Hill - Umbral and Vespertine; Ponent found only in center of Conemaugh Gorge (marked on map).

In addition to describing the various coal seams of the area, Rogers makes note of the iron ore beds and the limestones associated with the coal in the region. Rogers and his group had difficulty with the order of the various coal seams and limestone layers because the limestones were not continuous throughout the area. He (H. D. Rogers, 1858, II, Pt. 1, p. 653) said:

> "By adhering to the limestone bands as fixed horizons, we are here greatly puzzled to affix names establishing the identification of the coal-beds."

Even in 1885 the nomenclature and stratigraphic order of the coal seams were still giving geologists problems. I. C. White used Rogers' general nomenclature of "Upper Coal Measures", etc., but in the detailed work he put the equivalent of the "Johnstown cement bed", the Johnstown limestone of today, under the Middle Kittanning coal (White, 1885). However, as White was adopting the Pennsylvania names, Henry M. Chance of the University of Pennsylvania, who had worked on the Second Pennsylvania Geological Survey, pointed out the error in White's nomenclature:

> "It will be seen that the Johnstown cement bed is placed by Prof. White beneath the Kittanning Middle coal, whereas the position assigned it by Mr. Wm. G. Platt (who first demonstrated that this was not the Ferriferous Limestone and added it to the series as a new member) is below the Kittanning Upper coal. Mr. Platt seems certainly the only Pennsylvania geologist entitled to fix the position of this member in the coal series, and his classification as given in Reports H5 and H has been adopted by the state geologists in subsequent work." (Chance, 1885, p. 41).

Figure 55A is the section Rogers gave for the typical Johnstown coal strata, but he does not indicate where it was measured. He does make special note of the iron ore bed in the upper portion, 60 ft (18.2 m) above the highest workable coal. Rogers indicates that this is the unit that the "Cambria Iron works" was mining extensively as early as the middle 1830's. He goes on to say:

> "Although mined for a long time on the N. side of the Conemaugh, it has not been detected on the S. side in its full thickness: examinations have been made of it [the iron ore layer]. The stratum has a roof and floor of slate, and is divided into two bands differing in character and thickness. The upper band varies in thickness from 18 inches to 2½ feet. Under good cover it quarries in square blocks...The Cambrian Iron Company work this ore with coke, and sometimes without limestone." (H. D. Rogers, 1858, II, Pt. 1, p. 653-654).

Although the measured section for Johnstown (Figure 55A) was not given a specific location, several other sections do. Figure 55B is a section on Stony Creek, "...at Red Bridge, above the mouth of Ben's Creek...", Figure 55C taken "...made half a mile W. of the latter [Figure 55B], and upon the slope of the 'Hog's Back'..." In this section Rogers identifies the coal as belonging to either the Clarion or Freeport formations. Figure 55D was measured on Paint Creek "...between the confluence of Paint Creek with Stoney Creek, and the Paint Creek Falls..." (The above quotations are from H. D. Rogers, 1858, II, pt. 1, p. 654-655.)

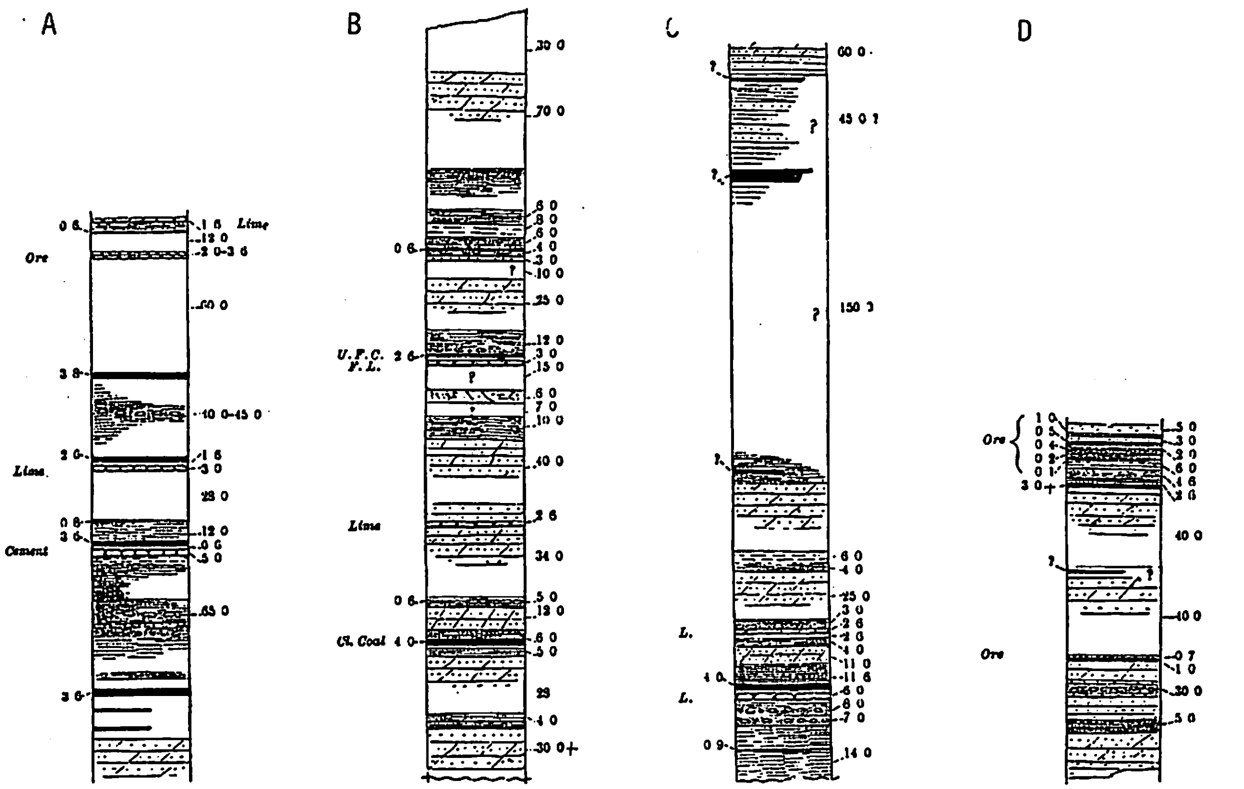


Figure 55 Stratigraphic sections (from H. D. Rogers, 1858). (A) Johnstown. (B) Stony Creek at Red Bridge. (C) One half-mile west of Red Bridge. (D) At Paint Creek.

Thus the teams from the First Pennsylvania Survey concentrated upon the economically exploitable resources in the area, but at the same time gave basic descriptions of the geology.

SECOND PENNSYLVANIA GEOLOGICAL SURVEY

The next major geologic work that was undertaken in the Johnstown area was during the Second Pennsylvania Survey created by an act of the legislature in May, 1874, and J. P. Lesley, who had joined the First Survey in 1839, became the director. The publications from this survey were to be small separate volumes about specific areas or specific topics rather than massing everything into one or two large books as Rogers had done. Lesley (1876) acknowledged that the first survey was, by its very nature, a reconnaissance because the people in the field had little to use beyond a compass and a hammer. The Second Survey was intended to fill in the detail and replace the earlier estimates with precision measurements (Lesley, 1876).

The Cambria County volume, published in 1877, was the work of Franklin and William G. Platt during the field season of 1875. For the sections around Johnstown they were assisted by Mr. John Fulton, General Mining Engineer for Cambria Iron Company (Figure 53). The stratigraphic nomenclature used by Platt and Platt is a strange mixture of Rogers' original names and the letter designation for the coal seams, but already some of the Rogers names were being replaced:

> "...four new names have been placed (proposed by the present State Geologist of Pennsylvania [J. P. Lesley] viz:
> Pottsville Conglomerate, for Rogers' "Seral," No. XII.
> Mauch Chunk Red Shale, for Rogers' "Umbral," No. IX.
> Kenawha Coal Measures, for Fontaine's "New River" Series.
> Pocono Sandstone, for Rogers' "Vespertine," No. X.
> This is done in order to get geographical names for the formations."
> (Platt and Platt, 1877a, p. xxvi).

However, they still used the general names of "Lower Productive Coal Measures" and "Barren Measures", etc. The Fontaine mentioned above was a professor at West Virginia University at Morgantown.

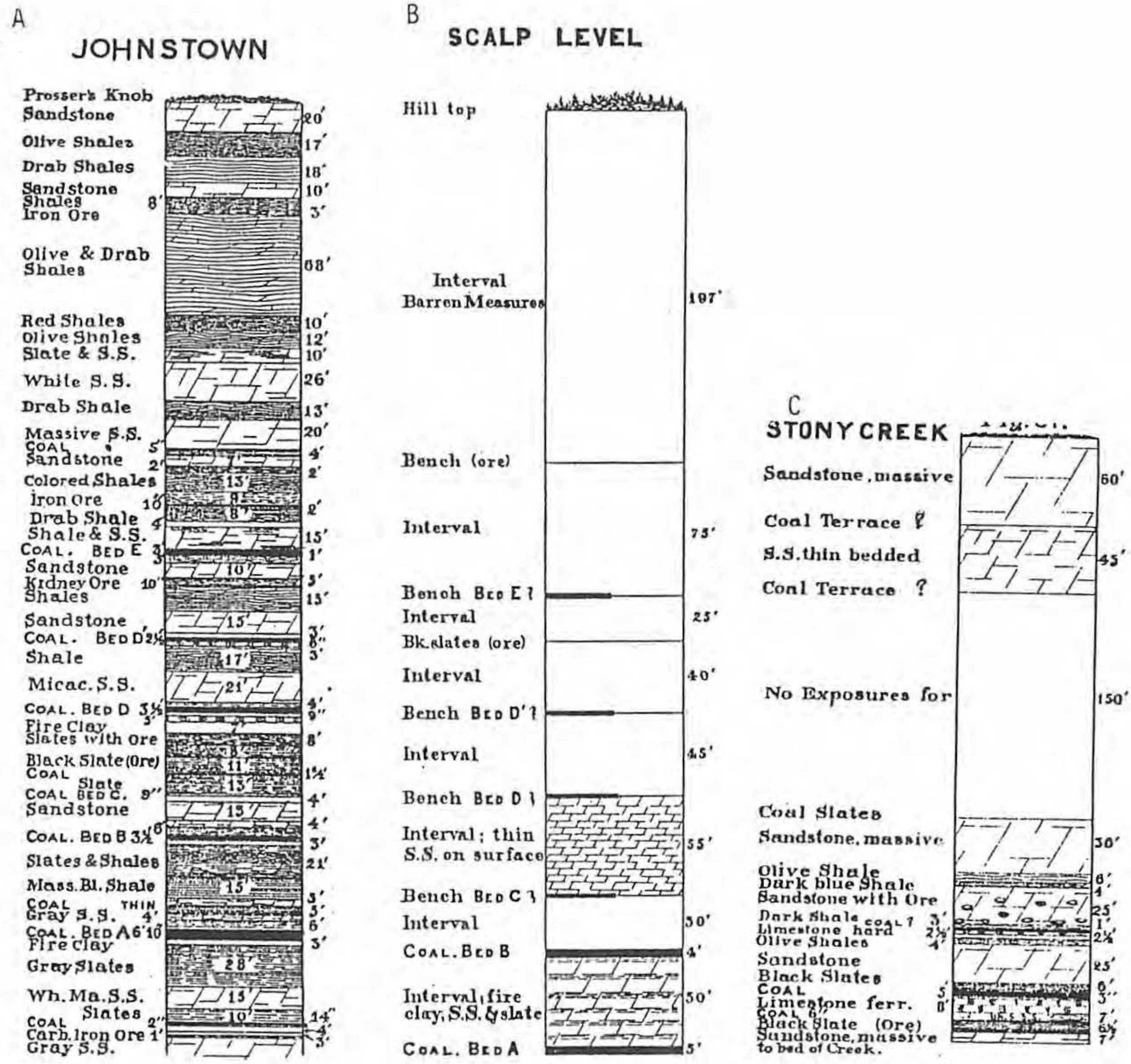
The Second Survey report gives detailed descriptions and measured sections across the Johnstown region. Figures 56A to C illustrate several of these and should be compared with the sections of Rogers' 1858 report. Figure 56D is a section measured within the gorge of the Conemaugh River, "...near the center of the arch, [and] gives the lowest measures exposed" (Platt and Platt, 1877a, p. 95), which would be the Upper Devonian strata. In addition, Platt and Platt give details of the iron ore beds in the region, especially one called the Johnstown Iron Ore. They noted, as did Rogers before them, that the iron ore beds are found only on the northern side of the Conemaugh River, despite repeated searches for it by them and Fulton. Analysis of the ore (Platt and Platt, 1877a, p. 117) reveals the following (assuming weight percent):

"Silica	4.885
Alumina	1.552
Carbonate of iron	52.330
Sesquioxide of iron	15.230
Carbonate of lime	15.285
Carbonate of magnesia	9.390
Phosporic acid	0.530
Sulfur	0.850
Water	[no value given]
Metallic iron	35.930"

By burning the ore in large piles near the mines to remove the carbonate, the iron content of some of the ores went up to 54.350 percent. Often the furnaces were charged with only the ore and coke, no extra limestone was needed due to the high carbonate content of the ore. Platt and Platt (1877a) noted that when they were doing their work in 1875, some of the iron ore beds already were mined out.

Details on the economically important clay deposits were missing from the earlier survey, but Platt and Platt fill that gap well with descriptions of location, geology, and analyses of the clay deposits in the region. One large deposit, almost 4 ft (1 m) thick, was being worked by Mr. A. J. Hawes just southwest of Johnstown that provided raw material to make the refractory items needed by the Cambria Iron Company.

The report provided quite detailed descriptions of the limestone layers that are found beneath several of the coal layers. Platt and Platt (1877a) mentioned



D

Red shale................	....	4'
Concealed, soil reddish..	....	12'
Red clay.................	....	5'
Red and olive shales....	....	8'
Olive shales	....	0' 6"
Olive sandstone and shales................	....	9'
Olive shales	....	2'
Red shales...............	....	3'
Sandstone (reddish)	....	2' 6"
Olive shales	....	1'
Red shales, with occasional thin bands of olive shales........	....	12'
Sandstone (reddish)	....	15'
Olive shales	....	1'
Red shales, with bands of olive shales........	....	7'
Olive shales.............	....	0' 6"
Red shales...............	....	12'
Massive sandstone (olive)	....	20'
Conemaugh river.		

Figure 56. Stratigraphic sections from Platt and Platt (1877a). (A) Johnstown section prepared by John Fulton; (B) Stony Creek; (C) Scalp Level; (D) Conemaugh Gorge in Laurel Hill, near the center of the anticline.

the difficulty that exists when trying to differentiate between limestone layers; the same problem that Rogers faced (see above). However, they seemed satisfied with the stratigraphic order after they realized that a unit known as the "Johnstown Cement Bed" was being confused with "Ferriferous Limestone" of the Allegheny River sections (see Platt and Platt, 1877b, Chapters XVII-XVIII). To make matters worse, what Platt and Platt call the Lower Freeport or coal bed D in the Johnstown area was known, in 1877, as the "Upper Kittanning" in the western part of the state. They listed only one Kittanning seam, coal bed C; bed B was identified as the Clarion and bed A as the Brookville (Platt and Platt, 1877a). In addition, where Platt and Platt have the "Johnstown Cement Bed" under their bed D or Lower Freeport in the Cambria County report (v. HH), by the time the Somerset volume was completed, the names and positions had changed because they found extra coal seams. The new grouping is seen in Figure 57.

Even as the Second Survey was drawing to a close and Lesley was preparing his summary (Lesley, 1895), changes were being made in the stratigraphic order of the coal seams in Cambria County. In the early portion of the summary, Lesley used information as it appeared in the county reports, but later he (Lesley, 1895, III, Pt. 2, p. 2221) modified it and added a footnote to warn the reader that previous plates in the summary were not really correct:

> "The reader must be careful to note the necessity to revise the names and letter of the coal beds in all sections prior to plate CCLXXXIX on page 1820, which plates have been reproduced in the early pages of this report by Prof. J. P. Lesley without any correction, from the original county reports. This remark does not refer to the revised plates in this report, subsequent to plate 396. (Lesley, 1895, III, Pt. 2, p. 2221).

Lesley's action appears to have been the final word, for he had the Johnstown Cement Bed under the Upper Kittanning coal, where it still resides today.

John Fulton, mentioned above (see Figure 53), was very active with the Second Geological Survey work in Cambria and Somerset Counties. Fulton had worked previously in the Broad Top coal fields and has a coal seam there named after him (Fulton, ND, II, p. 63). While working in the Broad Top area, Fulton became acquainted with J. P. Lesley and worked with him on some of the stra-

Allegheny River.	Terms used in Cambria and Somerset.	Re-grouping of Cambria and Somerset.
E. Up. Freeport C.	E. Up. Freeport C.	E. Up. Freeport C.
Freeport Limestone.	Freeport L.	Up. Freeport L.
D. L. Freeport C.	D'. Mid. Freeport C.	D. L. Freeport C.
	Mid. Freeport L.	L. Freeport L.
Freeport SS.	Freeport SS.	Freeport SS.
Coal.	D. L. Freeport C.	C'. Up. Kittanning C.
	Limestone, ferriferous,	Johnst'n Cement B.
C. Kittanning C.	C. Kittanning C.	C. L. Kittanning C.
Ferriferous Limestone.		

Figure 57. Revised nomenclature for coal and limestone layers (from Platt and Platt, 1877b, p. 316).

tigraphic problems there. In 1874, the same year that the Second Survey started, Fulton moved to the Cambria Iron Company in Johnstown. So it was only natural that Lesley called upon his friend from the Broad Top area to assist, not only with the Johnstown geology, but also to assist with mapping Cambria and Somerset Counties (Fulton, ND, II, p. 61 3/4).

Several of the sections in the Cambria County volume are the work of Fulton, (e.g. Platt and Platt, 1877a, pl. 47; see Figure 56A). When Lesley (1885) published the atlas of county maps, not all of them had been finished, at least not in detail. In 1886 Fulton became General Superintendent of the Cambria Iron Company, at the time the largest such operation in the United States (Lesley, 1876). Fulton's position of prestige was not overlooked by Lesley, for Fulton (ND, III, p. 137a) recorded in his diary:

> "In the fall of 1887, I received a sad note from my dear friend Prof. J. P. Lesley, State Geologist, of the Second geological survey of Pennsylvania saying, 'I have not money to go to market-' I immediately went to Harrisburg, and in company with Senator Lemon called on the Governor. The State at this time owed Prof. Lesley nearly $6000.00 - Inattention at Harrisburg.
>
> "Shortly after this I received a cordial note from Prof. Lesley saying, 'I have only $1100.00 left for the geological survey and mapping of Cambria and Somerset Counties, won't you undertake the work-' I employed a small force at very limited salaries, and the maps of these two counties were completed...The stupidity of the Legislature and its inability to grasp the value of this work was most discouraging."

Thus, although the county reports for Cambria and Somerset were published in 1877, the final county maps for them did not come out until 1888, eleven years later.

The maps, e.g. Figure 58, made by Fulton and his party, "Issac A. Harvey, Geologist; Alfred G. Prosser, M.E.; and Edward B. Harden, Top. & Assist. Geologist" (Fulton, 1889), do show considerably more detail than the ones in Lesley's (1885) county atlas, especially the older Catskill rocks that Lesley did not include at all. Fulton did not use the transcendental names of Rogers' (1858) report, but did use his more general terms, "Barren Measures" and "Lower Productive Measures" and common names such as "Pocono Series".

In the "Appendix to the Report of 1877" which, from the narrative, Fulton appears to have written in 1889, though no date is given in the heading, he wrote more about Cambria County. In these notes he brings in another natural resource of the region, natural gas, that first reached Johnstown in 1887. The first gas used in Johnstown came from a well at Grapeville in Westmoreland County, about 41 mi (65.9 km) away. Cambria Iron Company, Fulton's employer, drilled a test well at Johnstown in 1884, "...a short distance north of the Pennsylvania railroad passenger station...the top at 1189 feet above Ocean level, and 12 under the Cement coal bed, the third workable bed of the Lower Coal Measures." (Fulton, 1889, p. 364-365). The bottom of the hole was at a depth of 2,824 ft (860.8 m) below the top of the hole - 1,635 ft (498.3 m) below tide level. The well, whose log is reproduced in Figure 59, showed gas at 640 ft (195.1 m) down, 549 ft (167.3 m) above sea level, but not a strong flow. At

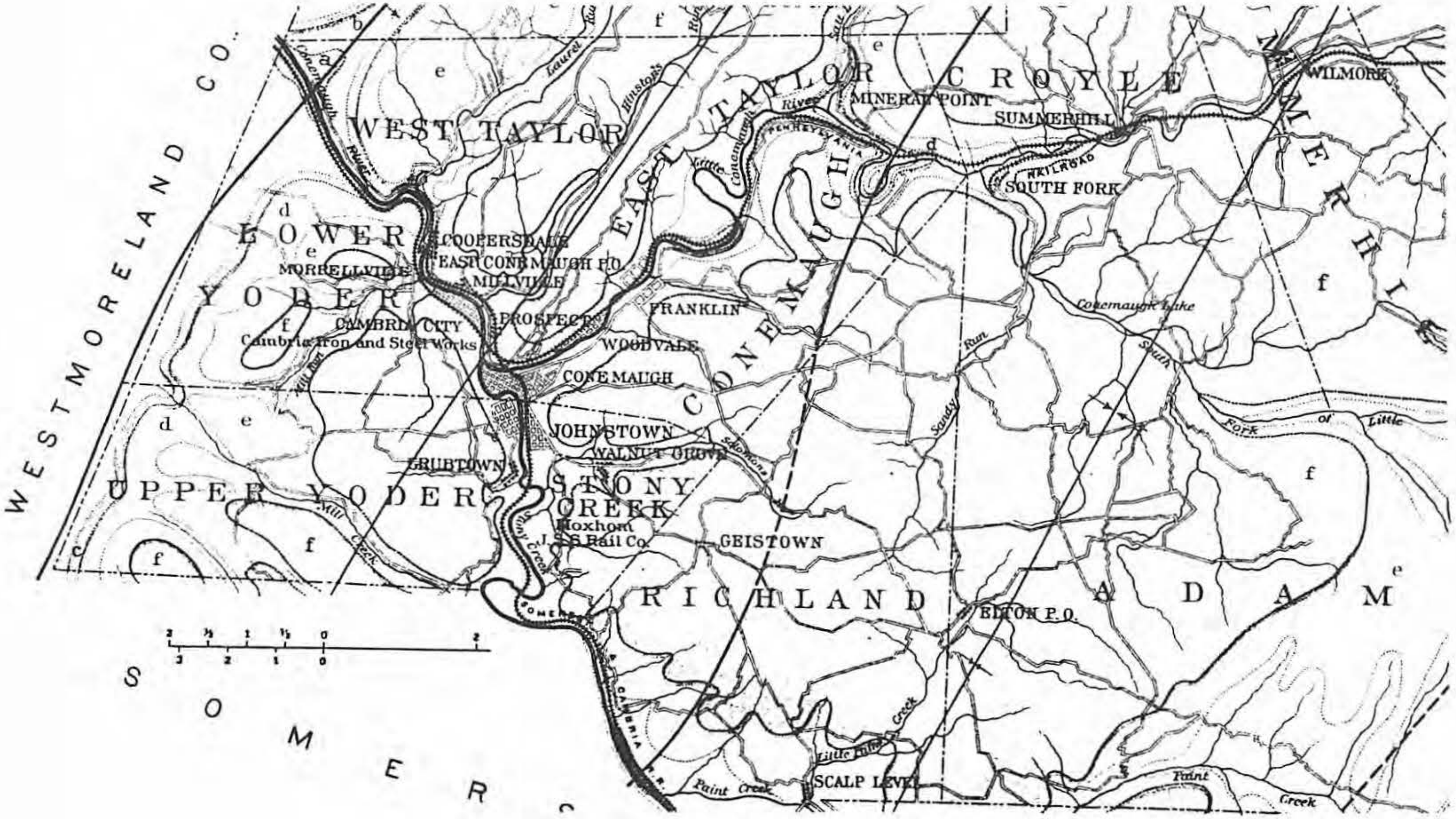


Figure 58. A portion of the Cambria County geologic map prepared by John Fulton in 1888 (from Fulton, 1889). Key: f = Barren Measures; e = Lower Productive; d = Pottsville Conglomerate; b = Pocono Sandstone; a = Catskill Sandstones and Shales. Scale is in miles.

Johnstown test hole for gas.

		Feet.	Feet.
Wash,		48 to	48
Slate,		30	78
Hard sandstone,		12	90
Slate and sandstone,		19	109
Coal,		1	110
Slate,		30	140
Hard fine sandstone,		50	190
Sandstone,		15	205
Slate and sandstone,		5	210
Coal,		3	213
Hard sandstone,		15	228
Slate and sandstone,		5	233
Coal,		2	235
Hard sandstone,		15	250
Slate,		7	257
Hard blue sandstone,		46	303
Gray sandstone,		20	323
Red slate.		20	343
Slate,		27	370
Red sandstone,		15	385
Slate,		12	397
Hard sandstone,		10	407
Red rock,		25	432
Red sandstone,		18	450
White sandstone,		35	485
White slate,		15	500
Hard blue sandstone,		25	525
White sandstone,		75	600
Slate,		15	615
Gas,	+519		640
Salt water,	+509		680
Sand rock,		100	715
Red rock,		3	718
Hard sandstone,		65	783
White pebbly clay,		2	785
Gas,	+389		800
Shaly sandstone,		40	825
Hard sandstone,		85	910
Slate and shales,		60	970
Black sandstone,		15	985
Black slate,		30	1015
Sandstone,		75	1090
Slate,		90	1180
Shales and sandstone,		60	1240
Black slate,		45	1285
White sandstone,		15	1300
Slate,		18	1318
Gray sandstone,		20	1338
Shaly slate,		50	1388
Sandstone,		20	1408
Slate,		30	1438
Red shale,		15	1453
White sandstone,		20	1473
Slate and shale,		60	1533
Red shale,		30	1563
Gray sandstone.		75	1638
Red rock and shales,		340	1978
Salt water,	—941		2130
Slate and shales,		200	2178
Red slate,		25	2203
Slate and shales,		80	2283
Slate and shales,		200	2483
Red rock,		35	2518
Sandrock,		15	2533
Slate,		55	2588
Red rock,		30	2618
Slate and shales,		125	2743
Red rock, (Salt water,)	—1635	81	2824

Figure 59. Well log from a gas well in Johnstown, near the railroad station, drilled in 1884 (from Fulton, 1889).

800 ft (243.8 m) depth, a second gas horizon was struck, but even less flow than the first one. Gas was not plentiful, but salt water was; at 640 ft (195.1 m) depth and again at 2,130 ft (649.2 m). At least the test indicated a source for the natural gas that was a problem in the mines, rising from below through the cracks and fractures in the rocks. Fulton felt the gas bearing horizons were in the "Pocono Sandstones" or "Formation X".

Mr. A. J. Haws (Hawes?) put down another well at Sag Hollow in West Taylor Township that struck gas at 846 ft (257.9 m), 301 ft (91.5 m) above tide level, but the gas flow was weak in this well also. The top of this well was in the Catskill and started at an elevation of 1,147 ft (349.6 m). Although there was little gas flow, Haws got a good flow of salt water (Fulton, 1889).

CONCLUSION

Shortly after the turn of the century, a U.S. Geological Survey team, W. C. Phelan and Lawrence Martin, came to the Johnstown area and worked under the supervision of George Ashley of the Pennsylvania Geological Survey. This joint effort during the field season of 1906 produced a folio atlas (Phalen, 1910) and a bulletin (Phalen and Martin, 1911), but, by that time, the basic geology had been established; established by the people of the First and Second Surveys and by those early settlers who noticed the economic potential of the native rocks. Generally when people are concerned with the geology around Johnstown, the earliest references listed are the two USGS publications mentioned above. As I have illustrated here, however, there was a long and productive history of geologic exploration in the region before Phalen and Martin came on the scene.

THE FLOODS OF JOHNSTOWN

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It is well known that Johnstown's best claim to fame is derived from its floods. For years, however, civic leaders preferred to talk about everything but this notoriety. In this, the centennial year of the 1889 flood, the community seems to have finally accepted this part of its history.

In terms of location, Johnstown is well situated in living up to its nickname "Flood City". It is nestled in a narrow valley at the confluence of the Little Conemaugh and Stonycreek rivers, which in turn form the Conemaugh River. The city and its satellite communities on the flood plain are flanked by steep valley walls having a relief in excess of 1,000 ft (305 m). From the highlands around the city a well-developed dendritic drainage pattern delivers runoff from approximately 657 sq. mi (1,700 sq. km). In addition to the local topography, the flooding potential is further enhanced by the fact that Johnstown is located along the western edge of the Appalachians and therefore experiences increased precipitation due to orographic effects.

Johnstown is prone to both regional flooding and flash flooding. Regional flooding is characterized by a slowly rising river stage over several days due to prolonged, but not necessarily intense, precipitation. An example of this type flood is be the 1936 event. Flash flooding, on the other hand, is far more common in the area. This type is caused by high-intensity rainstorms over short periods of time. The result is highly localized flooding; the 1977 flood is be a good example.

Since the early 1800's the Johnstown area has experienced at least 47 floods. The majority of these floods were due to natural conditions, but a few were enhanced by the activities of man. The best example of this was the 1889 flood.

THE 1889 FLOOD

On the 28th of May, 1889 a large storm system began to form in eastern Kansas and Nebraska (Blodget, 1890). As the storm moved eastward it dropped 2 to 4 in of rain in the Ohio valley, but there was no cause for great alarm because barometric readings indicated only a moderate storm. However, by the 30th, as it approached the Allegheny Front, the storm intensified due to orographic effects. By the afternoon of the 30th rain was falling in the area from Johnstown to Harrisburg. The storm continued on the 31st and by 11 a.m., the Johnstown weather observer had reported 2.3 in (Blodget, 1890). By this time there was already some flooding in downtown Johnstown, but the populace, having experienced this sort of thing many times in the past, considered it more of a nuisance than a cause for alarm. It is not clear what was the total precipitation amount because the Johnstown station observer (a Miss Ogle) became one of the casualties in the subsequent flood. Blodget (1890) estimated that the Johnstown valley received 3 to 3.5 in of rainfall, and that the highlands areas perhaps twice that amount. The Franklin Institute isohyetal (equal rain-fall) map for the storm shows Johnstown experienced 5 to 6 in for the 26 hour duration of the storm. What is clear is that the area east of the Allegheny Front was actually hit harder by the storm than Johnstown. For example, the storm dumped 8.2 in on Harrisburg, 8.99 in on McConnellsburg, and caused record flooding in the Juniata River valley (Blodget, 1890). Floods also devastated the James and Potomac River basins in maryland and Virginia, and the upper Allegheny River and Genessee River in New York. Of all the destruction caused by this storm system, across an area in excess of 12,000 sq mi (31,000 sq. km), however, it is the flooding in Johnstown that is remembered to this day.

The obvious reason is the exceptionally high death toll. Out of a population of 20,000 to 30,000 people, the local communities had at least 2,200 reported deaths, with an additional 1,000 people reported as missing. It was not the regional flooding that caused the destruction but the failure of South Fork Dam (see the description for Stop #10). Twenty million tons of water contained in Lake Conemaugh swept down the Little Conemaugh River valley as a flood wave. Shortly after 3 p.m. the flood wave reached the Conemaugh Viaduct two mi (3.2 km) below the dam site. The viaduct was a 78.5 ft (23.9 m) high stone arch built in 1834 for the Portage Railroad across the neck of an oxbow meander immediately upstream from Mineral Point (Figure 60). Initially the viaduct held against the water's onslaught, creating a debris dam in the river. Before it failed, the river had backed up debris until it topped the arch. When the viaduct finally failed, a rejuvenated flood wave rushed toward Johnstown, destroying riverside communities along the way. When the debris-laden water reached Johnstown shortly after 4 p.m. the height of the flood wave was estimated at 36 ft (10.9 m) (McCullough, 1968). Those parts of the city that were not immediately destroyed were inundated by up to 24 ft (7.3 m) by backwater effects from a 1/2 mi (0.8 km) long debris jam that had formed at a stone railroad bridge just downstream from the confluence of the Little Conemaugh River and Stone Creek (Figure 60; also, see road log for Day 1). Figure 61 illustrates scenes of downtown Johnstown before and after the flood.

The flood of 1889 was the greatest human catastrophe in the United States up to that time. It was also the occasion of the first national relief effort by the newly organized American Red Cross. The general flooding across central Pennsylvania also finished off what was left of the state's canal system (Blodget, 1890).

THE 1936 FLOOD

After the 1889 flood Johnstown was rebuilt in the same ill-chosen place. Small-scale flooding was almost a part of normal life. Flood stage was reached or exceeded every year until 1913 (U.S. Corps of Engineers, 1949). Local channel improvements at the time raised the level of the flood stage and there were "only" 14 floods between 1913 and 1936. However, none of these floods involved catastrophic loss of human life or property and, therefore, it was not until St. Patrick's Day in 1936 that Johnstown once again made national headlines.

A large storm system moved across the northeastern Mississippi Valley causing widespread flooding. The major river systems in western Pennsylvania were especially hard hit. In the area around Johnstown the rainfall amount was not extremely great, about 5 in during March 17 and 18. However, the melting of up to 2 ft (0.6 m) of snow cover, combined with frozen ground conditions, resulted in a flood stage only about 4 ft (1.2 m) lower than the 1889 flood. There was a major difference, however, as it took 36 hours for the flood waters to crest. Altogether in a five county area there were about 25 deaths from

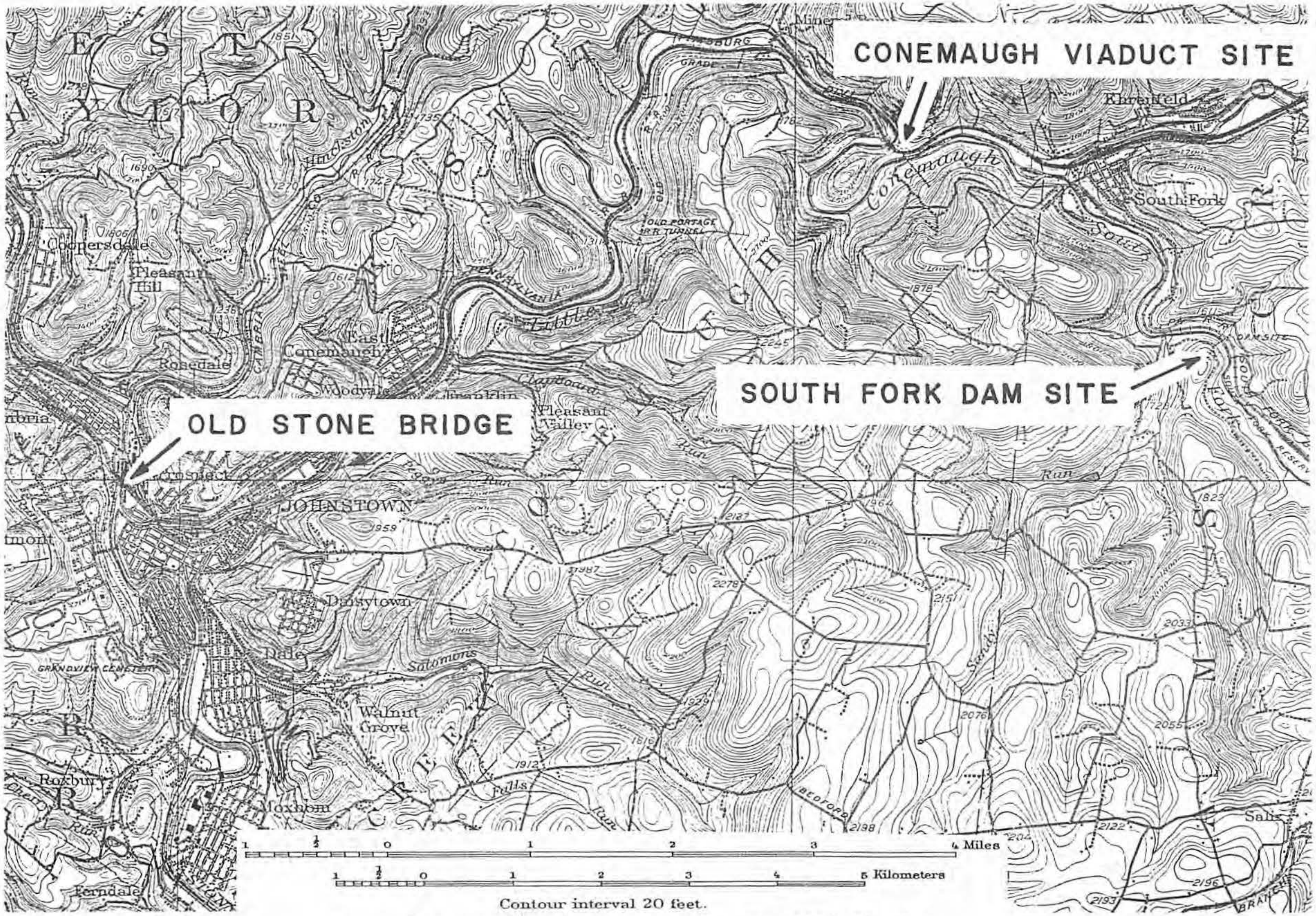


Figure 60. Location map for the 1889 flood.

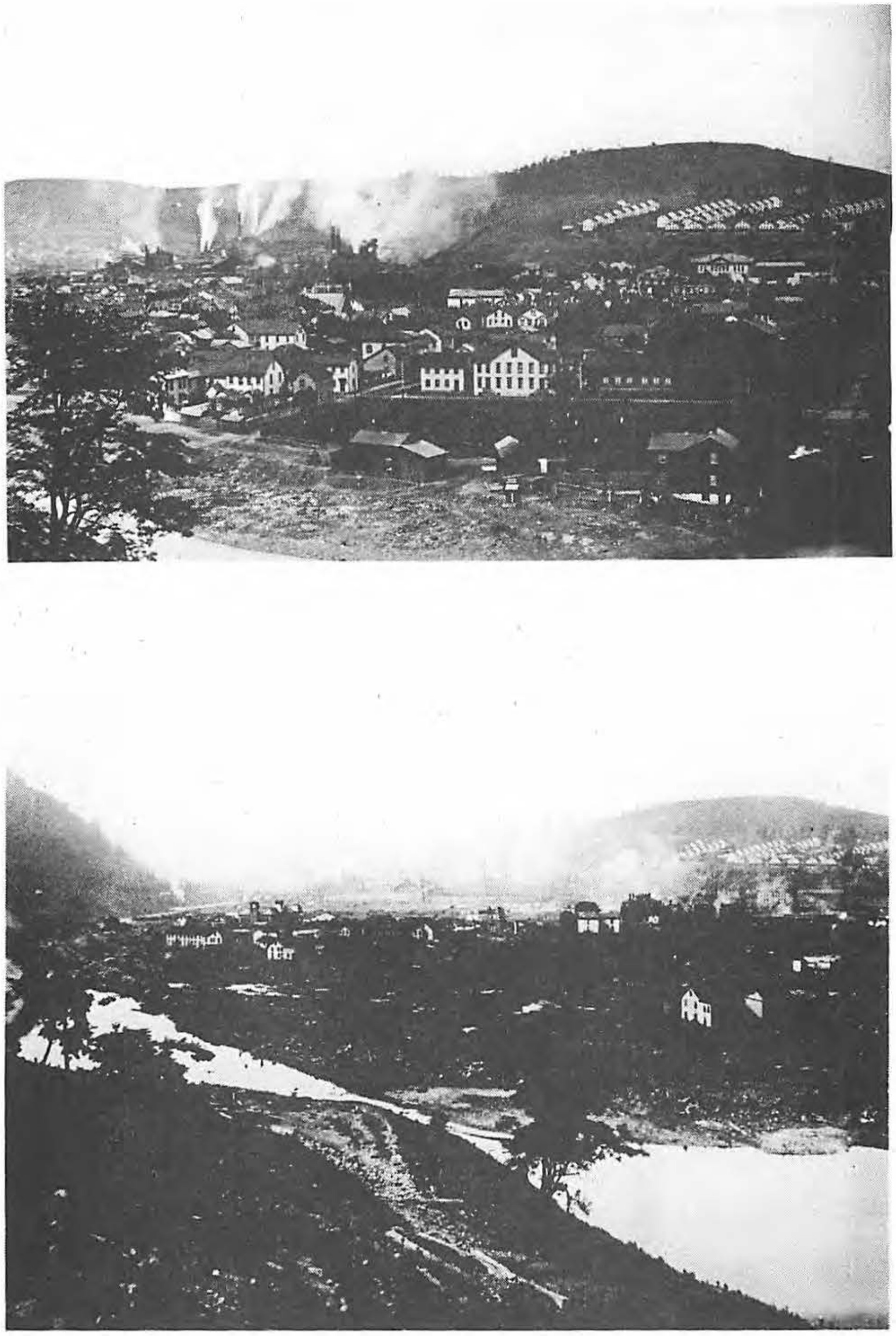


Figure 61. Scenes from the Johnstown flood of 1889. Top: Photograph of downtown Johnstown taken the day before the flood. Stony Creek is in the foreground. The smokestacks on the left identify the Cambria Iron works. Note the lack of vegetation on the surrounding hills. Bottom: Photograph of the same area taken a few months after the flood. Photos courtesy of the Johnstown Flood Museum.

various causes. But by 1936 Johnstown had become a fair-sized industrial city and the resulting property damage was close to $50 million (in 1936 dollars). Johnstown had once again been visited by a major disaster and flood relief again poured into the area. At first it seemed as if the local citizens would just "take their lumps", rebuild and go on as usual. But in August, 1936 President Franklin Delano Roosevelt, on the campaign trial for his second term of office, came to town. Since campaign speeches are, by definition, filled with promises, it is perhaps not startling that F.D.R. promised the good citizens that, if elected, he would see to it that Johnstown got a flood control project. Roosevelt was, of course, reelected, but at first there was no sign of any federal flood control project. The U. S. Army Corps of Engineers had surveyed the situation, decided that it was not feasible to construct flood control reservoirs in the area, and had abandoned the project.

A flood in May of 1937, however, galvanized the local leaders to take matters into their own hands. Cambria County approved a sum of $2 million toward channel improvements and then proceeded to lobby Washington for the project. The Corps of Engineers was greatly impressed by the willingness of the locals to spend their own money and was most willing to do the work. The only problem was that the Corps, up to that time, was not empowered to construct channel improvements on nonnavigable waterways such as the rivers in the Johnstown valley. Special legislation was eventually passed to remedy this problem and the project was begun in August, 1938. The Johnstown flood protection channel was then the first of its kind to be built by the Corps. The project extends along 9 mi (14.5 km) of the downtown reaches of Stony Creek and the Little Conemaugh and Conemaugh Rivers. Channels were widened and deepened, bank slopes paved with concrete, dikes and flood walls erected, and certain channel obstructions removed. The channel was designed to accomodate a 1936-magnitude flood of 83,000 cfs in the vicinity of the Old Stone Bridge. Total cost of the project was $8.7 million when completed in 1943.

It is important to understand the psychological effects of a flood control structure on the local inhabitants. There was a tendency, whether justified or not, for people to assume that they were protected from any and all flooding. And so it was decreed that all high water marks were to be eradicated from downtown buildings and Johnstown should henceforth be known as the "Flood Free City". Furthermore the civic leaders urged citizens to write to friends and relatives all over the country to proclaim Johnstown's "flood free" status and to drop the word "flood" in reference to the city for all time.

THE 1977 FLOOD

During the period from early through mid-July, 1977 the Johnstown area experienced frequent thundershower activity with the total rainfall ranging from 2 to 5 in and Johnstown itself receiving an additional 1.34 in during the two days preceding the flood. Consequently, the soil conditions were close to their infiltration capacity.

The night of July 19, 1977 seemed to be a typical summer night around Johnstown with relatively high temperatures and humidity. The forecast of the weather bureau office in Pittsburgh for that day was for thundershowers throughout Pennsylvania, drifting eastward and diminishing during the evening/early night hours.

As the day progressed, a line of cumuliform clouds developed along an east-west line from eastern Indiana state to Johnstown, Pennsylvania. It was from this line of activity during the late evening hours that a thunderstorm approached the Johnstown area from the northwest. The major attention of the staff at the weather bureau office in Pittsburgh was to thunderstorms in northern and eastern counties of the state that were producing some high winds and heavy showers. But in general, as they watched their radar screens, everything appeared as expected; the storms were drifting eastward and diminishing in size. To the inhabitants of Johnstown and vicinty, the storm appeared somewhat differently.

There were three basic differences to this one as compared to the usual summer storms. First, there was almost continuous lightning, mostly of the cloud-to-cloud variety, that gave the Johnstown region almost continuous illumination. The second difference was the extremely slow movement of the storm. Typical summer thunderstorms usually travel about 30 to 35 mi per hour, but this particular storm took six hours to pass over the Johnstown region. The last factor, which is linked to the second one, is the rainfall. The rate of precipitation of 2 in per hour is not that unusual in a thunderstorm, but combined with the "snail's pace" movement, the storm produced record amounts of rainfall in the river basins surrounding Johnstown.

Consequently, between the hours of 8 p.m. of the 19th and 4 a.m. of the 20th, the area was drenched with up to 12 in of rain (Figure 62). Johnstown itself received 8.9 in as compared to an average precepitation for the month of July of 4 to 4.5 in. Although the rainfall total alone was sufficient to cause flooding, it was the rate of precipitation that was responsible for the severity of the flood. In the period from 8 to 11 p.m. on the 19th the rain gauge at Johnstown recorded 4.4 in and small-scale flash flooding was occuring on the upland tributaries of the basin. An additional 4.5 in fell between 11 p.m. and 4 a.m., but the flood crest in the trunk streams was the result of 2.2 in within a 40-minute period around 3 a.m. (Figure 63). The result was a dramatic increase in river stage. For example, the Conemaugh River at Seward (downstream from Johnstown) rose about 9 ft (2.7 m) in one hour (Figure 64). It was the rapid rise in flood stage that accounted for the high death toll (82) and extensive property damage ($140 million).

As for the weather bureau, in retrospect, they did not suspect that any of the storms would intensify as their size diminished, as did the one at Johnstown. One "saving grace" was the fact that the size of this storm was relatively small and affected much less than half of the nearly 700 sq. mi (2,065 sq. km) drainage basin upstream from Johnstown. Had the entire basin received the above rates of precipitation, Johnstowners would have experienced a much greater catastrophe.

But why didn't the flood control project protect Johnstown? The answer to this question is not a simple one. First of all the channel improvements were only on the trunk streams in the downtown area because the project was designed to cope with a regional flood such as had occurred in 1936. The 1977 event was a flash flood that caused extensive flooding along small tributaries draining the highlands. The surface runoff was so extreme that in some cases overland flow as deep as 3 ft (0.9 m) cascaded down the valley sides (U.S. Corps of Engineers, 1979). Yet another part of the problem lies with the fact that it is not economically feasible to build flood protection that would contain all

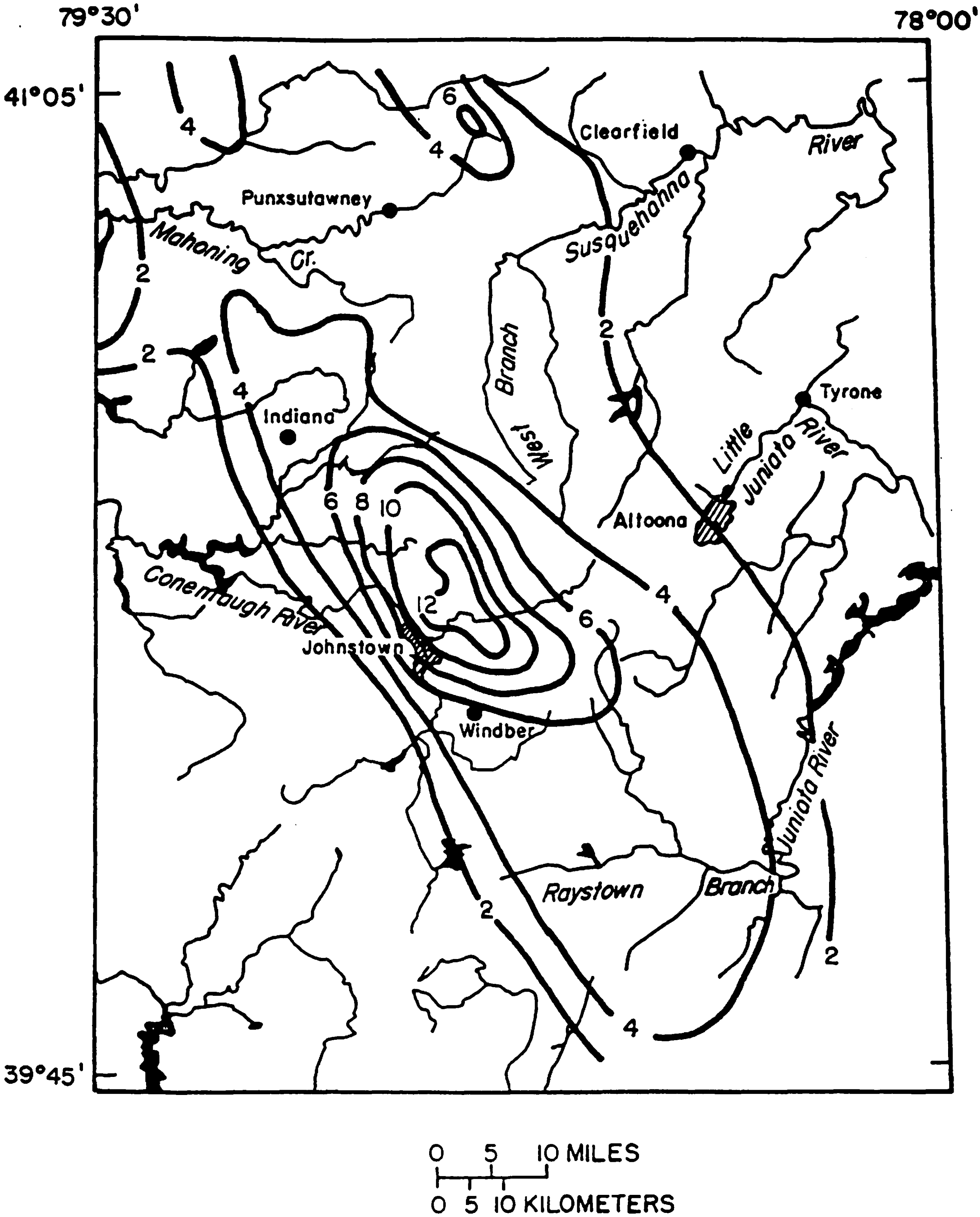


Figure 62. Isohyetal map of total precipitation (in inches) for the storm of July 19-20, 1977 (from Brua, 1978).

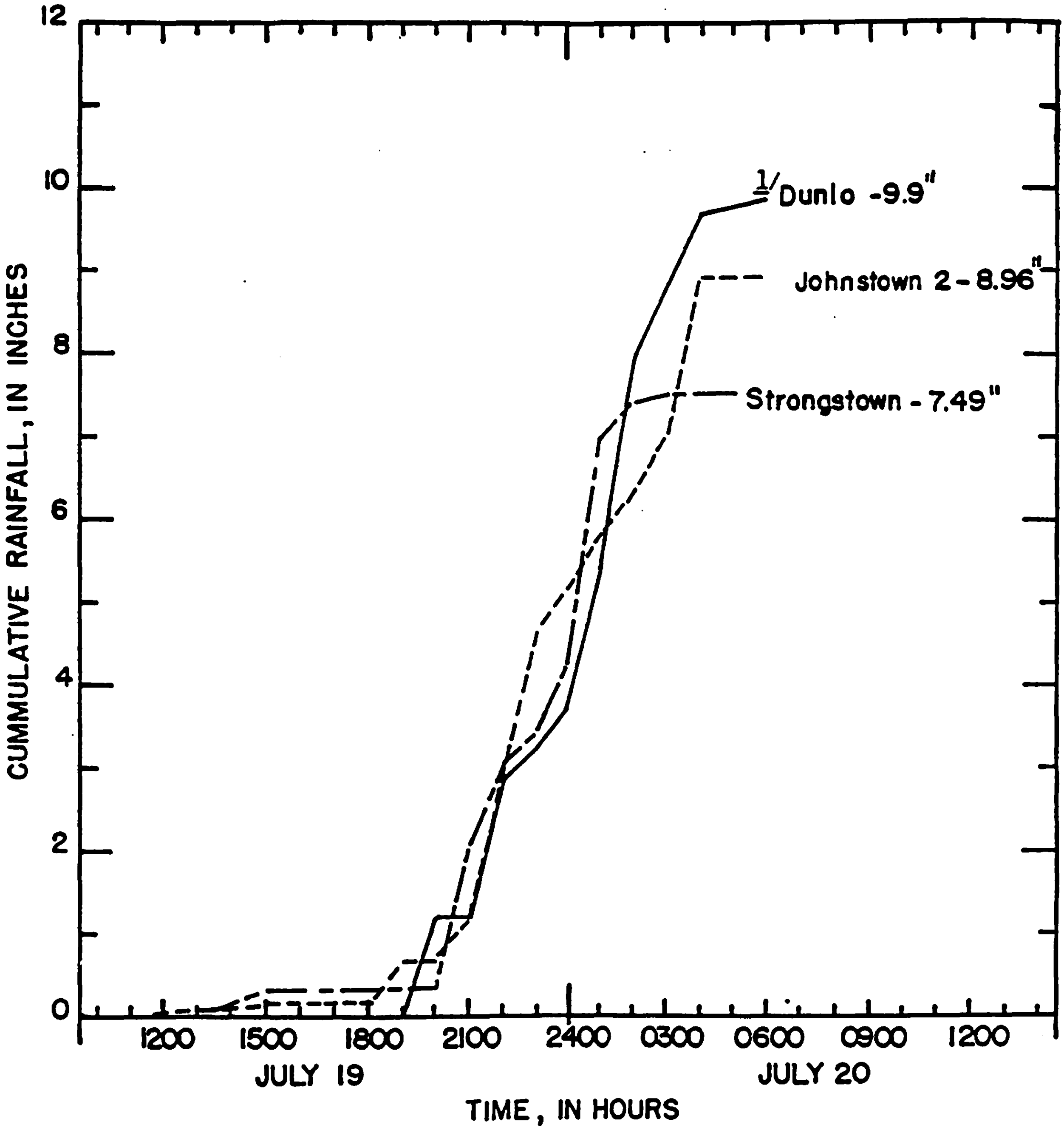


Figure 63. Cumulative rainfall amount at stations in the Johnstown area (from Brua, 1978).

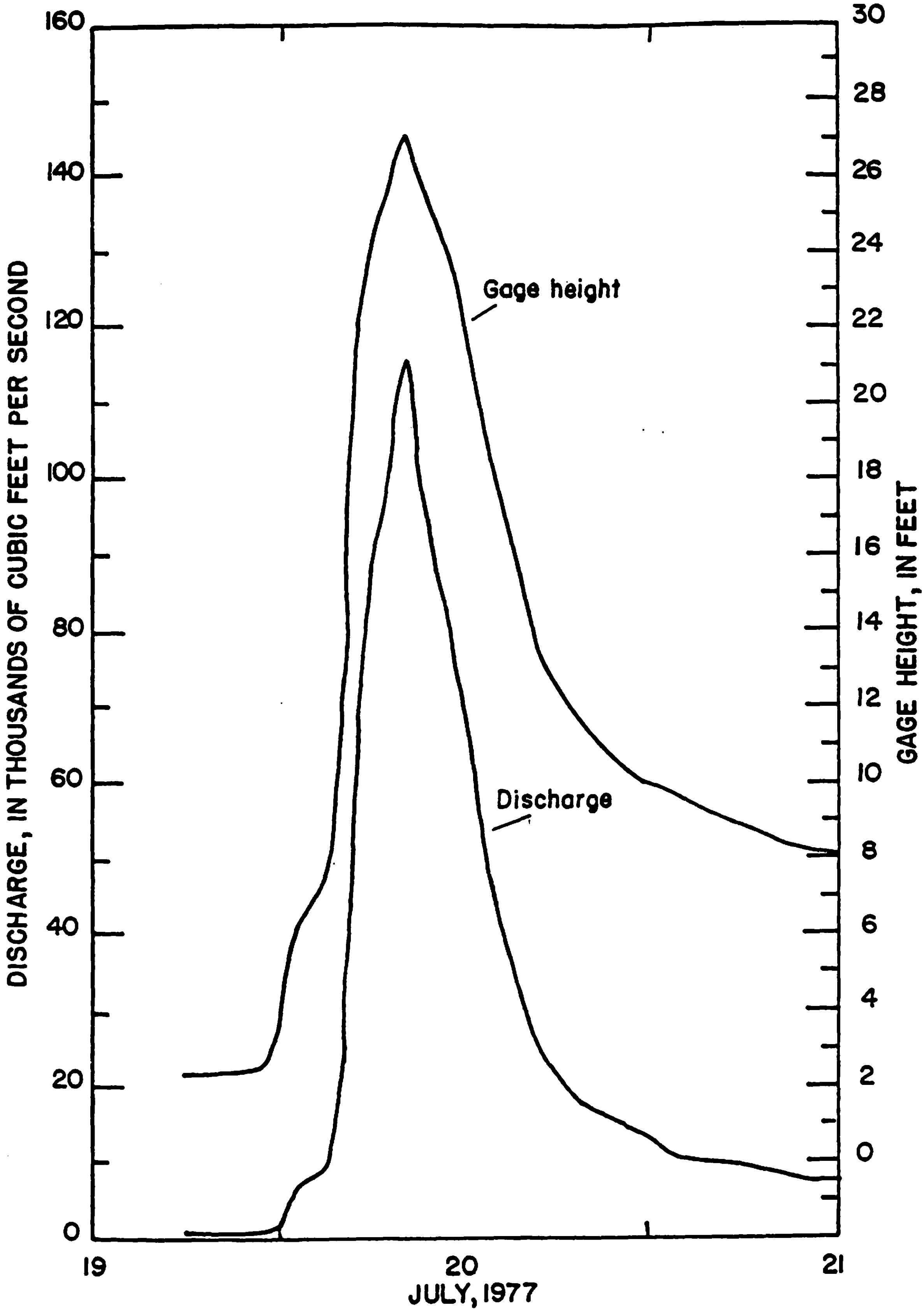


Figure 64. Flood hydrograph for the Conemaugh River at Seward (from Brua, 1978).

possible floods. The Corps of Engineers' design was for what they believed to be the 100-year recurrence interval (R.I.) event.

The calculated return frequencies for the Conemaugh and Little Conemaugh Rivers were somewhat in excess of 100 years, their respecitve flow (Q) being 115,000 and 40,000 cfs (Brua, 1978). It should also be noted that for a storm of this type return frequencies will vary from one drainage to another. For the tributary streams they ranged from in excess of 10,000 years to a few hundred years. However, the SCS Upland Method used to calculate these extremely low frequencies consistently gives a lower Q for a given R.I. and, therefore, the values should be accepted with some reservation. Nevertheless, the fact remains that the tributaries experienced extraordinarily high-magnitude events.

It is common knowledge that urbanization affects flood magnitude and frequency. After the 1977 flood there were questions as to how urbanization might have played a part in the disaster. Calculations for the most heavily urbanized basin (Sams Run) show that there would theoretically be a 90 percent reduction in runoff lag time between a natural basin and one that was completely urbanized with 100 percent of the area serviced by storm sewers and a channelized stream. At first glance it would seem that urbanization might have been a major factor. However, the effect on runoff per unit area (cfsm) is greater for the higher frequency, lower magnitude events, with a general trend toward greater flashiness, and lower baseflow.

Analyses of discharge data for the main rivers shows no trend over the years in increasing magnitudes for the $Q_{1.58}$ or $Q_{2.33}$ events, nor is there any measurable change in the baseflow recession constant. This is really not surprising since the basins are relatively large and as a whole have only 5 to 6 percent urbanization. However, the tributaries in the Johnstown area have up to 65 percent urbanization in some cases. Unit discharge on these tributaries ranged from 573 to 2,390 cfsm (Brua, 1978). This latter value is one of the highest known runoff rates in the northeast. This particular basin is completely unurbanized and the runoff amount was affected solely by the intensity of precipitation in the area. In general, a comparison of urbanized and unurbanized basins in the region shows no discernable increase in cfsm that can be clearly attributed to urbanization.

There are a number of reasons for this. First of all the high antecedent moisture conditions, coupled with the extremely heavy and high intensity rainfall, produced a situation where the area behaved pretty much like a huge parking lot. Infiltration capacity was close to zero and natural depression storage was full. Another factor masking any urbanization effect was the very high topographic relief and the steep stream gradients, maximum gradients being in excess of 200 ft/mi (38 m/km). Even the effect of storm sewers on lag time was overridden because their design capacity was usually for a 10-year R.I. Although they did not have an effect on peak Q, in a number of cases they did contribute to local problems. This was especially true for some homeowners along Sams Run who discovered artesian flow conditions in their toilets.

It should not be assumed, however, that man's activities did not play a part in the disaster. For example, seven small dams failed, adding to the flood waters. The largest of these, Laurel Run Dam, accounted for almost one half of the flood victims (see the description for Stop #5). The other major problem involved bridges and culverts. In both cases they served as obstructions to water flow and often resulted in the flood waters overtopping the channel banks. With the culverts the problem can be attributed in large part to the fact that they were emplaced long before intensive urbanization. As in any design problem both costs and benefits have to be considered. Therefore, in a semi-rural area, culverts having a 5 to 10-year R.I. design capacity may be perfectly acceptable. However, the discharge capacity of these structures is usually not adjusted as an area is urbanized, and the cost/benefit ratio changes. Perhaps the best example of this is Sams Run. Prior to channel improvement, culvert capacity from Lorain Borough downstream decreased almost 90 percent as the drainage area increased. Furthermore, some of the culverts had their capacity reduced by up to 80 percent by sedimentation and a number of them had debris racks installed across the upstream opening. The combination of the various restrictions forced Sams Run to occupy an alternate channel, which happened to be a main thoroughfare.

It is interesting to note that each of the three great floods of recorded history in Johnstown had somewhat different causes. The famous 1889 flood was the result of a prolonged, late spring rain and a catastrophic dam failure. The 1936 "St. Patrick's Day" flood was the result of a combination of early spring rains with the melting of an unusually high snow accumulation from the previous winter that affected wide areas of Pennsylvania and surrounding states. The 1977 flood was the result of intense precipitation over many hours in a relatively small geographic area, compounded by dam failures.

Of course, there are a few MINOR problems in the spring due to melting snow, but you have to admit that the view is beautiful!!!

(From Freedman, 1977)

REFERENCES CITED

Abel, K. D., and Heyman, L. (1981), The Oriskany Sandstone in the subsurface of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 81, 9 p.

Adams, R. W. (1970), Loyalhanna Limestone - cross-bedding and provenance, in Fisher, G. W., and others, eds., Studies of Appalachian geology: central and southern: Interscience Publishers, New York, p. 83-100.

Allen, J. R. L. (1965), Fining upwards cycles in alluvial successions: Geological Journal, v. 4, p. 229-246.

——— (1970), Studies in fluviatile sedimentation: a comparison of fining-upwards cyclothems, with special reference to coarse-member composition and interpretation: Journal of Sedimentary Petrology, v. 40, p. 298-323.

Aller, R. C. (1982), Carbonate dissolution in nearshore terrigenous muds: the role of physical and biological reworking: Journal of Geology, v. 90, p. 79-95.

Arkle, T., Beissel, D. R., Larese, R. E., and others (1979), The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States - West Virginia and Maryland: U.S. Geological Survey Professional Paper 1110-D, p. D1-D35.

Ashburner, C. A. (1880), The geology of McKean County, and its connection with that of Cameron, Elk and Forest: Pennsylvania Geological Survey, 2nd ser., Report R, 371 p.

Ashley, G. H., and others (1933), Classification and nomenclature of rock units: Geological Society of America Bulletin, v. 44, p. 423-459.

———, and Sisler, J. D. (1933), Stratigraphy of the oil and gas fields of Pennsylvania, in Sisler, J. D., and others, Contributions to oil and gas geology of western Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 19, p. 5-15.

Barwis, J. H. (1985), Tubes of the modern polychaete Diopatra cuprea as current velocity indicators and as analogs for Skolithos-Monocraterion: Journal of Paleontology, v. 59, p. 225-235.

Bates, R. L., and Jackson, J. A., eds. (1980), Glossary of Geology: American Geological Institute, Falls Church, VA, 751 p.

Batten, R. L. (1972), The ultrastructure of five common Pennsylvanian pleurotomarian gastropod species of eastern United States: American Museum Novitates 2501, 34 p.

Baumann, D., and Keller, W. D. (1975), Bulk densities of selected dried and fired kaolin clays: Clays and Clay Minerals, v. 23, p. 424-427.

Bayles, R. E. (1949), Subsurface Upper Devonian sections in southwestern Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 33, p. 1682-1703.

Berg, T. M., Barnes, J. H., Sevon, W. D., and others (1989), Physiographic provinces of Pennsylvania, 2d ed.: Pennsylvania Geological Survey, 4th ser., Map 13.

———, and Dodge, C. M., compilers (1981), Atlas of preliminary geologic quadrangle maps of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 61.

———, and Edmunds, W. E. (1979), The Huntley Mountain Formation: Catskill-to-Burgoon transition in north-central Pennsylvania: Pennsylvania Geological Survey, 4th ser., Information Circular 83, 80 p.

———, ———, Geyer, A. R., Glover, A. D., and others (1980), Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 1.

———, McInerney, M. K., Way, J. H., and MacLachlan, D. B. (1986), Stratigraphic correlation chart of Pennsylvania, revised: Pennsylvania Geological Survey, 4th ser., General Geology Report 75.

Bjerstedt, T. W. (1987), Latest Devonian-Earliest Mississippian nearshore trace-fossil assemblages from West Virginia, Pennsylvania, and Maryland: Journal of Paleontology, v. 61, p. 865-889.

———, and Kammer, T. W. (1988), Genetic stratigraphy and depositional systems of the Upper Devonian-Lower Mississippian Price-Rockwell deltaic complex in the central Appalachians, U.S.A.: Sedimentary Geology, v. 54, p. 265-301.

Blodget, L. (1890), The floods in Pennsylvania, May 31 and June 1, 1889: Commonwealth of Pennsylvania, Annual Report of the Secretary of Internal Affairs, Part I, p. A143-A149.

Boher, B. F., and Triplehorn, D. M. (1981), Volcanic origin of the flint clay parting in the Hazard No. 4 (Fire Clay) coal bed of the Breathitt Formation in eastern Kentucky, in Cobb, J. C. and others, eds., Coal and Coal-Bearing Rocks of Eastern Kentucky: Kentucky Geological Survey, Lexington, KY, p. 49-53.

Bolger, R. C. and Weitz, J. H. (1952), Mineralogy and origin of the Mercer fireclay of north central Pennsylvania, in American Institute of Mining and Metallurgical Engineers, St. Louis Meeting (1951) Symposium, Problems of Clay and Laterite Genesis, Maples Press Co., York, PA, p. 81-93.

Boswell, R. M. (1988), Eustacy, Acadian orogeny, and Famennian shorelines of the central Appalachian Basin (abs): Nineteenth Annual Appalachian Petroleum Geology Symposium, Geology of Appalachian Basin Devonian clastics, Program and Abstracts, West Virginia Geological and Economic Survey Circular C-42, p. 8-11.

———, Donaldson, A. C., and Lewis, J. Scott (1987), Subsurface stratigraphy of the Upper Devonian and Lower Mississippian of northern West Virginia: Southeastern Geology, v. 28, p. 105-131.

Bouma, A. H. (1978), Bouma sequence, p. 78-81 in Fairbridge, R. W., and Bourgeois, J., eds., The encyclopedia of sedimentology: Dowden, Hutchinson, and Ross, East Stroudsburg, 901 p.

Bouroz, A., Dolle, P., and Puirabuad, C. (1958), La serie stratigraphique et les tonstein du Westphalien C du Sud-ouest de la concession de Noeux: Annales du Societe Geologique du Nord, v. 78, p. 108-123.

Brady, K. B. C., and Hornberger, R. J. (1989), Mine drainage prediction and overburden analysis in Pennsylvania: Annual West Virginia Surface Mine Drainage Task Force Symposium Proceedings,

1989, Morgantown, WV, no pagination.
———, and ——— (in preparation), A manual for premining-prediction of coal mine drainage quality: Pennsylvania Department of Environmental Resource, Harrisburg, PA.
———, Shaulis, J. R., and Skema, V. W. (1988), A study of mine drainage quality and prediction using overburden analysis and paleoenvironmental reconstructions, Fayette County, Pennsylvania, in Proceedings, Mine Drainage and Surface Mine Reclamation, v. 1, Mine Water and Mine Waste: U.S. Bureau of Mines Information Circular 9183, p. 33-43.
Bradley, W. H., and Pepper, J. F. (1938) Geologic structure and occurrence of the Oriskany Sandstone in Steuben, Yates, and parts of the adjacent counties: U. S. Geological Survey Bulletin 899-A, 68 p.
Bragonier, W. A. (1970), Genesis and geologic relations of the Mercer Fireclay, western Pennsylvania: Unpublished MS thesis, Pennslyvania State University, 212 p.
Brand, U. (1989), Aragonite-calcite transformation based on Pennsylvanian molluscs: Geological Society of America Bulletin, v. 101, p. 377-390.
———, and Morrison, J. O. (1987a), Diagenesis and pyritization of crinoid ossicles: Canadian Journal of Earth Sciences, v. 24, p. 2486-2498.
———, and ——— (1987b), Paleoscene #6. Biogeochemistry of fossil marine invertebrates: Geoscience Canada, v. 14, p. 85-107.
Brezinski, D. K. (1983), Developmental model for an Appalachian Pennsylvanian marine incursion: Northeastern Geology, v. 5, p. 92-99.
——— (1984), Dynamic lithostratigraphy and paleoecology of Upper Mississippian strata of the northcentral Appalachian Basin: Unpublished PhD dissertation, University of Pittsburgh, 120 p.
——— (1989a), Late Mississippian depositional pattern in the north-central Appalachian Basin, and their implications to Chesterian hierarchal stratigraphy: Southeastern Geology (in press).
——— (1989b), The Mississippian System in Maryland: Maryland Geological Survey Report of Investigations 52 (in press).
Brua, S. A. (1978), Floods of July 19-20 in the Johnstown area, western Pennsylvania: U.S. Geological Survey Open-File Report 78-963, 62 p.
Busch, R. M., and Rollins, H. B. (1984), Correlation of Carboniferous strata using a heirarchy of transgressive-regressive units: Geology, v. 12, p. 471-474.
Buswell, K. S. (1980), A depositional model for the Lower Freeport coal seam in central western Pennsylvania: Unpublished MS thesis, University of South Carolina, 34 p.
Butts, C. (1904), Description of the Kittanning quadrangle: U.S. Geological Survey Folio 115, 15 p.
——— (1905), Description of the Ebensburg quadrangle: U.S. Geological Survey Folio 133, 10 p.
——— (1908), Pre-Pennsylvanian stratigraphy: Pennsylvania Geological Survey, 3rd ser., Report of 1906-1908, p. 190-264.
——— (1940), Geology of the Appalachian Valley in Virginia: Virginia Geological Survey Bulletin 52, Part I, Geologic text and illustrations, 568 p.
Campbell, M. R. (1902), Masontown-Uniontown folio, Pennsylvania: U.S. Geological Survey Folio 82, 21 p.
Carll, J. F. (1980), The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties, including surveys of the Garland and Panama Conglomerates in Warren and Crawford, and in Chautauqua Co., N.Y., descriptions of oil well rig and tools, and a discussion of the preglacial and postglacial drainage of the Lake Erie country: Pennsylvania Geological Survey, 2nd ser., Report I3, 482 p.
——— (1890), Seventh report on the oil and gas fields of western Pennsylvania for 1887, 1888: Pennsylvania Geological Survey, 2nd ser., Report I5, 356 p.
Carrucio, F. T. (1970), The quantification of reactive pyrite by grain size: Third Symposium on Coal Mine Drainage Proceedings, 1970, Monroeville, PA, p. 123-131.
———, and Geidel, G. (1983), Induced alkaline recharge zones to mitigate active acid seeps: West Virginia Acid Mine Drainage Technical Advisory Committee, Program and Proceedings, 1984, Morgantown, WV, no pagination.
———, ———, and Pelletier, M. (1981), Occurrence and prediction of acid drainages: Journal of the Energy Division, ASCE, v. 107(EY1), Proceedings Paper 16278, p. 167-168.
Caster, K. E. (1934), The stratigraphy and paleontology of northwestern Pennsylvania: Pt. 1, Stratigraphy, Bulletins of American Paleontology, v. 21, no. 71, 185 p.
Casshyap, S. M. (1975), Cyclic characteristics of coal-bearing sediments in the Bochumer Formation (Westphal A 2) Ruhrgebiet, Germany: Sedimentology, v. 22, p. 237-255.
Cate, A. S. (1961), Stratigraphic studies of the Silurian rocks of Pennsylvania. Part I. Stratigraphic cross sections of Lower Devonian and Silurian rocks in western Pennsylvania and adjacent areas: Pennsylvania Geological Survey, 4th ser., Special Bulletin 10, 3 p.
——— (1965), Stratigraphic studies of the Silurian rocks of Pennsylvania. Part 2. Subsurface maps of the Silurian rocks of western Pennsylvania and adjacent areas: Pennsylvania Geological Survey, 4th ser., Special Bulletin 11, 8 p.
Chadwick, G. H. (1935), Faunal differentiation in the Upper Devonian: Geological Society of America Bulletin, v. 46, p. 305-341.
Chalard, J. (1951), Tonstein du bassin houiller du Nord de la France: III Congress Intern. Stratigr. et Geol. du Carbonifere, Heerlen, p. 73-77.
Chance, H. M. (1885), Work of the U. S. Geological Survey in the Great Kanawha Coal-field (Letter to the Editor): The Virginias, v. 6, no. 3, p. 40-41.
Chaplin, J. R. (1985), Conodont biostratigraphy of Lower Carboniferous strata in the southern Appalachians: International Congress of Carboniferous Stratigraphy and Geology, 9th, Compte

Rendu, v. 2, p. 265-281.
Chukhrov, F. V. (1970), Analogues of flint clay in Soviet literature: Clays and Clay Minerals, v. 18, p. 1-5.
Clark, W. J. (1979), An interfluve model for the Upper Freeport bed in part of western Pennsylvania: Unpublished MS thesis, University of South Carolina, 54 p.
Claypole, E. W. (1883), On the Kingsmill white sandstone: American Philosophical Society Proceedings, v. 20, p. 666-673.
Clemson, T. G. (1835), Analysis of the minerals accompanying Mr. E. Miller's donation: Geological Society of Pennsylvania Transactions, v. 1, p. 271-274.
Collinson, J. D. (1978), Alluvial sediments, in Reading, H. G., ed., Sedimentary environment and facies: Elsevier Publishing Co., New York, p. 15-60.
Colton, G. W. (1970), The Appalachian Basin - its depositional sequences and their geologic relationships, p. 5-48 in Fisher, G. W., and others, eds., Studies of Appalachian Geology: Central and Southern, Interscience Publishers, New York, 460 p.
Conrad, T. A. (1835), Description of five new species of fossil shells in the collection presented by M. Edward Miller to the Geological Society: Geological Society of Pennsylvania Transaction, v. 1, p. 267-270.
Darton, N. H. (1892), Notes on the stratigraphy of a portion of central Appalachian Virginia: American Geologist, v. 10, p. 10-18.
Davies, D. K., and Ethridge, F. G. (1975), Sandstone composition and depositional environment, American Association of Petroleum Geologists Bulletin, v. 59, p. 239-264.
Davis, D. C. (1986), Statistics and data analysis in geology, 2d ed.: John Wiley and Sons, New York, 646 p.
Demarest, D. F. (1946), Map of the Berea and Murrysville sands of northeastern Ohio, western Pennsylvania, and northernmost West Virginia: U.S. Geological Survey Oil and Gas Investigations, Preliminary Map 49.
Dennison, J. M. (1982), Geologic history of the 40th parallel lineament in Pennsylvania: Appalachian Basin Industrial Associates, Spring Meeting, Program, Knoxville, Tennessee, 19 p.
——— (1985), Catskill Delta shallow marine strata, in Woodrow, D. L., and Sevon, W. D., eds., The Catskill Delta: Geological Society of America Special Paper 201, p. 91-106.
———, deWitt, W., Hasson, K. O., and others (1972), Stratigraphy, sedimentology, and structure of Silurian and Devonian rocks along the Allegheny Front in Bedford County, Pennsylvania, Allegheny County, Maryland, and Mineral and Grant Counties, West Virginia: Guidebook, 37th Annual Field Conference of Pennsylvania Geologists, Bedford, PA, 114 p.
Department of Environmental Resources (1986), Annual report on mining activities, 1985: Commonwealth of Pennsylvania, Harrisburg, 500 p.
——— (1988), Annual report on mining activities, 1987: Commonwealth of Pennsylvania, Harrisburg, 450 p.
deWitt, W., Cohee, G. V., and McGrew, L. W. (1979), Oil and gas in Mississippian rocks in part of eastern United States, in Craig, L. C., and others, Paleotectonic investigations of the Mississippian System in the United States - Part II, Interpretive summary and special features of the Mississippian System: U.S. Geological Survey Professional Paper 1010-U, p. 441-455.
———, and McGrew, L. W. (1979), The Appalachian Basin region, in Craig, L. C., and Connor, C. W., coordinators, Paleotectonic investigations of the Mississippian System in the United States - Part I, Introduction and regional analyses of the Mississippian System: U.S. Geological Survey Professional Paper 1010-C, p. 13-48.
Dickey, P. A., Sherrill, R. E., and Matteson, L. S. (1943), Oil and gas geology of the Oil City quadrangle, Pennsylvania, Pennsylvania Geological Survey, 4th ser, Mineral Resource Report 25, 201 p.
Dickinson, W. R. (1970), Interpreting detrital modes of graywacke and arkose: Journal of Sedimentary Petrology, v. 40, p. 695-707.
———, and Suczek, C. A. (1979), Plate tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 63, p. 2164-2182.
diPretoro, R. S. (1986), Premining prediction of acid drainage potential for surface coal mines in northern West Virginia: Unpublished MS thesis, West Virginia University, 217 p.
Donaldson, A. C. (1974), Pennsylvanian sedimentation of Central Appalachians, in Briggs, G., ed., Carboniferous of the southeastern United States: Geological Society of America Special Paper 148, p. 47-78.
———, and Shumaker, R. C. (1981), Late Paleozoic molasse of central Appalachians, in Miall, A. D., ed., Sedimentation and tectonics in alluvial basins: Geological Association of Canada Special Paper 23, p. 99-124.
Doveton, J. H. (1971), An application of Markov chain analysis to the Ayrshire coal measure succession: Scottish Journal of Geology, v. 7, p. 11-27.
Durika, N. J. (1987), Mineral preservation of the Brush Creek fauna of western Pennsylvania (abs.): IUP Geoscience Day Program and Abstracts, v. 13, p. 5.
———, Taylor, J. F., and Cercone, K. R. (1987), Mineralogy and fluorescence of skeletal carbonates, Brush Creek marine interval, Glenshaw Formation, southwestern Pennsylvania (abs.): Geological Society of America Abstracts with Programs, v. 19, no. 7, p. 649.
Eames, L. E. (1974), Palynology of the Berea Sandstone and Cuyahoga Group of northeastern Ohio: Unpublished PhD Dissertation, Michigan State University, 252 p.
Edmunds, W. E., Berg, T. M., Sevon, W. D., and others (1979), The Mississippian and Pennsylvanian (Carboniferous) systems in the United States --Pennsylvania and New York: U.S. Geological

Survey Professional Paper 1110-B, p. B1-B33.
Einsele, G., and Seilacher, A., eds. (1982), Cyclic and event stratification: Springer-Verlag, New York, 536 p.
Elliot, T. (1974), Interdistributary bay sequences and their genesis: Sedimentology, v. 21, p. 611-622.
Engelder, T., and Engelder, R. (1977), Fossil distortion and decollement tectonics of the Appalachian Plateau: Geology, v. 5, p. 457-460.
———, and Geiser, P. (1980), On the use of regional joint sets as trajectories of paleostress fields during the development of the Appalachian Plateau: Journal of Geophysical Research, v. 84, p. 6319-6341.
Erickson, E. S. (1963), Mineralogical, petrographic and geochemical relationships in some high-alumina and associated claystones from the Clearfield basin, Pennsylvania: Unpublished PhD dissertation, Pennsylvania State University, 190 p.
Ettensohn, F. R., and Barron, L. S. (1980), Depositional model for the Devonian-Mississippian black shale sequence in North America: A tectonoclimatic approach. U.S. Department of Energy, DOE/METC/12040-2, Morgantown, WV, 80 p.
Faill, R. T. (1977), Fossil distortion, Valley and Ridge Province, Pennsylvania: Geological Society of America Bulletin, v. 89, p. 262-263.
——— (1985), The Acadian orogeny and the Catskill Delta, in Woodrow, D. L., and Sevon, W. D., eds., The Catskill Delta: Geological Society of America Special Paper 201, p. 15-37.
Falla, W. S. (1967), The petrology and geochemistry of the Clarion flint clay, western Pennsylvania: Unpublished MS thesis, Pennsylvania State University, 84 p.
Fauth, J. L. (1968), Geology of the Caledonia Park quadrangle area, South Mountain, Pennsylvania, Pennsylvania Geological Survey, 4th ser., Atlas 129a, 133 p.
Fergusson, W. B., and Prather, B. A. (1968), Salt deposits in the Salina Group in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 58, 41 p.
Ferm, J. C. (1970), Allegheny deltaic deposits, in Morgan, J. P., ed., Deltaic sedimentation, modern and ancient: Society of Economic Paleontologists and Mineralogists Special Publication 15, p. 246-255.
———, and Smith, G. C. (1981), A guide to cored rocks in the Pittsburgh Basin: University of Kentucky and University of South Carolina Departments of Geology, 109 p.
Fettke, C. R., and Bayles, R. E. (1945), Conemaugh gorge section of the Mississippian System southeast of Cramer, Pennsylvania: Proceedings of the Pennsylvania Academy of Science, v. 19, p. 86-95.
Field, M. E. (1980), Sand bodies on coastal plain shelves: Holocene record of the U.S. Atlantic inner shelf off Maryland: Journal of Sedimentary Petrology, v. 50, p. 505-528.
Flint, N. K. (1965), Geology and mineral resources of southern Somerset County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., County Report 56A, 267 p.
Flores, R. M. (1981), Coal deposition in fluvial paleoenvironments of the Paleocene Tongue River Member of the Fort Union Formation, Powder River area, Powder River Basin, Wyoming and Montana, in Flores, R. R., and Etheridge, F. G., eds., Recent and ancient non-marine depositional environments: International Association of Sedimentology Special Publication 6, p. 169-190.
Flowers, R. R. (1956), A subsurface study of the Greenbrier Limestone in West Virginia: West Virginia Geological and Economic Survey Report of Investigation 15, 17 p.
Folk, R. L. (1974), Petrology of Sedimentary Rocks: Hemphill Publishing Co., Austin, TX, 185 p.
Foose, P. M. (1944), High-alumina clays of Pennsylvania: Economic Geology, v. 39, p. 557-577.
Freedman, J. L., ed. (1977), "Lots" of danger: Property buyer's guide to land hazards of southwestern Pennsylvania: Pittsburgh Geological Society, 85 p.
Frey, M. G., 1973, Influence of Salina salt on structure in New York-Pennsylvania part of Appalachian Plateau: American Association of Petroleum Geologists Bulletin, v. 57, p. 1027-1037.
Frey, R. W., and Howard, J. D. (1986), Mesotidal estuarine sequences: A perspective from the Georgia Bight: Journal of Sedimentary Petrology, v. 56, p. 911-924.
Friedman, G. M., and Johnson, K. G. (1966), The Devonian Catskill delta complex of New York, type example of a "tectonic delta complex", in Shirley, M. L., and Ragsdale, J. A., eds., Deltas in their geologic framework: Houston Geological Society, Houston, p. 171-188.
———, and Sanders, J. E. (1978), Principles of Sedimentology: John Wiley and Sons, New York, 73 p.
Fulton, J. (No Date), Diaries of John Fulton, A.M.E.M.: Unpublished, Johnstown Flood Museum Archives, Johnstown, v. I, II, and III.
——— (1889), Notes on Cambria County; Appendix to the Report of 1877: Pennsylvania Geological Survey, 2nd ser., Atlas to Reports HH and HHH, 1877, p. 361-404.
Galloway, W. E. (1981), Depositional architecture of Cenozoic Gulf Coastal Plain fluvial systems, in Ethridge, F. G., and Flores, R. M., eds., Recent and ancient nonmarine depositional environments: models for exploration: Society of Economic Paleontologists and Mineralogists Special Publication 31, p. 127-155.
Glenn, L. C. (1903), Devonic and Carbonic formations of southwestern New York: New York State Museum Bulletin 69, p. 967-989.
Goldberry, R. (1979), Sedimentology of the Lower Jurassic flint clay bearing Mishhor Formation, Makhtesh Ramon, Israel: Sedimentology, v. 26, p. 229-251.
Goodwin, P. W., and Anderson, E. J. (1985), Punctuated aggradational cycles: A general hypothesis of episodic stratigraphic accumulation: Journal of Geology, v. 93, p. 515-533.

Greaves-Walker, A. F. (1939), The origin, mineralogy and distribution of refractory clays of the United States: North Carolina College of Agriculture and Engineering, State College Record, v. 39, no. 4, 87 p.
Grim, R. D., and Allen, V. T. (1938), Petrology of the Pennsylvanian underclays of Illinois: Geological Society of America Bulletin, v. 49, p. 1485-1514.
Guber, A. L. (1972), Pyritic sulfur as a paleoecologic indicator in Carboniferous cycles, in Stratigraphy and Sedimentology - Stratigraphie et Sedimentologie, Section 6: 24th International Geological Congress, Montreal, p. 389-396.
Halm, L. (1952), Comparative study of American and French flint clays: American Ceramic Society Bulletin, v. 31, p. 79-84.
Hantzschel, W. (1975), Trace fossils and problematica, 2d ed., Part W, Supplement 1, in Teichert, C. and others, eds., Treatise on Invertebrate Paleontology: Geological Society of America and University of Kansas, 269 p.
Harlan, R. (1835), Notice of fossil vegetable remains from the bituminous coal measures of Pennsylvania, being a portion of the illustrative specimens accompanying Mr. Miller's essay or geological section of the Allegheny Mountain, near the Portage Railway: Geological Society of Pennsylvania Transactions, v. 1, p. 256-259.
Harper, C. W. (1984), Improved methods of facies sequence analysis, in Walker, R. G., ed., Facies models, 2d ed.: Geological Association of Canada, p. 11-13.
Harper, J. A. (1979), Subsurface rock correlation diagram, Allegheny Plateau, Pennsylvania: Pennsylvania Geological Survey, Pittsburgh Office, Open-file Report 7.
——— (1987), Affects of pre-Alleghanian tectonics on Late Devonian and Early Mississippian rocks in southwestern Pennsylvania (abs.): Geological Society of America Abstracts with Programs, v. 19, no. 1, p. 17.
———, and Laughrey, C. D. (1980), Pennsylvania oil and gas fields project, in Piotrowski, R. G., Oil and gas developments in Pennsylvania in 1979: Pennsylvania Geological Survey, 4th ser., Progress Report 193, p. 35-38.
———, and ——— (1987), Geology of the oil and gas fields of southwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 87, 166 p.
———, and Morris, R. W. (1978), A new encrinasterid ophiuroid from the Conemaugh Group (Pennsylvanian) of western Pennsylvania, and revision of the Encrinasteridae: Journal of Paleontology, v. 52, p. 155-163.
———, and Piotrowski, R. G., 1979, Stratigraphic correlation of surface and subsurface Middle and Upper Devonian, southwestern Pennsylvania, in Dennison, J. M., and others, Devonian shales in south-central Pennsylvania and Maryland: Annual Field Conference of Pennsylvania Geologists, 44th, Guidebook, Bedford, Pennsylvania, p. 18-37.
Heckel, P. H. (1986), Sea-level curve for Pennsylvanian eustatic marine transgressive-regressive depositional cycles along midcontinent outcrop belt, North America: Geology, v. 14, p. 330-334.
Heyman, L. (1977), Tully (Middle Devonian) to Queenston (Upper Ordovician) correlations in the subsurface of western Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 73, 16 p.
Hickock, W. O., and Moyer, F. T. (1940), Geology and mineral resources of Fayette County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., County Report 26, 530 p.
Hodson, F. (1927), The origin of bedded Pennsylvanian fire clays in the United States: Journal of the American Ceramic Society, v. 10, p. 721-746.
Hohos, E. F. (1979), Paleoenvironmental model of the Upper Freeport coal seam in parts of Indiana and Armstrong Counties, Pennsylvania: Unpublished MS Thesis, University of South Carolina, 59 p.
Holbrook, P. W., and Williams, E. G. (1973), Geologic and mineralogic factors controlling the properties and occurence of ladle brick clays: Pennsylvania State University, College of Earth and Mineral Sciences, University Park, PA, Special Publication 1-73, 89 p.
Hopkins, T. C. (1898), Clays and clay mineral industries of Pennsylvania, Part I. Clays of western Pennsylvania: Appendix to the Annual Report of the Pennsylvania State College for 1897, p. 48-54.
Hoque, M. (1968), Sedimentologic and paleocurrent study of Mauch Chunk sandstones (Mississippian), south-central and western Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 52, p. 246-263.
——— (1975), Paleocurrents and paleoslope - a case study: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 17, p. 77-85.
Hornberger, R. J. (1985), Delineation of acid mine drainage potential of coal-bearing strata of the Pottsville and Allegheny Groups in western Pennsylvania: Unpublished MS thesis, Pennsylvania State University, 558 p.
———, Parizek, R. R., and Williams, E. G. (1981), Delineation of acid mine drainage potential of coal-bearing strata of the Pottsville and Allegheny Groups in western Pennsylvania: Pennsylvania State University, Research Project Technical Completion Report OWRT Project B-097-PA, 359 p.
Hoskins, D. M., Inners, J. D., and Harper, J. A. (1983), Fossil collecting in Pennsylvania, 3rd ed.: Pennsylvania Geological Survey, 4th ser., General Geology Report 40, 215 p.
Hubbert, M. K. (1928), Directions of stresses producing given geologic strains: Journal of Geology, v. 36, p. 83-84.
Huddle, J. W., and Patterson, S. H. (1961), Origin of Pennsylvanian underclay and related seat rocks: Geological Society of America Bulletin, v. 72, p. 1643-1660.

Iannacchione, A. T., Ulery, J. P., Hyman, D. M., and Chase, F. E. (1981), Geologic factors in predicting coal mine roof rock stability in the Upper Kittanning coalbed, Somerset County, Pa.: U.S. Bureau of Mines Report of Investigations 8575, 41 p.
Inners, J. D. (1979), The Onesquethaw Stage in south-central Pennsylvania and nearby areas, in Dennison and others, Devonian shales in south-central Pennsylvania and Maryland: 44th Annual Field Conference of Pennsylvania Geologists, Guidebook, Bedford, PA, p. 38-55.
——— (1987), Upper Paleozoic stratigraphy along the Allegheny topographic front at the Horseshoe Curve, west-central Pennsylvania, in Roy, D. C., ed., Northeastern Section of the Geological Society of America: Geological Society of America Centennial Field Guide, v. 5, p. 29-36.
Jaron, M. G. (1967), A method for determining post-depositional alteration in underclays and associated lithologies: Pennsylvania Geologic Survey, 4th ser., Information Circular 57, 14 p.
Johnson, J. G., Klapper, G., and Sandberg, C. A. (1985), Devonian eustatic fluctuations in Euramerica: Geological Society of America Bulletin, v. 96, p. 567-587.
Jones, T. H., and Cate, A. S., 1957, Preliminary report on a regional stratigraphic study of Devonian rocks of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Special Bulletin 8, 5 p.
Kaktins, U., and Brice, W. R. (1985), Field trip guidebook for Pittsburgh Geological Society: University of Pittsburgh at Johnstown, Johnstown, PA, 25 p.
Kammer, T. W., and Bjerstedt, T. W. (1986), Stratigraphic framework of the Price Formation (Upper Devonian-Lower Mississippian) in West Virginia: Southeastern Geology, v. 27, p. 13-33.
Keller, W. D. (1952), Observations on the origin of Missouri high-alumina clays, in American Institute of Mining and Metallurgical Engineers, St. Louis Meeting, 1951, Symposium, Problems of Clay and Laterite Genesis: Maple Press Co., York, PA, p. 115-143.
——— (1968), Flint clays and a flint clay facies: Clays and Clay Minerals, v. 16, p. 113-128.
——— (1975), Refractory clay in the lower part of the Pennsylvanian System, in Paleotectonic Investigations of the Pennsylvanian System in the United States, Part 2: U.S. Geological Survey Professional Paper 853, p. 65-71.
——— (1976), Scan electron micrographs of kaolin collected from adverse origins - III. Influence of parent material on flint clays and flint-like clays: Clays and Clay Minerals, v. 24, p. 262-264.
——— (1978a), Classification of kaolins exemplified by their textures in scan electron micrographs: Clays and Clay Minerals, v. 26, p. 15-19.
——— (1978b), Flint-clay facies illustrated within one deposit of refractory clay: Clays and Clay Minerals, v. 26, p. 237-243.
——— (1981), The sedimentology of flint clay: Journal of Sedimentary Petrology, v. 51, p. 233-244.
——— (1982), Scanning electron micrographs of claystone altering to flint clay: Clays and Clay Minerals, v. 30, p. 150-152.
Kelley, D. R. (1967), Geology of the Red Valley Sandstone in Forest and Venango Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 57, 49 p.
———, and Wagner, W. R. (1970), Surface to Middle Devonian (Onondaga) stratigraphy: Pennsylvania Geological Survey Open-file Report, Pittsburgh Office.
Kent, D. V. (1985), Paleocontinental setting for the Catskill Delta, in Woodrow, D. L., and Sevon, W. D., eds., The Catskill Delta: Geological Society of America Special Paper 201, p. 9-13.
Kleinman, R. L. P., Crerar, D. A., and Pacelli, R. R. (1980), Biogeochemistry of acid mine drainage and a method to control acid formation: Mining Engineering, v. 33, p. 300-306.
Laird, W. M. (1941), The Upper Devonian and Lower Mississippian of southwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Progress Report 126, 23 p.
——— (1942), The stratigraphy of the Upper Devonian and Lower Mississippian of southwestern Pennsylvania: Unpublished Ph.D. dissertation, University of Cincinnati, 244 p.
Lapham, D. M. (1975), Interpretation of K-Ar and Rb-Sr isotopic dates from a Precambrian basement core, Erie County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Information Circular 79, 26 p.
———, and Root, S. I. (1972), Summary of isotopic age determinations in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Information Circular 70, 29 p.
LaPointe, P., and Judson, J. (1985), Characterization and interpretation of rock mass joint patterns: Geological Society of America Special Paper 199, 37 p.
Laughrey, C. D., 1982, High-potential gas production and fracture-controlled porosity in Upper Devonian Kane "sand", central-western Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 66, p. 477-482.
———, and Harper, J. A., 1986, Comparisons of Upper Devonian and Lower Silurian tight formations in Pennsylvania - geological and engineering characteristics, in Spencer, C. W., and Mast, R. F., eds., Geology of tight gas reservoirs: American Association of Petroleum Geologists Studies in Geology 24, p. 9-43.
Lentz, L. J., Dodge, C. H, and Berg, T. M. (1986), Discussion of Stop 10, in Sevon, W. D., ed., Selected geology of Bedford and Huntingdon Counties: 51st Annual Field Conference of Pennsylvania Geologists, Guidebook, Huntingdon, PA, p. 192-200.
Lesley, J. P. (1876), Historical sketch of the geological explorations in Pennsylvania and other states: Pennsylvania Geological Survey, 2nd ser., v. A, 200 p.
——— (1883), Mr. Lesley remarked on this paper of Prof. Claypole's, that he could not agree with the sentiment expressed in its introduction respecting the doubtful propriety of the use of the term "Catskill formation" as an equivalent of Prof. Roger's [sic] "Ponent formation.": American

Philosophical Society Proceedings, v. 20, p. 673-675.
——— (1885), A geological hand atlas of the sixty-seven counties of Pennsylvania embodying the results of the field work of the survey from 1874 to 1884: Pennsylvania Geological Survey, 2nd ser., v. X.
——— (1895), A summary description of the geology of Pennsylvania: Pennsylvania Geological Survey, 2nd ser., Final Report, 3 vol., p. 1-1915, 2153-2188, 2189-2588.
Levine, L. (1969), The potential for human resources and economic growth in a declining local community: A socio-economic study of the Johnstown, Pennsylvania Economy: Pennsylvania State University, 452 p.
Lovejoy, E. (1925), Theory of coal measure fire clays: Journal of the American Ceramic Society, v. 8, p. 758-761.
Lovering, T. S. (1959), Significance of accumulator plants in rock weathering: Geological Society of America Bulletin, v. 70, p. 781-800.
Lyons, P. C. (1988), "Alleghany orogeny" - A misspelling (?) and web of confusion: Geology, v. 16, p. 91.
——— (1989), Letter to editor: Geology, v. 17, p. 578. Marshak, S., and Mitra, G. (1988), Basic Methods of Structural Geology: Prentice Hall, Englewood Cliffs, NJ, 446 p.
McCulloch, C. M., Diamond, W. P., Bench, B. M., and Deul, Maurice, 1975, Selected geologic factors affecting mining of the Pittsburgh coalbed: U.S. Bureau of Mines Report of Investigations 8092, 72 p.
McCullough, D. G. (1968), The Johnstown Flood: Simon and Schuster, New York, 302 p.
McEachran, D. B. (1986-1988), Stereographic projection programs for the Macintosh: Rockware Inc., Denver, 37 p.
Meckel, L. D. (1970), Paleozoic alluvial deposition in the central Appalachians: a summary, in Fisher, G. W., and others, eds., Studies in Appalachian geology: central and southern: John Wiley and Sons, New York, p. 49-63.
Mentz, J. W., Gorton, W. T., Yuill, C. B., and Ahnell, G. (1978), Abandoned mine lands survey demonstration, Indiana and Cambria Counties, Pennsylvania and Boone County, West Virginia: U.S. Bureau of Mines Open-file Report 138(1)-78, 348 p.
Merrill, G. P., ed. (1920), Contributions to a history of American state geological and natural history surveys: U.S. National Museum Bulletin 109, 549 p.
Merrill, W. M. (1952), Replacement of the Middle Kittanning Coal by interfingering clastics in southeastern Ohio (abs): Geological Society of America Bulletin, v. 62, p. 1463.
Miall, A. D. (1977), A review of the braided river depositional environment: Earth Science Reviews, v. 13, p. 1-62.
——— (1978), Lithofacies types and vertical profile models in braided river deposits: a summary, in Miall, A. D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 597-604.
Miller, E. (1835), Geological description of a portion of the Alleghany mountain, illustrated by drawing and specimens: Geological Society of Pennsylvania Transactions, v. 1, p. 251-255.
Milliman, J. D. (1974), Marine carbonates: Springer-Verlag, New York, 375 p.
Millott, G. (1942), Relations entre la constitution et la genese des roches sedimentaires angileuses: Geol. Appliq. et. Prosp. Min., v. 2, 353 p.
Moore, l. R. (1968), Some sediments closely associated with coal seams, in Murchinson, D., and Westoll, T. S., eds., Coal and Coal Bearing Strata: Oliver and Boyd, London, p. 105-123.
Morris, R. W., Rollins, H. B., and Shaak, G. D. (1973), A new ophiuroid from the Brush Creek Shale (Conemaugh Group, Pennsylvanian) of western Pennsylvania: Journal of Paleontology, v. 47, p. 473-478.
Morrison, J. O., Brand, U., and Rollins, H. B. (1985), Paleoenvironmental and chemical analysis of the Pennsylvanian Brush Creek fossil allochems, Pennsylvania, USA: 10 International Carboniferous Congress, Madrid, Sept. 12-17, 1983, Compte rendu (Madrid), v. 2, p. 271-280.
Nemec, W., and Steel, R. J. (1984), Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits, in Koster, E. H., and Steel, R. J., eds., Sedimentology of gravels and conglomerates: Canadian Society of Petroleum Geologists Memoir 10, p. 1-31.
Nickelsen, R. P. (1966), Fossil distortion and penetrative rock deformation in the Appalachian Plateau, Pennsylvania: Journal of Geology, v. 74, p. 924-931.
———, and Hough, V. (1967), Jointing in the Appalachian Plateau of Pennsylvania: Geological Society of America Bulletin, v. 78, p. 609-630.
Noll, D. A., Bergstresser, T. W., and Woodcock, J. (1988), Overburden sampling and testing manual: Pennsylvania Department of Environmental Resources, Contract no. ME86120, 78 p.
Nummedal, D. (1987), Preface, in Nummedal, D., and others, eds, Sea-level fluctuations and coastal evolution: Society of Economic Paleontologists and Mineralogists Special Publication 41, p. iii-iv.
———, and Swift, D. J. P. (1987), Transgressive stratigraphy at sequence-bounding unconformities: Some principals derived from Holocene and Cretaceous examples, in Nummedal, D., and others, eds., Sea-level fluctuations and coastal evolution: Society of Economic Paleontologists and Mineralogists Special Publication 41, p. 241-260.
Parrish, J. B., and Lavin, P. M., 1982, Tectonic model for kimberlite emplacement in the Appalachian Plateau of Pennsylvania: Geology, v. 10, p. 344-347.
Patterson, S. H., and Hosterman, J. W. (1960), Geology of the clay deposits in the Olive Hill district, Kentucky, in Swineford, A., ed., Clays and Clay Minerals, Proceedings of the 7th

National Conference: Pergamon Press, New York, p. 178-194.
Pedlow, G. W. (1977), A peat island hypothesis for the formation of thick coal: Unpublished PhD dissertation, University of South Carolina, 104 p.
Pedone, V. A., and Cercone, K. R. (1987), Ultraviolet and blue-light fluorescence of modern carbonates: a comparative study (abs.): Geological Society of America Abstracts with Programs, v. 19, no. 1, p. 51.
———, ———, and Burruss, R. C. (1989), Identification of organic and inorganic activators of photoluminescence in calcite by Laser Microprobe Spectroscopy (abs.): American Association of Petroleum Geologists Bulletin, v. 73, p. 398.
Pepper, J. F., deWitt, W., and Demarest, D. F. (1954), Geology of the Bedford Shale and Berea Sandstone in the Appalachian Basin: U.S. Geological Survey Professional Paper 259, 111 p.
Pettijohn, F. J., Potter, P. E., and Siever, R. (1988), Sand and Sandstone, 2d ed.: Springer-Verlag, New York, 618 p.
Phelan, W. C. (1910), Johnstown folio, Pennsylvania: U.S. Geological Survey Folio 174, 15 p.
———, and Martin, L. (1911), Mineral resources of Johnstown, Pa., and vicinity: U.S. Geological Survey Bulletin 447, 142 p.
Platt, F., and Platt, W. G. (1877a), Report of progress in the Cambria and Somerset District of the bituminous coal-fields of western Pennsylvania, Part I, Cambria: Pennsylvania Geological Survey, 2nd ser., v. HH, 194 p.
———, and ——— (1877b), Report of progress in the Cambria and Somerset District of the bituminous coal-fields of western Pennsylvania, Part II, Somerset: Pennsylvania Geological Survey, 2nd ser., v. HHH, 348 p.
Piotrowski, R. G. (1981), Geology and natural gas production of the Lower Silurian Medina Group and equivalent rock units in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 82, 21 p.
———, and Harper, J. A., 1979, Black shale and sandstone facies of the Devonian "Catskill" clastic wedge in the subsurface of western Pennsylvania: Morgantown Energy Technology Center, EGSP Series no. 13, 40 p., Morgantown, WV.
Powers, D. W., and Easterling, R. G. (1982), Improved methodology for using embedded Markov chains to describe cyclical sediments: Journal of Sedimentary Petrology, v. 52, p. 913-923.
Price, P. H., and Woodward, H. P. (1940), Resume of the Devonian System of West Virginia: American Association of Petroleum Geologists Bulletin, v. 24, p. 1983-1994.
Quinlan, G. M., and Beaumont, C. (1984), Appalachian thrusting, lithospheric flexure, and the Paleozoic stratigraphy of the Eastern Interior of North America: Canadian Journal of Earth Sciences, v. 21, p. 973-996.
Rand, J. R. (1980), Alleghanian? Alleghenian: Maine Geologists, v. 7, no. 2, p. 5.
Reger, D. B. (1927), Pocono stratigraphy in the Broadtop Basin of Pennsylvania: Geological Society of America Bulletin, v. 38, p. 397-410.
Rexroad, C. B., and Clarke, C. E. (1960), Conodonts from the Glen Dean Formation of Kentucky and equivalent formations of Virginia and West Virginia: Journal of Paleontology, v. 34, p. 1202-1206.
Richardson, G. B. (1934), Somerset-Windber folio, Pennsylvania: U.S. Geological Survey Folio 224, 14 p.
Rogers, H. D. (1838), Second annual report on the geological exploration of the State of Pennsylvania: Harrisburg, 91 p.
——— (1841), Fifth annual report on the geological exploration of the State of Pennsylvania: Harrisburg, 179 p.
——— (1858), The geology of Pennsylvania: Pennsylvania Geological Survey, 1st ser., v. I, 586 p. and v. II, 1045 p.
Rogers, J. (1989), Letter to editor: Geology, v. 17, p. 577-578.
Rollins, H. B. (1967), The phylogeny and functional morphology of the Knightitinae, Carinaropsinae, and Praematuratropidae (Gastropoda, Bellerophontacea): Unpublished PhD dissertation, Columbia University, 187 p.
Root, S. I., 1980a, Possible recurrent basement faulting, Pennsylvania: Part 1, geologic framework: Pennsylvania Geological Survey, Open-file Report, 23 p., Harrisburg, PA.
———, 1980b, Possible recurrent basement faulting, Pennsylvania: Part 2, economic geology: Pennsylvania Geological Survey, Open-file report, 19 p., Harrisburg, PA.
———, and Hoskins, D. M. (1977), Lat 40°N fault zone, Pennsylvania: A new interpretation: Geology, v. 5, p. 719-723.
Ross, C. A., and Ross, J. R. P. (1985), Late Paleozoic depositional sequences are synchronous and worldwide: Geology, v. 13, p. 194-197.
Saylor, T. E. (1968), The Precambrian in the subsurface of northwestern Pennsylvania and adjoining areas: Pennsylvania Geological Survey, 4th ser., Information Circular 62, 25 p.
Schofield, R. D., and Sampson, H. R. (1954), Flocculation of kaolinite due to attraction of oppositely charged crystal faces: Discussions of the Faraday Society no. 18, p. 135-145.
Schultz, L. G. (1958), Petrology of underclays: Geological Society of America Bulletin, v. 69, p. 363-402.
Seaman, D. M. (1942), The Brush Creek limestone of western Pennsylvania: Pennsylvania Academy of Sciences Proceedings, v. 16, p. 72-76.
Sevon, W. D. (1985), Nonmarine facies of the Middle and Late Devonian Catskill coastal alluvial plain, _in_ Woodrow, D. L., and Sevon, W. D., eds., The Catskill Delta: Geological Society of America Special Paper 201, p. 79-90.

———, Rose, A. W., Smith, R. C., and Hoff, D. T. (1978), Uranium in Carbon, Lycoming, Sullivan, and Columbia Counties, Pennsylvania: 43rd Annual Field Conference of Pennsylvania Geologists, Guidebook, Hazelton, PA, 99 p.

———, and Woodrow, D. L., 1981, Upper Devonian sedimentology and stratigraphy, in Berg, T. M., and others, Geology of Tioga and Bradford Counties, Pennsylvania: 46th Annual Field Conference of Pennsylvania Geologists, Guidebook, Wellsboro, PA, p. 11-26.

Shaffner, M. N. (1958), Geology and mineral resources of the New Florence quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Atlas Series 57, 165 p.

Sheldon, P. (1912), Some observations and experiments on joint planes: Journal of Geology, v. 20, p. 53-79.

Shumaker, R. C., 1974, Influence of Salina salt on structure in New York-Pennsylvania: Discussion: American Association of Petroleum Geologists Bulletin, v. 58, p. 543-544.

Slatkine, A., and Heller, L. (1960), A petrological study of the flint clay from Makhtesh Ramon, Israel: International Geological Congress, 21st, International Commission for the Study of Clays, Proceedings, pt. 24, p. 88-107.

Smith, D. G. (1986), Anastomosing river deposits, sedimentation rates and basin subsidence, Magdalena River, northwestern Colombia, South America: Sedimentary Geology, v. 46, p. 177-196.

———, and Putnam, P. E. (1980), Anastomosed river deposits: modern and ancient examples in Alberta, Canada: Canadian Journal of Earth Sciences, v. 17, p. 1396-1406.

Smith, W. H., and O'Brien, N. R. (1965), Middle and Late Pennsylvanian flint clays: Journal of Sedimentary Petrology, v. 35, p. 610-618.

Smyth, A. L. (1980), Pedogenesis and diagenesis of the Olive Hill clay bed, Breathitt Formation (Carboniferous) northeastern Kentucky: Unpublished MS thesis, University of Cincinnati, 201 p.

Sobek, A. A., Schuller, W. A., Freeman, J. R., and Smith, R. M. (1978), Field and laboratory methods applicable to overburden and Mine soils: U.S. Environmental Protection Agency Report EPA-600/2-78-054, 203 p.

Speyer, S. E., and Brett, C. E. (1986), Trilobite taphonomy and Middle Devonian taphofacies: Palaios, v. 1, p. 312-327.

———, and ——— (1988), Taphofacies models for epeiric sea environments: Middle Paleozoic examples: Palaeogeography, Palaeoclimatology, and Palaeoecology, v. 63, p. 225-262.

Stach, E. (1950), Vulkanische Aschenreyen uber dem Steinkohlenmoor: Gluckauf, 86, p. 41-50.

Staub, J. R., and Cohen, A. D. (1978), Kaolinite-enrichment beneath coals; a modern analog, Snuggedy Swamp, South Carolina: Journal of Sedimentary Petrology, v. 48, p. 230-210.

——— (1979), The Snuggedy Swamp of South Carolina: A back barrier estuarine coal-forming environment: Journal of Sedimentary Petrology, v. 49, p. 133-144.

Stevenson, J. J. (1877), Report of progress in the Fayette & Westmoreland district of the bituminous coal-fields of western Pennsylvania. Part II. The Ligonier Valley: Pennsylvania Geological Survey, 2nd ser., v. K3, 331 p.

——— (1878), The Upper Devonian rocks of southwestern Pennsylvania: American Journal of Science, 3rd ser., v. 15, p. 423.

Stokey, H. W. (1907), History of Cambria County, Pennsylvania: Lewis Publishing Company, New York, v. I, 590 p.; v. II, 575 p.

Stone, R. W., and Clapp, F. G. (1907), Oil and gas fields of Greene County, Pa.: U.S. Geological Survey Bulletin 304, 110 p.

Stout, W., Stull, R. T., McCaughey, W. J., and Demorest, D. J. (1923), Coal formation clays of Ohio: Geological Survey of Ohio, ser. 4, Bulletin 26, p. 109-150, 533-568.

Sturgeon, M.T., 1958, The geology and mineral resources of Athens County, Ohio: Ohio Geol. Survey Bull. 57, 600 p.

Swartz, F. M. (1929), The Helderberg Group of parts of West Virginia and Virginia: U.S. Geological Survey Professional Paper 158-C, p. 25-68.

Swift, D. J. P., Figueiredo, A., Greeland, G., and Oertel, G. (1983), Hummocky cross-stratification and megaripples: a geological double standard: Journal of Sedimentary Petrology, v. 53, p. 1292-1317.

———, Gaynor, G. C., and Phillips, S. (1986), Shelf sands and sandstone types (abs.): Society of Economic Paleontologists and Mineralogists Annual Midyear Meeting, 1986, Abstracts, v. II, p. 108.

Tschinda, F. (1988), Trough cross-stratification geometry and methods for determination of paleoflow directions: Unpublished MS Thesis, Pennsylvania State University, 141 p.

Tennissen, A. C. (1974), Nature of Earth Materials: Prentice-Hall, Inc., Englewood Cliffs, NJ, 439 p.

Tissot, B. P., and Welte, D. H. (1978), Petroleum formation and occurrence: Springer-Verlag, New York, 538 p.

Turekian, K. K., and Armstrong, R. L. (1961), Chemical and mineralogical composition of fossil molluscan shells from the Fox Hills Formation, South Dakota: Geological Society of America Bulleten, v. 72, p. 1817-1828.

U.S Army Corps of Engineers (1949), Flood-control project for Johnstown, Pennsylvania: Technical Memorandum No. 2-303, 88 p.

——— (1979), Post flood report on the storm and flood of 19-20 July 1977, southwestern Pennsylvania flood, Johnstown vicinity; Section 2 - Data summary: Pittsburgh District, 18 p.

Vail, P. R., Mitchum, R. M., and Thompson, S. (1977), Seismic stratigraphy and global changes of sea level: Part 4, Global cycles of relative changes of sea level, in Payton, C. E., ed., Seismic stratigraphy - applications to hydrocarbon exploration: American Association of Petroleum

Geologists Memoir 26, p. 83-97.
Veevers, J. J., and Powell, C. M. (1987), Late Paleozoic glacial episodes in Gondwanaland reflected in transgressive-regressive depositional sequences in Euramerica: Geological Society of America Bulletin, v. 98, p. 475-487.
Wagner, W. R. (1966), Stratigraphy of the Cambrian to Middle Ordovician rocks of central and western Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report 49, 156 p.
——— (1976), Growth faults in Cambrian and Lower Ordovician rocks of western Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 60, p. 414-427.
Walker, J. E., ed. (1975), the journal of Joshua Gilpin, 1809: Pennsylvania Historical and Museum Commission, Harrisburg, 156 p.
Walker, R. G. (1984), Facies, facies sequences and facies models, in Walker, R. G., ed., Facies Models, 2d ed.: Geological Association of Canada, p. 1-10.
———, and Cant, D. J. (1979), Facies models 3: Sandy fluvial systems, in Walker, R. G., ed., Facies models: Geological Association of Canada Reprint Series 1, p. 23-32.
Way, J. H., Smith, R. C., and Roden, M. (1986), Detailed correlations across 175 miles of the Valley and Ridge in Pennsylvania using 7 ash beds in the Tioga zone, in Sevon, W. D., ed., Selected geology of Bedford and Huntingdon Counties: Annual Field Conference of Pennsylvania Geologists, 51st, Huntingdon, Pennsylvania, p. 55-72.
Weedman, S. D. (1988), Depositiona environment and petrography of the Upper Freeport limestone in Indiana and Armstrong Counties, Pennsylvania: Unpublished Ph.D. dissertation, Pennsylvania State University, 257 p.
Weitz, J. H. (1954), The Mercer fire-clay in Clinton and Centre Counties, Pennsylvania: Unpublished PhD dissertation, Pennsylvania State University, 107 p.
———, and Bolger, R. C. (1951), Mineralogy and nomenclature of the Mercer fire-clay in north central Pennsylvania: Pennsylvania Academy of Sciences Proceedings, v. 26, p. 124-130.
Wells, R. B. (1974), Loyalhanna Sandstone extended into north-central Pennsylvania (abs.): Geological Society of America, Abstracts with Programs, v. 6, no. 1, p. 84-85.
White, I. C. (1885), Resume of the work of the U. S. Geological Survey, in the Great Kanawha Valley, during the summer of 1884: The Virginias, v. 6, no. 1, p. 7-16.
Willard, B. (1933), Chemung of southwestern Pennsylvania: Pennsylvania Academy of Sciences Proceedings, v. 7, p. 1-12.
——— (1934), Early Chemung shore line in Pennsylvania: Geological Society of America Bulletin, v. 45, p. 897-908.
——— (1939), Middle and Upper Devonian, in Willard, B., Swartz, F. M., and Cleaves, A. B., The Devonian of Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report 19, p. 131-307.
———, and Caster, K. E. (1935), Age of Devonian of southwestern Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 19, p. 1546-1550.
Williams, E. G. (1960), Marine and freshwater fossiliferous beds in the Pottsville and Allegheny Groups of western Pennsylvania: Journal of Paleontology, v. 34, p. 908-922.
———, Bergenback, R. E., and Weber, J. N. (1968), Relationship between paleotopography and the thickness and geochemistry of a Pennsylvanian freshwater limestone: Journal of Sedimentary Petrology, v. 38, p. 501-509.
———, ———, Falla, W. S., and Udagawa, S. (1968), Origin of some Pennsylvanian underclays in western Pennsylvania: Journal of Sedimentary Petrology, v. 38, p. 1179-1193.
———, and Bragonier, W. A., 1974, Controls of Early Pennsylvanian sedimentation in western Pennsylvania: Geological Society of America Special Paper 148, p. 135-152.
———, and Keith, M. L. (1963), Relationship between sulfur in coals and the occurrence of marine roof beds: Economic Geology, v. 58, p. 720-729.
———, Rose, A. W., Parizek, R. R., and Walters, S. W. (1982), Factors controlling the generation of acid mine drainage: U.S. Bureau of Mines, Final Report on Research Grant No. G5105086, 265 p.
———, ———, Waters, S. A., and Morrison, J. (1985), The distribution of sulfur and carbonate minerals in Pennsylvanian rocks and their significance in predicting acid mine drainage, in Gold, D. P., and others, Central Pennsylvania geology revisited: Annual Field Conference of Pennsylvania Geologists, 50th, Guidebook, State College, Pennsylvania, p. 226-236.
Wilson, M. J. (1965), The origin and geological significance of the South Wales underclay: Journal of Sedimentary Petrology, v. 35, p. 91-99.
Woodcock, N. H. (1977), Specification of fabric shapes using the eigenvalue method: Geological Society of America Bulletin, v. 88, p. 1231-1236.
Woodrow, D. L. (1985), Paleogeography, paleoclimate, and sedimentary processes of the Late Devonian Catskill Delta, in Woodrow, D. L., and Sevon, W. D., eds., The Catskill Delta: Geological Society of America Special Paper 201, p. 51-63.
———, Fletcher, F. W., and Ahrnsbrak, W. F. (1973), Paleogeography and paleoclimate at the deposition sites of the Devonian Catskill and Old Red facies: Geological Society of America Bulletin, v. 84, p. 3051-3064.
Wray, L. L., and Smosna, R. A. (1982), Sedimentology of a carbonate-red bed association, Mississippian Greenbrier Group, eastern West Virginia: Southeastern Geology, v. 23, p. 99-108.
Yeilding, C. A., and Dennison, J. M. (1986), Sedimentary response to Mississippian tectonic activity at the east end of the 38th Parallel fracture zone: Geology, v. 14, p. 621-624.

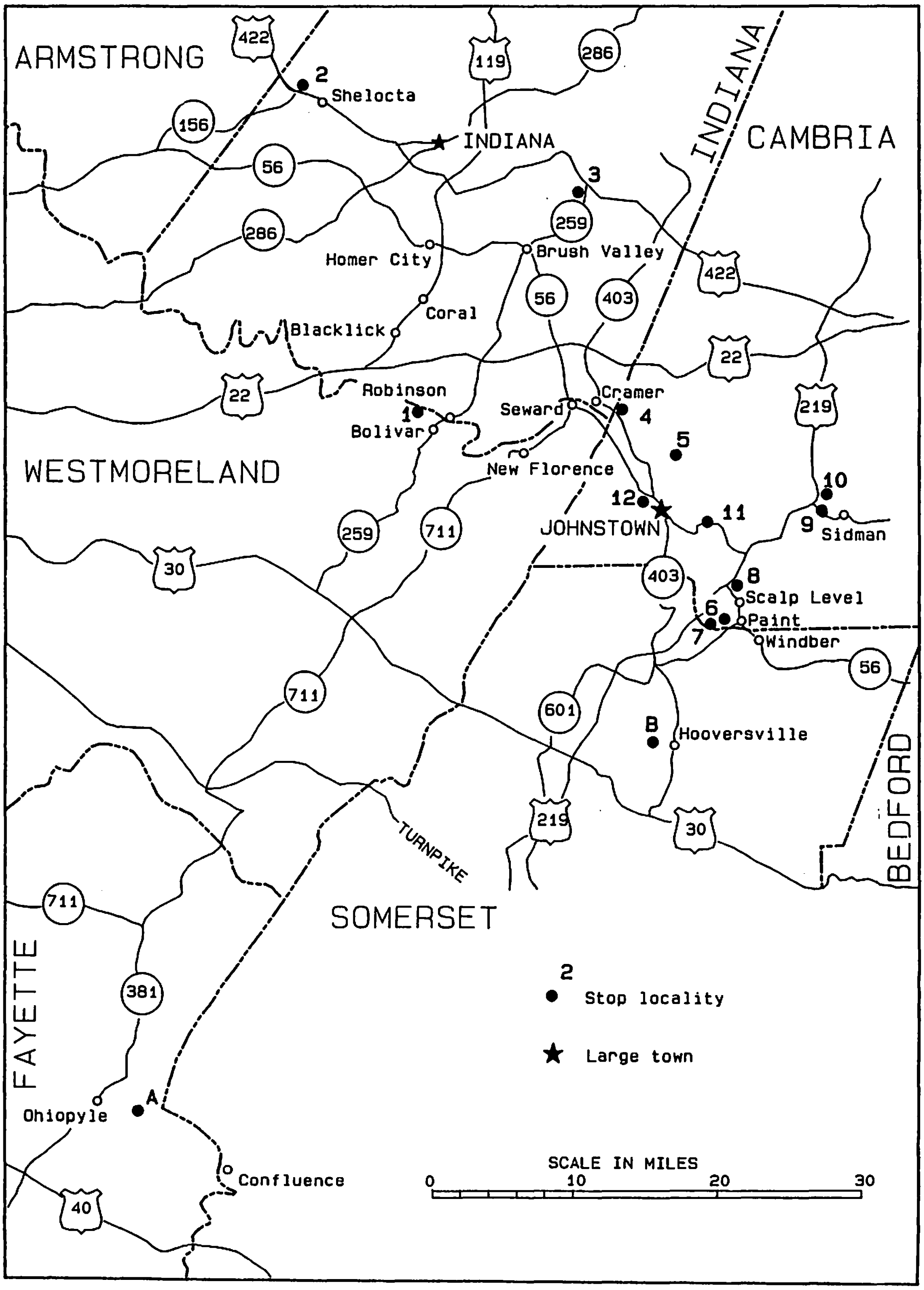


Figure 65. Field trip route map with Stop locations and selected geographic names.

STOP #A: YOUGHIOGHENY GORGE THROUGH LAUREL HILL; LATE DEVONIAN STRATIGRAPHY AND SEDIMENTOLOGY OF THE VENANGO GROUP, LOWER SANDY ZONE

LEADERS: Christopher D. Laughrey and John A. Harper

At this locality we will be examining an outcrop of the oldest rocks exposed in southwestern Pennsylvania. These rocks crop out along the CSX railroad lines at Victoria in the Youghiogheny River gorge through Laurel Hill anticline. They comprise the "Lower sandy zone" of the Venango Group. Here we will see the only exposure of the lower productive sandstones of the Venango Group (the Bayard and Elizabeth sands of drillers) in the state.

In southeastern Fayette County the Youghiogheny River crosses Laurel Hill in a deep gorge. Rocks of Late Devonian age crop out in the deepest part of the gorge between Victoria and Bidwell (Figure 66). The outcrop is partially brush

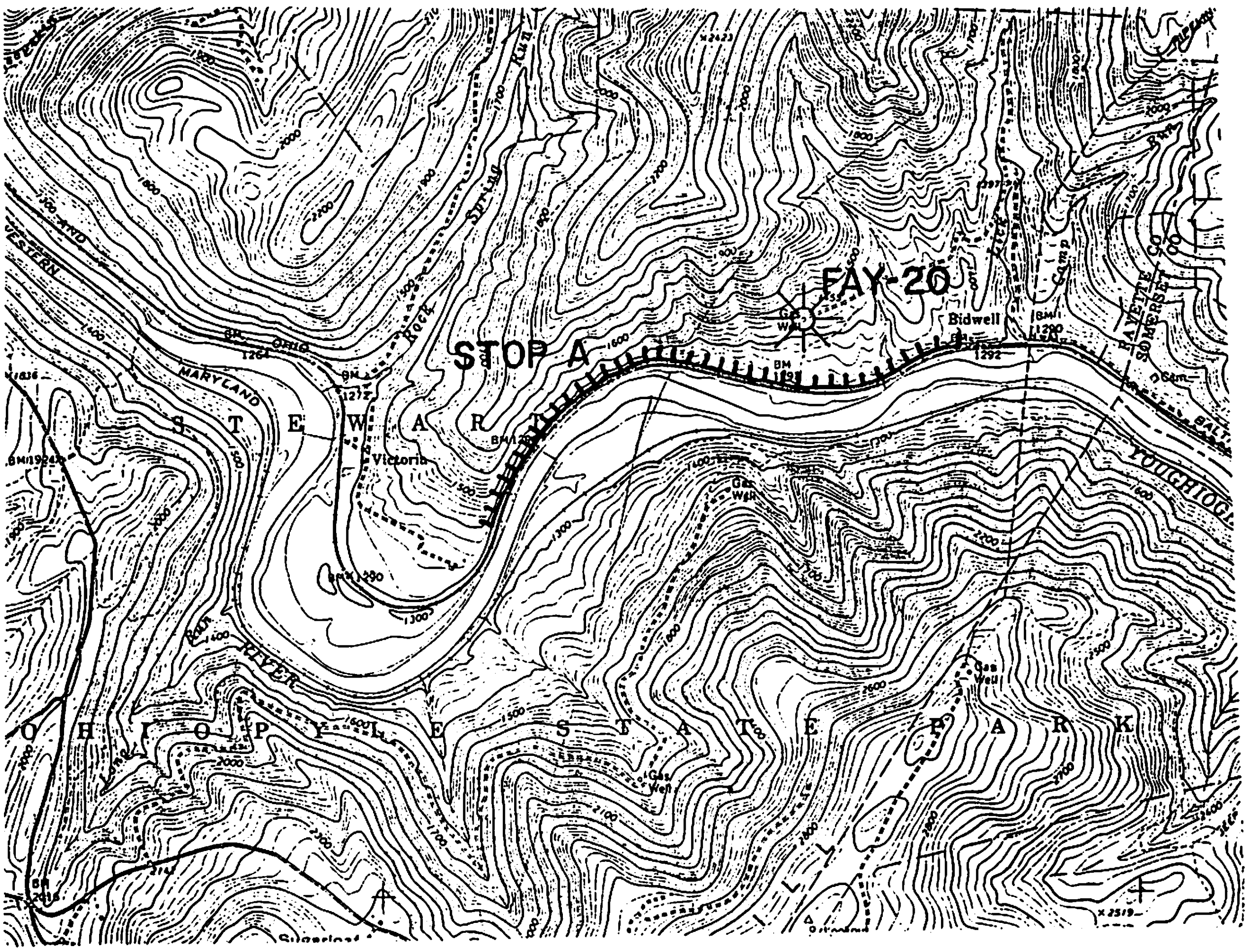


Figure 66. Location of Stop #A (Ohiopyle quadrangle).

covered and greatly mantled with talus and slump, but many sedimentary, biogenic, and structural features are exposed and evident in the rocks despite the partial cover. Geophysical logs from a gas well located about 5,000 ft (1,524 m) northeast of the outcrop (Figure 66) facilitate the determination of the gamma ray signature of the different sedimentary units exposed along the tracks (Figure 67).

This exposure demonstrates the relationship of typical Venango Group sedimentary facies to various processes that acted on the original sediments during a fifth-order regressive-transgressive cycle of Late Devonian sea level fluctuations (such as those shown by Dickey and others, 1943 and, later, Kelley, 1967). A progradational-retrogradational sequence is represented here at Victoria within approximately 390 ft (119 m) of sandstone and mudrock. The imprints of fluvial, paralic, and marine processes are evident in this section. We feel that the facies sequence exposed at Victoria deigns even the most adroit of subsurface interpreters among us who depend on geophysical log data for mapping depositional trends. Let us know what you think after studying the outcrop and comparing it with the log of the adjacent subsurface section.

We have divided this Victoria section into three principal depositional units. These are: A) a progradational fluvial-deltaic unit; B) a retrogradational barrier-bar unit; and C) a transgressive basin-margin unit (Figure 67). The interpretation of these three units is based on the recognition of six sedimentary facies that are characterized by unique combinations of mineralogy, textural character, sedimentary structures, fossils, and gross geometry. Each of the depositional units and the particular facies that comprise them are briefly described below.

FLUVIAL-DELTAIC

Facies 1

These are medium- to fine-grained, siliceous subarkoses and sublitharenites. The rocks fine upward into bedded siltstones and mudrocks. Common sedimentary structures include plane beds, trough cross-beds, and climbing ripples. No trace or body fossils are evident. We interpret the depositional environment of this facies as a fluvial distributary channel. This sequence matches the classic point bar model of Allen (1970; Figure 68). The lowermost plane beds represent sandy-bedload channel-flow deposits. The trough cross-beds and upper plane beds represent point bar deposits. The climbing ripples represent the point bar top.

Some things to look for: plane beds, trough cross beds, and climbing ripples. Conferees may wish to discuss the following questions/problems:

1. What flow regimes are represented by the different sedimentary structures?

2. Tidal-inlet fills often exhibit the same sequences of sedimentary structures as do fluvial-channel fills. As you soon will see, much of the associated sediments here are clearly paralic to marine. What criteria led us to assign this facies a fluvial origin? (Consider Facies 2 and the composition of this facies.)

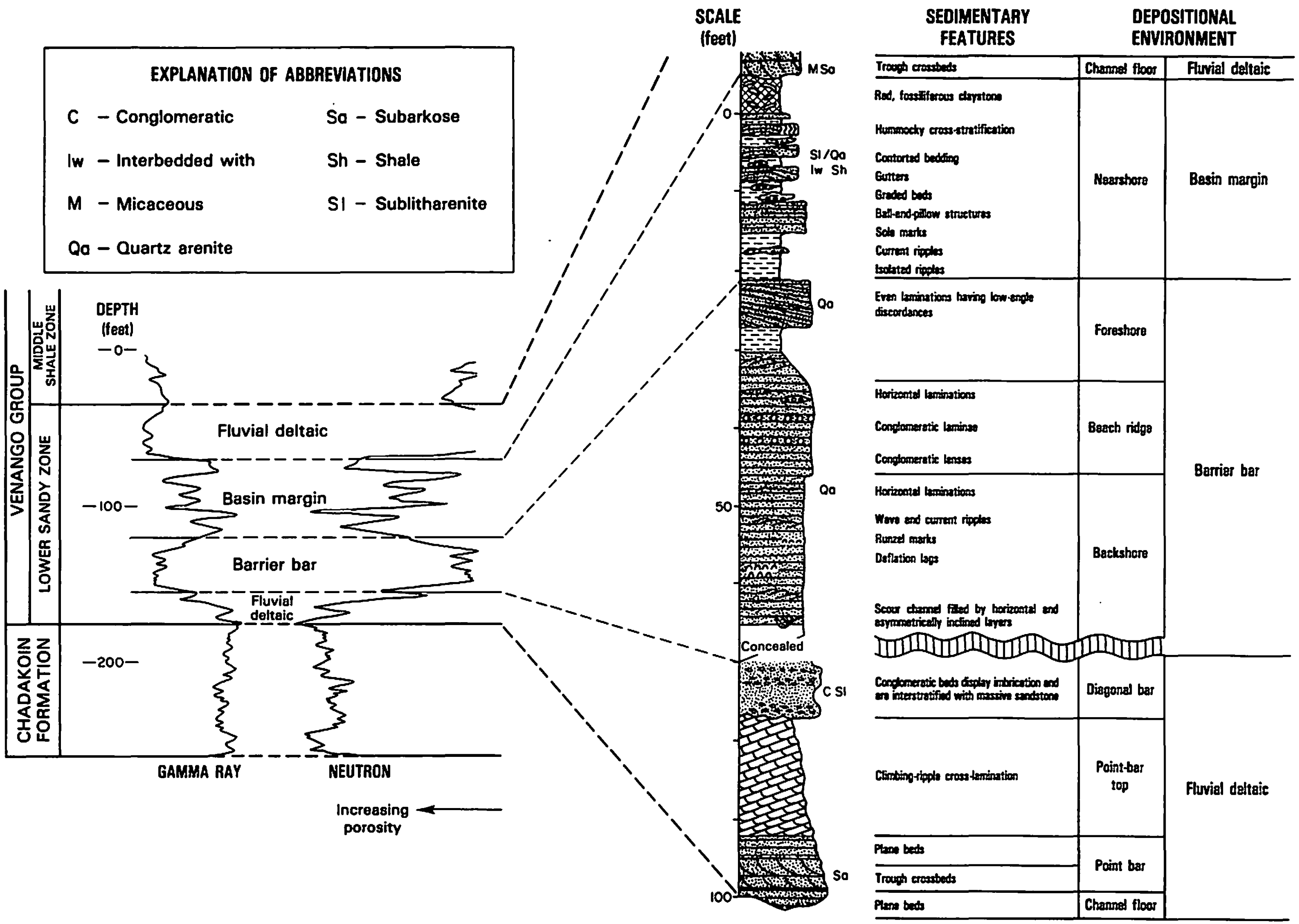


Figure 67. Composite vertical sequence of sandstone types that occur within the Lower sandy zone of the Venango Group at Stop #A, correlated to a subsurface geophysical log for well permit FAY-20 in Fayette County (from Harper and Laughrey, 1987).

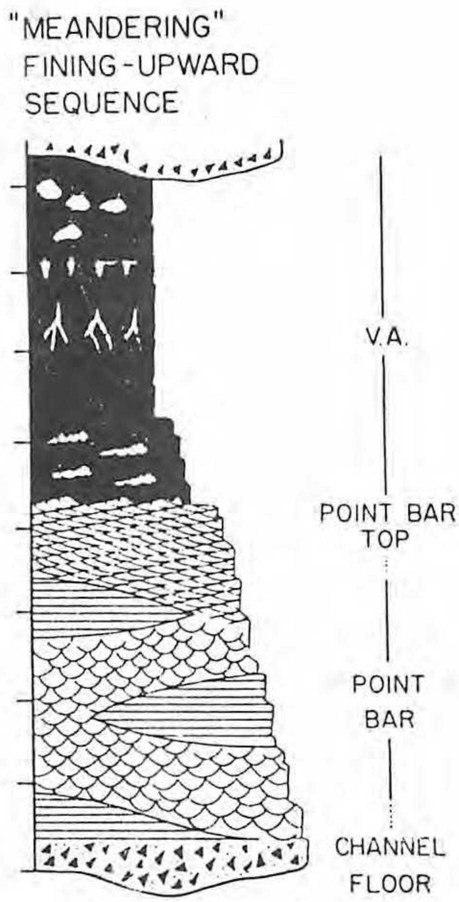


Figure 68. Model for lateral and vertical accretion deposits of meandering rivers (modified from Allen, 1970).

Facies 2

These rocks are medium- to coarse-grained, conglomeratic, feldspathic sublitharenites. The conglomeratic beds display imbrication and are interstratified with massive sandstones. In some places, broad shallow scours, planar bedding, and tabular cross-stratification may be discerned, but such sedimentary structures are generally indistinct. Trace fossils and body fossils are absent. We interpret the depositional environment of this facies as a fluvial-distributary channel - probably longitudinal, transverse, or marginal channel bars interspersed with small braid-channel lenses, or a chute bar deposited on the upper surface of the subjacent point bar sequence.

Some things to look for: poor to fair pebble imbrication, size and angularity of the feldspar grains, and position of the coarser fluvial sediments of Facies 2 with respect to Facies 1 fluvial sediments. Compare this sequence (Facies 1 and 2) with that of the George West fluvial axis of the Texas Cenozoic Gulf Coast fluvial system (Figure 69).

Note the vertical lineations (foliations?) in the sandstone that is sandwiched between the conglomeratic sandstones. In more weathered parts of the sand, these features appear step-like and resemble columnar jointing. In some places these joints become open fractures with curved surfaces. We suspect that these features are a kind of axial plane foliation, i.e. cleavage developed parallel to the axial plane of the anticline (fracture cleavage then would be the proper name for the closely-spaced open fractures). Such cleavage could be the result of shear; in this case, the cleavage is a shear surface parallel to a principal plane of the mean strain ellipsoid. This situation occurs when the bed surfaces, which were initially perpendicular to the cleavage, is also perpendicular after deformation (folding). Petrographic examination of the sandstone reveals that it is micaceous. The micas show deformation as sketched in Figure 70, and may have behaved as strong fibers. When lateral stress was applied, asymmetrical kinks or crenulations developed in these platy minerals. The length of the micas, however, remained constant (AB = A'B' and CD = C'D') and continuity was preserved along the boundaries AD and BC. Therefore, the area of rectangle ABCD decreased with increasing strain (AB X CD > A'B' X C'D'). Development of the folds established the pressure gradient shown by the arrows. Material in solution migrated away from the area ABCD resulting in the observed cleavage.

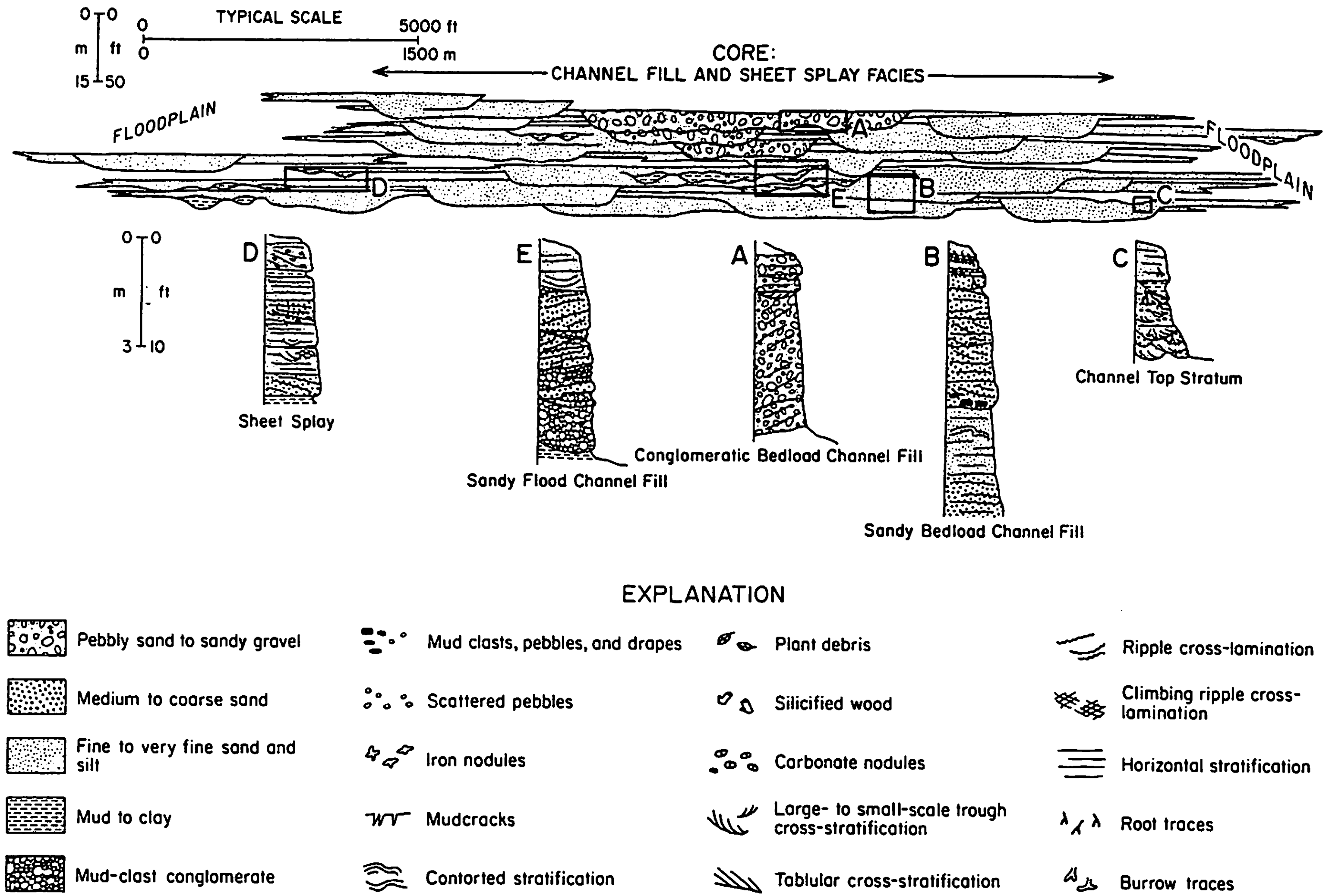


Figure 69. Schematic facies architecture of a composite sand belt typical of the George West fluvial axis. The sand body consists of amalgamated sandy and conglomeratic channel fill and sheet splay units interfingering laterally with floodplain deposits. Measured sections illustrate common internal features of component sand facies (from Galloway, 1981).

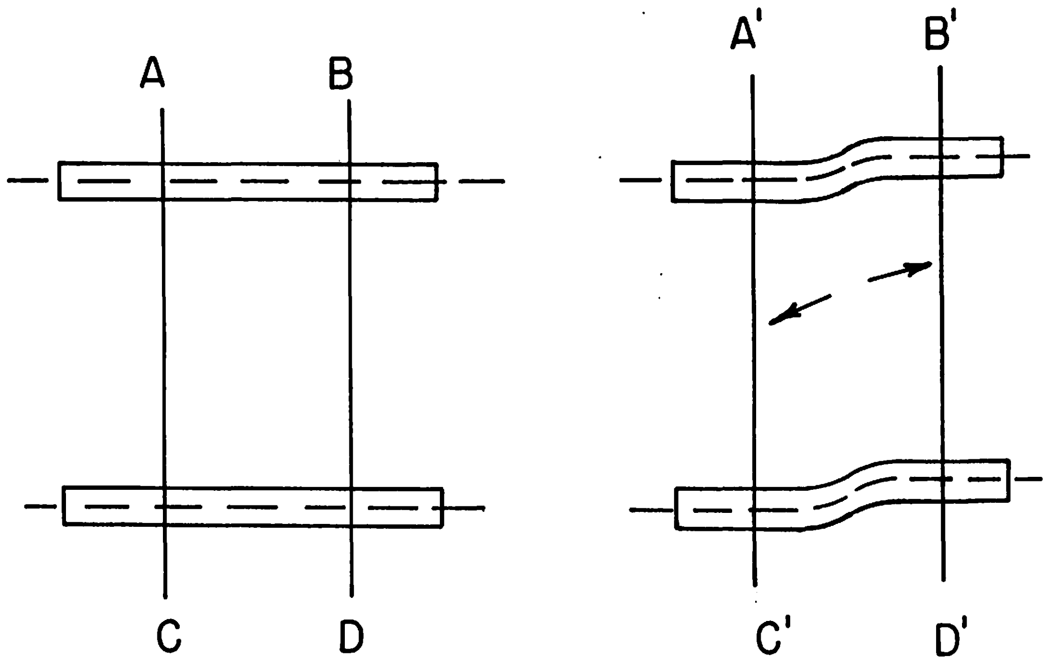


Figure 70. Graphic demonstration of the vertical lineations seen in Facies 2 (see text for explanation).

BARRIER BAR

Facies 3

These rocks are fine-grained, micaceous, quartz arenites and sublitharenites. Sedimentary structures include horizontal laminations, wave and current ripples, runzel marks, deflation lags, and scour channels filled by horizontally layered and asymmetrically-inclined layers. Fossils include macerated and carbonized plant debris, horizontal and vertical burrows, tracks, and trails, and molds and casts of brachiopods and bivalves. We interpret the depositional environment of this facies as the backshore of a barrier bar.

Facies 4

The rocks of facies 4 include fine- to medium-grained, occasionally pebbly quartz arenites in coarsening-upward sequences. Horizontal laminations and conglomeratic laminae and lenses occur within the sequence. There are some scattered brachiopod fragments preserved as molds and casts in the rocks. This is the beach ridge of the barrier bar sequence.

Facies 5

These rocks are fine- to medium-grained quartz arenites that coarsen upwards. Even laminations with low-angle discordances can be observed here. Broken shell fragments of brachiopods and bivalves, preserved as molds and casts, are common. This is the foreshore of the barrier bar.

BASIN MARGIN (TRANSGRESSIVE MARINE)

Facies 6

Facies 6 rocks consist of fine-grained sublitharenites and quartz arenites interbedded with mudrocks. Sedimentary structures include hummocky cross-stratification, contorted bedding, slump structures, ball-and-pillow structures, sole marks, graded beds, current ripples, and isolated ripples. Brachiopods and bivalves are common, preserved as molds and casts. Vertical burrows, and horizontal tracks and trails are also common. We interpret these rocks as part of a muddy nearshore environment with isolated lenticular sand bodies. Sands were introduced to the muddy lower shoreface by storm-generated turbidity currents (tempestites) that transported sands from the foreshore and upper shoreface. Sands were reworked by storm-related currents and waves (hummocky cross-stratification) but were enclosed in mud during more normal, fair weather conditions.

Some things to look for include hummocky cross-stratification, Bouma sequences, and fossils. We propose that all of the sand in this facies was introduced onto the muddy shelf by turbidity currents, which leads to two questions:

1. Why?

2. The Bouma sequences and the hummocky sequences are well-preserved in the rock record. How did these physical structures escape extensive reworking by organisms?

STOP #B: TOUR THROUGH AN UNDERGROUND COAL MINE

LEADERS: Fred Baldassare and Biff Walker

Coal mining has played an important role in the heritage and economics of Somerset and Cambria Counties. Today, however, its image is marred by acid mine drainage and unemployed coal miners. In 1925 coal mines in Somerset and Cambria Counties employed over 32,000; today they employ fewer than 2,500 (Department of Environmental Resources, 1985).

The Solar Fuel #7 mine is one of only four operating coal mines in Somerset County. This small mine (Figure 71) opened in 1975 and employs 62, down from 78 in 1980. It has approximately a 22-year coal reserve.

Solar Fuel #7 is a room and pillar mine working the Upper Kittanning coal seam. In this area the Upper Kittanning is a metallurgical grade coal that is used primarily in steam generation. The seam is 42 to 60 in (1.1 to 1.5 m) thick and the overburden ranges from 70 ft (21 m) to less than 600 ft (180 m).

At the entrance to the mine we will observe the thick Freeport sandstone apparent in the highwall. This sequence fines upward through large cross-beds;

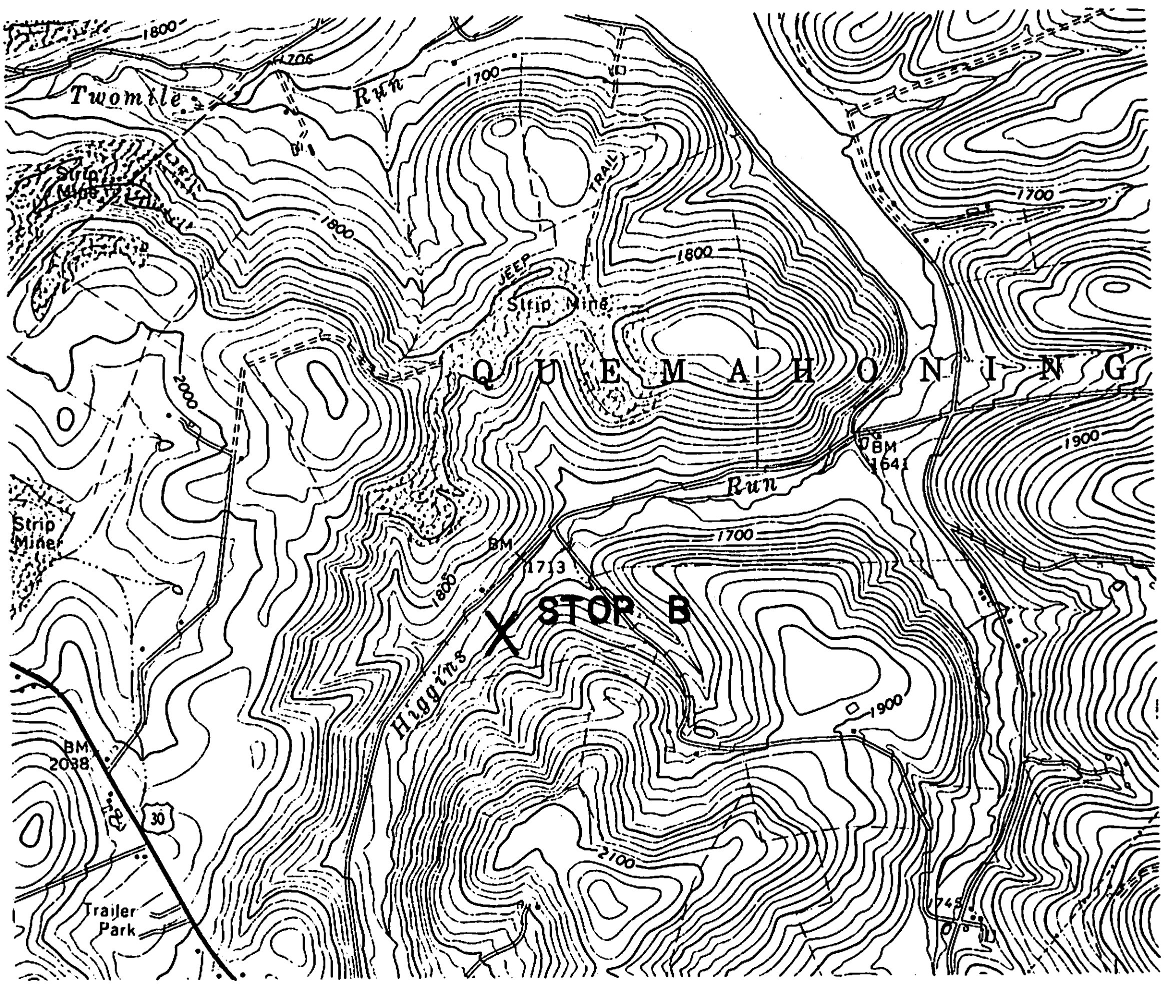


Figure 71. Location of Stop #B (Hooversville quadrangle).

it has been characterized as a high-energy channel-phase sandstone. We will also note the two mechanical fans that ventilate the mine. The smaller fan exhausts 38,000 cubic feet per minute (cfm) and is powered by a 30 hp motor. The main fan exhausts 90,000 cfm and is powered by a 50 hp motor. As we enter the mine you will feel the air current being pulled through the entry. The air is pulled into the mine through the intake entries. Eventually the air reaches the working face. Pennsylvania mining laws mandate that the current be at least 4,000 cfm to ventilate dust and methane from the face. After passing the working face the air is directed into the return entries (exhaust) and out of the mine.

The next stop will be in the main entries approximately 4,800 ft (1,460 m) into the mine. At this location we will observe thrust faults and slickensided planes that were characterized and mapped by the U.S. Bureau of Mines (Iannacchione and others, 1980). This work was part of a study conducted in order to predict the occurrence of other areas of unstable roof in advance of mining. The study resolved that there were two distinct trends of unstable shale roof-rock. One trend has both high frequency, small slickensided roof-rock and large low-angle slickensided planes. This trend is within the sandstone-shale sedimentary facies change and is the result of differential compaction. The second trend with horizontal slickensided planes and small scale thrust faulting is entirely within the thick shale facies. The thrust faults have small displacements measured in inches and are believed to be related to the large scale structural deformation of the Allegheny Mountain Section (Iannacchione and others, 1980). The authors of this study predicted other areas of incompetent shale roof-rock based on sedimentary facies change, and according to mine personnel their predictions thus far are very accurate.

Our next stop will be in a section that has been developed and retreat-mined. Mining advanced in this section, and then the coal pillars that had been left as support were "pulled" as the section retreated. The pillars are pulled from left to right. First, the continuous miner splits the pillar in half and then takes as much coal as possible from the remaining sides. Theoretically, the roof-rock should fall as the retreat mining continues. If this does not happen, pressure (strain) can build over the mining crew and result in a significant roof fall.

Our final stop will be at the working face of the mine. Here entries are driven 18 to 20 ft (5.5 to 6.1 m) wide and no more than 20 ft (6.1 m) in length before supports must be set. The pillars are on 60 to 70 ft (18.3 to 21.3 m) centers. The entries are being developed by a continuous miner. This machine severs the coal from the face and loads it onto a shuttle car that transports the coal to a conveyor belt. The continuous miner first takes a "cut" from the air side (where the ventilation canvas is set) and then an equal size cut is taken from the opposite side. During each cut ventilation canvas and engineer's sights are advanced and methane checks are made. After each cut the roof bolter installs either mechanical or resin roof bolts on 4 ft (1.2 m) centers 3 to 6 ft (0.9 to 1.8 m) in length into the roof. The cycle continues as the continuous miner and shuttle cars move to the next entry and continue mining. The shuttle cars haul approximately 4.5 tons; in one 8-hour shift the sections have loaded from 0 to 229 shuttle cars. This variability is due primarily to roof conditions and to a myriad of potential mechanical/electrical problems.

Mileage Inc.	Cum.	
0.0	0.0	START. Leave from the front of the Holiday Inn (Market St.), Johnstown, PA.
0.1	0.1	TURN RIGHT on Vine St.
0.2	0.3	TURN RIGHT onto PA Routes 403/56. Inclined Plane on left.
0.1	0.4	Point Stadium on right marks the confluence of the Little Conemaugh River and Stony Creek to form the Conemaugh River.
0.4	0.8	Pass under railroad crossing the Conemaugh River on the Old Stone Bridge at right. This bridge was the scene of a massive debris jam in the 1889 flood that created a backwater effect and increased the flood level in the city (Figure 72; also see the Frontispiece). The debris also caught fire, and an unknown number of flood victims trapped in the debris perished due to the fire. Allegheny Group strata exposed at road level on left. Old deep mine openings have been sealed with concrete.
0.3	1.1	Bear left, CONTINUING on PA Routes 403/56 (Broad St.). Stay in left lane through Cambria City.
0.9	2.0	TURN LEFT at traffic light to follow PA Route 56 (Fairfield Ave.) which, at this point, splits off from PA Route 403 and goes through Morrellville.
0.6	2.6	TURN RIGHT at traffic light, CONTINUING north on PA Route 56.
1.0	3.6	Enter Lower Yoder Township.
0.2	3.8	Entering the Conemaugh Gorge, a water gap formed by the Conemaugh River as it crosses Laurel Ridge, an anticlinal ridge. The local relief in the gorge is in excess of 1,500 ft (460 m), and the crest of the ridge approximates the axis of the Laurel Ridge anticline.
0.1	3.9	Mauch Chunk Formation red beds on left.
0.6	4.5	Strata of the "Rockwell tongue" crop out on left. Notice the distinctive spheroidal weathering of these fissile siltstones and shales.
0.6	5.1	Heffley Spring on left.
0.3	5.4	Red beds of the "Middle red shale zone", Venango Group, crop out on left, dipping southeast (back toward Johnstown).
0.6	6.0	"Middle red shale zone" red beds on left, dipping northwest (away from Johnstown). We are now on the northwest limb of the anticline.
0.4	6.4	Cambria/Westmoreland County line.
1.0	7.6	Large blocks of Lower Pennsylvanian Pottsville Group sandstone float can be seen along left side of road.
1.1	8.5	Access road to Laurel Ridge Trail parking area. CONTINUE north on PA Route 56.
1.0	9.5	TURN LEFT (south) on PA Route 711 at Seward.
3.9	13.4	Enter New Florence.
0.4	13.8	TURN RIGHT at stop sign onto Ligonier Street. PA Route 711 goes to the left. Uni-Mart on right.
0.4	14.2	Bridge over Conemaugh River marks the Indiana/Westmoreland County boundary. Conemaugh Power Station can be seen to the right.
0.4	14.6	BEAR LEFT after crossing railroad tracks.

Figure 72. Scenes of the Johnstown flood of 1889 (photos courtesy of the Johnstown Flood Museum). Top: The debris dam behind the Pennsylvania Railroad's "Old Stone Bridge" some time after clearing operations had begun. Bottom: The John Schultz house, which was a favorite subject for the photographers. Strange as it may seem, the six people living in the house survived.

1.4	16.0	New Florence Mining Company general offices on left.
1.9	17.9	Intersection with PA Route 259 at stop sign. TURN LEFT (south) onto PA Route 259.
1.4	19.3	Enter Robinson.
0.9	20.2	BEAR LEFT onto bridge across Conemaugh River. Bridge marks the Indiana/Westmoreland County boundary.
0.1	20.3	Enter Bolivar. Narrow, single-lane railroad underpass.
0.2	20.5	Second railroad underpass. TURN LEFT onto brick-paved lane. Park at old Bolivar railroad station.

STOP #1: LATE MISSISSIPPIAN STRATA IN THE CONEMAUGH RIVER GORGE THROUGH CHESTNUT RIDGE

LEADER: David K. Brezinski

Passengers will leave the buses and walk into the Conemaugh Gorge through Chestnut Ridge via the Conrail right of way. From here it is about a 25 minute walk to the outcrop.

LOYALHANNA FORMATION

The contact between the Burgoon Sandstone and the Loyalhanna Formation is not exposed at this stop (Figure 73); however, we will have the opportunity to examine the contact at the Cramer stop (Stop #4).

The Loyalhanna Formation was named by Butts (1904) for exposures along Loyalhanna Creek about 7.5 mi (12 km) to the south of this outcrop. It is characterized by medium- to large-scale, festoon cross-bedding. Individual foresets are composed of alternating layers of quartz sand and carbonate sand. Quartz-rich layers weather less readily than do the carbonate-rich layers. As a result of this differential weathering, the zebra-stripe appearance that may be observed here is one of the major distinctive characteristics of the Loyalhanna throughout much of southwestern Pennsylvania. The Loyalhanna is 43 ft (13 m) thick at this locality, and consists of up to 62 percent fine-grained quartz sand and silt (Adams, 1970). The remainder of the sand is carbonate grains of various kinds, including ooids, indeterminate peloids, grapestone aggregates, and abraded fossil remains (echinoderms, bryozoans, brachiopods, and endothyrid foraminiferans).

This exposure is one of the most northern outcroppings of "typical" Loyalhanna. To the north and northeast red shales and mudstones of the Mauch Chunk Formation are interbedded with the cross-bedded lithology. In the Broad Top coal basin this interbedded facies of the Loyalhanna is termed the Trough Creek Limestone (see Lentz and others, 1986). Northeastward from here the intercalated sandstones and shales have been traced into Sullivan County (Wells, 1974). To the south the Loyalhanna becomes progressively less quartz-rich; however, the festoon cross-bedding is retained. The Loyalhanna can be recognized as a distinct unit into north-central West Virginia where it is considered a member of the Greenbrier Formation.

Loyalhanna paleocurrents, as studied by Adams (1970) and Hoque (1975), are almost unidirectional and oriented to the northeast. Adams (1970) proposed that the Loyalhanna was deposited on a shallow marine shelf that received detrital quartz sand from the north, presumably from an eroding Burgoon upland (Edmunds and others, 1979), and subsidiary amounts of red clays and metamorphic rock

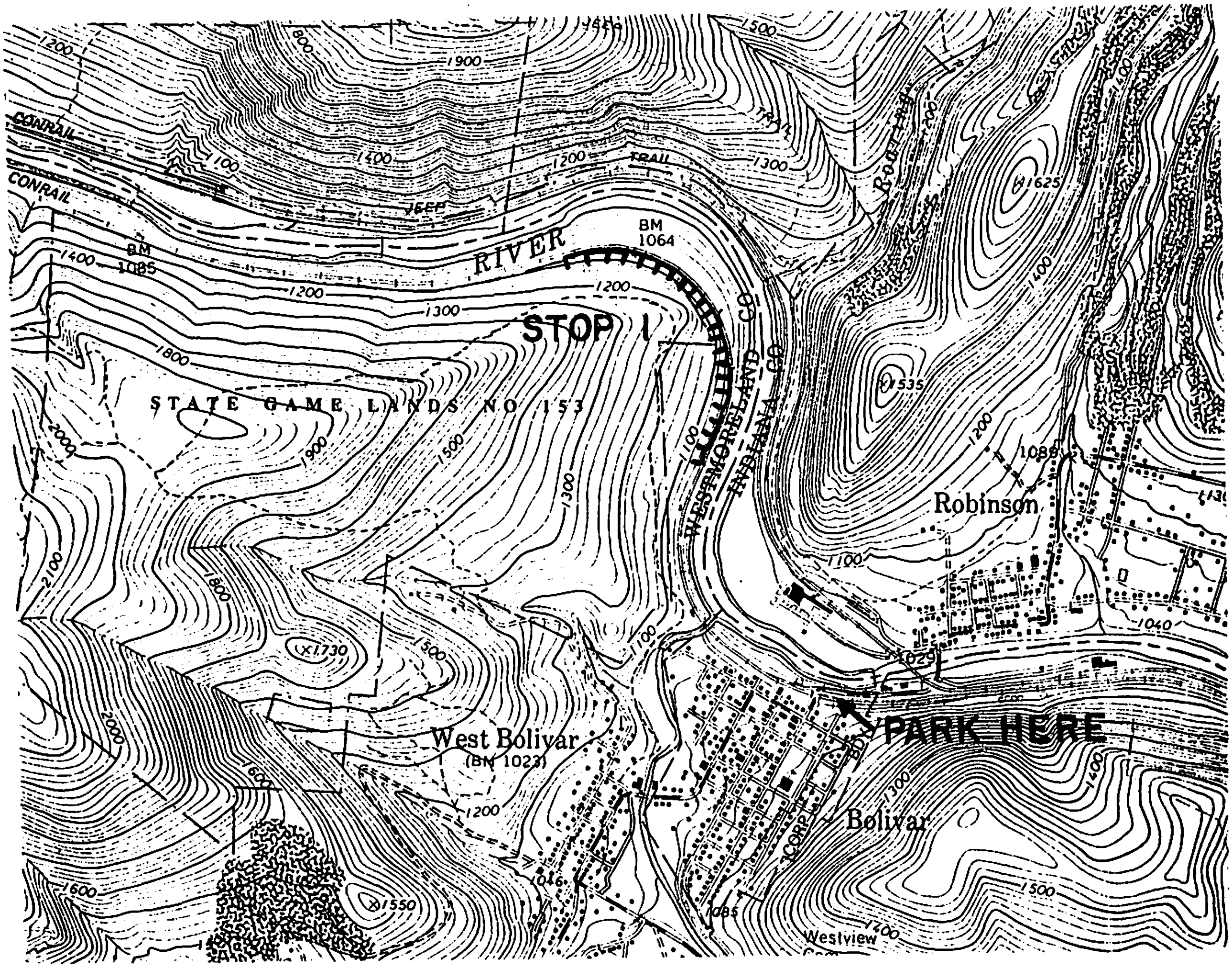


Figure 73. Location of Stop #1 (Bolivar quadrangle).

fragments from an eastern (tectonic highland) source. Brezinski (1984) likened the Loyalhanna environments to a large estuarine shelf on which strong tidal currents produced an extensive submarine sand-wave complex. A possible modern analogue might be the North Sea.

MAUCH CHUNK FORMATION

The Mauch Chunk Formation is named for exposures in the vicinity of Mauch Chunk (currently Jim Thorpe) in Carbon County, Pennsylvania. In the type area as much as 400 ft (1,200 m) are present and the rocks are nonmarine in character. At this stop we are very near the northwestern limit of the Mauch Chunk progradation (Figure 74). As a result, only about 115 ft (35 m) of Mauch Chunk strata are present. Moreover, the Mauch Chunk in this area consists of interbedded marine and nonmarine strata, and can be informally subdivided into lower and upper detrital members. These two members are only recognized where they are separated by the intervening Wymps Gap Limestone Member (formerly termed the Greenbrier Limestone of Pennsylvania). The lower member generally consists of interbedded marine and nonmarine strata and the upper member is characterized by green-gray, lenticular channel-phase sandstones and red-brown and green-gray mudstones.

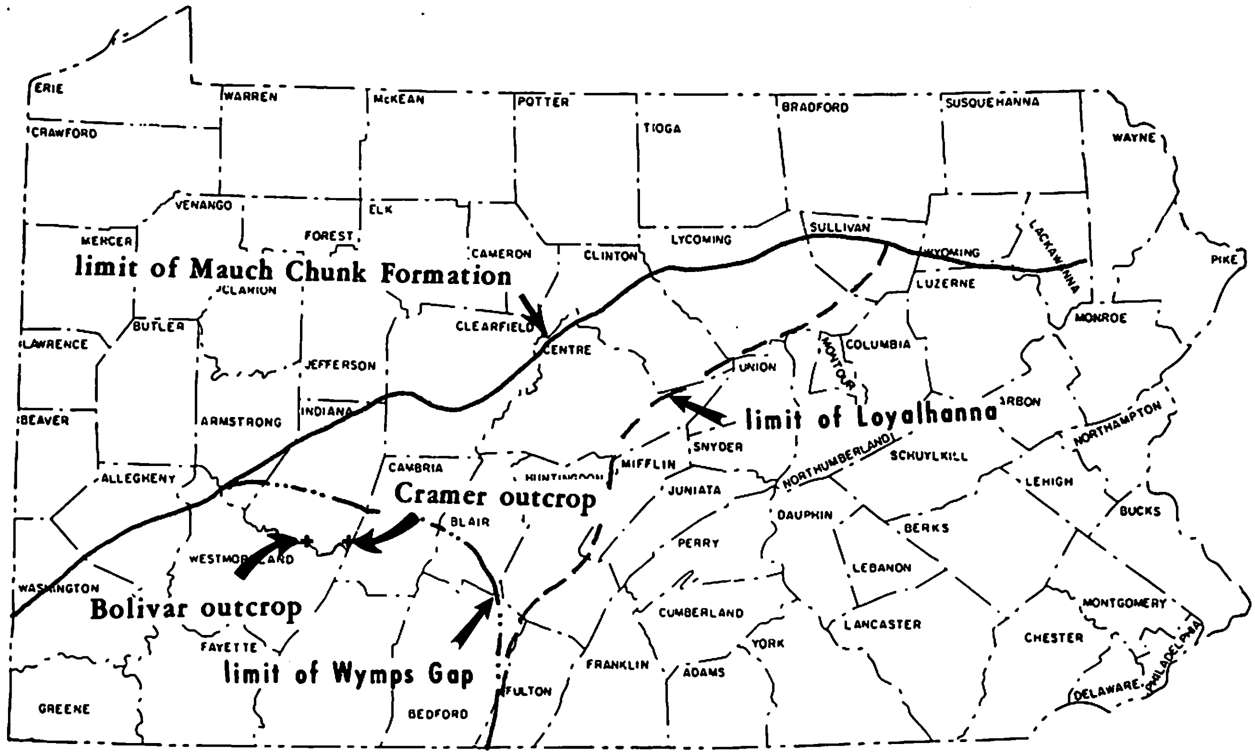


Figure 74. Map illustrating relative geographic extents of the Mauch Chunk Formation, Loyalhanna Formation, and Wymps Gap Member of the Mauch Chunk Formation (from Edmunds and others, 1979; Berg and Edmunds, 1979; Brezinski, 1984).

Lower Member of the Mauch Chunk

Inasmuch as this stop is very near the margin of the Mauch Chunk clastic wedge the character of the lithologies exposed here are considerably different than that to the south and east. The most notable differences are the lower percentage of red shale and mudstone and the higher percentage of quartzose sandstone. This is because near the limits of the Mauch Chunk clastic wedge (Figure 74) the dominant sediment supply was from the northern (Burgoon?) source rather than the eastern (tectonic) source.

At this stop the lowermost strata of the Mauch Chunk consist of 17 ft (5.2 m) of white to tan, planar cross-bedded sandstone containing carbonate clasts (Figure 75, units C-E). This sandstone is separated from the underlying Loyalhanna by 18 in (45.7 cm) of red siltstone (Figure 75, unit B) that marks the base of the Mauch Chunk at this stop. Near the Middle of this sandstone unit is a one ft (30.5 cm) thick limestone exhibiting fenestral fabric. The upper 5 ft (1.5 m) of this sandstone contains abundant carbonate clasts.

This sandstone unit represents littoral deposition at the edge of the Mauch Chunk clastic lobe. The red siltstone at the base indicates that the shoreline conditions that produced the overlying sandstone were separate from the conditions that produced the underlying Loyalhanna. Indeed, in south-central Pennsylvania (Somerset County) a marine limestone (the Deer Valley Limestone)

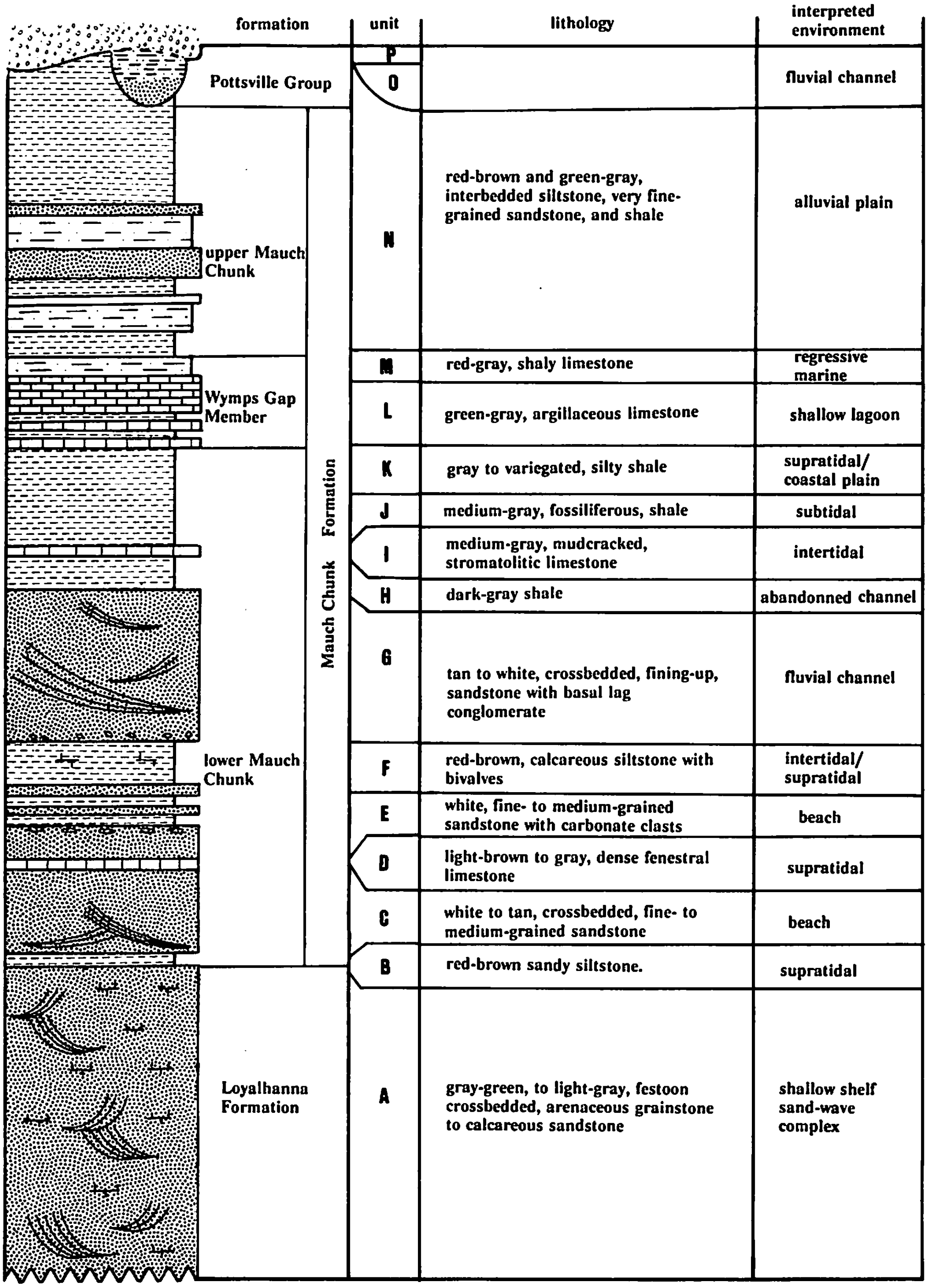


Figure 75. Measured section of the Bolivar outcrop of the Mauch Chunk Formation with interpreted depositional environments. Vertical scale: 1 in equals approximately 20 ft (6 m).

occupies this stratigraphic position. The Deer Valley probably represents subtidal marine deposits equivalent to the shoreline sands of units C-E. The fenestral limestone near the middle of the unit (unit D) suggests that, in this shoreface setting, periodic supratidal conditions existed.

Progressing upsection, unit E grades into a red-brown silty mudstone (unit F). Near the middle of the unit F abundant myalinid bivalves are present. Modern myalinids typically inhabit intertidal marshes.

Unit F is overlain by approximately 20 ft (6 m) of tan, cross-bedded sandstone (unit G), which in turn is overlain by a gray shale (unit H). Unit G exhibits a sharp base with a shale pebble-lag conglomerate, and an upward fining into unit H. Looking closely at the upper surface of the sandstone and its relationship with the gray shale, one can see that the shale thickens into what appears to be a topographic low. This topographic low appears to be the result of differential compaction of the sandstone, or channel abandonment.

The top of unit H is marked by a 6 in (15.2 cm) mudcracked, stromatolitic, argillaceous limestone (unit I). This stromatolitic limestone is overlain by a gray, calcareous shale (unit J) containing abundant gastropods, bivalves, productid brachiopods, and bryozoans. This progression from unit I to unit J indicates a transgressive episode going from intertidal to subtidal conditions. The marine episode (unit J) can be traced to exposures to the southwest and northeast and appears to be of considerable areal extent.

Unit J is overlain by 10 ft (3.1 m) of gray-green, red-brown, and variegated micaceous shale (unit K) containing plant impressions. This interval was deposited under nonmarine conditions.

Wymps Gap Member of the Mauch Chunk

Unit K is in turn overlain by 8 ft (2.4 m) of interbedded green-gray shale and argillaceous limestone (unit L) containing a diverse assemblage of brachiopods, bryozoans, corals, gastropods, and bivalves. This thin limestone, known as the Wymps Gap Limestone Member of the Mauch Chunk, was formerly called the Greenbrier Limestone of Pennsylvania. At this locality we are very near the northern extent of the Wymps Gap. To the south this limestone tongue increases in thickness so that at the Pennsylvania-West Virginia border it attains a thickness of over 40 ft (12 m). Brezinski (1984) demonstrated that the Wymps Gap Limestone exhibited a southwest to northeast progression of facies and their respective environments from subtidal open shelf to intertidal shoal to shallow subtidal lagoon. At this locality the Wymps Gap exhibits criteria suggestive of deposition in a subtidal lagoonal environment.

Upper Member of the Mauch Chunk

Overlying the Wymps Gap Limestone is the upper Mauch Chunk (unit N). The upper Mauch Chunk differs from the lower Mauch Chunk by the lack of marine intervals in the former. Instead, the upper Mauch Chunk is characterized by red-brown and green-gray siltstones and shales and lenticular green-gray and brown sandstones. Hoque (1968) interpreted this part of the Mauch Chunk as having formed in an alluvial plain setting. Meckel (1970) proposed that the lenticular sandstones represented channel-phase deposits and the finer grained siltstone and shale overbank deposits.

At this locality the upper Mauch Chunk is only about 40 ft (12 m) thick. To the southeast this interval thickens quite rapidly so that in the vicinity of Negro Mountain in Somerset County approximately 500 ft (150 m) are present.

Near the top of unit N an abandoned fluvial channel of the Pottsville Group (unit O) has cut into the upper Mauch Chunk strata. One can actually see the three-dimensional geometry of this channel by looking across the railroad tracks along what would have been depositional strike. This unit likely represents an oxbow lake deposit.

POTTSVILLE GROUP

The Mauch Chunk is unconformably overlain by coarse-grained sandstones and conglomerates of the Pottsville Group. The base of the more massive Pottsville strata is sharp and has even truncated the fine-grained channel fillings of the incised channel (unit O).

To the north of this locality pre-Pennsylvanian erosion removed progressively older and older Mauch Chunk strata so that sandstones of the Pottsville actually rest upon sandstones of the Burgoon (Edmunds and others, 1979, fig. 7).

		LEAVE STOP 1. TURN RIGHT (north) onto PA Route 259.
5.1	25.6	Junction with US Route 22. TURN RIGHT onto entrance ramp and BEAR LEFT to stop sign.
0.1	25.7	TURN LEFT (west) onto US Route 22.
2.9	28.6	Summit of Chestnut Ridge anticline.
3.2	31.8	Outcrop of Pennsylvanian age Glenshaw Formation (Conemaugh Group) sandstones on left.
0.4	32.2	TURN RIGHT onto exit ramp for US Route 119.
0.1	32.3	TURN LEFT (north) onto US Route 119.
1.4	33.7	Enter Blacklick.
0.7	34.4	Intersection with traffic light. Entrance to Homer City Power Station on left. CONTINUE north on US Route 119.
0.8	35.2	Slag dump on right.
0.5	35.7	Gas wells producing from Upper Devonian Venango and Bradford Group sandstones in field on right.
0.9	36.6	Enter Coral.
2.9	39.5	Enter Homer City.
0.2	39.7	Junction with PA Route 56 at traffic light. CONTINUE north on US Route 119.
1.9	41.6	Cross Twolick Creek.
0.5	42.1	TURN RIGHT onto exit ramp for US Route 422 westbound. Glenshaw Formation strata crop out along exit ramp.
1.7	46.3	TURN LEFT at traffic light. Holiday Inn ahead on right, Fisher Scientific on left. CONTINUE west on US Route 422 (Indian Springs Rd.).
1.0	45.2	Junction with PA Route 286. Peoples Natural Gas regional office on left, PennDOT maintenance garage on right. CONTINUE west on US Route 422.
1.4	46.6	TURN LEFT at traffic light and CONTINUE west on US Route 422.
6.1	52.7	Enter Shelocta. Shelocta Power Station ahead in the distance.
0.1	52.8	Cross Crooked Creek.
0.6	53.4	Junction with PA Route 156. CONTINUE west on US Route 422.
0.5	53.9	TURN RIGHT on Wood Rd. Park on right hand side. Passengers will leave the buses, and the buses will continue down Wood Rd. a short distance where they will be able to turn around.

STOP #2. SHELOCTA FOSSIL LOCALITY: TAPHONOMY AND GEOCHEMISTRY OF THE BRUSH CREEK MARINE INTERVAL, GLENSHAW FORMATION, CONEMAUGH GROUP

LEADERS: Karen Rose Cercone and John F. Taylor

At this exposure the marine shales and core limestone of the Brush Creek interval, together with the underlying Brush Creek coal and overlying deltaic siliciclastics of the Buffalo sandstone, form a symmetrical transgressive-regressive cycle. The exposure has served for more than 20 years as an invaluable educational aid to geology programs at Indiana University of Pennsylvania (IUP) and other nearby institutions to crystallize fundamental concepts in introductory and advanced courses. The outcrop (Figure 76) is privately owned and the owner has graciously granted access for field trips (including this Field Conference) whenever notified of the date and time of the visits in advance. To assure that access to this very important outcrop does not become a problem in the future, it is recommended that anyone wishing to return to this exposure at a later date contact Dr. John Taylor at the IUP Geosciences Department to arrange for permission from the land owner.

Even introductory (e.g. Historical Geology) students have sufficient background to appreciate the environmental significance of the succession of lithofacies from the Brush Creek coal at the base of the outcrop, through the core limestone representing the peak of transgression, to more nearshore

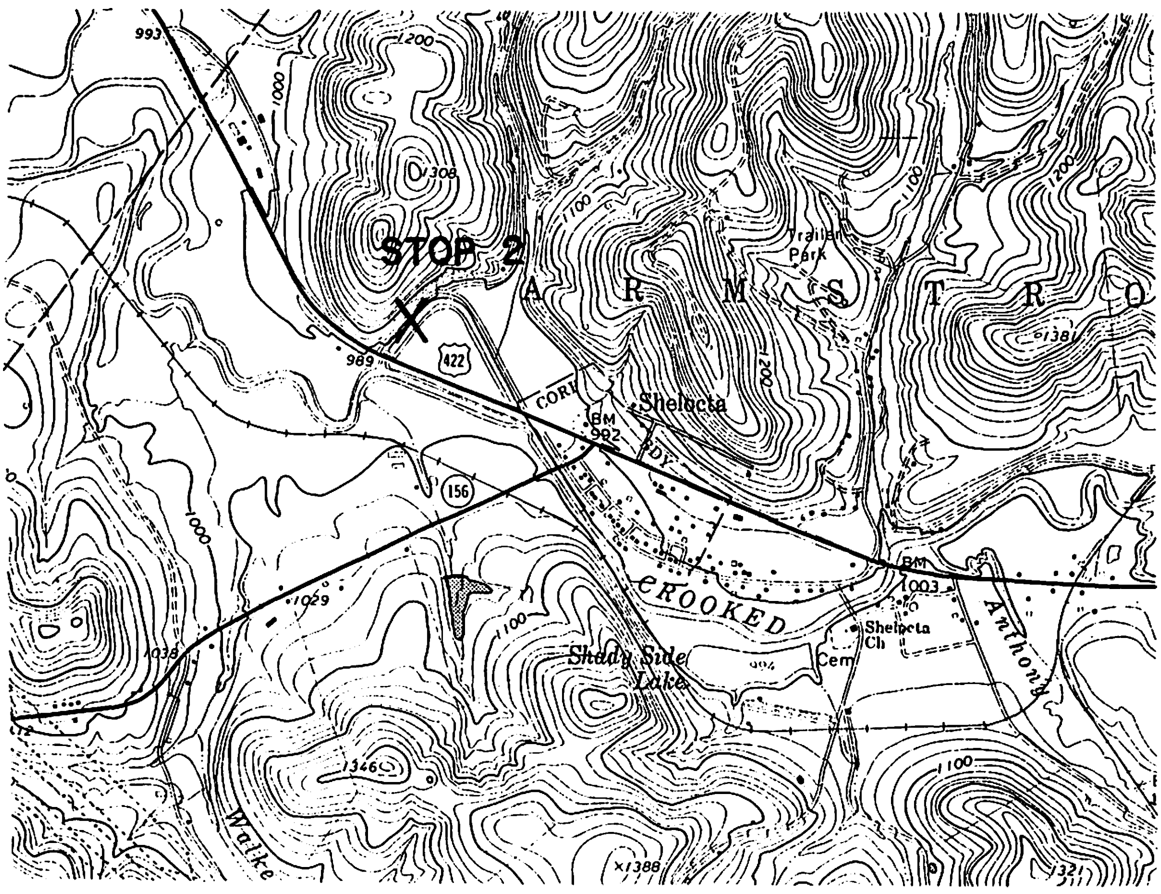


Figure 76. Location of Stop #2 (Elderton quadrangle).

siliciclastics of the Buffalo sandstone - an exemplary illustration of Walther's Law, complete with gradational contacts between adjoining components. A closer examination reveals that the biofacies follow a similar succession, reflecting the close control of environment on the composition of the faunas within each lithofacies. The biofacies within the Brush Creek interval mirror those thoroughly documented by Brezinski (1983) for the slightly younger but very similar Ames marine interval at the top of the Glenshaw Formation. The brachiopod-dominated fauna of the core limestone differs dramatically from the high diversity mollusc-dominated assemblage within the overlying and underlying calcareous shales. Highly fissile, non-calcareous shales slightly higher in the outcrop contain a low diversity assemblage in which small pectiniform bivalves and large, well-preserved pinnules of fern-like foliage (e.g. Neuropteris) are the commonest components.

The most extraordinary aspect of the Shelocta exposure is the pristine nature of the metastable bioclasts. A separate paper within this guidebook describes in detail the taphonomy and geochemistry of the Brush Creek interval; a brief summary is provided in the sections below.

NATURE OF PRESERVATION

Preservation of the metastable components is restricted to the dark, calcareous shale intervals. Fossils of originally aragonitic composition within the core limestone have been recrystallized to stable low-magnesium calcite. Molluscs (gastropods, bivalves, and cephalopods) in the organic calcareous shales still consist of aragonite and often display on the outcrop a distinctive chalky appearance that is produced by the decomposition of nacreous aragonite (Turekian and Armstrong, 1961). Although the chalky appearance is a useful trait for quick recognition of nonstabilized skeletal material in the field, not all bioclasts composed of metastable carbonate display this texture. More thorough examination, involving a variety of analytical procedures, is necessary to conclusively evaluate the degree of alteration of a given fossil assemblage (Brand and Morrison, 1987b).

Fossils from the Brush Creek interval at Shelocta have been tested with chemical stains for aragonite and high-magnesium calcite, examined under scanning electron microscope (with an energy dispersive analyzer) to assess the degree of ultrastructural alteration and elemental composition, examined by fluorescence microscopy, and analyzed for trace element and isotopic composition (Morrison and others, 1985; Durika and others, 1987). These tests have shown Brush Creek skeletal material to be some of the best preserved Paleozoic fossils in the world. In addition to the aragonitic molluscs, the Brush Creek at Shelocta has yielded echinoderm fragments that are virtually unaltered high-magnesium calcite and rugosan corals that are still composed of primary intermediate-magnesium calcite.

MECHANISM FOR PRESERVATION

The most conspicuous characteristic of the shale interval containing the nonstablized fossils is its high organic content. Chemical analyses of these shales confirms what is apparent from visual inspection of the outcrop - the shales containing metastable skeletal material have a significantly higher total organic carbon (TOC) content than the core limestone. The organics obviously have the potential to have acted as a seal that isolated the bioclasts from circulating pore fluids essential to the stabilization process. This potential, along with the high organic content of enclosing strata associated with other sites of preserved Pennsylvanian aragonite (e.g. the asphaltic limestones of the Boggy Formation in southern Oklahoma - Brand, 1989), makes the organic nature of the enclosing sediment a plausible (in fact, very attractive) explanation for the unusual preservation. There is, however, some inconsistencey in the relationship between TOC and degree of preservation of metastables in the geochemical data from other localities. Additional work is needed to unravel what apparently is a somewhat more complicated relationship, but an important role for organics in the preservation still seems likely.

Another factor that was probably important, indirectly or directly, in the preservation is degree of bioturbation (churning of the sediment by burrowing organisms). The type and extent of infaunal activity has been cited in recent research on fossil diagenesis (Speyer and Brett, 1986 and 1988) as an important factor in determining how fossils will ultimately be preserved, significant churning of the sediment generally contributing to the physical and chemical degradation of the skeletal material. On initial inspection, the organic shales at Shelocta appear to be strongly bioturbated. Closer examination, however, reveals that the trace fossils are common only at particular horizons and are primarily horizontal trails and shallow feeding traces. The abundance (predominance) of articulated bivalves, barely disrupted crinoid columns, and somewhat clustered occurrence of rugosan corals arranged calyx-up at an oblique angle to the bedding (essentially in situ) attest to the minimal degree of sediment churning affected by the trace-making organisms. The absence of intermediate and deep burrowing very likely contributed to the preservation of the bioclasts in unaltered form by allowing isolation of the fossils within the organic rich sediment without connection to the oxic bottom waters and organisms that could have destroyed the protective organic films.

SIGNIFICANCE OF THE EXCEPTIONAL PRESERVATION

Aside from their value as geologic curiosities, the nonstabilized Pennsylvanian bioclasts of the Brush Creek marine interval have considerable value in determining the original skeletal composition and ultrastructural characteristics of certain extinct groups. This information, in turn, provides insight into taxonomic assignments and the suitability of the skeletal material from these groups for isotopic and trace element analysis. A few examples follow.

Skeletal ultrastructure has proved extremely useful in the higher level taxonomic classification of many groups, among them the Mollusca. Several extinct families of molluscs are represented within the Brush Creek fauna and the exceptional preservation of these aragonitic fossils includes the preservation of skeletal ultrastructures that are obliterated by recrystallization during normal preservation. Similarities or differences in ultrastructure verified in extinct groups from Shelocta compared to those domumented for extant groups have shed some light on upper level taxonomic affinities of extinct groups like the bellerophontid and pleurotomariid gastropods (Rollins, 1967; Batten, 1972).

The primary mineralogy of rugosan corals (aragonite vs. calcite) and trilobite cuticle (high-magnesium vs. low-magnesium calcite) has long been debated with arguments based on such diverse criteria as petrographic features, mineralogy of related extant groups, and trace element composition. The occurrence of rugosan corals composed of intermediate-magnesium calcite in strata where aragonitic bioclasts are preserved (as aragonite) provides a potent argument against an original aragonitic composition for this group. Similarly, the documentation of trilobite cuticle, verified as low-magnesium calcite, closely associated with crinoid ossicles that are preserved as pristine high-magnesium calcite, argues strongly for a primary stable low-magnesium calcite composition for trilobite skeletal material. This is particularly exciting in that a stable low-magnesium calcite composition warrants confidence in the trace element and isotopic compositions of trilobite cuticle as reliable signatures of the composition of ancient sea water. It is also testimony to the power and importance, even in this age of increasingly sophisticated and effective analytical instrumentation and procedures, of careful and thorough documentation of field relationships.

Table 17. Fossils from the Brush Creek marine interval at Shelocta.

Coelenterata	Gastropoda
<u>Stereostylus</u>	<u>Euphemites</u>
	<u>Bellerophon</u>
Conulata	<u>Pharkidonotus</u>
Unidentified conulariid	<u>Amphiscapha</u>
	<u>Trespospira</u>
Brachiopoda	<u>Glabrocingulum</u>
<u>Chonetinella</u>	<u>Worthenia</u>
<u>Crurithyris</u>	<u>Shansiella</u>
<u>Derbyia</u>	<u>Meekospira</u>
<u>Juresania</u>	<u>Strobeus</u>
Crinoidea	<u>Cephalopoda</u>
Columnals	<u>Brachycycloceras</u>
	<u>Pseudorthoceras</u>
Bivalvia	<u>Metacoceras</u>
<u>Nuculopsis</u>	<u>Schistoceras</u>
<u>Astartella</u>	
<u>Dunbarella</u>	
<u>Phestia</u>	

FOSSILS

A list of the fossils found in the Brush Creek at Shelocta (taken from Hoskins and others, 1983, with taxa added from IUP paleontological collections) is provided in Table 17.

		LEAVE STOP #2. Return to US Route 422. TURN LEFT (east) and follow US Route 422.
7.4	61.3	TURN RIGHT at traffic light. CONTINUE east on US Route 422.
1.3	62.6	Junction with PA Route 286. CONTINUE east on US Route 422.

1.5	64.1	TURN RIGHT and stay on US Route 422. Get in left hand lane.
0.9	65.0	TURN LEFT at intersection with US Route 119. Stay on US Route 422.
1.0	66.0	BEAR RIGHT and merge with US Route 422 expressway.
6.6	72.6	Intersection with PA Route 553. Pikes Peak on right is the northern extension of Chestnut Ridge in Indiana County. CONTINUE on US Route 422.
3.3	75.9	Cross Yellow Creek.
0.3	76.2	Intersection with PA Route 259. TURN RIGHT (south) onto PA Route 259. Enter Yellow Creek State Park.
1.2	77.4	TURN RIGHT onto road leading to Beach and Boat Rental areas.
0.2	77.6	Cross Little Yellow Creek.
0.1	77.7	TURN RIGHT onto road to picnic area.
0.1	77.8	Buses will park at the pavillion and passengers will disembark. STOP #3 AND LUNCH: YELLOW CREEK STATE PARK
		LEAVE STOP #3. Return to PA Route 259. TURN RIGHT (south) onto PA Route 259.
1.1	78.9	Cross Little Yellow Creek.
0.2	79.1	TURN RIGHT and CONTINUE on PA Route 259.
3.5	82.6	Junction with PA Route 56 in Brush Valley. TURN LEFT (east) onto PA Route 56.
4.1	86.7	Cross Blacklick Creek.
2.3	89.0	TURN LEFT (east) onto entrance ramp of US Route 22. MERGE with traffic on US Route 22.
1.0	90.0	TURN RIGHT onto exit ramp for PA Route 403. TURN RIGHT (south) onto PA Route 403.
2.6	92.6	Enter Cramer.
0.3	92.9	Joyland bar on right. Note "Ladies Entrance".
0.6	93.5	Pottsville and Mauch Chunk strata exposed in roadcut on left across from "adult" bookstore. Entering Conemaugh Gorge.
0.3	93.8	Clark Run Nature Area parking lot on left. Lower Mauch Chunk red beds at road level.
0.1	93.9	Loyalhanna Formation calcareous sandstones/arenaceous limestones at road level on left.
0.1	94.0	Burgoon Sandstone at road level on left.
0.3	94.3	Strata of the "Rockwell tongue" at road level on left. Notice the characteristic spheroidal weathering of the upper fissile siltstones and shales.
0.3	94.6	Conglomerates and conglomeratic sandstones of the "Weir sand" at road level on left. Dark-colored strata of the Riddlesburg Shale a few hundred feet further on.
0.1	94.7	Massive sandstone characteristic of the "Murrysville sand" at road level on left.
0.3	95.0	Indiana/Cambria County line. Buses will discharge passengers here and will pick them up at Clark Run Nature Area parking lot.

STOP #4. CONEMAUGH GORGE THROUGH LAUREL HILL: MISSISSIPPIAN AND DEVONIAN STRATIGRAPHY, DEPOSITIONAL SYSTEMS, AND STRUCTURES

LEADERS: Christopher D. Laughrey, John A. Harper, Uldis Kaktins, David K. Brezinski, and Assad Iranpanah

At this stop (Figure 77) we will have an opportunity to examine a very long and complicated stratigraphic sequence ranging from the Upper Devonian Venango

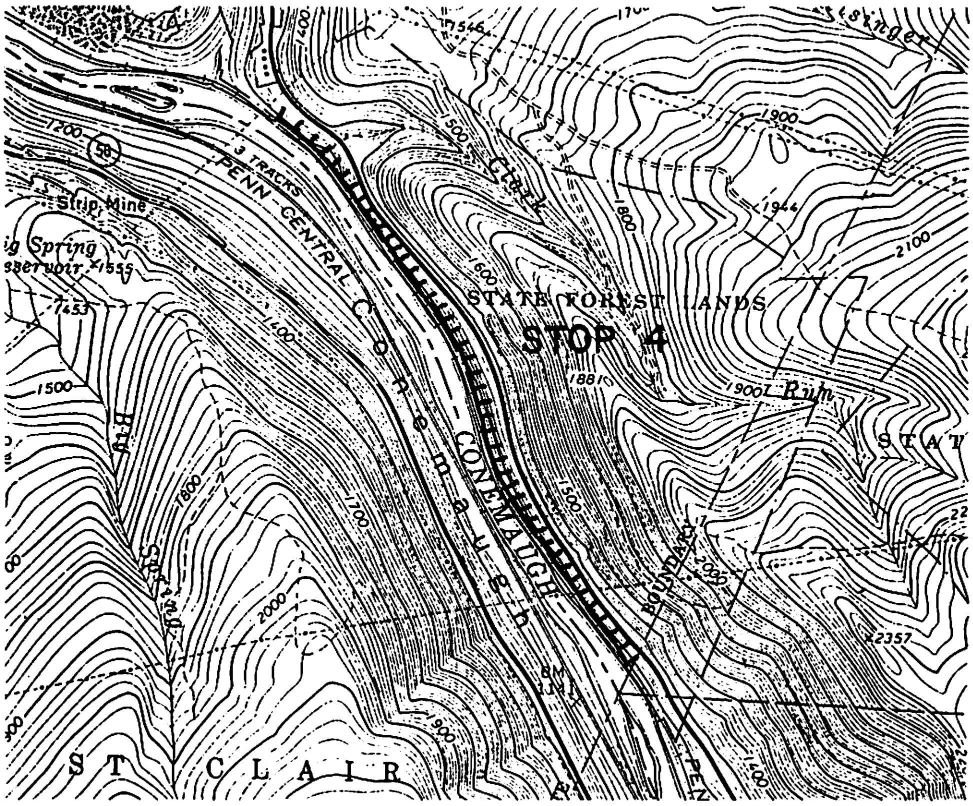


Figure 77. Location of Stop #4 (Vintondale quadrangle).

Group (Middle red shale zone) through the Upper Mississippian Mauch Chunk Formation. This stop will be divided into two trips. Trip 1 will require strength and endurance; it requires climbing into and out of the Conemaugh Gorge via the steep hillside between PA Route 403 and the Conrail railroad tracks below. This trip will enable conferees to examine the Middle red shale zone and Upper sandy zone of the Venango Group, a portion of the Cussewago equivalent member of the Murrysville sand, the Burgoon/Loyalhanna contact, the Loyalhanna Formation, and the Mauch Chunk Formation. Cursory examination of the Rockwell tongue and the Burgoon Sandstone will be allowed, but there will be no presentation on these formations. Trip 2 is designed for those who may feel themselves incapable of descending and ascending the steep hillsides of the Conemaugh Gorge. This trip will focus on the outcrops along PA Route 403, particularly the Murrysville sand, Riddlesburg Shale, and Weir sand. As with trip 1 Conferees will have the opportunity to examine the Rockwell tongue and Burgoon Sandstone in a cursory fashion.

UPPER DEVONIAN AND LOWER MISSISSIPPIAN

(Laughrey, Harper, and Kaktins)

Venango Group

Upper Devonian strata cropping out in the Conemaugh Gorge near Cramer consist of the Middle red shale zone (or, ostensibly, the "Hampshire tongue") and the Upper sandy zone of the Venango Group. The Middle red shale zone contains nonmarine rocks that were deposited during the maximum progradation of the Catskill Delta complex. The Upper sandy zone consists of fluvial, paralic, and marine rocks that were deposited both at maximum sea level lowstand and throughout the subsequent transgression that shifted the shoreline eastward at the end of the Devonian (Figure 78). The topmost lithologies of the Upper sandy include fascinating carbonate rocks whose deposition represents maximum sea level highstand at the end of the Devonian and whose diagenetic mineralogy might reflect the progress of the ensuing sea level drop in earliest Mississippian time.

Middle Red Shale Zone

We will not spend much time examining or discussing the Middle red shale zone exposures in the Conemaugh Gorge near Cramer. Conferees choosing to take the more physically exhausting trip down to the railroad tracks will reach the outcrop at the contact between this unit and the superjacent Upper sandy zone lithologies. Our measured section of this Middle red shale zone exposure is presented in Figure 29 for those of you who may be interested in the nature of the "Catskill" sequence developed here. Interested participants are referred to pages 48 to 50 in this guidebook.

The Middle red shale zone was deposited in this area during the maximum progradation of the Catskill Delta complex in Late Devonian time. This regression is represented by the positive slope of that portion of the sea level curve shown in Figure 78 labeled "Maximum Progradation". Falling sea level should have resulted in erosional dissection of these coastal plain sediments. The surface produced by this process would initially control the depositional architecture of later transgressive facies. According to Nummedal and Swift (1987, p. 246):

> "Transgression of a coastal plain previously dissected by an episode of falling sea level will produce estuaries (shore normal) and flanking back-barrier lagoons and marshes. The consequent stratigraphy will be

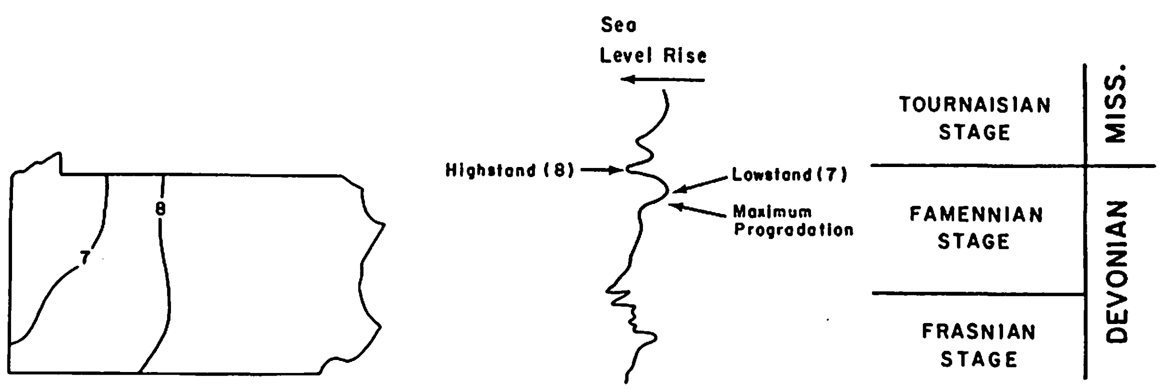


Figure 78. Shoreline positions postulated by Dennison (1985) for lowstand (7) and highstand (8) of Late Devonian sea level in western Pennsylvania. The relavent portion of Dennison's curve is shown to the right of the map. A more detailed sea level curve for the Late Devonian can be found in Johnson and others (1985).

characterized by an inner shelf sand sheet above back barrier deposits and 'ribs' of fluvial and estuarine sediments filling former subaerial valleys."

The predictive power of transgressive facies models such as those proposed by Nummedal and Swift (1987) becomes apparent when we examine the stratigraphic sequence that was deposited here after the erosional dissection of the Middle red shale coastal plain.

Upper Sandy Zone

Sea level variations, such as those shown in Figure 78, exert a profound influence on the development of unconformities, facies, and depositional systems in coastal plain and shallow marine settings (Nummedal, 1987). The recognition and interpretation of depositional sequences and their internal architecture in terms of sea level variations depends upon our capability to correctly identify sequence boundaries (unconformities) and construe the arrangement of facies within the sequence. The Upper sandy zone exposure here in the Conemaugh Gorge through Laurel Hill provides an unusual and excellent opportunity to observe the internal architecture of transgressive facies within an unconformity-bounded stratigraphic unit.

Regional correlations, subsurface mapping, and facies patterns at this outcrop and in the Conemaugh Gorge through Chestnut Ridge at Bolivar all support the recognition of a sequence boundary produced by coastal encroachment during the period of relative sea level rise represented by the negative slope between points 7 and 8 in Figure 78. This sea level rise produced an onlapping sequence (the Upper sandy zone). At Bolivar the onlap was associated with the transgression because the rate of Late Devonian sea level rise exceeded the rate of coastal sedimentation. Paralic strata were truncated by the retreating shoreface and only marine strata of the Upper sandy zone crop out there. The situation at Cramer is somewhat different. Here, coastal sedimentation surpassed the relative sea level rise and a regressive facies succession is associated with the basal onlap of the Upper sandy zone; this is exactly what is predicted in the statement made by Nummedal and Swift (1987) quoted above. Figure 79 shows the sequence of facies exposed within the Upper sandy zone at Cramer. Interbedded cycles of fluvial deposits overlain by estuarine accretionary deposits and tidal shoal/flat deposits comprise roughly the lower 2/3 of the Upper sandy zone. Marine mudrocks and poorly developed carbonates complete the approximate upper 1/3 of the interval (the "Oswayo Formation" of Harper and Laughrey, 1987) and represent open bay and/or inner shelf deposits. Compare the sequence of Upper sandy facies shown in Figure 79 to the sequences from Holocene marginal marine settings shown in Figure 81. The comparison is remarkable.

Fluvial Deposits - Fluvial facies in the Upper sandy zone at Cramer consist of cross-bedded and ripple-laminated, fine- to very fine-grained, sublitharenites and litharenites with subordinate amounts of siltstone and shale. The outcrop sequence begins with a spectacular display of climbing-ripple laminations (Figure 82). Ripple current directions are N to N12°W and their angle of climb varies from 10° to 31°. The steeper angles are more common. Macerated plant debris and carbon residues are very abundant within the ripple laminated sandstone. Minor shales occur interbedded with the sandstones. The climbing ripple-bedded sequence is overlain by relatively coarser cross-bedded

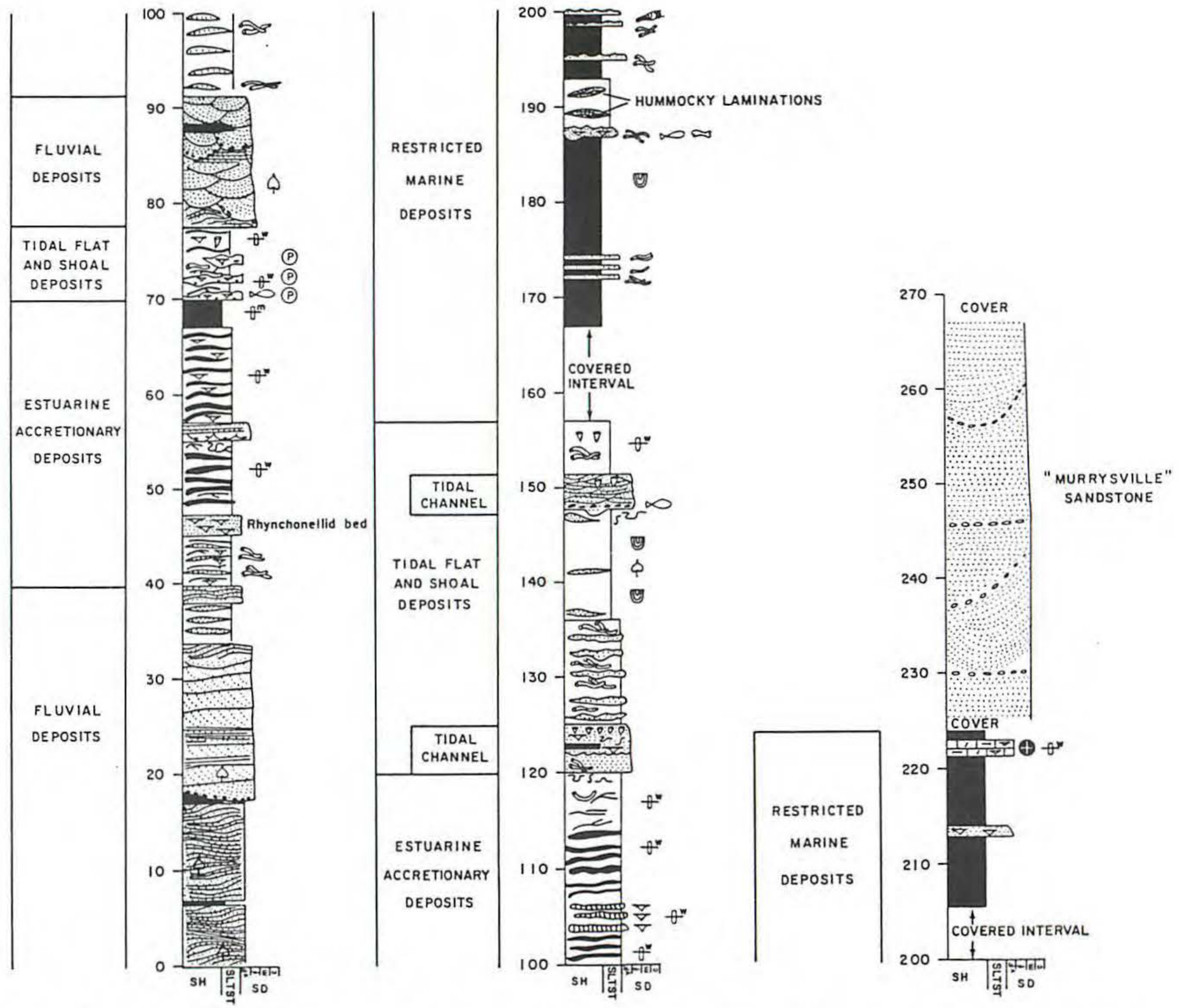


Figure 79. Interpretive measured stratigraphic section of the Upper sandy zone exposed along the Conrail railroad tracks below PA Route 403 near Cramer. Symbols are explained in Figure 80.

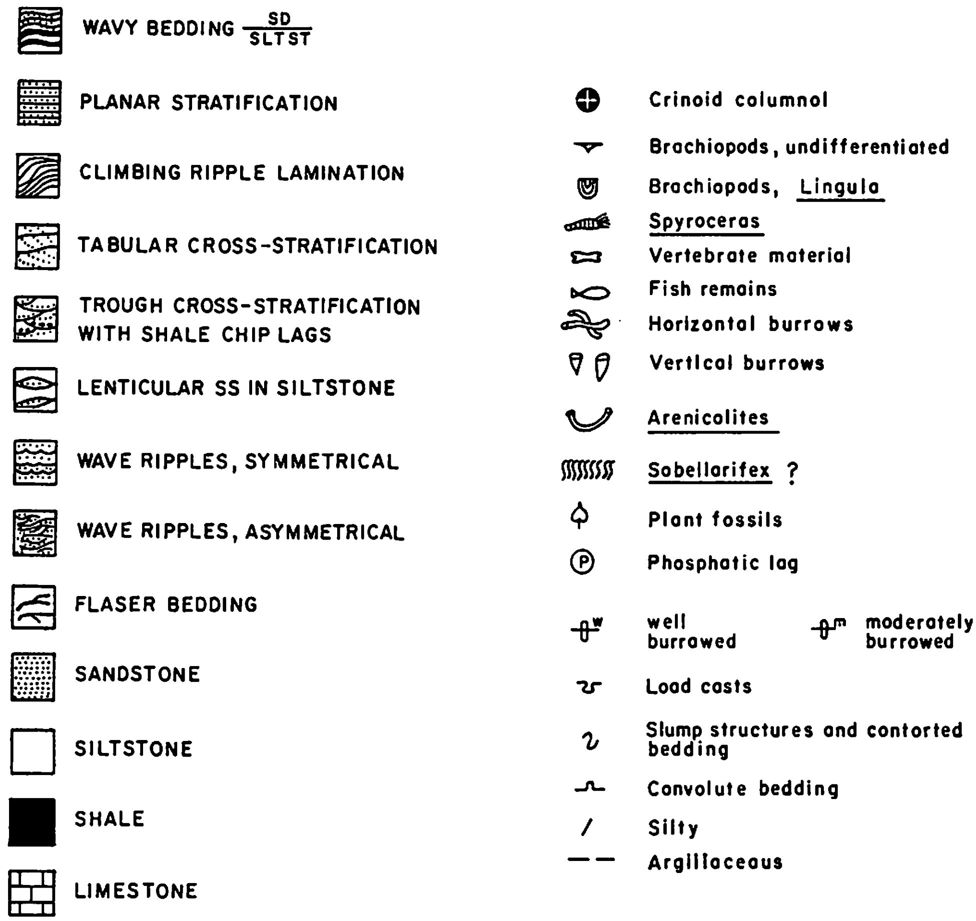


Figure 80. Explanation of symbols used in Figures 79, 88, 89, and 90.

sandstone. The cross-bedding is tabular, with tangential foresets that grade upwards into subhorizontal to horizontal bedding with numerous discontinuities and reactivation surfaces. Shale rip-up clasts are concentrated at the base of the cross-bedded interval. Tabular cross-bed foreset inclinations are near the angle of repose and oriented N30°W. Trough cross-bedding and more climbing ripple-laminations occur higher in the section. These megaripples appear to have scoured the underlying tabular sets. The top of the first fluvial sequence fines abruptly into siltstones with thin lenses of very fine sandstone. This lowermost fluvial sequence within the Upper sandy zone may represent the top of a point bar sequence interbedded with sand wave and overbank or point-bar top deposits.

Fluvial deposits preserved higher in the Upper sandy interval consist of trough cross-bedded, plane-bedded, and ripple-laminated sandstones with shale interbeds and rip-up clasts. These deposits represent in-channel megaripples and point bar sediments.

<u>Estuarine Accretionary Deposits</u> - These rocks consist of wavy, flaser, and lenticular bedded very fine-grained sandstones, siltstones, and shales. The sandstones are bioturbated and contain both trace fossils and brachiopod body fossils. These lithologies reflect the dominance of tidal influence and its

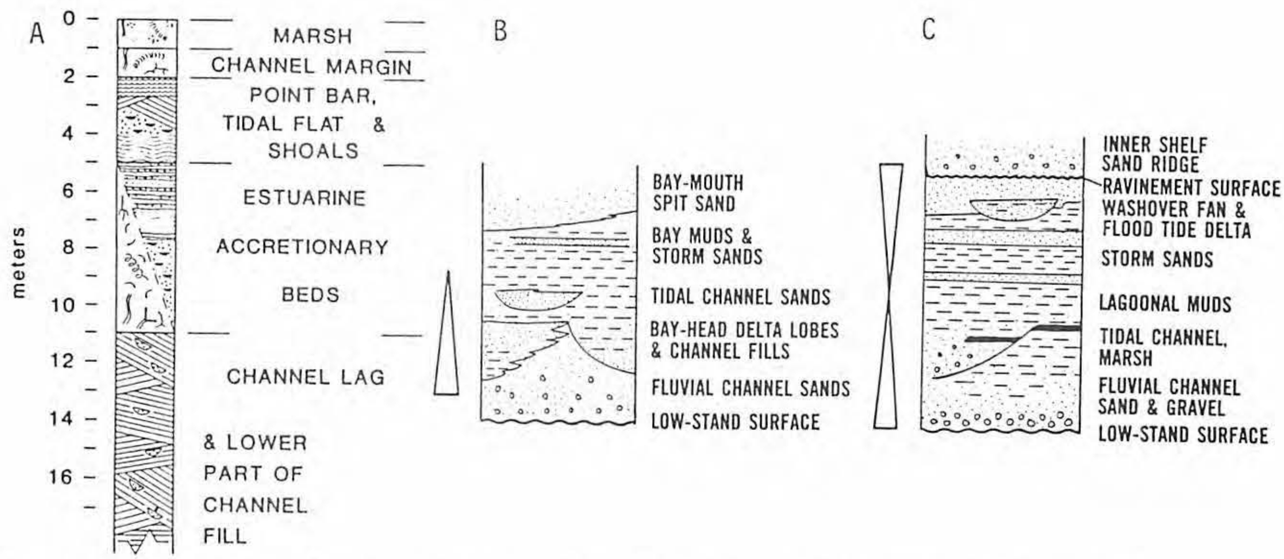


Figure 81. Models of estuarine sections from the Holocene and Recent. A. Idealized vertical section and bedding features for riverine estuary sequences in the Georgia Bight (from Frey and Howard, 1986, p. 913); B. Stratigraphic column for the Holocene fill of Lavaca Bay on the central Texas coast (from Nummedal and Swift (1987, p. 248); C. Stratigraphic column for the Beach Haven ridge complex of the New Jersey coast (from Nummedal and Swift, 1987, p. 248). Compare all three models with the stratigraphic column for the Upper sandy zone shown in Figure 79.

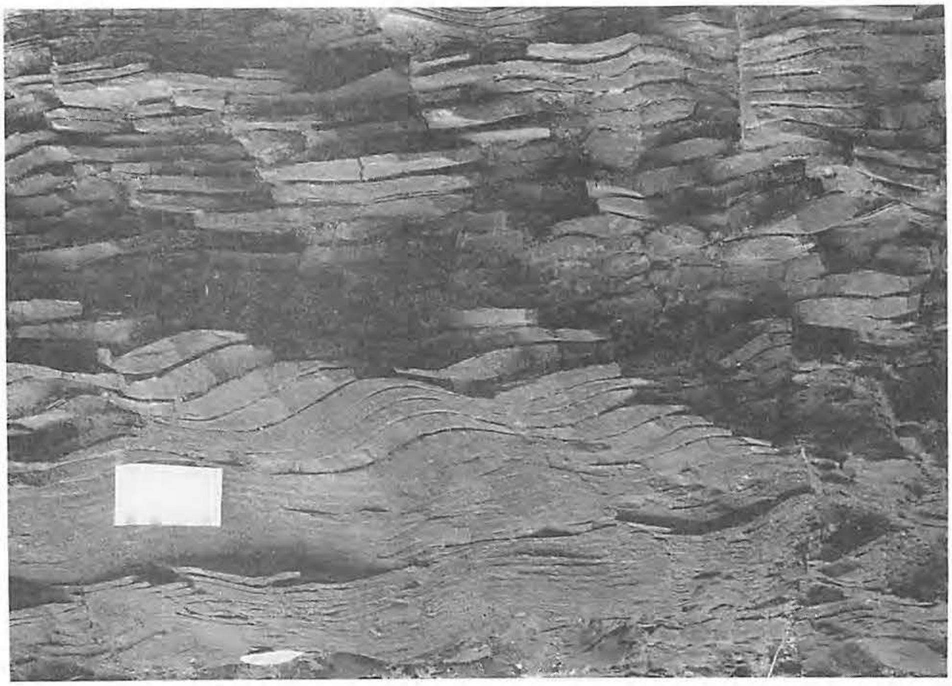


Figure 82. Photograph of climbing ripple-laminations in the fluvial facies of the Upper sandy zone exposed along the Conrail railroad tracks in the Conemaugh Gorge near Cramer.

associated fluctuation in depositional energy. A few fining-upwards, coarser sandstone beds occur interbedded with the wavy, flaser, and lenticular bedded rocks. One of these contains an abundance of the rhynchonellid brachiopod Ptychomaletoechia. The other displays trough cross-stratification and parallel bedding.

Estuaries are, by definition, confined to former river valleys and channels. Estuarine sedimentation is characterized by channel migration and lateral accretion, and thus most deposition occurs in association with tidally-influenced point bars. High energy sides of the estuarine channel developed at Cramer are represented by the fossiliferous and/or cross-bedded and laminated sandstones. The wavy, flaser, and lenticular bioturbated lithologies reflect the lower energy bank sides of the estuarine channel.

Some of the fossiliferous, lenticular, very fine-grained sandstones within the estuarine accretionary intervals contain a dense concentration of subvertical to vertical trace fossils that we are tentatively calling Sabellarifex (Figure 83). These traces are similar to Skolithos but not as straight or crowded (Hantzschel, 1975). If our identification is correct, these traces may be useful for suggesting in what position within the estuarine point bars these rocks were deposited, i.e. bar crest or flank (Barwis, 1985).

Tidal Flat, Channel, and Shoal Deposits - This facies consists of interbedded sandstone, siltstone, and shale. Common sedimentary structures include wave and current ripples and wavy, flaser, and lenticular bedding. Both body fossils and trace fossils are common. The rocks are moderately to very well bioturbated. Fining-upward sandstone bodies with basal scour surfaces and shale-chip and fossil lags, current and/or wave ripples, slump structures and load casts, body and trace fossils, and minor shale interbeds comprise tidal channels. Tidal flat and shoal deposits display lenticular, flaser, and wavy bedding, which indicate alternation of tidal current bedload and sediment transport, and abundant evidence of organic activity (marine fossils, trace fossils, bioturbation, and plant debris). Phosphatic pebble lags occur at the base of the lenticular sandtones; current and wave reworking of the sediments accompanied by winnowing of finer material concentrated the phosphatic grains. The phosphatic pebble lags also include fish remains suggesting a possible vertebrate source of the initial phosphate minerals.

Restricted Marine Deposits - Restricted marine deposits occur in the upper portion of the Upper sandy zone and represent the final drowning of the former river valley and estuary by marine waters at Cramer. Dark gray to black shales are the principal lithology. The shales contain a sparse restricted marine fauna. We have found a few specimens of the inarticulate brachiopod, Lingula and fragments of a cephalopod, probably Spyroceras. Regional stratigraphic cross sections (Kelley and Wagner, 1970) and isopach maps (Piotrowski and Harper, 1979) show that the shales of this interval are flanked by sandstone shoals to the west. This supports our interpretation of a bay environment with restricted marine circulation for the deposits exposed here. Minor thin sandstone and siltstone beds occur within the thicker shale sequence. These coarser lithologies exhibit small basal scour surfaces with vertebrate fossil lags, planar laminations, hummocky laminations, and wave ripples. Horizontal burrows and brachiopods also occur in these sandstones and siltstones. These lithologies probably were deposited during storms that provided enough energy to transport coarser sediment into the restricted bay environment.

A

B

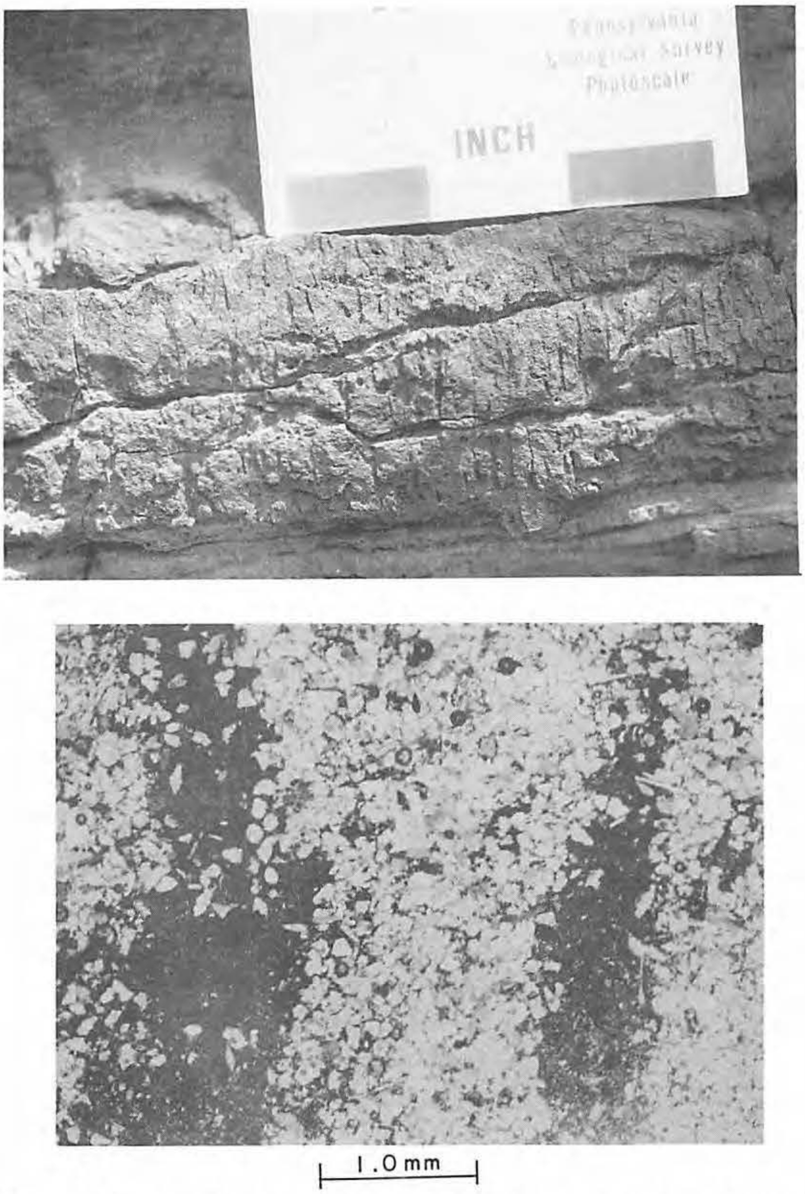


Figure 83. Photographs of the trace fossil Sabellarifex(?) in lenticular, very fine-grained sublitharenite of the Upper sandy zone estuarine accretionary facies. (A) Outcrop exposure showing the abundance of the traces in the sandstones. (B) Photomicrograph of the traces in the sandstone. The tubes are similar to those constructed by the Recent annelid Sabellaria alveolata (Hantzschel, 1975).

Limestones, the uppermost lithology in the Upper sandy zone, occur directly below the Murrysville sand. The carbonates consist of one or two beds 12 to 24 in (30.5 to 70.0 cm) thick that seem to bifurcate in places; they occur along both PA Route 403 and along the Conrail railroad tracks below. These carbonates also occur at the Bolivar section in the Conemaugh Gorge through Chestnut Ridge, and can be recognized on geophysical logs in the numerous boreholes around the region. These rocks represent the highstand of Late Famennian sea level at the end of the Devonian (Figure 78, highstand 8). Terrestrial sediment input was low enough to permit carbonate sedimentation to occur.

The uppermost limestones of the Upper sandy zone are argillaceous, silty, dolomitic, mixed-fossil wackestones. The major components, determined by X-ray diffraction, are calcite, dolomite, and quartz. Minor components include plagioclase, mica, siderite, kaolinite, and chlorite. Petrography reveals that the rocks consist of an argillaceous and silty pseudospar groundmass that supports mostly recrystallized fossil shell material (Figure 84). The clastic silt is coarse and is composed of subangular quartz and muscovite. Clay minerals are present as matrix. Fossils include brachiopods, bivalves, crinoids, and conodonts. Much of the recrystallized shell material is difficult to identify. Numerous solution zones, marked by stylolitic, insoluble residues, cut across recrystallized shell material. Scattered patches and fragments of opaque organic matter are common. The rocks are strongly bioturbated. Dolomite occurs as discrete, zoned, euhedral to subhedral crystals. It is most abundant in the more argillaceous intervals.

A number of diagenetic changes in the limestones are apparent. These changes include neomorphic fabrics of the original lime matrix represented by the pseudospar groundmass, neomorphic alteration of the original fossil shell material, and the dolomitization fabric in the rocks (Figure 84). These diagenetic fabrics might reflect the role of meteoric water in the post-depositional alteration of the marine sediments and thus contain a mineralogical record of falling sea level in earliest Mississippian time. We have not had much time and opportunity to study these carbonates so our idea is only a curious suggestion. It certainly is a worthwhile topic for futher detailed study.

Murrysville sand

Field relationships - The Murrysville sand is 36 to 97 ft (10.9 to 29.6 m) thick in outcrop exposures at Stop #4 near Cramer. In nearby gas wells the Murrysville has an average thickness of 60 ft (18.3 m). The base of the Murrysville lies disconformably on shales and thin limestones of the subjacent Venango Group (Figure 85). The main body of the Murrysville consists almost entirely of sandstone. Along PA Route 403, however, the uppermost 30 ft (9.1 m) of the Murrysville interval fines upward rather abruptly into a sequence of interbedded sandstones, siltstones, and shales that appear to grade conformably into the superjacent Riddlesburg Shale. The principal thick sandstone interval comprising the lower 2/3 of the Murrysville is what we call the "Cussewago equivalent member", whereas the upper 1/3 of the interval, consisting of mixed sandstone, siltstone, and shale is what we call the "Berea equivalent member" of the Murrysville sand.

Exposures of the Cussewago equivalent member of the Murrysville sand along the railroad tracks below PA Route 403 are massive and featureless. Along the road itself, however, the Cussewago displays a great many sedimentary features. Trough cross-stratification is the dominant sedimentary structure in the sandtones, but minor occurrences of tabular cross-stratification, planar stratification, and current-ripple laminations also occur at this outcrop. Trough cross-bedded sets are quite thick within the lower 1/3 of the exposed interval; their lower bounding surfaces are denoted by coarse quartz pebble lags. Trough cross-bedded sets in the upper 2/3 of the Cussewago are more medium bedded,

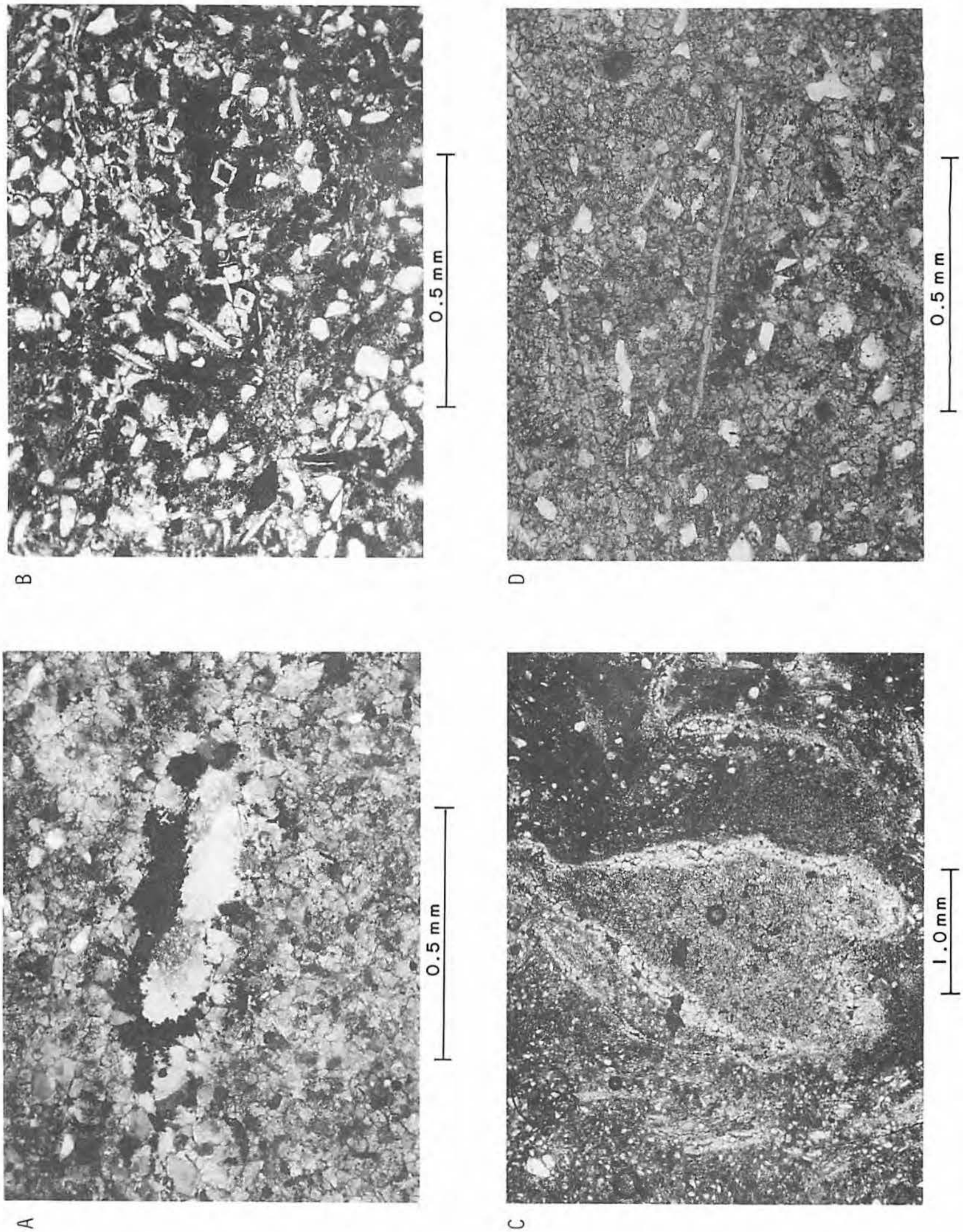

A
0.5 mm
B
0.5 mm
C
1.0 mm
D
0.5 mm

Figure 85. Photograph of the basal exposure of the Murrysville sand along PA Route 403 near Cramer. The base of the thick sandstone lies on the unconformity that marks the top of the subjacent Upper sandy zone of the Venango Group. Geologist's heads are at the traditionally accepted Devonian-Mississippian boundary.

broader, and shallower than those below, and their lower bounding surfaces are marked by shale-chip conglomerate lags. Scour surfaces and groove casts are abundant on the bases of most groups of trough cross-bedded sets. The latter exhibit paleocurrent directions between N40°W and N60°W.

A few feet of sandstone in the upper half of the Cussewago interval display tabular cross-stratification, planar stratification, and current-ripple laminations. Siltstones at the very top of the interval display climbing-ripple laminations and parallel laminations, and contain iron-mineral concretions. Plants comprise the only fossils found in the Cussewago equivalent at Cramer. Some of these are quite impressive. Large log casts occur at the base of the

Figure 84. Photomicrographs of the carbonate rock at the top of the Upper sandy zone. (A) Low-magnification view of the limestone. Note the pseudospar groundmass, recrystallized fossil shells, dark organic matrix, quartz silt, and stylolite seams associates with some fossil allochems. (B) Higher magnification view highlighting anhedral to subhedral crystals of the pseudospar groundmass, quartz silt, and fossil material. (C) Neomorphic calcite replaces original wavy, parallel-laminated shell structure of a brachiopod. Note the dark, opaque organic matter surrounding the fossil and dispersed within the adjacent pseudospar groundmass. (D) Zoned dolomite crystals within the more bioturbated, argillaceous portion of the Upper sandy zone carbonate.

thick trough cross-stratified sets in the lower portion of the interval as do 1 to 3 in (8 to 15 cm) long plant fragments. Macerated plant debris is common throughout the entire stratigraphic interval.

Berea equivalent sandstones, siltstones, and shales exposed along PA Route 403 appear quite different from the subjacent Cussewago sandstones. They display spectacular wave-ripple patterns, current ripples, parallel laminations, wavy, flaser, and lenticular bedding, shallow scour surfaces, and some rip-up clasts. In addition to plentiful plant-fossil debris, marginal-marine trace fossils are abundant. These include both horizontal and vertical burrows, and the U-shaped burrow of Arenicolites.

Hand Sample Description - The Murrysville sand, in outcrop, is light to moderately olive brown. The Cussewago equivalent is medium- to coarse-grained, locally conglomeratic sandstone. The Berea equivalent is very fine- to fine-grained sandstone. "Cussewago" sandstones are mostly moderately sorted, but conglomeratic zones at the base of thick trough cross-bedded sets are poorly sorted. "Berea" sandstones are well sorted to moderately well sorted. Cementation is poor to moderate in the Cussewago; most hand samples are easily disaggregated between two fingers. Grains appear subrounded to rounded. Berea equivalent sandstones, in contrast, are well indurated, and quartz cement in the form of overgrowths imparts an angularity to many of the framework grains.

Texture - Cussewago and Berea equivalent sandstones in the Murrysville have a grain-supported fabric, with quartz, chert, and feldspar providing structural support for the rock frameworks. Metamorphic and sedimentary rock fragments exhibit varying degrees of plastic deformation; some of these mechanically labile grains are squashed severely enough to be confused with clay matrix (pseudomatrix of Dickinson, 1970). Grain contacts are mostly long and concavo-convex, indicating a certain amount of compaction and rearrangement of framework grains, possibly in response to the squashing of rock fragments.

Preferred shape orientation of grains is not obvious in the Murrysville sandstones because a large number of grains are equidimensional and because compaction and rotation have determined much of the post-depositional fabric.

Porosity and permeability in the Cussewago equivalent sandstones are very high for a Paleozoic clastic sequence in the central Appalachian Basin (Figures 86A and B). Porosity is largely secondary. Most secondary porosity formed through dissolution of framework silicates, principally chert and metamorphic rock fragments. Some secondary porosity formed through dissolution of calcite cement. A small amount of primary intergranular porosity is preserved, but much of this was reduced by cementation, compaction, and grain rotation.

Porosity and permeability are low in the Berea equivalent sandstones due to substantial cementation of the framework by quartz.

The grain-size distribution of Cussewago equivalent sandstones is that of a moderately sorted, medium-grained sandstone (Figure 86). The break in the cumulative frequency curve (Figure 87) suggests a mixture of two size populations and this bimodal trend is apparent in thin section (Figure 86). Berea equivalent sandstones are moderately well sorted to well sorted.

Framework grains in all of the Murrysville sandstones are subrounded to rounded. Sphericity is somewhat variable, but most grains are of low to intermediate sphericity.

Cussewago equivalent sandstones are texturally submature and Berea equivalent sandstone are mature according to Folk's (1974) classification.

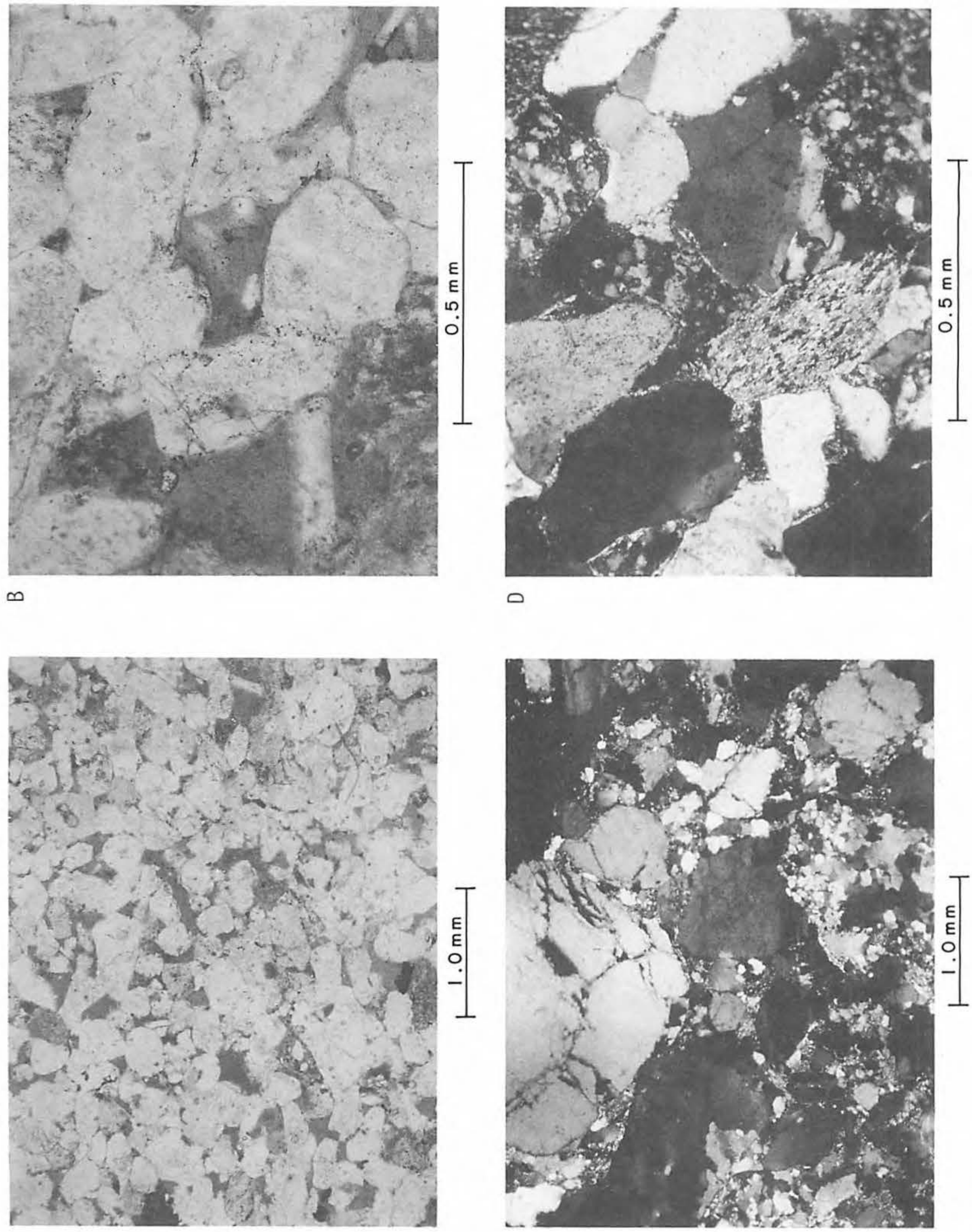
Mineralogy - Quartz occurs in the Murrysville sandstones as monocrystalline and polycrystalline varieties, chert, and secondary overgrowths. Only a small amount of feldspar is present in the rocks, and although some of it is plagioclase, most of it is potassium feldspar. Metamorphic rock fragments consist of both low- and high-rank lithic grains. The former are mostly micaceous phyllite and slate fragments; the latter are derived from schists and gneisses or metaquartzites. Sedimentary rock fragments include dolomite, siltstone, and shale. A small amount of muscovite occurs in the sands. Pyrite is disseminated throughout the sandstones in clusters of very small (0.01 to 0.03 mm) crystals. Typical compositions of the Murrysville sandstones are listed in Table 18 and shown in Figures 86C and D.

The "Cussewago" sandstones are cemented by calcite, clay minerals (chlorite, illite, and smectite), and minor amounts of quartz. The calcite cement is developed as pore-filling euhedral to subhedral crystals, 0.05 to 0.2 mm in diameter. Some calcite has corroded and replace framework grains. The calcite itself shows evidence of dissolution. This process has contributed to part of the porosity in the sandstone. The clays are present as grain coats and pore linings. Quartz cement occurs as syntaxial overgrowths and as prismatic crystals bridging pore spaces (Figure 86A and B).

The "Berea" sandstones are cemented by the same minerals as the Cussewago, but quartz overgrowths are more pervasive, yielding a tight, low-porosity rock.

Interpretation - Pepper and others (1954) stated that the Murrysville sandstone had a southeastern source, a conclusion consistent with the compositional data obtained from the thin sections we examined. Provenance of the framework grains was identified by plotting detrital-sandstone compositional parameters on ternary plots that reflect the tectonic settings of source areas (Dickinson and Suczek, 1979). The relative proportions of quartz, feldspar, and lithics, and the relative proportions of monocrystalline quartz versus polycrystalline quartz, lithics, and feldspar in the Murrysville suggest a recycled orogen provenance for the sediments. Recycled orogen sands are distinguished by an abundance of quartz and sedimentary/metasedimentary lithic fragments (Dickinson and Suczuk, 1979). Further consideration of the relative proportions of polycrystalline quartz, sedimentary and metasedimentary rock fragments, and volcanic rock fragments (absent in our samples) indicate that the region of recycled orogen provenance that shed the Murrysville detritus northwestward during the Kinderhookian most probably was a foreland uplift terrane. According to Edmunds and others (1979), the orogenic source area lay in what is now southeastern Pennsylvania (see their fig. 12C).

Two very different interpretations for the Murrysville's depositional origin are available in the published literature. Pepper and others (1954) concluded that the Murrysville sand originated as a distinctive prograding delta complex in Early Mississippian time. Bjerstedt and Kammer (1988), however, offered a rather reciprocal view and interpreted the Murrysville sand as part of a basal transgressive sandstone deposited through shoreface retreat during a major


A
B
C
D
0.5 mm
0.5 mm
1.0mm
1.0mm

marine transgression. We suggest that the exposures at Cramer clearly are of nonmarine and transitional marine origin.

In the Conemaugh Gorge all of the sedimentary characteristics of the Cussewago equivalent sandstones indicate a dominantly alluvial origin. These characteristics include detrital composition and texture, sedimentary structures and their internal organization, size, and shape, associated lithologies, the nature of the interval's upper and lower bounding surfaces, and the fossil composition (or lack thereof).

The composition and texture of the Cussewago are typical of alluvial sands (Pettijohn and others, 1978), but these parameters are by no means conclusive. The relative abundance of medium- to coarse-grained polycrystalline quartz, chert, and metamorphic rock fragments indicate an orogenic sediment source that was located a substantial distance to the southeast and requires a vigorous and efficient transport mechanism for delivering sediment into the depositional basin. Processes active in alluvial depositional settings can provide a great amount of detritus shed from marginal to distant uplifts into a depositional basin via large rivers (Pettijohn and others, 1988). The moderate sorting of the framework grains is typical of, but not confined to, most rivers (Friedman and Sanders, 1978).

It so happens that the composition and texture of the Cussewago sandstones, as well as their cross-bedding and stratigraphic position, share a number of characteristics with typical transgressive shelf sands deposited by erosional shoreface retreat, as well as with typical alluvial sands. These factors deserve consideration. Transgressive shelf sands generally are distinguished from regressive shelf sands by their medium- to coarse-grain size, poor to moderate sorting, cross-bedding, and basal position within an unconformity-bounded stratigraphic sequence (Swift and others, 1986). As a transgression progresses, deltas and coastal plains are embayed and fluvial sands are mined by waves and currents and released into the shoreface environment. The transgressive shelf sands are deposited as thin, discontinuous, coarse-grained sheets on ravinement and/or marine erosional surfaces developed seaward of the shoreline's maximum seaward position (Swift and others, 1986). Thus, many of the Cussewago's sedimentary characteristics superficially resemble those of many transgressive shelf sands and might support the interpretation of Bjerstedt and

Figure 86. Photomicrographs of Cussewago equivalent sandstones in plane light (A and B) and under crossed nicols (C and D). The thin sections were impregnated with blue epoxy (dark areas of A and B) to facilitate the recognition of porosity in the rock. A. The overall nature of the abundant pore space in the rock - note that most pore spaces are as large as, or larger than, the framework grains themselves. B. Higher magnification of (A) - note the small size of triangular primary intergranular pores compared to the large size of secondary pores formed through dissolution of framework silicates. Also note the authigenic prismatic quartz crystal that bridges and supports the large pore in the lower left portion of the figure. C. Bimodal distribution of framework grains, the abundance of partially deformed labiles, and large conglomeratic quartz grain. D. Higher magnification of (C) provides detailed view of metamorphic rock fragments and detrital quartz varieties.

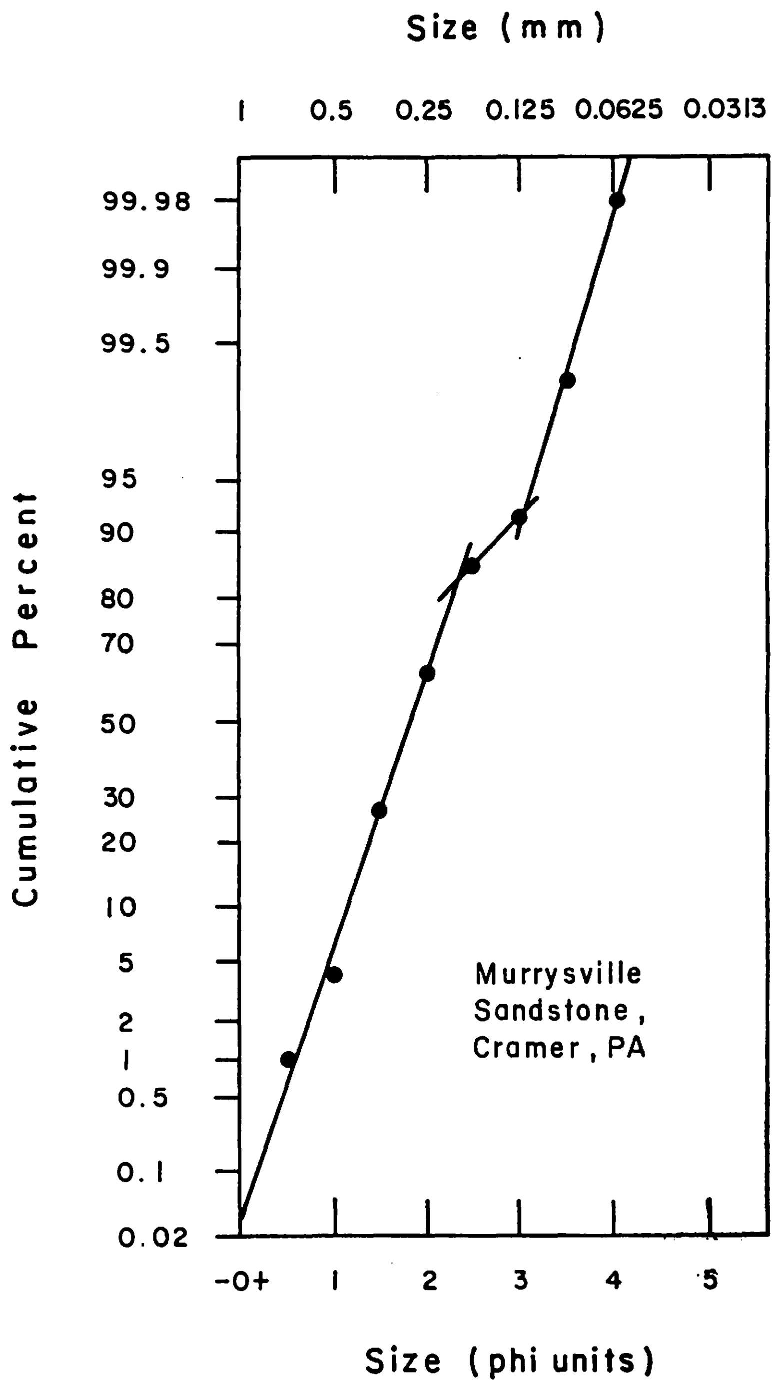


Figure 87. Cumulative frequency plot of grain size in the Cussewago equivalent of the Murrysville sand.

Kammer (1988). The geometry of the Cussewago, however, is inconsistent with the observations of Swift and others (1986) concerning shelf sands. Regional cross sections and isopach maps (Pepper and others, 1954) show that the interval is widespread and relatively thick, rather than thin and discontinuous. The shoreline, as defined by Pepper and others 1954) appears well to the west of the Cramer section, another fact in conflict with the observations of Swift and others (1986) concerning transgressive sands.

Table 18. Modal analysis of the Murrysville sand (Cussewago equivalent).

MINERALS	PERCENT
Quartz (Q)	
monocrystalline	56.3
polycrystalline	18.4
chert	7.8
Feldspar (F)	
potassium feldspar	1.9
plagioclase	0.9
Rock Fragments (L)	
metamorphic rock fragments	4.8
sedimentary rock fragments	1.0
Mica	0.95
Accessories	
pyrite	0.08
Clay Minerals	3.0
Cement	
calcite	3.9
silica	0.97

CLASSIFICATION: chert considered rock fragment (L). Recalculation of Q + F + L = 100%. Composition yields Q_{82} F_3 L_{15}, i.e. sublitharenite

Sedimentary structures, the conspicuous lack of any marine fossils, and the abundance of plant fossils all support an alluvial interpretation for the Cussewago at Cramer. Interpretation of the Cussewago equivalent sand is supported by use of the lithofacies types proposed by Miall (1977, 1978) for fluvial deposits (Table 19). Our interpretation of the Cussewago equivalent, using these lithofacies types, is shown in Figure 88. Cross beds are consistently oriented to the northwest down the paleoslope and away from the source area. There is little variation in paleocurrent directions. Lithofacies associations reveal a preponderance of scouring and sediment breaks. Gradational contacts are confined to thin zones in the middle and near the top of the stratigraphic interval. These subordinate gradational cycles are upward-fining and bounded by erosional surfaces. Plant debris, large log casts, and plant fossils are common in most of the section. The exposed sequence of lithofacies at Cramer resembles that of the braided river model proposed by Walker and Cant (1979). One cycle of in-channel sand deposition and sand bar/sand flat aggradation is followed by

Table 19. Lithofacies and sedimentary structures of fluvial deposits (from Miall, 1978).

FACIES CODE	LITHOFACIES	SEDIMENTARY STRUCTURES	INTERPRETATION
Gms	massive, matrix supported gravel	none	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough cross-beds	minor channel fills
Gp	gravel, stratified	planar cross-beds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough cross-beds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omikron) planar cross-beds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse, may be pebbly	horizontal laminations, parting or streaming lineation	planar bed flow (l. and u. flow regime)
Sl	sand, fine	low angle (<10°) cross-beds	scour fills, crevasse splays, antidunes
Se	erosional scours with intraclasts	crude cross-bedding	scour fills
Ss	sand, fine to coarse, may be pebbly	broad shallow scours including eta cross-stratification	scour fills
Sse, She, Spe	sand	analogous to Ss, Sh, Sp	eolian deposits
Fl	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with fresh-water molluscs	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank or drape deposits
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

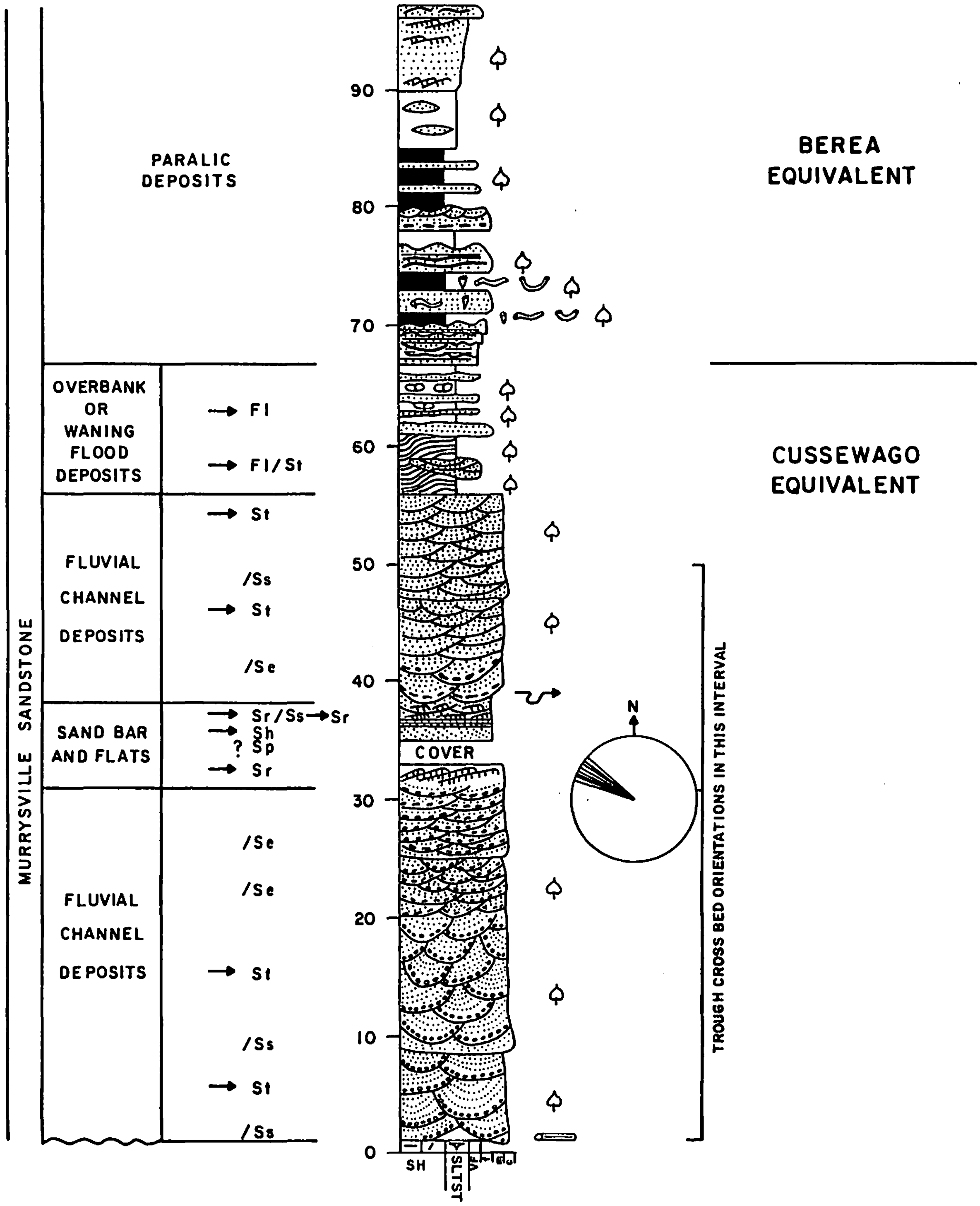


Figure 88. Measured section of the Murrysville sand along PA Route 403 near Cramer showing sedimentary features and their interpretation. Fluvial facies designation of Miall (1977 and 1978) are explained in Table 19. Symbols are explained in Figure 80.

another cycle of renewed channel aggradation and fill. Vertical accretion deposits cap the latter cycle. We suggest that a braided river flowed across a coastal plain or lower delta plain at the location during Lower Mississippian time and was responsible for deposition of the Cussewago lithologies exposed at this outcrop. We envision the environment of that time as similar to the fluvial depositional architecture of the Cenozoic Texas Gulf coastal plain described by Galloway (1981). This interpretation is consistent with the conclusions of Pepper and others (1954).

Sedimentary characteristics of the Berea equivalent suggest deposition in a setting dominated by littoral processes. These characteristics include wave ripples, interference ripples, wavy, flaser, and lenticular bedding, scour surfaces, and washout structures. Trace fossils within the Berea equivalent, particularly <u>Arenicolites</u>, <u>Planolites</u>, and <u>Skolithos</u>, support an upper shoreface and/or tidal channel-flat interpretation for these rocks (Bjerstedt, 1987).

Riddlesburg Shale

The Riddlesburg Shale is poorly exposed at the Cramer locality, along both PA Route 403 and the Conrail railroad tracks below the road. The contact with the subjacent Murrysville sand is completely covered and the bulk of the Riddlesburg's middle portion is obscured by talus. Where sandstones occur in the upper 8 ft (2.5 m) of the Riddlesburg, the unit crops out distinctly. Twenty-one ft (6.4 m) of dark gray, fissile, fossiliferous shale crop out beneath considerable talus beginning about 17 ft (5.2 m) above the Murrysville. Above this the Riddlesburg consists of interbedded sandstone, siltstone, argillaceous limestone, and shale (Figure 89).

Bjerstedt (1987) and Bjerstedt and Kammer (1988) suggested that the Riddlesburg Shale exposure at Cramer represents open bay and/or estuarine deposition. They cite trace fossils, a restricted marine fauna, and specific sedimentary structures in suppost of their interpretation. The trace fossils include <u>Bifungites</u>, <u>Cruziana</u>, <u>Helminthopsis</u>, and <u>Planolites</u>. The restricted marine fauna included <u>Syringothyris</u>, <u>Schellwienella</u>, <u>Dictyoclostus</u>, <u>Orbiculoidea</u>, <u>Lingula</u>, rhynchonellid brachiopods (mostly <u>Ptychomaletoechia</u>), bivalves, crinoids, orthocone nautiloids, and gastropods. The sedimentary structures listed as evidence for shallow bay/estuarine sedimentation are wave ripples and flaser bedding.

While measuring the Riddlesburg Shale section exposed along PA Route 403, we collected lingulid and rhynchonellid brachiopods, bivalves, and trace fossils. Additional collections by Uldis Kaktins and William Brice of the University of Pittsburgh at Johnstown included fragments of an orthocone nautiloid as well. Horizontal and vertical burrows are common. Plant debris is notable in the shales too. The fossil evidence available in the Riddlesburg at Cramer suggests a restricted marine environment near enough to shore to include terrestrial contributions of plant material.

Rocks within the upper portion of the Riddlesburg Shale at Cramer are heterolithic and comprise mixed sandstones and shale subfacies. Some of the sandstones are conglomeratic. The shales are similar to those in the shale-dominated portion of the Riddlesburg below. The sandstones are thin, wave rippled, and contain parallel and low-angle laminations. This upper portion of the Riddlesburg section also contains two or three argillaceous, dolomitic

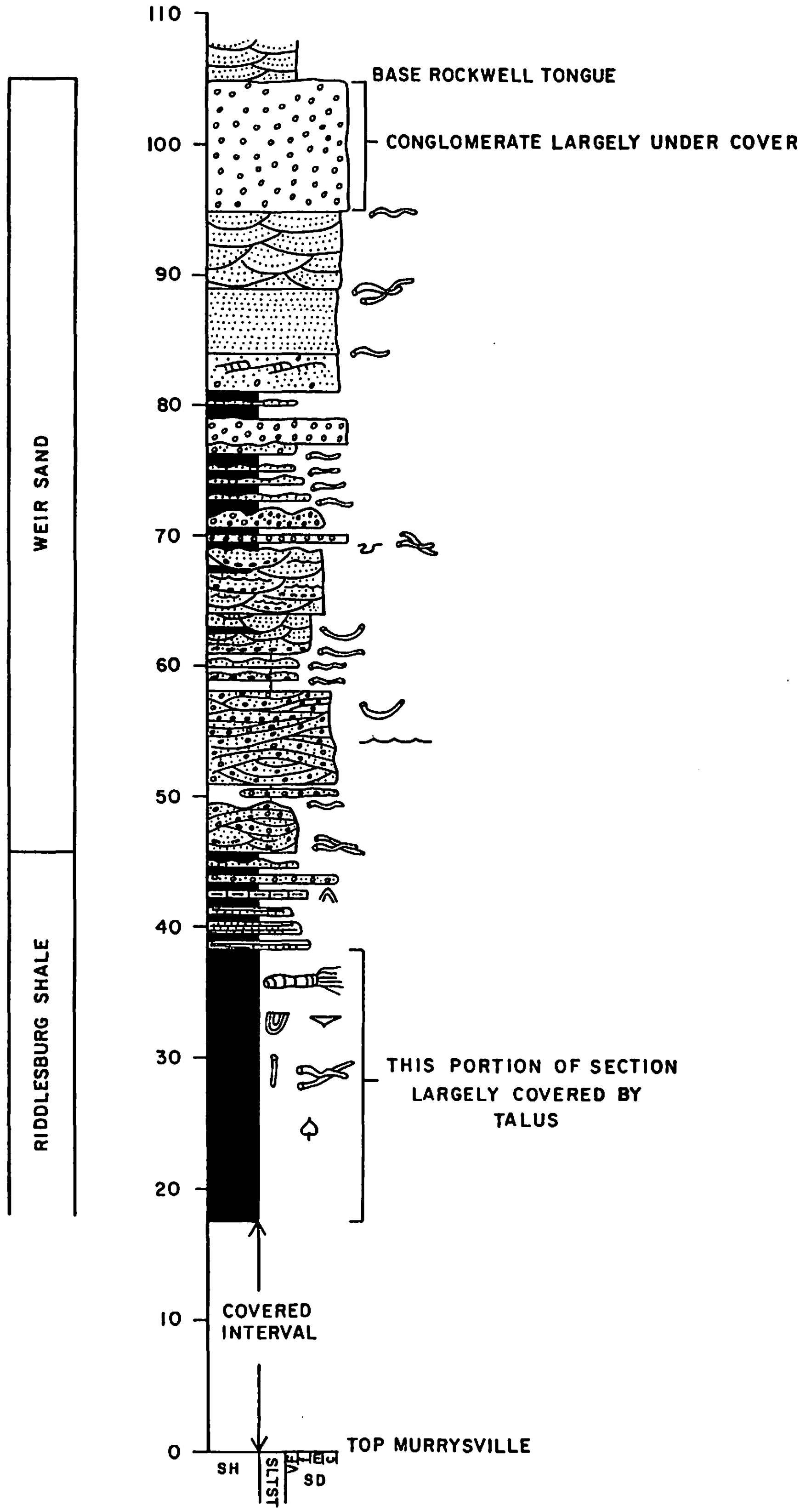


Figure 89. Measured section of the Riddlesburg Shale and Weir sand along PA Route 403 near Cramer showing sedimentary features. Symbols are explained in Figure 80.

limestone beds displaying distinctive cone-in-cone structures.

Although some of the bedforms present in the uppermost Riddlesburg at Cramer certainly could have originated in a tidally influence estuarine setting, we feel that evidence for the tidal influence inferred by Bjerstedt (1987) and Bjerstedt and Kammer (1988) is scant at this location. The heterolithic facies at the top of the Riddlesburg are transitional between the shale-dominated lithofacies of the Riddlesburg's principal section below and the coarsening upward marine sandstone and conglomerate sequence of the Weir sand above. The sandstones in the upper Riddlesburg have scour surfaces at their bases and are graded. Except for the wave ripples, they resemble thin-bedded turbidites with erosional bases, pebbly lags, and horizontal to low-angle laminations grading upwards into ripple laminations before the next shale break. These sandstones are true tempestites - Bouma-type cycles topped by wave ripples (Pettijohn and others, 1988). Tempestites are produced by storm surge in deeper parts of shelf environments below average wave base (Pettijohn and others, 1988). They represent storm events that interrupt the record of more typical, continuous fair weather sedimentation within marine stratigraphic sequences (Einsele and Seilacher, 1982). We suggest a restricted bay or marine shelf environment for the Riddlesburg Shale.

Weir sand

The outcrop of "Weir sand" exposed along PA Route 403 at Cramer is a fascinating stratigraphic sequence. The interval coarsens upwards, displays large-scale bedforms, and is littered with trace fossils (Figure 5). The lowermost sandstone of the sequence displays trough cross-bedding at its base. These bedforms pass upwards into intercalated lenticular sand bodies that swell and pinch. Individual sand lenses within the sequence have wave rippled tops, and the sequence contains sporadically concentrated conglomerate, shale interbeds, and shale rip-up clasts. Burrows are abundant at the base. The sandstone interval passes upward abruptly into bioturbated silty shale with conglomeratic lenses. Another, coarser, sandstone interval follows that again displays the intercalation of lenticular sandstones yielding a swelling and pinching appearance. Wave ripples cap individual lenses. Trace fossils occur within the interval.

We have not had the opportunity to study and interpret these bedforms in any detail, but they certainly deserve careful consideration. Strong scour appears to have occurred in swales ("pinched" intervals), whereas smoothing and rounding seems to have occurred along hummocks ("swells"). These bedforms might be analogous to the hummocky megaripples of the inner Atlantic shelf described by Swift and others (1983). Those features developed in response to combined-flow storm currents; the principal flow consists of along shelf wind-driven currents and the subordinate flow is a storm-wave oscillatory component.

Sandstones in the middle and upper portions of the Weir interval display trough cross-bedding and current ripple-bedding, and contain shale intraclasts. Trace fossils are abundant. The amount of conglomeratic components increases upwards. We suspect that the sequence comprises marine sandstones and conglomerates deposited in a setting dominated by fluvial output; upward coarsening originated through mouth-bar progradation. The Weir sequence is similar to others that developed in this manner described by Nemic and Steel (1984).

Rockwell tongue

The Rockwell tongue at Cramer consists of approximately 160 ft (48.8 m) of interbedded sandstone, siltstone, and shale. Greenish-gray sandstone is the dominant lithology. The rocks constitute a series of stacked, fining upward sequences that display trough cross-bedding, current ripples, rip-up clasts, and basal scour surfaces (Figure 90). Plant fossils are abundant and some vertebrate material (fish plates) has been found. We presume that these rocks delineate a series of stacked, meandering-river channel deposits that developed on a coastal alluvial plain. The sequence is similar to that described in the Rockwell Formation at Horseshoe Curve by Inners (1987).

Burgoon Sandstone

The Burgoon Sandstone at the Cramer locality consists of medium- to coarse-grained, medium light- to very light-gray sublitharenite. Quartz pebble conglomerate zones occur within the interval, and subordinate amounts of shale occur within the section. The sandstones are somewhat micaceous. Trough cross-bedding is the dominant sedimentary structure. Current ripples, shale rip-up clasts and large fossil log impressions and casts are also present in the sandstones. We measured 304 ft (92.7 m) of Burgoon Sandstone along the Conrail railroad tracks below PA Route 403. The Burgoon generally is considered fluvial in origin (Edmunds and others, 1979). We will not discuss the Burgoon on this trip. Instead, interested participants should consult Edmunds and others (1979) for further information.

UPPER MISSISSIPPIAN

(Brezinski)

Burgoon/Loyalhanna contact

One of the better exposures of the Burgoon/Loyalhanna contact can be observed along the Conrail tracks just west of Clark Run. At first glance the contact appears to be gradational; however, upon closer scrutiny one can see that a 6 in (15.2 cm) interval of spherical globules marks the uppermost strata of the Burgoon Sandstone. Although no significant erosional relief is present at this contact it is generally considered to be disconformable in southwestern Pennsylvania (Berg and others, 1986; Harper and Laughrey, 1987; Brezinski, 1989a). Farther to the east, in the Broad Top coal basin, the contact between the Burgoon and Loyalhanna appears to be gradational. The amount of time represented by this unconformity is not clear. Berg and others (1986) proposed that the Burgoon Sandstone is Osagean and Meramecian in age and that the Loyalhanna is middle to late Meramecian. If this is so, then very little time is missing. However, conodonts from Loyalhanna equivalents in West Virginia (Chaplin, 1985) indicate that the Loyalhanna is correlative with the Ste. Genevieve (Meramecian-Chesterian) of the upper Mississippi Valley. Edmunds and others (1979) placed the Burgoon within the Osagean. If these correlations are correct, the Burgoon/Loyalhanna hiatus would span most of the Meramecian (7-10 ma).

Loyalhanna Formation

At this stop the Loyalhanna is almost identical to that exposed at Bolivar

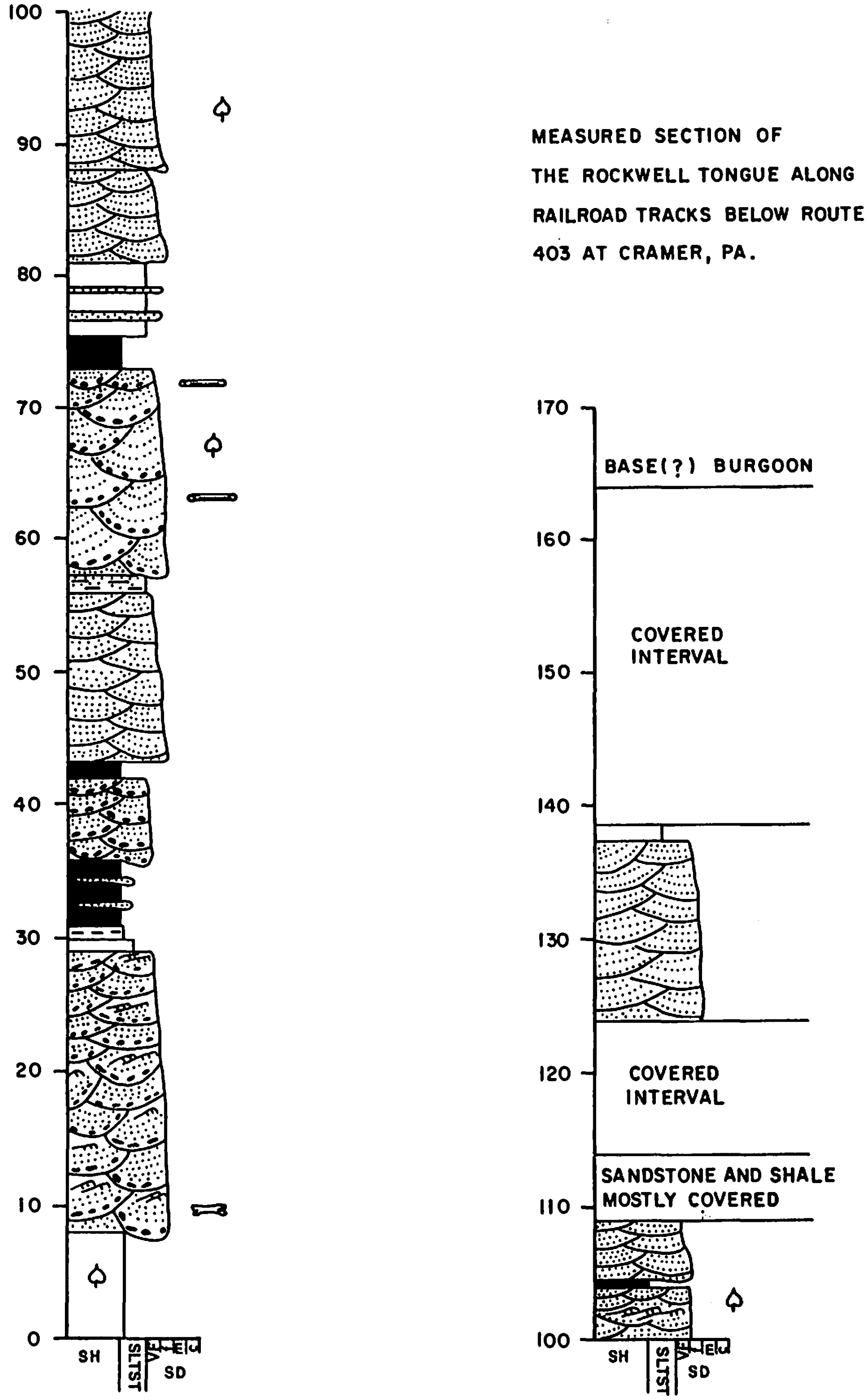


Figure 90. Measured section of the Rockwell tongue along the Conrail railroad tracks below PA Route 403 at Cramer. Symbols are explained in Figure 80.

(Stop #1), except that here we will begin to see a feature that characterizes the Loyalhanna farther to the north and to the east. This feature is the interbedding of red siltstones with the cross-bedded sandstone lithology. This red siltstone interbed (Figure 91, unit B) pinches out laterally, exhibits a gradational base, a sharp upper contact, and contains mudcracks and plant remains. The overlying cross-bedded sandstone of typical Loyalhanna composition (unit C) seems to have eroded the top of the siltstone interbed.

The siltstone interbed in the Loyalhanna represents an episode of shallowing and subaerial exposure followed by another period of marine sedimentation during which the overlying marine sandstone was deposited. That these types of siltstone interbeds are prevalent in the Loyalhanna in the nearshore settings suggests that adjacent to the Loyalhanna shoreline minor fluctuations in relative sea level occurred.

The Loyalhanna at this exposure has, in the past, been quarried and cut for dimension stone and road cobbles. Many of the streets and curbs in Pittsburgh formerly were constructed from this unit. Presently, the Loyalhanna is quarried and crushed only for road aggregate. We will have an opportunity to more closely examine an old quarry face as we climb back up to road level.

Mauch Chunk Formation

The Mauch Chunk can be observed at this locality along the railroad tracks, along PA Route 403, and along Clark Run just north of the road. Figure 91 illustrates a composite measured section of all three outcrops.

Lower Mauch Chunk

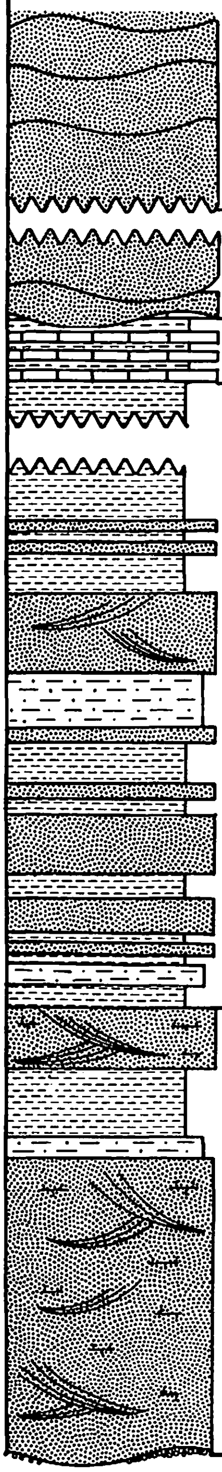
The lower Mauch Chunk is well exposed along both the railroad tracks and PA Route 403. Both exposures allow examination of units D through G. Furthermore, the PA Route 403 exposure allows the examination of units H, I, and N. The Clark Run exposure allows examination of units K through M, as well as units E through G.

The lower Mauch Chunk at this locality exhibits similar lithologic characteristics and environmental distribution to its counterpart at Bolivar. These characteristics consist of shoreline and shallow subtidal lithologies (units E, I, L) interbedded with mudcracked coastal-plain and alluvial-plain lithologies (units D, F, G, H, K).

Figure 92 illustrates the change in lithology and faunal diversity from southwest to northeast within the lower Mauch Chunk (units 1-4) and Wymps Gap Member (unit 5). The section on the left (column A) was measured at Loyalhanna Creek in Westmoreland County, columns B and C are from Bolivar and Cramer, respectively. Note that within each marine unit total generic diversity generally increases to the southwest (toward the marine seaway), whereas molluscan diversity increases to the northeast, presumably in the direction of the paleoshoreline.

Wymps Gap Member

This locality is the northeasternmost exposure of the Wymps Gap Limestone known. Consequently, to the north and east the Mauch Chunk cannot be subdivided



formation		unit	lithology	interpreted environment
Pottsville Group?		N	tan to very-light gray, highly crossbedded, medium-grained sandstone exhibiting upward fining, and multistacked channels	fluvial channel (braided)
	Mauch Chunk Formation	M	tan to green-gray, crossbedded, lenticular sandstone	fluvial channel (meandering)
Wymps Gap Member	Mauch Chunk Formation	L	interbedded, variegated limestone and shale	shallow marine
lower Mauch Chunk	Mauch Chunk Formation	K	red siltstone and shale	alluvial plain
lower Mauch Chunk	Mauch Chunk Formation	J	section concealed	
lower Mauch Chunk	Mauch Chunk Formation	I	green-gray, fossiliferous shale	subtidal marine
lower Mauch Chunk	Mauch Chunk Formation	H	interbedded, red-brown mudstone and green-gray sandstone	alluvial plain
lower Mauch Chunk	Mauch Chunk Formation	G	tan, crossbedded sandstone with erosional base	fluvial channel
lower Mauch Chunk	Mauch Chunk Formation	F	interbedded, white and green-gray sandstone, and red and green mudstone and shale containing mudcracks	supratidal/ coastal plain
lower Mauch Chunk	Mauch Chunk Formation	E	white, calcareous sandstone with thin lenses of red siltstone	beach
lower Mauch Chunk	Mauch Chunk Formation	D	interbedded, red, mudcracked mudstone, and thin white sandstone	intertidal/ supratidal
Loyalhanna Formation		C	light-gray, crossbedded, calcareous sandstone with carbonate clasts	subtidal sand-wave
Loyalhanna Formation		B	upward fining red and green-gray siltstone and mudstone	supratidal
Loyalhanna Formation		A	light-gray, to green-gray, festoon crossbedded, arenaceous grainstone to calcareous sandstone	shallow sand-wave complex

Figure 91. Composite measured section of the Late Mississippian exposures with interpreted depositional environments. Vertical scale: 1 in approximately equal to 6 m.

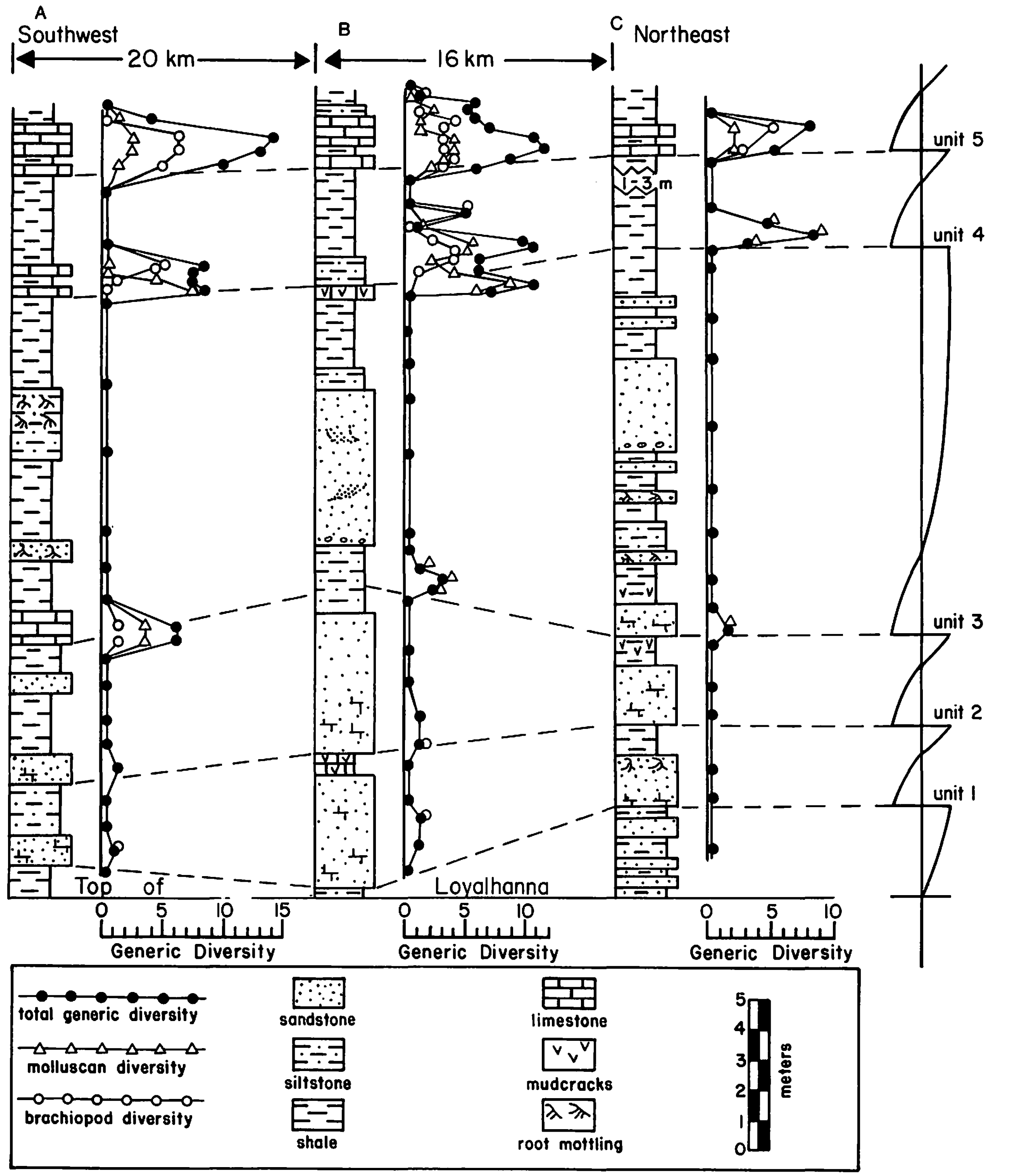


Figure 92. Lithologic and faunal diversity variations within the marine units of the lower Mauch Chunk and Wymps Gap Member of the Mauch Chunk at (A) Loyalhanna Creek; (B) Bolivar; and (C) Cramer.

into lower and upper members. The Wymps Gap Member here is exposed in Clark Run, up the nature trail from the parking lot, and will not be examined during this excursion. It consists of green-gray, red-brown, and variegated, thinly interbedded limestones and shales 4.5 ft (1.4 m) thick (unit L). Fauna contained within the Wymps Gap consists largely of bivalves, gastropods, bryozoans, and, less commonly, brachiopods and trilobites. Just as at Bolivar, the Wymps Gap here appears to have been deposited under shallow-water nearshore conditions. Based upon the rate of thinning and faunal change between Bolivar and Cramer, the original Wymps Gap sea would not have extended very much farther to the north and east.

Upper Mauch Chunk

Directly overlying the Wymps Gap in Clark Run are two thin green-gray, medium-grained sandstone units 3 ft (0.9 m) thick (unit M) that are part of the upper Mauch Chunk. The section above these sandstones is covered; consequently, one can only estimate the amount of section represented to the base of the sandstone questionably assigned to the Pottsville along PA Route 403.

Mauch Chunk or Pottsville?

Unit N, which is exposed along PA Route 403 west of the mouth of Clark Run, consists of white to tan, medium- to coarse-grained, highly cross-bedded sandstone. This unit contains coal spars, many reactivation surfaces, and grades upsection into gray and then red shales and mudstones. The thickness and character of this sandstone unit is more consistent with that found in the Pottsville than the Mauch Chunk. However, the red mudstone at the top of the sandstone would suggest that it is part of the Mauch Chunk. What do you think?

STRUCTURE

(Iranpanah)

Subsurface data indicate that the Conemaugh Gorge is fault controlled, but there is little surface expression to substantiate this. Landsat, topoimage, and gravity and magnetic anomaly maps, however, indicate that there is a large-scale lineament trending northwest-southeast that crosses Laurel Hill anticline. This lineament also subparallels and almost coincides with the gorge. In addition, the axis of the Johnstown syncline is offset to the northwest directly southeast of the gorge. If a line is drawn connecting the two ends of this interrupted axial trace, the resulting line will also subparallel and approximately coincide with the northwest trend of the gorge. This evidence suggests that the Conemaugh Gorge is fault controlled, and further suggests the presence of a basement fault in the area.

In the Weir sand along PA Route 403, drag folds can be observed (see also Figure 5B). The drag folding occurs on top of megaripples in competent sandstone layers with the characteristic incompetent mud-shales above and below it.

A couple hundred ft northwest of where Clark Run crosses the Conrail tracks, a bedding fault can be seen (Figure 5C). This fault occurs in the Burgoon Sandstone between two of its sandstone beds. A second-order disharmonic fold is also present in the Burgoon Sandstone (Figure 5A). This fold has been overturned and faulted. The fold axis trends N44°W and plunges 18° to the southeast. The core of the fold is readily apparent and the fault can be seen directly below with its associated breccia. The linear features seen on the outer arc of the fold are interpreted as crenulation cleavages. These are created when the rock is compacted and stretched during folding. The trend of these cleavages were measured to be identical to the fold axis N44°W.

Preferred orientations of joints in the gorge are between N50°W and N40°W (Figure 8). This orientation is closely related to the azimuth of compression that probably originated from the nearby "Eastern Overthrust Belt". The earliest bending of strata to form synclines and anticlines under compression would develop tension in each bed, which would be directed in the same azimuth.

The shale bed that was studied in Conemaugh Gorge adhered very well to the observation that strike joints are more prevalent in the shale. Joint orientations in the shale varied widely but some had an affintity for a northeast strike. This northeast orientation subparallels the Laurel Hill fold axis which is, by definition, a strike joint characteristic.

		LEAVE STOP #4 at Clark Run Nature Area. TURN LEFT (south) onto PA Route 403 southbound.
2.1	97.1	Red beds and channel sandstones of the "Middle red shale zone" (Venango Group) crop out on left.
1.5	98.6	Tipple for an old quarry in the Loyalhanna Formation on left.
0.7	99.3	Cross railroad tracks.
0.1	99.4	TURN LEFT (north) onto SR 3041 immediately after crossing bridge over Laurel Run.
1.8	101.2	TURN RIGHT at sign for St. Rochus Church picnic area.
0.1	101.3	Park near St. Rochus school building. Please note that the dam site is private property and that permission has to be obtained from Laurel Management Corp. in order to visit this area.

STOP #5: LAUREL RUN DAM AND THE JOHNSTOWN FLOOD OF 1977

LEADER: F. James Knight

Laurel Run Dam (Figure 93) was constructed in 1915-1918. Its original purpose was to supply water to the system of navigational canals that served the area. It eventually became part of the water supply system for local steel producing operations and about 1960 it was acquired by the City of Johnstown to be incorporated into the municipal water system.

The dam was 47 ft (14 m) high and about 620 ft (189 m) long. It impounded a portion of the flow from a watershed of 7.92 square mi (20.5 sq. km). Water was conveyed to the city's service area via a 24 in (60.9 cm) cast iron pipe that ran down the Laurel Run Valley to its confluence with the Conemaugh River.

By today's standards, the dam's embankment was constructed in an unusual manner. It was what is called a "hydraulic fill". The clay material that comprised the core of the dam was obtained from the local area, where it occurred in conjunction with coal deposits as "underclay". It was excavated by washing with water jets and was conveyed to the dam by a series of sluiceways. This fluid and its suspended load of soil was contained at the embankment site by dikes of pervious rocky material placed across the valley both upstream and downstream from the axis of the structure. The dikes became the containing shell of the dam, and as the central fluid dewatered by seepage and evaporation,

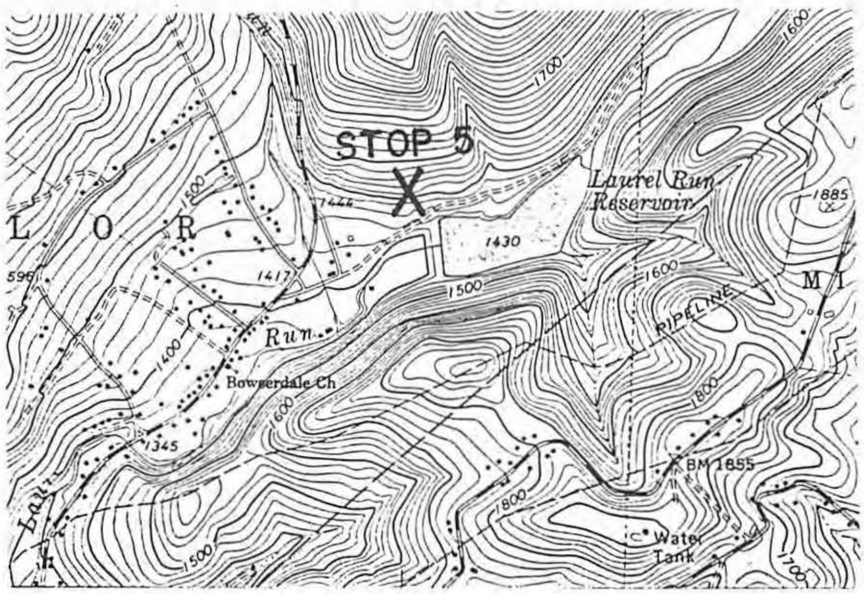


Figure 93. Location of Stop #5 (Vintondale quadrangle).

the remaining clay became the core of the dam. Construction continued by successively placing new containing dikes atop those of the previous lift and sluicing clay bearing fluid into the central space. No compactive effort using rollers or other mechanical devices was employed in the placement of the core. The material simply was allowed to dewater and to consolidate naturally.

Although the resulting embankment was very effective in its containment of the reservoir, the strength characteristics of the core were somewhat different than those of a fill placed by more conventional methods. The core material never achieved full consolidation and it was relatively soft and plastic. It was gray in color and had the consistency and texture of stiff putty or glazing compound. Though highly impervious, it could be deformed and was somewhat erodable.

On the night of July 19-20, 1977, a storm (or storms) of gigantic proportion hit the Johnstown area. Rainfall totals of 6 to 12 in were recorded in a 6- to 8-hour period. The maximum depths of precipitation were approximately centered on the Laurel Run watershed. The Laurel Run Dam was overtopped, and sometime around 2:00 a.m., on July 20 it failed. A breach developed near the left abutment (looking downstream) and the reservoir completely emptied in a very short time.

The flood wave that carried down the Laurel Run valley was substantial and disastrous. Damages exceeded $10 million and 36 lives were lost. The flow continued on into the Conemaugh River, reaching that channel several hours before it crested under the influence of its larger drainage area.

Following the storm it was decided not to rebuild Laurel Run Dam. The remaining embankment was removed to stable slopes and the appurtenant structures were destroyed. Subsequent studies of other dams in the area have led to the removal of some and major modifications to others.

Intense rainfall in the Johnstown area also caused extensive regional damage. In total, at least 77 people lost their lives in the flooding, and damages were estimated at about $500 million. Although two other dams in the local area also were destroyed, most of that impact had little to do with any structural or system failure. It was the result of severe overland flow in a topographic setting that is dominated by steep terrain and deeply incised stream valleys. Few areas in greater Johnstown escaped damage from this major event.

Although there are many lessons to be learned from the 1977 Johnstown disaster, the most significant may be the one least frequently discussed. The storm was indeed severe and produced flows exceeding the expected 100-year recurrence interval at several sites, but the event demonstrated that such things most surely can happen. If they can happen in Johnstown, they can happen elsewhere. If a storm of similar magnitude occurs in the Pittsburgh area, the damages and lives lost would, without doubt, far exceed the Johnstown experience. Although the topography in the Pittsburgh area is similar to Johnstown's and there appears to be little difference is storm track potential, the larger, more intensely developed area would without doubt suffer much greater impact. Like the potential for severe earthquakes in California, it doesn't seem to be a question that such an occurrence will happen. The questions are: when will it happen? (an obvious unknown); and what precautions are being taken? (basically none). Assuming that no drastic change occurs in Pittsburgh area lifestyles, a flood related disaster is quite easily predicted. The only question is "when?".

		LEAVE STOP #5. Return to PA Route 403. TURN LEFT (south) onto PA Route 403.
2.1	103.4	Brookville/Clarion coal at road level on left.
1.1	104.5	BEAR RIGHT at bridge over Conemaugh River.
0.1	104.6	TURN LEFT at traffic light. CONTINUE south on PA Route 403.
0.4	105.0	Junction with PA Route 56. CONTINUE on PA Routes 56 and 403.
0.8	105.8	BEAR RIGHT at U-Haul store. CONTINUE on PA Routes 56 and 403.
0.4	106.2	Railroad underpass.
0.1	106.3	TURN LEFT onto PA Route 271 at traffic light. Cross bridge over Stony Creek at confluence with the Little Conemaugh River.
0.2	106.5	TURN RIGHT onto Johns St. Point Stadium on corner.
0.1	106.6	TURN LEFT onto Main St.
0.2	106.8	TURN RIGHT onto Market St.
0.1	106.9	Holiday Inn main entrance.
		END OF 1ST DAY.

ROAD LOG - DAY 2

Mileage Inc.	Cum.	
0.0	0.0	START. Leave from the front of the Holiday Inn (Market St.), Johnstown, PA.
0.2	0.2	TURN RIGHT at traffic light onto Napoleon St. Cambria County War Memorial at intersection.
0.1	0.3	TURN LEFT (east) onto PA Route 56.
0.6	0.9	Cross Stony Creek.
0.2	1.1	Bedford St. exit. Allegheny Group strata exposed in roadcut on left. CONTINUE east on PA Route 56.
1.3	2.4	Widman St. exit. Allegheny Group strata (Kittanning and Freeport Formations) exposed in roadcut on left. CONTINUE east on PA Route 56.
2.4	4.8	Airport exit. Freeport Formation exposed at road level. CONTINUE east on PA Route 56.
0.9	5.7	Junction with US Route 219. BEAR RIGHT onto exit ramp for US Route 219/PA Route 56.
0.8	6.5	PA Route 756 (Bedford St./Elton Rd.) exit. CONTINUE east on PA Route 56 (and US Route 219 S).
1.1	7.6	TURN RIGHT onto exit ramp for PA Route 56 (Windber Exit).
0.2	7.8	TURN RIGHT from exit ramp onto PA Route 56 E.
0.4	8.2	TURN RIGHT at traffic light onto Eisenhower Blvd. Sunoco station and Sheetz store on opposite corners on right side.
0.8	9.0	TURN LEFT onto SR 3015 (just before Alberter Buick dealership) toward Mine #37.
0.4	9.4	TURN RIGHT onto dirt access road to mine spoil area. Note: This road is closed to the general public. Park buses near spoil pile and passengers will disembark.
		STOP #6. EUREKA MINE 37 REFUSE PILE

LEADERS: Robert Naylor and Randy W. Wood

HISTORY AND BACKGROUND

The site we are now approaching is the old Berwind-White Coal Mining Company Eureka Mine Number 37 rock dump or boney pile (Figure 94). The first Berwind-White Mining Company mine in the Windber area opened in September, 1897 and was called the Eureka Mine Number 30. Eureka Mines 30 through 42 were opened in rapid order soon afterwards. Eureka Mine 37 is located in Richland Township, Cambria County on top of the hill above Scalp Level Borough. The Berwind-White Coal Mining Company mined coal in the Windber area Windber from 1897 through 1962, a period of 66 years. The major coal seams mined by Berwind-White were the Lower Kittanning coal (B seam) and the Upper Kittanning coal (C prime seam) with 13 mines on the B seam and 6 on the C prime seam. The Eureka Mine Number 37 operated for 64 years, from 1899 through 1962 and remained productive longer than any other Berwind-White mine in the Windber area. The Number 37 Lower Mine (B coal seam) operated from 1899 to 1959 and the Number 37 Upper Mine (C prime coal seam) operated from 1904 to 1962, producing 39,169, 958 tons of coal between the two seams.

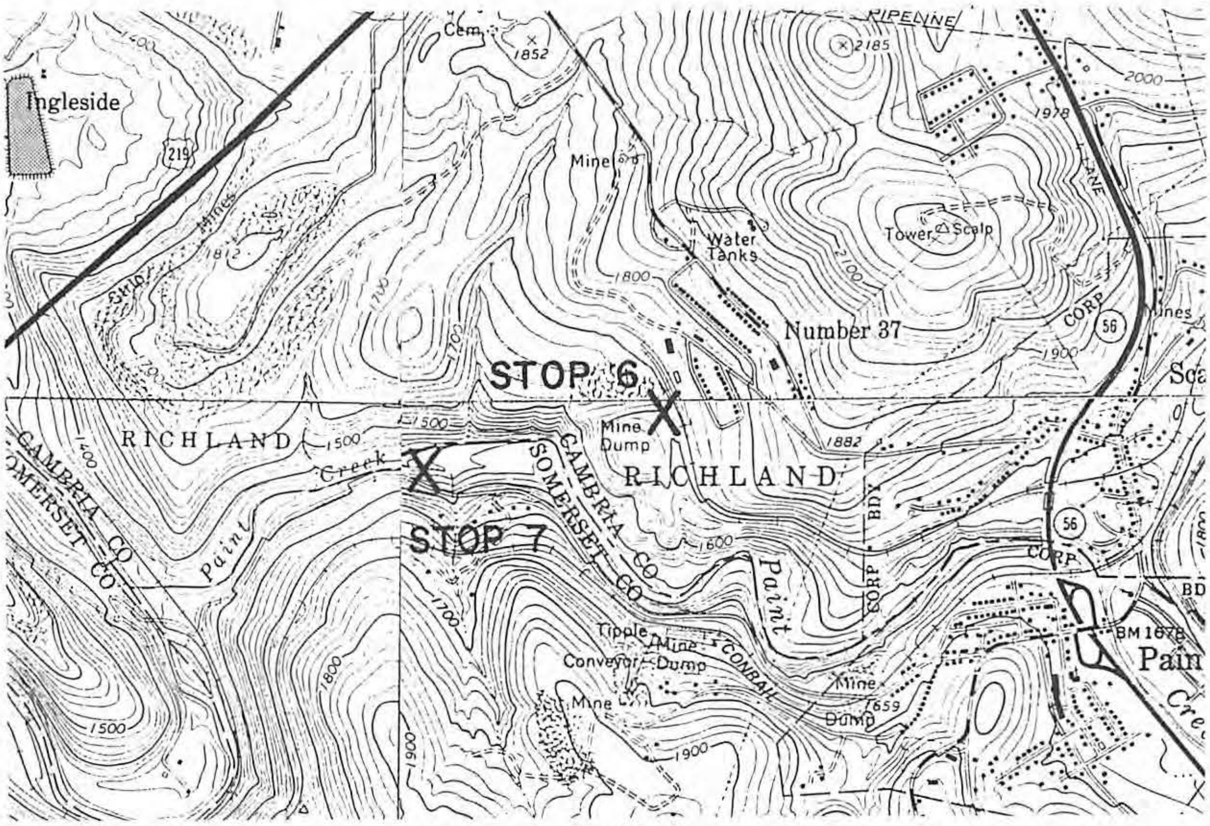


Figure 94. Location of Stops #6 and #7 (Johnstown, Geistown, Hooversville, and Windber quadrangles.

The complete tonnage produced by the Windber mines is a staggering figure of 146,000,000 tons shipped, of which 80 percent was from the B seam mining. It would take a train of 2,918,704 railroad cars, each with fifty ton capacity, to transport the entire production. This train would be over 19,000 mi (30,571 km) long and circle the earth at the 40th parallel (Alcamo, The Windber Story, 1983).

SITE DESCRIPTION AND GEOLOGY

The "37 Rock Dump", as called by the local residents, is a combination of binder and boney coal, roof rock, bottom coal, and other impurities that were encountered during the mining of the Lower Kittanning coal, Eureka 37 Lower, and the Upper Kittanning coal, Eureka 37 Upper. The rock dump is presently being reprocessed for recoverable coal for commercial sales by Greenley Energy Holdings of PA, Inc.

As we approach the rock dump through the haulage road gates the remains of the Eureka 37 Upper Kittanning deep mine can be seen to the left. Within the rock dump area are the remains of the maintenance shed, bath house, and generator plants of the Eureka 37 Upper and Lower Kittanning deep mine. The remains of the Eureka 37 Lower Kittanning deep mine entry is north of these buildings across the old railroad load-out. Unlike the majority of the Windber-Scalp Level coal fields, the Mine 37 area is influenced by a geologic structural feature known as the Ebensburg anticline. The axis of this anticline runs through the Mine 37 mining area, with the Wilmore syncline just to the east of the Mine 37 site. The geologic strata affected by these mines is the Allegheny Group, Kittanning Formation. When walking on the material deposited by the miners from the 37 Upper and Lower mining operations observe to the right, in the Paint Creek stream valley, the outcrop of Mauch Chunk Formation sandstones. These will be visited at the next stop (Stop #7).

The Paint Creek watershed encompasses 35 square mi (90.7 sq. km) above the Mine 37 refuse pile. The rock dump consists of 55 acres (22.3 ha) of refuse over 100 ft (31 m) high and contains an estimated three million tons of material. Extensive deep mining and surface mining in the Paint Creek and Little Paint Creek watersheds has resulted in numerous similar refuse piles. These mining activities over the past 100 years have caused a noticeable change in the water quality of the streams.

Table 20 illustrates the changes in water quality in the Paint Creek watershed. The water sample MP-7 is taken approximately 3 mi (4.8 km) upstream on PA Route 160 and exhibits excellent water quality. This segment of Little Paint Creek is not influenced by mining operations. Sample point MP-6 is located approximately 0.75 mi (1.2 km) downstream from MP-7, just above the Mine 40 rock dump and deep mine complex but below previous surface and deep mining activities. This point is showing increased metal concentrations and lowered pH. MP-2 is a point located just above the influence of the Mine 37 rock dump and mining complex on the Upper and Lower Kittanning coal seam but below the Mine 40 rock dump and mine complex. Between MP-6 and MP-2 the iron has increased form 3.4 mg/l to 6.3 mg/l; manganese has increased from 0.15 mg/l to 4.4 mg/l; the pH went from 6.4 to 4.1; and the sulfates have increased dramatically from 44 mg/l to 416 mg/l. Sample point MP-1 is located just below the influence of the Mine 37 rock dump and deep mine complex and approximately 0.5 mi (0.8 km) below MP-2. The influence of acid mine drainage (AMD) from this mining operation on the receiving stream, Paint Creek, is evident. Between MP-1 and MP-2 the pH has dropped to 3.0 from 4.1; the iron has increased from 6.3 mg/l to 34.1 mg/l; the sulfates have increased from 416 mg/l to 668 mg/l; and overall the metal concentrations have increased. This change in quality is due to three discharges, MP-3, MP-4, and MP-5, which emanate from the refuse pile. The location of these discharges and their quality can be seen on Figure 95 and Table 20, respectively. These samples with pH's in the 2.0's have iron concentrations ranging from 590 mg/l to a prodigious 1,540 mg/l; sulfates range from 3,600 mg/l to 11,500 mg/l; and contain high acidity, aluminum, and manganese. This typical AMD production by the pyrites, marcasites, and other weathered acid-producing shales, clays, and sandstones has caused severe degradation of Paint Creek. For ninety years weathering of this refuse material, deposited during mining, has created this apparently irreversible effect on the environment.

As you walk across the refuse pile take note of the abundance of iron sulfide minerals, such as pyrite and marcasite, within the refuse. Also present are rocks coated with accumulations of white substances assumed to be weathering products of the sulfide minerals present in the refuse. Note the relatively fresh appearance of the pyrite samples and the apparent lack of weathering products in association with the pyrite. Also note the lack of visible iron sulfide minerals in some of the samples encrusted with these white weathering products.

Table 20. Water quality in Paint Creek basin above and below Mine 37. See Figure 95 for location of sampling points.

SAMPLE POINT	pH	ALKALINITY*	ACIDITY*	Fe*	Mn*	Al*	SO_4*	LOCATION
MP-1	3.0	0	290.0	34.1	6.9	2.2	668	Paint Creek directly below Mine 37
MP-2	4.1	0	59.9	6.3	4.4	1.9	416	Paint Creek directly above Mine 37
MP-3	2.2	0	9,524.0	1,540.0	78.0	880.0	11,500	Seep @ Mine 37 refuse pile
MP-4	2.3	0	3,968.0	590.0	25.0	280.0	5,000	Seep @ Mine 37 refuse pile
MP-5	2.2	0	3,734.0	630.0	25.0	210.0	3,600	Seep @ Mine 37 refuse pile
MP-6	6.4	26.0	4.0	3.4	0.15	3.3	44	Little Paint Creek upstream from Mine 40 site
MP-7	7.4	66.0	0	0.30	<0.01	0.56	85	Little Paint Creek upstream from any mining areas

* Values in mg/l

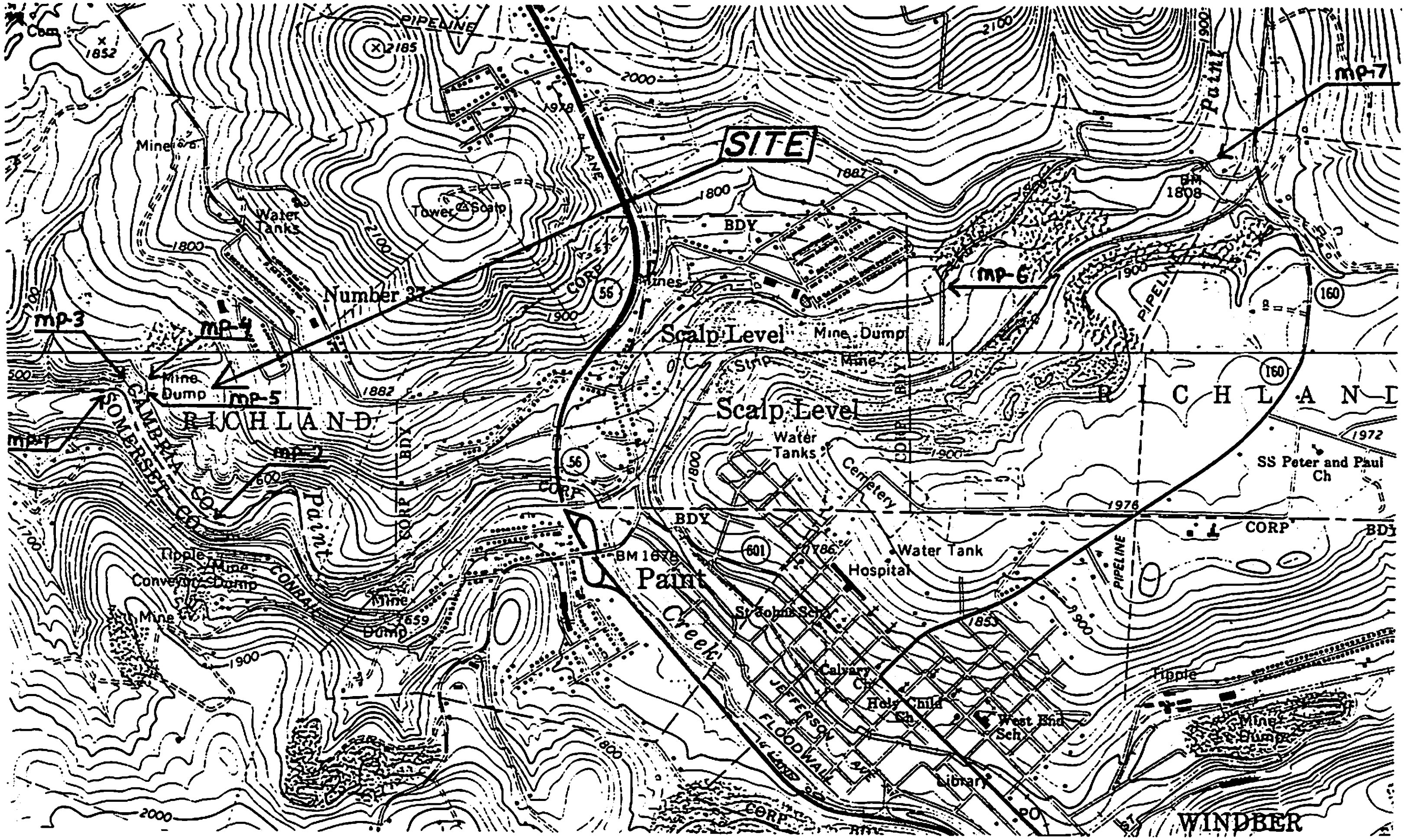


Figure 95. Site location map for AMD studies.

The demand for energy coupled with the need for reclamation of major AMD sources has produced new technology that promises to mitigate discharges from refuse piles such as the Mine 37 rock dump. Planning is currently underway to use the Mine 37 refuse pile, and other, similar, refuse piles, as a fuel in a new type of powerplant. One of these new powerplants is currently being constructed in the Ebensburg area. These new powerplants will utilize a fluidized-bed combustion process to burn the refuse. In the process of burning the refuse materials, large quantities of lime will be added to the refuse producing ash that is high in alkalinity. These operations propose to return the alkaline ash to the refuse sites for disposal and reclaim the sites. This process provides hope that what was once considered a cost prohibitive reclamation program may now be undertaken as a private enterprise that will reclaim and mitigate these omnipresent pollution problems in the Johnstown area.

		LEAVE STOP #6. Return to main road. TURN RIGHT toward Mine #37.
0.9	10.3	Entering Borough of Scalp Level.
0.4	10.7	Pass under PA Route 56.
0.1	10.8	T-intersection; TURN RIGHT at stop sign.
0.2	11.0	Cross Little Paint Creek.
0.1	11.1	BEAR RIGHT at junction with PA Route 601. Enter Borough of Paint at Cambria/Somerset County boundary.
0.1	11.2	Cross PA Route 56. CONTINUE south on PA Route 601.
0.3	11.5	BEAR RIGHT onto SR 4022.
0.2	11.7	Cross railroad tracks.
1.3	13.0	Stop along road by Paint Creek. The passengers will leave the buses at this point and walk upstream along the old trolley bed to the outcrop. There is no place to park along the road. The buses will continue on down the road to the mouth of Paint Creek, turn around, and return to pick up the passengers.
		STOP #7: PAINT CREEK GORGE

LEADERS: Uldis Kaktins and Assad Iranpanah

For about a mile prior to its junction with Stony Creek, Paint Creek flows over a thick sequence of trough cross-bedded sandstones of the upper Mauch Chunk (Figure 94). In general, the upper Mauch Chunk in this area differs from the lower portion by the presence of thick sandstone units and relatively few red mud-stones. Along Paint Creek about 45 ft (13.7 m) of sandstone is exposed; in the Little Conemaugh River gorge near Mineral Point there is about 40 ft (12.2 m) present; and at Cramer (Stop #4) the total thickness is close to 90 ft (27.4 m), with a 4 ft (1.2 m) red, silty shale break in the middle. Exceptions can be found, however, such as in the Conemaugh River gorge through Chestnut Ridge. At Bolivar (see the description of Stop #1) there is no major sandstone body, whereas at the other end of the gorge (near Torrance) there is about 35 ft (10.7 m) of sandstone (Shaffner, 1958).

The most distinctive feature of these sandstones is the extremely well-developed trough cross-bedding. Along this section of Paint Creek the large-scale troughs are exposed in both cross sectional and plane view. This cross-stratification was described in detail by Tschinda (1988). The troughs vary in width from about 2 to 20 ft (0.6 to 6.1 m), and in thickness from about 0.3 to 3.3 ft (0.1 to 1.0 m). The sandstones can be divided into two members, separated by a 1.5 ft (0.5 m) red calcareous sandstone (Figure 96). Each member starts out with a basal-scour surface containing mud rip-up clasts in a medium-

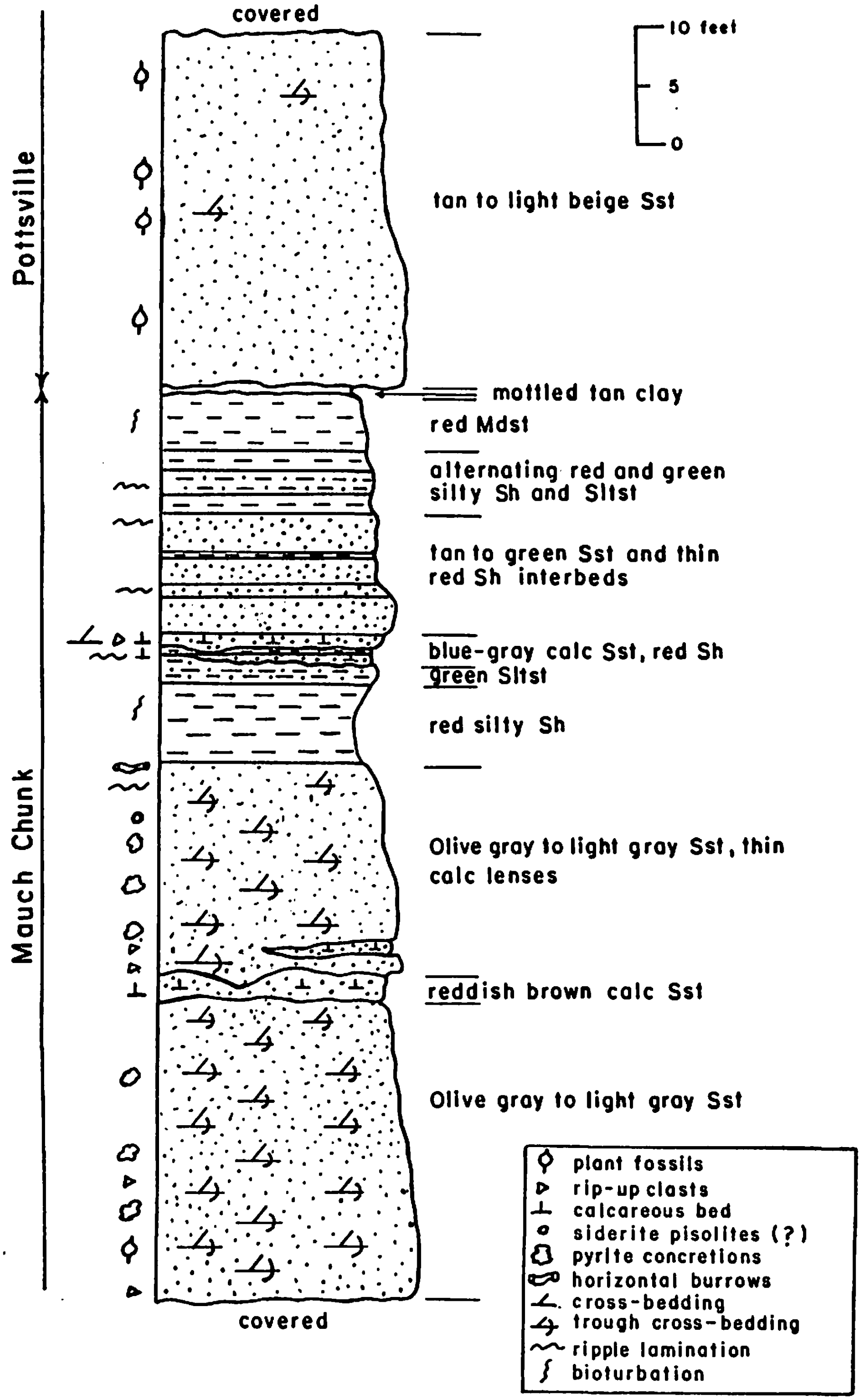


Figure 96. Stratigraphic section exposed at Paint Creek.

grained sublitharenite and ends with ripple cross-stratified, fine-grained sandstones that are sometimes bioturbated. Individual trough sets may also contain rip-up clasts. Tschinda recognized two facies in these sandstone units. A lower facies, comprising about 80 percent of each unit, consists of large sheet-like trough sets. This, in turn, grades upward into smaller scale trough cross-stratification.

The sandstones are sublitharenites that range from poorly sorted to well sorted. Monocrystalline and polycrystalline quartz dominate the clast-supported fabric. Lithic clasts are mainly metamorphic rock fragments; accessory minerals include micas and pyrite. These units also contain scattered pyrite "balls" up to 2 in (5.1 cm) in diameter whose origin can perhaps be determined by some of the conferees. Small siderite nodules (pisolites?) less than 0.25 in (0.6 cm) in diameter are present in some of the cross-bed sets. Plant fossils are very rare in these sandstones.

Tschinda (1988) determined that the dominant paleoflow direction was to the northwest (N50°W). Except for some basal sets in the lower member that had trough current directions of S70°E, the paleocurrent directions were remarkably consistent and correspond very well to regional data.

Gradations from relatively flat sets to more typical trough shapes are thought to represent bedform transitions from large, straight-crested ripples to sinuous crested dunes (Tschinda, 1988). The out-of-phase nature of the troughs indicates that the channel dunes were migrating under high flow conditions. An upper flow regime is further indicated by transitions from plane beds to cross-laminated strata.

Red and green silty shales and siltstones top the upper trough cross-bedded sandstone unit, representing mudflats adjacent to the channel. Interbedded with these mudstones are thin sandstone beds that have ripple laminations, small-scale cross-stratification, and planer beds. The sandstones are fine-grained to very fine-grained sublitharenites and probably represent small crevasse splays. Also included in this sequence are several calcareous lenses about 0.5 ft (0.2 m) thick. One is a very fine-grained calcareous sublitharenite containing minor amounts of pyrite and rare peloids(?). The other is a calcarenite with clay-micrite clasts (that may have been burrowed), peloids(?), siltstone clasts, sparry calcite cement, and scarce unidentified fossil fragments.

The top of the Mauch Chunk section is represented by a massive, bioturbated, strongly cleaved, red mudstone. At the presumed contact with the overlying Pottsville sandstones is a 0.5 ft (0.2 m) layer of tan clay. The Pottsville sandstones are characterized by a tan to light tan color, medium to thick bedding, and abundant plant fossils. Brezinski (see the description of Stop #4) has brought up the possibility that the whole sequence exposed here at Paint Creek may in fact belong to the Pottsville. Look around and tell us what your thoughts may be in this matter.

Joints along Paint Creek are present in the sandstone of the upper Mauch Chunk Formation. Joint orientation is very uniform about the strke of N60°W. This orientation roughly approximates the preferred orientation of sandstone joints in Conemaugh Gorge. The strike of these joints also corresponds with the axis of compression from the "Eastern Overthrust Belt".

		LEAVE STOP #7 and drive back toward Paint Borough and PA Route 56.
0.3	13.3	The large boulders on the right side of the road are Homewood sandstone float.
1.2	14.5	TURN LEFT at stop sign at top of the hill onto PA Route 601 N.

0.3 14.8 TURN LEFT onto entrance ramp for PA Route 56 W. Allegheny Group sandstones are exposed at bottom of ramp. Merge with westbound traffic on PA Route 56.

0.2 15.0 Cambria/Somerset County boundary.

1.8 16.8 Intersection of PA Route 56 and Eisenhower Blvd. CONTINUE west on PA Route 56. Stay in right lane.

0.1 16.9 TURN RIGHT into University Park Shopping Center. Drive past Penney's to T-intersection in front of GeeBee store. TURN LEFT and drive to rear of GeeBee. This is private property and permission should be obtained from Glosser Brothers Stores, Inc. before visiting the site.

STOP #8. GEEBEE FOSSIL LOCALITY AT GEISTOWN: FAUNAL AND LITHOLOGIC CHARACTERISTICS OF THE PENNSYLVANIAN (MISSOURIAN) BRUSH CREEK MARINE INTERVAL, GLENSHAW FORMATION, CONEMAUGH GROUP

LEADERS: Karen Rose Cercone and John F. Taylor

Like the underlying Allegheny Group, the Conemaugh Group consists primarily of fluvio-deltaic siliciclastics that form a complex mosaic of interfingering channel, levee, and overbank deposits. Unlike the Allegheny Group, the Conemaugh contains few economically significant coal seams but does contain several thin but laterally extensive marine intervals that are valuable as key beds in physical (and temporal) correlation of outcrops and cores across the western Pennsylvania region.

Each marine interval represents a rise in sea level that caused a shoreward (eastward by present coordinates) shift in lithofacies, recorded in nearshore areas by inundation of the deltaic margin and deposition of marine shales and argillaceous limestone atop more typical Conemaugh deposits, i.e. fluvio-deltaic sandstones, non-calcareous shales, and thin coals. The Brush Creek is the lowest and one of the two most extensively developed of these marine intervals. At this stop, the GeeBee locality (Figure 97), the marine limestone that represents maximum transgression rests directly atop the appropriately named Brush Creek coal. The limestone is in turn overlain by approximately three ft (0.9 m) of highly fossiliferous, dark, calcareous shale. At the Shelocta outcrop of the Brush Creek marine interval (Stop #2), we saw a section where a thin interval of marine shale separates the "core limestone" of the interval from the underlying Brush Creek coal, producing a much more symmetrical transgressive-regressive cycle.

The marine shales contain a diverse, mollusc-dominated fauna. many of the invertebrate groups that characterize Late Paleozoic marine assemblages are represented here, a noteable exception being the fusulinids that probably were unable to tolerate the large amount of fine-grained siliciclastic sediment in the turbid waters so close to the deltaic margin. Bellerophontid gastropods are common, represented by at least three genera. Productid brachiopods are present but scarce, again probably due to the turbid conditions under which these rocks were deposited. A partial list of the genera represented in this outcrop, taken from Hoskins and others (1983), is provided in Table 21; it includes primarily the most common forms. The Brush Creek interval in western Pennsylvania has yielded a remarkable array of well-preserved marine invertebrates, including such delicate forms as ophiuroid starfish ("brittle stars) (Morris and others, 1973; Harper and Morris, 1978), several genera of nautiloid and goniatite cephalopods, and an impressive variety of Pennsylvanian bivalve and gastropod species

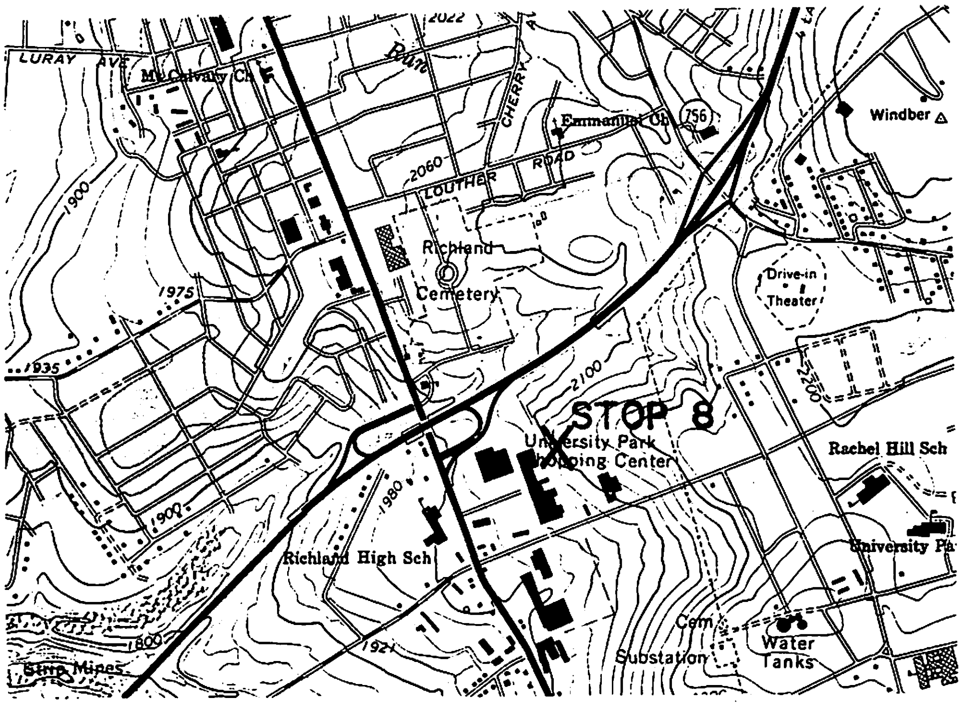


Figure 97. Location of Stop #8 (Geistown quadrangle).

(Seaman, 1942; Hoskins and others, 1983). A single genus of small rugosan coral (Stereostylus) is fairly common, attesting to the unusual tolerance of this coral of highly turbid and probably also brachish conditions that at least periodically prevailed during deposition of the Brush Creek strata in this area (Morrison and others, 1985).

The Brush Creek marine interval is best known for the extremely unusual diagenetic history of its fossil components. At some locations metastable skeletal fragments are preserved in virtually pristine condition as primary aragonite and high-magnesium calcite (Morrison and others, 1985; Brand and Morrison, 1987a). At Stop #2 on this field trip we visited one such location at Shelocta from which possibly the least altered skeletal material yet documented from Pennsylvanian age strata has been recovered. The nature, mechanism, and significance of this exceptional preservation are discussed in a separate paper within this guidebook, and was the focus of discussion at the Shelocta stop. However, the degree of preservation of skeletal material within the Brush Creek interval is not uniform across the western Pennsylvania region; at many (most?) localities the metastable carbonate components have undergone the normal stabilization to low-magnesium calcite. The molluscs, corals, and echinoderms here at the GeeBee outcrop appear well preserved but, to date, chemical staining procedures have documented no remaining aragonite or high-magnesium calcite at this location (Durika and others, 1987). Still another rare type of fossil preservation has been documented in Brush Creek strata near Sewickley, Allegheny County, where crinoid ossicles (almost always unaffected by pyritization because of their unit crystallinity) display partial to complete replacement by pyrite (Brand and Morrison, 1987a).

LEAVE STOP #8 and return to PA Route 56.

Table 21. Fossils from the Brush Creek marine interval at the GeeBee locality, Geistown.

Coelenterata	Gastropoda
Stereostylus	Euphemites
	Pharkidonotus
Brachiopoda	Amphiscapha
Chonetinella	Worthenia
Juresania	Meekospira
	Strobeus
Bivalvia	
Nuculopsis	Crinoidea
Phestia	Columnals

0.6	17.5	TURN RIGHT (west) onto PA Route 56.
0.1	17.6	TURN RIGHT onto entrance ramp for US Route 219 N.
0.7	18.3	Exit for PA Route 756. CONTINUE north on US Route 219.
1.0	19.3	Exit for PA Route 56. CONTINUE north on US Route 219.
4.9	24.2	TURN RIGHT onto exit ramp for PA Route 869 (Sidman Exit).
0.3	24.5	TURN RIGHT from ramp onto PA Route 869 going toward Sidman.
0.3	24.8	Enter St. Michael.
1.0	25.8	TURN LEFT at sign for Johnstown Flood National Memorial onto access road to park. Cross South Fork of Little Conemaugh River.
0.2	26.0	TURN RIGHT into 1889 Park picnic area. STOP #9 AND LUNCH
		LEAVE STOP #9 and TURN RIGHT back onto Flood Memorial access road.
1.1	27.1	Parking lot on left for dam spillway and overlook.
0.3	27.4	TURN RIGHT into Flood Memorial parking lot road. STOP #10: JOHNSTOWN FLOOD NATIONAL MEMORIAL

LEADER: Uldis Kaktins

The dam that stood at this site (Figure 98) was originally built to supplement the Pennsylvania Mainline Canal during low-flow periods. When completed in 1852 it was about 70 ft (21 m) high and over 900 ft (225 m) long. At the time it was the largest earthfill dam in the world, and it impounded the largest man-made lake (Lake Conemaugh). The dam was provided with a 70 ft (21 m) wide spillway that was cut through bedrock (Conemaugh Group sandstones) and cast-iron pipes at the base of the dam to control the lake level.

Just as the dam was completed, however, its reason for existence, the canal system, was put out of business by the Pennsylvania Railroad. Eventually the Pennsylvania Railroad purchased the canal properties from the state, but the South Fork Dam was of no use to them and it was left to deteriorate. During this time the dam suffered a partial failure due to a leak around the culverts at the base and the tower for controlling outflow through these culverts burned down. A subsequent owner (a congressman Reilly) sold the cast-iron discharge pipes for scrap.

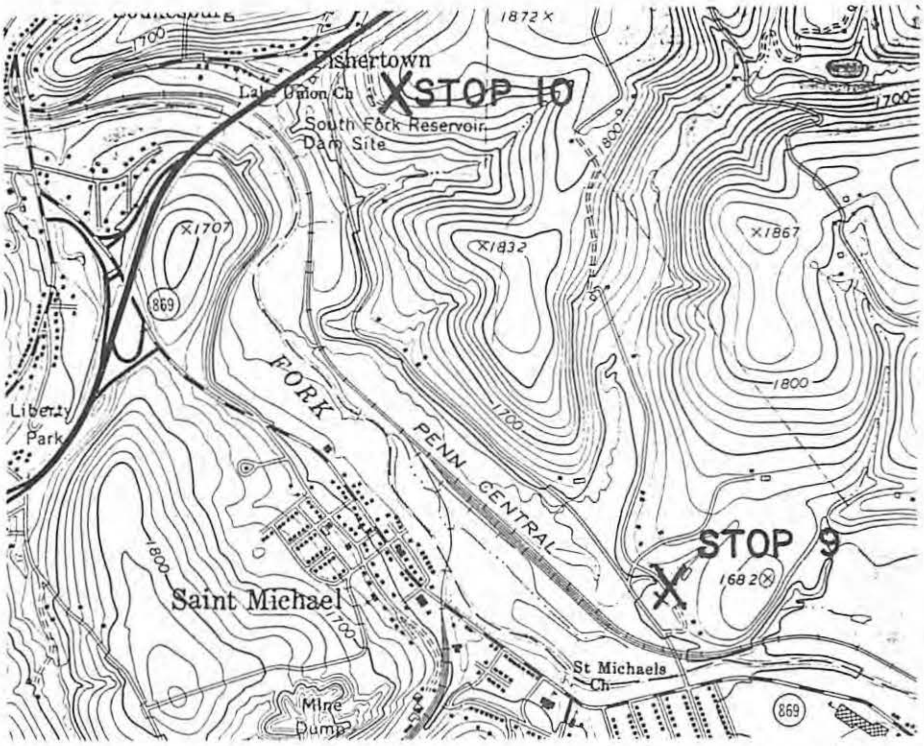


Figure 98. Location of Stops #9 and #10 (Geistown quadrangle).

When the newly formed South Fork Fishing and Hunting Club acquired the dam in 1879 for $2,000, it was in a state of disrepair. This club was composed primarily of wealthy industrialists from Pittsburgh who wanted a summer retreat away from the polluted environment that their industries had created in that city. The leading personalities in the organization were Henry Clay Frick, Andrew Carnegie, Philander Knox (all associated with the steel industry), Andrew Mellon (banker), Robert Pitcairn (president of the Pennsylvania Railroad), and Durbin Horne (Horne's department stores). They set about having the dam repaired, but in spite of the wealth at their disposal, they did not bother with the expense of hiring qualified engineering expertise to oversee the work. As a result the repairs were of the patch-work type. Nor did they repair the culverts needed to control the lake level, but instead blocked up the openings. Furthermore, they lowered the dam to some extent by putting a road across the breast. With the underflow culverts no longer in operation, the lake level was allowed to rise until it reached the level of the spillway. However, the spillway capacity had been reduced not only by the previously mentioned road but also by a sag in the middle of the dam. The result was that the base of the spillway was now less than half of the original 10 ft (3.1 m) below the dam breast.

The rains of May 30-31, 1889 had already caused some local flooding in the area prior to the dam failure, and a considerable amount of debris had washed into Lake Conemaugh. This further reduced the spillway capacity because debris jammed at a fish screen that had been installed across the spillway. The end result was that the earthen dam was overtopped by water in the center of the breast and the dam failed catastrophically (Figure 99).

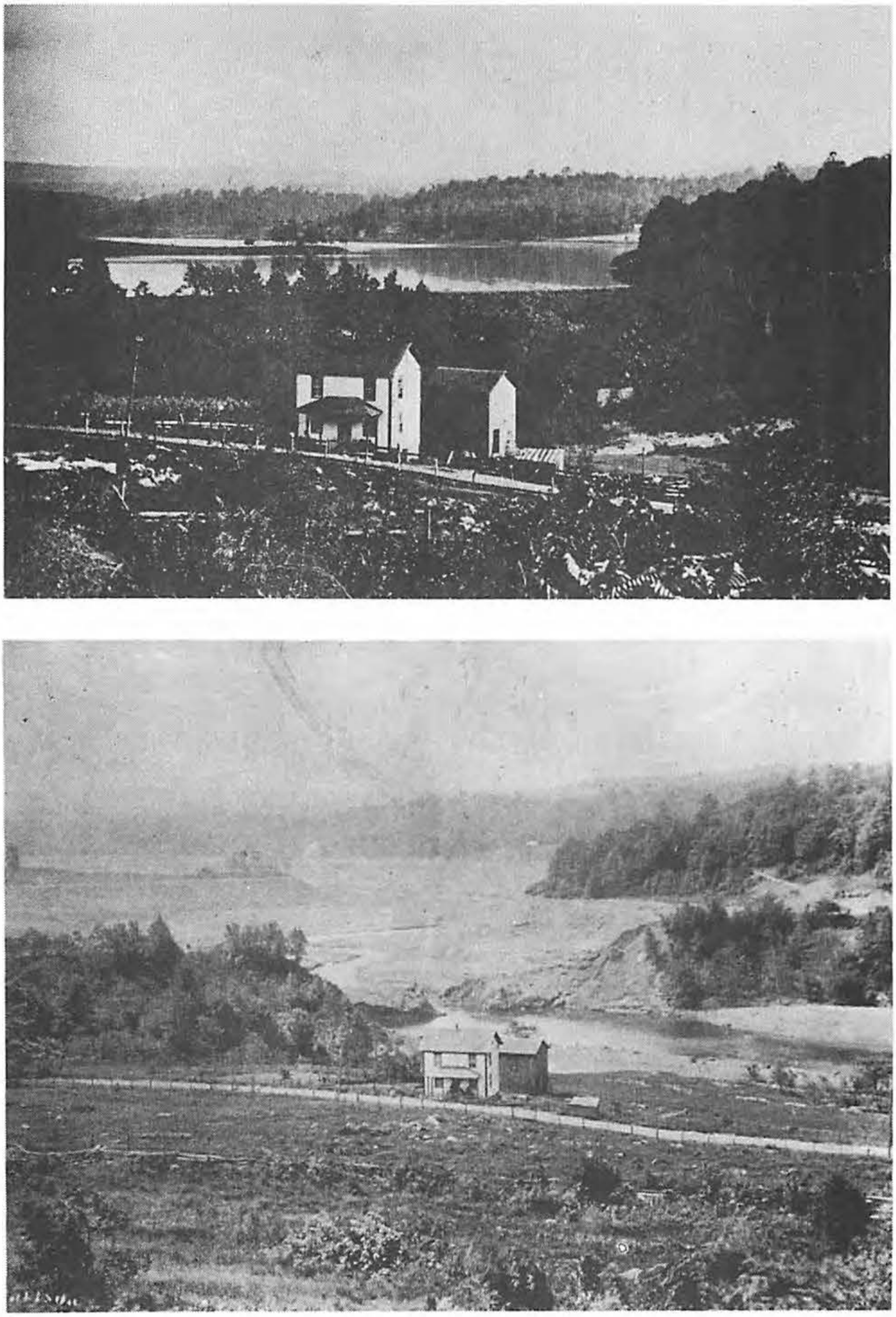


Figure 99. Scenes of the South Fork Dam before and after the 1889 flood. Top: the South Fork Dam and Lake Conemaugh. Note the height of the water level in the lake. The house in the foreground belonged to Elias J. Unger, manager of the South Fork Fishing and Hunting Club. Immediately above the house on the far side of the lake the "Club House" can be seen. It is still standing today as the "1889 Hotel-Restaurant & Lounge" in the town of St. Michael. Bottom: View of the dam site after the flood.

The resultant disaster, which was the third worst calamity in U.S. history (after the San Francisco earthquake and the Galveston hurricane) prompted an outpouring of donations from across the land and even foreign countries. Curiously, the club members responded hardly at all to the plight of the ravaged communities below the dam. The total contributions of some of the wealthiest men in the country amounted to only $20,000, as compared to the millions collected for flood relief. Actually, Carnegie, who had successfully kept his club membership secret in order to avoid undue embarrassment, donated $10,000 of the above amount for a new library. Some of the club members donated as little as $15.

A few lawsuits were filed against the club, but they were either dropped or the courts ruled against them. The rulings reflected the legal opinions of the day, i.e. the club was not negligent because the fault lay with the victims who had been in the wrong plance at the wrong time; the flood was considered an "Act of God". Absolved of all guilt, or the need to pay restitution, the club members were free to amass ever greater fortunes and, in some cases, to hold positions of public trust. For example, Knox went on to become Secretary of State under Taft, and Mellon served as Secretary of the Treasury under three different presidents. Carnegie eventually contributed around $300 million to various charities but his largesse, as far as the local area was concerned, did not extend beyond the library building. It is ironic that this building now houses the Johnstown Flood Museum.

For those who are interested in a more complete description of the events leading up to and following the flood, David G. McCullough's excellent book <u>The Johnstown Flood</u> is recommended.

		LEAVE STOP #10 and TURN LEFT back onto access road toward St. Michaels.
2.0	29.4	TURN RIGHT onto PA Route 869 W.
1.4	30.8	Pass beneath US Route 219 and TURN LEFT (south) onto entrance ramp for US Route 219. Merge with traffic.
1.3	32.1	Roadcut exposing Glenshaw Formation strata on right.
3.7	35.8	TURN RIGHT (west) onto ramp for PA Route 56.
0.8	36.6	Lower Freeport coal exposed at road level on left.
0.2	36.8	Airport exit. CONTINUE west on PA Route 56.
0.8	37.6	Kittanning Formation strata in roadcuts on right.
1.3	38.9	TURN RIGHT onto exit ramp for Widman St.
0.2	39.1	Park on Widman St. Passengers will debark and walk back to PA Route 56.

STOP #11. WIDMAN ST. EXIT OF PA ROUTE 56: ALLEGHENY GROUP FRESHWATER LIMESTONES AND FLINT CLAYS

LEADERS: Suzanne D. Weedman and William A. Bragonier

The accessible part of the road cut at the Widman Street exit of PA Route 56 (Figure 100) exposes a portion of the Allegheny Group from the Middle Kittanning coal to the sandstone over the Upper Kittanning coal. On a higher bench west of Widman Street, the section is exposed to above the Upper Freeport coal. The lithologic sequence for the lower portion of the roadcut is shown in Figure 101. Figures 102 and 103 represent a continuous diagram of the outcrop, based on photographs.

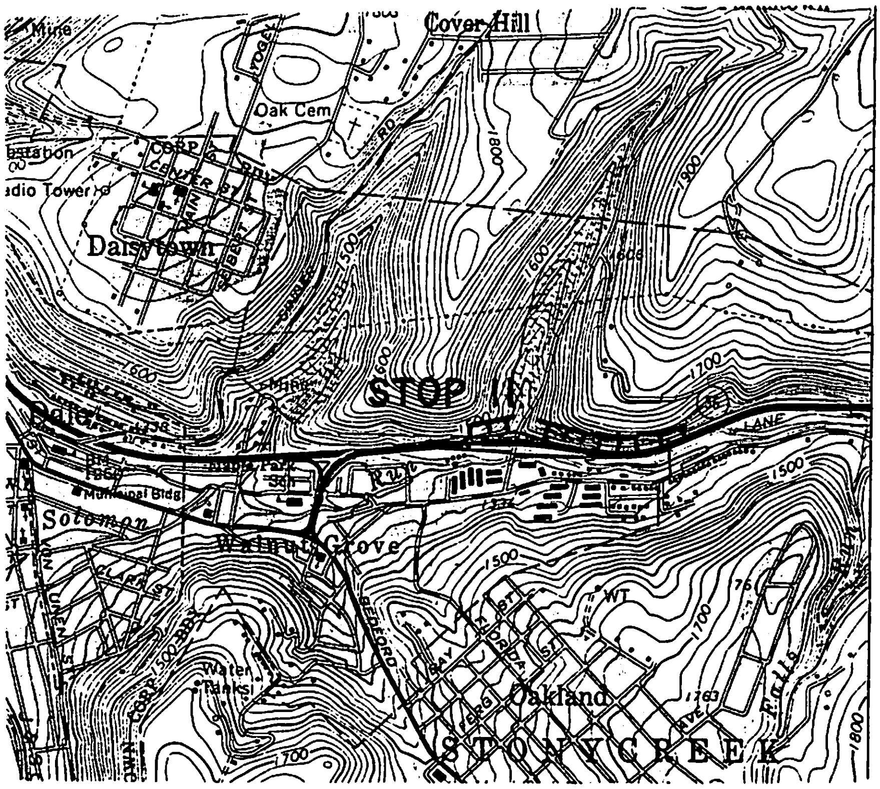


Figure 100. Location of Stop #11 (Johnstown quadrangle).

The Upper Kittanning coal has been extensively mined in the Johnstown area, including this location. The coal at this stop is represented only by remnant pillars. In areas of the roadcut where the coal has been mined, subsidence has been complete, and the overlying sandstone rests directly upon the Upper Kittanning underclay. At several locations, mine rails may be seen protruding from between the sandstone and underclay.

The Johnstown limestone, directly beneath the Upper Kittanning underclay, traverses the entire length of the outcrop, but can best be examined at the far west end of the exposure. The unusual knobby texture of the limestone, common in freshwater limestones, is attributed to expulsive dewatering of the underlying muds as they compacted. Close inspection of the base of the limestone bed shows that the underlying clay was carried up into the limestone. The early-cemented limestone fractured as it was compacted and allowed non-cemented muds to be extruded through the fractures. Pressure solution due to deep burial has enhanced these structures.

About 15 ft (4.6 m) below the Johnstown limestone is a flint clay that is the basal unit of a coarsening-upward sequence. Lithologic units in the coarsening-upward sequence have been subjected to sedimentary slumping. This is evidenced by the existence of slump planes and extreme changes in the dip direction of these units. The flint clay is not highly brecciated but has been moved, as indicated by severe thickness changes and an intermixing of the overlying shale with flint clay. The fracture of the clay is conchoidal, yet planar, indicative of internal movement. Of significance, however, is the fact that sandy shale immediately underlying the flint clay is <u>not</u> slumped. There is

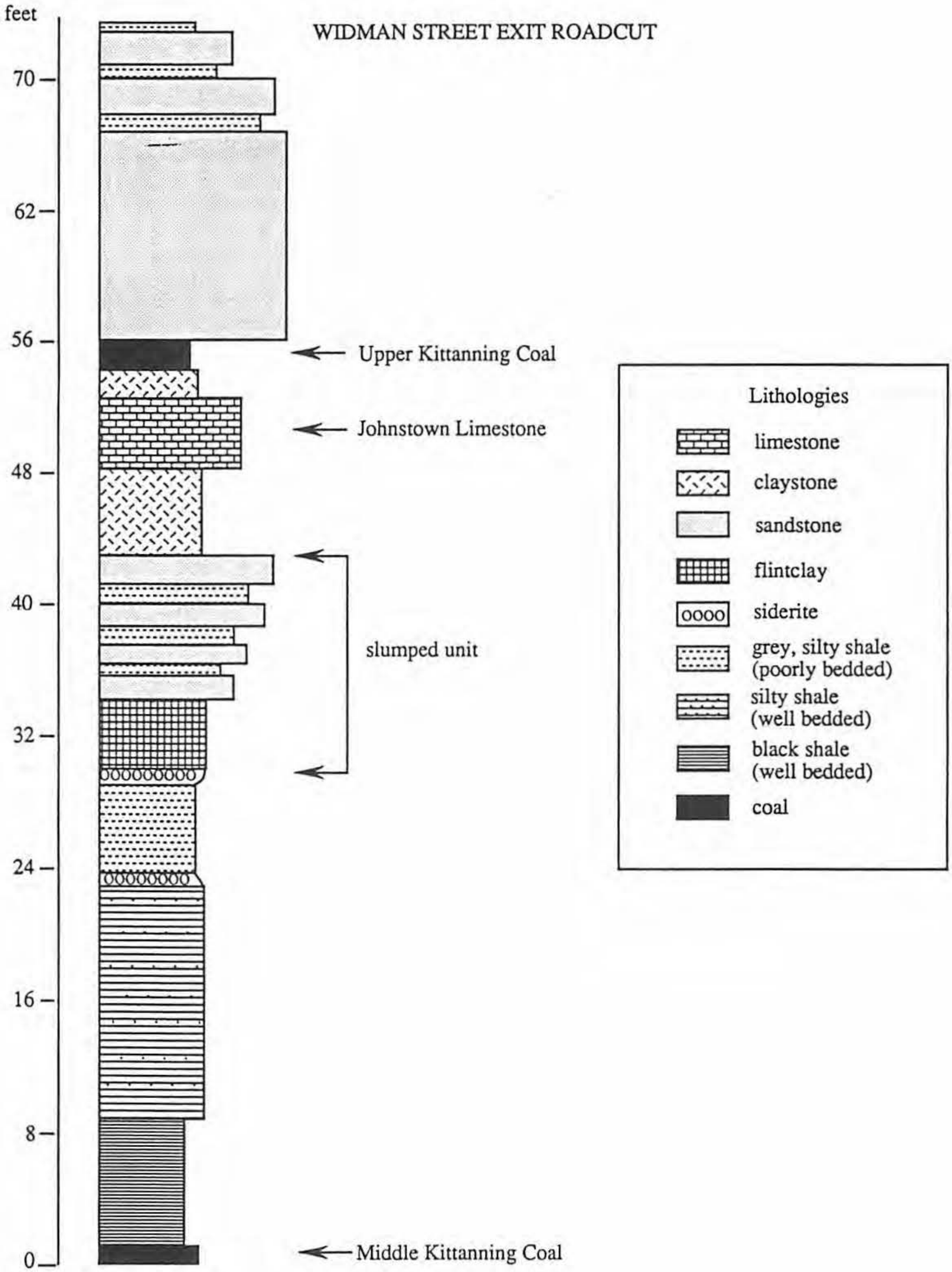


Figure 101. Measured stratigraphic section of the middle Allegheny Group exposed at the Widman St. Exit of PA Route 56 at Johnstown.

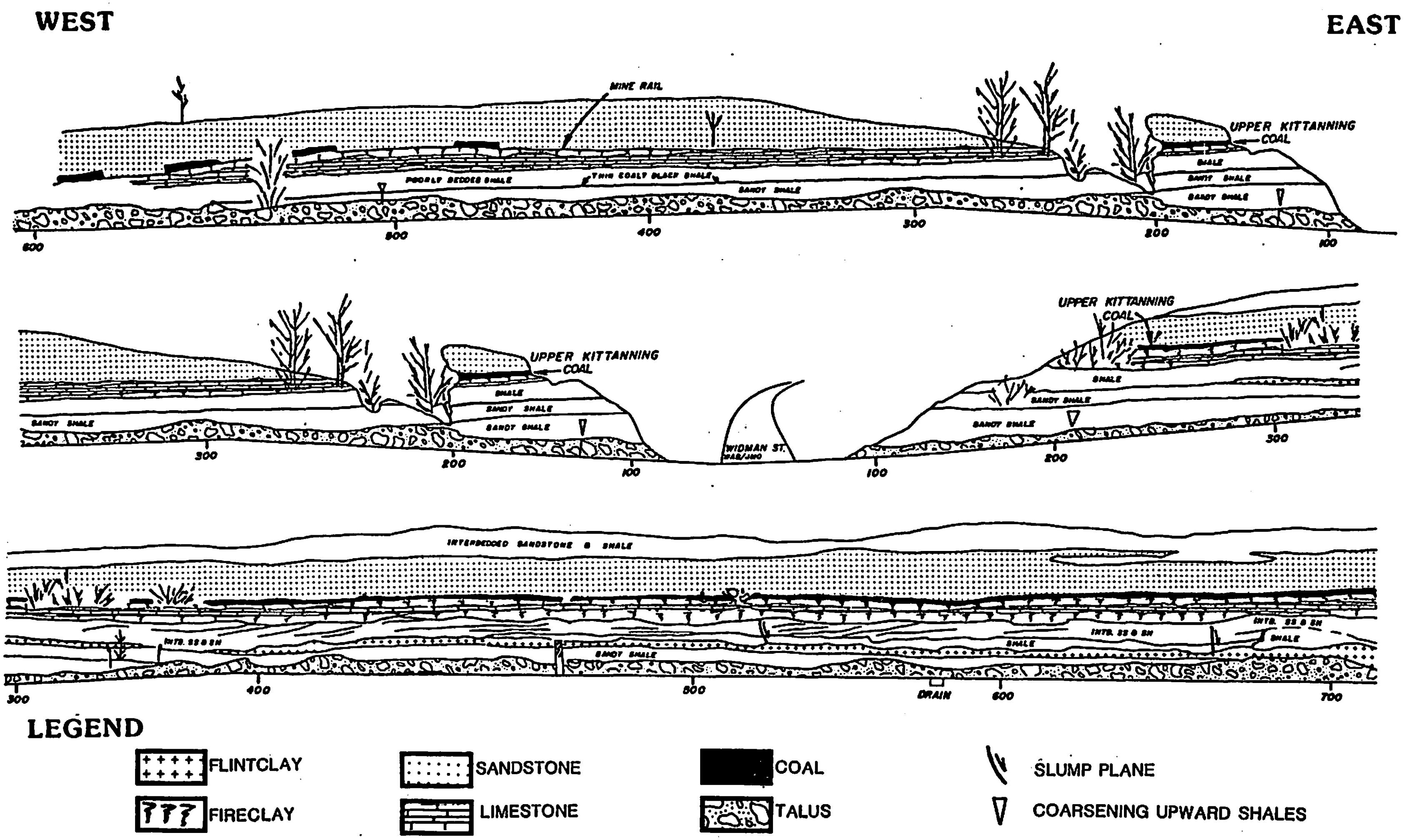


Figure 102. Diagram of the western portion of the roadcut at the Widman St. exit of PA Route 56. The diagram is constructed from photographs and is not to scale. Numbers indicate feet from the centerline of Widman St. along exit ramps to PA Route 56.

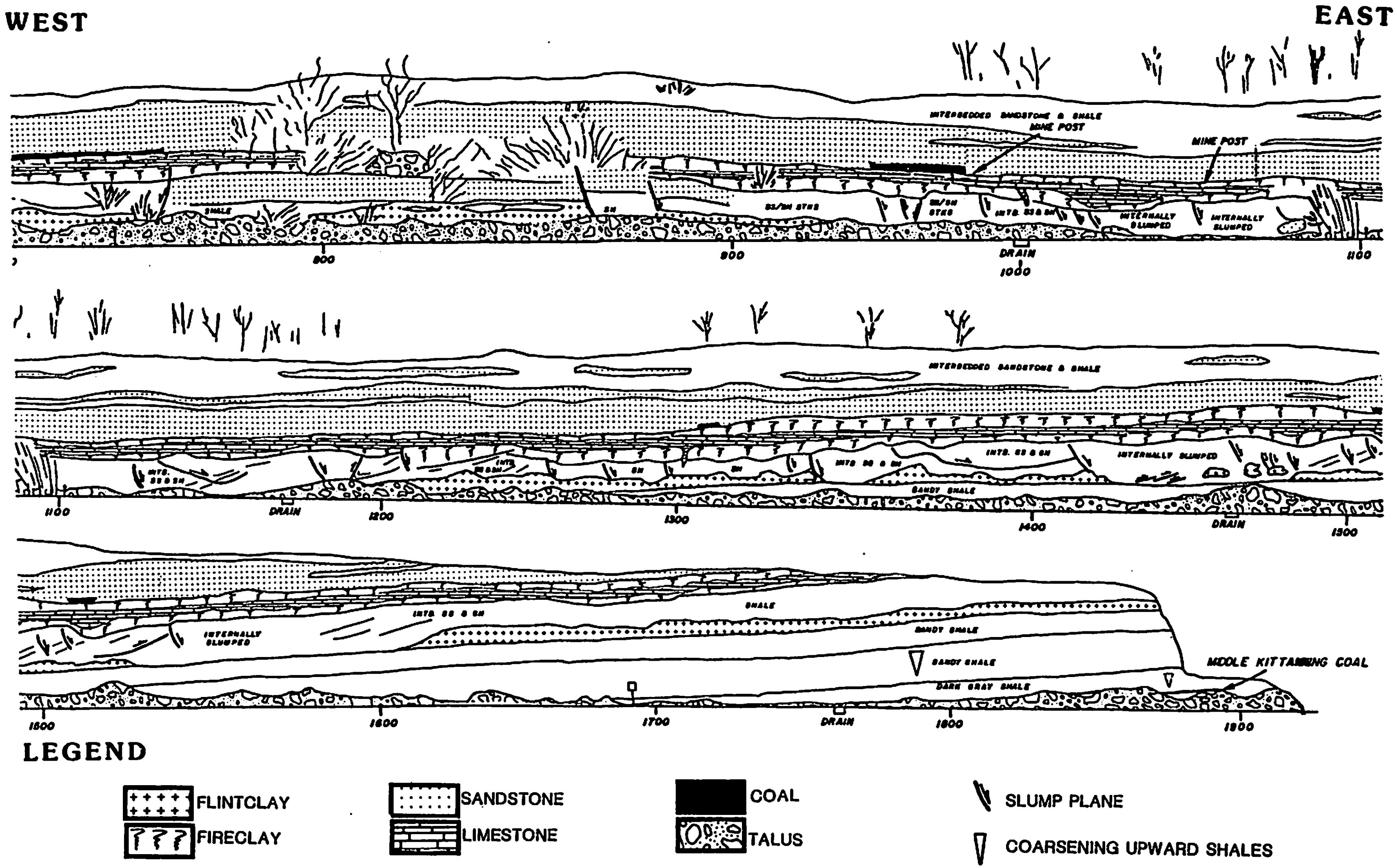


Figure 103. Diagram of the eastern portion of the roadcut at the Widman St. exit of PA Route 56. See Figure 102 for explanation.

a very planar contact at the base of the clay. This indicates that the flint clay was much less structurally cohesive than the underlying shales at the time of slumping. The clay, in fact, acted as a "shock-absorber" for the underlying shales. Furthermore, the time of slumping can be placed after the deposition of the slumped units but before the deposition of the Johnstown limestone, which is not slumped (i.e. shortly after the flint clay was loaded).

An argument for the lacustrine origin of the flint clay can be made at this stop (aside from the fact that the coarsening-upward sequence is typical of some lacustrine deposits). In the roadcut west of Widman Street, where the flint clay has been replaced by several inches of black shale with coal streaks, the distance from the base of the limestone to the black shale is only 7 to 8 ft (2.1 to 2.4 m) as opposed to the 14 to 16 ft (4.3 to 4.9 m) interval where the flint clay is present. This indicates that the flint clay formed in a topographically low area relative to the black shale with coal streaks.

Units below the flint clay are largely a series of coarsening-upward shales interpreted as a bay-fill sequence. Several specimens of the bivalve <u>Anthraconaia</u> have been collected from these shales. The presence of freshwater or brackish water fossils over the Middle Kittanning suggests that the depositional environment was on a lower delta plain. The environmental interpretation of the sequence is: peat swamp (M.K.) -> bay -> lake -> crevasse splay (into the lake) -> carbonate lake (sediment starved) -> peat swamp (U.K.) -> larger crevasse splay or channel (with very little erosion). In other words, this area was a sediment starved coastal swamp that received two periods of sediment influx, the second one being the larger.

		LEAVE STOP #11 and follow exit ramp back onto PA Route 56.
1.3	40.4	Bedford St. exit (PA Route 271). CONTINUE west on PA Route 56. Enter Johnstown.
1.1	41.5	Inclined Plane on left. Buses will stop to discharge those who wish to ride on the Inclined Plane to get an overview of the city and see the flood protection channels. TICKETS FOR INCLINED PLANE RIDE ARE IN YOUR REGISTRATION PACKETS. You may leave your coats, etc. on the bus. The buses will proceed to the hotel and await your return. The Holiday Inn is two blocks away. Those who do <u>not</u> wish to ride the Inclined Plane and walk back to the hotel <u>should stay on the bus</u>.
		STOP #12: <u>INCLINED PLANE</u>
		LEAVE STOP #12. TURN RIGHT onto Union St.
0.2	41.7	TURN RIGHT onto Lincoln St.
0.1	41.8	TURN RIGHT onto Market St. to Holiday Inn.
		END OF DAY 2.

NOTE for those who are walking back from the Inclined Plane: Walk down the steps (not the car ramp), cross PA Route 403/56 and turn right onto Vine Street. The Holiday Inn is on the corner of Vine and Market.

54TH FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS
Field Guidebook

Errata

Page 1. Last line, 1st paragraph - "...Johnstown floods of **1889** and 1977."

19. 3rd line, 2nd paragraph - there is **no** Appendix 1.

32. 5th line, 1st paragraph - "...**especially** in outcrop..."

52. 3rd line, 4th paragraph - "...quartz, **feldspar**..."

55. Figure 32: "> 75% sandstone" and "> 75% shale/siltstone"

57. 6th line, 3rd paragraph under Riddlesburg Shale - "...railroad **is** covered."

69. 1st line, 3rd paragraph under PHYSICAL PROPERTIES - "Ferm and Smith (**1981**)..."

72. Caption to Table 2 - "...(from Smyth, **1980**)."

77. 5th line, 3rd paragraph - "...(**Buswell**, 1980)."
2nd line, 1st paragraph under GENESIS - "Smyth (**1980**)..."

81. 5th line, 3rd paragraph - "...Patterson and Hosterman, **1960**..."
3rd line, 1st paragraph under Mineralogical - "...Smyth, **1980**..."
2nd line, 2nd paragraph under Mineralogical - "...Hosterman, **1960**; Bragonier, 1970; Smyth, **1980**)."

82. 1st line - "...Patterson and Hosterman, **1960**)."
1st line under Geochemical - "...Smyth, **1980**..."
3rd line under General - ditto.

83. 4th line, 1st paragraph - "Chalard, **1951**..."
6th line, 1st paragraph under Differential Colloidal Flocculation - "...roughly correspond to..." (delete **not only**).

125. 3rd line - "I **could** not ascertain..."

130. 1st line, 5th paragraph - "Figure **55A** is the section..."

148. 3rd line, 4th paragraph - "...pretty much like a **huge**..."

153. Under Fulton, J. (1889) - reference should be to "Atlas to Reports HH and **HHH**, 1877, p. 361-404."

155. Under Keller, W. D. - date of last reference should be **1982** instead of 1983.

192. Figures A and B should be labeled **C** and **D**, respectively, whereas figures C and D should be labeled **A** and **B**.