GUIDEBOOK

51 st. Annual Field Conference Of Pennsylvania Geologists

SELECTED GEOLOGY OF BEDFORD AND HUNTINGDON COUNTIES

September 25, 26, and 27, 1986

Huntingdon, Pa.

Hosts: Pennsylvania Geological Survey
Juniata College

TABLE

SHEWING THE ORDER OF STRATIFICATION, GEOGRAPHICAL POSITION, COMPOSITION, AND THE MAXIMUM THICKNESSES OF THE LOWER SECONDARY FORMATIONS OF PENNSYLVANIA, EAST OF THE SUSQUEHANNA RIVER.

Formations in the ascending order.	GEOGRAPHICAL POSITION.	USUAL COMPOSITION.	MAXIMUM THICKNESS.
XIII.	Anthracite coal basins.	Dark blue shales, blueish grey argillaceous sandstones, and coarse quartzose conglomerates, and seams of Anthracite coal.	6,750 feet nearly, at Pottsville. —Not yet positively ascertained.
XII.	Sharp mountain, and the other mountain barriers of the Anthracite coal basins.	Coarse quartzose conglomerates, alternating with white and grey sandstones, and occasional thin beds of dark carbonaceous shale.	1,400 feet. Tamaqua.
XI.	Surrounds the mountain barriers of the Anthracite coal basins, usually in a narrow valley, immediately outside of them.	Red shales and soft argillaceous red sandstones, and occasional beds of compact siliceous red and grey sandstones, also a few thin calcareous bands.	2,949 feet. Mount Carbon.
X.	Second mountain, Peter's mountain. Mahantango mountain, Berry's mountain, Line mountain, Little mountain, Catawissa or Nescopeck mountain, Wyoming mountain, Shickshinny mountain, and the south-eastern summit of the Allegheny mountain.	White and grey siliceous sandstones, with dark blueish and olive coloured slates, also coarse siliceous conglomerates, alternating with grey, yellow and white sandstones, and bands of black carbonaceous slate; the latter sometimes erroneously taken for coal slate.	2,400 feet, very nearly. Second mountain.
IX.	Occupies the north-west part of Pike and Monroe, the eastern part of Wayne, all except the northern side of Susquehanna county, the whole south-east side and base of the Allegheny mountain, and the bases of the mountains consisting of Formation X. on the sides remotest from the Anthracite coal basins.	Red shales and argillaceous red sandstones, also brown, grey, greenish and buff coloured sandstones.	6,000 feet, or more. Below Mauch Chunk, Lehigh.
VIII.	Middle of the valley between the Kittatinny and Second mountains, valley of Delaware river from Water Gap to Carpenter's Point, middle of Roaring creek valley, North Branch from Bloomsburg to Berwick, Muncy hills.	Alternating strata of dark grey, greenish and olive coloured slates, and grey argillaceous sandstones. Contains many fossils. A stratum of blue fossiliferous limestone near the bottom of the formation.	5,000 feet at least. Below Mauch Chunk, Lehigh.
VII.	The sharp rugged ridge next north of the Kittatinny mountain.	A coarse and rather loosely cemented white and yellowish sandstone, with cavities shewing the forms of shells, and other organic remains.	700 feet. Susquehanna river, Dauphin county.
VI.	A very narrow belt occurring in places along the northern base of the Kittatinny mountain, and thicker strata along both the northern and southern bases of Montour's ridge.	A blue argillaceous limestone, sometimes grey and sandy, and frequently very full of fossil shells, encrini, &c.	900 feet. Fishing creek, Bloomsburg.
V.	Northern base of the Kittatinny mountain, and on the sides and summit of Montour's ridge.	Red and variegated sandstones and shales The lowest layers abound in several species of the marine vegetable fossils called *fucoides*.	2,000 feet, at least Delaware Water Gap.
IV.	Kittatinny or Blue mountain.	Hard white and grey sandstones, and coarse massive quartzose conglomerates. Contains impressions of several species of *fucoides*.	1,886 feet. Lehigh Water Gap.
III.	Northern side of the Kittatinny valley.	Dark fissile slates usually blue, dark grey black and dingy olive, and sometimes drab, yellow and red. Contains also some beds of sandstone, and a few of conglomerate.	6,000 feet at least. Delaware river, below Water Gap.
II.	Southern side of the Kittatinny valley.	A blue limestone, with thin interposed layers of chert.	6,000 feet. Not yet ascertained, but probably as much as stated.
I.	Southern margin of the Kittatinny valley, and northern side of the chain of hills called the South mountain.	A very compact, rather fine grained white and light grey sandstone.	Not ascertained, but probably 1,000 feet.

Guidebook for the

51st ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

in commemoration of the

150th ANNIVERSARY OF THE PENNSYLVANIA GEOLOGICAL SURVEY

SELECTED GEOLOGY OF BEDFORD AND HUNTINGDON COUNTIES

Guidebook Editor:
William D. Sevon, PA Geological Survey
Field Trip Leaders:
Thomas M. Berg, PA Geological Survey
Samuel W. Berkheiser, Jr., PA Geological Survey
Edward Cotter, Bucknell University
Clifford H. Dodge, PA Geological Survey
William E. Edmunds, Consultant, Harrisburg, PA
Rodger T. Faill, PA Geological Survey
Albert D. Glover, PA Geological Survey
Jon D. Inners, PA Geological Survey
Teresa L. Kaktins, PA State University
Leonard J. Lentz, PA Geological Survey
Joan Cullen-Lollis, University of Cincinnati
Allan M. Thompson, University of Delaware
Eugene G. Williams, Emeritus, PA State University
Additional Contributors:
Mary Roden, Rennselaer Polytechnic Institute
Rudy L. Slingerland, PA State University
Robert C. Smith, II, PA Geological Survey
Alton M. Sternagle, PennDOT, Hollidaysburg
John H. Way, Jr., Lock Haven University

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Hosts: The Pennsylvania Geological Survey and the Dept. of Geology, Juniata University, Huntingdon, PA

Cover: Huntingdon and Jacks Mountain, from Warrior Ridge. A George Lehman etching from H. D. Rogers, The Geology of Pennsylvania, 1858, v. 1, p. 13.

Frontispiece: Stratigraphic chart from Rogers, H. D., 1838, Second annual report on the geological exploration of the State of Pennsylvania: Harrisburg, Packer, Barrett and Paree, p. 19.

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Indian Chief-rock, Canoe Valley, PA. A George Lehman lithograph in Rogers, 1858, v. 1, opposite p. 503.

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150TH ANNIVERSARY

1836 - 1986

ERRATA

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11		16	Butts, C., and Hoff, D. T. should be Berkheiser, S. W., and Hoff, D. T.
11			Missing references:

Miller, B. L., 1925, Limestones in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resources Report 7, 368 p.

____________, 1934, Limestones of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resources Report 20, 729 p.

National Historic Association, 1936, A history of the Juniata Valley, in three volumes: Harrisburg, Pennsylvania, v. 1, p. 294-298.

Platt, F., 1881, The geology of Blair County: Pennsylvania Geological Survey, 2nd ser., Report of Progress T, 311 p.

Rogers, H. D., 1838, Second annual report of the geological exploration of the state of Pennsylvania: Harrisburg, Packer, Barrett, and Parke, 91 p.

____________, 1858a, The geology of Pennsylvania: Pennsylvania Geological Survey, 1st ser., v. I, 586 p., and v. II, 1045 p.

____________, 1858b, Geological map of the state of Pennsylvania, accompanying the final report on the geological survey of the State, 1858: Pennsylvania Geological Survey, 1st ser., Map.

Rosenkrans, R. R., 1934, Correlation studies of the central and southcentral Pennsylvania bentonite occurrences: American Journal Science, 5th ser., v. 27, no. 158, p. 113-134.

White, I. C., 1885, The geology of Huntingdon County: Pennsylvania Geological Survey, 2nd ser., Report of Progress T3, 471 p.

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15	1	5	Figure C6. should be Figure 9.
25		3	See Figure T2 should be See Figure 11.
55			John H. Way's affiliation should be listed as Lock Haven University.
58	3	7	Conkin-and-Conklin should be Conkin and Conkin.
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122	2	7	155 **should be** 157°
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122	3	5	167 **should be** 167°
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173	2	2	(Figure TA). **should be** (Figure 78).
174	3	1	dip 50 SE **should be** dip 50°SE
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196			Figure caption, line 3: b, or contorted **should be** b, convolute or contorted
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198	1	15	Figures D3a, D3b, D3c, and D3d. **should be** Figures 86a, 86b, 86c, and 86d.
199	1	3	D3b, D3c, D3d, and D3e **should be** 86b, 86c, 86d, and 86e
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SELECTED GEOLOGY OF BEDFORD AND HUNTINGDON COUNTIES

INTRODUCTION

from Lesley, 1876, p. 29-55

"In the early spring of 1832, seven men of science met in Philadelphia and organized the Geological Society of Pennsylvania.

"Mr. Peter A Browne was a leader in this movement, so important in its results for the scientific and practical study of the mineral resources of the Commonwealth, and was elected to be its Corresponding Secretary.

"John B. Gibson, Richard Harlan and Henry S. Tanner appear as a committe to memorialize the Legislature for a Geological Survey. . . .

"The Society fast grew in numbers and influence. The list of its members given at the end of the first part of the first volume of its Transactions (the only volume it ever published), bearing the date 1834, states their number as follows: Resident members 83; correspondents in Europe and America 32; honorary members 4. . . .

"The organization of the Geological Society of Pennsylvania, in April 1832, marks then the beginning of a new era in American science, and agrees in time with the commencement of that series of State Geological Surveys, which up to 1843, had been carried on in three-fourths of the States of the Union.

"The Constitution of the Geological Society of Pennsylvania is given on page 208 of Hazard's Register, Vol. IX, for 1832; its circular letter to the citizens, on page 306, of Vol. X, for 1832; and its memorial to the Legislature, with the report of the Legislative Committee on a Geological Survey, on page 225 of Vol. XI, for 1833.

"The Constitution reads as follows:

> 'The objects of this Society are declared to be, to ascertain as far as possible, the nature and structure of the rock formations of this State--their connection or comparison with other formations in the United States, and of the rest of the world; the fossils they contain--their nature, positions and associations, and particularly the uses to which they can be applied in the arts, and their subserviency to the comforts and conveniences of man.
>
> 'To effect these desirable objects, its members promise to contribute their individual exertions, and to use their influence to have the State geologically surveyed, to assist in making a State geological mineralogical collection, to be geographically arranged, at such place as the Society shall appoint; and to disseminate the useful information thus obtained by geological maps, charts and essays." . . .

"The Geological Society of Pennsylvania pressed for a survey of the State, even to the extent of proposing to take on the task itself:

. . .'The committee goes on to argue the value of the survey to the Commonwealth, and to quote the example of three sister States, Tennessee, South Carolina and Massachusetts, which had commenced their respective State surveys, under the direction of Dr. G. Troost, Mr. Lardner Vanuxem, and Prof. Edward Hitchcock. The whole report is well written, and shows advanced views both of a scientific and business kind.

'An act providing for a Geological Survey of the State" was then reported and read as follows:--

'Section 1. Be it enacted," &c., &c., "That if the Geological Society of Pennsylvania shall, within 60 days after the passage of this act, engage, by writing, under their corporate seal, to take upon themselves the duty of causing to be accurately located and designated, at least three meridian lines, crossing this State, and one other line at right angles therewith extending through the State, and shall in like manner engage to conduct a geological and topographical survey of the State and to furnish for the use of the State [blank] copies of the map, profiles and sections of such survey; in such case the Governor be and he is hereby directed to draw his warrant on the State Treasurer in favor of the President, Vice-President and Secretary of the said Society, for such sums of money, not exceeding $15,000 in all, and not exceeding $5,000 in any one year, as he shall judge proper, to be expended by the said Society for the purposes aforesaid: Provided, however, "that the manner of making such location and survey shall be first submitted to the Governor, and by him approved.'

"Could any appropriation be more modest, considering that it was to be made by the 'wealthiest mineral State of the Union.' The Legislature considered the subject in its session of 1832-3; and considered it again the following year 1833-4; but when at the close of the session of 1834-5, the Committee of Inspection of the Geological Society made their annual report (Feb. 25, 1835), they write:

'This Society has again to regret the further postponement of this all-important measure by the State Legislature. During the recent session, discussions relative to the political state of our country generally appear, in too many instances, to have occupied the attention of the members, to the exclusion of measures of permanent utility.

'In the meantime, the Legislatures of our sister States have shown increased interest in obtaining a correct knowledge of the mineral wealth of their respective States. In addition to those portions of our country whose Legislatures have already availed themselves of the scientific labors of native geologists, we are now enabled to add the States of Virginia, New Jersey, New York, Connecticut and Maine, where active measures are at present in operation to secure complete geological surveys.'

"One year more was spent in the manufacture of public sentiment by men of science and enlightened men of business, and then, in the spring of 1836, a resolution passed both houses of the Legislature and was signed by the Governor; this was four years after the date of the presentation of the memorial of the Secretary of the Geological Society of Pennsylvania.

"Of the Society itself we hear no more. After accomplishing the sole object of its creation it seems to have gone to rest. But if its corporate body died, its spirit continued active. Its members haunted the halls of the Academy, and at length, in 1840, as has been said above, organized the Association of American Geologists. But they took no part in the Geological Survey of the State. The Geological Society, after all its efforts, was never entrusted with the work. In fact, none of its members, singly, was capable of such a task; and no society habituated to debates, collectively, could be. The direction of the survey was entrusted to a stranger; but to one at least as much at home in Pennsylvania as any of the geologists of the Society; . . .

"The act of Legislature appointing a survey of the State was dated the 29th of March, 1836, and authorized an annual appropriation of expenditure of $6,400 for five years, to pay the salaries of a geologist, two assistants, and a chemist.

"Professor Henry D. Rogers was appointed geologist, Mr. James C. Booth and Mr. John F. Frazer, assistants, and Dr. Robert E. Rogers, chemist.

"The first season's field work sufficed to make known with certainty the geological order of the rocks of Middle Pennsylvania; and on this determination, as a sure foundation, all subsequent work in the Appalachian mountain belt of the Atlantic States was based. Until then the mountains of IV (Oneida) and of X (Catskill) had been confounded together. But when Mr. Frazer made his descending section along Yellow creek in Huntingdon county, from the Broad Top Coal Measures at Hopewell, through the gaps in Terrace mountain (X) and Tussey mountain (IV), to the Lower Silurian limestones in Morrison's cove,--and Dr. Booth reported the same unmistakable order of formations on his return from a tour round by the Potomac,--we may consider that then the general geology of Pennsylvania and of the Atlantic States was settled. It has, in fact, suffered no modification of any great importance since that time.

"Yellow creek (with its prolongation Sandy run) will always have a classical interest for American geologists. It is one of the few lines of continuous one-dip section, straight across the Old-Age System, through all its slanting formations, from the coal measures at its top to the magnesian limestones near its bottom; with a total thickness of rock deposits of about twenty-five thousand feet.

"Professor Frazer was fond of telling his geological friends the story of this adventure, explaining how, up to the rendezvous of the geologist and his two assistants at Huntindon one summer Sunday, their explorations had been a series of embarrassments; their note books filled with a confused mass of irreconcilable statements; their cross-sections conradictory in themselves when compared together; and the geology of Pennsylvania apparently at variance with that of the neighboring State of New York. His Yellow Creek section was, however, disbelieved, until verified by Prof. Rogers himself the following week, and by Prof. Booth afterwards on the Potomac. From that moment everything went smoothly; all contadictions vanished; their back notes became luminous, and the northern outcrops of Hall and Vanuxem, in New York, were seen to be all represented in the same regular order, although on an immensely enlarged scale, by the southern outcrops of the same formations in Pennsylvania; Tussey mountain being made of the Oneida conglomerate, No. IV; and Terrace mountain by the Catskill sandstones of New York, Nos. IX and X.

"Prof. Rogers was able to recognize, in co-operation with his equally distinguished brother, the State Geologist of Virginia, the persistency of the same formations, under slight variations of color, size and mineral ingredients, across the Old Dominion and into Tennessee and Alabama; and therefore, we may truthfully claim for the work of the first year of the Pennsylvania Geological Survey, 1836, that it gives the epoch for American Old-Age Sedimentary Geology.

"The Paleozoic system was divided into twelve parts or Formations, the lowest being that the limestone of Harrisburg and Reading, the highest being that of the Coal Measures. This earliest classification, modified somewhat in the following year affixed the following numerals to the formations: . . ."

See Frontispiece.

". . .No modification of this system of numbers would have been needed had the survey been commenced on the Schuylkill, instead of along the Juniata. But no one can take exceptions to the plan of the first reconoissance because it assumed the fact that a long section through the central district of the State would be the one most likely to reveal the structure in all its completeness. It could not be forseen that all the elements exhibited along one hundred miles of one river, the Juniata, were compacted along twenty miles of the other, the Schuylkill; nor could it be anticipated that formations thousands of feet thick on the Schuylkill would be found dwindled away to hundreds on the Juniata.

"It was glory enough for the first year's survey to have swept away the enormous fictions of previous years,--demolished the theories of Taylor respecting the Broad Top and Anthracite Coal Measures,--put a stop to all talk about "Transition Rocks,"--and separated the mountains of IV and the mountains of X into two distinct groups of very different ages.

"We may with equal truth assert that American Structural Geology was born in 1836. For it was during this first season's work that that system of anticlinal and synclinal folds, or rock-waves, was first fairly seen and understood by Professor Rogers, with which his name will ever be identified as closely and honorably as the names of Thurmann of Switzerland, and Elie de Beaumont of France,--although, it was not until the results of subsequent seasons' work were plotted to scale, that he had the opportunity of demonstrating the normal shape of these waves, and the evident movements of the earth-crust towards the north-west, which their almost uniformly steeper dips towards the north-west exhibited."

This was the beginning of the Pennsylvania Geological Survey. This was the beginning we celebrate by returning to the Bedford and Huntingdon counties area for the 51st Field Conference of Pennsylvania Geologists. I suggest that for further information about the early years of the Pennsylvania Geological Survey you read all of Lesley (1876), a beautifully illustrated article in Pennsylvania Heritage (Hoskins, 1986), and the 4 articles about the 4 Pennsylvania Geological Surveys in Pennsylvania Geology (1986, v. 17, no. 4).

Frequently we fail to examine and consider the heritage acquired from our predecessors. In this year of the 150th anniversary of the start of the Pennsylvania Geological Survey, many of us at the Survey have given time and thought to this heritage and feel enriched by it. We hope that this field trip and this guidebook will impart to you some feeling for the significant efforts of our predecessors.

As is evident by the title page, this guidebook is the product of the efforts of many. The Pennsylvania Geological Survey, which assumed major responsibility for this field trip, has been aided by many friends. This is in keeping with our heritage. Let the tradition continue!!

William D. Sevon

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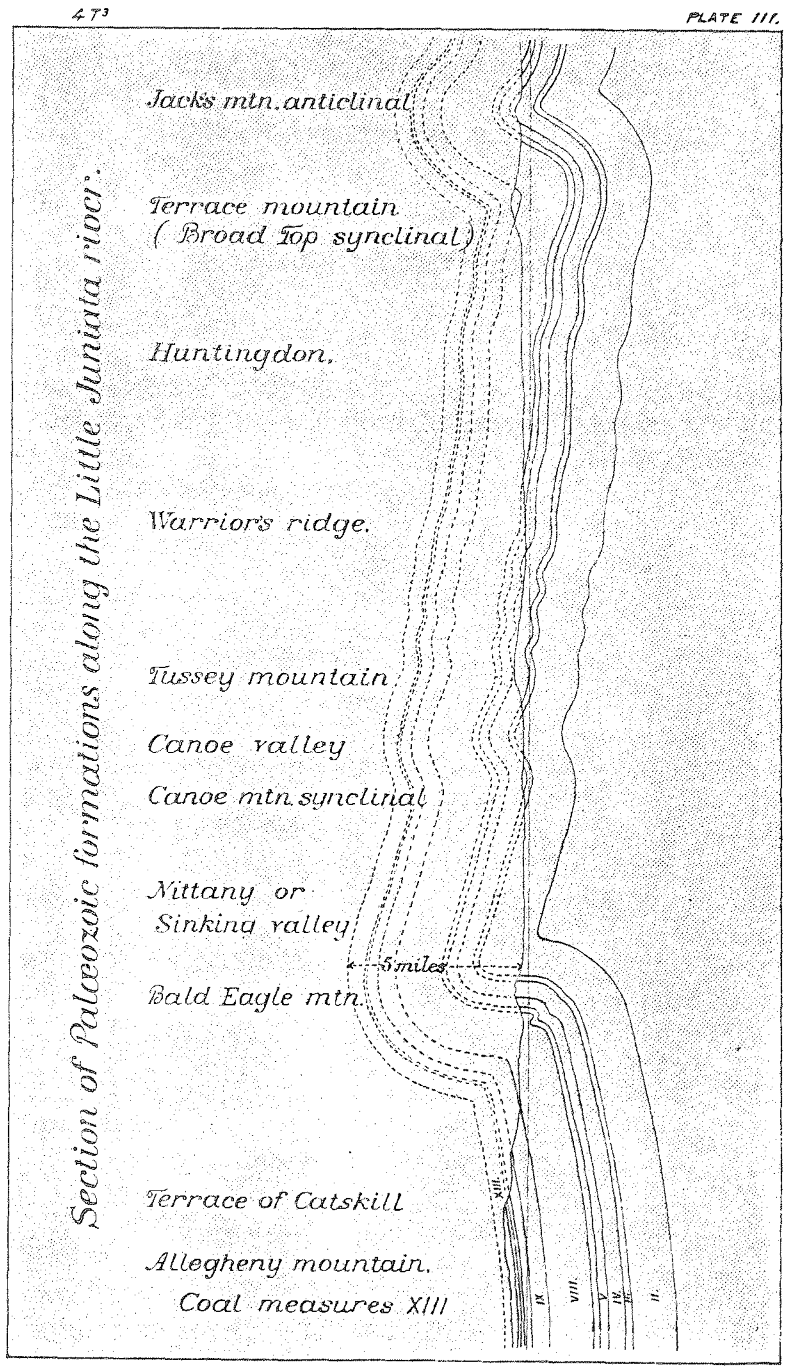
Hoskins, D. M., 1986, Celebrating a century and a half: Pennsylvania Heritage, v. 12, no. 3, p. 26-31.

Lesley, J. P., 1876, Historical sketch of geological explorations in Pennsylvania and other states: Pennsylvania Geological Survey, 2nd ser., Report of Progress A, 200 p.

Stone ridge near Jacks Narrows, Juniata River. A George Lehman lithograph in Rogers, 1858, v. 1, opposite p. 520.



Cross section along Little Juniata River, from White, 1885, p. 4.

UNION FURNACE ORDOVICIAN CARBONATES: PAST, PRESENT, AND FUTURE

by
Samuel W. Berkheiser, Jr.
Pennsylvania Geological Survey

The Juniata River and its tributaries, which provided easy routes for pioneers and traders, were explored as early as 1732 by settlers in Pennsylvania. Prior to 1754, these routes remained primarly the domain of Indians because lawful white settlements were prohibited by treaty. However, trade with Indians and pioneer settlement were the impetus for creating Huntingdon County out of a portion of Bedford County in 1787 as the 18th of the Commonwealth's 67 counties (National Historic Association, 1936).

The rivers and streams that formed major trade routes also provided the best rock exposures where probably the local rock was first examined. The Juniata River Valley limestones and dolomites probably were first used as building stone for barn foundations and dwellings. Because "Indians and lawless whites" made travel between towns dangerous up to about 1840, early settlers had to be a self-sufficient people (Huntingdon County Historical Society, 1937, p. 81). Thus, the influx of settlers in the 1800's undoubtly caused a demand for locally produced agricultural lime as well as lime for mortar, whitewash, and plaster. Vertical shaft kilns, similar to one described by Berkheiser and Hoff (1982), and local outcroppings of Ordovician-age carbonates were well suited to meet early demands for these products. Besides supplying agricultural and construction materials, local fluxing material was in demand when the Union Furnace iron works was built in 1810 or 1811 (Africa, 1883). Nearby river-bank quarries probably supplied the flux.

Little recorded data pertaining to local carbonate rocks and products was recorded by the 1st, 2nd, and 3rd Pennsylvania Geological Surveys. However, carbonate rock played an important role in the agricultural and industrial development of the region. Platt (1881, p. 52) made a vague statement pertaining to Blair County that "...limestones are quarried in many places for burning for lime for agricultural purposes; also for building stone and to furnish flux...." Some 53 lime and limestone producers were reported by Hice (1911) to be operating in Huntingdon County in 1911. Today there are only four limestone producers in this county (Berkheiser and others, 1985).

Miller reported in 1925 and 1934 that scores to hundreds of small quarries developed for building foundations, crushed stone, agricultural lime, and flux were being replaced by a small number of large operators quarrying high-grade limestone for flux and lime. He also thought that the Bellefonte ledge ("Valentine Member" or uppermost beds of the Linden Hall Formation) was present in what today is known as the Narehood Limestone Company quarry, east of Tyrone, and the Warner Company quarry (Figure 1) at Union Furnace (1/2 mile northeast of STOP 1). The former was reported to manufacture crushed limestone, pulverized limestone filler, agricultural ground limestone, rock dust for coal mines, and cupola flux; and the latter mainly lime (Figure 2), fluxstone, crushed stone, and ballast (Miller, 1934). Apparently, much of the lime was for agricultural use only, because Miller (1934, p. 413) also stated that the "Bellefonte ledge" would yield chemical lime if selectively mined.

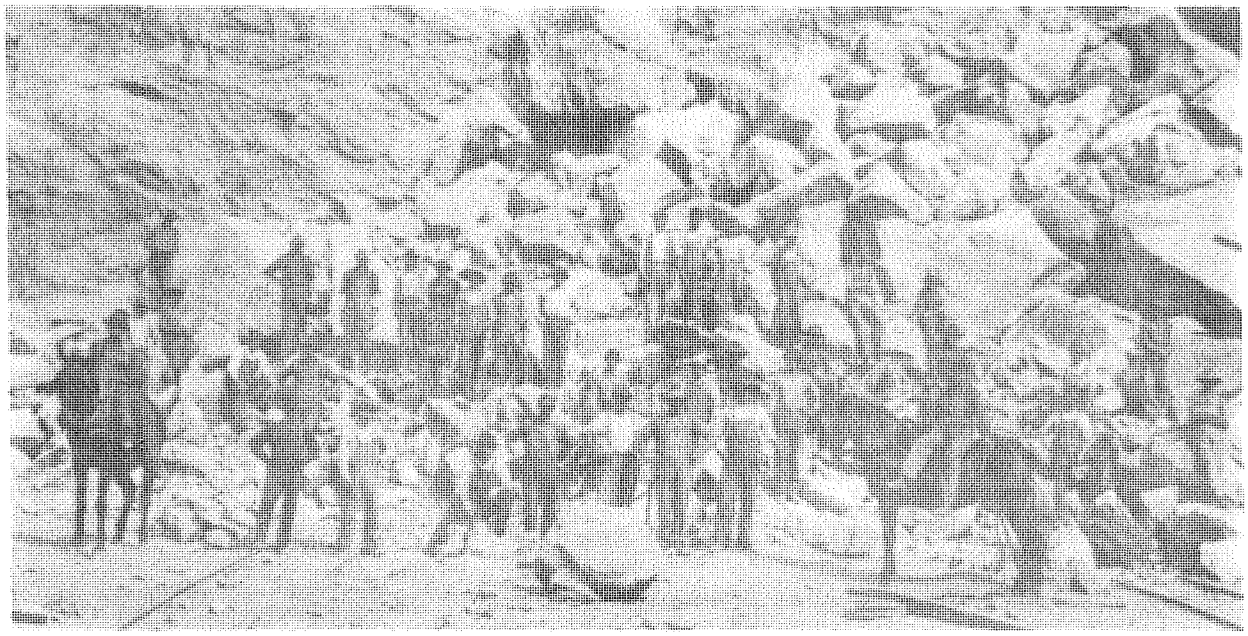


Figure 1. Photograph of Warner Company's Union Furnace No. 2 quarry and work force (circa, 1916). Machine-drilled blast holes are noticable in the quarry face. Mule-powered railcars apparently transported sized stone from the face to the lime kilns. Notice that pry bars, sledge hammers, and stone forks were required tools in making "little ones out of big ones." Photograph courtesy of Warner Company.

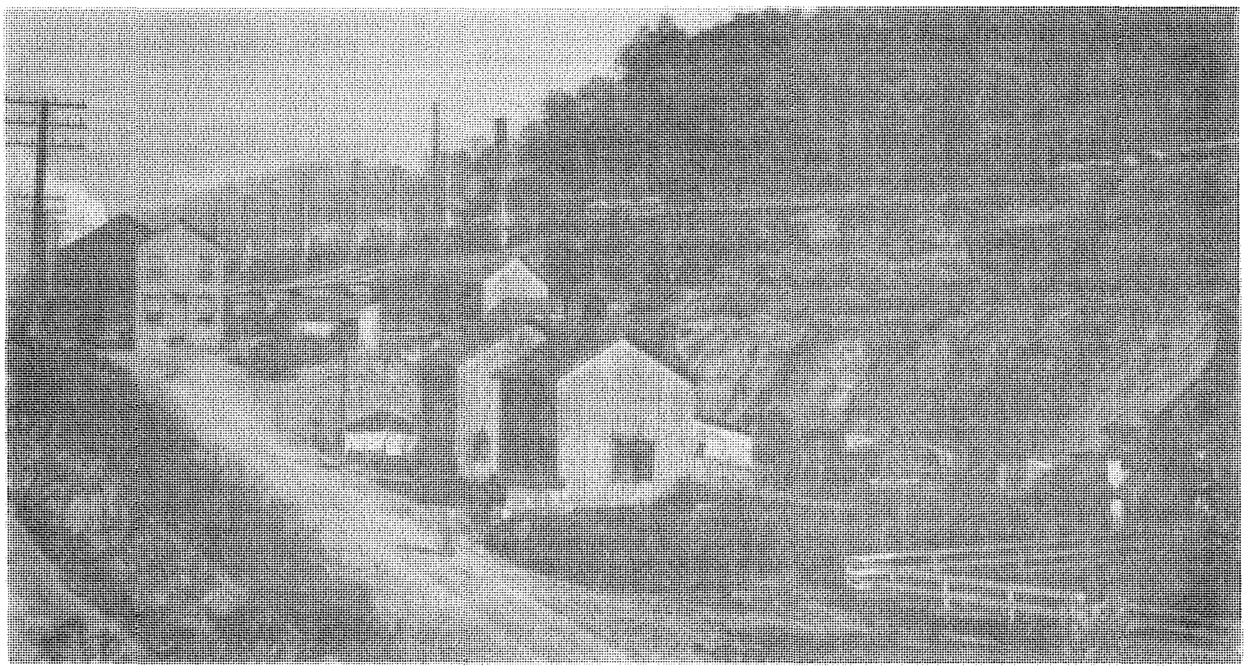


Figure 2. Photograph of 8 vertical-shaft draw kilns at Union Furnace (circa 1916). Railcars of kiln-stone are to the right and on the service trestle or quarry level. Typical quotas for quarry workers were to fill two cars per trick (shift) (Carl Leamer, personal communication, 1986). Wood appears to be the kiln fuel. Northwest face of quarry No. 2 is vaguely visible behind the kiln stacks. Photograph courtesy of Warner Company.

Narehood Limestone Company today produces PennDOT-approved coarse and fine aggregate and pulverized agricultural limestone. Warner Company at Union Furnace produces PennDOT-approved coarse and fine aggregate, and, to a lesser degree, railroad ballast (Berkheiser and others, 1985). Neither company is fully exploiting its higher-calcium intervals which, if selectively mined could produce materials suitable for acid mitigation (such as removal of SO_2 from stack gases, buffering acid waters, and filter beds), coal-mine rock-dust, cement raw material and sweetener, poultry grit, mineral fillers, and mineral feeds. Miller (1934) reported that 1917 and 1919 analyses from the Union Furnace Quarry No. 1 identified 220 stratigraphic feet of 94 percent $CaCO_3$ and an additional 120 feet of 91 percent $CaCO_3$ while Butts and others (1939) reported the same quarry averaged 93 percent $CaCO_3$ over 220 feet and contained about 3 percent silica. Present investigations, based on 4- to 6-inch subsample intervals in the nearby roadcut (see STOP 1), suggest that 210 feet of upper portion of the Snyder Formation and the entire Linden Hall Formation average at least 90 percent $CaCO_3$ and about 4 percent insoluble residues. The acid mitigation market probably holds the largest potential future use for these carbonates.

The stratigraphic nomenclature and the postulated hypotheses concerning the environment of deposition of these beds have undergone a complex and convoluted evolution through time. Witness the varied stratigraphic nomenclature summarized in Figure 3. Rogers was a diluvialist, which partly explains his nomenclature with the highest divisions of geologic time being related to intervals in a day where auroral equals dawn and matinal equals early morning. He did, however, recognize and correlate with the "nearest European equivalents," and put this sequence of rocks in the Cambrian System (Rogers, 1858b, map). Common delination by the 1st Pennsylvania Geological Survey was also by Roman numerals, with I logically being the oldest (Rogers, 1838). Geologists of the 2nd Pennsylvania Geological Survey used the numeral system because of its familiarity, but also introduced geographically-based stratigraphic names. However, no stratigraphic names were applied to the rocks at Union Furnace and its No. II rocks became correlated with the European Silurian System (White, 1885). During the 3rd and early 4th Pennsylvania Geological Surveys the section was divided into numerous formations, portions of it being classified as belonging to the Canadian System (Butts, 1918 and Miller, 1934). Finally, this section and equivalent rocks were restructured into their present position in the Upper Ordovician System (Kay, 1944a & b).

Kay (1944a & b) unraveled many stratigraphic complexities associated with these rocks by recognizing various facies and unconformities. Some of this insight was gained by using bentonites as time-stratigraphic boundaries. His efforts form the basic stratigraphic framework in use today. It should be noted that economic geology was the driving force behind the scientific curosity of Kay. Bonine and Honess (1929), however, may have been the first to recognize bentonites in Pennsylvania during the summer of 1924. They described 4 distinct bentonites at Union Furnace and recognized their significance with respect to regional stratigraphic studies. Later, Rosenkrans (1934) made detailed chemical and mineralogical studies of these and 8 other distinct occurrences at Union Furnace. Today, state-of-the-art studies, using trace elements to "fingerprint" and correlate individual bentonites, are revealing further insights into this complex stratigraphy (see p. 13-19).

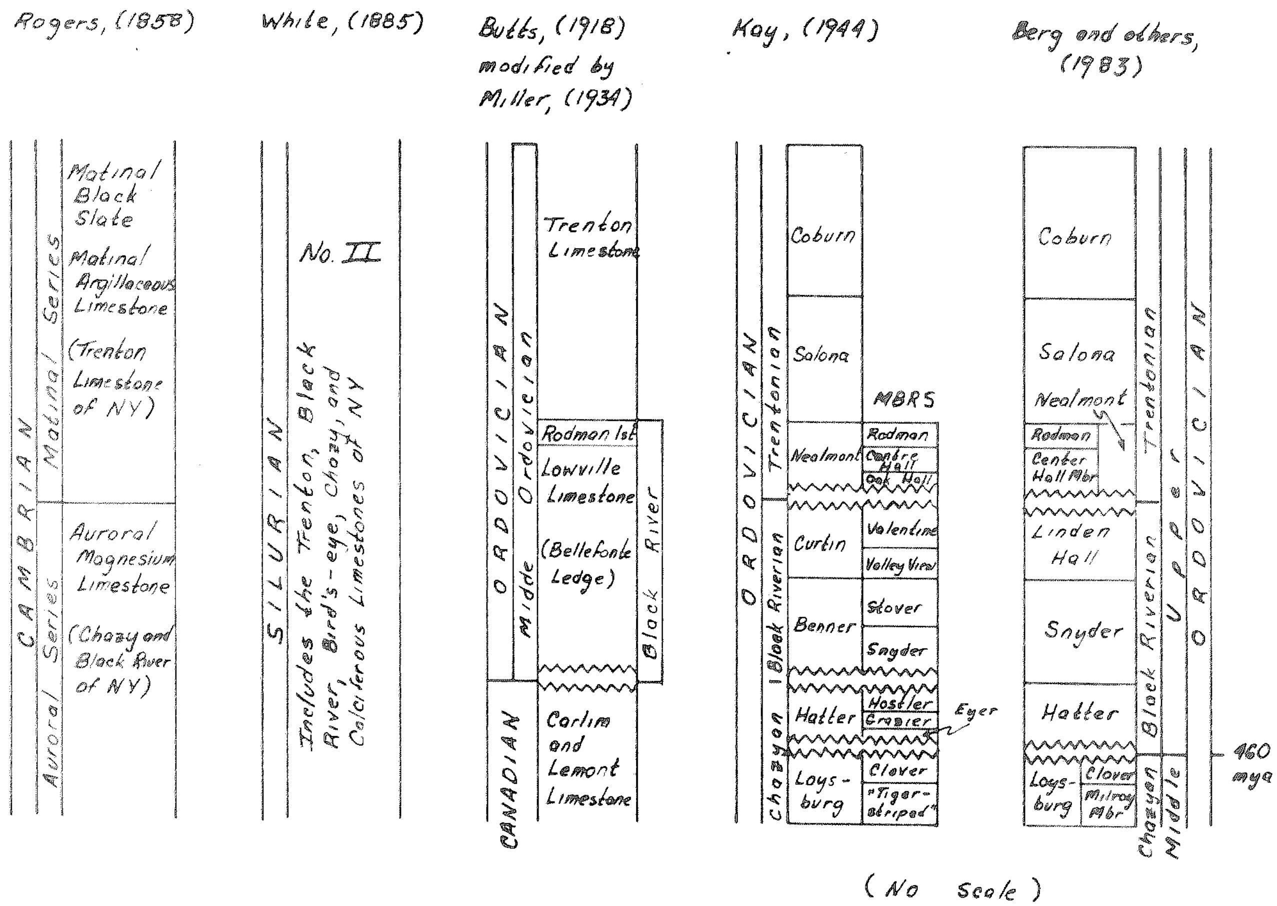


Figure 3. Evolution of stratigraphic nomenclature and correlation of the Union Furnace area carbonate rocks from the 1st through the 4th Pennsylvania Geological Survey.

Rogers (1858a, p. 469) stated that carbonate rocks, equivalent to those seen at STOP 1, consisted mostly of "oceanic precipitates." Furthermore, he rather obfuscatorily stated that the Auroral Magnesium Limestones "...consist apparently of excessively comminuted particles, that have cohered into rocks from the condition of an impalpably fine pulp" (Rogers, 1858a, p. 470). Today, we recognize various cyclic biogenic activities as a principal carbonate source. We also recognize at the Union Furnace road cut a sequence of environments of deposition which refect increasing depth of water. These environments range from supratidal and tidal-flat, represented by the Bellefonte and Loysburg Formations, to ramp and shallow basin, represented by the Salona and Coburn Formations. In general, this represents a gradual and episodic (?) subsidence of a cratonic carbonate platform (foreland basin) as a prelude to the Taconic Orogeny, called by Rogers (1858a, p. 784) a "stupendous crust-movement and revolution in the earth's inhabitants at the close of the Matinal Period."

In the last 150 years the Indians have disappeared from their land, some lawless whites have remained, vertical-shaft kilns have fallen in ruin, PennDOT has graciously provided geologists with a nearly complete Ordovician carbonate section, and formation names, systems, and erathem have come and gone. The variety of quarry products has diminished almost entirely to aggregate products only. In recent years more than 20 bentonites have been identified as geologists have continued to study the complexities of stratigraphy, chemistry, and origin of these rocks. Quite an amazing transformation in culture, landscape, and geologic perception in the last 150 years. One wonders what marvels remain to be discovered in the next 150 years.

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FIG. 103.—Woodcock Valley at McConnellstown.

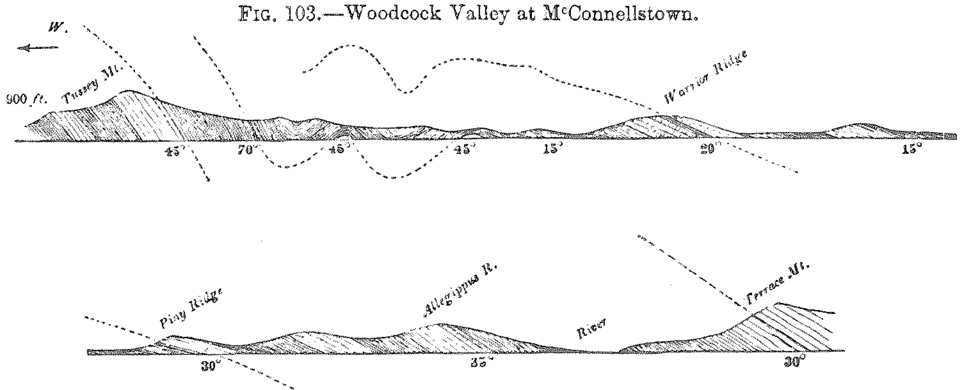
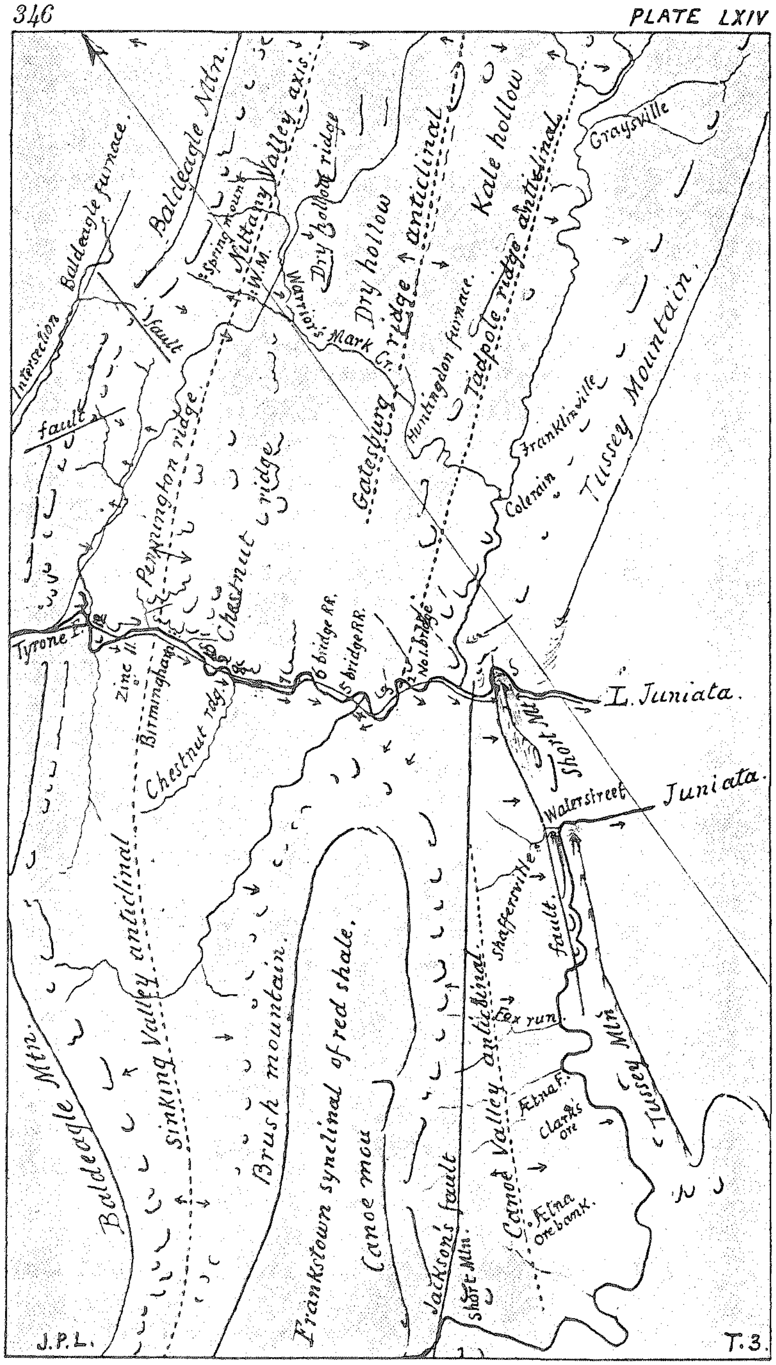


FIG. 103—*Continued.*

Cross section of Woodcock Valley at McConnellstown from Rogers, 1858, v. 1, p. 523.



Structure map of northwestern Huntingdon County, from White, 1885, p. 346.

UPPER ORDOVICIAN K-BENTONITES IN PENNSYLVANIA

by
J. Cullen-Lollis
University of Cincinnati

INTRODUCTION

Many altered volcanic ash beds, or K-bentonites, occur within Upper Ordovician carbonate sequences throughout much of the eastern midcontinent of North America (Kay, 1935; Templeton and Willman, 1963), and thus record volcanic activity of varying intensity during that period. These beds comprise regularly interstratified illite-smectite clays along with accessory minerals such as biotite, apatite, and zircon. As the products of air-fall volcanic ash, individual beds are of stratigraphic interest because they have wide areal distribution within a narrow stratigraphic interval, and, as such, serve as ideal time lines. Correlations of these key horizons provide the framework from which interpretations of faunal and lithologic facies may be made.

The Ordovician carbonate units in Pennsylvania display considerable variation in extent, thickness, and lithic and faunal character. These rocks are exposed in 2 areas of the state, one in the central and southern portions of the Appalachian Mountain section and the other in the Great Valley section, both within the Valley and Ridge physiographic province (Figure 4). In the central part of the state, they comprise shallow platform carbonates (Thompson, 1963; Rones, 1969), and become more variable to the southeast reflecting shelf-edge and slope deposits adjacent to deeper basinal facies (Craig, 1949; Kay, 1960). Extensive folding and faulting, missing section, poor exposures often containing covered intervals, and the inconsistent use of stratigraphic nomenclature have all contributed some misunderstanding to this geologic interval. Careful correlation of the K-bentonites within this interval, both within and between the outcrop belts, may permit a modern interpretation of the facies changes that have occurred within the Appalachian Basin.

ORDOVICIAN ASH BEDS IN CENTRAL PENNSYLVAINA

At least 20 K-bentonite beds occur in the Upper Ordovician of central Pennsylvania. Rosenkrans (1934) and Whitcomb (1936) made important con tributions to K-bentonite stratigraphy by describing and correlating 5 K-bentonite beds in the Salona Formation (Figure 5). Later, Kay (1944) and Thompson (1963) confirmed these correlations and reported several additional beds.

The stratigraphic relations of K-bentonites which are found in rocks below the Salona Formation, as well as those in southeastern Pennsylvania, are less well understood and typically illustrate problems that have been associated with correlations of K-bentonite beds on both local and regional scales. Differences in number, thickness, and distance between the Ordovician K-bentonite beds in various outcrops, even those closely spaced, have made correlation of individual beds difficult (Rones, 1969). In addition, the lithology and mineralogy of all K-bentonites are too similar to identify individual beds (Weaver, 1953; Mossler and Hayes, 1966). For these reasons, the use of K-bentonites has been limited and their potential as stratigraphic tools has never been fully realized.

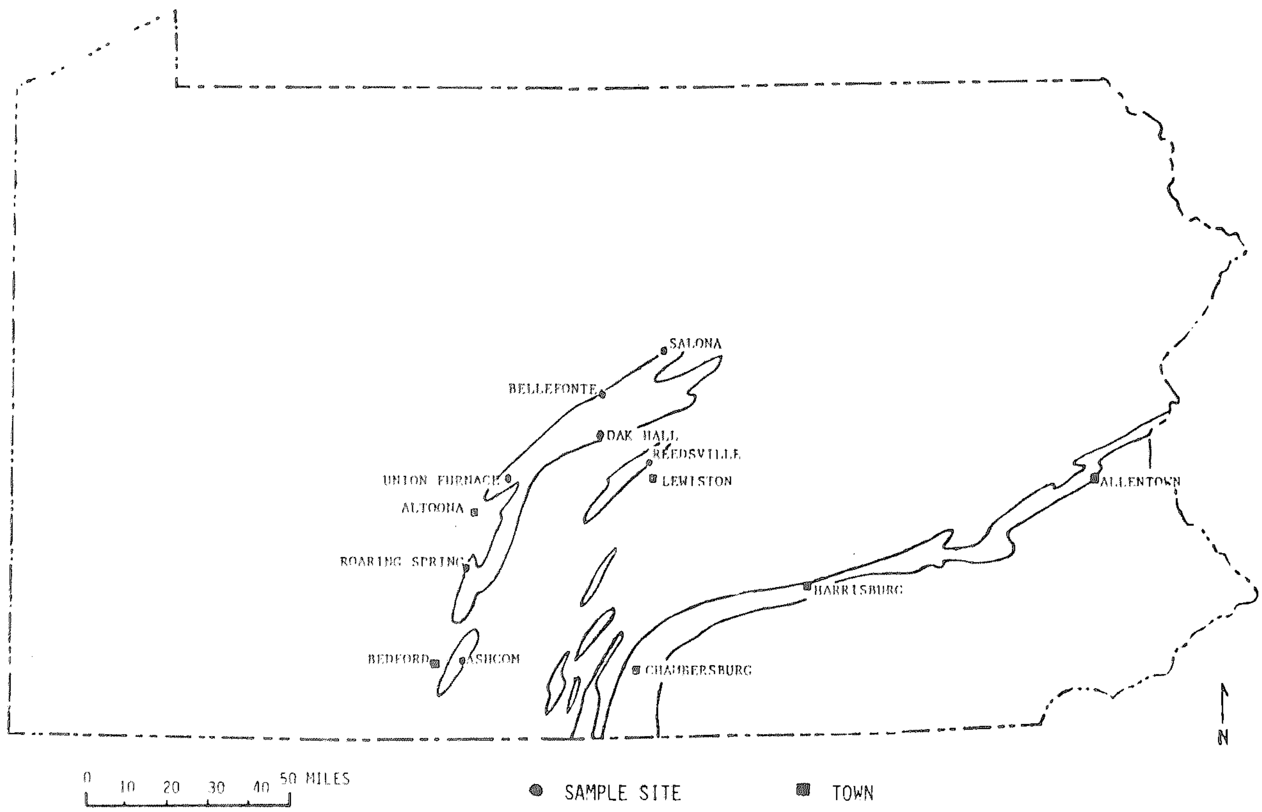


Figure 4. Middle Ordovician outcrop areas in Pennsylvania, and sample localities in central Pennsylvania.

Recent studies of K-bentonites along the Cincinnati Arch and in the Mississippi Valley have demonstrated that individual K-bentonite beds have different chemical compositions or fingerprints which can be used to correlate beds over considerable distances (Huff, 1983; Kolata, Huff, and Frost, 1983). Chemical fingerprinting has also been applied to K-bentonites in the Middle Ordovician of central Pennsylvania with excellent results (Lollis and Huff, 1983, in press).

CHEMICAL FINGERPRINTING OF THE K-BENTONITE BEDS

Five K-bentonite beds, numbers 0 through 4 as described by Rosenkrans (1934), Whitcomb (1932), Kay (1944), and Thompson (1963) in the Salona Formation, were sampled at 7 localities in central Pennsylvania (Figure 6) and analyzed for 26 elements by instrumental neutron activation analysis (INAA) and X-ray fluorescence (XRF).

Step-wise discriminant analysis was used to identify the best group of discriminating elements. These are listed in order of their discriminating power in Table 1. Binary diagrams, Figures 7 and 8, were constructed using several of the best discriminating elements. These diagrams show good sample clustering relative to bed membership, illustrating the rather distinct chemical composition of the individual ash beds.

In addition to identifying and ranking the most effective group of discriminating elements, discriminant analysis also maximizes the separation between

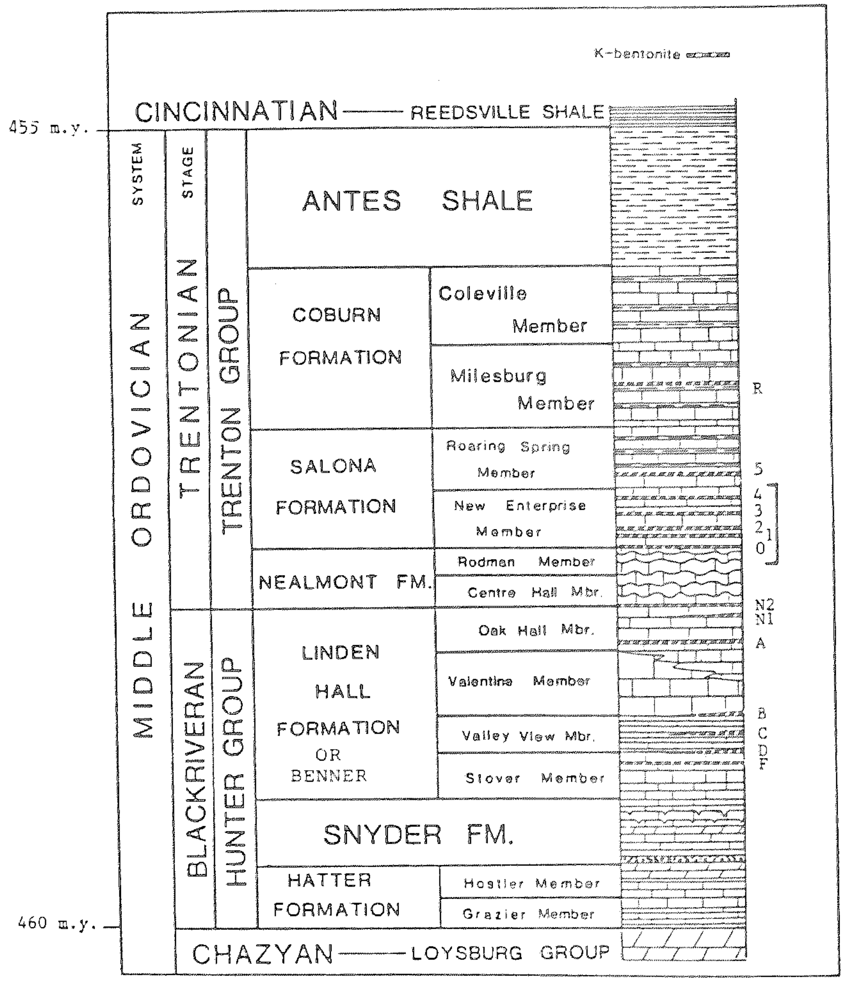


Figure 5. Generalized stratigraphic section of Middle Ordovician rocks in central Pennsylvania with describe K-bentonite beds (after Thompson, 1963; Rones, 1969). K-bentonite beds used in this study are indicated by bracket. Age dates after Berg and others (1983).

beds by computing discriminant functions. Four functions were computed for the central Pennsylvania data. The eigen values, listed in Table 2, show the effectiveness or ability of these functions to discriminate between K-bentonite beds. The first 2 functions can account for 81 percent of the differences between beds and this is illustrated by a territorial map, Figure C6. The addition of the third and fourth discriminant function to the analysis further adds to the effectiveness of the discriminant model to identify and classify K-bentonite samples.

The discovery that K-bentonite beds in central Pennsylvania have chemical fingerprints represents a major contribution to stratigraphy. K-bentonite samples from the Salona Formation at other localities can now be compared with this data, and, along with other stratigraphic criteria, correlations can be made with a high degree of confidence. Continued studies of these beds should provide stratigraphers with a powerful tool for refining the stratigraphy and interpretation of geologic history of Pennsylvania and eastern North America during Upper Ordovician time.

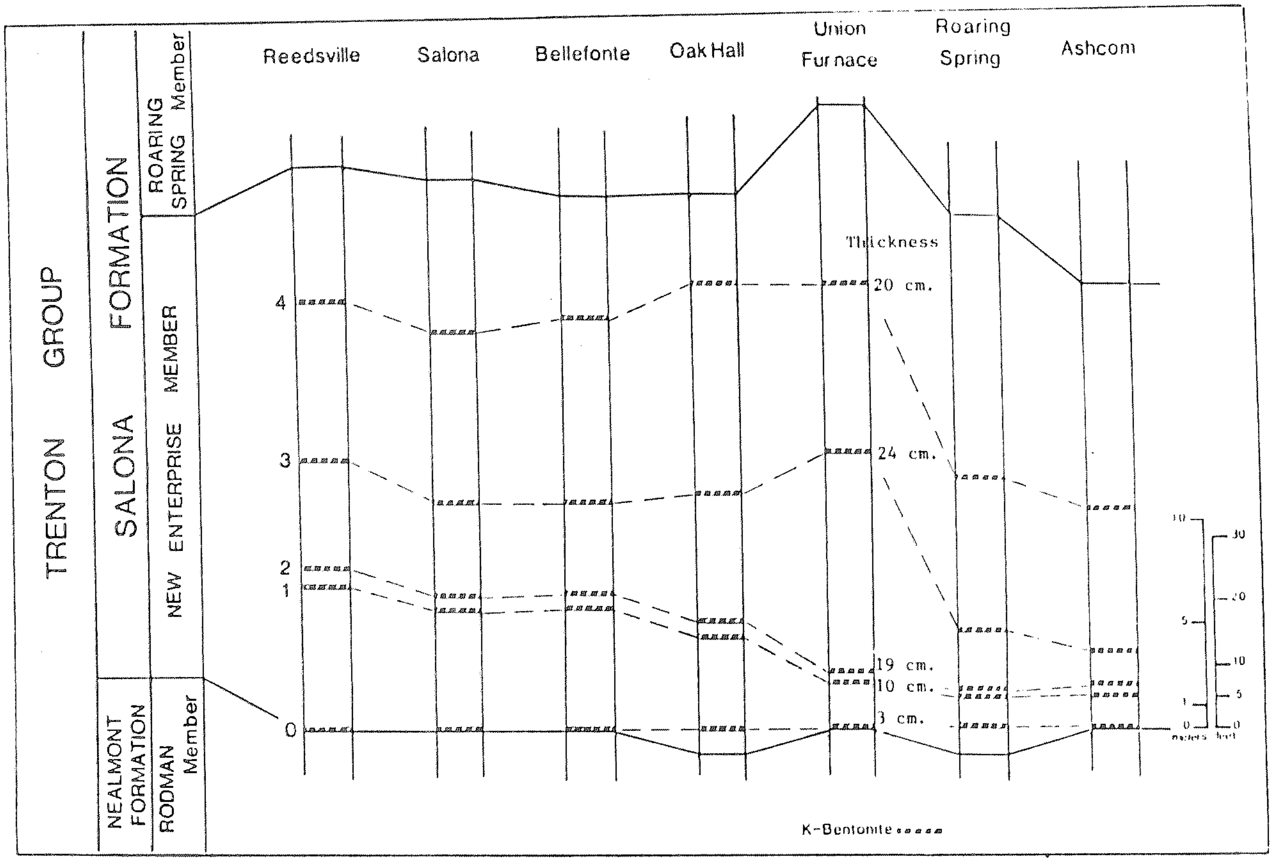


Figure 6. Distribution and correlation of K-bentonite beds in the New Enterprise Member of the Salona Formation in central Pennsylvania. K-bentonite beds are designated 0 through 4 after Rosenkrans (1934), Kay (1944), and Thompson (1963). Thicknesses of individual beds are given for the Union Furnace roadcut section.

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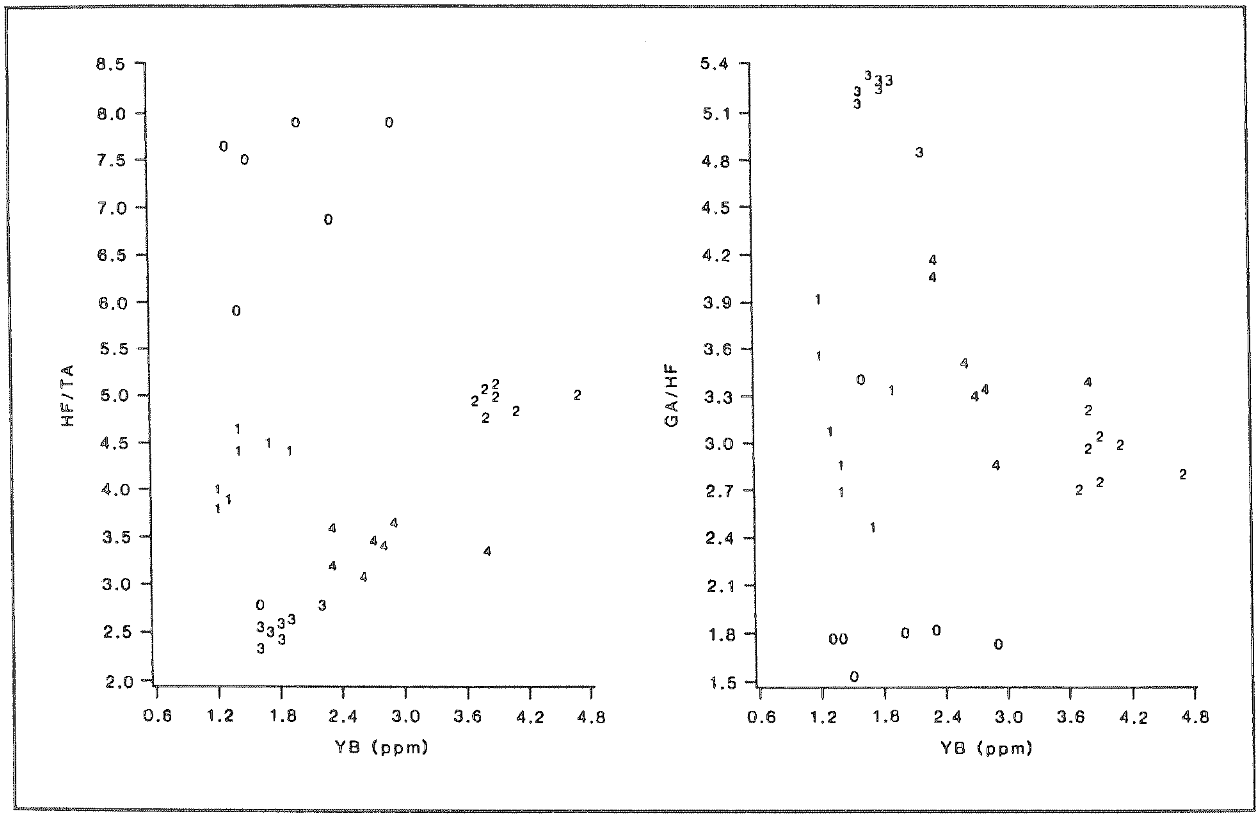

Figure 7. Binary diagram of best discriminating elements Hf/Ta versus Yb for samples indicated in Figure 6

Figure 8. Binary diagram of best discriminating elements Ga/Hf versus Yb for samples indicated in Figure 6.

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Table 1. Summary of stepwise discriminant analysis.

STEP	ELEMENT Entered	ELEMENT Removed	WILKES' LAMBDA
1	Yb		0.143224
2	Sc		0.045029
3	Ti		0.017676
4	Th		0.005745
5	Dy		0.002342
6	Ta		0.000714
7	Ga		0.000364
8	As		0.000182
9	Hf		0.000110
10	Fe		0.000066
11	Tb		0.000035
12	Na		0.000024
13	Lu		0.000016
14		As	0.000018
15	Ce		0.000012
16	Sm		0.000007
17	Mn		0.000005
18	Co		0.000004
19	Cr		0.000002
20	K		0.000002
21		Mn	0.000002
22	Cs		0.000002
23	Eu		0.000001

Table 2. Discriminant functions and associated eigenvalues, canonical correlation coefficients, and Wilks' Lambda.

Function	Eigenvalue	Percent of Variance	Cumulative Percent	Canonical Correlation	After Function	Wilks' Lambda
1	80.20382	50.12	50.12	0.9938236	0	0.0000012
2	49.72609	32.07	81.19	0.9900941	1	0.0048588
3	22.24558	13.90	95.09	0.9782541	2	0.0048588
4	7.85378	4.91	100.00	0.9418354	3	0.1129461

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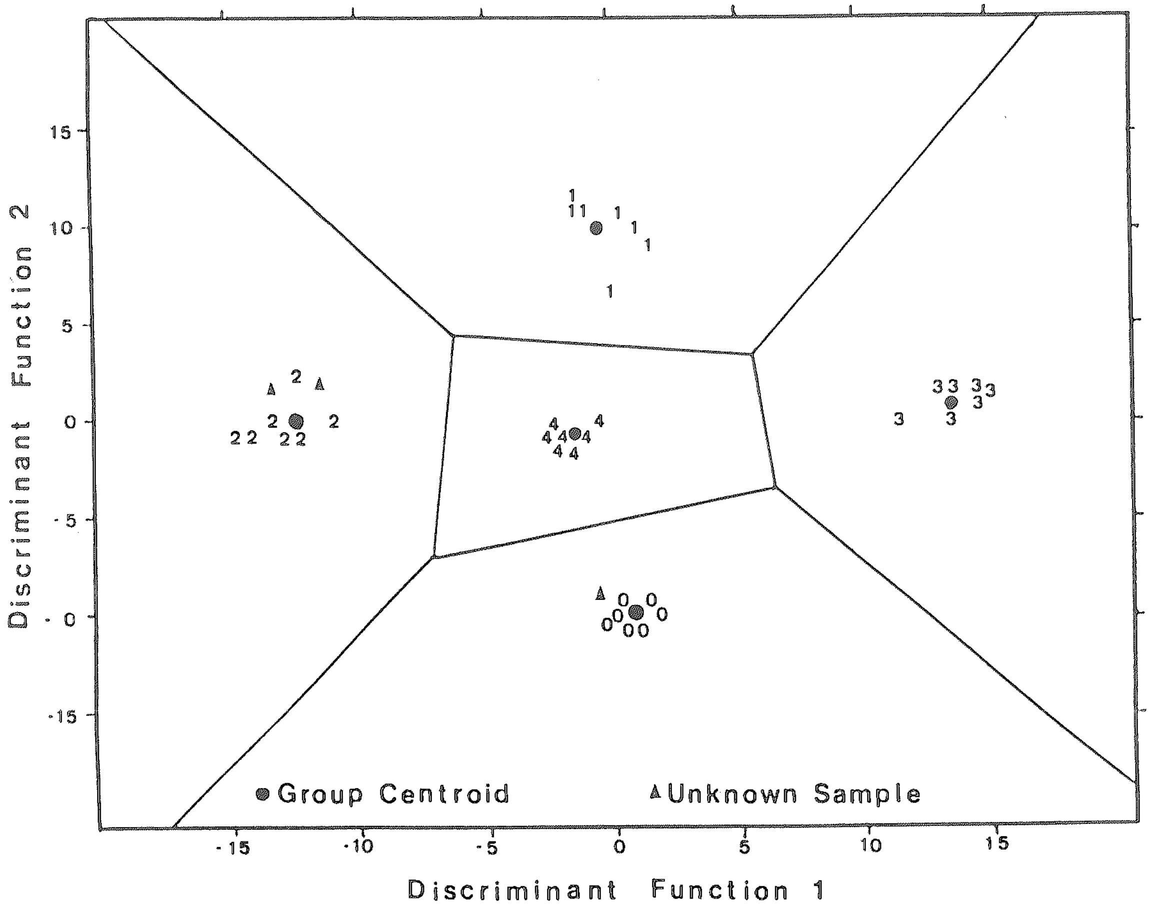
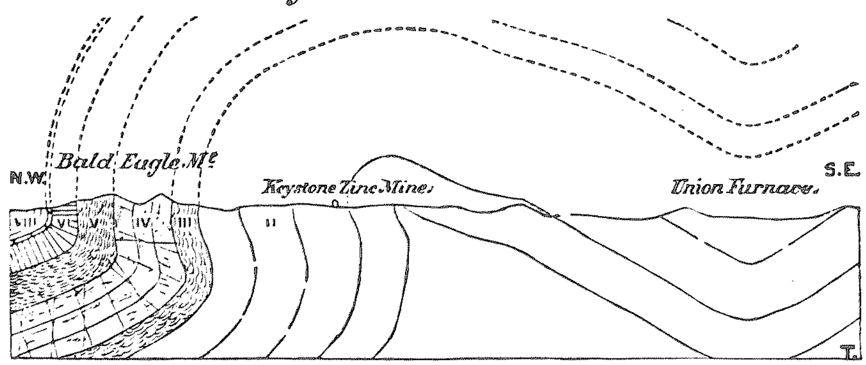
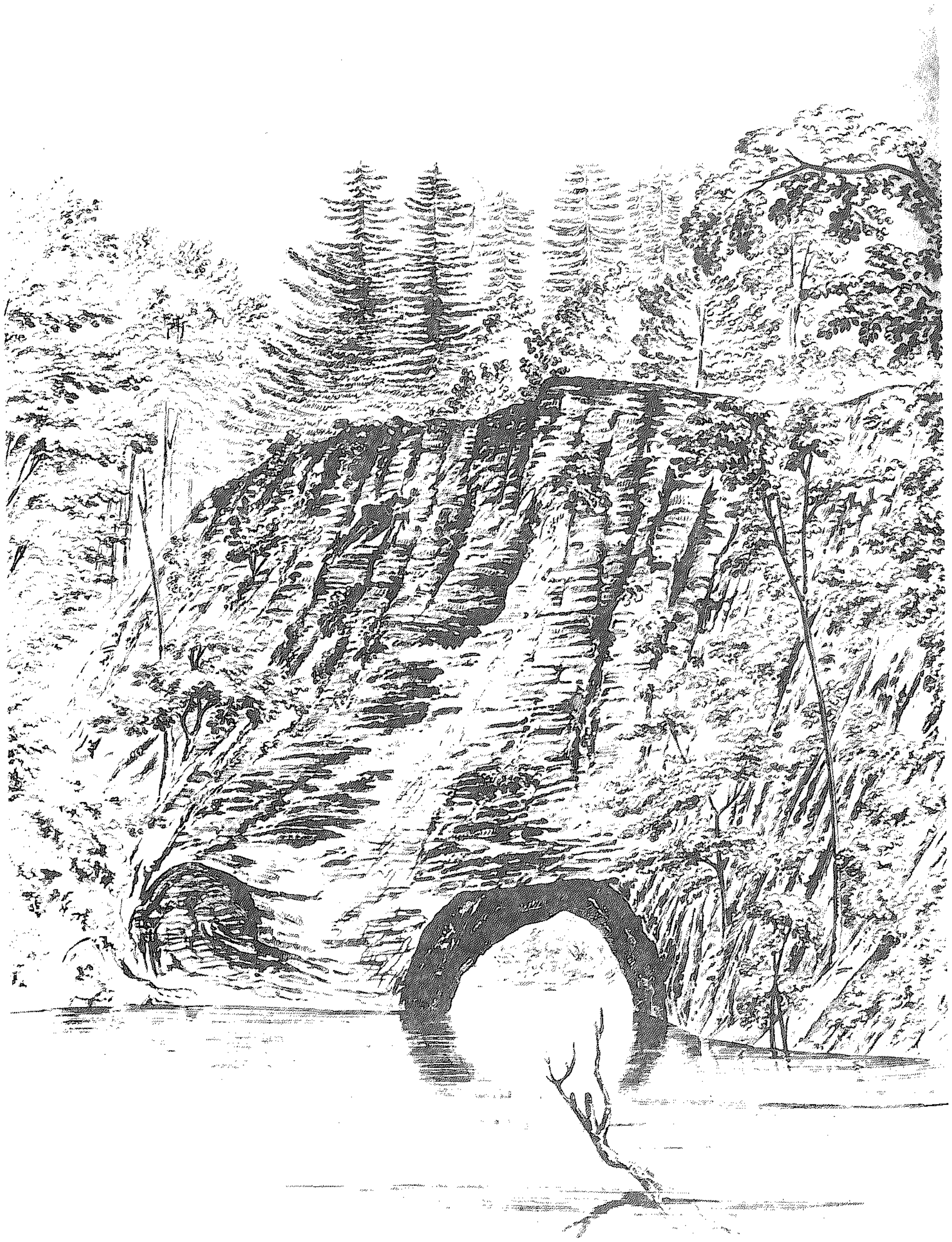


Figure 9. Territorial diagram of discriminant functions 1 and 2 showing effectiveness of discrimination of samples indicated in Figure 6.

Fig. 33.
Section from Bald Eagle Mtn. through the Keystone Zinc Mine.



Section from Platt, 1881, Figure 33, p. 249.



Natural bridge, Canoe Valley, Pa. A George Lehman lithograph in Rogers, 1858, v. 1, opposite p. 503.

STRATIGRAPHY OF UPPER ORDOVICIAN CLASTIC ROCKS IN SOUTH-CENTRAL PENNSYLVANIA

by
Allan M. Thompson
University of Delaware

INTRODUCTION

The itinerary of this field conference includes the Upper Ordovician clastic section which totals nearly a 1000 m thickness in the Valley and Ridge region and comprises the medial to distal portions of the Taconic Clastic Wedge. These rocks will be seen on Saturday at Loysburg Gap (Stop 7).

STRATIGRAPHY

Upper Ordovician rocks northwest of the Great Valley were originally assigned to the Silurian by Stevenson (1882, p. 91-92), and were given the New York names Utica, Oneida, and Red Medina. The inevitable nomenclatural progress brought forth the present terminology for the sequence: in ascending order the Reedsville, named by Ulrich in 1911; the Bald Eagle, named by Grabau in 1909; and the Juniata, named by Darton and Taff in 1896. All type sections are in central Pennsylvania and the rocks are well exposed on the flanks of breached anticlines.

The Reedsville Formation is interbedded marine, fossiliferous shale and sandstone that becomes more sandy upward. The Bald Eagle Formation consists of unfossiliferous sandstone, conglomerate, and minor shale that generally coarsens upward. The Juniata Formation consists of unfossiliferous, red sandstone and shale. A generalized stratigraphic cross-section of the Taconic clastic wedge is shown in Figure 10.

FORMATIONS VERSUS LITHOFACIES

Traditional stratigraphic usage has not been based on consistent or reproducible criteria. The Reedsville Formation is defined by interbedded gray fossiliferous shale and sandstone, and is anchored by marine fossils. The Juniata Formation is defined by red beds of any lithology lying directly beneath the Tuscarora Formation (Figure 11). The Bald Eagle Formation comprises any and all rocks between the last fossils and the first red beds, regardless of lithology.

This usage has led to confusion and error in regional correlation and sedimentological interpretation. Thickness and lithology variations of the Bald Eagle and Juniata as defined above are inconsistent and follow no detectable pattern. The gray-red color change at the base of the Juniata varies as much as 200 m in distance above the top of the Reedsville across the Valley and Ridge outcrop belt (Thompson, 1970). A hands-on example of this variation occurs at Loysburg.

Field and petrographic studies have shown that, independent of the position of the gray-red color change, it is possible to recognize within the Upper Ordovician portion of the Taconic clastic wedge a sequence of 6 lithofacies that are

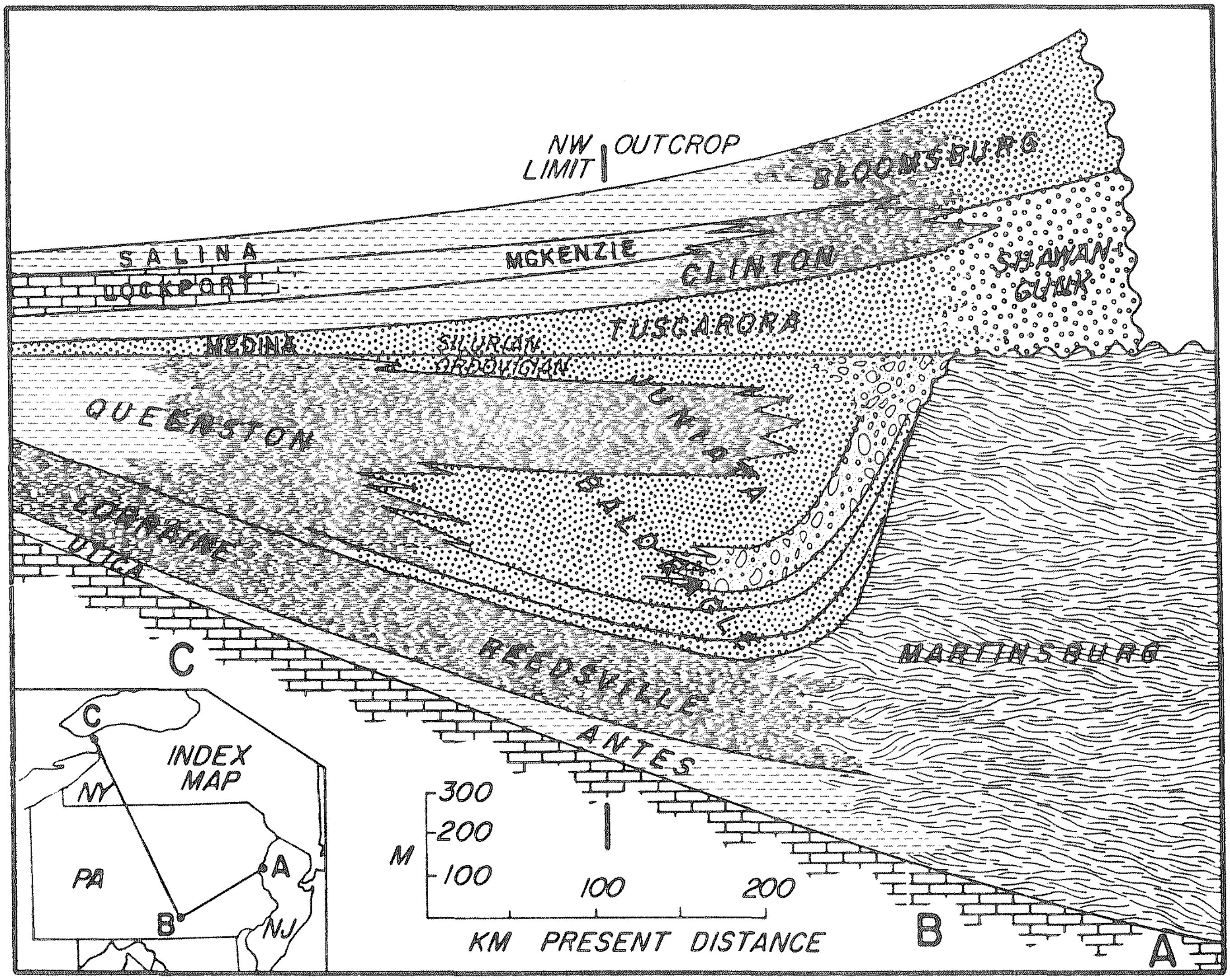


Figure 10. Generalized stratigraphic cross section through the Taconic clastic wedge in Pennsylvania and western New York.

objectively definable and regionally correlatable (Thompson, 1970). The 6 lithofacies, labelled A through F, are shown in Figure 11.

Lithofacies A contains 100-150 m of interbedded shale, thin sandstone, and minor limestone. The sandstones are current-bedded, size-graded and cross-bedded, hummocky-bedded, and contain delicately articulated skeletal debris. The limestones are skeletal packstones containing abundant brachiopods, bryozoa, trilobites, and green algae. This facies is always gray in Pennsylvania and is assigned to the Reedsville Formation.

Lithofacies B comprises 10 to 25 m of intensely bioturbated, fossiliferous quartz wacke and siltstone with bedding nearly destroyed by bioturbation. A strophomenid-lingulid brachiopod fauna dominated by Orthorhynchula and Lingula, inhabits the lithofacies, and shows vertical zonation of distinct assemblages (Bretsky, 1969). The skeletal remains are often concentrated into coquina beds. This facies is nearly always gray and is assigned to the Reedsville Formation.

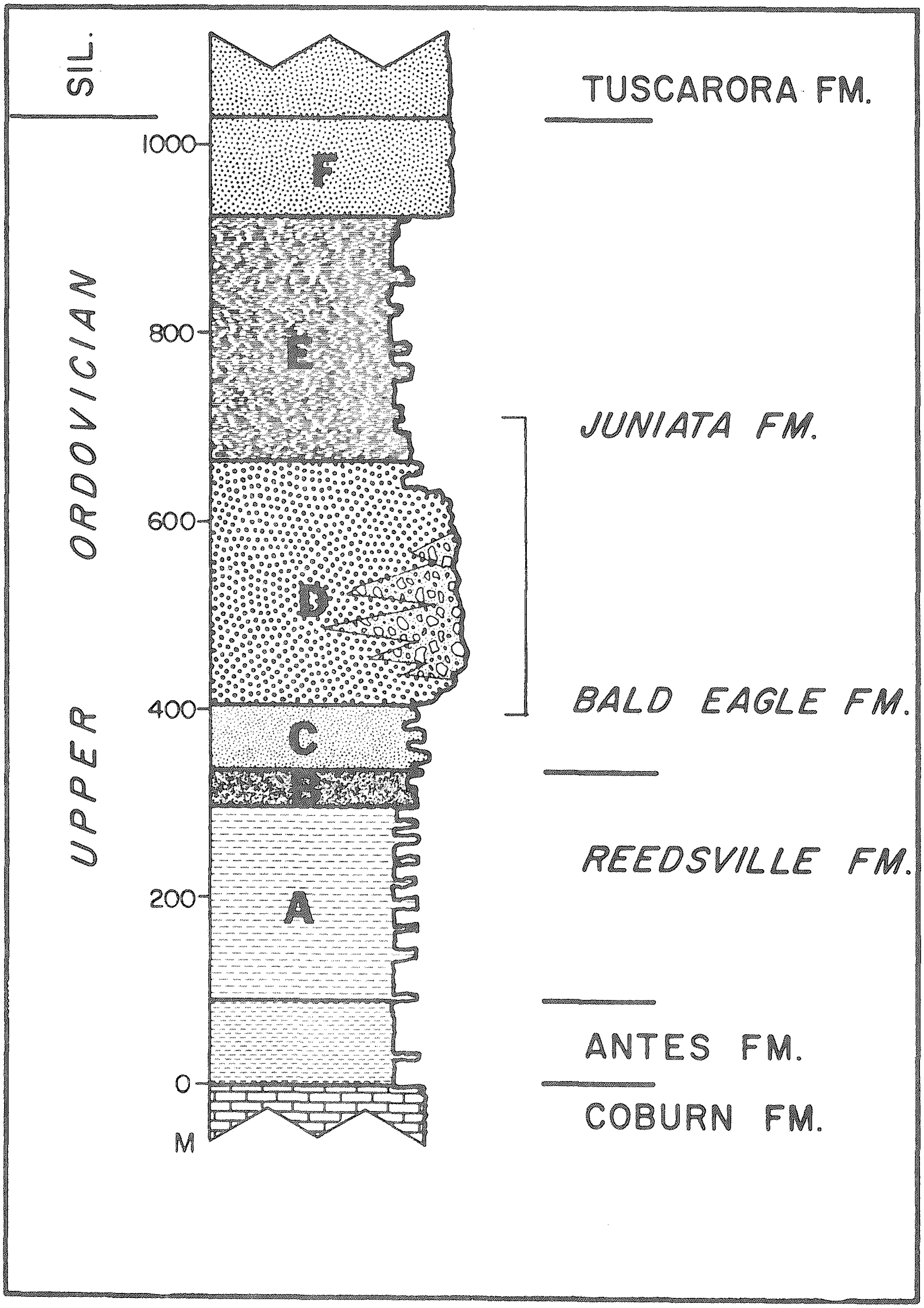


Figure 11. Formation and lithofacies nomenclature in Upper Ordovician stratigraphy in central Pennsylvania. Bracket indicates stratigraphic range over which gray-red color boundary occurs in Pennsylvania. See text for discussion of individual lithofacies.

Lithofacies C comprises 30 to 80 m of well-bedded sandstones of several types interbedded with minor shale and rare red beds. Skeletal fossils and bioturbation are absent. The lithofacies is heterogeneous in both lithology and primary sedimentary structures. Occasionally the upper parts of this facies are red and are assigned to the Juniata Formation; otherwise it is assigned to the Bald Eagle Formation.

Lithofacies D consists of 0 to 400 m of coarse-grained, cross-bedded sandstone and conglomerate with very rare lenticular shale partings. The rocks are resistant and underlie subsidiary ridges flanking the major Tuscarora ridges. The lithofacies coarsens and thickens to the east before rapidly pinching out near Harrisburg. Paleocurrent azimuths show generally west- and northwest-directed dispersal (Yeakel, 1962). This lithofacies normally, but not always, contains the gray-red color change that marks the Bald Eagle-Juniata boundary.

Lithofacies E consists of 100 to 400 m of interbedded lithic wacke, siltstone, and mudstone in roughly equal proportions, generally arranged in recognizable fining-upward sequences. Several mudstone horizons in this facies at Reedsville and Potters Mills have been identified as fossil soils (paleosols) by Retallack (1985) and Feakes and Retallack (in press). This facies is characteristically red and is assigned to the Juniata Formation. Occasionally the lower beds in the facies are gray and are then assigned to the Bald Eagle Formation.

Lithofacies F consists of 0 to 100 m of well-sorted red, greenish-gray and gray quartz arenite and interbedded shale of several colors. Although shown as continuous in Figure 10, its occurrence is decidedly discontinuous in the Valley and Ridge, and its origin and significance is presently not well understood.

Figure 11 shows the relations between formation and lithofacies nomenclature, and indicates the stratigraphic range over which the gray-red color change has been observed in central Pennsylvania. The Reedsville Formation is fossiliferous; it consistently includes Lithofacies A and, in Pennsylvania, Lithofacies B. The Bald Eagle Formation is unfossiliferous, and comprises those parts of Lithofacies C, D and E that are gray. The Juniata Formation is unfossiliferous, and comprises Lithofacies F and those parts of Lithofacies C, D and E that are red.

EVOLUTION

Regardless of the nomenclatural difficulties, these three formations comprise the initial phases of the Taconic Clastic Wedge, an east-derived, east-thickening wedge of generally coarsening-upward clastic sediment shed from the upper parts of a nascent orogen rising in what probably is now New Jersey-Delaware-southeastern Pennsylvania. The stratigraphic sequence records the filling of an exogeosynclinal, foreland molasse basin with detritus from low-grade metamorphic and sedimentary source rocks in what may have been a subduction complex or accretionary prism (e. g. Lash and others, 1984; Lash and Drake, 1984). Dispersal was generally to the northwest, and apparently radiated from a point source in southeastern Pennsylvania during Bald Eagle time. The Reedsville-Bald Eagle-Juniata succession thus records a regional marine regression to the west, and a transition from marine to continental deposition. The array of paleoenvironments spanning the marine-to-continental transition may have looked something like that shown in Figure 12.

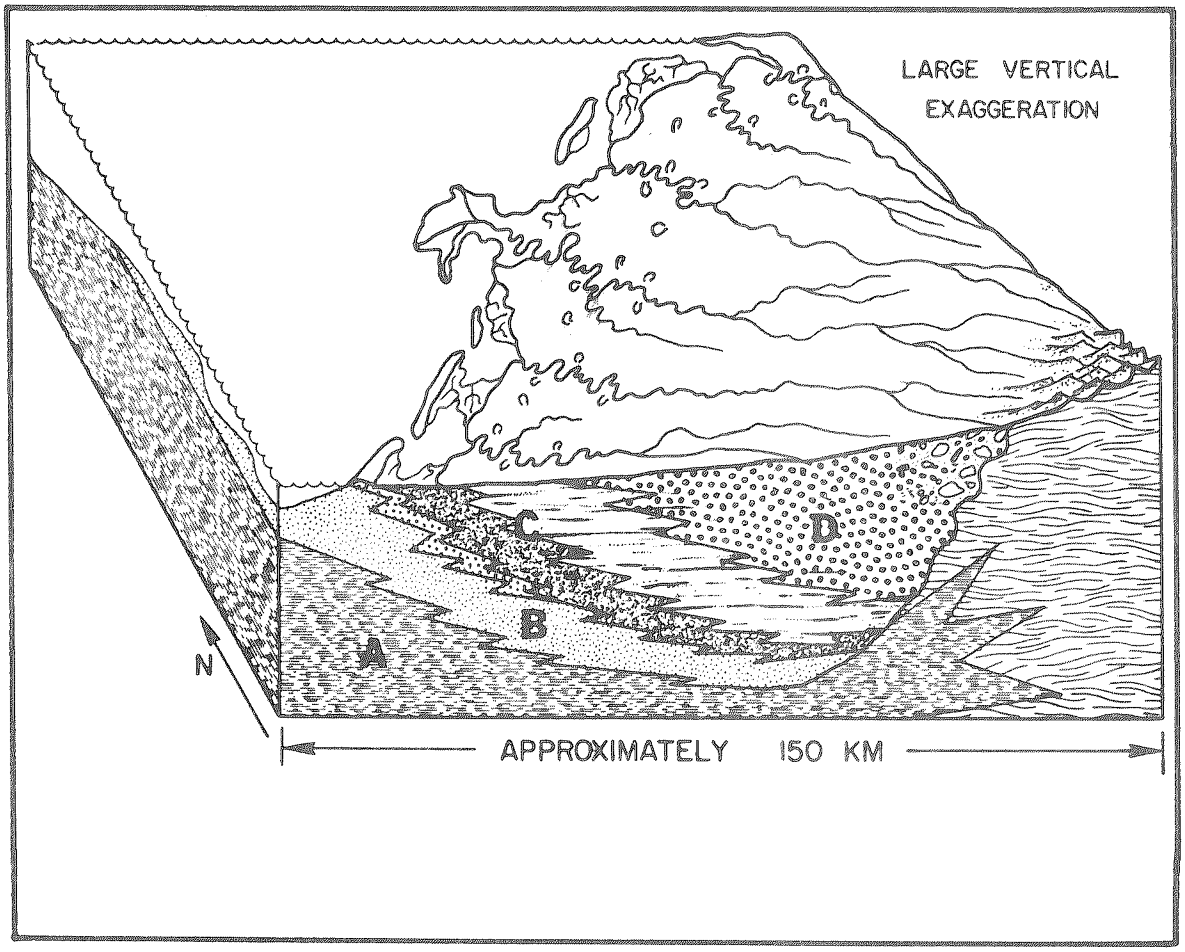


Figure 12. Inferred paleogeography of facies during the major Upper Ordovician marine regression in central Pennsylvania. Letters denote lithofacies. See Figure T2 for lithofacies nomenclature and text for discussion of lithofacies.

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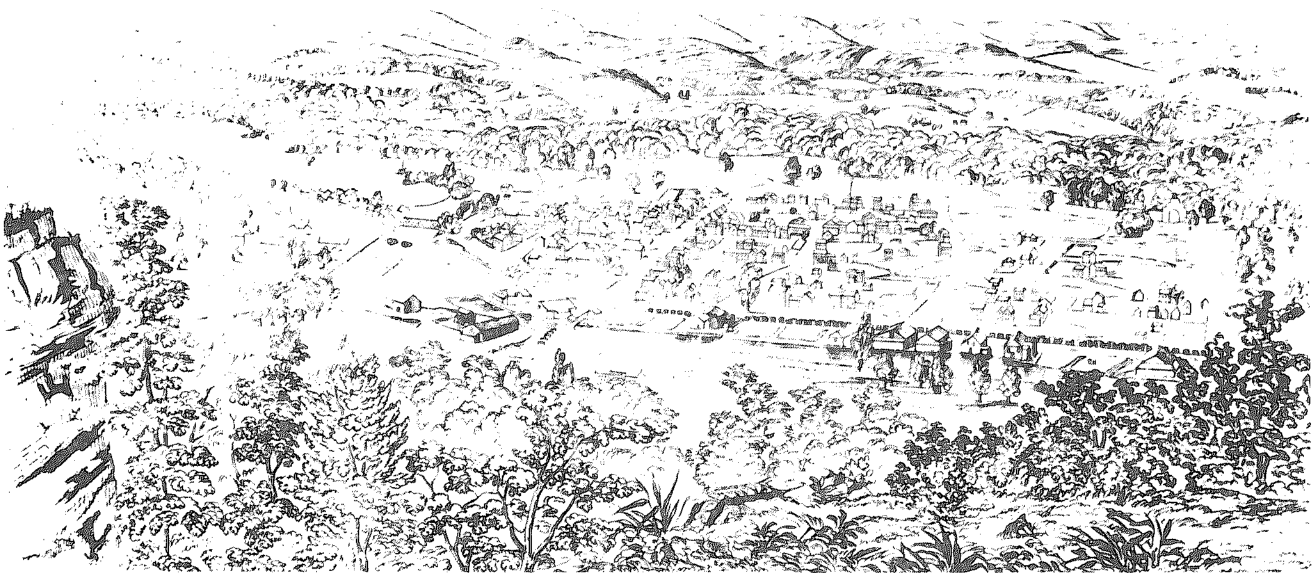

Eastern point of the Alleghany Mountain from near Hollidaysburg. A George Lehman lithograph in Rogers, 1858, v. 1, opposite p. 559.

SILURIAN STRATIGRAPHY AND SEDIMENTOLOGY IN THE HUNTINGDON COUNTY AREA

by
Edward Cotter
Bucknell University
Jon D. Inners
Pennsylvania Geological Survey

HISTORICAL SUMMARY

The evolution of pertinent stratigraphic nomenclature from the early days of the First Pennsylvania Geological Survey down to the present time is shown in Figure 13. Although few geographic names were introduced until the twentieth century, it is evident that the basic "Silurian" rock succession was well established by the 1850's.

There were few fixed stratigraphic principles in 1836 to guide the initial stages of the First Survey. Not only had the systems of the Paleozoic Era largely yet to be defined, but the term Paleozoic had not yet been proposed (Berry, 1968). Arguments were bitter about the appropriate criteria to make meaningful subdivisions of the stratigraphic record (see Rudwick, 1985, for a fascinating account of The Great Devonian Controversy from 1834 to 1837). Yet by the time of publication of the report of the First Survey (Rogers, 1858) that same stratigraphic record was largely codified into units (the geologic time scale) that could be recognized world-wide. In this period of growth and development of the geologic time scale, Rogers and his associates divided the Pennsylvania succession into a number of "natural groups of strata", which they called series. An example of such a natural group of strata is their Levant Series, consisting of 3 units (known today as the Bald Eagle, Juniata, and Tuscarora Formations) that resulted from westward regression accompanying crustal disturbances to the east (Rogers, 1858, p. 788).

Rocks exposed at Stop 6 consist of the greater part of 2 of Rogers' series - the Surgent and the Scalent (Figure 13). The Surgent Series, identified as being equivalent to the Clinton Group of New York, was judged to represent a quiescent period, when there was "no violent commotion within the Appalachian area" (Rogers, 1858, p. 789). The Scalent Series above it was said to continue to accumulate during tectonic calm, with the passage from the Surgent marked by gradual changes in the composition of the sediment and in the fossilized organisms. Within these 2 series there were defined sub-groups or formations, many of which are similar to units in use today under other names.

Under the First Survey, the initial geologic investigations in Mifflin and Huntingdon Counties were conducted during the 1839 field season by Andrew A. Henderson of Huntingdon (Rogers, 1840). Henderson placed much emphasis on the iron ores of the area, especially the "fossiliferous ores" of Formation No. V (Clinton) and the brown ores of No. VIII (Marcellus). He also recognized the importance of the "ore sandstone" (Keefer) as a stratigraphic marker. Continuing his work through the field season of 1840, Henderson ultimately completed a beautiful topographic and geologic sketch map of the Juniata Valley region which was "one of the monuments of the first survey" (Lesley, 1876).

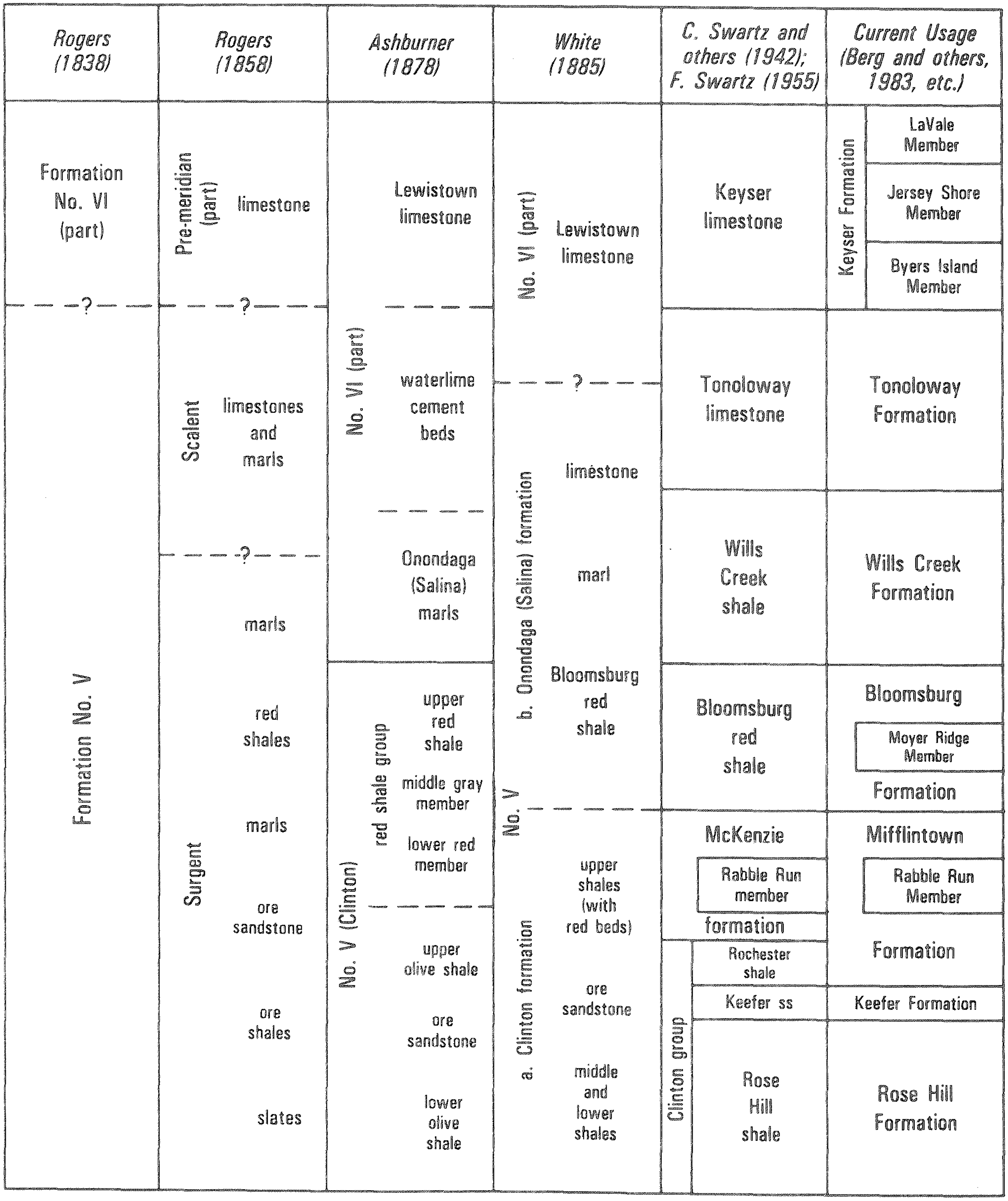

Figure 13. Historical development of Silurian stratigraphic nomenclature in the Juniata Valley region.

The Second Pennsylvnia Geological Survey devoted considerable effort to investigating the stratigraphy and economic resources of this portion of the Juniata Valley. From 1874 to 1877, John H. Dewees mapped the "fossil ore" beds of the Juniata district and, at the same time, described many of the "brown hematite" banks at the Helderberg, Oriskany, and Marcellus horizons (Dewees, 1878). In 1874 and early 1875, Charles A. Ashburner constructed several stratigraphic and structural sections through the Aughwick Valley region (Ashburner, 1878). Somewhat later (1883), Israel Charles White (with considerable editorial assistance from J. Peter Lesley) prepared a geologic map and report that covered most of Huntingdon County (White, 1885). These studies refined the stratigraphic sequence developed by the First Survey, related some of the units to the New York standard section, and delineated nearly all the lithic subdivisions now recognized (Figure 13).

In the early part of the present century, Edward O. Ulrich, Charles K. Swartz, and George W. Stose, working mainly in western Maryland and northern West Virginia, developed the mid-Silurian stratigraphic nomenclature which, with minor revisions, is currently in use (Ulrich, 1911; Stose and Swartz, 1912; Swartz, 1923; Swartz and others, 1942).

ROSE HILL-KEEFER-MIFFLINTOWN FORMATIONS

Depositional Setting

An image for the setting in which these 3 formations accumulated is that of a ramp, deepening gradually from the southeasterly proximal margin to the basin axis, located approximately near what is now the Alleghany Front. Much of the evidence and reasoning for the interpretations of the various aspects of the depositional setting was presented in the 1983 Field Conference of Pennsylvania Geologists (Cotter, 1983). A generalized paleoenvironmental reconstruction is illustrated in Figure 14.

The southeastern margin of the depositional ramp was a tidal flat coast, whose deposits are exposed in Schuylkill Gap (Smith, 1968) and in Susquehanna Gap north of Harrisburg. Seaward of the coast were mid-shelf, megarippled shoal complexes. During deposition of the Rose Hill Formation, iron-cemented sandstone (Hunter, 1970) accumulated on these shoals, but with the development of the Keefer Formation the composition changed to quartz-arenite sand fringed by shell banks. Then, with the overall evolution of the depositional ramp to carbonate during the time of the Mifflintown Formation, the shoals further changed to essentially all skeletal debris. To the northwest, in the basin axis, featureless mud accumulated under anaerobic to dysaerobic conditions.

Storms made a significant imprint on these shallow-marine deposits. Not only were structures such as hummocky cross stratification (HCS) produced on the shoals themselves, but coarser sediment was flushed basinward from these shoals as storm beds. Thus, between the shoal facies and the basin-axis mud facies there is a transitional heterolithic facies consisting of interbedded mudrock and thin sandstone and/or shell beds. The sequence of features recognized as typical of storm beds (Dott and Bourgois, 1982; Walker, 1985) indicates that this heterolithic facies was deposited at depths between fairweather and storm wave bases. The storm beds become systematically finer-grained and thinner toward the basin axis.

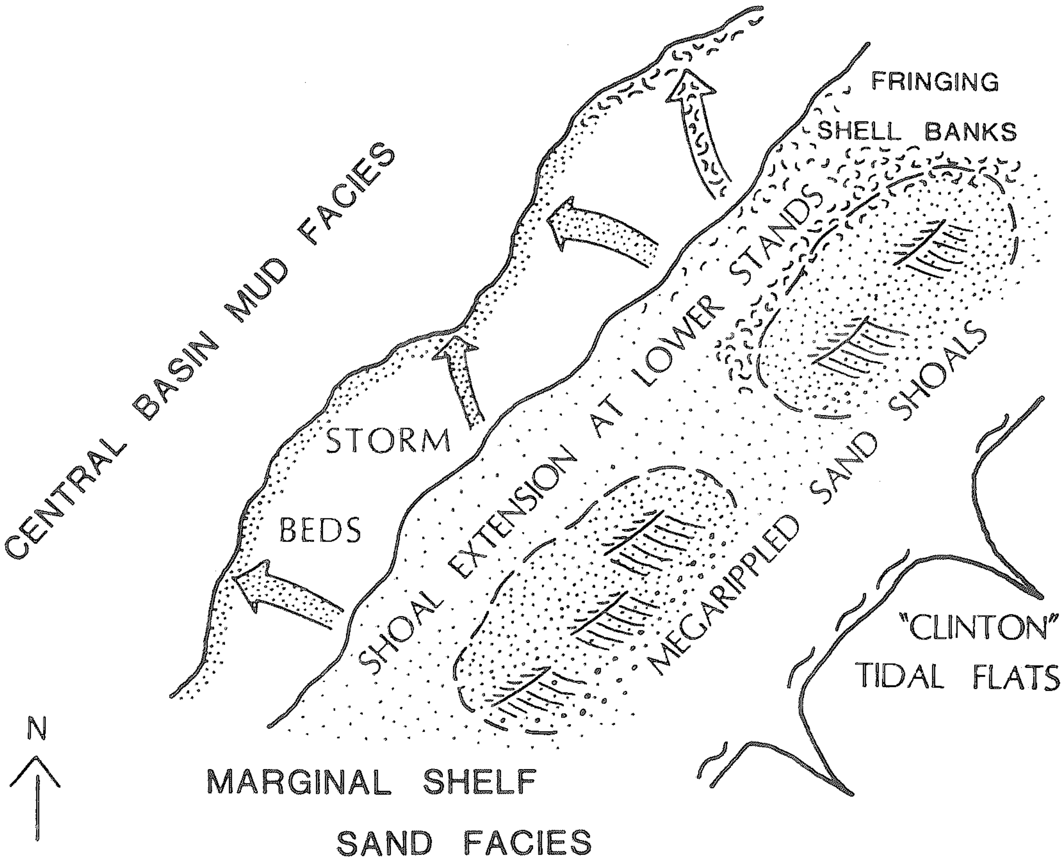

Figure 14. Conceptual model of mid-Silurian paleoenvironments on southeastern side of Appalachian Basin.

Lithofacies Architecture

There are systematic changes in the lithofacies pattern of these medial Silurian formations across the Valley and Ridge Province in central Pennsylvania (Figure 15). Dominating the proximal, southeastern margin are the coarser-grained, sandstone-rich lithofacies, while along the distal basin axis there is little other than mudrock. Tongues of the basin-margin, sandstone-rich lithofacies thin and wedge out toward the basin axis. These include the hematite-cemented Cabin Hill and Centre Members of the Rose Hill Formation, the quartz-arenite Keefer Formation, and the Rabble Run Member of the Mifflintown Formation.

Hierarchy of Cycles

Cyclic fluctuations of relative sea level occurred during the medial Silurian in the Appalachian Basin. This judgement is based on the facies architecture described above and on the sedimentological interpretation of depth changes in a variety of nearshore and offshore facies. Part of a second-order global cycle of Vail and others (1977) is shown by the gradual compositional evolution of the succession from clastic to carbonate and by development of an exceptionally high sea-level stand during Mifflintown Formation accumulation.

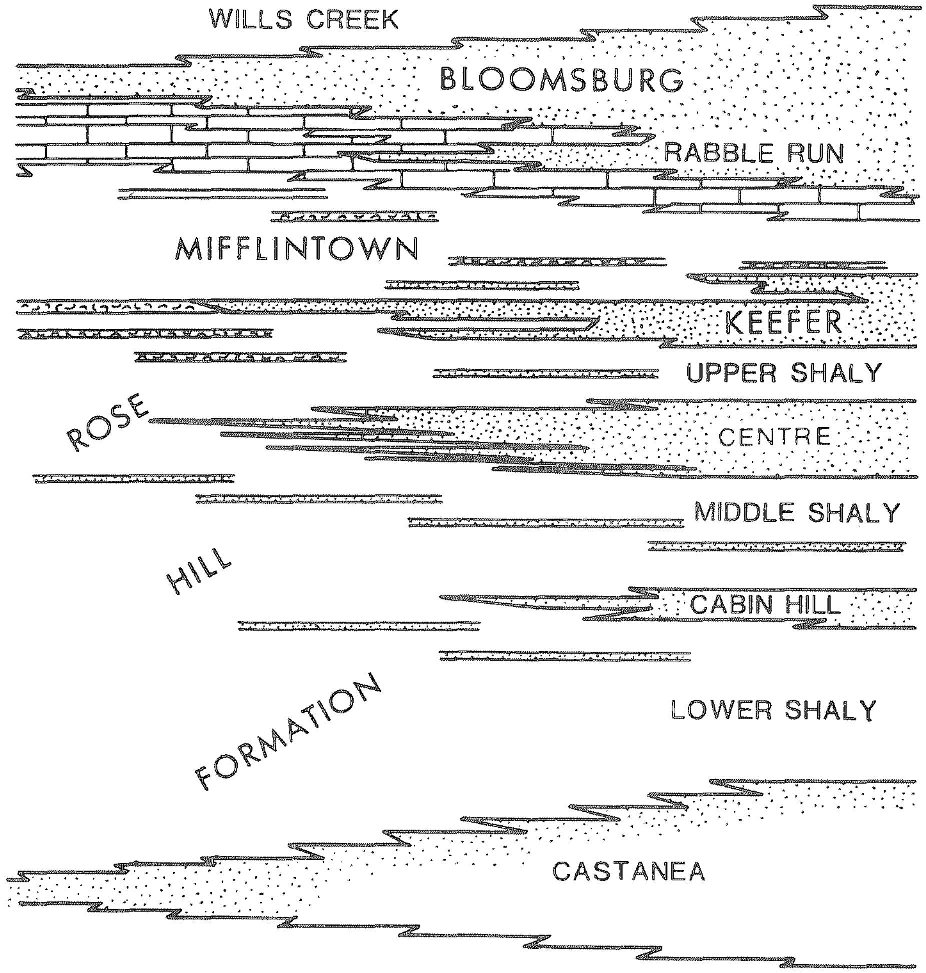

Figure 15. Mid-Silurian lithofacies profile normal to Appalachian Basin axis.

Within this broad trend there is a series of third-order cycles, demonstrated by the regional lithofacies architecture (Figure 15). Low stands of sea level are associated with the tongues of sandstone extending toward the basin axis. These alternated with higher stands, during which the basin-axis mudrock encroached toward the southeastern margin of the basin. These cycles comprise tens to hundreds of meters of strata, and a rough estimate indicates a periodicity of about 2.5 million years.

Smaller-scale cycles are superimposed upon these third-order cycles. They are recorded in different ways in different lithofacies, but they are typically 1 to 3 meters thick, and thus resemble the punctuated aggradational cycles of Goodwin and Anderson (1985). At the basin margin they consist of fining-upward, shallowing-upward tidal flat cycles. In the mid shelf they are coarsening-upward, shallowing-upward offshore bar cycles. And in the heterolithic transition between the offshore bars (shoal complexes) and the basin axis there is cyclic clustering in the proportion and robustness of storm beds. Another set of approximations is necessary to estimate the periodicity of these cycles; they appear to have a period of 100,000 years. With these thicknesses and periodicities, these cycles can be classed as fifth-order.

BLOOMSBURG-WILLS CREEK-TONOLOWAY-KEYSER FORMATIONS

The Cayugan stratigraphic sequence in central Pennsylvania records approximately 8 million years (Berg and others, 1983) of intermittent, but progressive, sea level rise following the maximum progradation of the Bloomsburg-Vernon delta in mid-Silurian time. Terrestrial sedimentation decreased from virtually 100 percent in the Bloomsburg Formation to 10 percent or less in the upper Tonoloway and Keyser. The nature of the local mid-Cayugan stratigraphic succession (see below), as well as the widespread occurrence of evaporites to the north and west, indicate that an arid, tropical climate prevailed over the field trip area (see paleogeographic maps in Bambach and others, 1980). The modern Persian Gulf with its coastal salt flats (sabkhas) is a possible, though far from exact, analogy to central Pennsylvania 410 million years ago (Tourek, 1970).

Cyclicity in the Wills Creek and Tonoloway Formations

The Wills Creek and Tonoloway Formations are composed of shallowing-upward cycles 2 to 10 m thick that presumably represent recurrent progradational events on vast tidal-sabkha flats (Figure 16; Tourek, 1970; see James, 1985). Intratidal to supratidal deposition of the bulk of these sediments is shown by the abundance of mudcracking, "birdseye", and structures indicative of evaporative disruption (e.g. massive bedding and crystal-lined vugs), all of which increase upward in the great majority of cycles. Whereas most of the cycles in the Tonoloway Formation begin with a distinct subtidal phase, the depositional environment of the basal sediments of the Wills Creek cycles is often obscured by diagenetic dolomitization. Leperditiid ostracodes and stromatolites are the only common fossil remains, and these are far more common in the Tonoloway than in the Wills Creek.

Is the mechanism behind this cyclicity autogenic or allogenic? Tourek (1970) favors an autocyclic model in which the continuous subsidence of a gently inclined basin floor was the only tectonic or eustatic control. In his study of about a dozen sections in Maryland, West Virginia, and south-central Pennsylvania (including Mount Union), he found that individual cycles could not be traced more than 8 km (p. 234). This suggests a localized, basinal control of sedimentation. The "PAC-Men" (Anderson and Goodwin, 1980; Goodman and others, 1986; etc.), on the other hand, strongly advocate allocyclic (chiefly eustatic) control of these depositional events. They are able to correlate individual "punctuated aggradational cycles" (PACs) in the upper Tonoloway and Keyser between Tyrone, Pennsylvania, and Keyser, West Virginia, a distance of 150 km (Sullivan and Anderson, 1985). Since it is impossible to choose between these 2 hypotheses on the basis of one outcrop, the issue must remain unresolved, or at least left to the individual's preference, as far as Stop 6 is concerned.

There are approximately 62 cycles in the Wills Creek-Tonoloway interval at the Allenport section Stop 6. Assuming approximately 5 m.y. for the duration of "Salina" time (see Berg and others, 1983), each cycle represents approximately 80,000 years. Since some cycles are as much as 5 times thicker than others, it is likely that what is preserved is interference between the 100,000 year cycles of Cotter (see above) and the 10,000 year cycles of Anderson and Goodwin (1980).

Regional Relationships

The paleogeography of Pennsylvania and nearby areas for much of Cayugan time is illustrated in Figure 17.

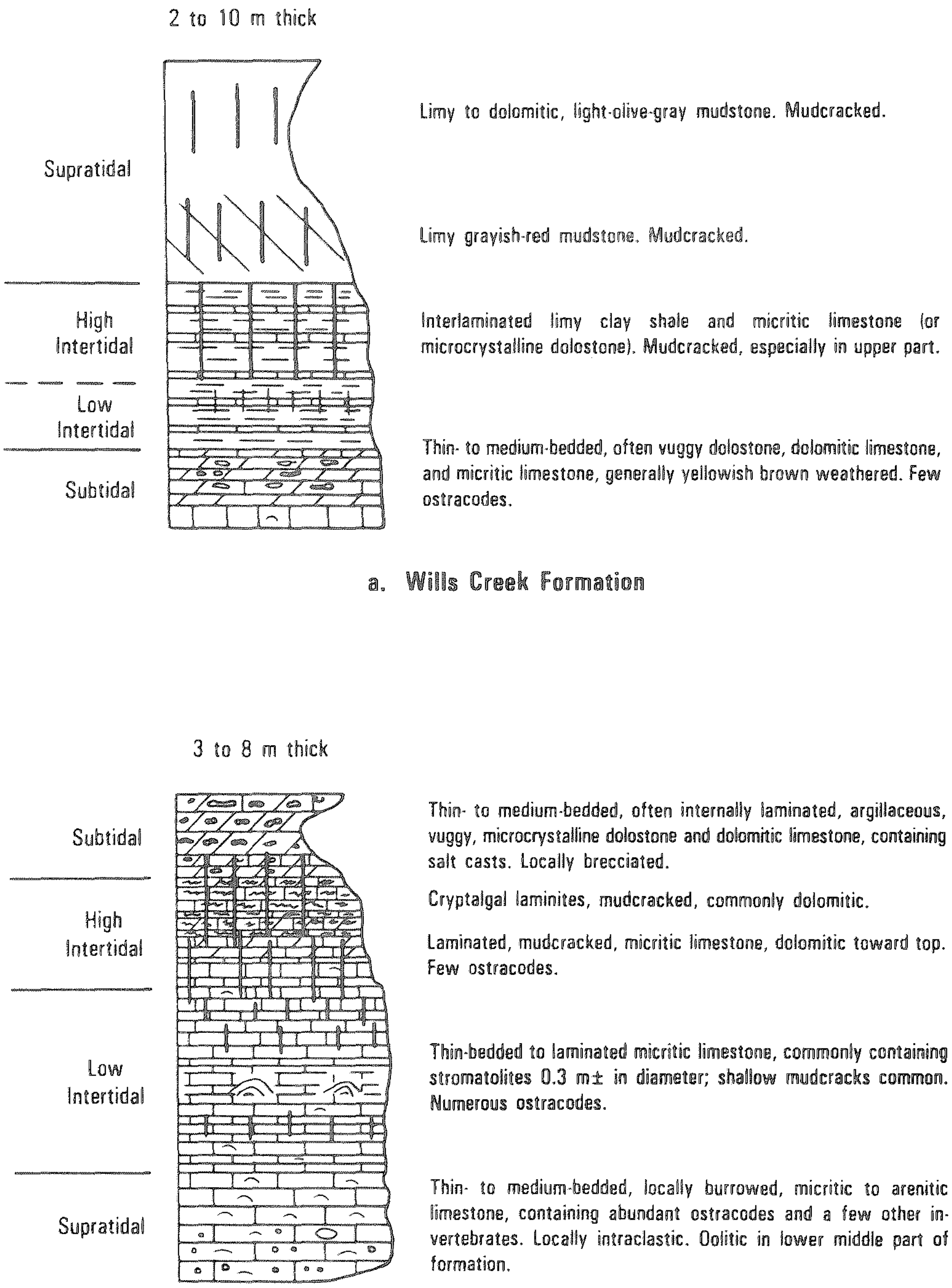

Figure 16. Typical cycles in the Wills Creek and Tonoloway Formations (modified from Lacey, 1960, and Tourek, 1970).

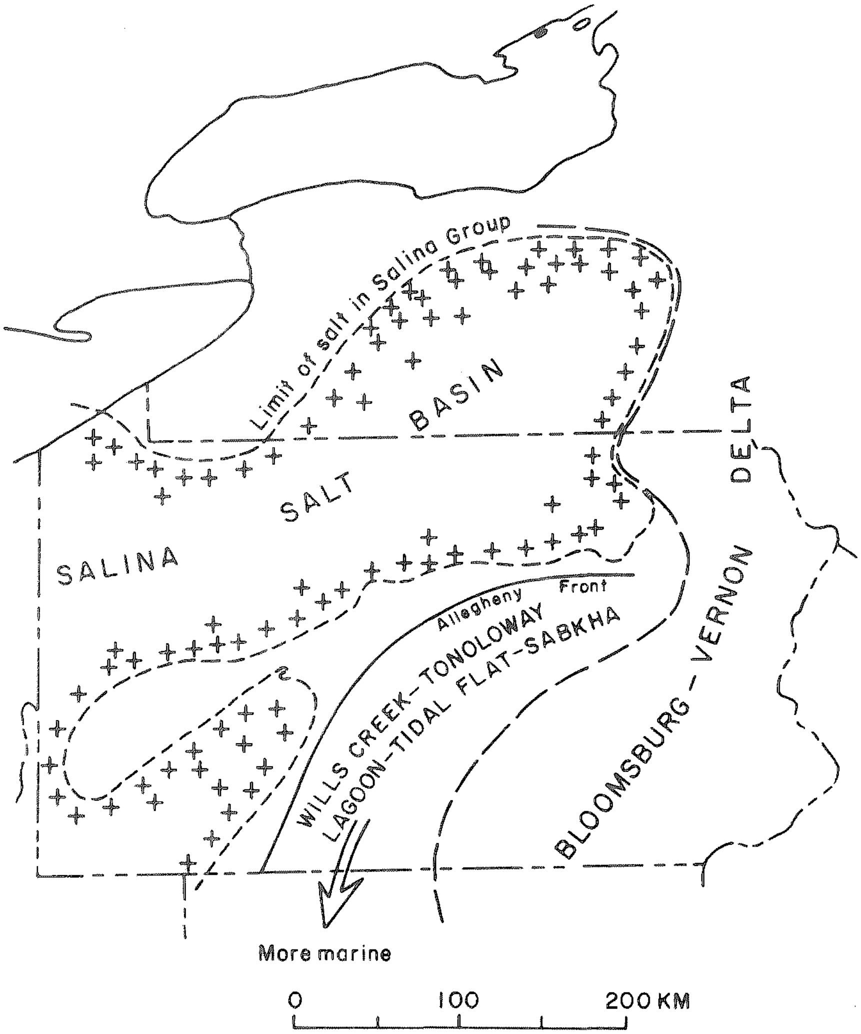

Figure 17. Generalized paleogeography of central Appalachian area in mid-Cayugan time (after Fergusson and Prather, 1968, and Rickard, 1969).

The main input center for the Bloomsburg-Vernon delta was apparently located in what is now northern New Jersey. Red clastic sediments that aggregate more than 450 m in the Delaware Valley region (Epstein and Epstein, 1967) correlate with the bulk of the Mifflintown through Wills Creek interval of central Pennsylvania (Hoskins, 1961; Berg and others, 1983). It appears that the main deltaic input center shifted southwestward in middle to late Cayugan time. The grayish-red to olive-green Landisburg tongue at the top of the Wills Creek Formation in Perry County (a miniature version of the Moyer Ridge-Williamsport sandstone complex) attests to a major source of red clastics in the vicinity of the present Susquehanna River valley (Miller, 1961; Dewindt, 1973). Dyson (1967) reports the occurrence of grayish-red mudstone in the upper part of the Tonoloway Formation in the southeastern part of the same county.

West and north of the Wills Creek-Tonoloway embayment in central Pennsylvania lay the great Appalachian Salina salt basin. The major salt beds in the Salina Group (those in units D and F) correlate with parts of the Tonoloway Formation (Figure 18). Greatest salt thicknesses in Pennsylvania are in the northern tier counties of Bradford, Tioga, and Potter (Fergusson and Prather, 1968; Rickard, 1969). While Niagaran reefs may have been a major cause of the restricted circulation that led to the deposition of early Cayugan evaporites in the Michigan Basin (Alling and Briggs, 1961; Gill, 1977), evidence for large reef-buildups on the rim of the Appalachian salt basin is lacking (Rickard, 1969; Smosna and others, 1977; but see Fergusson and Prather, 1968). Restriction of circulation in the Appalachian region may have been caused by an extremely low paleoslope and a resulting long interval of shallow water in the area to the south and southeast of the salt basin (Alling and Briggs,1961; Smosna and

	Series	Central and western NY (outcrop and subsurface) and north-central PA (subsurface) (Rickard, 1969)			Central PA (outcrop)
Upper Silurian (part)	Cayugan	Cobleskill-Akron Formation			Keyser Formation
		Salina Group	Bertie Formation	Unit H	
			Camillus Formation	Unit G	? Tonoloway Formation
			Syracuse Formation	Unit F*	
				Unit E*	
				Unit D*	
			Vernon Formation	Unit C	Wills Creek Formation
				Unit B*	
				Unit A	Bloomsburg Formation (part)

*Salt beds in Pennsylvania.

Figure 18. Correlation of salt-bearing units in the Salina Group with formations in the Bloomsburg to Keyser interval.

others, 1977). Certainly water depths in the Juniata Valley region did not exceed 10 or 15 m during the whole of Wills Creek-Tonoloway deposition. Within the salt basins themselves, however, the water may have been significantly deeper: Rickard (1969) believes that halite in New York and northern Pennsylvania was deposited in waters 30 to 120 m deep, and possibly up to 180 m deep.

Although bedded evaporites are not known to outcrop in the Valley and Ridge of Pennsylvania, discrete layers of anhydrite do occur in the subsurface. In the Albert No. 1 well, Snyder County, Wagner (1958) reports several beds of anhydrite up to a meter or more thick in the Tonoloway Formation. Fettke (1960) notes a "great deal of anhydrite" at several horizons in the Tonoloway of the Miller No. 1 well, Bedford County. At outcrop sections, a few deeply weathered, brecciated or contorted zones in the Tonoloway may represent the former position of similar anhydrite beds (see description of Stop 6B).

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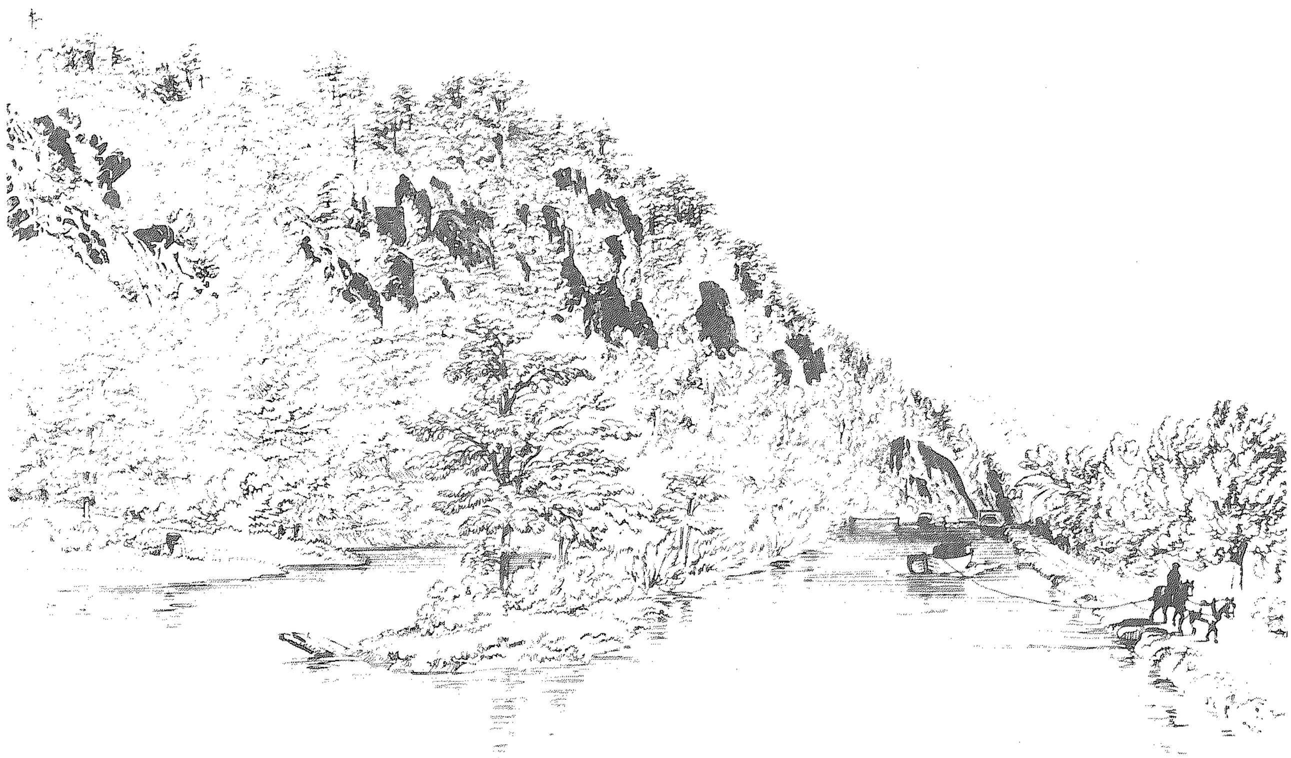
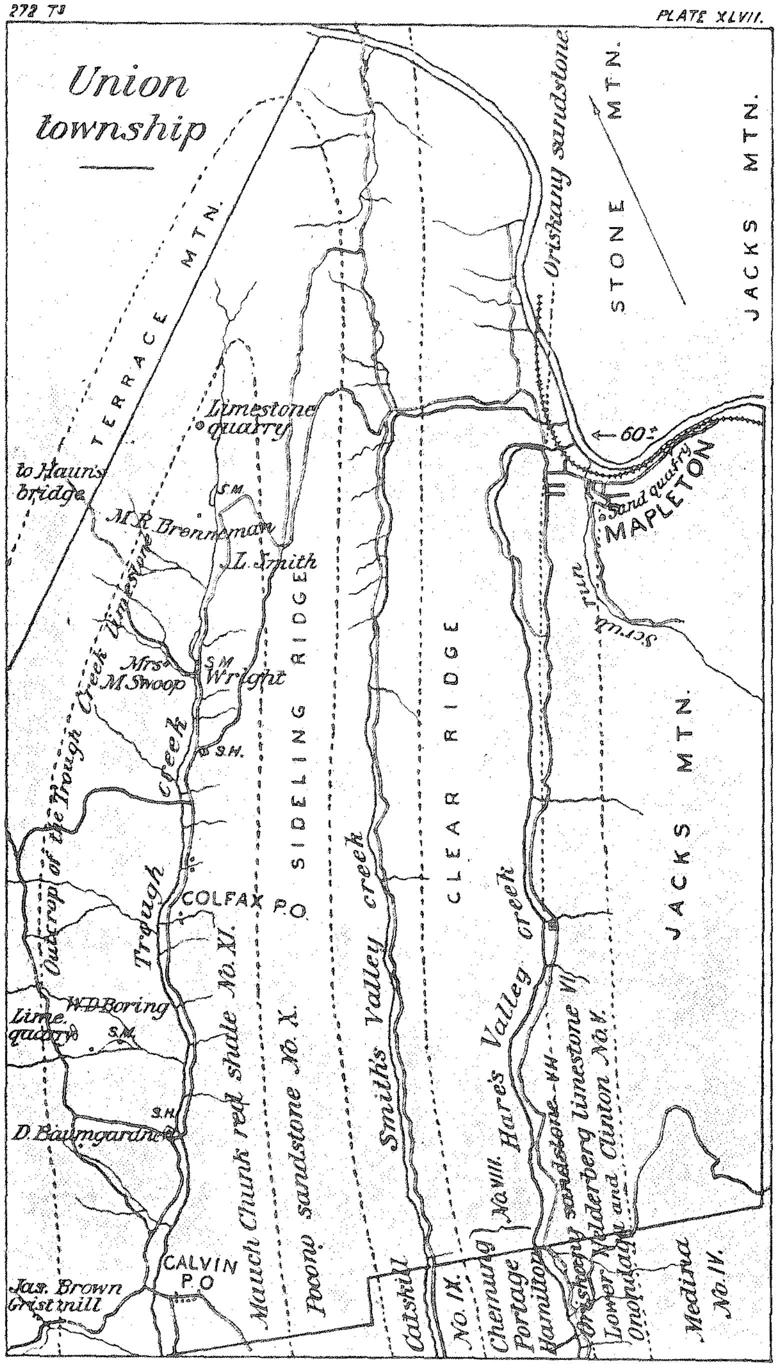


Stone ridge near Jacks Narrows, Juniata River, Pa. A George Lehman lithograph in Rogers, 1858, v. 1, opposite p. 519.

272 T3 PLATE XLVII.



Geologic map of Union Township, from White, 1885, p. 272.

IRON FURNACES OF BLAIR AND HUNTINGDON COUNTIES

by
Alton M. Sternagle
PennDOT, Hollidaysburg

INTRODUCTION

As strange as it may seem the enormous steel industry which played such a large role in Pennsylvania's economy saw much of its origin in the many furnaces and forges that existed in Blair and Huntingdon Counties throughout the early and middle years of the nineteenth century. The first settlers set up these iron works soon after they had provided themselves with saw and grist mills. Iron ore was found to be abundant, the surrounding forests supplied charcoal for fuel, and the streams and rivers furnished all the power that was needed.

The first bloomery forge for making iron in Pennsylvania was established in 1716 along Manatawny Creek approximately 5 km from Pottstown in Montgomery County. At this works, wrought iron was made directly from raw ore, a process soon to be abandoned as the iron industry spread. Later technology favored the intermediate step of making cast iron in large blast furnaces, then taking the pig iron to nearby forges for conversion to wrought iron. For the next 100 years, the iron industry migrated westward, reaching the west bank of the Susquehanna by the mid-1700's. During the last quarter of the eighteenth century, large numbers of settlers moved into the Juniata River valley, a few bringing their knowledge of the iron trade with them.

It was discovered in the late 1700's and early 1800's that the hills and mountains of Huntingdon County (Blair County was to be formed from Huntingdon County in 1846) contained rich deposits of iron ore. Following from previous iron-making experiences, the first furnace in the Juniata region was established in present-day Orbisonia around 1785 and named Bedford after the company which formed it. Mining techniques to extract the iron ore in large quantity were then developed, and over the next 90 years furnaces and forges with such unusual and picturesque names as Sarah, Rebecca, Springfield, Rough and Ready, and Paradise were erected to smelt the ore. During this period, Blair and Huntingdon Counties together constituted one of the largest iron-producing areas in the United States (Figure 19).

THE FURNACES

As mentioned previously the first furnace in the Juniata Valley was Bedford furnace on Black Log Creek, built around 1785. It made from 8 to 10 tons of pig iron a week. The stack was built mostly of wood. A forge was later built on Little Aughwick Creek, some distance away. Bar iron and castings were taken down the Juniata on arks, eventually arriving in either Philadelphia or Baltimore. Legend has it that the first American-made wrought-iron bars taken to Pittsburgh were made at Bedford forge; the bars were bent over the backs of pack horses to be carried over the Allegheny Mountains.

The first furnace and forge in Blair County was built at Mount Etna in Catharine Township, near Williamsburg (Figure 20). (For a detailed description of this uniquely well-preserved iron plantation, see Inners, 1986). An interesting detail is that when the U. S. Capitol building was renovated in the early

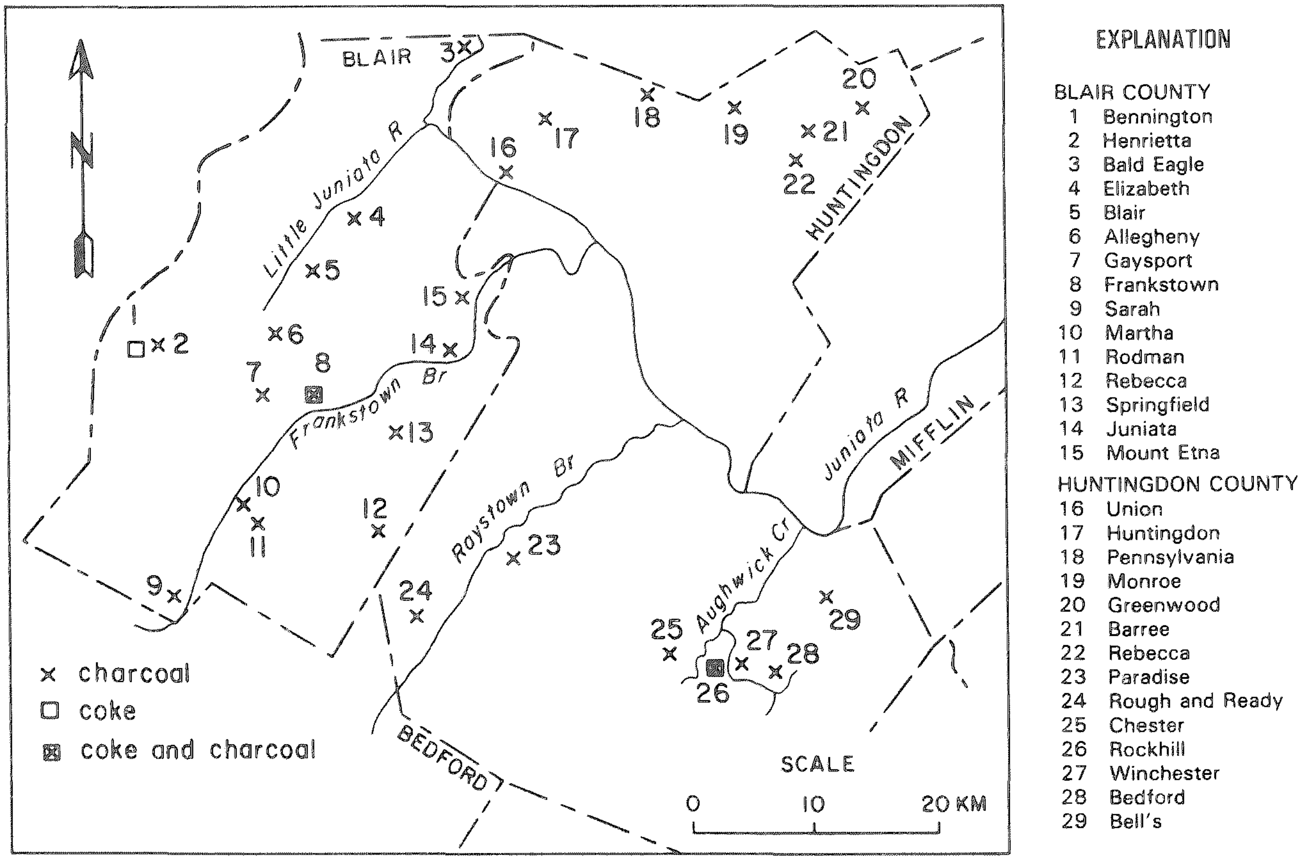


Figure 19. Map showing location of important iron furnaces in Blair and Huntingdon Counties.

1960's, a bar of Etna iron, plainly marked, was found to have been used in the construction a century before.

The second iron works in what is now Blair County was the Allegheny furnace, built in 1811. Since it did not prove profitable for the speculators, it was put out of blast in 1817. Elias Baker (who in 1844 built the Baker Mansion in what is now Altoona) purchased the furnace in 1835 and soon turned it into a paying proposition. For the next 50 years, the furnace produced from 50 to 80 tons of pig iron a week during active "campaigns." It went out of blast for the last time in 1885.

Rebecca furnace located on Clover Creek in Huston Township was the third furnace in Blair County. Built by Dr. Peter Shoenberger (see p. 51-54) in 1817, it was operated for over 40 years after his death in 1854.

In the northern part of the county was Elizabeth furnace and "Sabbath-Rest" forge (Figure 21). The furnace was built in 1832 by Edward Bell, a native of Alexandria (Huntingdon County). Later the furnace was modified so that employees would not have to work on Sundays, giving the forge and nearby village (now Pinecroft) the name of "Sabbath."

Also built by Dr. Peter Shoenberger was the Bloomfield furnace at Ore Hill.

Erected in 1846, the furnace turned out 1,350 tons of pig iron annually. Iron ore from the Ore Hill area was also used at Sarah and Martha furnaces and Rodman forge. A very extensive washing operation for the cleaning of the iron ore was a major factor in the superior quality of the iron produced at the Bloomfield furnace. The high-quality iron was used during the Civil War in the manufacture of the famous Rodman naval guns. It was suggested at the time that the U. S. Government purchase the Bloomfield mines and furnaces to assure a supply of iron for the manufacture of heavy ordnance.

The Canoe (or "Soap-Fat") furnace, located in Point View, was built around 1837. This furnace differed from all others in the area by having a round stack. It had an annual capacity of 1,400 tons. The name "Soap Fat" was acquired because of the quality of pork offered for sale at the company store.

Frankstown furnace, located at the eastern end of Frankstown and built in 1836, was one of the last furnaces in Blair County to be put out of blast. It operated into the late 1880's, and during its last years produced 550 tons of pig iron a month. This furnace was unusual among early furnaces in its use of coke for reducing the iron ore.

Other furnaces located in Blair County were: Blair in Logan Township, Bald Eagle in Snyder Township, Juniata in Williamsburg borough, Springfield in Woodbury Township, Sarah in Greenfield Township, Martha (Gap) in Freedom Township, Bennington and Henrietta in Allegheny Township, and Chimney Rocks and Gaysport in Hollidaysburg borough.

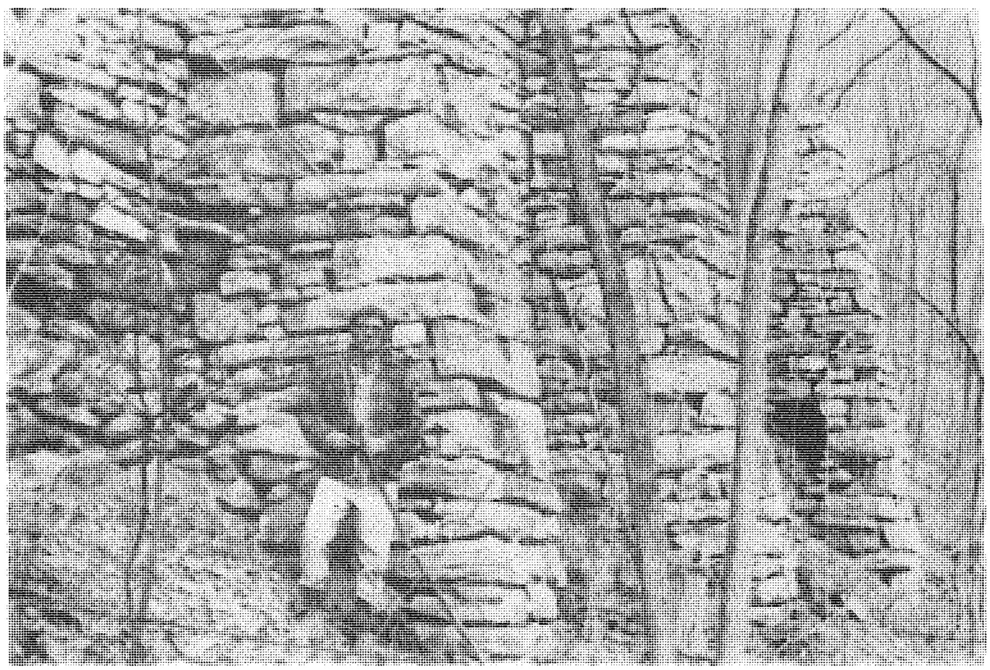


Figure 20. Dolomite-block buttresses of the charcoal house at Mount Etna iron furnace plantation. The ruins of this structure are located about 60 m east of the old blast furnace. William I. Richardson provides scale.

Figure 21. Ruins of Elizabeth furnace near Pinecroft. Like many of these old furnace stacks, this one has collapsed over the broad work arch (where the molten iron was drawn from the furnace). Note the unmortered limestone block facing on the exterior, and the random, unsorted material forming the middle layer of the furnace. The inner brick lining is not exposed. The author provides scale.

In present-day Huntingdon County there were many other furnaces in addition to Bedford already mentioned. Probably the best preserved blast furnace stack in the area is that of Huntingdon furnace in Warrior's Mark Township. This furnace was first erected in 1796 on Warrior's Mark Run. The location was not favorable, and the site was abandoned when it was found that the water power was not sufficient to work the furnace to the capacity required. Another furnace was erected about a mile further down the same stream. In 1870 a deficiency of wood for making charcoal forced the closing of the works. Several other local industries grew from this establishment - Colerain forge on Spruce Creek, built about 1800; the Tyrone forge complex with various mills and nail factories, and Bald Eagle furnace (already noted in Blair County.

Another furnace in an excellent state of preservation is Greenwood furnace in Jackson Township (Figure 22). Now a State Park, funds have been used to restore some of the remaining buildings and establish a museum. The earliest furnace (no longer standing) was built by the Freedom Forge Company of Lewistown in 1837/38. Later the operation was enlarged under the ownership of the Logan Iron Company, also of Lewistown. Furnaces No. 1 and 2 at Greenwood continued to produce charcoal iron into the early years of the twentieth century; but the high cost of production, the dwindling supply of wood, and the distance from markets caused it to be "blown-out" in 1904. The mansion, barns and workers' houses were all sold. The following year the Forestry Department acquired much of the land belonging to the old furnace company and established a tree nursery which is still in use.

Other furnaces and forges in present Huntingdon County were Barree ("Little") and Rebecca in Jackson Township; Barree in Porter Township; Bell's in Shirley Township; Chester, Rockhill (charcoal and coke) and Winchester in Cromwell Township; Monroe in Barree Township; Pennsylvania in Franklin Township; Paradise in Todd Township (Figure 23); Rough and Ready in Hopewell Township; and Union in Monroe Township.

The once-extensive iron operations in this section of the state were nearly moribund by the turn of the present century. Actually the Juniata iron industry entered a period of sharp decline after 1870, due mainly to the high cost of production at the small, low-output works. Cheaper ore and improved methods at Pittsburgh and other iron centers had reduced the market price below a profitable price. Then again, the ore deposits in central Pennsylvania were tiny in

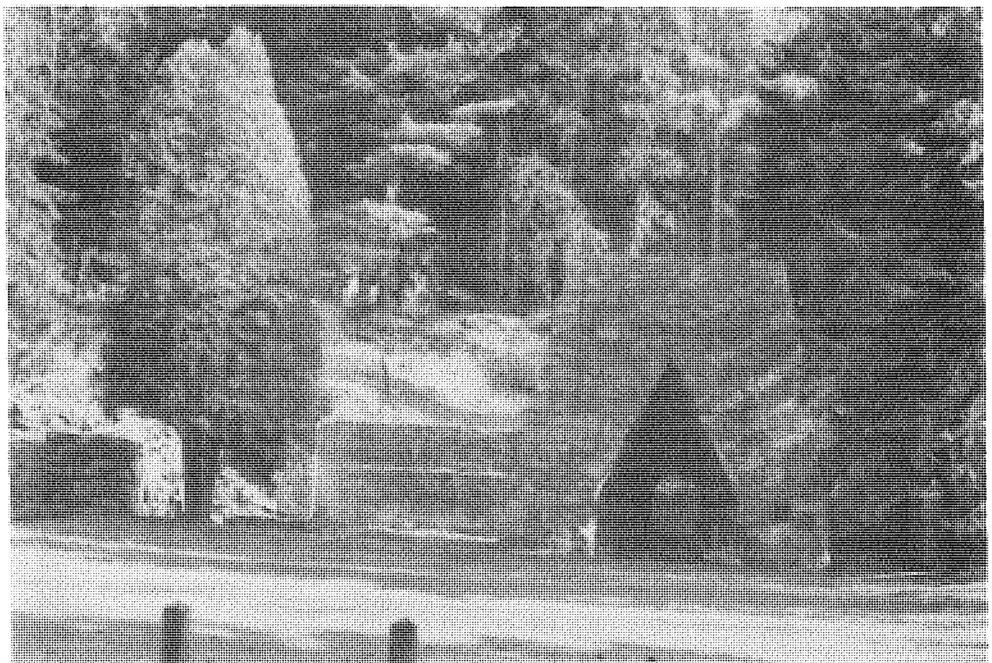


Figure 22. Greenwood Furnace Stack No. 2 at Greenwood Furnace State Park. Constructed in 1866 and restored in 1935, this was a hot-blast charcoal furnace in which the escaping exhaust gases were used to heat the air blast. the ruins to the left are the remains of Stack No. 1, a cold-blast charcoal furnace erected in 1854 (?). These furnaces used a mixture of Clinton "fossil" ore from nearby Brush Ridge and "brown hematite" ore from Kishacoquillas Valley on the other side of Stone Mountain.

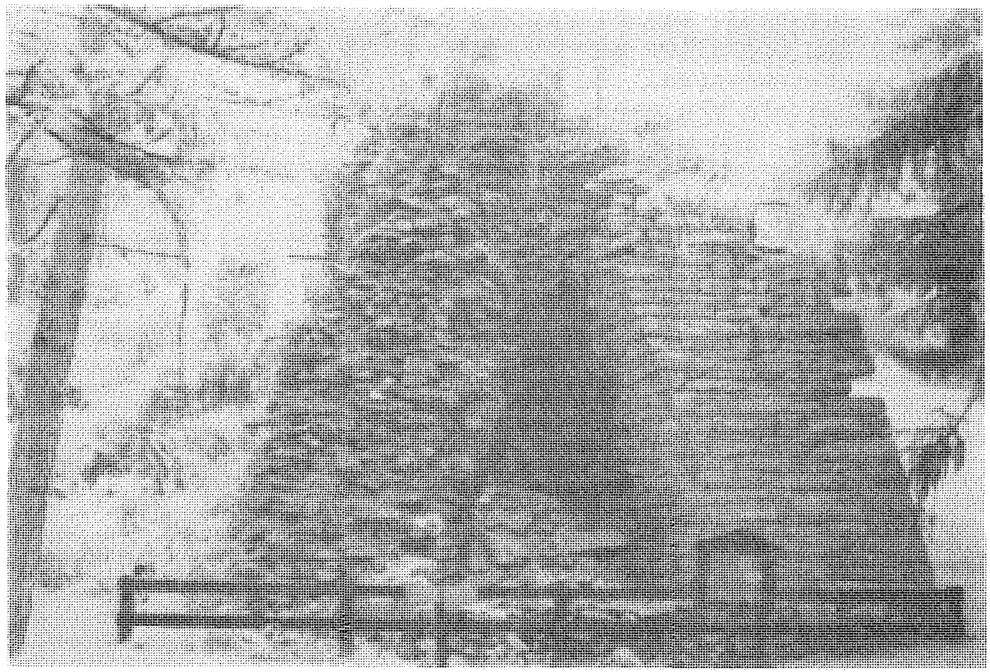


Figure 23. Sandstone stack of Paradise furnace behind park office at Trough Creek State Park, Todd Township. Erected by Lubin Trexler in 1832, this furnace used "Mauch Chunk" limonite ore during its two periods of operation 1832 to 1845 and 1860 to 1868. The ironmaster's mansion on the hill overlooking the furnace is currently used as the Park Superintendent's residence.

comparison to the vast iron deposits of the Lake Superior region, and mining costs were correspondingly much higher.

THE ORES

Both limonite and hematite ores are common in the upper Juniata Valley. The limonite (or brown) ores occur at a variety of stratigraphic positions; they formed mainly from supergene enrichment processes under near surface conditions, probably during an extended period of humid, tropical climate that prevailed over much of the eastern United States in Cretaceous and early Tertiary time (Sevon, 1985). The hematite ores, on the other hand, are primary sedimentary deposits restricted to the Lower Silurian Clinton Group. Although these ores are widespread, only a limited number of deposits are of sufficient size to have warrented exploitation, even in those early days of the iron industry. Many a farmer who turned up lumps of ore while plowing his fields found his dreams of instant wealth dashed after only a few weeks of excavation.

The important ores are discussed below in order of stratigraphic position, the highest first.

MAUCH CHUNK ORE. The "brown hematite" of the Mississippian Mauch Chunk Formation occurs mainly at the position of the Trough Creek Limestone in the lower part of the formation. It was primarily mined in Huntingdon County around Trough Creek and used in furnaces there. This ore was generally very high in manganese and hence rarely of much use (see Foose, 1945). A typical analysis

(McCreath) showed 23.7 percent metallic iron, 19.68 percent manganese, and 0.49 percent phosphorous (also extremely high).

MARCELLUS ORE. This limonite ore, which occurs at the contact of the Middle Devonian Marcellus black shale and Selinsgrove (Onondaga) limestone, was widely in Huntingdon County (as well as in Mifflin and Perry Counties). Near Orbisonia and Rockhill in Huntingdon County, the Marcellus ore attained a thickness of 1.2 to 1.5 m in many places. At depth the limonite ore typically gave way to carbonate (siderite), a situation very similar to conditions in the Clifton Forge district of Virginia (Lesure, 1957). In some areas the ore was so plentiful that only lump ore was used, the finer wash ore being discarded on the dump. This is apparently the ore smelted at the old Bedford furnace in the late 1700's. In Blair County this ore was mined only around McKee's Gap for Martha furnace. An analysis (McCreath) of an excellent ore from Opening No. 17 of the Rockhill Iron and Coal Company near Orbisonia showed 51.7 percent metallic iron, 0.023 percent sulfur, 0.068 percent phosphorus, and 10.49 percent insoluble residue (Dewees, 1878).

ORISKANY ORE. This ore consists mainly of "brown hematite" up to 3.6 m thick that occurs locally at the top or bottom of the Lower Devonian Ridgeley sandstone. Much of the iron for the upper ore horizon probably came from the weathering of pyrite in the overlying Needmore shales. Among the furnaces that used Oriskany ore in Huntingdon County was Bell's furnace on West Licking Creek, Shirley Township. A typical analysis (McCreath) of a good quality Oriskany ore showed 47.5 percent metallic iron, a trace of sulfur, 0.40 percent phosphorus, and 17.26 percent insoluble residue.

HELDERBERG ORE. The Lower Devonian to Upper Silurian Old Port, Keyser, and Tonoloway limestones were a widespread source of iron in the Juniata district (Figure 24). Ore from this horizon was mixed with Clinton "fossil" ore (see below) at Allegheny, Blair, and Elizabeth furnaces in Blair County. In many places, however, the Helderberg ore was found to be sandy and of little or no value for furnace work. Two analyses (McCreath) of this ore are as follows:

	1	2
Metallic iron	47.05 percent	58.15 percent
Manganese	0.68	0.24
Sulfur	0.11	0.04
Phosphorus	0.22	0.19

CLINTON ORES. The several ores of the Lower Silurian Keefer and Rose Hill Formations (Clinton Group) were probably the most important overall sources of iron in the Juniata Valley district. Distinctive ore beds recognized by the early miners in various parts of Blair and Huntingdon Counties were (in descending stratigraphic order):

Blair	Huntingdon
Upper Fossil ore	Saltillo ore
(Double) Fossil ore	Sand-vein ore
	Fossil ore
Frankstown ore	Block ore
Keel ore	

Upper Fossil and Saltillo Ores. These ores were opened at several places in the 2 counties, but were rarely usable in the furnaces. Both of the ores apparently occur within what is now recognized as the Mifflintown Formation.

(Double) Fossil Ore, Sand-Vein, and Fossil Ores. These important beds were widely mined in the 2 counties. Many mines were located along the ridge in the "Loop" near Frankstown. In some places ore beds at this horizon (Keefer and upper Rose Hill) became quite complex both structurally (faults) and stratigraphically (pinch-outs). The calcareous fossil ore beds were commonly leached of carbonate to form enriched "soft" hematite ores, while locally more intense weathering resulted in the formation of clayey, limonite ores. An analysis (McCreath) of 1 sample (probably "soft" ore) revealed 48.55 percent metallic iron, 0.01 percent manganese, 0.003 percent sulfur, and 0.33 percent phosphorus.

Frankstown Ore. This ore bed generally occurs approximately 120 m below the "fossil bed", but it was not as persistent. Widely mined near Frankstown, the bed ranges from 0.2 to 0.5 m thick in the old mines. Numerous small faults added considerably to the cost of mining. The ore was used in Juniata furnace at Williamsburg and Martha furnace, as well as in furnaces in Frankstown and Hollidaysburg. A typical analysis (McCreath) of the Frankstown ore is as follows: 41.90 percent metallic iron, 0.28 percent manganese, 0.03 percent sulfur, 0.25 percent phosphorus.

Block Ore. In Blair and Huntingdon Counties, this bed apparently occurs low in the Rose Hill shale. Generally it is a sandy, oolitic bed that was mined on a relatively small scale at only a few localities.

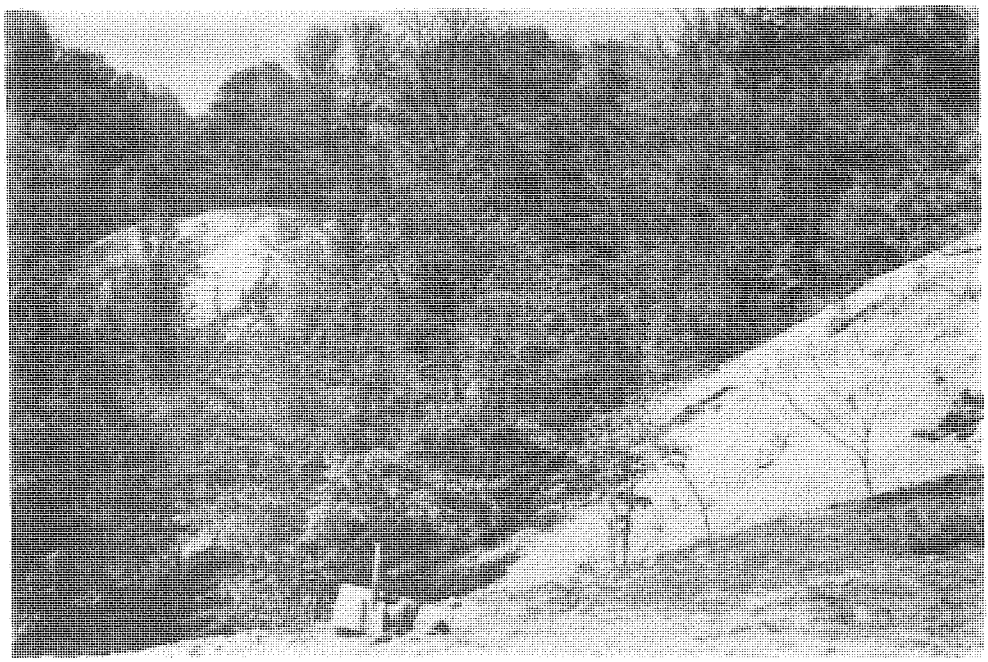


Figure 24. The Baker mine near East Altoona in Logan Township, Blair County. This was one of the largest "Helderberg" iron ore mines in central Pennsylvania, having been 183 m long, 121 m wide, and 41 m deep in its later days of operation (Platt, 1881). The ore occurs as limonitic lumps in white, ping, and black clay weathered from the Old Port, Keyser, and upper Tonoloway limestones; it yielded 50 to 60 percent metallic iron.

Keel (Hard Fossil) Ore. In Blair County the Keel ore consisted of a worthless iron-rich sandstone ("block" ore) containing only about 10 percent metallic iron. What was considered an equivalent bed in Huntingdon County was more "fossil" in character and contained sufficient iron to be mined in a number of townships.

CALCIFEROUS ORES. The "brown hematite" ores that are so abundant in the Cambro-Ordovician limestones (especially the Gatesburg Formation) of the great anticlinal valleys in central Pennsylvania were extensively mined in both Blair and Huntingdon counties. Extensive surface mines worked these ores throughout the Morrison's Cove-Canoe Valley area in Blair County, while many large "banks" were opened at the southwestern end of the Nittany Valley in Huntingdon County. Because the limonite occurred in stalactitic and botryoidal masses in variegated clays weathered from the underlying carbonate rocks, nearly all of the ore required washing. Absence of water to accomplish this vital phase of ore preparation not infrequently limited exploitation of otherwise good deposits. Many of the best ore accumulations overlie the sandy Gatesburg dolomite (Upper Cambrian) that outcrops in the great "Barrens" of Nittany Valley and Morrison's Cove. Such ore is generally mixed with chert and sandstone fragments in a clay matrix. Most of the ore for the Rodman, Springfield, Etna, Pennsylvania, Huntingdon, and Rebecca furnaces came from banks on the Gatesburg barrens. At one time the Springfield mines at Oreminea were among the most extensive iron-ore workings in the United States. Some typical analyses (McCreath) of the "Calciferous" ores are the following:

	1	2	3
Metallic iron	36.70 percent	59.10 percent	54.71 percent
Manganese	0.94	0.25	0.07
Sulfur	0.03	0.09	0.07
Phosphorus	0.03	0.05	0.06

EPILOGUE

Although the "Juniata iron" industry is gone and will in all likelihood never be resurrrected, it has left us a rich historical and environmental heritage. Numerous iron furnace ruins provide not only picturesque scenes, but also prompt us to inquire into the techniques of the early ironmasters. Several of the old iron plantations - namely those at Greenwood Furnace in Huntingdon County and Curtin in Centre County - are currently undergoing restoration and archeological study. The outstanding group of buildings and ruins at Mount Etna (Inners, 1986) is richly deserving of preservation and historical investigation. And let us not forget contemplation of the human tragedies told in the old worker's cemetaries. In the graveyards at Etna and Rebecca furnaces are buried many children who were victims of a smallpox epidemic that swept the "Cove" in the early 1850's.

Periodically, the old iron mine workings cause environmental or engineering problems. Such is the case of the underground Clinton mines at Lakemont in Blair County which prompted extensive subsurface investigations during the construction of new U. S. Route 220 around Altoona (Inners and others, 1985). On the positive side, abandoned Clinton iron workings are providing a municipal water supply to the borough of Everett in Bedford County.

The author thanks Jon D. Inners for providing the photographs used in this paper.

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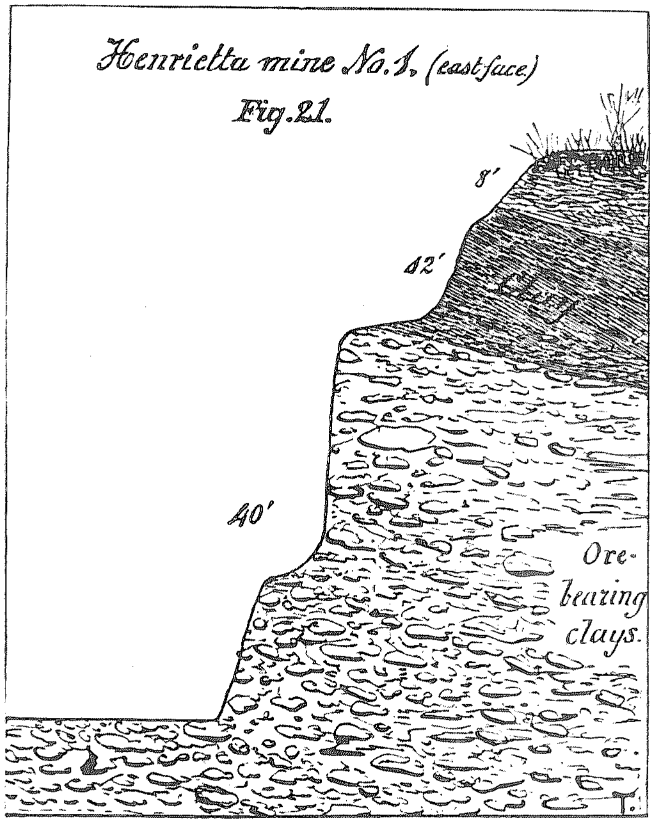

Henrietta mine, from Platt, 1881, p. 189.

PETER SHOENBERGER, IRONMASTER OF THE JUNIATA

by

Alton M. Sternagle
PennDOT, Hollidaysburg
Jon D. Inners
Pennsylvania Geological Survey

Of the many ironmasters who gave "Juniata iron" such a high reputation during the middle years of the nineteenth century, none was more enterprising and successful than Dr. Peter Shoenberger (Figure 25). Although we of today have all but forgotten his contributions, he was widely admired by his contemporaries and by the next generation of industrialists. Andrew Carnegie, founder of U.S. Steel and the archetypal entrepreneur of the "Gilded Age", is reputed to have said, "...old Dr. Shoenberger, who became the great ironmaster of his times, I have always considered him my predecessor. He was to the iron industry what I later became to the steel..."

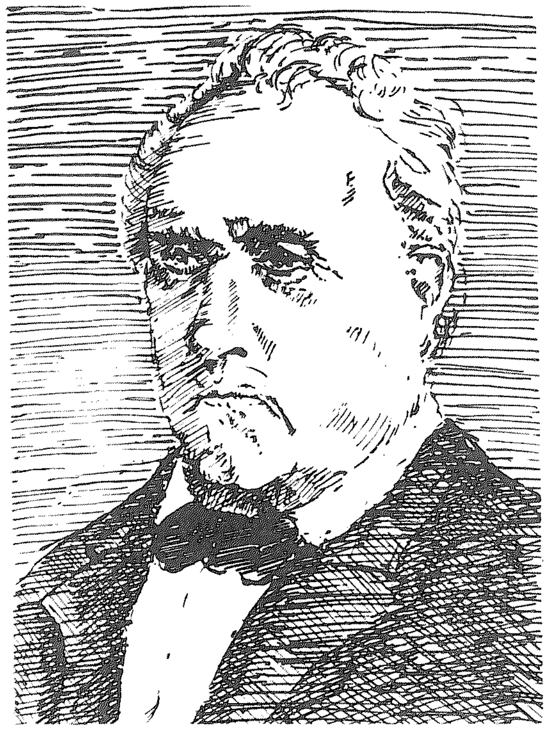

Figure 25. Dr. Peter Shoenberger (1782-1854). (Sketched by Mary Ann Miles from a photograph.)

Who was this man Shoenberger? Little is known of his early life; in fact his very birthplace is a mystery. Most biographical sketches state that he was born in Lancaster County on October 16, 1782. But other information indicates that his father George Shoenberger did not arrive in this country from Germany until August of 1785, suggesting that Peter must have been born in the "old country". Although his father apparently became involved in the iron trade not long after coming to America, the young Peter was attracted to medicine. He apprenticed under one of Lancaster's leading physicians - probably Dr. Samuel Fahnestock, who shared the elder Shoenberger's interest in metallurgy - and some time in the first or second decade of the nineteenth century moved to Pittsburgh to establish a practice.

Meanwhile George Shoenberger relocated to Huntingdon County where in about 1800 he bought Huntingdon furnace (Figure 26) on Warrior's Mark Run. He also reportedly obtained partial or complete ownership of Juniata forge near Petersburg on the Juniata River at about the same time.

Figure 26. Huntingdon furnace stack, Franklin Township, Huntingdon County. Originally erected in 1795-96, the furnace was later moved to this site from a point nearer the ore banks 2 miles to the west. George Shoenberger was associated with this furnace from its original construction and later acquired full ownership.

In 1815 the elder Shoenberger died, and Peter moved temporarily to Petersburg to run his father's iron businesses, which now included not only the above named operations but several other charcoal blast furnaces as well. Once his interest was whetted, he soon abandoned the stethoscope and scalpel for the crucible and forge-hammer. In the 1820's, attracted by the abundant "brown ores" of Morrison's Cove, Shoenberger began buying up large tracts of land in Blair, Huntingdon, and Bedford Counties, eventually owning more than 100,000 acres. In 1824 he moved back to Pittsburgh.

Although his empire soon spread to the far reaches of the commonwealth, the highest quality "Shoenberger iron" was still associated with the many relatively small iron works in the Juniata region. These included many furnaces and forges within the present limits of Blair County; i.e. Rebecca furnace (built in 1817) on Clover Creek near Fredericksburg, the Rodman furnaces (upper and lower Marie) (1828 and 1832, respectively) in McKee's Gap near Roaring Spring, Allegheny forge near Duncansville, and Sarah furnace (1831) near Sproul. He also operated Bloomfield furnace and mines near Ore Hill and Elizabeth furnace (1827) near Woodbury, both just over the line in Bedford County. The latter was moved twice, first to Bloomfield in 1847 and later to Rodman, where it became the Middle Marie furnace. (Wrought iron blooms from the forges were hauled to Pittsburgh where they were drawn into bars and rolled into plates at

Shoenberger's Juniata Iron Works). Following an old custom of Pennsylvania's ironmasters, Shoenberger named many of these furnaces and forges after his wife (Sarah) and daughters (Rebecca, Marie, and Elizabeth).

In addition to these Juniata Valley enterprises, Shoenberger owned or had part interest in Marietta anthracite furnace (1848) in Lancaster County, 4 charcoal furnaces in Cambria County, Sharon furnace (1846) in Mercer County, the before-mentioned Juniata Iron Works and rolling mill (later absorbed by U. S. Steel Corporation) in Pittsburgh, and a blast furnace in Wheeling, West Virginia. Probably his last venture was the founding - with George King - of the Cambria Iron Company (1852) in Johnstown.

His estate also included other tracts of land which furnished iron ore, wood for charcoal, coal for coke, and limestone for flux. These lands also contained numerous streams to provide the necessary water power for iron-making processes. He invested heavily in bridges, railroads, and turnpikes; and by acquiring large land holdings in Ohio and Kentucky, he extended his influence beyond the borders of Pennsylvania. For more than a quarter of a century Shoenberger survived one after another of the depressions that periodically rocked the iron industry. The exact value of his combined businesses and properties is not known, but it has been estimated as high as $4 or 5 million (in mid-nineteenth century dollars!).

After Dr. Shoenberger's death on June 18, 1854 (while on a business trip to Marietta Furnace), each of his surviving children inherited an iron furnace and a forge. One daughter (Elizabeth Shoenberger Lytle, the most estute and financially able of his offspring) inherited 33,000 acres in Blair, Bedford, Huntingdon, and Cambria Counties. Most of his heirs eventually moved from Blair County; but Oak Lawn Manor, the home he had built for Elizabeth still stands near the site of Rebecca furnace (Figure 27). Although his 3 sons met with considerable success in their inherited industries, none displayed the entrepreneural vigor that drove Peter Shoenberger to establish his once-famous iron empire.

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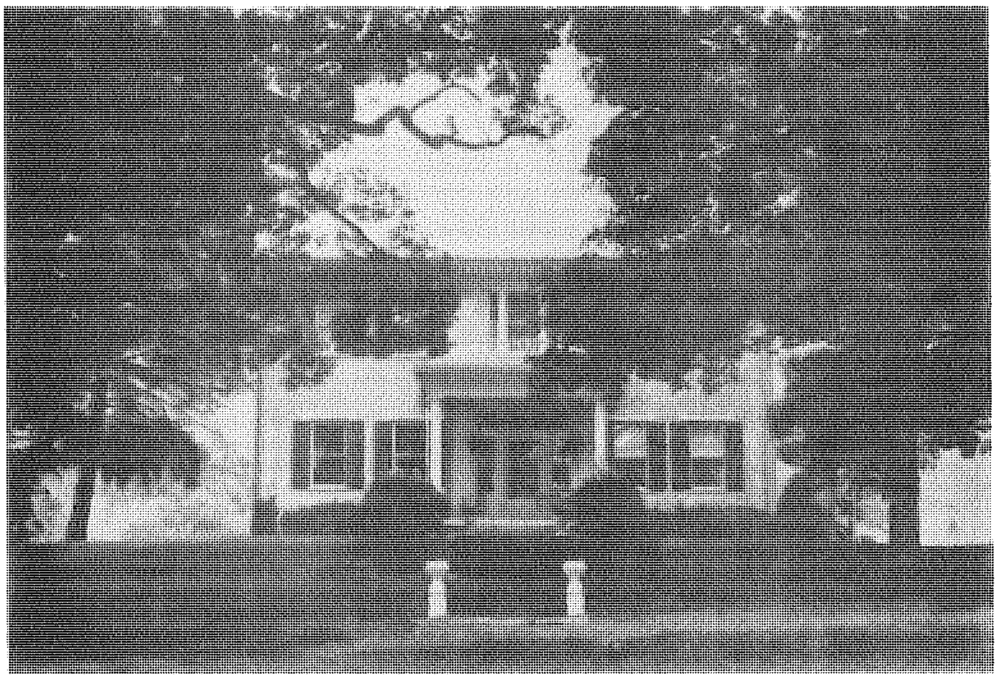
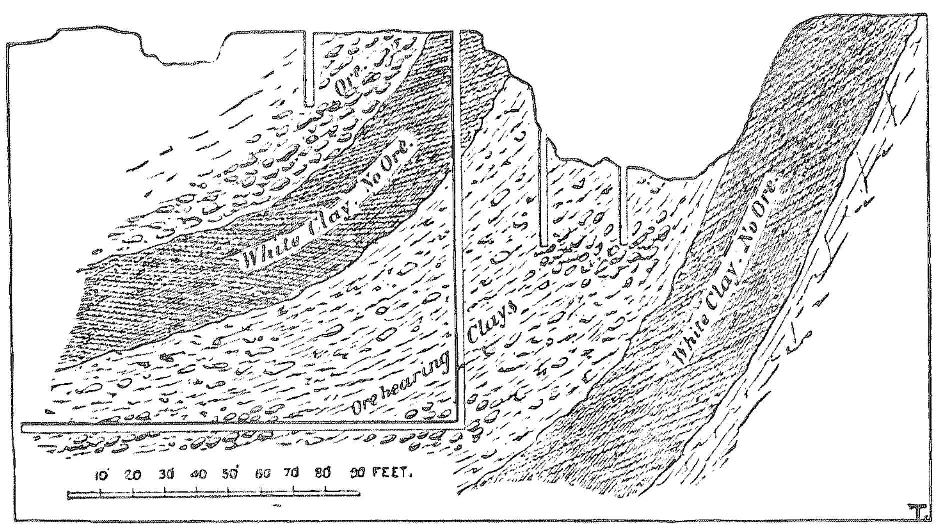


Figure 27. Oak Lawn Manor, built in about 1840 on Clover Creek near Rebecca furnace, Huston Township, Blair County. This was the home of Shoenberger's daughter Elizabeth Lytle until her death in 1893 at the age of 86.

Fig. 27.

Rebecca Ore Mine.



Cross section of Rebecca ore mine from Platt, 1881, p. 225.

DETAILED CORRELATIONS ACROSS 175 MILES OF THE VALLEY AND RIDGE OF PENNSYLVANIA USING 7 ASH BEDS IN THE TIOGA ZONE

by
John H. Way and Robert C. Smith, II
Pennsylvania Geological Survey
Mary Roden
Rennselaer Polytechnic Institute

INTRODUCTION

During the past century and a half, most of the effort of Pennsylvania's 4 successive geologic surveys has been devoted to field investigations, a large part of which involved describing and compiling data on the sedimentary rocks in the state. To that accumulated body of descriptive stratigraphy, considerable data has been added from the subsurface as a result of oil and gas exploration. From this progressive accumulation of knowledge, a reasonably comprehensive picture of the Paleozoic sedimentary package for Pennsylvania has emerged (Berg and others, 1980; Berg and others, 1983).

The first formal investigations in Pennsylvania and surrounding states, which laid the foundations for all succeeding work, turned out to be remarkably sound. These were carried out by some of the best geological minds of the time; James D. Dana, James Hall, Henry Darwin and William Barton Rogers, and Lardner Vanuxem, among others.

A large portion of the earliest summary report on the geology of Pennsylvania, prepared by H. D. Rogers (1858), the first State Geologist, was devoted to "... the full classification and detailed description of the Appalachian Palaeozoic formations" (p. 59,60). Evaluating this state's strata with comparable sequences in Europe, he recognized 4 of the 5 "... great European divisions of Palaeozoic time ...," namely the Cambrian, Silurian, Devonian, and Carboniferous ages, as occurring in Pennsylvania (p. 60). Rogers divided the state's Paleozoic sequence into 15 series, using terms that were later described as "... a bizarre, Bizantine (sic) Latin nomenclature..." (Willard, 1939, p. 4), and further subdivided these into numerous formations. Using the prevailing terminology for the 3 generic classes of sedimentary rocks - sandstones, slates, and limestones, he correlated these units with those described in neighboring New York by Professor James Hall. Despite the somewhat archaic terminology, many of Rogers' divisions are, with minor changes, valid today, and his "... correlations of Pennsylvania's rocks with extraterritorial sections show a wide and accurate appreciation of Appalachian stratigraphy" (Willard, 1939, p. 6).

Demonstrating equivalency of mappable stratigraphic units, i.e., correlation, was an essential element in the work of Rogers and nearly all of those that followed. To these scientists of earlier generations, equivalency was stated in terms of geologic age. They had been trained to think of rock units and paleontological assemblages as being bounded by synchronous surfaces. Today, however, geologists are aware that rock units often cross time lines. Recognition of those units that are, in fact, synchronous enables the establishment of a time-stratigraphic framework essential in understanding the stratigraphy and geologic history of a region.

This manuscript is concerned with a stratigraphic interval comprising the upper Onondaga and lower Marcellus Formations that is exposed in several man-made cuts in the area covered by this year's conference. For various reasons, we will not be able to visit these exposures. The ash beds occurring within this interval are key horizons in correlating between stratigraphic sections. For example, 20 bentonite beds are present in the Upper Ordovician Union Furnace section at Stop 1 of this trip. These have been used as the basis of correlation within this stratigraphic interval for the last 50 years. The Tioga ash-bed zone has recently proven to be an important thread that has been woven into today's understanding of the fabric of Middle Devonian stratigraphy. This stratigraphic interval has some interesting historical significance. For the most part, the lower part of the interval, the Onondaga Formation, went unrecognized in Pennsylvania until the early 1900's (see Frontispiece). Because of the historical emphasis given to this year's Field Conference, it is interesting at times to reflect upon our nineteenth-century predecessors and their understanding of depositional settings and methods of correlation compared to those concepts and technological innovations available to geologists today. We continue striving to achieve Rogers' goal, the full classification and detailed description of the Appalachaian Paleozoic formations.

STRATIGRAPHIC INTERVAL

The Tioga ash zone in the central Pennsylvania region is enclosed in the Devonian Onondaga and Marcellus Formations and their equivalent units. In his early treatment of Pennsylvania stratigraphy, Rogers (1858, p. 107, 279) applied the names "Cadent Lower Black Slate (Cadent Series) " to rocks that equate with the "Marcellus Slate" of New York, and the "Post-Meridian Limestone (Post Meridian Series)" to those that are equivalent to the Onondaga and Corniferous limestones of the New York Geologic Survey. Rogers (1858, p. 138) refers to some of the Cadent formations as" ... among the most astonishingly persistent of all the Appalachian Palaeozoic deposits." In contrast, however, he states that the Post-Meridian Limestone is "... of insignificant extent in Pennsylvania, and exerts little influence on the physical features, and contributes almost nothing to the resources of the state" (Rogers, 1858, p. 279).

Early in the history of American geology, the Onondaga was recognized as an important datum plane in New York. Amos Eaton, geological surveyor for the Hon. Stephan Van Rensselaer, wrote of the lime-rock he called corniferous:

> "Its characters are so unequivocal, that it is recognized at sight throughout its whole line, of about five hundred miles. ...I use this rock as the line of reference for other strata; as strangers in New York City use Broadway as a place of reference for other streets. ... its vast extent and the important disposition it holds among North American rocks, will make it very useful to geological surveyors" (Eaton, 1839, p. 61, 62, 64).

However, according to most papers of that era dealing with the Devonian in the Allegheny region, the formation barely extends south from New York into New Jersey and Pennsylvania.

Later, county reports of the Second Pennsylvania Geological Survey that dealt with the Devonian sequences within the folded belt included the beds immediately overlying the Oriskany sandstone (the Meridian Sandstone of Rogers, 1858) in the Marcellus Formation. Running counter to this trend, one early paper by Ashburner (1877) refers to the shale and limestone beds at the base of the Marcellus as the "Upper Helderberg (Post Meridian)" limestone, or Onondaga.

However, in spite of this report and the fact that some of Ashburner's contemporaries included the "Corniferous" (Onondaga) in descriptions of measured sections from within the state, Claypole (1885, p. 64) stated emphatically that, based upon paleontological evidence, this interval was absent, and placed the shales and limestones above the Oriskany in the Marcellus Formation. Those that followed seemed to have acquiesced to Claypole's formidible opinions, and it was not until Kindle (1912) published his descriptive sections and faunal lists for the New York to Virginia region that the Onondaga was proven to be present in Pennsylvania.

Fettke's Tioga Bentonite

The recorded history of the name "Tioga Bentonite" began in the early 1930's with the opening of the Tioga gas field in north-central Pennsylvania (Fettke, 1952). C. R. Fettke (1952, p. 2039) originally proposed the name Tioga bentonite for the

> "... thin, but persistent seam of brown micaceous bentonitic shale occurring at or near the boundary between the Hamilton group and the Onondaga formation because it was first observed in drill cuttings from the Tioga gas field in Tioga County, Pennsylvania."

Because the Tully and the Onondaga limestones had been mistaken for each other in that area, Fettke (1931, p. 8) sought to distinguish the Onondaga in his description of cuttings from the Shoemaker well as follows:

> "The Onondaga ... is only a thin limestone in the Tioga region and after the first or second screw [a "screw" was less than or equal to 6 feet] has been drilled into it, the cuttings almost invariably contain particles of a brown shale which is present in the basal portion. These brown particles are easily recognized if the cuttings are examined under water on a watch glass."

Following this initial discovery, he observed the brown micaceous shale in drill cuttings throughout the Appalachian Plateau in Pennsylvania and proceeded to call attention to its usefulness as a marker in subsurface studies (Ebright and others, 1949). Subsequently, he traced it into New York, Ohio, West Virginia, and Kentucky (Fettke, 1952, p. 2039).

Fettke believed that only one ash layer was present (1952, p. 2039). However, the cable-tool drilling technology at the time was such that depth measurements were not highly accurate. William Lytle, a co-worker of Fettke, emphasized that errors depended on how often the bailer was run (personal communication, 1/29/85). Fettke was reputed to be "as good as anyone," but methods still suggest that depth-measurement errors of 1 or 2 screws (+/- 6 to 12 feet) are possible in the 17-foot-thick Onondaga Limestone of the Tioga gas field (Fettke, 1931, p. 5).

Rather than arbitrarily apply the name Tioga to one particular ash layer, and thereby imply a precision not possible with a cable-tool drill, the present authors have attempted to follow the lead of the classical workers on the Ordovician bentonites and to designate the persistent individual ash layers with letters, bed A being the lowest, and bed G the highest. Thus, the term Tioga ash zone is used by the present authors to include both volcanic and sedimentary beds "... at or near the boundary between the Hamilton group and the Onondaga formation" (Fettke, 1952, p. 2039).

The Tioga metabentonite was reported in outcrop in the Valley and Ridge Province by J. M. Dennison, first in West Virginia, and later throughout several contiguous states (Dennison, 1961). Subsequently, Dennison and Hasson (1976, p. 285) recognized "... a cluster of 3 sand-size tuff beds [within a generally tuffaceous interval] each 0.1 to 0.3 feet (0.03 to 0.09 m) thick and within an interval of about 2 feet (0.6 m)" and designated these as comprising the Tioga middle coarse zone. Prior to identifying the middle coarse zone, Dennison (1961, p. 10) proposed that the top of the Devonian Onesquethaw Stage in the Appalachian basin be defined by the Tioga metabentonite. Later, however, this definition was revised and the top of the middle coarse zone became this boundary (Dennison and Head, 1975, p. 1106). The present authors presume that the top of Dennison's middle coarse zone corresponds either to the top of bed F or bed B, using the present terminology. Several other workers recognized ash beds at approximately this stratigraphic horizon to the west and northwest of the Appalachian basin and have correlated these with the Tioga, extending the influence of the volcanic eruptions responsible for the Tioga ash beds into the Illinois and Michigan basins, and into southern Ontario (Meents and Swann, 1965; Droste and Shaver, 1975; Sanford, 1967).

Regional stratigraphic and petrologic analyses of the Tioga within the Valley and Ridge from Tennessee to Pennsylvania are summarized by Dennison and Textoris (1978). Based upon their grain-size and isopach data, they identified the Berea pluton, located 6 miles northwest of Fredericksburg, Virginia, as a possible source for the Tioga eruptions.

Most recently, a monograph published by Conkin and Conkin (1984) presents a protracted summary of their work with the Devonian metabentonites and the enclosing Paleozoic stratigraphy. They have assigned separate names to the different ash beds, e.g., the First and Second Cheektowaga Bentonites, the Onondaga Indian Nation Bentonite, and the Tioga Bentonite (restricted). The last 2 of these are presumably comparable to the present authors' ash beds B and F, respectively (Smith and Way, 1983). However, the Conkin-and-Conklin approach to the Tioga ash-bed sequence tends to isolate each bed, focusing on its individuality without giving consideration to the entire sequence and the relationship of each bed to that sequence.

Understanding of the Tioga interval gradually has evolved from 1 ash bed (Fettke, 1952; Dennison, 1961), to 3 or 4 (Dennison and Hasson, 1976), and now to 6 or more (Way and Smith, 1985). The fact that the "Tioga" comprises several ash beds went unrecognized for many years, thus resulting in some miscorrelations. Conkin and Conkin (1984), failing to put this improved resolution into perspective, claim to be the sole authorities on this stratigraphic interval:

> "The almost inconceivable stratigraphic misinterpretation, that the Tioga Metabentonite (restricted), in the base of the I Zone of the Delaware (the Marcellus of New York), is 14 meters (45 feet) below the "base of the Devonian shales" in Ohio (interpreted to mean Marcellus Shale by Smith and Way (1983, in Nichelsen [sic] and Cotter, p. 76) was the direct result of Oliver's (1954 to present) misidentification of the late Onesquethawan Onondaga Indian Nation Metabentonite of New York with early Cazenovian Tioga Metabentonite (restricted) of the subsurface of Tioga County, northern Pennsylvania, and of the surface and subsurface of the Appalachian Mountains and Oliver's (1954 to present) reverse misidentification of the Tioga Metabentonite (restricted) of northern and central Ohio with the Onondaga Indian Nation Metabentonite of New York; this is, indeed, a tangled stratigraphic web, but a pitfall into which

all workers (except Conkin and Conkin, 1975b to present) have become trapped" (Conkin and Conkin, 1984, p. 32).

PRESENT STUDY

Smith and Way (1983) recognized 6 ash beds at Selinsgrove Junction, Northumberland County, 3 more than had been described from this locality by previous workers. This analysis suggested that a detailed examination of this horizon at other localities could improve understanding of the stratigraphy and sedimentation of this interval. In addition, it seemed that more precise stratigraphic correlations across the Valley and Ridge outcrop belt were possible using these Middle Devonian ash beds as hyperfine time lines.

The easily weathered lithologies, combined with colluvial and vegetation cover, generally result in the Upper Onondaga/Lower Marcellus interval being poorly exposed throughout the province. Faulting, folding, or slumping at several localities account for missing and repeated section. At the Susquehanna River gap north of Harrisburg, the Onondaga is missing entirely, and a thin remnant of Marcellus rests unconformably upon Silurian Bloomsburg redbeds (Williard, 1939, p. 148).

To date, field work has consisted of the excavation, sampling, and detailed description of 11 nearly complete sections of the Tioga ash-bed zone within Pennsylvania (Figure 28). Mineral separations and thin-section, X-ray diffraction, flame- emission and atomic-absorption analyses have been performed on these samples in the Pennsylvania Geological Survey's laboratory. In addition, fission-track ages have been determined on apatite crystals that were concentrated from samples of bed B from all our localities as part of a regional study being carried out by M. Roden and Donald Miller of Rensselaer Polytechnic Institute.

Generalized Field Observations

Six ash beds and laminae, A through F, are readily identifiable in most good exposures. Beds B, D, and F are usually thicker than the others, with bed B consistently the thickest (Table 3).

Several of the ash beds have a field-recognizable character throughout the outcrop belt. In addition to its persistence and greater thickness, bed B usually consists of 2 parts: a lower, coarser grained, micaceous base that is overlain by a claystone. Such claystone might represent pumice that floated in the sea for some time prior to final deposition. Several millimeter-thick laminae, each separated by several millimeters of barren mudstone, characterize bed E; as many as 4 distinct ash laminae within a 3.5-cm-thick vertical section have been observed. Preservation of such thin laminae over large areas suggests an extremely low-energy depositional environment. Bed F usually contains the greatest amount of pyrite. At some locations, the lower part of the bed has been largely pyritized; fist-size masses of pyrite frequently weather out from the base of bed F. When it is observed, bed G contains angular, white-to-gray grains of feldspar up to 0.5 mm.

Most of the beds have sharply defined contacts. In only a few instances is there a gradational upper contact. Ash-bed thicknesses alternate between thin and thick with apparent consistency throughout the outcrop belt (Table 3).

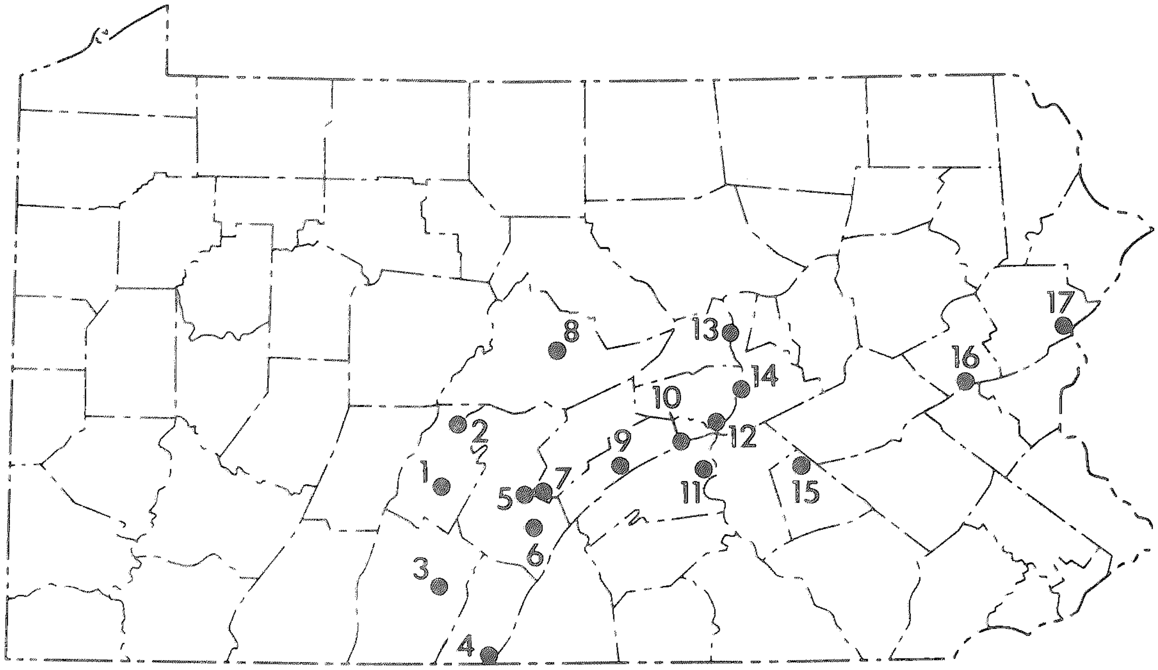


Figure 28. Map showing the location of 17 measured stratigraphic sections containing the Tioga ash-bed zone within the Valley and Ridge province of central Pennsylvania. From west to east, numbers refer to the following sections: 1) Frankstown, 2) Grazierville, 3) Everett, 4) Dickey's Mountain, 5) Mapleton, 6) Orbisonia, 7) Newton Hamilton, 8) Curtin Gap, 9) Ol Port, 10) Wardville, 11) Midway, 12) Mahantango Creek, 13) Zeigler Pit, 14) Selinsgrove Junction, 15) Swatara Gap, 16) West Bowmans, and 17) East Stroudsburg.

Coarse-grained, subhedral-to-euhedral biotite is one of the diagnostic characteristics of all the ash beds in the field. Large concentrations of sharp, euhedral, acicular zircon crystals, often containing clear, tubular inclusions oriented parallel to the C-axis (Figure 29), and euhedral-to-subhedral, stubby apatite crystals (Figure 30) are readily observable in heavy-mineral concentrates, and are also considered diagnostic in the identification of ash beds.

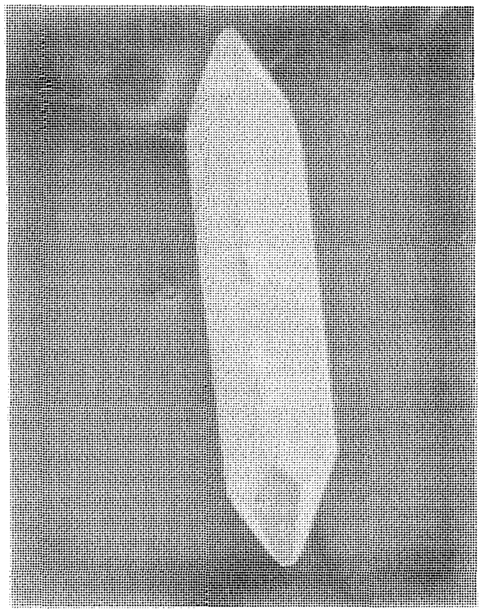
Stratigraphic Section at Frankstown

An excellent example of the detail that is observable within the Tioga ash zone occurs in a measured stratigraphic section (Figure 31) from an inactive quarry of the General Refractory Company at Frankstown, just east of Hollidaysburg. Here, 12 ash beds, ranging in thickness from 2 mm to 23.5 cm were excavated. Beds A through G were identified, as were additional beds below this sequence. All but 2 ash beds occur in the mudstones and fissile shales of the Marcellus Formation above the uppermost resistant limestone bed. (Several thin, dark-gray to black, unctious clay beds are present in the lowermost part of the black shales; these could represent the insoluble residue from calcareous mudstones - see below.)

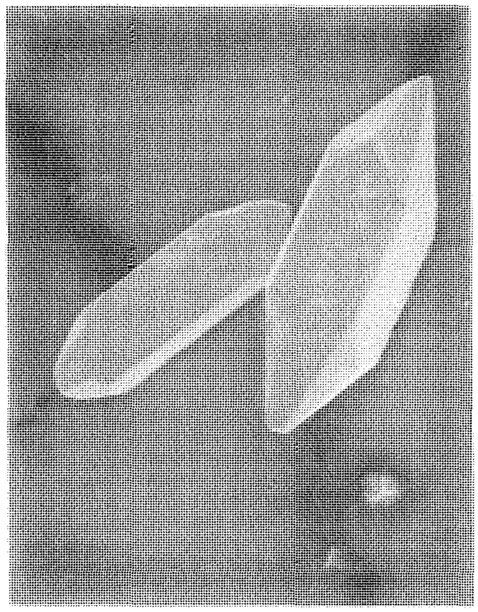
Table 3. Thicknesses in centimeters of ash beds and intervening sedimentary units in 17 measured stratigraphic sections in the Valley and Ridge province of central Pennsylvania.

ASH BEDS	FRANKSTOWN	GRAZIERVILLE	EVERETT	DICKEY'S MOUNTAIN	MAPLETON	ORBISONIA	NEWTON HAMILTON	CURTIN GAP	OLD PORT (P44)	WARDVILLE	MIDWAY	MAHANTANGO CREEK	ZEIGLER PIT	SELINSGROVE JUNCTION	SWATARA GAP	WEST BOWMANS	EAST STROUDSBURG	ASH BEDS
H													0.1					H
													31.1					
G	1.1 0.2						0.8	0.4	0.2		3. 3.5 3.		2.3		6.	2.5 2. 1.		G
	3.						15.	37.	18.		70.		1.		30.	4.		
F	9.5	9.			6.		5.2	13.	15.5	F? 23.	17.	3.	6.7	14.	10.	1. 5.		F
	100.	34.			220.		57.	188.	34.		60.		22.	262.	28.	53.		
E	1.2 8. 0.6	0.3		fault	fault		0.3	0.4 42. 0.7	0.3		0.8		0.7	0.8	1.	2.5		E
	10.	79.				fold -	16.	34.	60.		135.		27.	26.	57.	360.		
D	9.	7.5			9.	no additional exposure	11.	9.	10.		0.4		11.	9.	1.	9.		D
	26.	140.			2.5		18.	17.	25.	98.	180.	825.	8.5	12.	78.	170.		
C	1.4 0.2	0.2			0.8		0.3	0.8	0.4		2.2		1.9	0.8	5.	18.5		C
	120.	33.	45.		180.		184.	95.	36.5		152.		29.5	122.	48.	113.		
B	23.5	20.	58.	*45.	17.	28.	25.	18.5	17.5	24.	27.5	\	27.5	20.	40.	32.5	50.	B
	27.	31.	39.	60.	105.	43.	38.	18.	43.	67.	44.	\	28.	164.	1.5	211.		
A	3.3	3.	3.	0.2	1.1	2.5	1.1	2.	2.	2.	2.	8.	1.	0.8	2.5	2.5		A
	175.			52.							68.	70.						
A -1	2.			0.4							2.	2.						A -1
	68.		fault								186.							
A -2	1.5										1.							A -2
	100.																	
A -3	2.																	A -3
A-F Zone	48.7	40.0	61.	45.2	33.9	30.5	42.9	44.4	45.7	49.	49.9	11.	48.8	45.4	59.5	71.0	50.	A-F Zone
A-F ZOI	339.7	357.0	145.	105.2	541.4	73.5	355.9	438.4	244.2	214.	620.9		163.8	631.4	272.0	978.0		A-F ZOI

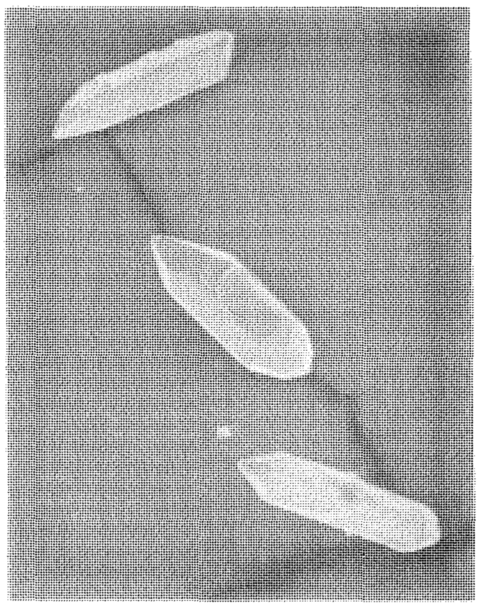
29-A



29-B



29-C



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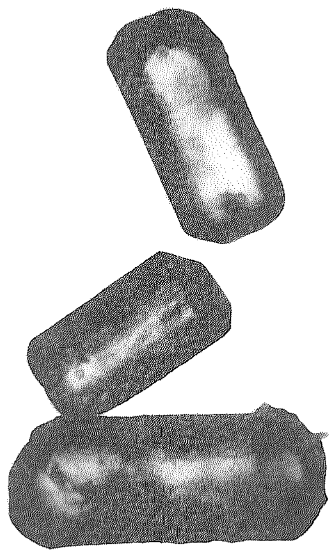


Figure 29. Scanning electron photomicrographs of zircon crystals from Tioga ash-bed B from three widely separated localities: A. Frankstown (265X), B. Midway (140X), C. West Bowmans (140X). Note the acicular, euhedral habit and the sharp edges of the crystals.

Figure 30. Photomicrograph of apatite crystals from a Tioga ash-bed-B concentrate from Grazierville. The subhedral-to-euhedral barrel-shape habit is typical for apatite in the Tioga ash beds.

The alternating, thin-thick aspect noted above is evident in the A-through-G sequence at Frankstown. And, as elsewhere, bed B is the thickest ash bed. The thinner beds, C, E, and G, are each made up of 2 smaller laminae in very close proximity, separated by non-micaceous interbeds ranging from 3 mm to 8 cm thick. Bed thicknesses along strike in the same outcrop vary slightly; slumping has produced additional variations here. However, there is little difference in the thickness of ash beds at Frankstown and Grazierville, less than 30 km apart in the same strike belt.

REGIONAL SYNTHESIS

Two composite diagrams, Figures 32 and 33, combine detailed stratigraphic data from 12 localities within the Valley and Ridge of central Pennsylvania. Two observations are perhaps worthy of note. First, the unctuous, sticky clay beds present in Swatara Gap (15) and West Bowmans (16) in Figure 32, and in Curtin Gap (8) and Zeigler Pit (13) in Figure 33, probably represent the insoluble residues of limy mudstones. Similar clay beds have been observed in highly weathered exposures of the Mandata Member of the Old Port Formation in central Pennsylvania. Second, single chert beds, noted in a few sections, tend to occur near ash bed C. At West Bowmans (16), however, at least 4 chert beds are present, and farther east at Stroudsburg (17), chert is the dominant host lithology. The observed chert appears to have replaced earlier deposited material.

Several stratigraphic and sedimentological interpretations of the data presented in Figures 32 and 33 are possible. The contact of the Onondaga Formation with the overlying Marcellus Formation, which represents a change from carbonate to clastic sedimentation, is traditionally marked by a sharp, conformable limestone-to-black-shale transition. As expected, this lithologic contact is not synchronous across the basin. Perhaps somewhat surprising is the fact that the contact does not become substantially younger to the west. Indeed, the oldest lithologically based contact is at Frankstown, the westernmost locality. Thus, the contact actually appears to become younger to the east.

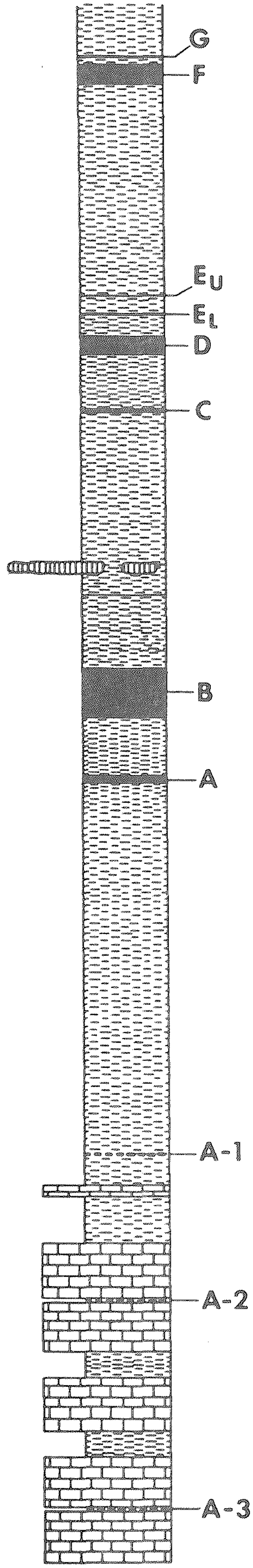
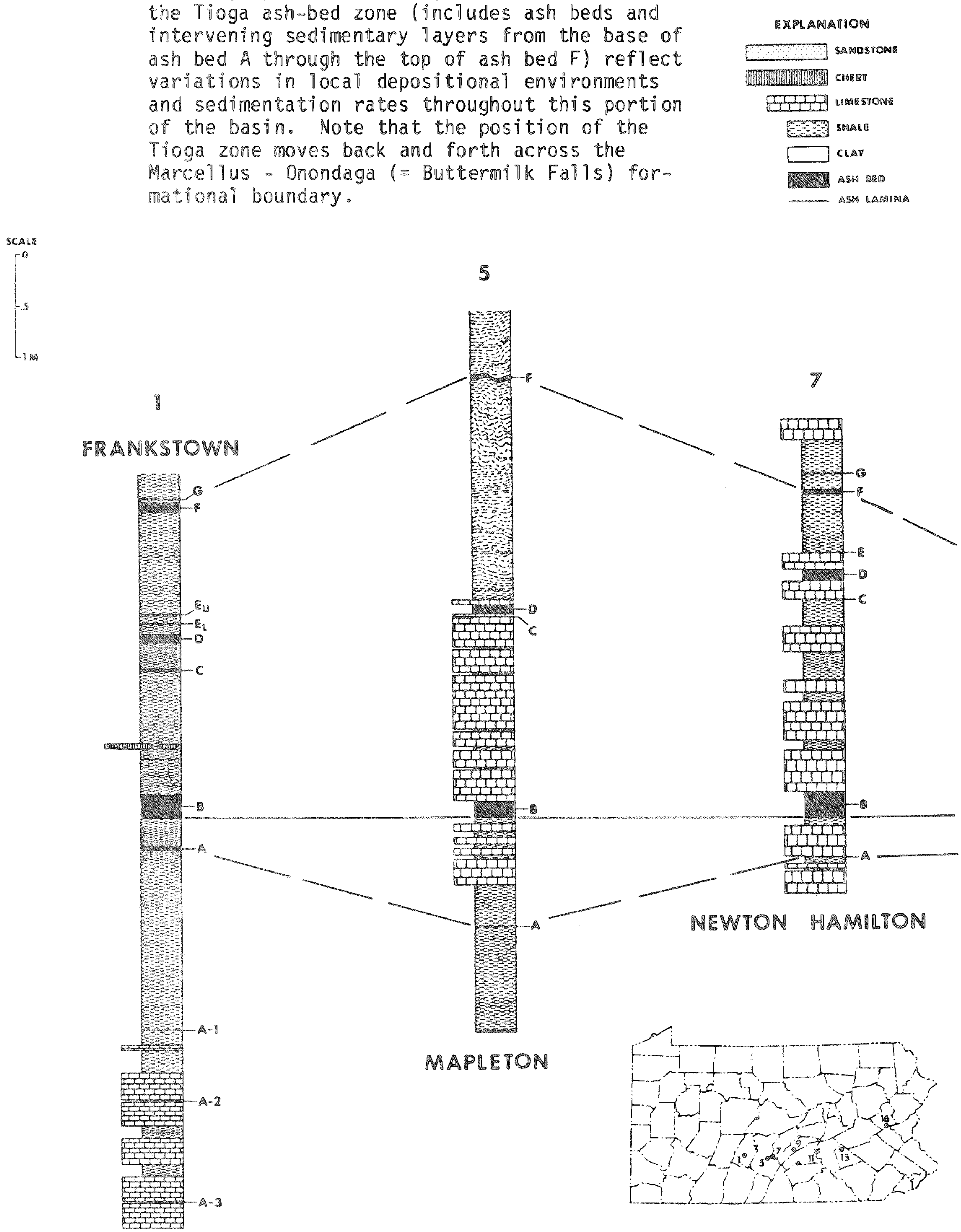


Figure 31. Measured stratigraphic section containing the Tioga ash-bed zone from General Refractories quarry near Frankstown, Blair County, Pa. (40°26'03"N; 78°20'43"W). In addition to the beds usually identified from this zone (A, B, C, D, F, and G), bed E is present as 2 thin laminae; there is a thin ash lamina between C and B; and three ash-influenced beds occur well below A. Here, ash beds A through G are contained within the black shales of the Marcellus Formation, whereas 25 km to the north at Grazierville, most of the ash-bed zone is contained within the limestones of the Onondaga Formation (see Figure 32).

Figure 32. West-east line of 7 measured stratigraphic sections (1, 5, 7, 9, 11, 15, 16) across the Valley and Ridge province. Changes in the thickness of the Tioga ash-bed zone (includes ash beds and intervening sedimentary layers from the base of ash bed A through the top of ash bed F) reflect variations in local depositional environments and sedimentation rates throughout this portion of the basin. Note that the position of the Tioga zone moves back and forth across the Marcellus - Onondaga (= Buttermilk Falls) formational boundary.



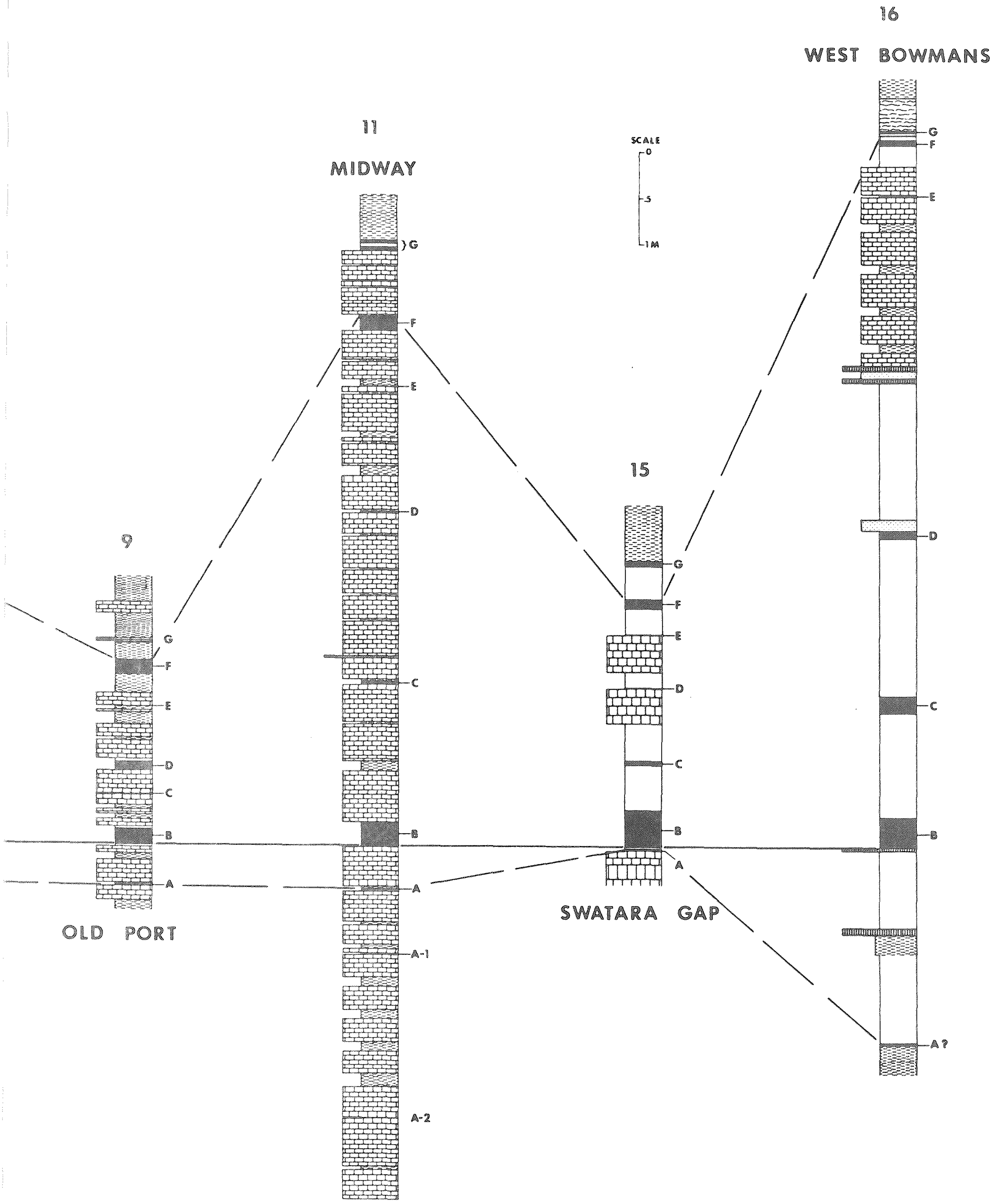
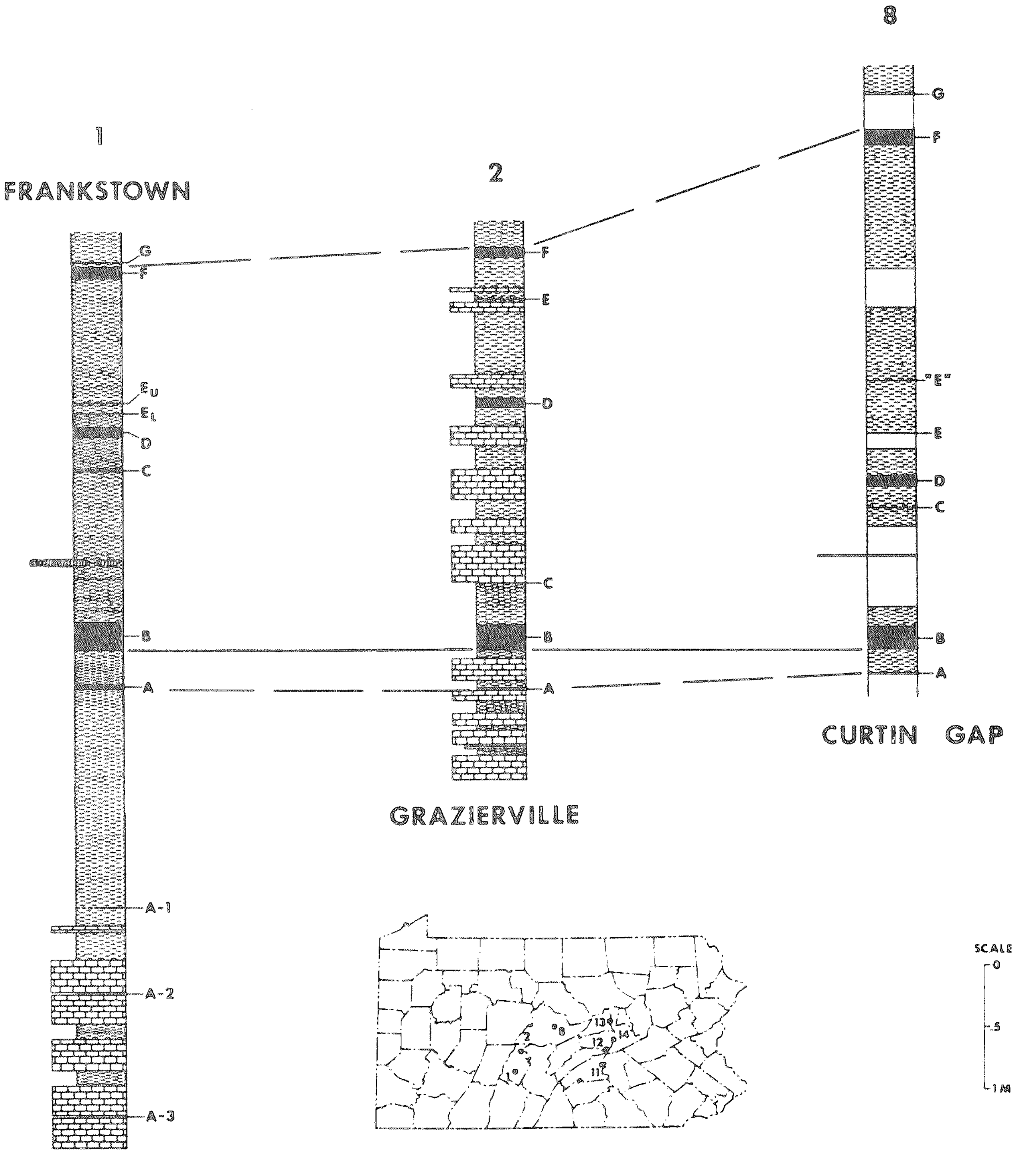
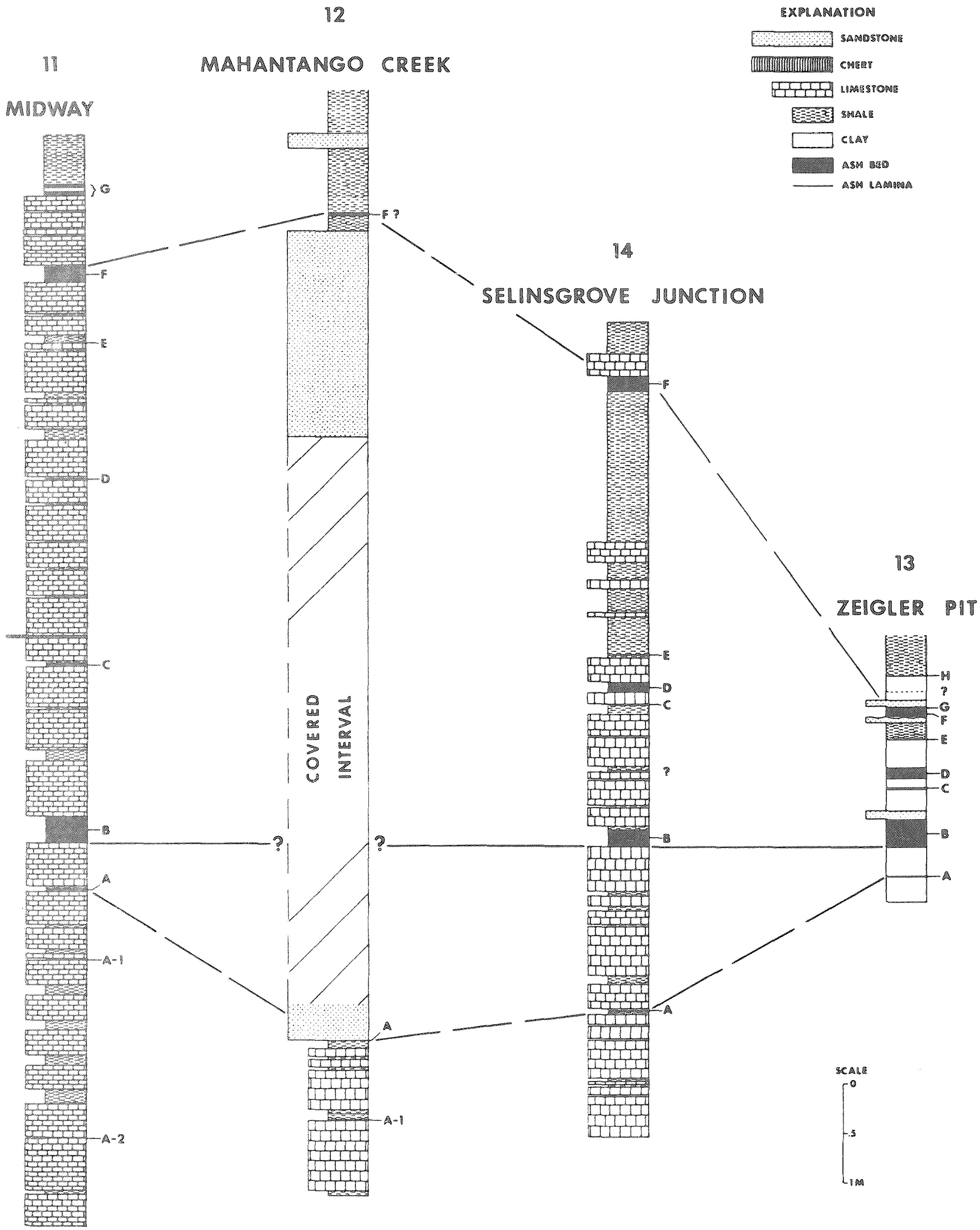

16
WEST BOWMANS
11
MIDWAY
SCALE
0
.5
1M
15
9
G
F
E
D
C
B
A
A-1
A-2
A ?
OLD PORT
SWATARA GAP

Figure 33. Two north-south lines of measured stratigraphic sections across the Valley and Ridge province. The westernmost line includes three sections (1, 2, 8) on the northwest limb of the major fold adjacent to the Allegheny topographic front. The host rock for the Tioga zone at Curtin Gap (8) and Frankstown (1) is black shale, mapped as the Marcellus Formation, whereas, at Grazierville, only the highest bed (F) occurs in the black shale, and the rest is interbedded with the limestones and shales of the Onondaga Formation.

The other line of 4 sections (13, 14, 12, 11) runs along the Susquehanna River. Most notable among these sections is Mahantango Creek (12) and the occurrence there of a prominent 8-meter-thick sandstone unit (see text). It lies directly on the Onondaga limestone beds and has been included in the basal Marcellus Formation (Hoskins, 1976; Faill, Hoskins, and Wells, 1978).





EXPLANATION
SANDSTONE
CHERT
LIMESTONE
SHALE
CLAY
ASH BED
ASH LAMINA
11
MIDWAY
G
F
E
D
C
B
A
A-1
A-2
12
MAHANTANGO CREEK
F ?
?
?
COVERED INTERVAL
A
A-1
14
SELINSGROVE JUNCTION
F
E
D
C
?
B
A
13
ZEIGLER PIT
H
?
G
F
E
D
C
B
A
SCALE
0
.5
1M

The hyperfine resolution of ash-bed details across tens and hundreds of kilometers suggests that deposition of this air-transported volcanic material occurred in a relatively large, quiet marine basin. Further, these materials probably accumulated below wave base (approximately 20 m below sea level).

Thin biotitic laminae and "lilac-colored" layers, observed at several localities, including Midway (11) and Frankstown (1), suggest a series of pre-ash-bed-A eruptions of limited duration and an ash coverage of modest areal extent. The multiple ash laminae associated with bed E, as mentioned earlier, also appear to record series of closely timed eruptions.

Lithofacies changes between sections reflect local variations in basin configuration and sedimentation patterns. For example, limestone serves as the host to most of the Tioga zone at Grazierville (2), whereas, to the north and south, black shales dominate throughout the sections (Figure 33). To the southeast, the great thickness of limestone at Midway (11) is somewhat enigmatic. More rapid basin subsidence here is possible. However, not far to the northeast, the Mahantango Creek section (12) contains a substantial thickness of sandstone, which is unique to this locality (Figure 33). These sandstones may represent shallow offshore bars that formed subparallel to the basin shoreline. The presence of an input center to the south-southeast that periodically supplied sediment to these bars in the north and abundant nutrients to the west cannot be ruled out.

Intricate details have been preserved in the Tioga ash zone, implying little if any erosion or disturbance to the ash beds. A relationship between preserved ash-bed thickness and the original thickness of ash deposition is deemed plausible. To further delineate patterns occurring during the time of deposition of the Tioga beds, three isopachous maps (Figures 34a, b, c) were drawn. Figure 34a shows the distribution and thickness of ash bed B in the study area. Because of its persistance, bed B has been selected as a datum for this study and is herein recommended for use in future chronostratigraphic studies.

The thickness of bed B generally increases toward the southeast (Figure 34a). Figure W7b, an isopachous map of the total thickness of Tioga ash beds A through F, shows a similar increase. (The thin stratigraphic section at Mapleton is located on the steep, deformed west limb of the Jacks Mountain anticline where local structural thinning is suspected.) Based on this thickness data, a source to the present south or southeast is postulated.

Assuming an average total-preserved ash thickness of 45 cm, an area of 57,950 km in a palinspastically restored Valley and Ridge province yields 26 km of preserved ash. In order to account for such a large volume of material, caldera collapse in the source area seems probable. Climatic change sufficient to stifle carbonate production and permit drowning of shallow-water facies appears to have occurred contemporaneously or shortly thereafter. As is the case for each of the 3 known ash zones in the Valley and Ridge (Upper Ordovician, Lower Devonian, Middle Devonian), the highest ash beds appear to be the harbingers of doom for carbonate-producing organisms and the signal of the beginning of large clastic influxes into the basin.

Narrow, irregular areas central to the basin, as outlined in Figure 34c, an isopachous map of the total thickness of the Tioga ash zone, are interpreted as

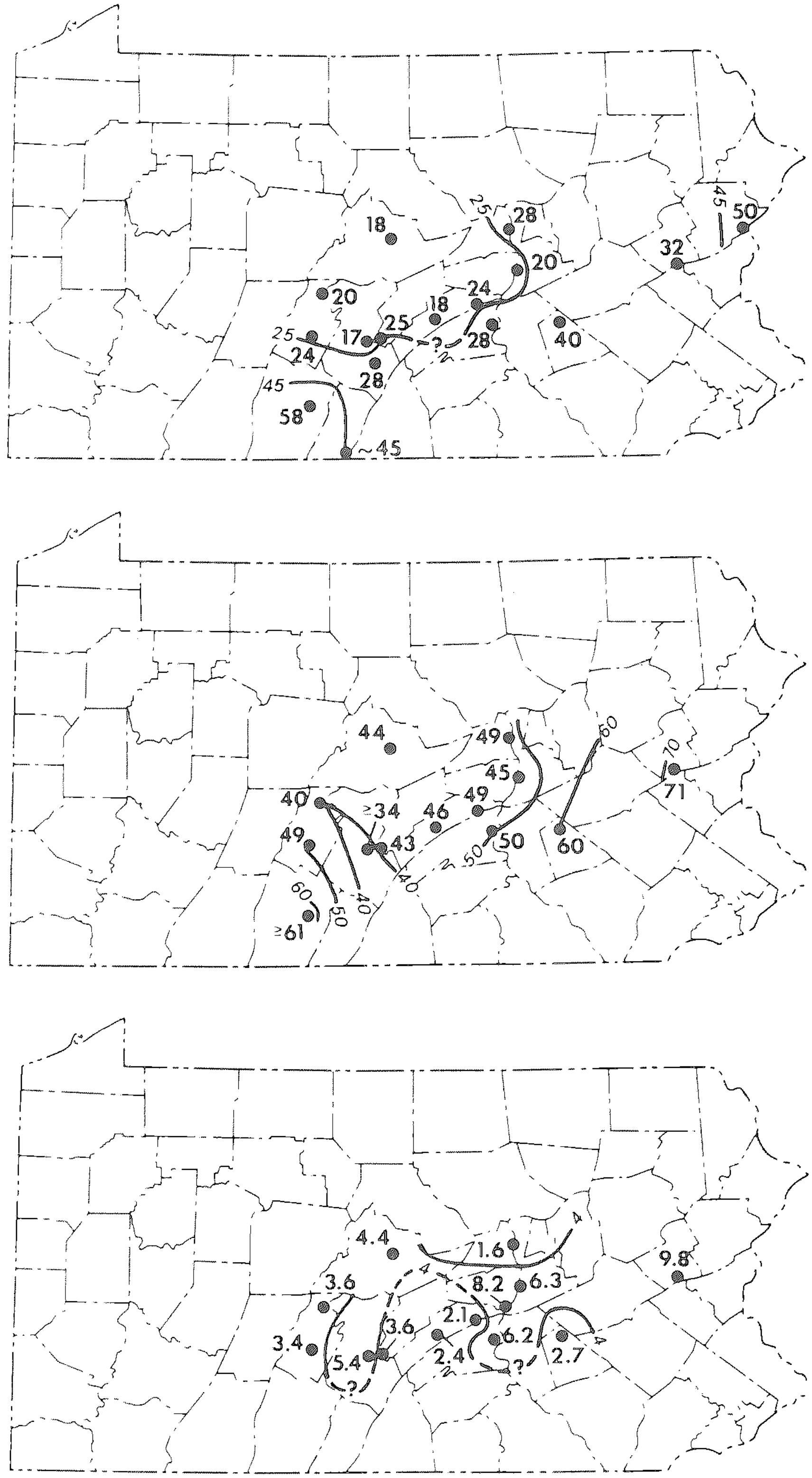


Figure 34. A. Isopachous map of Tioga ash bed B. Thicknesses in cm; contour lines are 25 cm and 45 cm.

B. Isopachous map of total thickness of Tioga ash beds A through F. Thicknesses in cm; contour lines are 40, 50, 60, and 70 cm.

C. Isopachous map of total thickness of the Tioga ash-bed zone (includes ash beds and intervening sedimentary layers from the base of ash bed A through the top of ash bed F). Thicknesses in meters; contour line at 4 m.

having the greatest rates of sediment accumulation or subsidence. These may correspond to deeper parts of the basin. Other data (Epstein, 1984) suggest more rapid development of carbonate-rich sediments and chert to the east.

FISSION-TRACK ANALYSES

Apatite ages from ash bed B were determined by fission-track analysis. Ages of 8 samples are reported here (Table 4). Seven samples from the main fold belt of the Valley and Ridge have an average apparent age of 223 +/- 14 Ma. These samples appear to have experienced a thermal history similar to that reported for Devonian sediments in central and western New York (Miller and Duddy, 1986).

Table 4. Apparent fission-track ages for apatites from ash bed B from eight Tioga ash-bed localities in central Pennsylvania (listed from west to east).

SAMPLE NUMBER	LOCATION	APPARENT FISSION-TRACK UNLOADING AGE (Ma)
8502-2	Grazierville	225 +/- 10
8500-4	Dickey's Mountain	228 +/- 12
8500-5	Mapleton	235 +/- 11
8500-2	Newton Hamilton	229 +/- 11
8500-1	Old Port	238 +/- 10
8500-3	Midway	208 +/- 10
8502-3	Selinsgrove Junction	199 +/- 9
84-92	Swatara Gap	153 +/- 6

The apatite fission-track dates represent the last time that Tioga ash bed B was buried deeply enough to anneal the scars (fission tracks) created by alpha particles from decay within the U238 series. In this area of Pennsylvania, such ages represent the time of unloading by erosion to near the present erosion surface. This 223 +/- 14 Ma date then, is a quantitative estimate of the last time the apatites were heated to 700°C for a geologically extended period. If a normal geothermal gradient of 200°C/1000 m and a temperature difference of 550°C are assumed, then an estimated 2.7 km of additional overburden at 222 Ma is reasonable. This, in turn, yields an estimate of erosion on the order of 1 cm / 1000 years.

The fission-track unloading age of the Tioga bed B apatite decreases from 223 +/- 14 Ma in the western part of the outcrop belt to 153 +/- 6 Ma at Swatara Gap in the east. This is consistent with the fission-track work done in New York on Devonian sediments (Miller and Duddy, 1986) and conodont alteration index (CAI) curves of Harris (1979), which indicate higher temperatures (greater burial) in eastern Pennsylvania.

Fission-track length distributions for apatites from the Tioga samples show bimodal frequency distributions with a small percentage of tracks shorter than 10 micrometers. This type of distribution can result from apatite being subjected to temperatures in the range of 700°C to 1250°C (partial annealing zone) during an extended period (80 to 100 Ma). The 153 +/- 6 Ma apatite fission-track age at Swatara Gap is consistent with an early Cretaceous uplift to the present level.

SUGGESTIONS FOR FURTHER RESEARCH

Data on the absolute age of deposition of the Paleozoic formations in the Valley and Ridge of Pennsylvania are sparse at best. It is suggested that zircons from the Upper Ordovician, Lower Devonian, and Middle Devonian bentonites and ash beds of Blair County be separated, sorted by habit, and isotopically dated. By limiting samples to those from the lowest possible metamorphic grade, a realistic interpretation of emplacement date should be possible.

Relative deposition rates of shale versus limestone within the Tioga ash zone should be calculated and interpreted to derive a more complete basin model. Correlations based on "the" Tioga ash should be reexamined.

Instrumental neutron activation analyses should be conducted first within the Valley and Ridge where there are relatively few uncertainties, and extended into adjacent portions of the basin, as done by Cullen-Lollis (p. 13-19) for the Upper Ordovician bentonites.

Finally, paleometeorologists may wish to examine the individual ash isopachous maps to attempt to infer wind directions during these brief periods of volcanic activity toward the end of the Middle Devonian. Perhaps some of these data will also be useful in paleo-latitude studies.

ACKNOWLEDGEMENTS

We wish to thank Jack B. Epstein, U. S. Geological Survey for information about the East Stroudsburg locality, and Donald M. Hoskins and Thomas M. Berg, Pennsylvania Geological Survey, for bringing the Mahantango Creek and Zeigler Pit locations respectively to our attention. John H. Barnes, Pennsylvania Geological Survey, provided the photomicrographs. Jay R. Hitchings, Foote Mineral Company, took the SEM photographs. John H. Barnes and Rodger T. Faill, Pennsylvania Geological Survey, critically reviewed the manuscript.

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CATSKILL SEDIMENTATION IN CENTRAL PENNSYLVANIA

by
Eugene G. Williams and Rudy L. Slingerland
The Pennsylvania State University

(This report is a summary of the
Ph.D. thesis by Victor Rahmanian [1979];
presented in more detail by Williams in 1985)

Strata of the upper Frasnian and Famennian age are exposed along two almost parallel, northeast-trending outcrop belts in central Pennsylvania: one along the northwest limb of the Broadtop syncline, and the other along the Allegheny Front in Centre, Blair, and Bedford Counties (Figure 35).

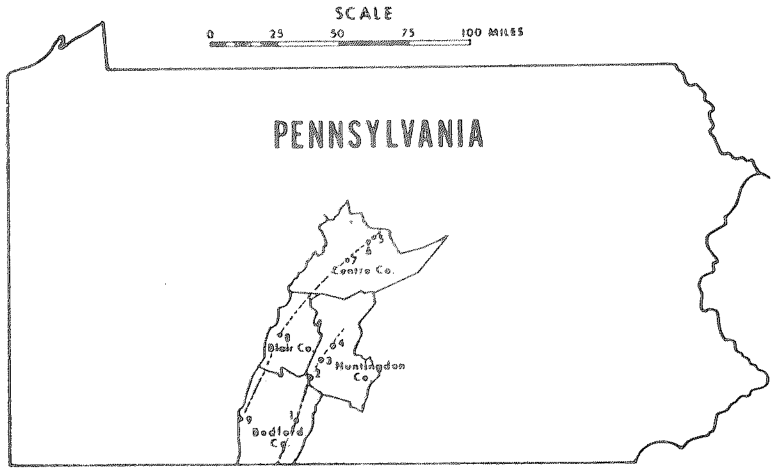

Figure 35. Index map of the study area. Numbers refer to measured sections (1-Everett, 2-Saxton, 3-Entriken, 4-Raystown Dam, 5-Milesburg, 6-Runfill, 7-Port Matilda, 8-Horseshoe Curve, 9-New Baltimore). Dashed lines show the position of the Upper Devonian Catskill-Trimmers Rock formational boundary along the west flank of the Broadtop synclinorium (sections 1-4) and the Allegheny Front (sections 5-9).

The strata presently are subdivided into 2 formations to the north (Lock Haven or Trimmers Rock and Catskill, Figure 36) and 3 to the south (Sherr, Foreknobs, Hampshire). They are the product of deposition in several environments identified as parts of the prograding Catskill coastline, the major ones being shallow-shelf/littoral, chenier-plain/tidal-flat, tidal-flat/barrier, shelf-delta, and a low slope alluvial plain.

The shallow-shelf/littoral facies is developed in the Lock Haven (Trimmers Rock) Formation, which underlies the Catskill Formation. These deposits consist of a sequence of thin- to medium-bedded, gray siltstone and olive-green to gray silty shale, interbedded with occasional thin layers of gray-green, very fine-grained sandstone layers which lower in the section are often hummocky cross-

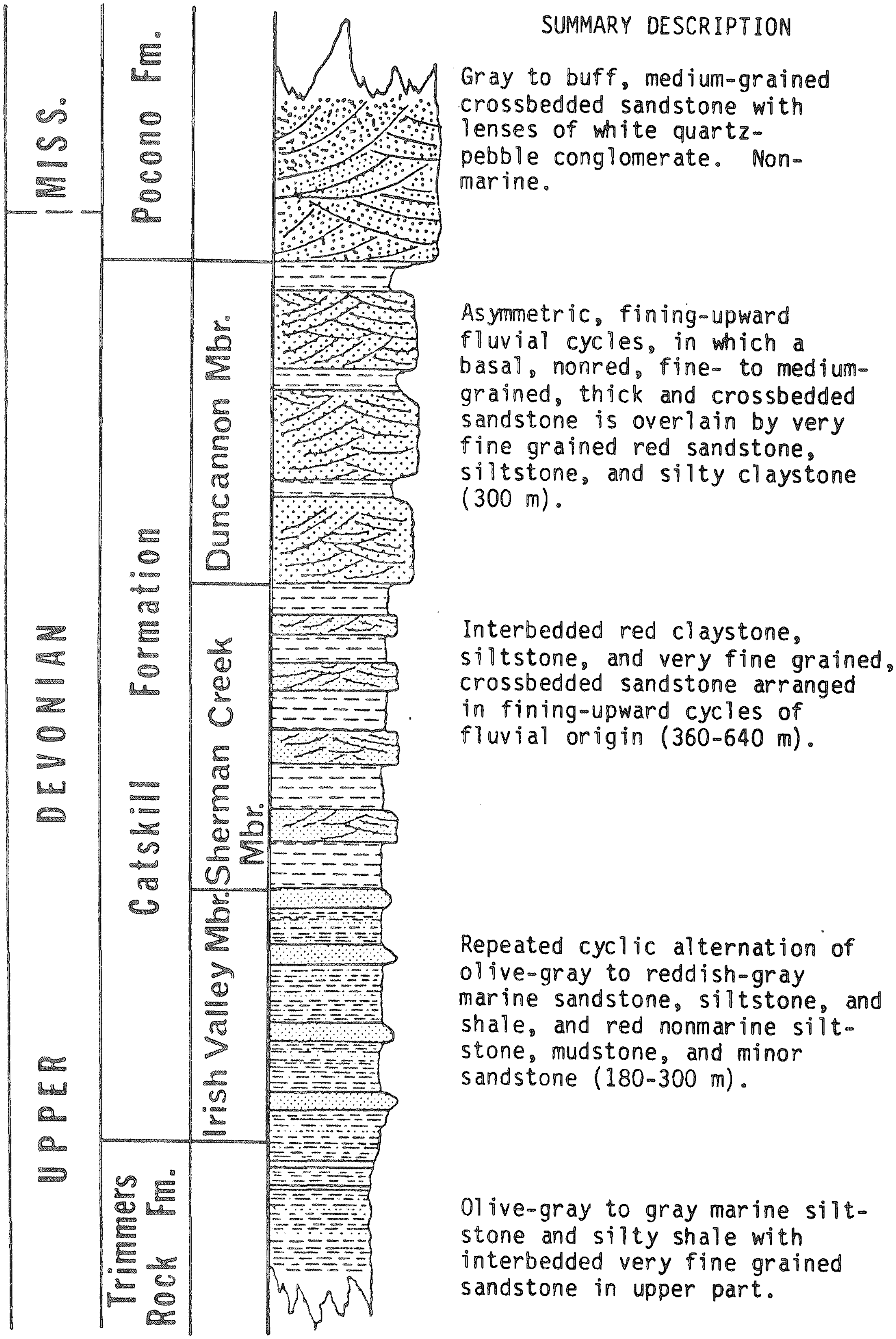

Figure 36. Generalized stratigraphic section of the Upper Devonian in central Pennsylvania.

stratified. Crinoid columnals, pelecypods, brachiopod shells, and occasional bryozoan fragments are common in most of these beds. Except in 2 localities, Saxton and Port Matilda, the underlying Lock Haven sediments pass abruptly into nonmarine deposits without establishment of major nearshore sand bodies.

After the first establishment of nonmarine conditions, the sedimentary pattern of the Irish Valley Member of the Catskill Formation (upper Foreknobs Formation) in the southern and central part of the study area is characterized by many (about 15-20) cycles consisting of repeated alternations from marine sandstone and shale to nonmarine siltstone and silty sandstone which were produced by repeated lateral shifting of the shoreline. The thickness of each cycle varies from 2 to about 27 m. These cycles begin with greenish-gray, fossiliferous, clean, sub-parallel laminates overlain by bioturbated, fine-grained sandstone of variable thickness representing a marine transgression, pass upward through a marine shoaling phase and an intertidal transitional phase, and finally grade into a nonmarine phase representing coastal-plain aggradation (Figure 37). The marine shoaling phase of each cycle commonly starts with gray-green to olive-green, fossiliferous shale and silty shale which grades upward to thin-bedded olive-green and chocolate-brown, fossiliferous and bioturbated shaly siltstone occasionally interlayered with thin layers of gray-green, very fine-grained, fossiliferous, micro-cross-ripple-laminated sandstone. The shoreline of this marine shoaling phase is represented by usually thin (1-2 m), olive-green, fine-grained moderately sorted, sub-parallel to flaser- and lenticular-laminated, fossiliferous, quartzitic sandstone. The transitional part of each cycle usually consists of interlayers of green, chocolate-brown, and red siltstone, shaly siltstone, and thin (1.5-3 m), fine-grained, clean, well-sorted, quartzitic sandstone.

Extensive bioturbation, diagnostic internal sedimentary structures such as large-scale herringbone cross-stratification, lenticular and flaser bedding, and presence of composite rock types in the shallow marine-transitional part of most cycles attest to tidal origins of these deposits. Tidal sedimentation in some of the sections is further demonstrated by good development of relatively thick (1.6 m) solitary cross-strata sets of gray-green to chocolate-brown, medium to coarse and pebbly, fossiliferous, quartzitic sandstones and conglomerates interpreted to be subtidal or intertidal sandbars.

The nonmarine part of the cycles is dominantly red siltstone and shale which are characterized by the presence of rootlets and mudcracks. Fining-upward alluvial cycles of a few feet in thickness may be present on top of some cycles.

Upward-fining cyclicity of fluvial origin is the common characteristic of the other 2 members of the Catskill Formation (the Sherman Creek and Duncannon Members). An ideal cycle consists of a basal brownish-gray to red, fine- to very fine-grained, micaceous, crossbedded sandstone with occasional plant fragments at its base and lenses of carbonate nodules and shale chips. This sandstone occupies a channel or irregular erosional surface cut into the underlying cycle. This sand body grades upward to red to reddish-gray, very fine-grained, silty sandstone, red siltstone, and silty shale which represents the levee-overbank portion of a meandering-channel facies.

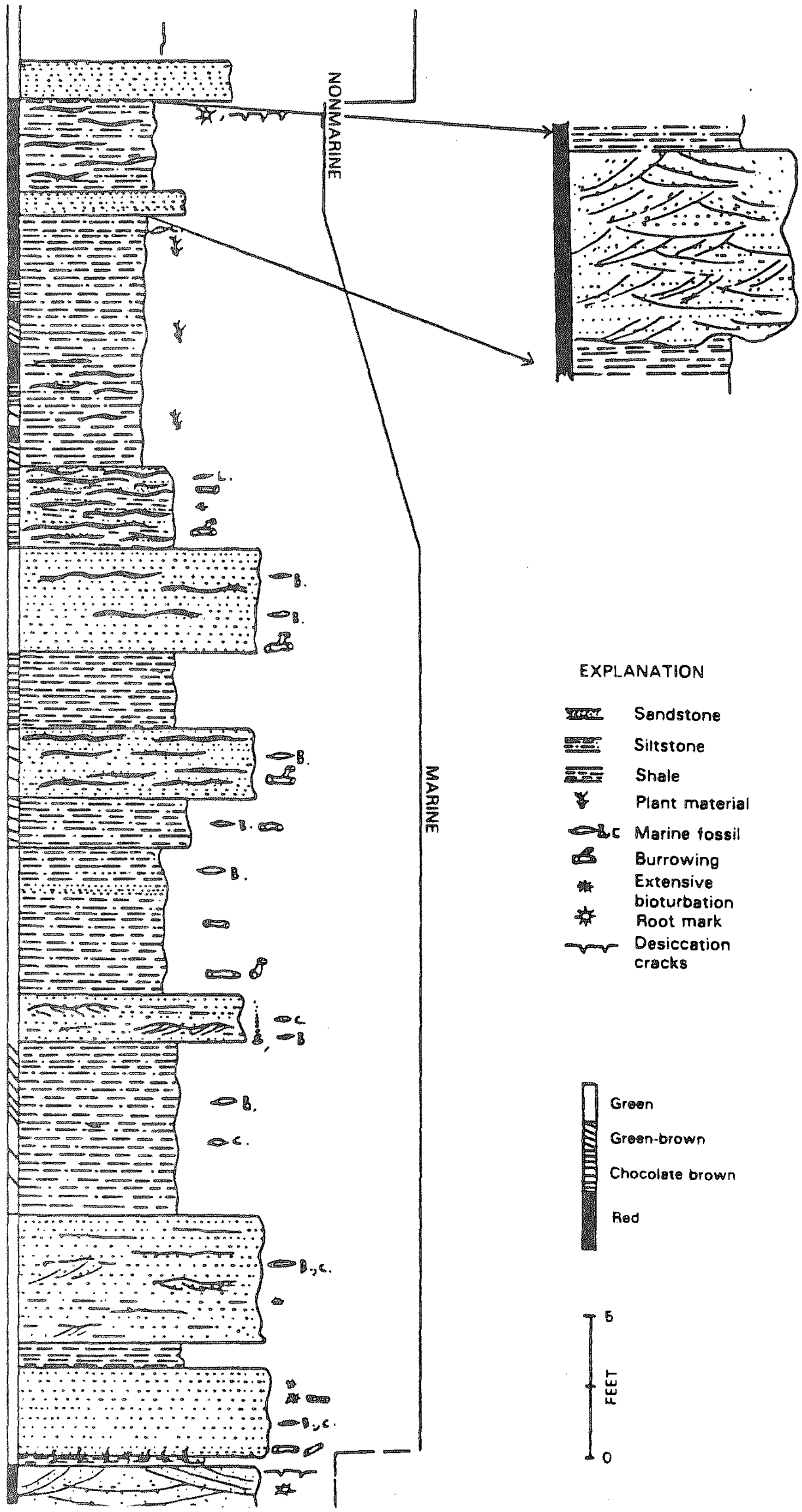

Figure 37. Generalized sequence of an Irish Valley motif from the Entriken section (from Rahmanian, 1979).

Facies assemblages and distribution of the Catskill Formation vary from the above description both south and north of Entriken along depositional strike (Figures 38 and 39). To the south, at the Saxton area, the first nonmarine deposition, marking the base of the Irish Valley Member, occurs higher in the section, and consequently shallow marine sedimentation went on for a longer period of time relative to the adjacent area. Apparently this was in response to a reduction of the rate of sediment supply, which prevented active coastal progradation and consequently resulted in more intensive marine reworking and a better development of shallow marine and nearshore sand bodies. In this area the sediments of the uppermost Trimmers Rock Formation and the Irish Valley Member are represented as tidal-flat and barrier-bay facies assemblages characterized by better developed and thicker marine sandbars and shoreface-foreshore sequences with associated tidal-channel sandstone bodies.

To the north (at Port Matilda, Centre County) the well-developed cyclic sediments of the Irish Valley Member grade into a complex assemblage of tidal-influenced deltaic facies comprising slope, prodelta, delta-front, and lower and upper delta plain facies (Figures 38 and 39).

In summary, the available data on Upper Devonian deposits of the study area suggest that the depositional system of Late Devonian time in south-central Pennsylvania was a complex prograding delta-interdeltaic system (Figure W6). The shoreline was fed by a tidally influenced delta at the northern part of the study area. Well-developed cycles of marine-nonmarine origin in the Irish Valley Member occur, farther to the south and north of this depocenter pointing to development of a prograding, tidally influenced, muddy shoreline, consisting of a tidal-flat/chenier-plain complex, marginal to the delta. Available evidence suggests that sediments were supplied to these environments from the adjacent deltaic lobe by long-shore currents and tidal currents rather than by local rivers crossing the coastal plain.

This shoreline shifted laterally several times in response to changes in position of the adjacent deltaic lobe or changes in sea level. Farther to the south, at the Saxton area, cyclic sediments are poorly developed. In this area, marine processes became dominant, as the rate of sediment supply through longshore currents from the north was reduced and a tidal-flat/barrier-bay complex formed the shoreline of this area (Figure 40).

At a given locality, along the Broadtop outcrop belt for example, the vertical succession of sedimentary facies indicates that the area, during the entire time of Irish Valley sedimentation, remained a part of an intradeltaic region, characterized by a coastal area largely composed of broad and extensive tidal flats. The lack of major sandstone units of fluvial or deltaic origin in the succession of these marine-nonmarine deposits indicates that the shoreline was not subjected to intermittent deltaic or intradeltaic sedimentation. In other words, neither the rivers from adjacent active sediment input systems nor a major river, heading directly from the south-eastern source area, crossed this shoreline during Irish Valley time. This leads to the important conclusion that the alongshore location of the major river systems remained fixed during their 5 million years of progradation across central Pennsylvania.

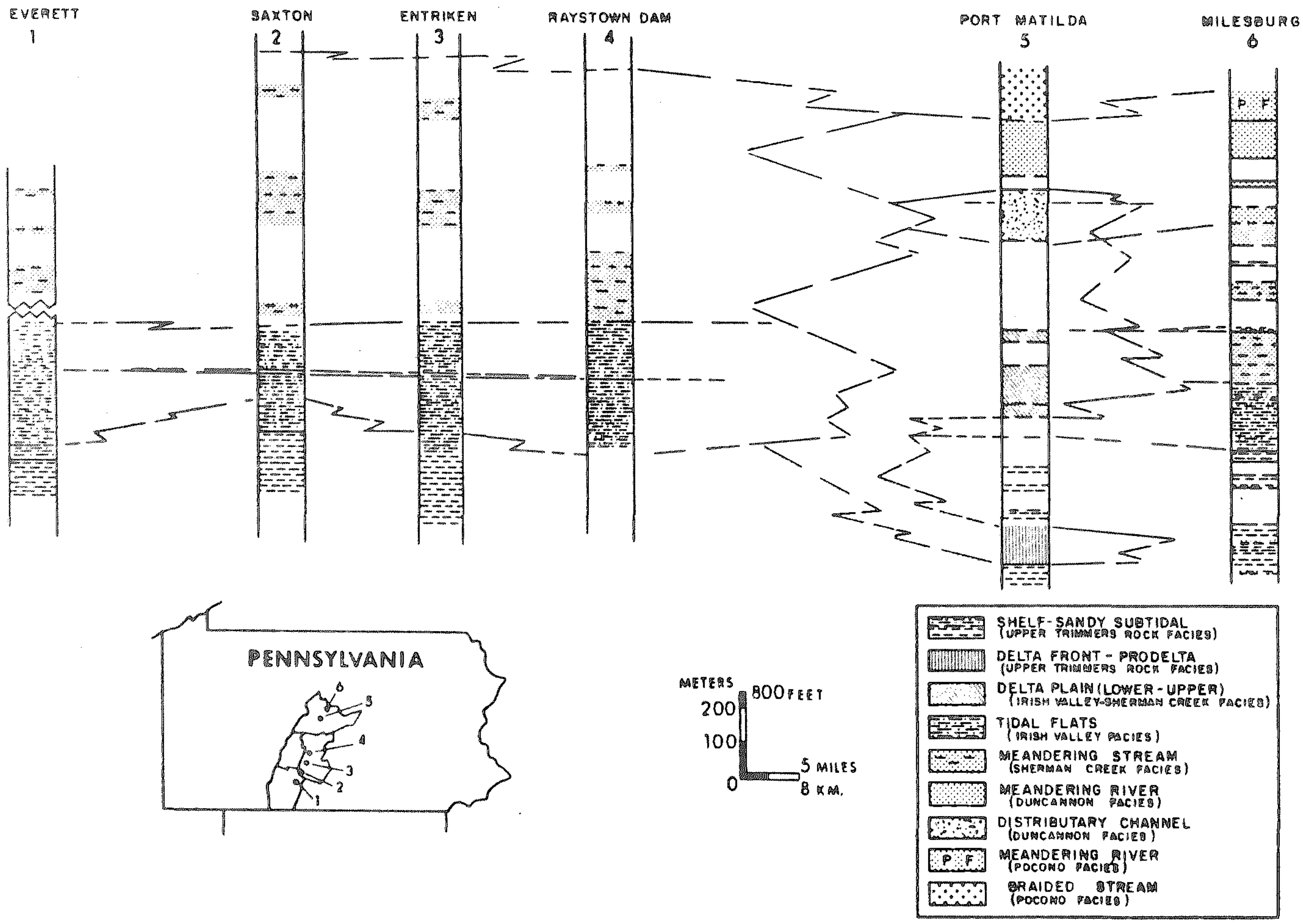

Figure 38. Correlation diagram of the major lithofacies in the Lock Haven (Upper Trimmers Rock) and Catskill Formations of central and south-central Pennsylvania and the inferred paleoenvironments (after Rahmanian, 1979).

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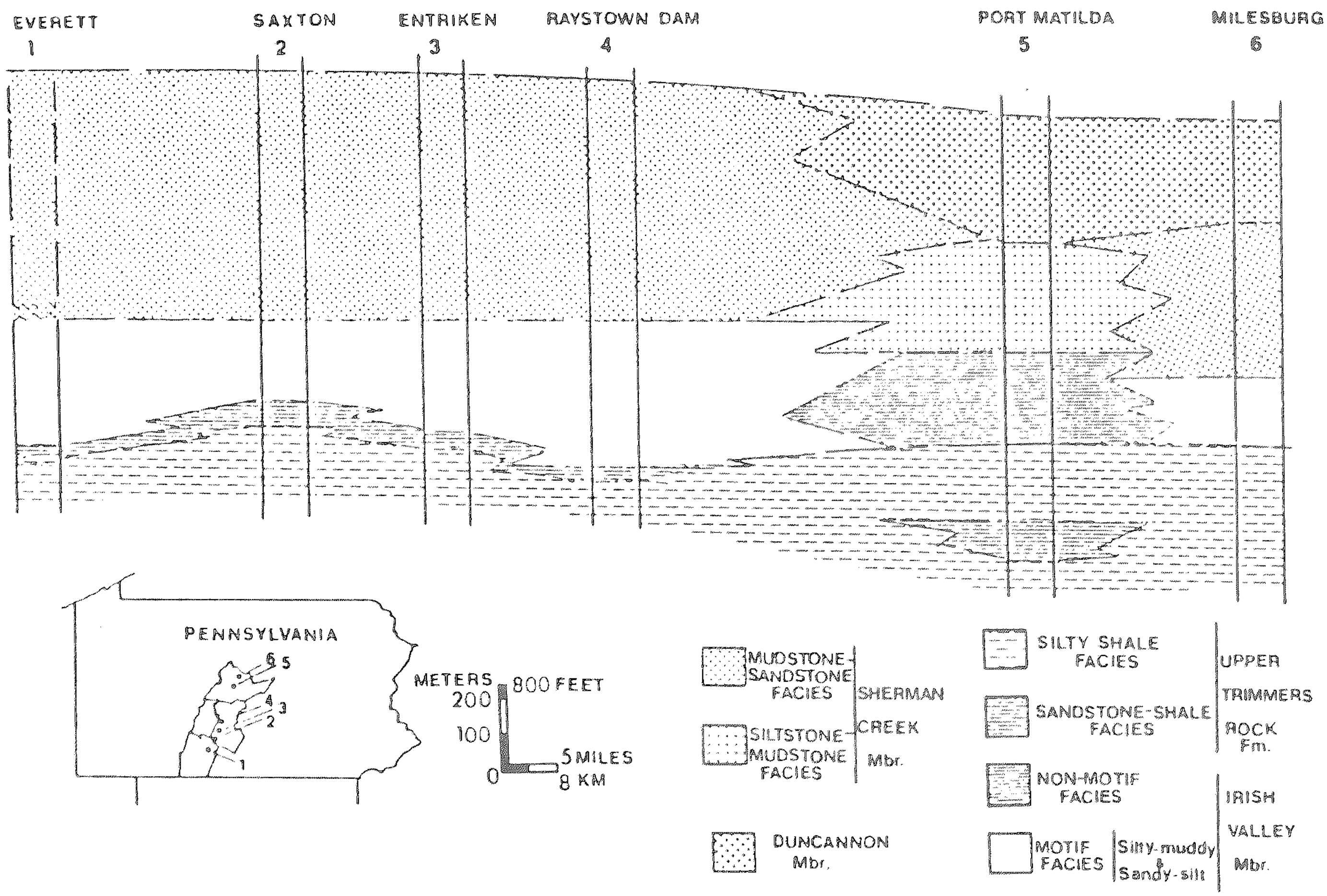


Figure 39. Generalized lithofacies cross section of the Upper Devonian rocks in central and south-central Pennsylvania (after Rahmanian, 1979).

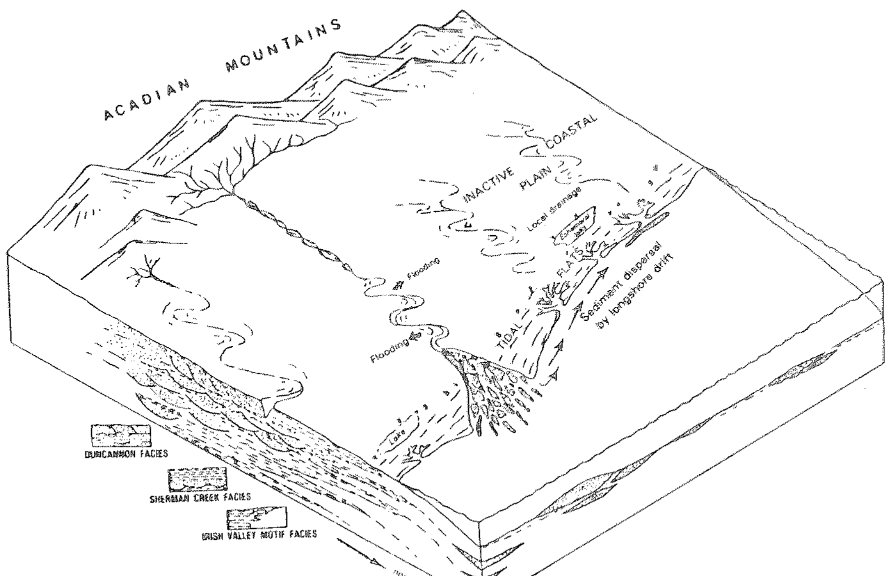
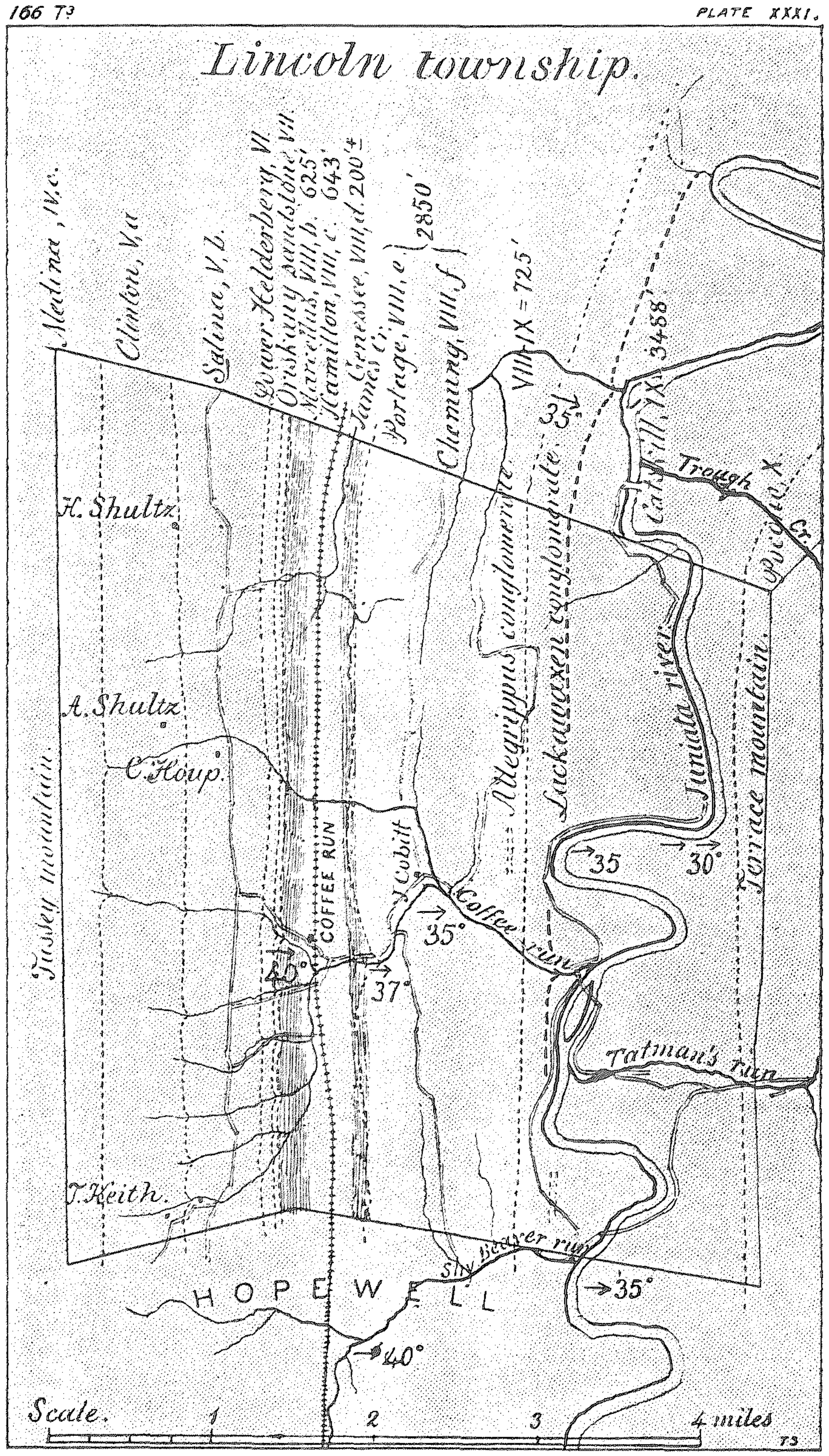


Figure 40. Sedimentation model of the Upper Devonian in central Pennsylvania. Refer to Figure 35 for exact location of stratigraphic sections (after Rahmanian, 1979).



Geologic map of Lincoln Township from White, 1885, p. 166.

UPPER DEVONIAN AND MISSISSIPPIAN STRATIGRAPHY OF THE BROAD TOP REGION

by
Thomas M. Berg, Clifford H. Dodge, and Leonard J. Lentz
Pennsylvania Geological Survey

INTRODUCTION

The uppermost Devonian (upper Famennian) and Mississippian rocks of this Field Conference area include in upward vertical sequence, the Catskill Formation, the Rockwell Formation, the Burgoon Sandstone, and the Mauch Chunk Formation. This nomenclature was utilized during compilation of the 1980 State Geologic Map (Berg and others, 1980), except for Burgoon Sandstone which was called Pocono Formation. Regional relationships and correlations are shown in the statewide correlation diagram prepared by Berg and others (1983). The history of development of stratigraphic nomenclature applied to these rocks is given in Figure 41.

CATSKILL FORMATION

Conceptually, the Catskill Formation is "the major body of redbeds" in the Upper Devonian of Pennsylvania. In the practice of some workers, the Catskill is defined on the basis of multiple, mutually non-exclusive criteria that generally speak of dominantly nonmarine deltaic deposition, and, if you're lucky, the rocks are red. For other workers, the Catskill embraces a large assemblage of marine and nonmarine terrigenous clastic rocks all related only by virtue of having been deposited in the Appalachian basin during the time of the Acadian orogeny. The state of the "art" of defining and interpreting the Catskill Formation is given most recently by Woodrow and Sevon (1985). The stratigraphic nomenclature and criteria for defining stratigraphic boundaries within this Upper Devonian "clastic wedge" are a veritable rat's nest that only the bravest and wildest-eyed stratigraphers are willing to enter.

As mapped by Don Hoskins for the 1980 State Geologic Map, the Catskill Formation shown in the Broad Top region reflects the stratigraphic framework proposed by Dennison (1970, p. 59ff) for the Upper Devonian along the Allegheny Front in West Virginia and Maryland. Dennison utilized "Hampshire" rather than Catskill, and the subjacent rocks were assigned to the Greenland Gap Group. The Greenland Gap includes the Foreknobs Formation above, and the Scherr Formation below. Coincidentally, Butts (1945) mapped the Upper Devonian redbeds as Hampshire Formation in the Broad Top area, but "Catskill" was used for the most recent state geologic map for purposes of consistency across the state. Foreknobs and Scherr were mapped throughout most of south-central Pennsylvania for the 1980 map. The base of the Catskill (top of Foreknobs) was mapped by Hoskins around the Broad Top synclinorium primarily by following a ridge-forming sandstone which was thought to correlate with the Pound Sandstone Member at the top of the Foreknobs Formation in West Virginia. A sequence of olive gray, marine siltstones and sandstones with some brownish beds and thin conglomerates occurs above the Pound Sandstone in West Virginia, but grades laterally by facies change to the northeast to the Hampshire redbeds (Dennison, 1970, p. 71). Presumably this interval is missing in Pennsylvania.

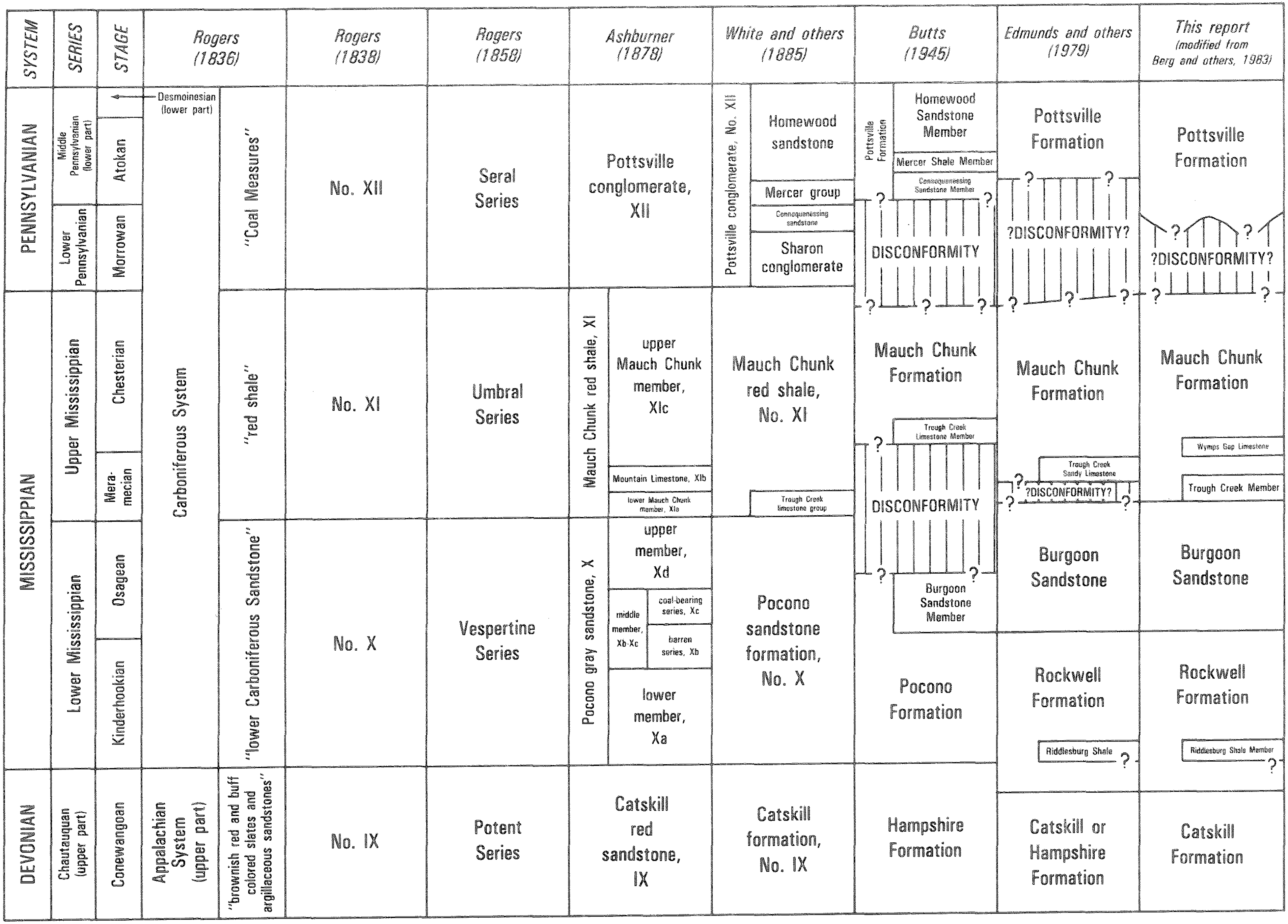


Figure 41. Historical development of stratigraphic nomenclature of part of the Upper Devonian to Pennsylvanian rocks in the Broad Top area, south-central Pennsylvania.

The main problem that arises when mapping the base of the Catskill Formation over much of Pennsylvania is that there is a substantial transition between the clear-cut fluvial redbeds and the underlying clear-cut marine beds. As mapped in this Field Conference area, the transition has been included as part of the Foreknobs Formation. This approach is consistent with Dennison's (1970, p. 66) framework wherein the Foreknobs includes "redbeds" that are more brownish than those of the overlying Hampshire (Catskill). In the Susquehanna Valley, the transition between clear-cut fluvial redbeds and the underlying clear-cut marine beds of the Trimmers Rock Formation is called the Irish Valley Member, and is included in the Catskill Formation. The Irish Valley Member is characterized in part by the occurrence of numerous marine-nonmarine cycles called "motifs" by Walker and Harms (1971, p. 383). Rahmanian (1979), Williams (1985), and Williams and Slingerland (see p. 00-00) have presented the most recent sedimentological analysis of Catskill sedimentation in central and south-central Pennsylvania. Rahmanian (1979, p. 74ff) recognized "Irish Valley motifs" in the transitional succession of his study area and felt that the Susquehanna Valley nomenclature could be validly applied. Thus the names Trimmers Rock Formation and Irish Valley Member of the Catskill were brought into central Pennsylvania from the Susquehanna Valley by the Penn State workers. We do not wish to say that this usage is completely wrong. We only point out that it is different from what is shown on the 1980 State Geologic Map by Hoskins who followed Dennison's usage. Hoskins did not extend Irish Valley into central and south-central Pennsylvania because specific lithologies such as the mappable sandstones and conglomerates of the Foreknobs do not occur in the Irish Valley of the Susquehanna Valley. Rahmanian's "Irish Valley Member" is correlative for the most part to what Hoskins mapped as "Foreknobs," but is an overextension of a name that was originally intended for more local use.

The Catskill Formation in the Field Conference area is 610 m thick on the west of the Broad Top synclinorium, and is 760 m thick east of Sideling Hill (Butts, 1945, p. 13).

Most of the Catskill rocks in the Field Conference area are probably the result of deposition in high-sinuosity meandering river environments, but this is a gross generalization, and we defer to the work of Rahmanian (1979) for a more sophisticated explanation of the depositional history of the Catskill Formation.

The contact between the Catskill and the overlying Rockwell is discussed below.

ROCKWELL FORMATION

The name "Pocono" has a long history of mixed usage as both a chronostratigraphic and a lithostratigraphic term. Berg and Edmunds (1979, p. 5-16) summarized the long and checkered career of "Pocono" and concluded that the term should be restricted to northeastern Pennsylvania as was originally intended. Kammer and Bjerstedt (1986) have concluded that "Pocono" should be abandoned in West Virginia also, and have recommended that Price Formation replace Pocono there. Many workers in the past regarded the boundary between the Catskill Formation and the Pocono Formation as the boundary between the Devonian and Mississippian Systems. Because the name Pocono was applied and mapped so widely in a chronostratigraphic sense, the real lithostratigraphic relationship between Catskill and Pocono (sensu stricto) was obscured. There is a transition between

Catskill and Pocono (Berg, 1979). In northeastern Pennsylvania, the rocks separating the Catskill Formation from the Pocono Formation are assigned to the Spechty Kopf Formation (Trexler and others, 1962; Sevon, 1969; Epstein and others, 1974; Sevon and others, 1978; Sevon, 1979; Sevon and Berg, 1986). In north-central Pennsylvania, the Burgoon Sandstone is recognized as the lithostratigraphic equivalent of the Pocono Formation, and the rocks comprising the transition from Catskill to Burgoon are assigned to the Huntley Mountain Formation (Berg and Edmunds, 1979).

In this Field Conference area, "Pocono" was mapped by Don Hoskins in its restricted, original lithostratigraphic meaning. The rocks between the Catskill and Pocono, called "lower Pocono" by earlier workers, were mapped as Rockwell Formation (Berg and others, 1980). The Rockwell Formation was named by Stose and Swartz (1912, p. 13), and was regarded as the lower part of the "Pocono group." The rocks above the Rockwell were named Purslane Sandstone by Stose and Swartz (1912, p. 13); Berg and Edmunds (1979, p. 44) correlated the Purslane with the Burgoon and Pocono (sensu stricto). The Rockwell Formation is best exposed today in a huge roadcut along U. S. Route 40 where the road passes through Sideling Hill in Maryland, 6.4 km west of the interchange with Interstate Route 70 at Hancock. This exposure has been described and interpreted by Bjerstedt (1986), and should be considered the prime reference section for the Rockwell. Application of the name Rockwell to the sequence between the Pocono and Catskill in central and south-central Pennsylvania for the 1980 State Geologic Map seemed useful and appropriate at the time. However, now that we have had a chance to examine the succession in more detail at Warriors Path (Stop 11), Sideling Hill in Maryland, and Horseshoe Curve near Altoona, we raise a concern that much of what was mapped as Rockwell really may be more closely related to the succession which is exposed to the west at Conemaugh Gorge (Fettke and Bayles, 1945; Kaktins, 1986). The Rockwell at Warriors Path and at Horseshoe Curve has some more well developed marine aspects than the Rockwell at Sideling Hill. The sedimentary rocks within this interval presently called Rockwell in Pennsylvania need to be examined in much more detail, and need to be interpreted in the light of present-day understanding of depositional environments. It would not be surprising to see the name Rockwell replaced by new local names.

The Catskill-Rockwell contact is the top of the "major body of redbeds" and marks the beginning of a section purportedly dominated by olive-gray buff-colored, fine-grained sandstones. The contact is interpreted to be sharp and conformable in the Warriors Path section (Stop 11). In Fulton County and in Maryland, along Sideling Hill, a polymictic diamictite occurs at the base of the Rockwell (Sevon, 1979; Bjerstedt, 1986). This is interpreted to be the result of deposition by debris flow in a standing body of water, and a minor disconformity may be inferred.

When examined in detail, the Rockwell is fairly heterolithic, especially in terms of texture, color, and sedimentary structures. Approximately half of the Rockwell Formation is very fine grained sandstone. The other half is a mixture of siltstone and shale. The finer clastics are usually light olive gray, but grayish red color is not uncommon. The presence of red shales has led some workers to extend the top of the Catskill upward in the section. The most familiar redbed is the Patton Shale which occurs just below the Burgoon Sandstone in both the Rockwell Formation and the Huntley Mountain Formation. At Warriors Path (Stop 11), at Horseshoe Bend, and at the Allegheny Front in Bedford County

(Terriere, 1951. p. 11) the lower quarter of the Rockwell is predominantly sandstone. Reger (1927, p. 406) correlated this intervel with the Berea Sandstone of Ohio. We believe this to be an overextension of Berea; a "Berea" interval would probably be more closely related to one of the sandstones above or below the Riddlesburg Shale of Reger (1927). The middle part of the Rockwell is either sandy or shaly, depending on where you are. At Warriors Path, the interval is dominantly shaly. It includes the Riddlesburg Shale Member whose type locality is at the Warriors Path section. The Riddlesburg represents a major marine transgression, and contains an open marine (albeit low-diversity) fauna. Marine fossils are also found at the Horseshoe Curve section, but they occur lower in the section, closer to the Catskill. The term "Riddlesburg" should not be applied carelessly to any marine unit in what has been mapped as Rockwell. We believe that transgressive events occurred at different places at different times during Rockwell deposition. The upper quarter of the Rockwell is sandy and shaly, and contains the Patton horizon mentioned above. In southern Bedford County, in Fulton County, and continuing south into Maryland and West Virginia, a number of relatively thin coals appear in the section (see Bjerstedt, 1986).

In the northern part of the Field Conference area, the Rockwell Formation is up to 315 m thick (Butts, 1945, p. 13). At the Warriors Path section, it is 225 m thick. At Horseshoe Bend, the Rockwell is 180 m thick. Terriere (1951, p. 10) reports approximately 125 m at the Allegheny Front in Bedford County. Bjerstedt (1986) measured 191 m of Rockwell at Sideling Hill in Maryland.

The depositional history of the Rockwell Formation within just the Field Conference area is complex. In very gross terms, the marine transgression that accompanied the dying gasps of the Catskill delta is contained within the Rockwell. As was stated above, this formation is very fertile ground for sedimentological research. We have made an attempt at interpreting the depositional environments represented at the Warriors Path section (Stop 11). Kammer and Bjerstedt (1986) and Bjerstedt (1986) have presented important new interpretations for the Rockwell in Maryland and West Virginia, and the story is quite different there.

BURGOON SANDSTONE

Butts (1945, p. 13) used the term "Burgoon" for the thick-bedded sandstone member at the top of the "Pocono" Formation, linking the usage at the Allegheny Front to the Broad Top area. When Don Hoskins mapped this area around the Broad Top synclinorium for the new State Map, he called this unit the Pocono Formation. Upon reexamining the rocks for this Field Conference area, we recommend that Butts' usage of Burgoon be followed. As stated above, Berg and Edmunds (1979, p. 16) concluded that the Burgoon Sandstone is the lithostratigraphic equivalent of the Pocono Formation of northeastern Pennsylvania, and that this correlation was in keeping with the original meaning of Rogers' "Formation X--Vespertine." The remainder of Butts' "Pocono" is now shown as Rockwell Formation.

The Burgoon Sandstone is an important mapping unit throughout the Allegheny Plateau and the Broad Top region. It is easily recognized as a resistant unit on aerial photographs. Petrographically, the Burgoon is usually medium-grained quartz arenite to sublitharenite, contrasting well with the fine-grained lithic graywackes of the subjacent Huntley Mountain or Rockwell Formations. Some interbedded carbonaceous silt shales do occur in the Burgoon, but these are generally discontinuous. Very thin, laterally discontinuous, uneconomical coals have been reported in the Burgoon. Few thin beds and lenses of granule to small pebble conglomerate occur sporadically in the Burgoon. The sparse conglomerates of the Burgoon contrast with the more common, thick conglomerates of the Pocono of northeastern Pennsylvania. Quartz pebbles in the Burgoon normally do not exceed pea-size. Although frequently hidden by colluvium, the Burgoon-Rockwell contact is considered sharp and conformable.

The most striking sedimentary structure in the Burgoon Sandstone is trough-style crossbedding. Some sets of cross-strata are close to 2 m thick, but the average set thickness is 1/2 to 1 m. Individual cross-strata are inclined at moderate to steep angles, and are tangential with the bases of sets. The breadth of some troughs exceeds 3 or 4 m, but probably averages 1 to 2 m. Crossbedding in the Burgoon contrasts with trough crossbedding in sandstones of the subjacent Rockwell and Catskill Formations, wherein the scale of sets is lesser and inclination of cross-strata is gentler.

The Burgoon Sandstone is approximately 90 m thick at the Allegheny Front. It is between 115 and 150 m thick in the northern part of the Field Conference area (Butts, 1945, p. 13). We measured 148 m at the Warriors Path section (Stop 11).

We interpret the Burgoon to be the result of deposition by braided rivers, or possibly, very low-sinuosity meandering rivers. The lack of fining-upward cycles similar to the Catskill cycles leads us to lean very heavily toward the braided river model. The Burgoon represents a major climatic and/or tectonic event in Mississippian time. Abundant sand with a little gravel was carried into this part of the Appalachian basin by multiple rivers flowing from an eastern source area. Pelletier (1958) carried out extensive analyses of paleo-current indicators in the Pocono Formation (sensu lato) of Pennsylvania and Maryland and concluded that river currents were directed mainly to the west and north. The average compass direction of crossbedding azimuths in the area of this Field Conference are oriented mostly west to west-northwest (Pelletier, 1958, pl. 1; p. 1048). Pelletier's observations were made throughout the entire "Pocono" as a chronostratigraphic unit. Furthermore, some of Pelletier's observations are known to mistakenly include some Pottsville Group localities in northeastern Pennsylvania (Sevon, 1986, pers. commun.). Thus, it would be valuable to analyze the Burgoon Sandstone alone for its paleocurrent information.

The upper contact of the Burgoon Sandstone is sharp, conformable, and easily defined as the first occurrence of the calcareous sandstones or sandy calcarenites of the Trough Creek Member of the Mauch Chunk Formation or the grayish-red siltstones of the Mauch Chunk Formation itself.

MAUCH CHUNK FORMATION

The uppermost Mississippian unit in the Field Conference area is the Mauch Chunk Formation. Grayish red and dark reddish brown silt shale and siltstone predominate in the Mauch Chunk, but some sandstone beds are present which show varying shades of gray, yellow, green, and brown. Calcareous sandstone or sandy calcarenite beds, along with few thin limestones are present, mostly in the lower 10 to 20 m of the formation. Hoque (1965, 1968) has done the most extensive examination of the Mauch Chunk in the Broad Top area; his work also includes exposures at the Allegheny Front and at the major anticlines west of the

Front. Brink (1984) examined the Mauch Chunk along the southwest side of the Broad Top synclinorium in the Everett East and Wells Tannery quadrangles. He verified the existence of the thin Wymps Gap Limestone Member in the Broad Top region (Brink, 1984, p. 54). White and others (1885, p. 73) indicate that at least two other thin limestone beds occur higher in the Mauch Chunk.

In the No. 1 Rockhill Iron and Coal Company drill hole about 6.5 km southeast of Saxton, 450 m of Mauch Chunk were penetrated. Hoque (1965) measured 338 m along PA Route 915 4 km northwest of Wells Tannery. He also measured 394 m near Cypher Station at the west end of Sherman Valley.

Overall, the Mauch Chunk Formation is the result of deposition by sluggish, high-sinuosity meandering streams, possibly confined for the most part to a lower delta plain. Great quantities of red mud were carried by the streams, and through-flowing major channelways carrying coarser sand load were widely spaced. Minor marine transgressions briefly inundated and covered large parts of the Mauch Chunk delta plain or muddy coastline. Prevailing winds, possibly accompanying quite arid conditions, carried some sediment (Burgoon sand, Greenbrier carbonates) from the west up onto the mudflats early in Mauch Chunk time.

The Trough Creek Member, and the Wymps Gap Limestone Member give strong evidence of the proximity of the Greenbrier sea to the west (Haney, 1963; Adams, 1970; Busanus, 1976). Brink (1984, p. 54) reports 2 m of Wymps Gap containing marine fossils, including Nuculana phestia, Nuculana rugodorsata (?), Paladin chesterensis, Straparolus similis, and several species of Composita. The Wymps Gap Limestone occurs approximately 45 m above the base of the Mauch Chunk and speaks of a very rapid and widespread transgression across the muddy lower delta plain.

The Trough Creek limestone group was named by White and others (1885, p. 283) for outcrops and quarry exposures distributed along the south side of the deeply incised course of Trough Creek in Todd Township of Huntingdon County. Several sections measured and illustrated by White are shown in Figure 42. Designating this interval as a "limestone" member (Butts, 1945, p. 14) is a little misleading, because there is little pure limestone. In fact, during our reconnaissance field work for this Field Conference, we were unable to find an outcrop of real limestone in this member. The "limestones" are in fact very calcareous quartz sandstones or extremely sandy calcarenites. The interval is a valid member for mapping purposes, and the name Trough Creek Member should be retained, but it should be understood that the major lithology is grayish-red, calcareous siltstone. The calcareous sandstones are light gray or grayish-red, and contain slightly more than 50 percent angular quartz grains along with fragments of foraminifera, ooids, micrite pellets, and other unidentified calcareous fossil fragments, all set in a sparry calcite cement. These calcareous beds are strongly crossbedded and look similar in many respects to the outcrops of Loyalhanna Formation exposed along the Allegheny Front. The top of the Trough Creek Member is the highest occurrence of very calcareous sandstone or sandy calcarenite. There are many similarities between the Loyalhanna Formation and the Trough Creek Member sandstones. Adams (1970, p. 98) has suggested that the Loyalhanna may have formed by migrating marine sand waves. Berg (1980, p. 14) has suggested that some unique lithologies in the Mauch Chunk may be eolianites. The presence of "floating" rounded quartz grains in the Trough Creek red mudstones of this Field Conference area may point to the action of wind. Further sedimentological analysis needs to be done on this very interesting interval,

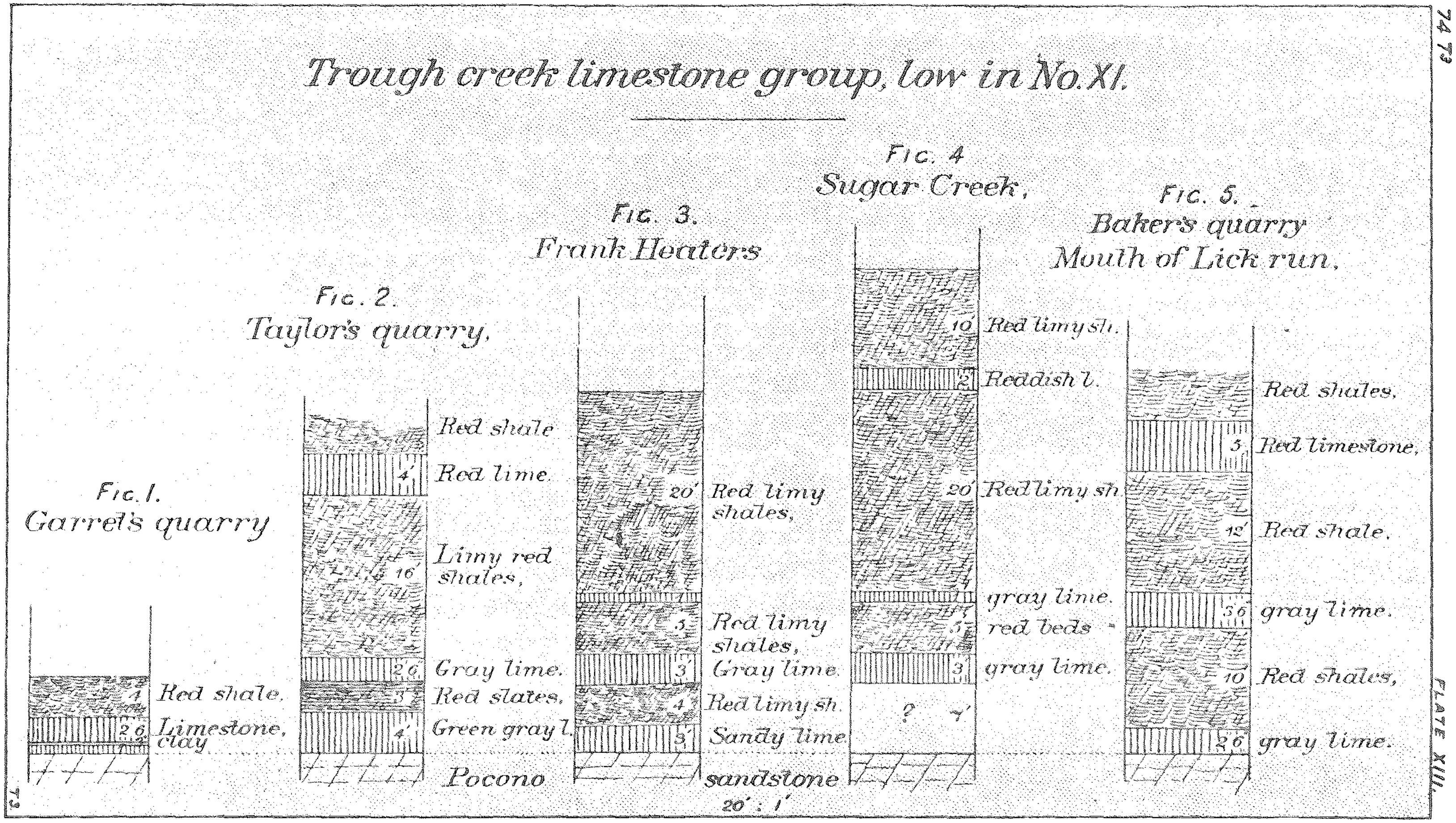


Figure 42. Stratigraphic sections of the Trough Creek "limestone." Figure is Plate XIII from White and others (1885, p. 74).

and we hope interest will be sparked by discussion of the Trough Creek at Stop 10.

The top of the Mauch Chunk Formation is the contact with the overlying coarse gray sandstone of the Pottsville Group. The lithologic contrast is striking, and some conglomerates occur at the base of the Pottsville, but whether or not this represents a major disconformity in the Field Conference area is unknown. Butts (1945, p. 14) believed that the contact is a major unconformity. More work needs to be done to resolve this issue.

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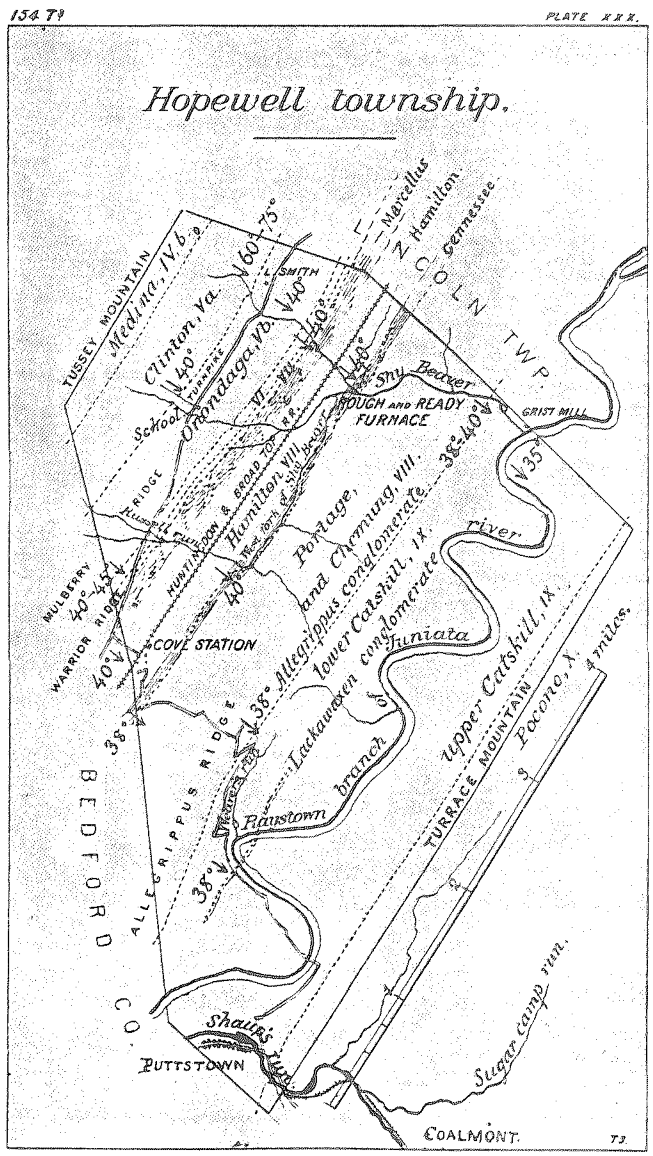
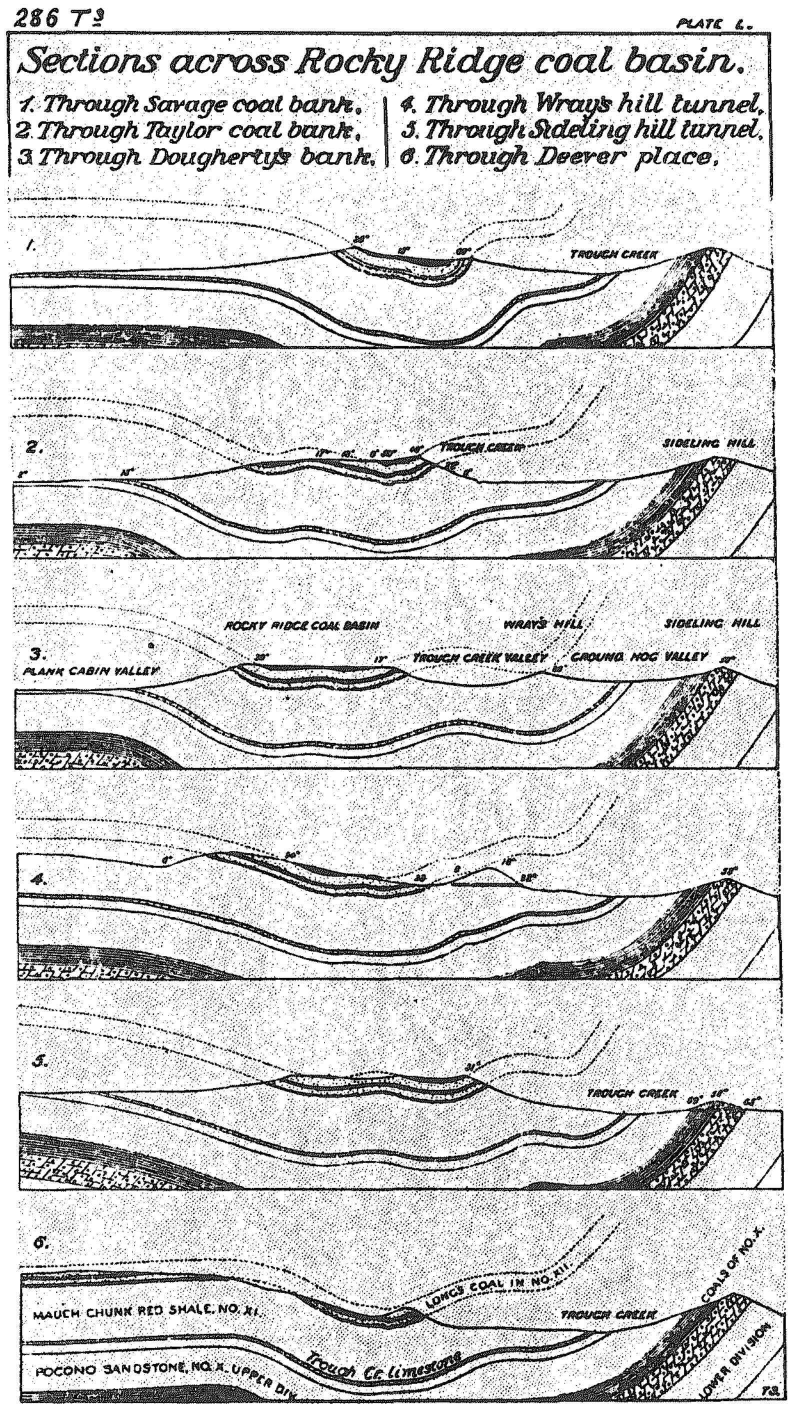


Geologic map of Hopewell township from White, 1885, p. 154.



Sections across Rocky Ridge coal basin from White, 1885, p. 286.

BROAD TOP COAL FIELD

by
William E. Edmunds
Consultant, Harrisburg
Albert D. Glover
Pennsylvania Geological Survey

GENERAL COMMENTS

The Broad Top Coal Field is an outlier of the Appalachian Coal Fields, cradled in the center of the Broad Top Synclinorium within the folded and faulted Valley and Ridge Province. The field covers the interior upper surface of Broad Top Mountain which, as the name implies, is a wide, flat-topped table mountain held up around its periphery by the up-turned rim of Pottsville sandstone rising above the surrounding valley of Mauch Chunk shales (Figure 43). The coal field itself covers approximately 45 square miles and lies in Bedford, Huntingdon, and Fulton Counties. It lies 25 to 30 miles east of the Alleghany Front in Cambria and Somerset counties.

One of the earliest published reports on the Broad Top coal field was by Richard C. Taylor in 1835, in which descriptions and analyses of Broad Top coals were given. This work should not be dismissed lightly when considered from an historical viewpoint. Lesley (1876, p. 41-55) considered the demolishing of Taylor's theories to be one of the major accomplishments of the first year of the First Survey. Taylor, in common with many others prior to the First Survey, did not understand the structure of the Valley and Ridge. Consequently, as a result of miscorrelation, he believed that the Broad Top coal was older than either the Bituminous coal of western Pennsylvania or the Anthracite coal of eastern Pennsylvania and suggested that it was either Devonian in age or only a little younger. He further stated that he saw no reason why coal shouldn't be found in other areas of middle Pennsylvania where rocks of this age occur. These incorrect conclusions, supported by the stature of the Geological Society of Pennsylvania, resulted in wasted expenditure of money and effort searching for coal where it did not exist. Frazer's descending section from the Broad Top to Morrison's Cove in 1836 (p. 3) was indeed important.

The field was discussed briefly by the First and Second Pennsylvania Geologic Surveys (Rogers, 1858; Stevenson, 1882; White, 1885). The last and most important work on the Broad Top Field was by Gardner (1913). This work largely represents our present knowledge of the area. Some new measured coal sections and analyses were included in Sisler (1926) and new coal resource calculations were made by Reese and Sisler (1928).

In 1984 the Pennsylvania Geological Survey completed a 1264-foot core hole which provides a single continuous section through the Pennsylvanian sequence and established for the first time the presence of Pennsylvanian marine zones in the Broad Top area.

At present, however, stratigraphic correlations are poorly understood both within the field and between Broad Top and other fields. Similarly, only the general aspects of the complex structural geology of the field are clear.

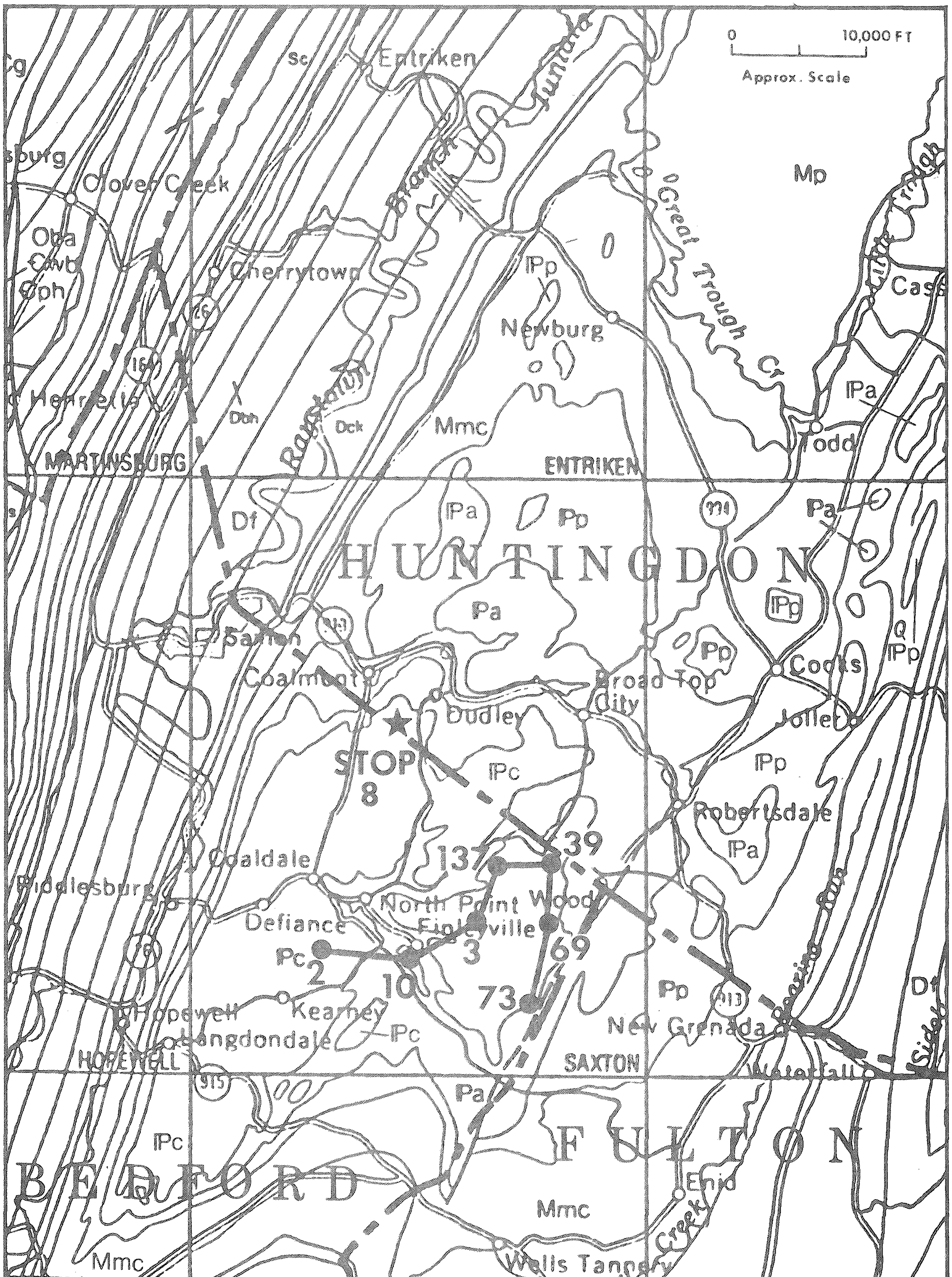


Figure 43. Map of Broad Top coal field showing geology, location of Stop 8 (star), and selected drill hole sites (numbers).

STRATIGRAPHY

The current understanding of the Broad Top Pennsylvanian sequence (Figure 44) is essentially that of Gardner (1913). Very little geologic work was done in the area before that report and almost nothing since. The interval containing most of the mineable coal beds (Gardner's Allegheny Formation) is probably reasonably clear, being drawn from exposures in and around deep mines which were widespread at the time of his work. The degree of continuity ascribed to individual coal beds may be open to serious question, however. The detail of the remainder of the section is likely to be less reliable as exposures and drill hole records were few and Gardner was forced to work without topographic ground control in a structurally complex area.

To emphasize the difficulty in correlating these coal beds where intervals between beds varied considerably, and where some beds were incorrectly named, we are including the following excerpts from Gardner's report (p. 57-59):

"The Dudley Coal Bed

"On the branch of Shoup's Run that heads southward from Dudley and just south of the town, a coal bed of no commercial value, but of considerable geologic interest, has been opened.

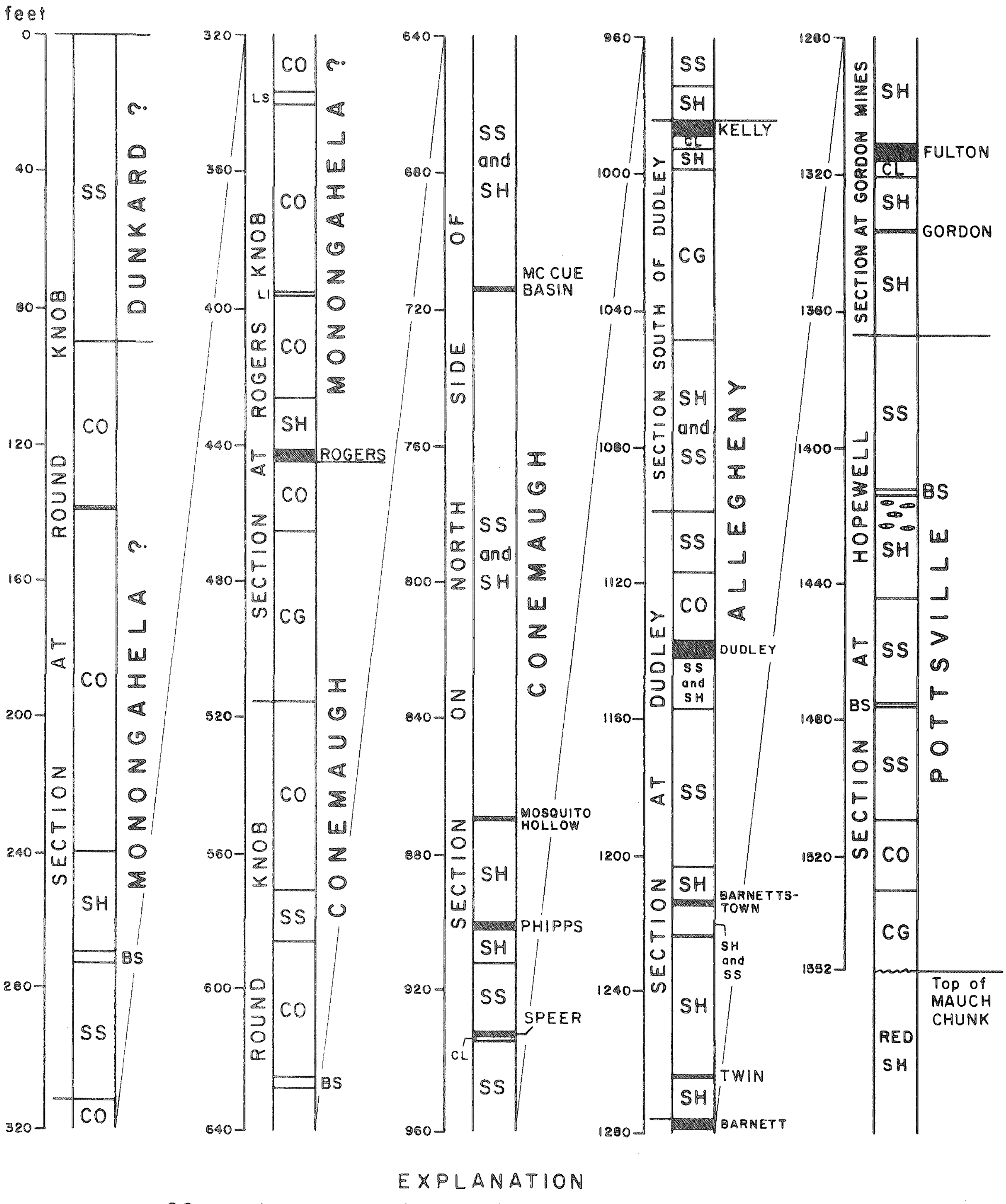
"This horizon has been considered by some as the Kelly bed. The same bed was once exposed 100 feet above the Barnett at the old Ocean mine. At a point 125 feet higher a four-foot bed is found in the hills toward Six Mile Run that is the true Kelly bed, overlain by massive, brown, Mahoning sandstone that can be traced around the outcrop westward to the property of the Mt. Equity Coal Company and thence to Six Mile Run. But the bed exposed lower down at Dudley is 125 feet lower in the series and is designated the Dudley bed, . . .

"In the report on Huntingdon County published in 1885 the bed at Dudley being considered Kelly, the four-foot bed higher in the series was thought to be a new bed entirely and the name 'Dudley' was applied to it. But the name has not been used subsequently because it was there applied to what is now known to be the true Kelly bed. The same name, however, is applicable for the bed at Dudley.

"The entire section from the Barnett bed up to the Kelley bed greatly thickened on Shoup's Run reaching its maximum in the vicinity of Dudley; here it is over 250 feet. It is in this territory of thickened interval that the extra coal beds are found, including the Barnettstown and Dudley beds. Some argue that such an interval is too great to be true and that the bed 250 feet or more above the Barnett south of Shoup's Run cannot be Kelly. But the proportion of the thickening of the interval from 100 feet on Six Mile Run to 250 feet on Shoup's Run is not inconsistent with various other changes in interval in the Broad Top field; . . .

"The Kelly Coal Bed

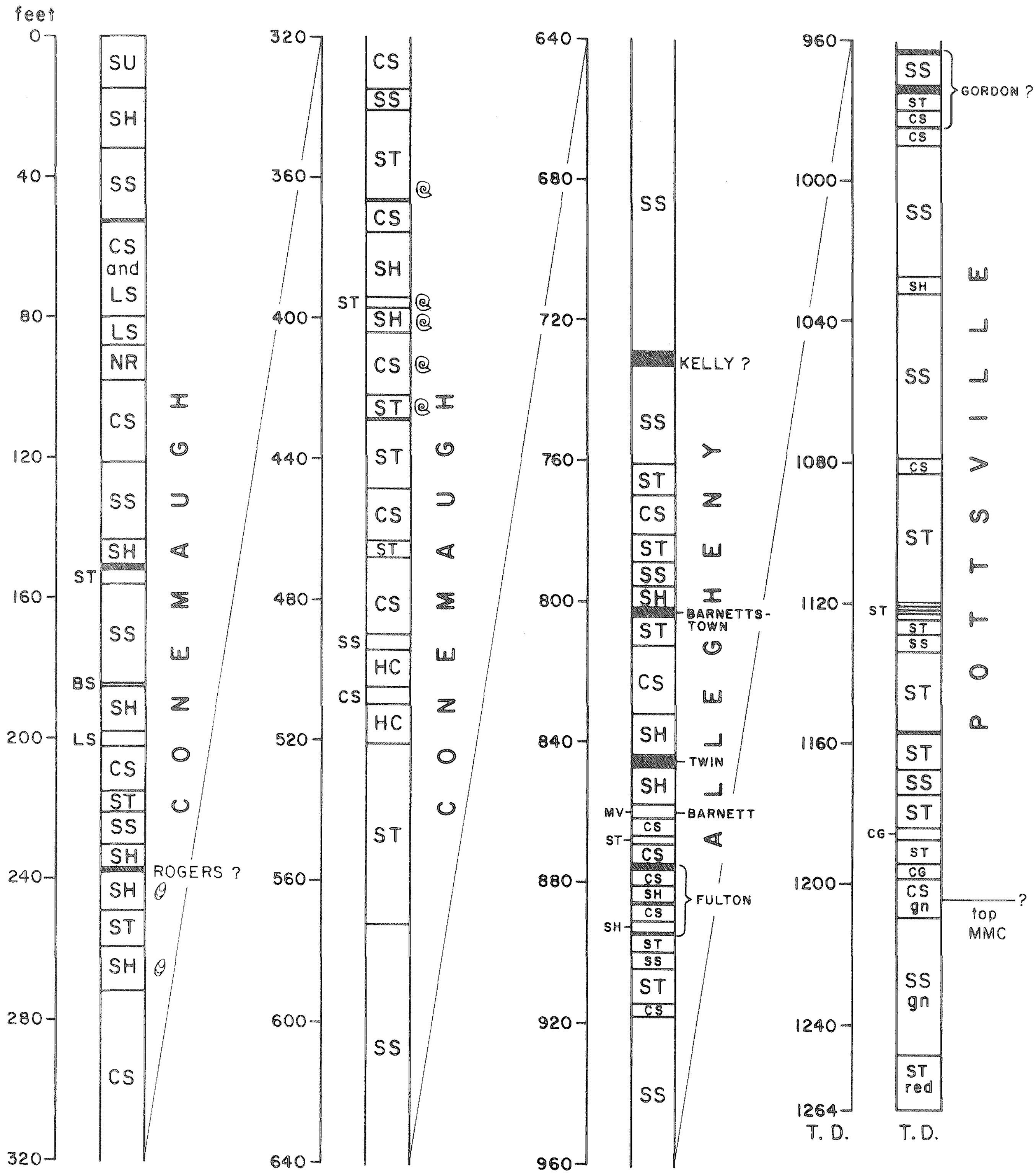
"The Kelly coal bed, according to Mr. A. J. Black, who has been allied with coal mining in Broad-Top for many years, and who was reared on the mountain, takes its name from a man named Barney Kelly. This statement was made to Mr. Black by his grandfather, Mr. W. W. Edwards. In the early history on mining,



EXPLANATION

SS = sandstone
SH = shale
BS = black shale
CG = conglomerate
CL = clay
CO = concealed
LS = limestone
LI = limonite
⊂⊃ = siderite nodules

Figure 44. Connected detailed sections in Broad Top coal field by J. H. Gardner (1913).



EXPLANATION

SU= surface	CS= claystone	CG= conglomerate
SS= sandstone	HC= hard clay	MV= mine void
SH= shale	LS= limestone	NR = no recovery
ST= siltstone	BS= black shale	gn = green
θ = brackish zone	T.D.= total depth	@ = marine zone

Figure 45. Pennsylvania Geological Survey diamond drill hole.

as has been brought out under the subject 'History of the Field,' the Cook bed (Fulton) at Broad Top City was thought to lie above the Barnett and was correlated with the so-called Kelly. The name Kelly spread from here to Six Mile Run and Sandy Run where it was applied to the third workable bed above the Pottsville, a true situation that has preserved the name."

Interpreting from the above, the authors suggest the following:

1. Probably the best established use of "Kelly" by Gardner is on Six Mile Run where it lies 100 feet above the Barnett.
2. Gardner thought the Kelly at Shoup's Run was 250 feet above the Barnett. This coal is probably 1 of the 2 that are strip mined at Stop 8, and they are approximately 600 feet above the Barnett.
3. Gardner put this higher coal in his column and called it Kelly when in fact no coal existed at that horizon. Then he made up the name Dudley for the coal 125 feet above the Barnett.
4. Therefore, Gardner's Dudley of Shoup's Run is probably his Kelly of Six Mile Run.

Completed in 1984, Pennsylvania Geological Survey drill hole 400907/781235 (Glover and Skema, unpublished) was started at what is believed to be the highest stratigraphic point in the Broad Top and penetrated 1200 feet of Pennsylvanian section plus about 65 feet of Mississippian Mauch Chunk Formation (Figure 45).

Correlation of the Broad Top sequence with the customary Pennsylvanian unit nomenclature of the west, is largely based on gross lithology and relative stratigraphic intervals. It is probably reasonable to equate most or all of the 220 feet below the Gordon coal in Gardner's column (Figure 44) and the 215 to 310 feet above the Mauch Chunk contact at about 1200 feet in the Survey drill hole (Figure 45) with the Pottsville Formation. The interval between Gardner's Fulton coal or Gordon coal and his Dudley (which may be the Kelly in most areas) is probably about equivalent to part of the Allegheny Group. Correlation of individual coal beds with those of the Main Field is pure speculation. Even within the Broad Top Field, there is considerable doubt that named coal seams actually represent single continuous beds.

The marine and brackish zones encountered in the Survey drill hole almost certainly correlate with 3 of the 4 (or 5) marine to brackish zones of the Conemaugh Group. Superficial speculation suggests that the best fit is Pine Creek to Ames horizons. There is no strong indication as to which of the zones correlates with a particular Conemaugh zone.

Internal correlation of coal beds and other units across the field are very confusing. It appears that many coals are actually discontinuous and attempts to rationalize individual beds to the standard seam nomenclature very likely involves jumping beds with the names. The Barnett-Twin complex (Figure 46) seems to be fairly persistant although one or the other is often thin or missing (where this happens the name Barnett is used regardless of which coal is actually present).

Comparison of Gardner's column with the Survey drill hole leads to a number of problems. Gardner gives the maximum thickness of the Pennsylvanian sequence as 1550 feet, the Survey drill hole shows only 1200 feet. Even more striking is

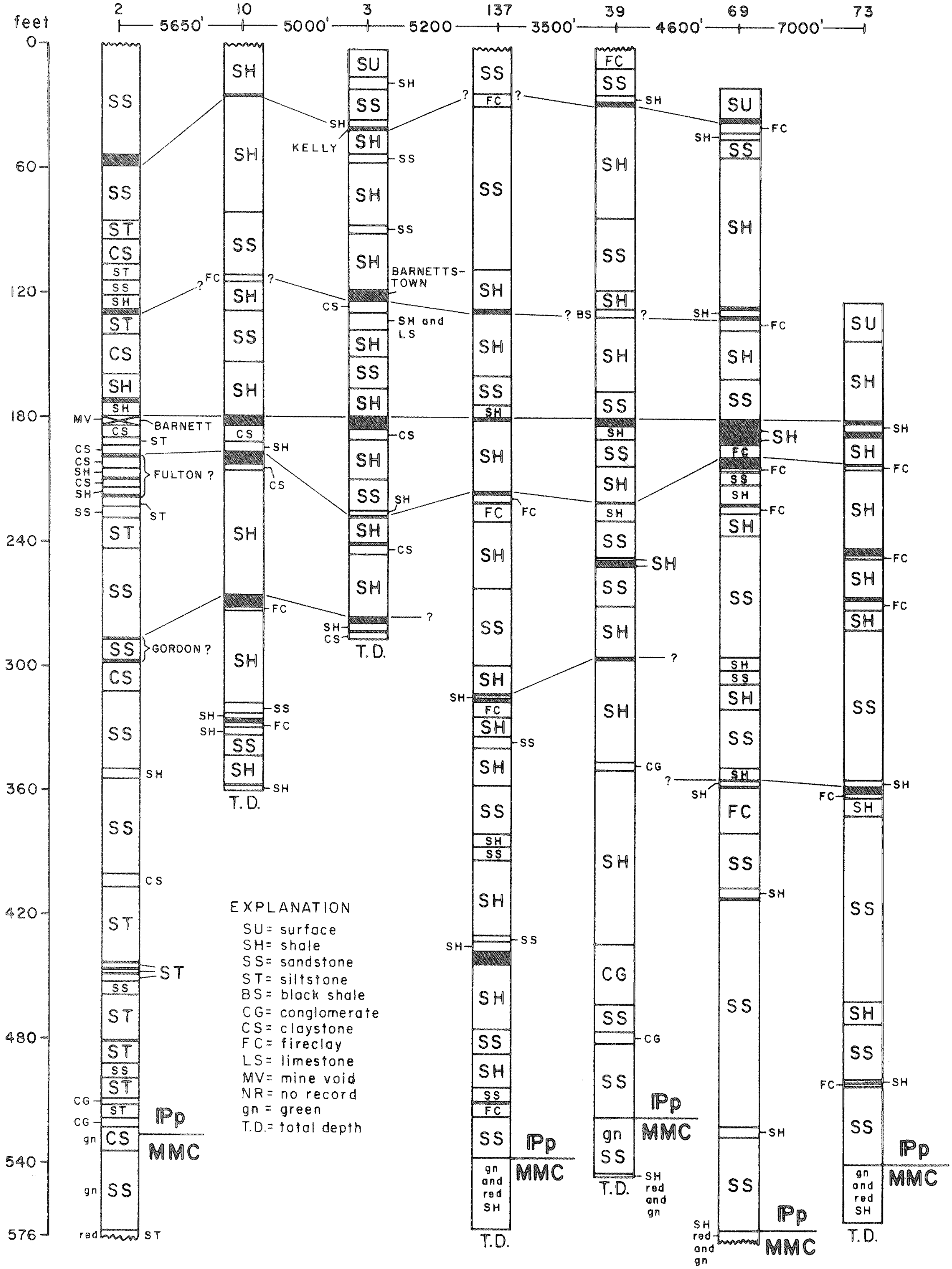


Figure 46. Broad Top stratigraphy as shown in selected drill records.

the fact that Gardner projects about 1275 feet above the Barnett coal, but the Survey drill hole, if correlated correctly, has only about 860 feet.

The advantage of a single complete drill hole penetrating the entire section over the piecing together of many short surface sections is overwhelmingly demonstrated.

A noteable miscorrelation contained in Gardner's nomenclature is the identification of the Rogers coal as equivalent to the Pittsburgh coal of the Main Field and the associated assignment of all overlying strata to the Monongahela Group. White (1885, p. 304) states that this correlation was originally made by J. P. Lesley, State Geologist of the Second Pennsylvania Survey. Richard R. Hice, State Geologist of the Third Pennsylvania Survey (quoted in Gardner's report) stated that there is "little room to doubt the correlation of the Rogers with the great Pittsburgh coal." The fact that Gardner regularly used a question mark after the name "Pittsburgh", leads one to suspect that he may have had serious doubts about the equivalency, but he prudently avoided pressing this view too far. Ashley (1928) and Sisler (1926) rejected this corrrelation, and the presence of marine or brackish invertebrates within a few feet of the Rogers (regardless of which of the 2 choices is correct) in the Survey drill hole makes it virtually untenable. It seems likely that all of the upper 600 to 700 feet of section in Broad Top is Conemaugh Group equivalent.

There is one other remote, but real possibility concerning the identification of the Rogers as Pittsburgh. Although most of the discussion of the Rogers is in terms of the coal so-correlated on Round Knob, the Rogers is named and identified as Pittsburgh on Rogers Knob 1 mile north of Defiance. This is near the west edge of Broad Top in an area of very intense folding with some dips near vertical. If the syncline under Rogers Knob is much deeper than believed (the Barnett would have to be 1300 feet or more below the Rogers), it might be possible to have the Rogers there equal the Pittsburgh.

The placement of the Mississippian-Pennsylvanian boundary at the contact between the Pottsville and the Mauch Chunk assumes that this contact is disconformable and that the time-boundary falls within a considerable gap of erosion and non-deposition. There is no clear physical evidence that any such disconformity exists in the Broad Top coal field. Paleobotanical studies may shed some light on the general correlation of the Broad Top sequence, but although plant fossils are abundant and sizeable collections have been made, no systematic zonation work has ever ensued.

STRUCTURAL GEOLOGY

The structure at Broad Top exhibits folding developed at a number of superimposed magnitudes. The Broad Top basin itself is a 10-mile wide synclinorium with a broad, relatively flat bottom and steeply upturned sides. Within this, the basin is divisible into western and eastern synclines separated by a broad anticline. Most structural features trend NNE-SSW.

The western syncline can be more properly thought of as a sub-synclinorium divided into a number of fairly tight anticlines and synclines. Individual structures may plunge out, but the overall folded nature of the western third of the basin persists. Along the western edge of Broad Top folding is very strong and some dips approach vertical. The middle third of the field is a broad arch which is slightly asymmetrical to the east.

The Trough Creek or East Broad Top syncline is a broad structure along the eastern edge of the field, broken only by a single major thrust fault. No other major faulting has been observed, although additional detailed studies may bring more to light.

COAL RESOURCES AND MINING

Broad Top coal is classified as low volatile bituminous rank. Most analyses are between 78 and 83 percent fixed carbon (dry, ash-free basis). Heat value is in the 15,600 to 15,800 Btu/pound range (dry, ash-free basis) which approaches the theoretical maximum for coal. Heat value on an as-received basis is usually about 15,000 Btu/pound. Ash content among mined coals has usually fallen between 5 and 10 percent. Sulfur content is usually from 0.5 to 3 percent with some analyses as high as 5 percent.

Coal from the highly folded western part of the Broad Top Field tends to be very closely fractured and often exhibits secondary directions of cleavage or slickensiding. As a result the coal disintegrates to splinters, chips, and fine cubes upon mining. Farther to the east the coal exhibits the more usual blocky fracture.

Broad Top coal cokes well and at one time supported a thriving coke industry. Several hundred beehive coke ovens operated at various sites within the field as well as at nearby Saxton, Riddlesburg, and Orbisonia.

Most coal production has come from the Fulton, Barnett, and Kelly seams with minor amounts from the Rogers, Barnettstown, and Twin. There is some question as to whether each of these named coals actually represents a single, discrete bed. The Barnett and its closely associated rider, the Twin bed, seem to be fairly continuous. The other named seams, however, may each be discontinuous beds occurring at more or less the same stratigraphic position.

The earliest mining in the Broad Top Field was probably some time prior to 1800, but significant development came with the construction of coal-hauling railroads. The Huntingdon and Broad Top Railroad, completed in 1856 from Saxton to Broad Top City opened up the northern part of the field along Shoup Run. Extensions Six Mile Run and Sandy Run shortly after gave access to the southwest portion of Broad Top. Mining in the eastern half of the field began with completion of the East Broad Top Railroad to Robertsdale in 1874.

Gardner (1913) estimated the original tonnage of mineable coal at 313 million short tons. Reese and Sisler (1928) recalculated the recoverable resources of coal over 18 inches thick at 415 million tons. Ashley (1944) placed remaining coal at that time at 122 million tons over 24 inches thick and 79 million tons over 36 inches. Using Ashley's figures as a base, Edmunds (1985) gave the remaining coal resources as of January 1, 1984 as 99 million tons over 24 inches, 87 million tons over 27 inches, and 65 million tons over 36 inches. Edmunds also gave total coal mined and otherwise lost as 110 million tons.

Production from Broad Top peaked in 1918 at somewhat over 2.5 million tons and again in 1947 at a little more than 1.5 million tons. From 1980 through 1984 production averaged about 330,000 tons per year.

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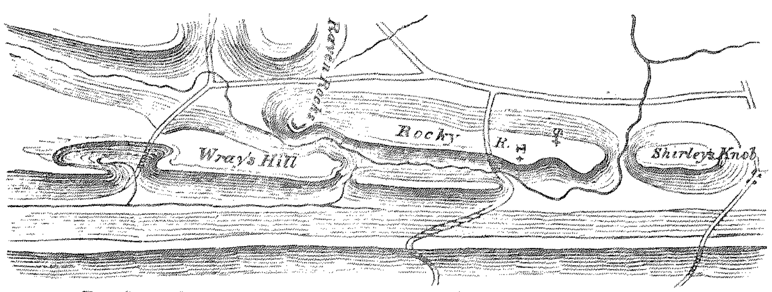

FIG. 314.—Topographical Sketch, Shirley's Knob, Broad-Top Mountain.

Topographic sketch from Rogers, 1858, v.1, p. 449.

GEOMORPHOLOGY AND SURFICIAL GEOLOGY IN HUNTINGDON COUNTY

by
William D. Sevon
Pennsylvania Geological Survey
Teresa L. Kaktins
The Pennsylvania State University

INTRODUCTION

Most published work treating the geology of Huntingdon County was done by the First and Second Pennsylvania Geological Surveys. Because the work of these Surveys was mainly descriptive and directed toward bedrock geology, little information exists about the geomorphology and surficial geology of the area. We have attempted to combine a general reconnaissance of the county, the landscape evolution concepts of Sevon (1985a & b), and the detailed work on the Juniata River terraces of Kaktins (1986) into a coherent overview of the geomorphology and surficial geology of the area.

HISTORICAL PERSPECTIVE

The most basic concept of landscape evolution, erosion, was in a state of confusion among American geologists in 1836 when the First Pennsylvania Geological Survey was organized. The idea that the present landscape resulted from fluvial erosion was apparently accepted by some (e.g., Darby, 1824, p. 24, 75) and denied by others (e.g., Rogers, 1858). The same was true of interpretations of what we now recognize as glacial drift (Daubeny, 1939, p. 8-14).

Henry D. Rogers, director of the First Pennsylvania Geological Survey, thought that all sedimentary rocks, even coal, were deposited in oceanic waters (1858, v. 2, p. 806-807) and remained there until the period of mountain building. He believed that "pulsation in the fluid matter beneath the crust, propagated in the manner of great waves of translation" produced the folds of the Applachian Mountains and lifted them above sea level (Rogers and Rogers, 1843; Rogers, 1858, v. 2, p. 916). Rogers envisioned that the repeated violent formation of waves of rock above the surface of the ocean generated paroxysmal oceanic waves which eroded the uplifted rock to the topographic forms we see today by

> "the carving force of waters working through breaches in the ridges, and scooping them at such enfeebled points into these terraced oval valleys by the revolving eddying currents of the tremendous waves which swept transversely all the summits of this chain. To this excavating action of water, propelled in gigantic billows and rushing sheets across our anticlinal ridges, when these were lifted by successive but sudden earthquake movements, higher and higher through and above the ocean, while at each paroxysm they were becoming more and more permanently arched, we must, I think, attribute, conjointly with the differences in the susceptibility of the strata, to erosion, all the phenomena of excavation which I have described." (Rogers, 1858, v. 2, p. 923-924).

We know that of Rogers' corps J. P. Lesley believed this scenario (Lesley, 1956, p. 166-169).

Prior to becoming director of the Second Pennsylvania Geological Survey, Lesley abandoned cataclysmic doctrines and accepted that "Erosion by wind and rain, sunshine and frost, slow chemical solution, and spring and fall freshets, has done the whole work." (Lesley, 1869, p. 310) Other Second Survey workers held similar views (e.g., Claypole, 1885, p. 38; White, 1885, p. 386).

Davis' classic paper "The rivers and valleys of Pennsylvania" (1889) and his concept of the peneplain (a widespread plain of low relief) as the end form of an erosional cycle had no effect on the writings of the Second Survey. Third Survey writings do not discuss Pennsylvania landscape for the most part except for a general review by Stone (1908, p. 109-127) in which he presented one of the first physiographic province maps of Pennsylvania (p. 110) and discussed the Schooley (higher) and Harrisburg (lower) peneplain surfaces (p. 120-121).

George Ashley, director of the Fourth Survey from 1919 to 1947, had considerable interest in geomorphology. He adhered to the concept of peneplanation in the Appalachians and believed that the landscape we see today was produced by erosion of the Schooley peneplain surface during the last million years (1933; 1935). Pierce (1966) elaborated on the relationships between many aspects of bedrock geology, surficial deposits, and topographic development and discounted the necessity of peneplanation to explain hypothesized remnant surfaces. Sevon (1985a & b) believes that Pennsylvania landscape is a complex, polygenetic aggregate of landforms resulting from successive episodes of climatically controlled weathering, erosion, and minor depostion since at least the end of the Paleozoic.

HUNTINGDON COUNTY LANDSCAPE

The landscape of Huntingdon County superbly expresses the extent to which long-continued erosion can accentuate initial differences in rock resistance. This is shown on a grand scale throughout the trip area by elongate ridges and adjacent valleys which reflect underlying bedrock types and geologic structure. The clarity of this erosional etching is due mainly to a lack of surficial cover. The crests and upper slopes of ridges and low hills are covered with very thin soil and some of the lower slopes have little or no colluvium. The middle and lower slopes of large ridges, such as Tussey Mountain, do have appreciable thicknesses of talus, boulder colluvium, and stony colluvium deposits which partially obscure geologic structure.

There are two contrasting stream-valley types in the area: (1) valleys with entrenched meanders, terrace deposits, and moderate to large streams, e.g. Raystown Branch Juniata River, Aughwick Creek, Great Trough Creek, and Yellow Creek, and (2) valleys with broad fluvial plains, no terraces, and small, apparently underfit streams, e.g. Emma Creek, Fort Run, Crooked Creek, Three Springs Creek, and Sinking Run. Some of these stream valleys change character along their length, e.g. Aughwick Creek and Great Trough Creek. These variations appear to be primarily the result of different potential bedrock erosion rates: large streams and rivers have terraces regardless of bedrock geology whereas terraces generally are absent along small streams in small drainage basins. Streams which appear underfit occur where the dominant bedrock type produces highly erosive soils. The floodplain of many such streams has aggraded in recent times in response to sediment produced by agricultural, mining, and foresting practices (Bilzi and Ciolkosz, 1977). Because small stream systems generally are sensitive to short-term changes, it is necessary to study large streams and rivers for records of long term geomorphic history.

Kaktins (1986) studied terraces along the main course of the Juniata River from Water Street and Barree to its junction with the Susquehanna River at Duncannon, a distance of 174 km (108 mi). She found a sequence of 5 correlative terrace levels and associated deposits (Figure 47), and some higher isolated

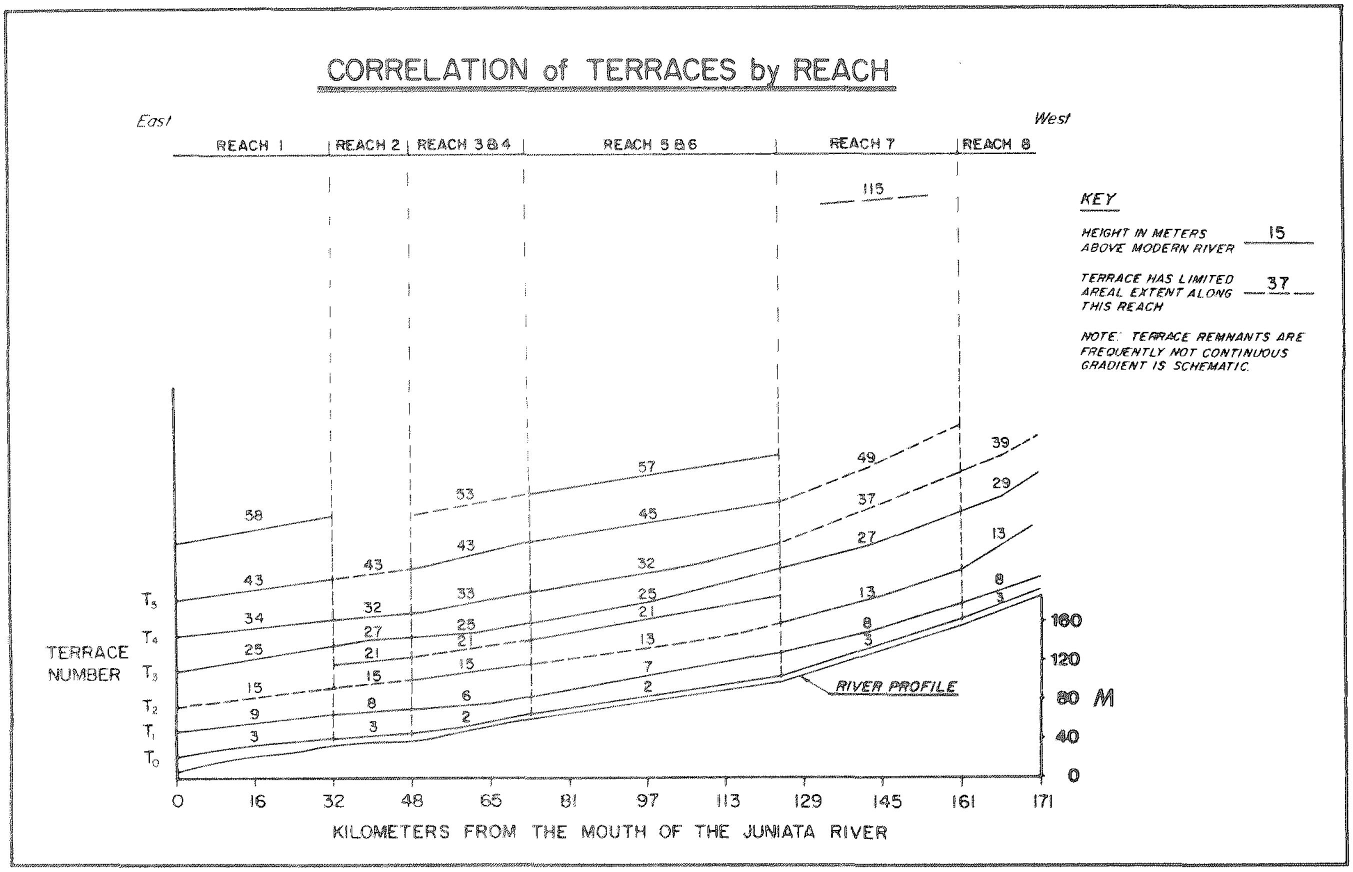

Figure 47. Correlation of Juniata River terraces by reach. Each Reach is a subdivision of river length based on contrasting structural geologic or lithologic settings. Terrace height is the approximate cluster midpoint on a height number of occurrences histogram.

Reach 1: From the mouth of the Juniata River to the first major bend in the rivercourse northeast of Thompsontown (at Durward Station).

Reach 2: From the major river bend at Durward Station to the sharp river bend 1/2 mile east of Mexico.

Reach 3: From Mexico to 2 miles north of Mexico, an approximately 4 1/2 $mile^2$ semicircle-shaped area.

Reach 4: From 1/2 mile east of Mexico to the mouth of Kishacoquillas Creek in Lewistown.

Reach 5: From the mouth of Kishacoquillas Creek in Lewistown to 1 mile south of Newton Hamilton (1/2 mile west of Silverford Heights).

Reach 6: Broad terrace remnants southwest, east, and southeast of McVeytown.

Reach 7: From 1 mile south of Newton Hamilton to the mouth of Shavers Creek 1/2 mile south of Petersburg.

Reach 8: From the mouth of Shavers Creek to Barree (along the Little Juniata River) and to Water Street (along the Frankstown Branch).

remnants with fluvial boulder lag deposits. Various features of the terrace deposits and the terrace levels (Table 5) indicate clearly that terrace age increases with increasing height above the river and that the terraces formed as a result of lateral migration and incision of the Juniata River. Reconnaissance work concentrated along the Raystown Branch Juniata River, Aughwick Creek, and Trough Creek indicates that terrace deposits occur along these streams and that their levels and respective ages probably correlate with deposits along the Juniata River.

SUGGESTED GEOMORPHIC HISTORY

Alleghanian uplift commenced in the Huntingdon County area sometime near the end of the Paleozoic (Van der Voo, 1979). The climate became increasingly arid (Schwarzbach, 1961) and, although the surface materials may have been readily eroded because of lack of cementation, the probable lack of perennial streams may have slowed removal of debris from the area. Erosion continued throughout the Triassic and Jurassic under the influence of a predominantly arid climate (Hay and others, 1982). The modern drainage network of Pennsylvania was at least partly established during this time and was probably complete by the mid Cretaceous.

Opening of the Atlantic Ocean in the Jurassic resulted in increased moisture and development of a hot climate with seasonal high rainfall (Hallam, 1984; 1985). Vegetation covered the landscape for a long period of time during the Cretaceous and the early Tertiary, diminishing the effectiveness of physical erosion processes, increasing the relative importance of chemical weathering processes, and facilitating the preservation of deeply weathered rock. These conditions presumably prevailed with an unknown amount of minor variation throughout the Late Cretaceous, Paleocene, and into the Eocene. Sevon (1985) has suggested that some basic features of the topography we see today were developed during this very long span of time. By the end of the Eocene the high ridges of Canoe, Tussey, Terrace, Sideling Hill, Jacks mountains, etc., would have been a few tens of meters higher than they are today, the intermediate valleys broad and gently graded, the streams meandering in structurally controlled patterns on valley floors, and the rock weathered to considerable depth.

Climatic cooling commenced at the end of the Eocene and culiminated in the periglacial climates which affected Huntingdon County at least 3 times during the Pleistocene. The effect of changes in climate and associated changes in vegetation was mainly increased physical erosion. Previously weathered materials were transported out of the area and the land surface was eroded to produce the topographic configuration we see today. Though much of this erosion probably occurred in the Tertiary, effective periglacial processes during the Pleistocene must have contributed significantly to sculpturing of the present landscape. Terraces up to 60 m above the modern Juniata River were presumably formed during this latter period and appear to fit a Pleistocene chronology (Kaktins, 1986), but ages of the higher terraces are uncertain. Kaolinitic clays developed from the Stormville Shales and Gatesburg Dolomite (White, 1885; Leighton, 1941), brown hematite ores and iron nodules (White, 1885), and bauxites developed on the Gatesburg (Parizek and White, 1985) indicate that in some favorable geologic settings the weathering products of pre-Pleistocene climates are still preserved.

Table 5. General characteristics of terraces and fluvial deposits along the Juniata River.

CHARACTERISTIC	TERRACE LEVEL T_0	T_1	T_2	T_3	T_4	T_5	Remnants above T_5	
Mean height above modern Juniata River (m)	1-3 (Floodplain)	5-9	13-17	25-29	32-39	43-49	51-62	100-130
Approximate local relief on surface (m)	1-2	2	2	3	3	5	7	7
	← Constructional	✕			Destructional →			
Typical slope (%)	0-2	0-2	1-3	2-4	2-5	2-6	0-6+	0-6+
Mean clast rind thickness (mm)	1.4	5.1	5.6	8.5	12.7	12.1	14.1	21.9
Lithologic variety of clasts at terrace surface	All preserved.	Limestones absent, shales degraded.	Red siltstone and shale absent; green shale and siltstone rare.	Quartzite, chert, graywacke present.			Quartzite, chert present.	
	Resistance: Quartzite, chert > graywacke sandstone > green siltstone, shale > red siltstone, shale > limestone.							
Soil group	Entisol	Inceptisol	Alfisol and Ultisol	Ultisol			Ultisol or soil developed from underlying bedrock.	
Structures in upper 1-3 m of sediment	Deposition and erosion active; fine laminae preserved in sediment.	Fine laminae absent medium to coarse stratification preserved.	Occasional cryoturbation wedge structures; stratification preserved below 1-2 m.	Cryoturbation wedge structures in upper 1-3 m; Fe-oxide laminae and pebble coatings occasionally present in coarse sediment.			No stratification observed; Fe-oxide thick laminae and nodules very common.	
Sedimentology	Deep exposures with stratification preserved show a fining-upward sequence of bouldery channel lag, to sandy point bar, and sandy to silty overbank deposits. This is the most common lateral migration fluvial facies association (Davis, 1983). The other major depositional environment is the abandoned channel fill, an alternating sequence of thin-bedded sands and clayey silt.						Fluvial deposits indicated by presence of smooth, waterworn cobbles and boulders.	
Estimated age	Recent	Late Wisconsinan	Early Wisconsinan	Illinoian			Pre-Illinoian	

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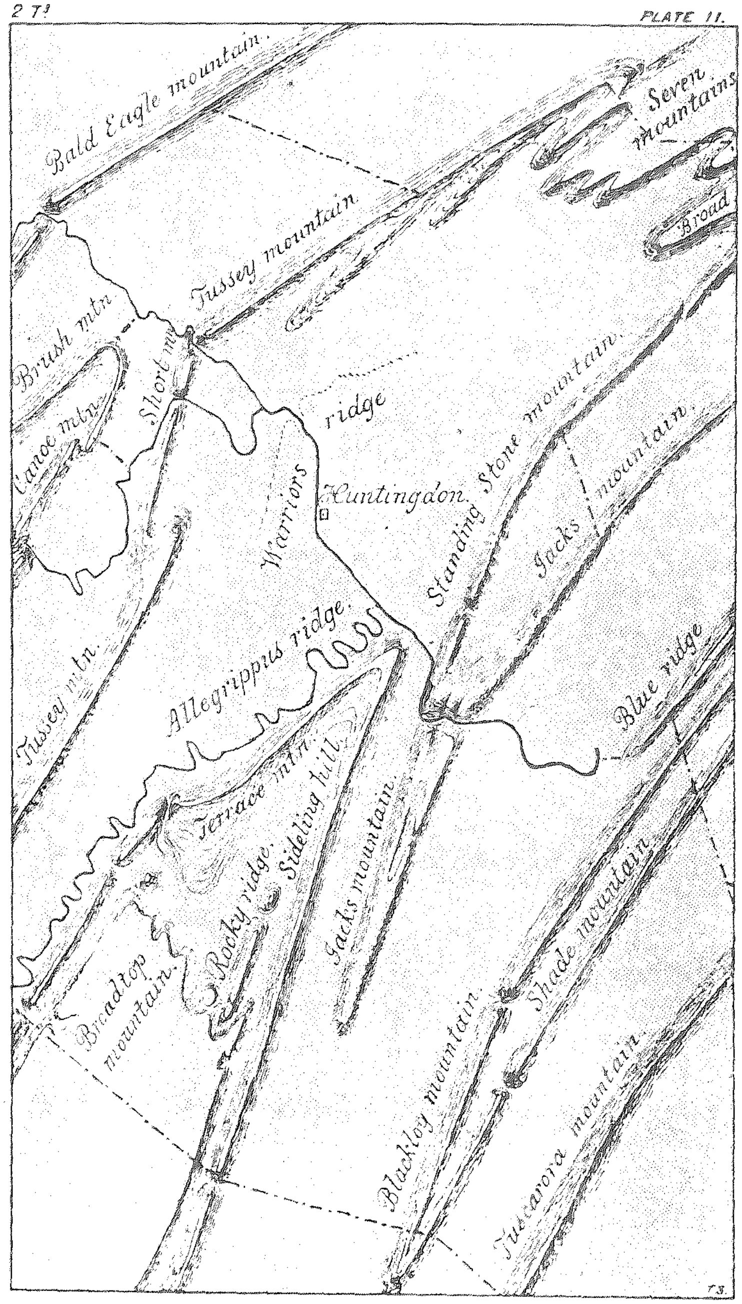


Plate 2. Mountain map, (White, 1885, p. 2).

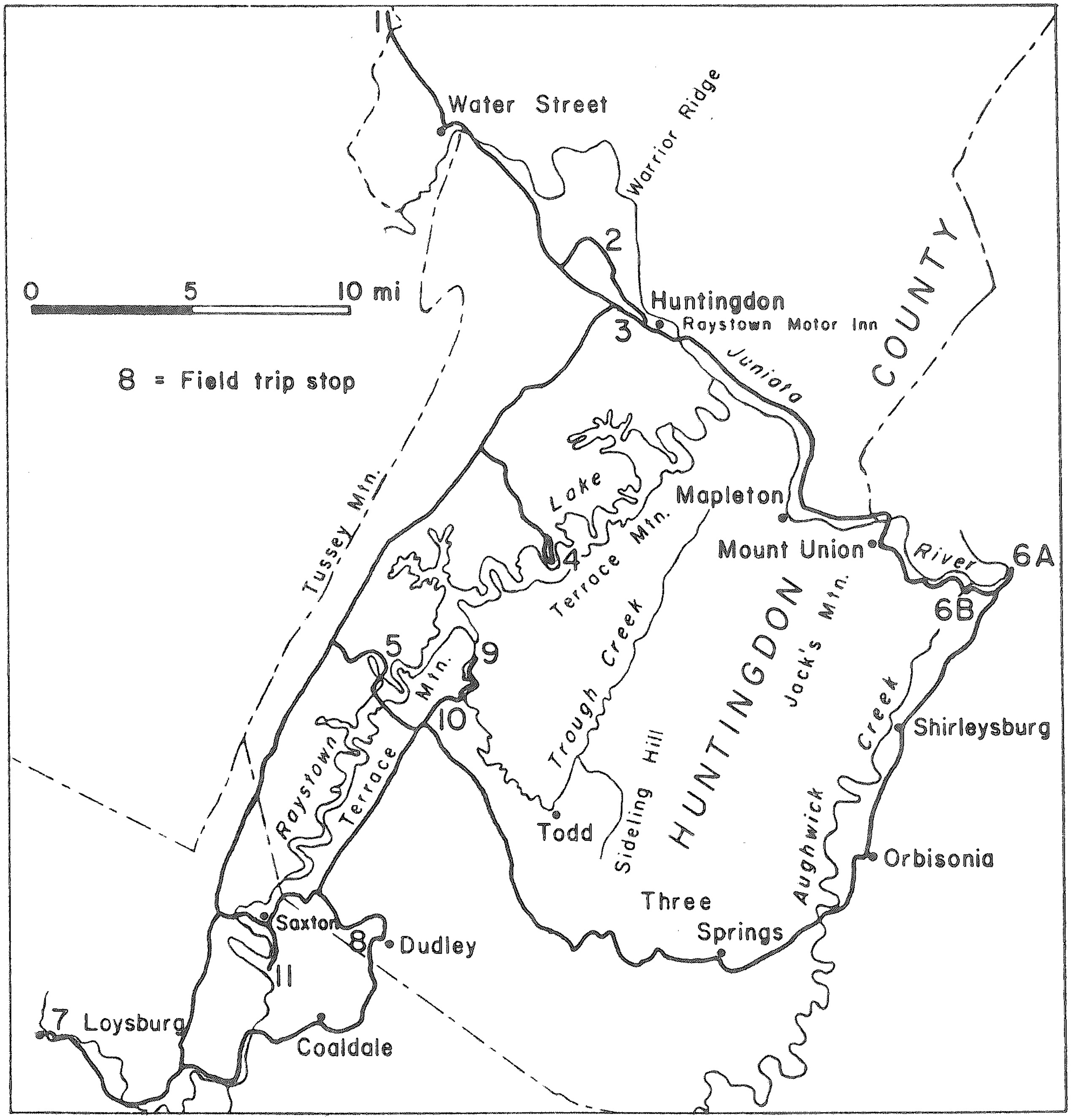


Figure 48. Field trip route map with Stop locations and selected geographic names.

ROAD LOG - DAY 1

Mileage Inc	Cum	
0.0	0.0	START. Leave parking in back of Raystown Country Inn, Huntingdon, PA. TURN RIGHT onto US Route 22 West.
0.7	0.7	Outcrop in roadcut is Mahantango Formation and site of Stop 3.
1.5	2.2	Climbing Warrior Ridge. Outcrops of Oriskany Formation in woods on both sides. Valley to left has had its surface drainage captured by Crooked Creek, whose mouth is about 0.3 mile west of Raystown Country Inn.
1.4	3.6	Entrance to Lincoln Caverns on right. Numerous outcrops ahead along the road show small folds in the Tonoloway Formation.
2.0	5.7	Outcrop of Wills Creek Formation on right.
0.4	6.1	Outcrop on left is the Charlie Hill Section (Stop 6, Field Trip 4, 50th Annual Field Conference of Pennsylvania Geologists Guidebook, p. 191-198).
0.7	6.8	PA Route 305 to right goes to Alexandria, formerly Hart's Log. US Route 22 is here traversing a terrace of the Juniata River and Alexandria is located on a lower terrace the floodplain of the Juniata River.
2.0	8.8	Bridge over Frankstown Branch Juniata River. Scree slopes of Tuscarora ahead on left are presumably of periglacial origin and formed during the Pleistocene.
0.2	9.0	Outcrop on right of Juniata Formation.
0.5	9.5	BEAR RIGHT to PA Route 453 North in Water Street. BEAR RIGHT at Stop Sign onto PA 453 North. Water Street is so named because the river bed was used as a passage through Tussey Mountain.
1.3	10.8	View to left of Canoe Mountain, nose of a plunging syncline. Becomes Brush Mountain on west side. Low outer ridge is Bald Eagle, inner ridge is Tuscarora. Flat surface being traversed is a high abandoned meander with fluvial gravels at the surface about 200 feet above the Juniata River.
1.2	12.0	View ahead on right of quarry in Bellefonte and Axemann Formations.
0.9	12.9	Crossing Sinking Valley. Add info. on Arch Spring and Union Furnace.
0.8	13.7	STOP 1. UNION FURNACE SECTION. Park buses at large pull-off at west end of roadcut.

** HAZARD ** CAUTION ** HAZARD **

This road cut is dangerous because of the presence of many widow and widower makers (loose, overhanging rocks)! For this reason:

Please!! DO NOT HAMMER ON THE OUTCROP! Please!!

The Traffic Guards you see today are also for your safety, the moving vehicles are not. Please obey the Guards' instructions so that you can enjoy tonight's "spirited" activities.

STRATIGRAPHY AND SEDIMENTOLOGY

DISCUSSANTS: SAMUEL W. BERKHEISER, JR. AND JOAN CULLEN-LOLLIS

INTRODUCTION

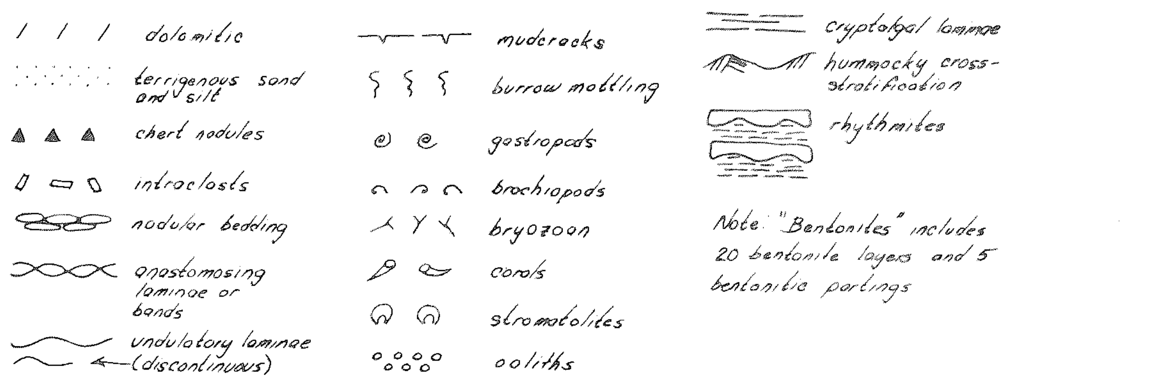
About 850 feet of Middle to Upper Ordovician-age (Black Riverian-Trentonian) carbonates are exposed in this roadcut (lat. 40°37'78" N, long. 78°10'25" W) which was completed in 1962 (A. Sternagle, personal communication, 1986). Exposed are the Loysburg, Hatter, Snyder, Linden Hall, Nealmont, Salona, and Coburn Formations, or what Rogers (1856) called the Auroral and Matinal Limestones (see p. 7-11).

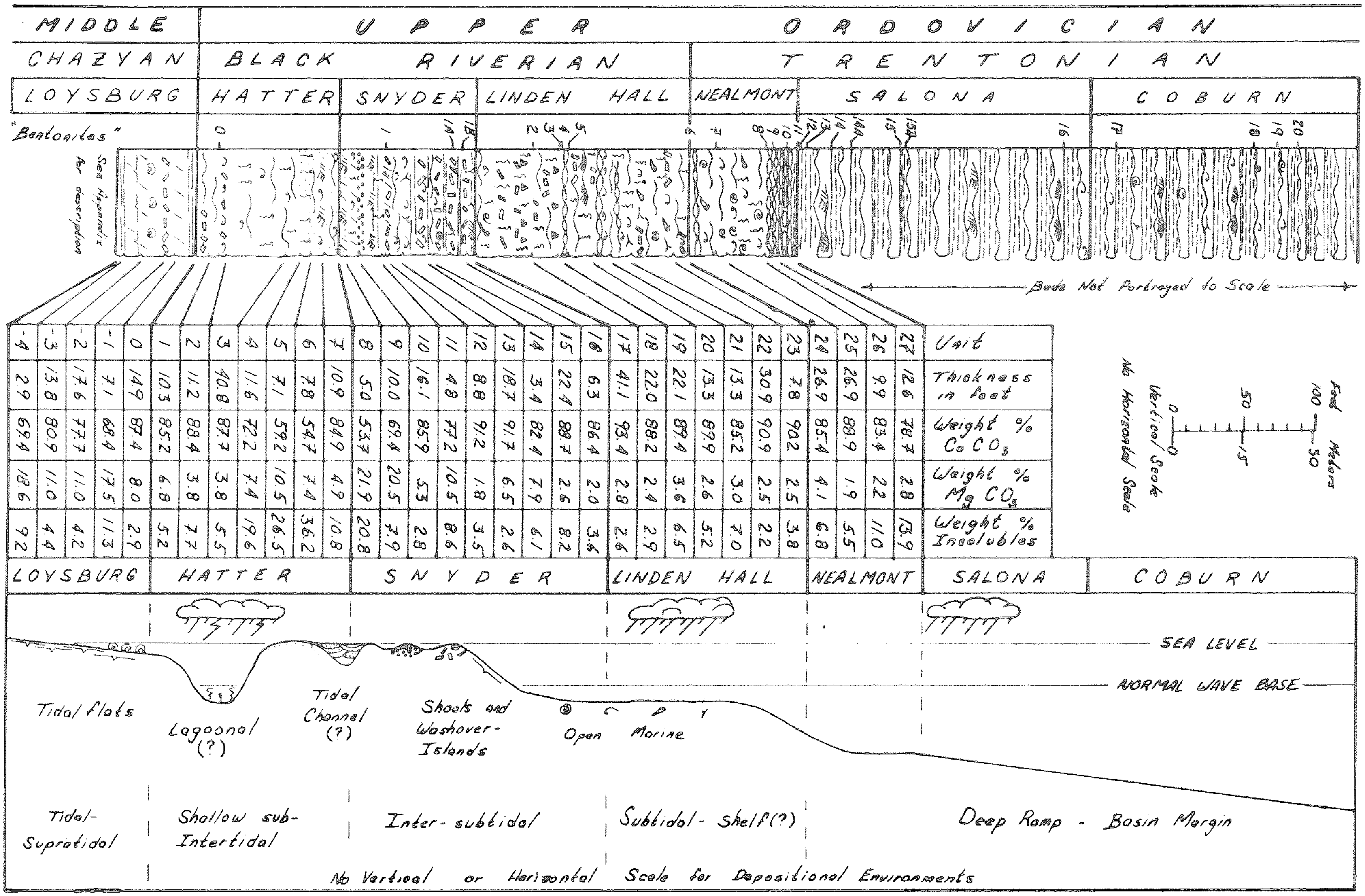
Historically, this part of the Paleozoic section has been economically significant. In view of this, 32 units of varying thicknesses, within the stratigraphic section from the Loysburg through Nealmont Formations, were sampled here and analyzed for $CaCO_3$, $MgCO_3$, and insoluble residues (Figure 49). These analyses combined with the excellence of the exposure provide an opportunity to examine the physical and chemical characteristics of this carbonate sequence and to speculate about the origin of these rocks for the amusement of geologists over the next 150 years.

The upper half of the Snyder Formation and the entire Linden Hall Formation average about 90 percent $CaCO_3$ and 4 percent insoluble residue. These values indicate that this 210-foot-thick interval has a good potential in the acid-mitigation markets. This interval appears to have been deposited in a subtidal or lagoonal environment of deposition. Generally, however, the entire carbonate section exposed here reflects an overall gentle deepening of a storm-dominated environment from the tidal flats of the Loysburg Formation through the shallow (less than 100 feet) ramp and basin setting of the uppermost Coburn Formation. The Loysburg through Snyder Formations appear to reflect a series of small-scale, episodic (?), fining-upward (shoaling-upwards) cycles within the tidal and intertidal zones while the Linden Hall through Coburn Formations were apparently deposited below sea level in more open-marine settings.

Twenty bentonite and 5 possibly bentonitic layers have been identified here (Table 6) in the Hatter through Coburn Formations. The trace-element geochemistry and the significance of these bentonites are discussed on pages 13-19. Bentonites have been used for more than 50 years in attempts to unravel stratigraphic complexities in the Valley and Ridge Physiographic Province of Pennsyl-

Figure 49. Columnar section showing the lithology, bentonites, chemistry, and environments of deposition for the Loysburg through Coburn Formations. Explanation for figure below. Figure-opposite page.





Unit	Thickness in feet	Weight % $CaCO_3$	Weight % $MgCO_3$	Weight % Insolubles
-4	2.9	69.4	18.6	9.2
-3	13.8	80.9	11.0	4.4
-2	17.6	77.7	11.0	4.2
-1	7.1	68.4	17.5	11.3
0	14.9	87.4	8.0	2.9
1	10.3	85.2	6.8	5.2
2	11.2	88.4	3.8	7.7
3	40.8	87.7	3.8	5.5
4	11.6	72.2	7.4	19.6
5	7.1	59.2	10.5	26.5
6	7.8	54.7	7.4	36.2
7	10.9	84.9	4.9	10.8
8	5.0	53.7	21.9	20.8
9	10.0	69.4	20.5	7.9
10	16.1	85.9	5.3	2.8
11	4.8	77.2	10.5	8.6
12	8.8	91.2	1.8	3.5
13	18.7	91.7	6.5	2.6
14	3.4	82.4	7.9	6.1
15	22.4	88.7	2.6	8.2
16	6.3	86.4	2.0	3.6
17	41.1	93.4	2.8	2.6
18	22.0	88.2	2.4	2.9
19	22.1	89.4	3.6	6.5
20	13.3	89.9	2.6	5.2
21	13.3	85.2	3.0	7.0
22	30.9	90.9	2.5	2.2
23	7.8	90.2	2.5	3.8
24	26.9	85.4	4.1	6.8
25	26.9	88.9	1.9	5.5
26	9.9	83.4	2.2	11.0
27	12.6	78.7	2.8	13.9

Precision and accuracy of the insoluble-residue and $MgCO_3$ analyses appear to be excellent, whereas, the accuracy of the $CaCO_3$ analyses is uncertain.

vania and with refined "geochemical fingerprinting" they have the potential of being even more useful. Furthermore, the acid-volcanic events that produced these bentonitic units appear to have signaled impending doom to the "carbonate factory." Relative subsidence (drowning) of this platform occurred contemporaneously or shortly after these events.

Faill (p. 119-126) discusses the effects of Alleghanian deformation present at this exposure. No structural evidence of the "stupendous" Taconian orogeny of Rogers (1858) are found here due to the early foreland setting (pericratonic or cratonic shelf). The only significant Taconian influence to be observed here, and only as a prelude to orogensis, is the change from a passive margin carbonate platform or shelf to a gradually deepening basinal depocenter. Evidence for this can be found in the character and thickness of the 100-million-year-long Cambro-Ordovician carbonate sequence, the thickness of the overlying Reedsville Shale, and in the observations of Kay (1951), Rogers (1971), Read (1980), Hardie and others (1981), Diecchio (1985), and others.

Appendix 1 contains a measured section of the Loysburg through Nealmont Formations. Thompson (1963) provides a detailed stratigraphic section of the Salona and Coburn Formations 0.75 mile north of Union Furnace between Warner Company's Quarry 1 and Quarry 2. Combined, these descriptions provide a composite section of the Loysburg through Coburn Formations.

BELLEFONTE FORMATION. Working upward through the stratigraphic section at Stop 1, the upper part of the Bellefonte Formation (Beekmantown Group) is the lowest unit encountered. Although not a focus of this stop, it is exposed in the northern portion of the roadcut across from the debarkation area on the west side of the road. The Bellefonte comprises dark-gray to light-olive-gray, magnesium-rich mudstones, and finely recrystallized dolomites. Within this unit, the presence of cryptalgal laminae, birds-eye or fenestral textures, mudcracks, horizontal burrowing, and possible relict anhydrite pseudomorphs suggest cyclic carbonate sediment accumulation on a tidal flat and supratidal platform. Chemical data for this part of the section are limited; about 53 percent $CaCO_3$, 41 percent $MgCO_3$, and 5.5 percent SiO_2 are average (Miller, 1934). This dolomite-rich formation is a source of railroad ballast and aggregate, generally having a skid resistance level (SRL) of G (Berkheiser and others, 1985). The Pennsylvania Department of Transportation evaluates the desirability of a material for use on road surfaces based on the degree to which a high coefficient of friction can be maintained over time. SRL designations, from best to worst, are E, H, G, M, and L.

LOYSBURG FORMATION. The Loysburg Formation is the lowermost carbonate unit we will examine in detail. It is exposed in the northern part of the roadcut on the west side of the highway and comprises about 56 feet of olive-gray to olive-black, cryptalgal dolomite and limestone (mudstone). It contains thin intraclastic zones (mostly as rip-up algal mats), horizontal worm burrows and burrow-mottling, mudcracks, minor thin skeletal wackstones, and occasional convex-up stromatolites (Unit 2 on Figure 49). These features have been interpreted to suggest a tidal to supratidal environment of deposition. The presumed reduced salinity of supratidal brines (therefore more limestone) of the Loysburg Formation versus the Bellefonte Formation may indicate a change from an arid climate to a wet and rainy climate as postulated by Hardie and others (1981). Chemical analyses reveal a weighted average of 79.5 percent $CaCO_3$, 11.4 percent $MgCO_3$, and 5.1 percent insoluble residue for this exposure of the entire formation (See

TABLE 6. Summary of Union Furnace bentonite and possible bentonitic horizons (Smith, Way, and Berkheiser).

Field Number	Thickness Inches	Color	Feet + or - from base of bentonite to top of Nealmont Fm.	Comments	Outcrop R/hr
			-422.0	Hatter Fm.	
0	1.2 in.	Lt brownish gray (5YR 6/1)	-407.7	shale, bentonitic (?)	3.8
			-322.3	Snyder Fm.	
1	0.8 in.	Pale yellowish brown (10 YR 6/2)	-288.9	clay + shale	5.0
1A	0.5 in.	Lt brownish gray (5 YR 6/1)	-243.7	shale, bentonitic (?)	5.5
1B	0.9 in.	Grayish orange (10 YR 7/4)	-236.4	shale + clay	5.0
			-226.8	Linden Hall Fm.	
2	0.6 in.	Yellowish gray (5 Y 8/1)	-185.7	clay	4.0
3	0.6 in.	Yellowish gray (5 Y 7/2)	-167.5	clay + shale	4.5
4	0.2 in.	Med. dark gray (N4)	-165.5	shale, tr. biotite	5.0
5	3.2 in.	Medium gray (N5)	-141.6	clay + shale	6.0
			-76.3	Nealmont Fm.	
6	0.2 in.	Grayish orange (10 YR 7/4)	-76.3	clay + shale	3.5
7	0.2 in	Light olive gray (5 Y 5/2)	-62.1	clay + shale, bentonitic	4.0
8	0.3 in.	Light olive gray (5 Y 5/2)	-20.9	clay + shale	4.3
9	0.6 in.	Pale yellowish brown (10 YR 6/2)	-17.7	clay + shale	5.6
10	0.7 in.	Yellowish gray (5 Y 8/1)	-8.9	clay	7.5
11	1.6 in.	Light olive gray (5 Y 8/1)	0, on Nealmont - Salona ct.	clay No. 1 of Thompson (1963)	7.5
			0.0	Salona Fm.	
12	2.4 in.	Yellowish gray (5 Y 8/1)	+1.6	clay, 1.6 ft above top of Nealmont (N)	16.3
	3.0 in.	Yellowish gray (5 Y 7/2)		shale + clay, upper part of 12, No. 2 of Thompson (1963)	
13	2.4 in	Grayish orange (10 YR 7/4)	+5.5	upper 1.5 in shale, lower 0.8 in. clay	8.5
14	7.1 in.	Polychromatic, grayish yellow (5 Y 8/4)	+22.8	upper 3.5 in. dark shale mid, 1.5 in. clay lower, 2.5 in. rusty shale	13.5
14A	1.0 in.	Dark yellowish brown (10 YR 4/2)	+37.0	shale, bentonitic (?)	4.5
15	9.8 in.	Yellowish gray (5 Y 7/2)	+71.8	clay, sparse fresh biotite. No. 4 of Thompson (1963)	14.5
15A	0.8 in.	Olive black (5 Y 2/1)	+74.6	shale + clay, bentonitic (?)	6.5
16	4.5 in.	Very pale orange (10 YR 8/2)	186.1	clay, possible trace fine-grained biotite	13.5
				Coburn Fm.	
17	1.7 in.	Light olive gray (5 Y 5/2)	223.0	shale + clay	5.7
18	1.0 in.	Medium gray (N5)	319.9	shale + clay from base of 6.5 in. zone	11.8
19	1.8 in.	Yellowish gray (5 Y 7/2)	336.2	shale + clay from base of 8.5 in. zone	16.1
20	1.4 in.	Light olive gray (5 Y 5/2)	350.6	shale + clay, R bed of Thompson (1963)	9.4
	Total thickness of bentonites exclusive of bentonitic partings				44.6 in.

Figure 49 for detailed chemical analyses). This formation is a source of aggregate, generally having the lowest possible SRL or L designation (Berkheiser and others, 1985).

HATTER FORMATION. The almost 100-foot-thick Hatter Formation is an argillaceous dark-gray to olive-black sequence of laminated carbonate mudstones and minor skeletal wackstones and packstones. Locally, it contains greater than 35 percent insoluble residue composed predominantly of clay and silica silt. Physical characteristics include undulatory, discontinuous laminations, planar laminations, brachiopod fragments and other skeletal debris, thin intraclast zones, minor fenestral textures (Unit 3), horizontal burrows and burrow-mottling, rare hardgrounds, lensoidal and pod-like forms of skeletal packstones and wackstones, and cross-bedded siliclastic-rich intervals. These features suggest shallow subtidal (probably lagoonal) to intertidal environments of deposition. The upper 37 feet of the formation averages about 22 percent insolubles (clay, silt, and silica sand), which suggests a possible intertidal or tidal-channel affinity. Recently, Gardiner (1985) recognized cyclic patterns for these rocks. She characterized both the Loysburg and the Hatter Formations as comprising thin (generally less than 6 inches) storm-deposited, fining-upward cycles (shoaling-upward), having scoured basal contacts and a basal intraclastic skeletal wackstone-packstone interval. The Hatter Formation may contain some previously unrecognized bentonitic partings, especially toward the base where a relatively low energy lagoonal environment is postulated (Figure 49).

Chemically the Hatter Formation averages about 80.8 percent $CaCO_3$, 5.4 percent $MgCO_3$ and 11.8 percent insoluble residue on a weighted average basis. Hypersaline environments apparently were not significant and dolomitization is minimal. During quarrying, the Hatter Formation is usually combined with the entire section producing an aggregate with a SRL rating of L. However, if it were selectively mined, it might have a higher SRL due to its siliclastic nature.

SNYDER FORMATION. The Snyder Formation consists of about 95 feet of grayish-black to olive-black, faintly laminated, burrow-mottled mudstones and skeletal wackstones and packstones. Horizontal and vertical burrows, ooliths, intraclastic zones typically less than 0.5-foot-thick, flat pebble conglomerates, mudcracks, cross-bedding, and fragments of bryozoa, brachiopods, gastropods, crinoids, and possible corals are common. Fining-upward cycles with basal intraclastic lag zones are conspicuous. Gardiner (1985) recognized these as thin, storm-deposited cycles comprising a basal intraclastic lag conglomerate, which is missing at times, overlain by a crossbedded pelletal wackstone-packstone which then grades into an uppermost burrowed mudstone. These features appear to be characteristic of shallow-water intertidal to subtidal shoals or washover islands, perhaps seaward of a lagoonal facies. The Snyder Formation contains the stratigraphically lowest observed definite bentonite beds (Table 6). Assuming an ash-to-bentonite compaction ratio of about 2:1 and ash injection into the stratosphere, from the observed thickness it can be postulated that these volcanic layers probably had climatic influence.

The Snyder Formation here consists of 84.2 percent $CaCO_3$, 7.2 percent $MgCO_3$, and 6 percent insoluble residue. The upper 60 feet averages about 89 percent $CaCO_3$, 4 percent $MgCO_3$, and 5 percent insoluble residue. This formation is a source of SRL L aggregate and in places is mined for agricultural limestone (Berkheiser and others, 1985). The upper portion of the unit has the potential to be used in the manufacturing of coal mine rock dust (pulverized carbonate rock which is sprayed on the interior of underground coal mines to reduce combustibility), cement raw materials, acid neutralization materials, mineral fillers, and feeds.

LINDEN HALL FORMATION. The Linden Hall Formation consists of approximately 151 feet of relatively pure, olive-black to brownish-black, burrow-mottled mudstones with undulatory laminae and thin discontinuous intraclastic wackstones and packstones. The mudstones characteristically average about 0.5 foot thick and commonly contain discontinuous and anastomosing laminae. The intraclastic wackstones and packstones are commonly about 0.2 foot thick and occur as discontinuous concave-upward lenses. Hardgrounds, irregular chert nodules, possible hummocky cross-stratification, brachiopods, gastropods, corals, crinoid fragments, and possible echinoderm fragments are present. These features may be interpreted to suggest an open-marine, subtidal depositional environment. The occurrence of possible hummocky cross-stratification and intraclastic wackstone-packstone lenses suggest that storms still influenced sedimentation, albeit below normal wave base. Here, the rate of subsidence apparently was greater than the rate of sedimentation. Numerous preserved bentonites are found thoughout the formation, some over 3 inches thick (Table 6). Logically, as the wave energy and sedimentation rates decreased, the possibility of preserving ash falls increased. However, this may be more than coincidental. The decrease in wave energy may have been caused by global climatic changes and relative subsidence brought about by these same volcanic eruptions. Possibly, these eruptions are related to an ensialic back-arc basin in Trenton Group rocks now located in North Wales (Orton, 1986).

Weighted chemical averages for the entire 150.5 feet of the Linden Hall Formation reveal 90.3 percent $CaCO_3$, 2.8 percent $MgCO_3$, and 3.8 percent insoluble residue. At this location, the basal ~40 feet is the purest in terms of $CaCO_3$, whereas toward Bellefonte, PA, the upper ~90 feet of the formation is the purest ("Valentine Member" or "Bellefonte Ledge"). This formation produces the same products as the Snyder and has the same economic potential as the upper 60 feet of that formation. If combined into a mining interval, the two would yield 210 feet of relatively pure limestone with about 4 percent insoluble residue.

NEALMONT FORMATION. This formation comprises about 76 feet of olive-black to grayish-black, laminated and nodular mudstones with minor (less than 0.2 foot thick) discontinuous skeletal wackstone lenses. Most argillaceous laminae and bands are undulatory and anastomosing, and gradually become nodular in the upper 18 feet of the formation (Rodman Member). Burrow-mottling, horizontal and minor vertical worm burrows, articulate and disarticulate brachiopods, gastropods, corals, and echinoderm fragments also are common. These features occur in rocks that appear to represent a transition between subtidal and deep ramp or basin margin settings. Anoxic black shales are present and represent quiet-water reducing conditions. The carbonate nodules may be due to pressure solution, compaction, and/or patchy sea-floor cementation. Most of the sediment has been washed in from the nearby subtidal "carbonate factory" and the skeletal wackstone lenses probably record storm events. Energy levels at the time of deposition of these rocks were less than those of the subjacent rocks. Bentonite beds up to 1.6 inches thick are present.

The Nealmont Formation consists of 85.3 percent $CaCO_3$, 2.9 percent $MgCO_3$, and 8.1 percent insoluble residue, which reflects a lower-energy subtidal depositional regime and more clayey nature of the sequence. This formation is also a source of SRL L aggregate and is usually combined with the previously described formations to yield a thicker mining interval.

SALONA AND COBURN FORMATIONS. These formations, 390 feet of "rhythmites," comprise fining-upward, alternating beds of dark carbonaceous mudstone to wackstone and black calcareous shale. Fossils are sparce in the Salona, and increase in abundance in the Coburn. Low-angle crossbedding and hummocky cross-stratification occur in both. Skeletal wackstone-packstone lags with scoured bases are present in the Coburn and commonly contain fragments of brachiopods, trilobites, gastropods, and bryozoa. These fine upwards into crossbedded wackstones, which usually grade vertically into hemipelagic shales. This sequence of rock appears to be a classical storm deposited deep ramp or slope setting. The lack of fossils in the Salona Formation might be attributed to the abundance of preserved volcanic ash we see here (see Smith and Way, 1983 for a discussion of chemical changes and variables related to ash preservation). Bentonite layers nearly 10 inches thick occur here (Table 6). About 200 feet of Salona section contains approximately 29 composite-inches of bentonite, or about 1 inch of preserved volcanic rock for every 7 feet of carbonate rock. Volcanic activity indicated here appears to be about 3 times greater on a sediment-to-ash ratio than in the underlying and overlying formations.

REMARKS

What type, or "model," of carbonate platform are we looking at here? One obvious conclusion should be that one outcrop does not a model make. It does not appear that organic build-ups are significant. It does appear, however, that we may be looking at some sort of carbonate that became drowned.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the field assistance of John H. Way, Lock Haven University, in helping to identify and sample the bentonites as well as helping in the laborious sampling of the thick carbonate section. Leslie T. Chubb, Pennsylvania Geological Survey, prepared the carbonate samples for analysis and performed the insoluble-residue analyses. John H. Barnes, Rodger T. Faill, and David B. MacLachlan, of the Pennsylvania Geological Survey, and John H. Way reviewed the manuscript and helped to keep us from straying too far afield, as did J. Fred Read of Virginia Polytechnic Institute and State University.

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STRUCTURE

DISCUSSANT: RODGER T. FAILL

The long, curved folds that sweep across the Valley and Ridge province of Pennsylvania are well known, and have been recognized since the days of H. D. Rogers. The numerous thrusts, ramps, and decollements that gave rise to these folds are less obvious, largely because most of them in the central Appalachians occur at depth underneath the folds. Their presence has been elucidated only in the past few decades by means of deep drilling and seismic exploration. Transverse structures are not widely known. Only a mere handful can be traced on topographic maps, and they are seldom discussed in geological reports or tectonic papers. Here, at Union Furnace, transverse structures are abundant.

The beds in the Union Furnace section are in the southeast limb of the Nittany anticlinorium; they dip rather uniformly to the southeast, ranging in dip from 27° to 43°. A few small mesoscopic folds are present but only at the south end of the roadcut. No large mappable faults pass through this exposure, yet smaller faults of various kinds are common. Many of the faults are transverse structures, running northwestward across the strike of bedding and the local fold axis direction. Other faults, including wedges, duplexes, and conjugate extension faults, are more congruent with the enclosing fold limb, having strikes more nearly in line with bedding. Stylolites--mostly parallel to bedding, but also perpendicular to it--are common in some of the stratigraphic units, and are essentially absent in others. A poorly developed cleavage also exhibits preferences among the various carbonate lithologies. A schematic diagram of the outcrop is shown in Figure 50.

One other structural aspect of this outcrop should be mentioned--Union Furnace sits directly on the Tyrone-Mount Union lineament (Kowalik and Gold, 1974), a major Valley and Ridge feature that crosses the province, largely following the valley of the Juniata River. The mean trend of this feature is 140 azimuth (S40E).

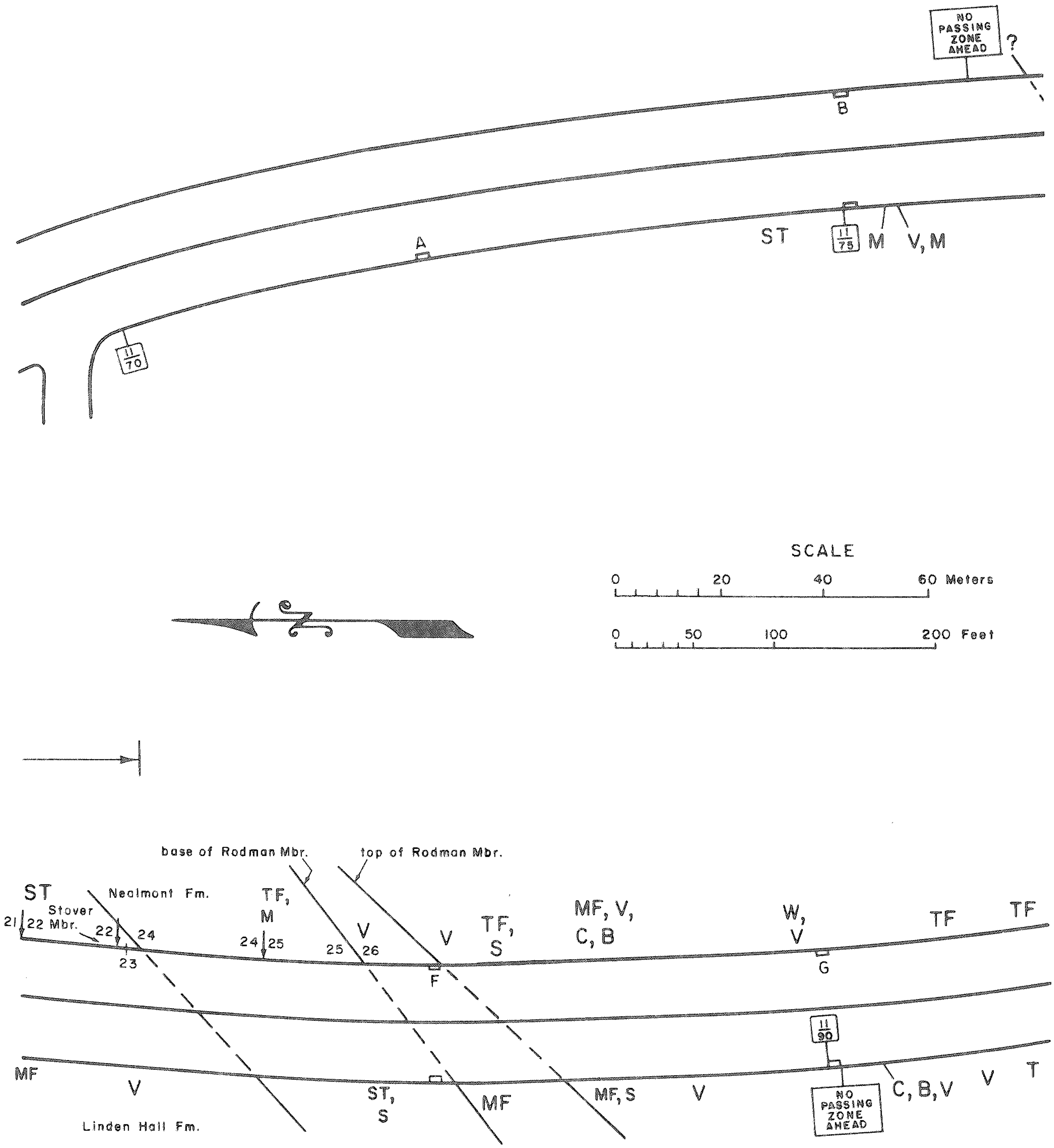
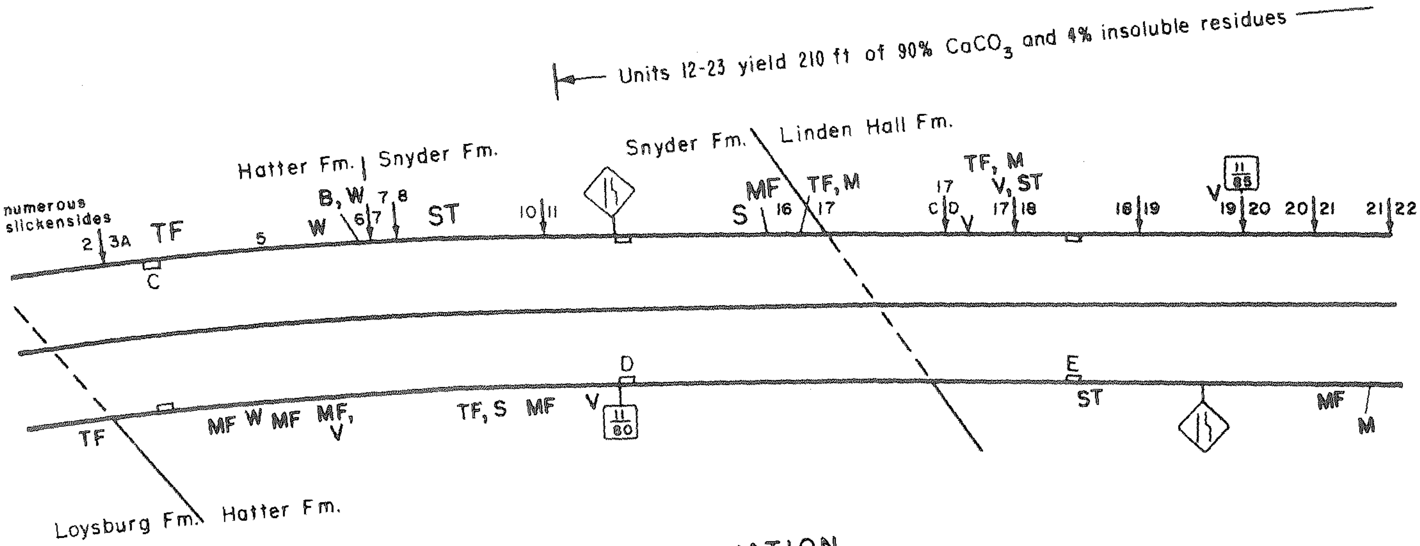
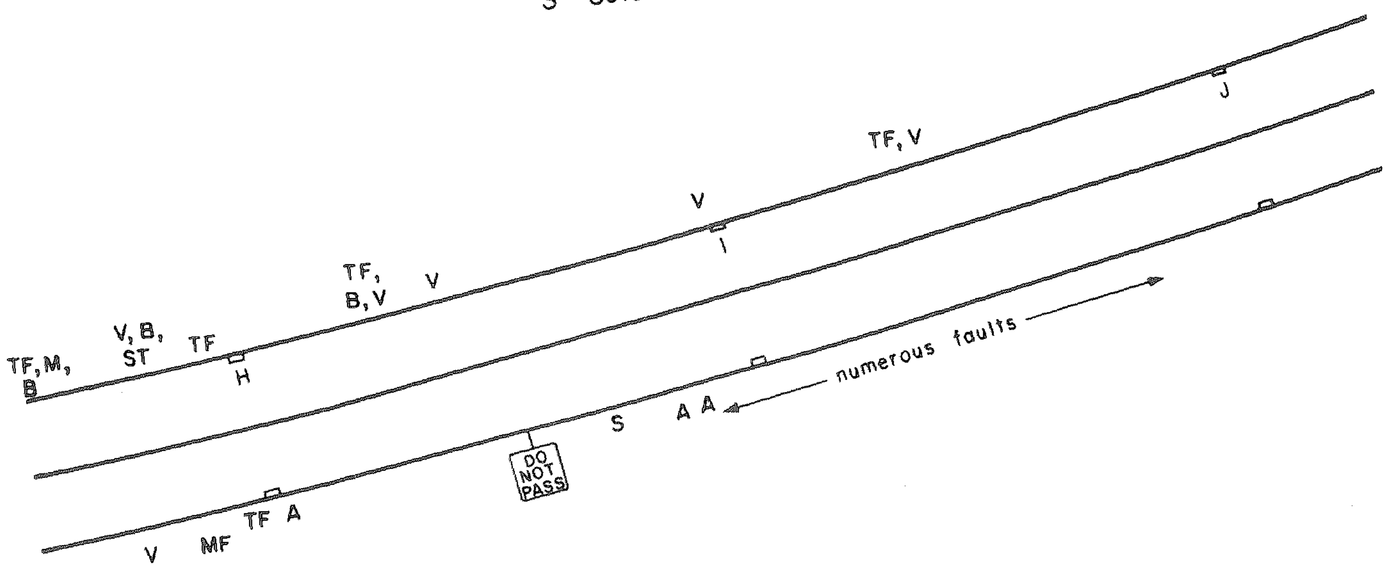


Figure 50. Geologic map of the Union Furnace outcrop along PA Route 453, showing locations of formation boundaries, chemical sample units, and some of the mesostructures. Also shown are the locations of the various highway signs, and the drainage culverts, which are labeled from the north end, A through J.



EXPLANATION

- TF - Transverse fault
- MF - Master fracture
- WF - Wedge fault
- V - Array of veins
- T - Thrust fault
- A - Anticline
- ST - Stylolite
- C - Cleavage
- M - Mullion
- B - Breccia
- S - Solution



BEDDING AND SMALL FOLDS

Bedding dips fairly uniformly throughout the outcrop (Figure 50) to the southeast, with a modal attitude of 155-30 (Figure 51). The principal exception is on the west side at the south end of the road cut (on the west side only) where the beds dip more directly to the south. It is in this part of the outcrop that the only folds appear, and these folds plunge gently to the west and southwest. This part of the outcrop is a distinct structural domain, separated from the rest of the exposure by a subvertical north trending fault that enters the outcrop area under the pavement at the south end and passes through the west outcrop some 150 m north of the south end, at the culvert marked 'H' (Figure 50).

FRACTURES AND FAULTS

Perhaps the most noticeable structures throughout this roadcut are the vertical, throughgoing planar fractures, which are called master fractures (or master joints) because they are much larger than the other fractures. Their much greater extent suggests that they may be of more fundamental significance than the more common variety of fractures which are ususally restricted to single, or at most, a few beds. Here at Union Furnace, the largest concentration trends southeast at 157 azimuth (Figure 52), almost exactly perpendicular to bedding. A subordinate group trends 137 , almost exactly the trend of the Tyrone-Mount Union lineament.

The majority of these master fractures possess slickensides which are indicators of the direction of slip, but not the sense of slip, that has occurred along these surfaces. These fractures exhibit 3 maxima on the stereogram in (Figure 53), 2 of which correspond with the maxima in Figure 52, the third one (167 azimuth) being masked by the non-slickensided data.

The majority of the slickenlines plunge gently to the southeast at about 27°, close to the dip of bedding (Figure 54). This shallow plunge, parallel to the bedding-fracture intersections, indicates that the movements on many of these master fractures occurred rather early, before the beds had been rotated by the regional folding to their present position. That is, there was an extensive horizontal displacement throughout these rocks that predated the Alleghanian folding.

Two other slickenline maxima are present on the slickenside diagram (Figure 54). One is also parallel to the bedding-fracture intersection, but the trend is distinctly more easterly at 129°. This maxima probably reflects the movement on the 136° trending fractures, and, being close to the bedding-fracture intersection, probably occurred before folding commenced. The other maxima is steeply plunging to the northwest. These slickenlines may represent a late movement that occurred towards the end of folding, or that may have occurred at some time since the Alleghanian deformation. More of this will be discussed at STOP 3.

Transverse faults include those fractures along which discernible offset of bedding has occurred. The amount of offset ranges from a few centimeters to several meters, and at one place, the amount of offset cannot be determined. These faults may be related to the master fractures, because slickenlines on them are at a similarly small angle to the bedding-fault intersection. Yet they differ, not only because of the offset, but also because many of them are not as planar as the master fractures, and considerable dissolution has occurred along

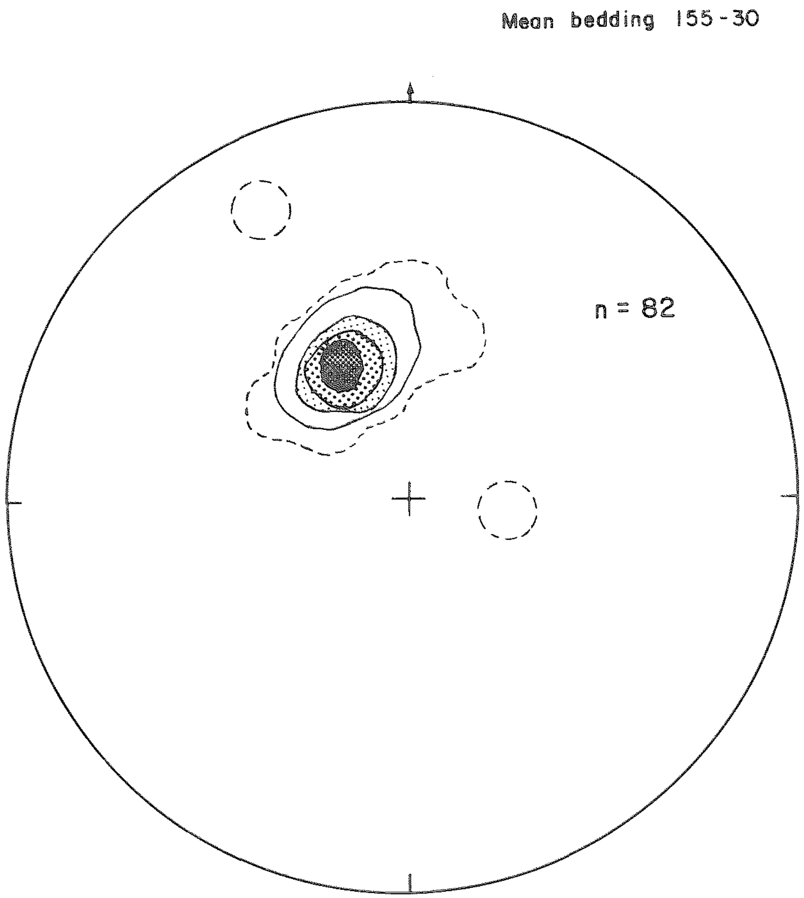


Figure 51. Stereogram of measured bedding poles. Contour intervals are 1, 5, 20, 40, and 60 percent.

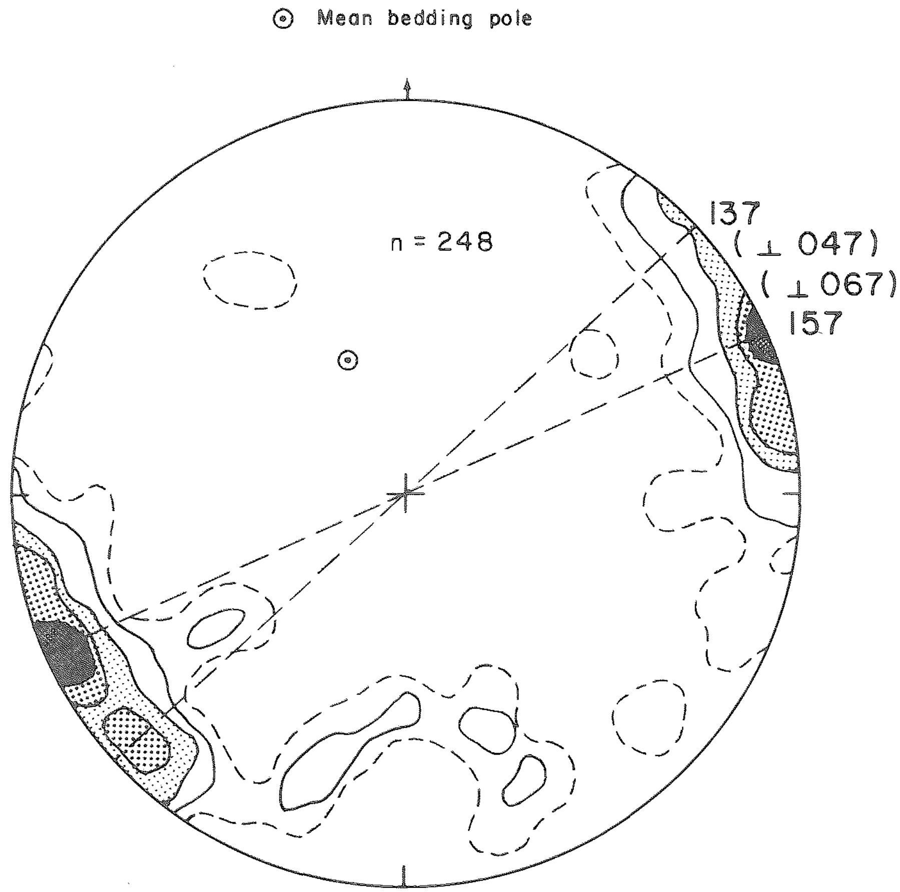


Figure 52. Stereogram of all measured fractures in the roadcut. The two maxima define two sets, trending 137 and 157 degrees azimuth, within a rather broad range of dip fractures. No sets of strike fractures are defined, which reflects the absence of planar fractures parallel to bedding strike. Contour intervals are 1, 2, 4, 6, and 10 percent.

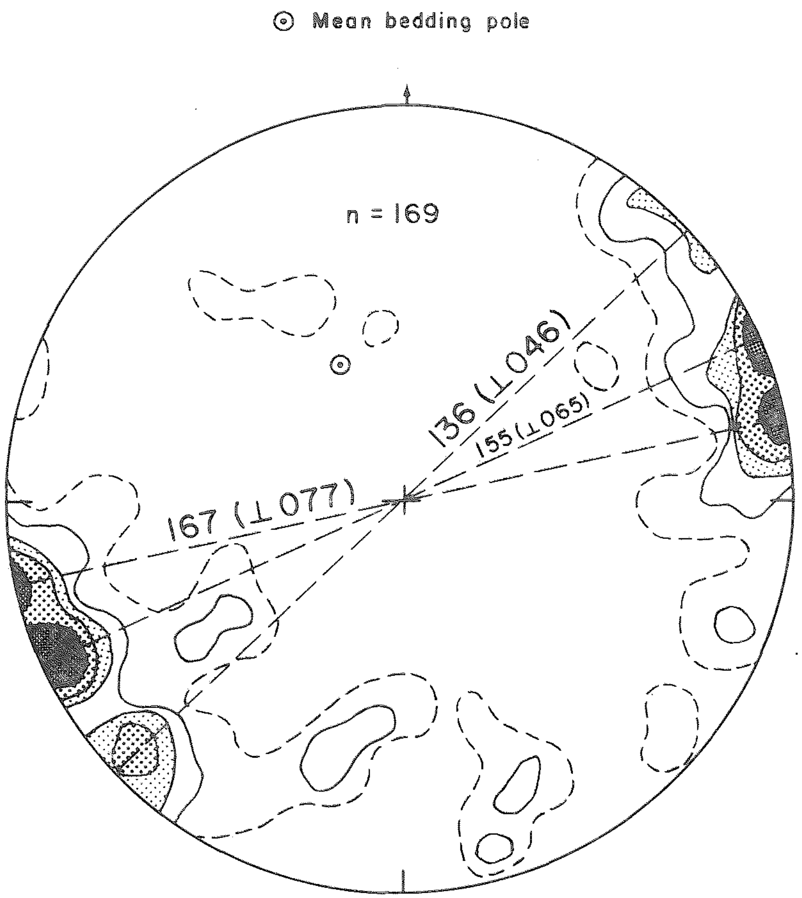


Figure 53. Stereogram of all fractures on which slickensides were measured. The broad range of dip fractures contains three maxima, two of which are nearly identical with the maxima in Figure 52, and a third more easterly trend. Contour intervals are 1, 2, 4, 6, and 10 percent.

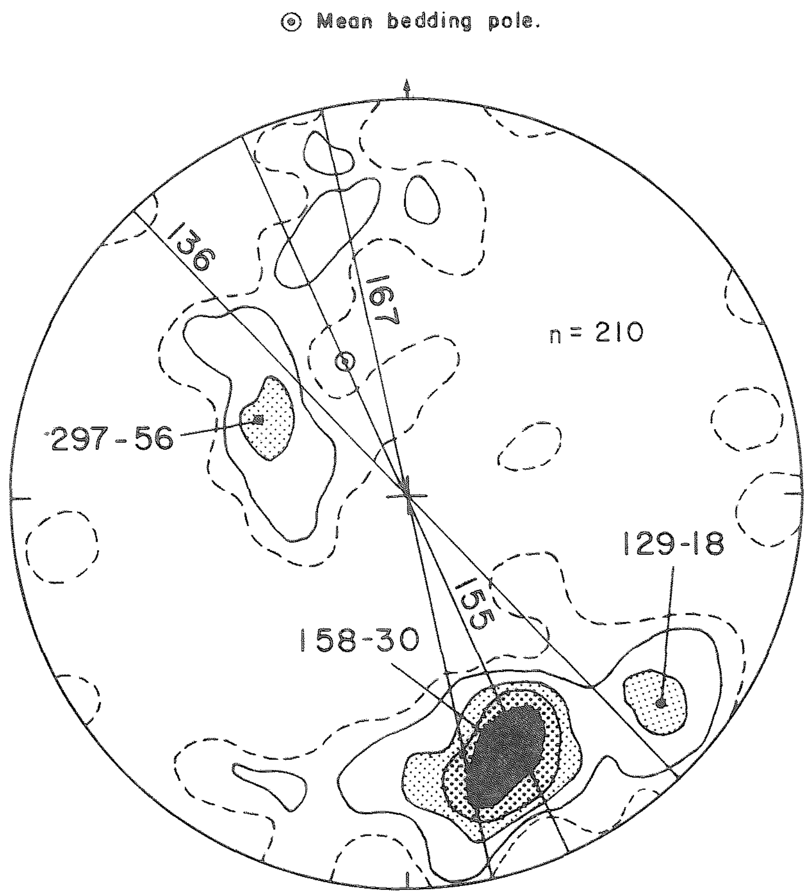


Figure 54. Stereogram of all measured slickenlines on fractures. Solid diameters represent the three trends of slickensided fractures in Figure 53. Contour intervals are 1, 2, 4, 6, 8 percent.

them. Because of the low angle of the slickenlines to the bedding, the actual displacements on the faults are several times that of the stratigraphic offsets. Most of the faults exhibit left-lateral displacements. A few of the faults are not vertical.

Mullions are a form of structure that is not common in the Valley and Ridge province of the central Appalachians. Here at Union Furnace, there are several good examples. Mullions lack the planarity usually associated with faults--they are undulatory, varying in attitude by tens of degrees, but always around a common axis. They even bend 90° and become part of a transverse fault system. Particularly good examples of mullions (on the west side) are (1) just south of highway paddle 11-75, and (2) between culverts 'E' and 'F', just south of a sign indicating narrowing of the highway (Figure 50).

Wedge faults are present, but are not common. They tend to parallel the bedding strike, making an angle of 20° to 30° to bedding. The slickenlines on the wedges, relative to original horizontal bedding, trend northwest, perpendicular to the bedding strike. This, and the congruence of geometry, suggest that the wedges were part of the folding process. They are usually interpreted as developing in the early stages of folding.

OTHER STRUCTURES

Stylolites occur both parallel to bedding and perpendicular to bedding. Those parallel to bedding consititute the largest percentage and are probably related to diagenetic processes (dissolution because of overburden pressure?) rather than Alleghanian deformational events. The bed-normal stylolites, on the other hand, are tectonic indicators, and probably represent dissolution under the influence of the horizontal stress that developed early in the decollement tectonics. This interpretation is supported by the perpendicularity of the stylolite to bedding; had they developed during or after the folding, they would be geometricaly congruent to the folds and not to bedding.

Veins are common at Union Furnace and are almost always filled with white calcite. They occur in all shapes and sizes from thin (less than 1 mm) to very thick and sigmoidal. Their lengths possess a much greater uniformity: rarely are they less than 10 cm nor more than 30 cm long. In some places, particularly near faults, they are profuse and seem not to have any particular preferred direction. Elsewhere they are arranged in en echelon arrays, 5 to 10 cm wide zones up to 1 to 2 m long, in which the individual veins make an angle of 20° to 40° to the zone boundary. These arrays are in effect fault shear zones in which the surrounding rock has moved parallel to the zone. The microlithons between the veins were rotated as the veins opened. The slip direction was perpendicular to the intersection between the individual vein and the vein array bounddary. Thus they not only yield the direction of movement, but the sense of direction as well. Where they occur adjacent to master fractures, they can be used to indicate the sense of movement.

The vein arrays are, in effect, ductile faults. The individual veins form as extension fractures, parallel to the maximum principal stress. Yet they are arranged in an en echelon array that forms a 30° to 40° angle to the maximum stress, the orientation appropriate for a fault. Several examples of these arrays are present throughout the outcrop, one being in association with a wedge fault just north of culvert 'C' (on the west side).

PRELIMINARY SYNTHESIS

The primary tectonic indicators at Union Furnace are the slickensides. These represent the direction of movement on the surface between 2 contiguous rock masses and thus provide a record of the movement directions, sequences of events, and relative times of the various structures. The primary assumption is that all the deformation was a product of the Alleghanian orogeny that produced the Valley and Ridge and other provinces of the central Appalachians. The fundamental tectonics was a decollement tectonics involving a horizontal transport of the Paleozoic section over the basement. Because bedding was initially horizontal, it is assumed, as a working hypothesis, that any movement (as shown by slickenlines) parallel to bedding probably occurred early in the deformation, before any significant regional folding developed. The larger the angle a slickenline makes with bedding, the later during folding that event occurred. With these premises, the variety of structure present at Union Furnace show a reasonable pattern.

The regional folding is the fundamental structure that can be seen at the surface in Pennsylvania. The folding process was flexural slip, with shape change occurring by slippage between adjacent beds. The slickensides on the bedding surfaces, and the fold geometries (orientation of the fold axes) indicate the primary tectonic and transport direction. All other structures were ancillary to the folding, developed before the folding commenced, or were late features that developed after the folds were largely in their present form. The few slickenlines on bedding here and nearby (Faill and others, in press) indicate that the principal transport direction was to the north-northwest.

REFERENCES CITED

Faill, R. T., Glover, A. D., and Way, J. H., Jr., 1987, Geology and mineral resources of the Altoona 15-minute quadrangle, Blair, Cambria, Centre, and Clearfield counties, Pennsylvania, Pennsylvania Geological Survey, 4th ser., Geological Atlas 86.

Kowalik, W. S., and Gold, D. P., 1974, The use of Landsat-I imagery in mapping lineaments in Pennsylvania: Proceedings of the First International Conference on the New Basement Tectonics, Salt Lake City, Utah, p. 236-249.

		LEAVE STOP 1. TURN AROUND AND RETURN ON PA 453 SOUTH.
0.9	14.6	Huntingdon-Blair county boundary. Road to right goes to Arch Spring.
0.2	14.8	Historical sign on left for Fort Roberdeau. The Revolutionary fort site is located a few miles from here. Built in 1778 by Daniel Roberdeau to protect lead mines in Sinking Valley which supplied the Continental army.
1.0	15.8	Good view to left of Little Juniata River water gap. Ahead will be good views of Tussey Mountain. The high ridge consists of the Tuscarora Formation. The gap is located on the Mount Union-Tyrone lineament.
2.1	17.9	Water Street. BEAR LEFT to US Route 22 East.
0.1	18.0	STOP SIGN. BEAR LEFT onto US Route 22 East.
0.2	18.2	Historical markers on right: Juniata Iron & Frankstown Path.
0.2	18.4	Outcrop of Juniata Formation on left and talus of Tuscarora Formation on right.
2.4	20.8	Views to left and ahead of Warrior Ridge.

0.8 21.6 Charlie Hill cut on right. Road ahead climbs Warrior Ridge which is underlain by gently dipping Oriskany (Old Port) sandstone and limestone with well-developed karst topography on top of the ridge.

2.3 23.9 Entrance to Lincoln Caverns on left.

0.4 24.3 TURN LEFT onto TR 472 at crest of hill just beyond State Police barracks on left. Road is at west end of large parking area around a Mobil station. Abundant float along route ahead is Oriskany. Large closed depressions occur in the woods on both sides of road.

1.4 25.7 TURN RIGHT at T-intersection.

0.6 26.3 STOP 2. PULPIT ROCKS.

DEDICATION

Pulpit Rocks on Warrior Ridge in Huntingdon County was given lasting fame by Henry D. Rogers when he included a full-color lithograph of the rocks as the Frontispiece in Volume I of his two volume work "The Geology of Pennsylvania" (Figure 55). The lithograph was done by George Lehman, one of the two artist-draftsmen employed by Rogers in 1840 and 1851. These artists traveled throughout Pennsylvania sketching scenes of the topography and geology.

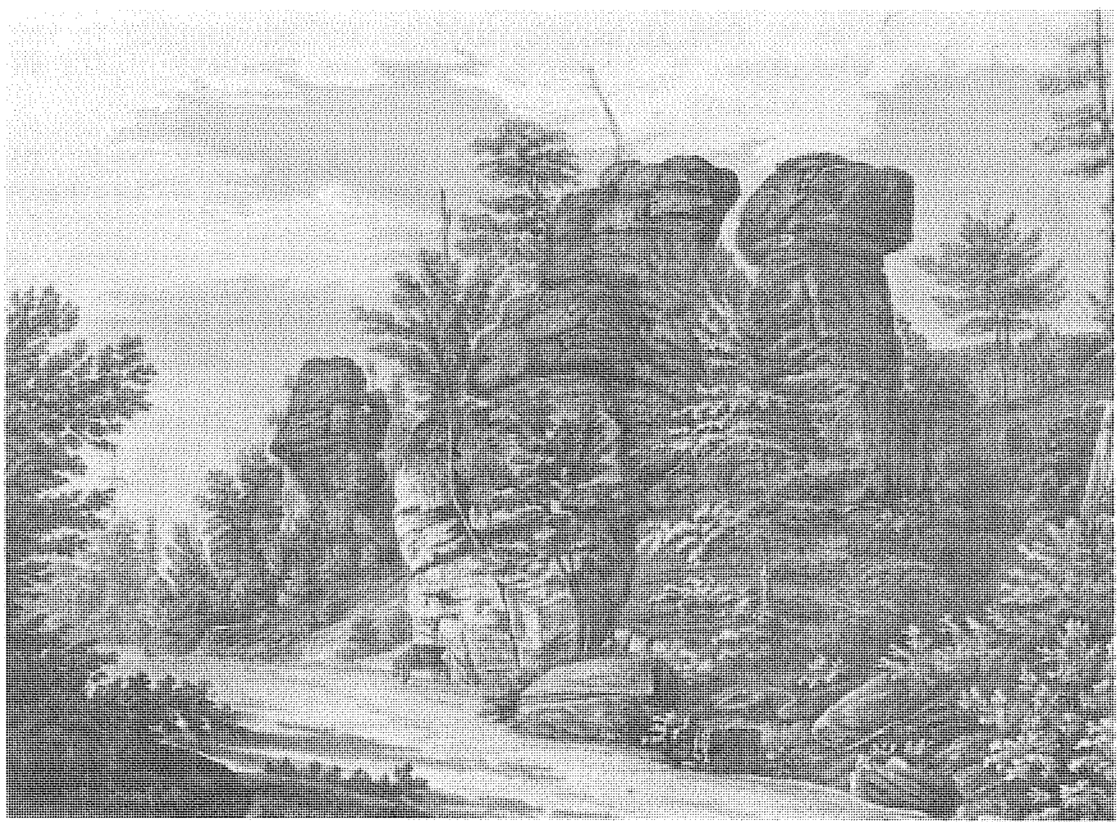


Figure 55. Pulpit Rocks, Warrior Ridge, Huntingdon County. A George Lehman lithograph (original in color) used as the Frontispiece in Rogers, 1858, v. 1.

Today a plaque commemorating Pulpit Rocks and the beginning of Geological Surveys in Pennsylvania in 1836 will be dedicated by the Field Conference of Pennsylvania Geologists, Inc. and Juniata College. The plaque reads:

PULPIT ROCKS

Pillars of sandstone of the Ridgeley Formation, an erosional remnant whose layers were deposited in an ancient sea nearly 390 million years ago. These rocks were visited by geologists of the First Geological Survey of Pennsylvania during 1836.

GEOLOGY

"Where the nearly horizontal outcrop of the Meridian sandstone forms the walls of the gorge of the Juniata through Warrior Ridge, it is fissured and weathered in remarkable shapes, generally thrown into a range of buttresses, advancing at right angle upon the river.

"But upon the upper plateau of the Warrior Ridge the traveller will see piles of blocks, called the Pulpit Rocks, remnants of the once more widely outspread upper strata, reared in rude columns one upon another. A correct sketch of a group of these is represented in the Frontispiece to this volume. The mode of their formation is suggested by the accompanying diagram. In all the ravines or gorges where the strata are inclined, they exhibit bluffs of characteristic aspect, often 30, 40, or 70 feet in height, such as are represented in the annexed drawing at a. The other, b, is meant to show one of these bluffs 20 feet in height.

"When at a steep angle, the outcropping strata show another form. They rise in a series of blocks, the edges of which are all rounded by weathering.

"Some of the layers are close-grained and more compact than others, splitting into larger and more regular masses, less intersected by cracks, and answering better for hearthstones for iron-furnaces, for which, when well selected, they are sufficiently durable.

"In the lower part of the formation are some light buff-colored highly-argillaceous beautifully-striated strata, perhaps peculiar to this district. They contain a few fossils, and may be studied on the Huntingdon and Hollidaysburg Turnpike west of the Pulpit Rocks, where they are used for the road; and on the bank of the canal, in the gap of Rocky Ridge, where they are curiously fissured.

"The whole thickness of the Meridian sandstone formation here must be over 100 feet" (Rogers, 1858, v. 1, p. 519-520).

"The Oriskany formation, No. VII.

"Warrior's ridge varies in height from 100' to 400' above the Marcellus black slate valley at its eastern, and the Onondaga and Clinton red shale valley at is western foot, being highest where the eastern dip is low and the eastern slope long, as is the case for five miles south and seven or eight miles north of the Juniata river, which cuts through it where it is four miles wide, making a wide gorge between vertical bluffs of limestone (No. VI) along the top of which runs a cornice of sandstone (No. VII) worn by the weather into lines and groups of "Pulpit Rocks," the tallest of which project their tops above the woods which cover the ridge. The sandstone is everywhere easily broken down into sand, and swept down the slopes far out over the Marcellus outcrops in the valley.

"It is usually a rather coarse sand varying in color from gray-white to brown; is more or less pebbly, and has limy streaks in it owing to the great number of fossil shells.

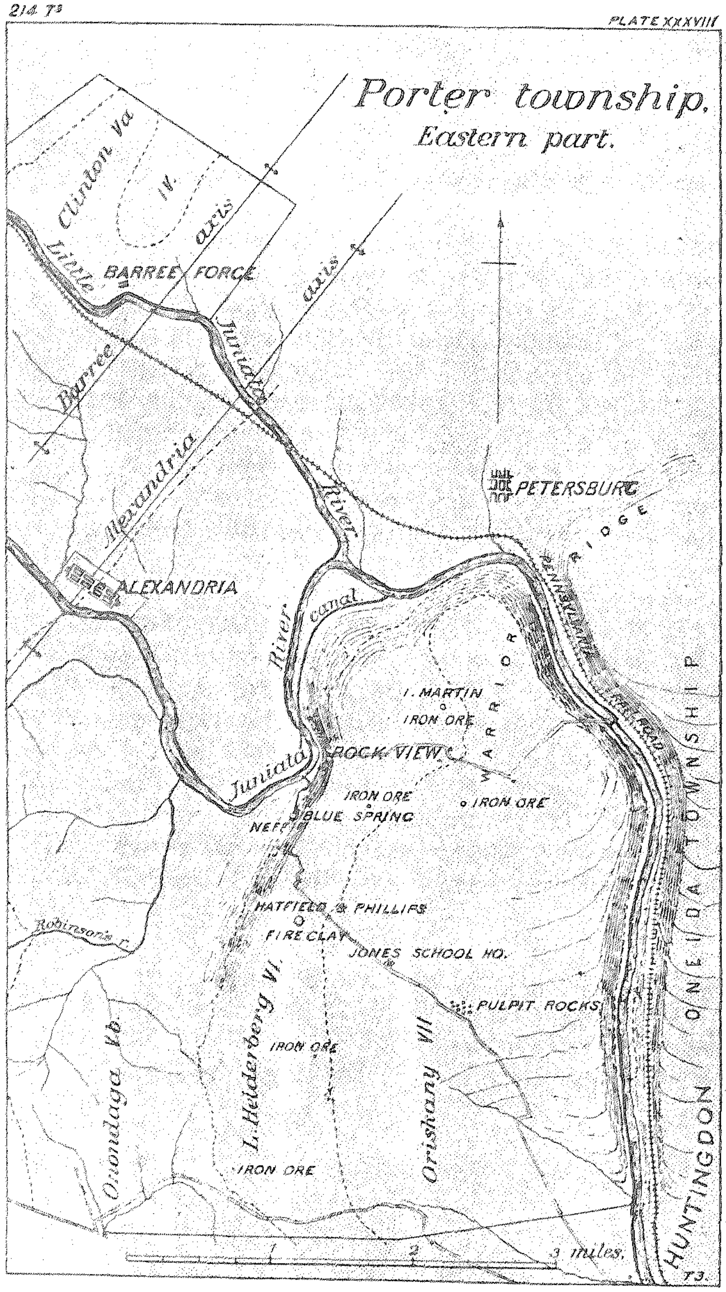
"It is never less than 50', and is sometimes more than 100' thick.

"Its steep (west 65° to 75° dipping) eastern outcrop at the Juniata river near Mapleton has been extensively quarried, the rock being crushed and washed for the Pittsburgh glass works. This outcrop, disengaged from the foot of Stone mountain, runs on northward as Sand Ridge, furnishing good glass sand. But the Warrior's ridge outcrop (dipping from 10 to 40 eastward) does not seem to be suitable for the purpose. This may be explained by the leaching out of the lime from the steep Sand Ridge rocks; and also of the iron, which is a large ingredient in the Warrior's ridge rock. This is in a measure caused on Warrior's ridge by the drainage finding an easier passage along the verical cleavage planes than through the rock itself along its planes of stratification" (White, 1885, p. 117).

"Warrior ridge is at its greatest height in this township, in some places rising to an elevation of 1250' A. T. (the Pennsylvania railroad station level at Huntingdon being 622' A. T.; at Petersburg 678'; and at Barree 724' A. T.) This is owing to the low and frequently reversed dips which cause the massive Oriskany sandstone to rise so slowly westward that its outcrop extends much farther west than in Walker township. In many places on the crest of Warrior ridge the sandstone may be seen forming rock cities, isolated piles of rock 50' high, with passage-ways from one to ten feet wide between them. One of these localities near the road to Alexandria is especially named the "Pulpit rocks" (Figure 56).

'At some points along this road, across Warrior ridge, the Oriskany has been wholly removed, leaving the top of the ridge composed of Stormville shales, which, at several localities, have been quarried for road fillings. They have a buffish gray color when their lime has been leached out, and they are sparingly fossiliferous.

"A short distance west from the cross-roads at Jones' school-house, a large bowl-shaped depression is seen in Warrior ridge, covering more than one acre of ground. It has, of course, been formed by the solution of the underlying Lower Helderberg limestones, thus allowing the overlying Stormville shales to fall into the cavern. Large caves may exist in this region, since the depression spoken of drains many acres, and the water must have an outlet somewhere along the Juniata River; and this indicates that the Limestone No. VI is the main water-bearing formation from which the people of the Huntingdon trough can get a plentiful supply of water by boring artesian wells to it" (White, 1885, p. 213-215).



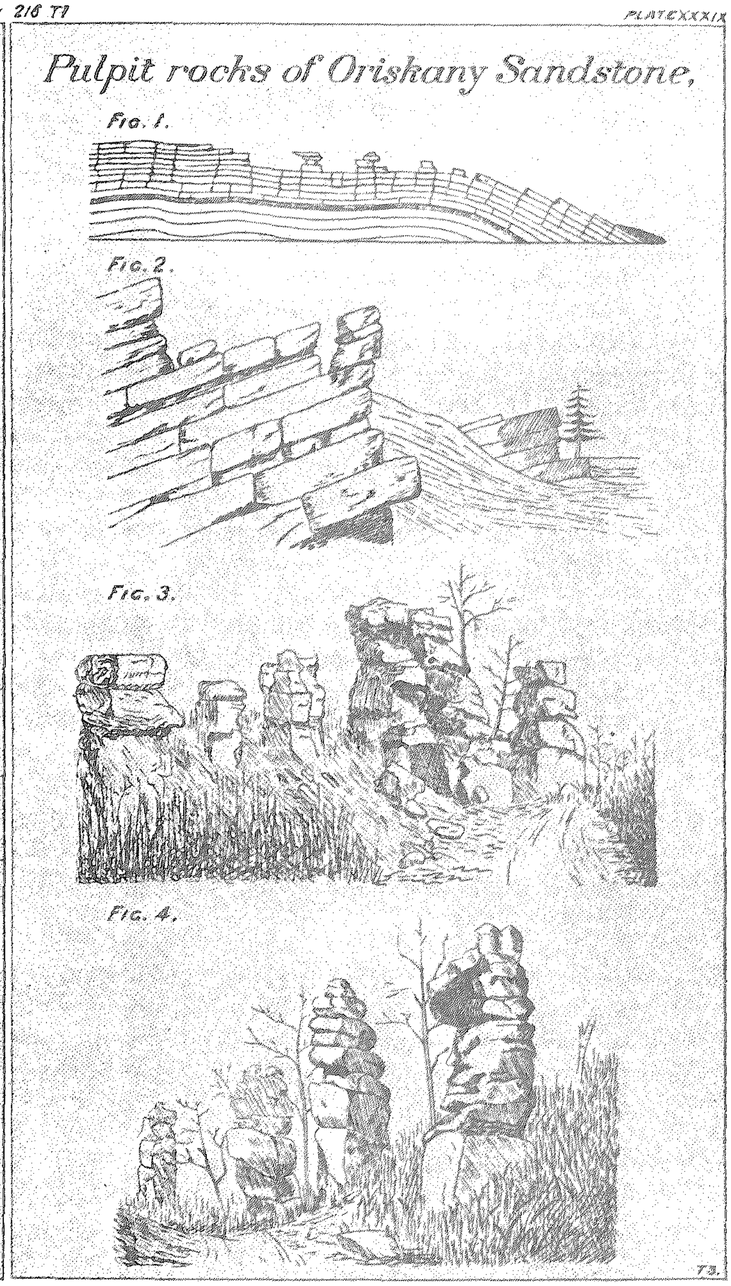


Figure 56. "Porter township. Eastern part" on the left above is typical of one of the small page-size maps found in White's report on "The geology of Huntingdon County" (1885, p. 214). "Pulpit rocks of Oriskany Sandstone" on the right above is found on page 215 of White's report. Fig. 1 and Fig. 2 are redrawn almost identically from Rogers (1858, v. 1, Fig. 100, p. 519 and Fig. 101, p. 520 respectively). Fig. 3 and Fig. 4 may be original for White's report.

The crest of Warrior Ridge in the vicinity of Pulpit Rocks has the appearance of an area of karst topography when viewed on aerial photographs. There is a vague integration of drainage, but few permanent stream channels are evident and the area may be a Pennsylvania example of silica karst. A sandstone quarry along the road 1 1/2 miles north of Pulpit Rocks shows that the binding agent of the sandstone has been totally removed in some of the rock to a depth of over 75 feet, but that large, well-indurated blocks of sandstone occur throughout the weathered zone.

LEAVE STOP 2. PROCEED STRAIGHT AHEAD.

1.5 27.8 View ahead of Huntingdon and valley of Juniata River is the same as that on the cover of the guidebook. State Correctional Insitute ahead on right.

0.6 28.4 STOP SIGN. TURN LEFT onto Pennsylvania Avenue. Ahead on left is dike which is part of DER Huntingdon and Smithfield Townships flood control project.

We are now on the flood plain of the modern Juniata River. This floodplain was the subject of a minor difference of opinion in the Second Survey literature (White, 1885, p. 34-35). The floodplain at Huntingdon is broad. Downstream at Jack's Narrows the river has no floodplain. Dr. Robert M. S. Jackson, of the First Pennsylvania Geological Survey and a native of Huntingdon, said that a great buried depression exists along the Juniata River at Huntingdon. White pointed out that all of the available geological evidence, in particular the fact that bedrock was either the floor or near the floor of all local tributaries and at hundreds of localities on the Juniata, indicated that no depression exists at Huntingdon despite the fact that there were no borings to prove his case. Lesley allowed the statement in the report, but argued that the opinions of a good man like Jackson could not be dismissed without facts to disprove him. Lesley felt that White did not have such facts for Huntingdon. He also recognized that the truth was important because similar situations exist elsewhere in Pennsylvania. Today we recognize that a broad floodplain commonly develops on soft rock upstream from a resistant rock barrier because the stream has ample time to meander and cut the soft rock laterally while the resistant rock is being lowered only a little and cut laterally not at all.

0.4 28.8 STOP LIGHT. TURN RIGHT onto PA Route 26 South.

0.1 28.9 TURN LEFT to US Route 22.

0.1 29.0 STOP SIGN. TURN RIGHT onto US Route 22 West.

0.4 29.4 STOP 3. MAHANTANGO FORMATION.
Buses unload and wait at west end of roadcut in pulloff area just before large green sign for Huntingdon & State College.

DISCUSSANT: RODGER T. FAILL

INTRODUCTION

The Cadent series, H. D. Rogers' designation of the Middle Devonian rocks, comprise a widespread and significant lithic unit throughout Pennsylvania, and beyond. It constitutes the beginning of the terriginous deposition in the Appalachian basin that brought an end to the long lasting paralic and marine deposition that had persisted through much of the Silurian and Lower Devonian. This terriginous depostion was to continue well into the Upper Carboniferous and perhaps even into the Permian, with only occasional limited marine incursions into the basin.

Rogers (1858, v. 1, p. 108) divided the Cadent series into three parts (Figure 57): a lower black shale (the Cadent Lower Black Slate); a medial Cadent Shales (with minor beds of sandstone); and a Cadent Upper Black Slate. These were correlated with similar lithologies along the Mohawk Valley in central New York, to which the name 'Hamilton Group' had been applied, and which included: the Marcellus black shales, the Hamilton shales and sandstones, the Tully Limestone, and the Genesee slate (Hall, 1851). Exposures in the Huntingdon vicinity were among several that Rogers used as the basis for this correlation (although of course this outcrop (STOP 3) was not exposed at that time).

The Second Pennsylvania Geological Survey abandoned Rogers' Primal to Seral age classification, and the New York name 'Hamilton' was formally brought into Pennsylvania (White, 1883, p. 78; White, 1885, p. 105). This name, 'Hamilton series', was initially applied to the same Marcellus through Genesee interval as in New York (Hall, 1851), and thus was the equivalent of the Cadent series (Figure F1). But following the establishment of the Tully Limestone as Upper Devonian (Williams, 1890), the term Hamilton was restricted to the Marcellus and Hamilton shales and sandstones, or to the Hamilton by itself (see Cooper, 1930, for a detailed accounting of the evolution of the Hamilton name up to then). In the 1930's Willard (1933) applied New York names from the Mohawk Valley such as Skaneateles, Ludlowville, and Moscow to the Middle Devonian rocks of eastern Pennsylvania. But the Hamilton lithologies in central Pennsylvania are so different from the New York rocks that he supplanted the New York terminology with the name Mahantango for the more complex sequence of shale, siltstone, and sandstone between the Marcellus and Tully in the Susquehanna and Juniata Valleys (Willard, 1935a), and for the finer grained sequence to the south and west (Willard, 1935b). Use of this new name, Mahantango, has continued to the present day, and this formation encompasses the bulk of the Middle Devonian in central and southern Pennsylvania.

The repeated changes in terminology and formational assignment during the succeeding years reflect the improved understanding of the nature of the Cadent rocks throughout Pennsylvania (Willard, 1939; Miller, 1961; Conlin and Hoskins, 1962; Dyson, 1963; Faill and Wells, 1974; and Hoskins, 1976; see Faill and others, 1978 for a synopsis of the more recent changes). The Middle Devonian in New York, especially western New York, consists mostly of shales, with a few intervening limestones that are used as marker beds. This fine-grained aspect indicates that the shoreline was quite far from this part of the basin. In contrast, the coarseness of the Cadent rocks in the Susquehanna Valley as represented by the Montebello sandstone (Claypole, 1885), especially near the southeast margin of the present Valley and Ridge province, suggests that this part of the basin was considerably closer to the Middle Devonian shoreline (Kaiser, 1972).

Deposition in the basin was subaqueous during the entire Middle Devonian because marine fossils occur throughout the entire section. The upward-coarsening cycles in the coarser parts (Faill and Wells, 1971; Kaiser, 1972) mark the near-shore deposition of the coarser sediments in delta lobes. Four Middle Devonian delta lobes have been delineated in Pennsylvania (Figure 58). These lobes probably represent the loci of major sediment input areas. The largest, thickest, and coarsest-grained lobe in the state is just north of Harrisburg and is reprsented by the Montebello Sandstone. Two smaller, older lobes are present to the northeast along the Blue Mountain front; the fourth,

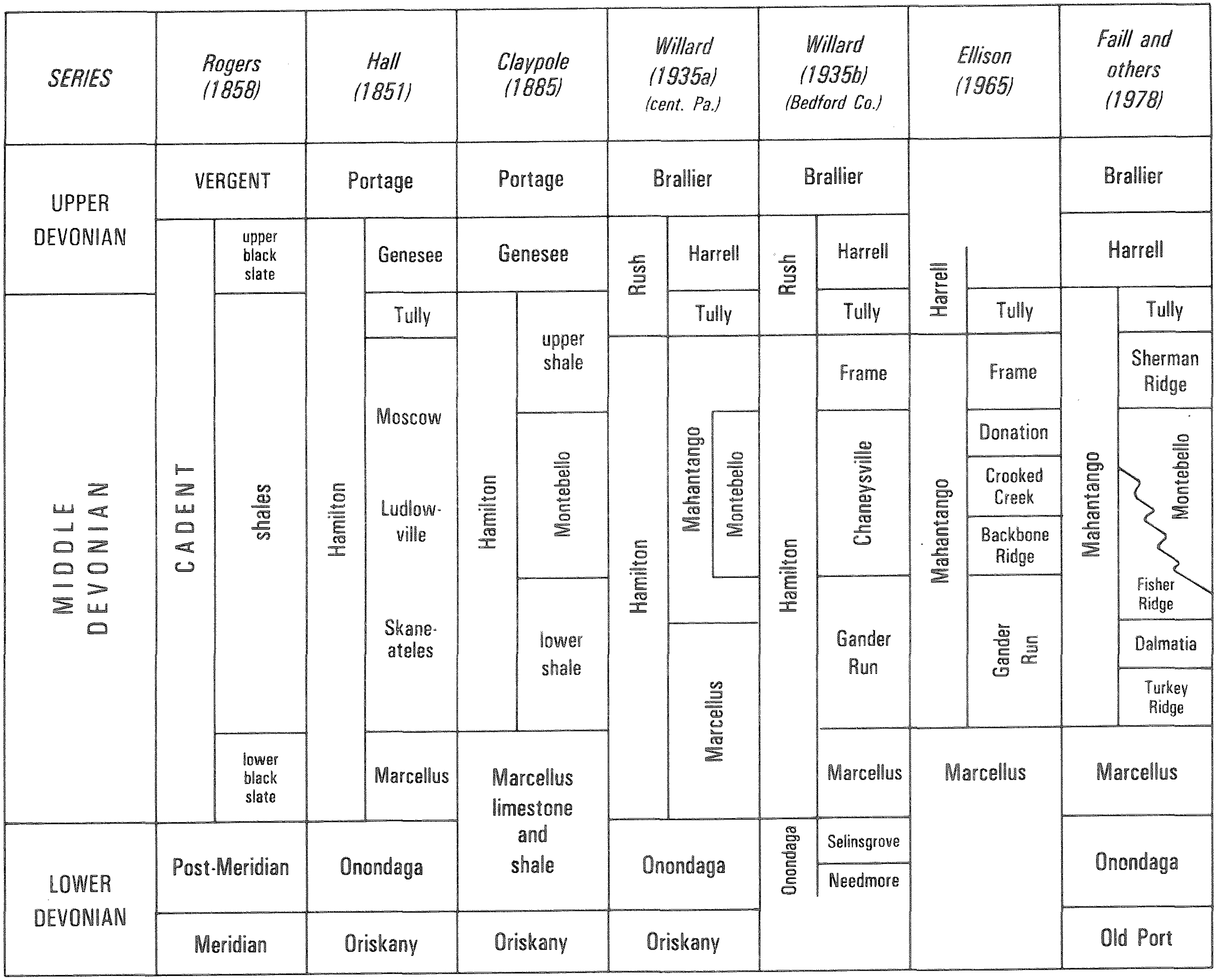


Figure 57. Stratigraphic correlation chart illustrating the change in terminology of Middle Devonian units since the First Pennsylvania Geological Survey.

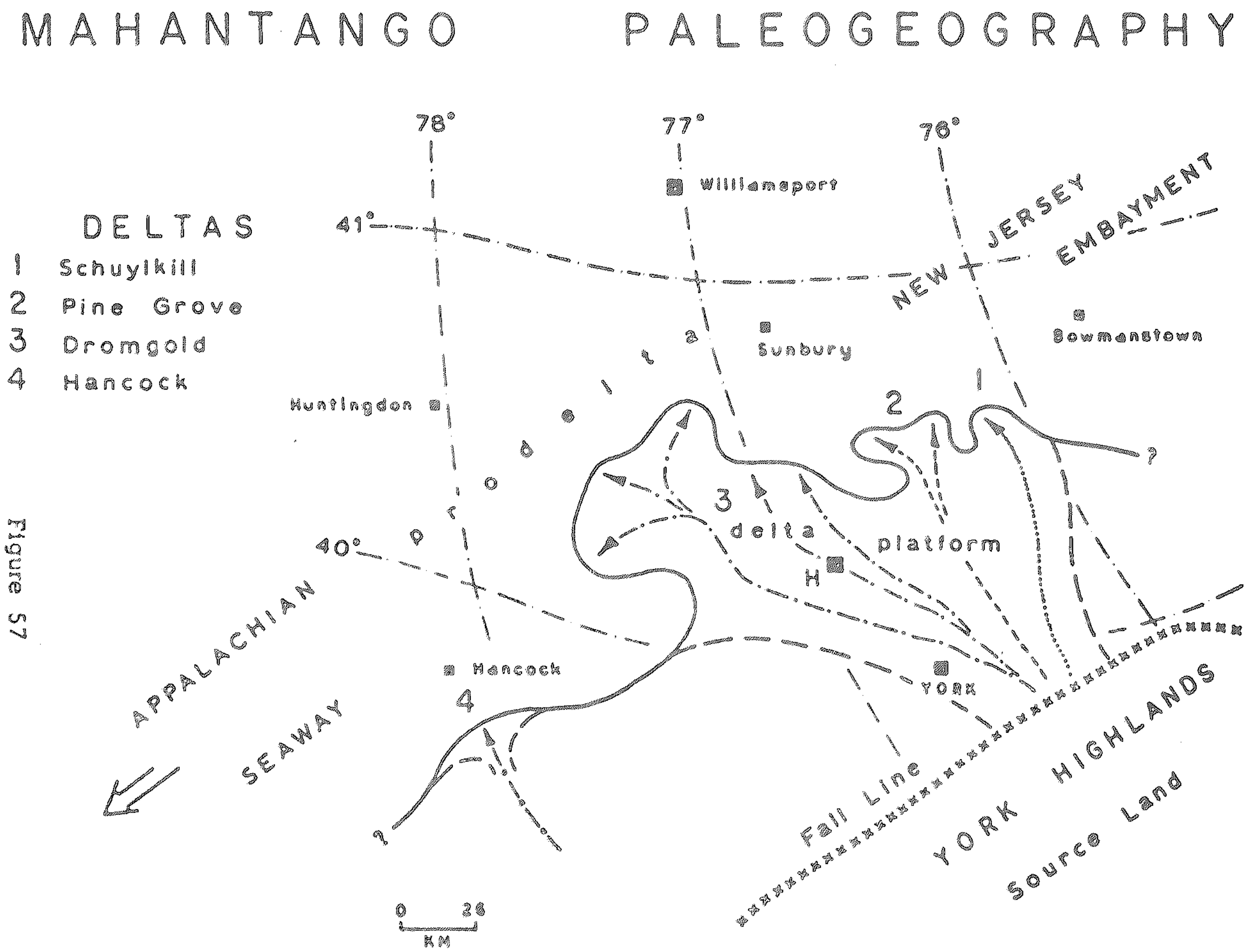


Figure 58. Paleogeographic map of the Mahantango basin during Middle Devonian, showing the relative locations of the 4 delta lobes (from Kaiser, 1972, Fig. 57).

southwest of Harrisburg near the Maryland-Pennsylvania border, began in the later part of Mahantango sedimentation and continued into the Upper Devonian (Kaiser, 1972, p. 131).

The finer grained portion of the Mahantango Formation here at Huntingdon is between and somewhat beyond the two lobes in central and southern Pennsylvania. In this part of the Mahantango, the formation is divided (in ascending order) into three parts (Figure 57): the Gander Run, Chaneysville, and Frame Members (Willard, 1935b). Locally, the Chaneysville Member has been further subdivided into the Backbone Ridge Siltstone, the Crooked Creek Shale, and the Donation Siltstone (Ellison, 1965). The absence of intervening mapping precludes precise correlation of the Chaneysville (or alternatively the Backbone Ridge and Donation) with the Montebello Sandstone of the lower Susquehanna Valley. The fact that these units are coarser grained than the rest of the Mahantango and the fact that they occupy a medial position in the formation certainly suggests a correlation, but the presence of several major upward-coarsening cycles to the east leaves such a conclusion uncertain at best.

These exposures of the Middle Devonian section along U. S. Route 22 are the most complete in the Huntingdon vicinity. The roadcuts just southeast of the cloverleaf intersection of U. S. Route 22 with PA Route 26 (Figure 59) display a good portion of the Marcellus Formation. Farther to the southeast, the upper portion of the Marcellus Formation and the lower part of the Gander Run shale are exposed in a borrow pit on the southwest side of U. S. Route 22. The main roadcut of (STOP 3) comprises the entire Backbone Ridge silty member and the lower part of the Crooked Creek shale member. The remainder of the Crooked Creek Member is concealed to the southeast under the valley that contains Crooked Creek. A fairly small outcrop on the southwest side of the road, some 500 m southeastward from the main outcrop shows the major part of the Donation siltstone member. Farther southeastward from Fourth Street is a fairly continuous exposure of the Frame Member along with the Tully and Burkett, mostly behind the buildings on the southwest side of U. S. Route 22.

The Backbone Ridge Siltstone is exposed at the northwest end of STOP 3 (Figure 59). If this is the lateral equivalent of the Montebello, it is a very distal feather edge. The Backbone Ridge consists predominantly of argillaceous siltstone, calcareous in part, and is medium to dark-grayish red, weathering to olive gray and light grayish red. Bedding is thick to very thick and quite planar. Laminations are present in some of the beds. Being coarser-grained in its upper part (a reflection of the upward-coarsening cyclicity?), the lower portion becomes increasingly argillaceous downward and grades into the underlying Gander Run member. Compared with the other members, the Backbone Ridge is sparingly fossiliferous, containing mostly brachiopods, and some crinoid columns and corals. Pelecypods and gastropods are also reportedly present (Ellison, 1965).

The lower part of the Crooked Creek Member occupies the remainder of STOP 3 (Figure 59). The 5 to 6 m part immediately overlying the Backbone Ridge is a silty mudstone, medium to medium-greenish gray (weathering mostly to olive gray). It is thick to very thick bedded, and planar bedded. Farther upsection (to the southeast), the Crooked Creek becomes more of a silty shale, still medium gray and weathering to an olive gray, but bedding is less distinct and very thick. Also, the rock weathers into small angular chips rather that the large fragments characteristic of the siltstones to the northeast. The Crooked Creek is sparingly fossiliferous--the assemblages that are present are dominated by brachiopods, with smaller fractions of gastropods and pelecypods (Ellison, 1965).

STRUCTURAL GEOLOGY

We have traveled some 20 km across the structural grain of the Valley and Ridge province from Union Furnace (STOP 1), but here at Huntingdon we find ourselves in a remarkably similar structural setting, despite the great contrast in lithology. We are in the gently southeast dipping beds of a large, first order fold, the Broad Top syncline. Also, we are still within the Tyrone-Mount Union lineament (see Gold, 1985 for additional references, and for discussion of third and fourth order structures elsewhere along this lineament). Not surprisingly, we find that many of the smaller structures we observed at Union Furnace are present here as well. Complicated structures such as fourth and fifth order folds are not present. No large mappable faults pass through or even nearby this outcrop, although if one were present I am not sure it would have been detected, given the lack of marker beds in this Middle Devonian section. And there are other similarities as well.

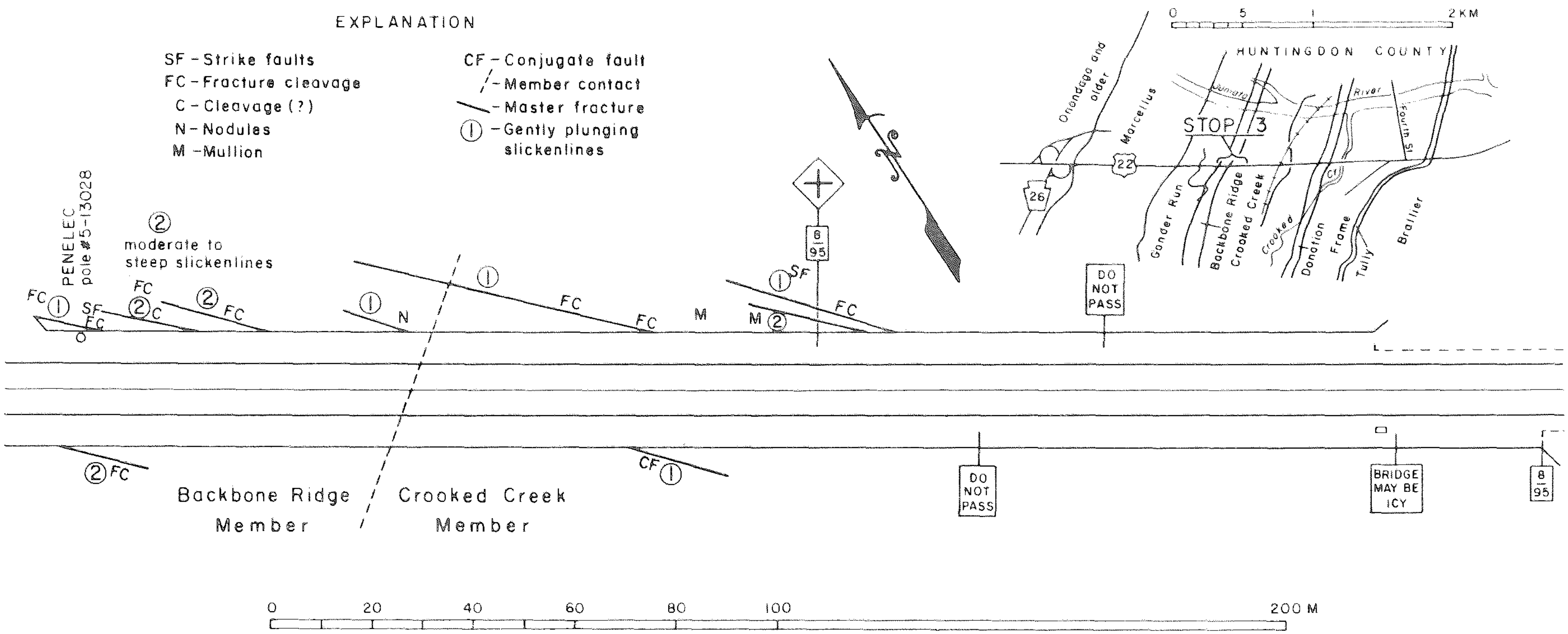


Figure 59. Geologic map of STOP 3, showing the geologic contacts, principal structures, and cultural markers.

FRACTURES

The most noticable structures in this road cut are the numerous large, planar fractures that pervade the rocks. Ninety percent of these planar fractures fall into two sets (Figure 60): the most prevalent constitute a dip (or transverse) set trending northwest (at 314° azimuth, almost parallel to the road); the other is a strike set that trends nearly east-west (070° azimuth). The dip fractures are very planar and large, extending for tens of meters through the outcrop and across all the beds. These exceptional partings, similar to those at Union Furnace, are master fractures because they are so much more extensive and prominent than most of the other fractures in the outcrop. Yet how pervasive are they? For example, the so wonderfully prominent master fracture west of highway paddle 8-90 (see Figure 59) should be present somewhere on the other side of the roadcut near the southeast end of the outcrop. But no clear evidence of it occurs, probably for 1 of 2 (or both) reasons. First, although they are prominent at the scale of tens of meters, perhaps they just do not extend for hundreds of meters. Second, the master fractures are common in the silty Backbone Ridge Member, but rare in the more shaly Crooked Creek Member. Perhaps its absence in the Crooked Creek is solely a reflection of the contrast in mechanical behavior. The Backbone Ridge Member may have behaved in a more brittle fashion than the Crooked Creek, in much the same way that fractures in limestones rarely extend into adjacent shale beds. Notice in the contoured stereogram (Figure 60) that the 2 sets are not orthogonal, but instead form a 64° angle with each other. The significance of this geometry is not immediately evident. The strike set of fractures seems to be more common in the Crooked Creek part of the roadcut than in the Backbone Ridge portion. This may be due to a measuring bias--strike fractures are also common in the latter, but they may have been ignored because of attention being focussed on the master (dip) fractures.

SLICKENSIDES

First, a word about bedding. Slickensides were not found on any bedding surface in this roadcut. Considering the nature of the bedding surfaces, this is not surprising. Bedding planes in the Mahantango Formation in this part of the basin are widely spaced, and the lithology changes little or not at all across them. Because of this lack of material contrast across bedding, they do not provide the mechanical anisotropy (surfaces) that is utilized in flexural slip folding. Hence, no slickensides on bedding surfaces.

The fractures, however, are another story. On close inspection, one notices that slickensides are on many of the master fractures, which indicates that movement has occurred along them at some time since their origin. Whether they formed as faults, and very closely spaced faults at that, or whether they were initially developed as a brittle fracture set that was later utilized for fault movements is not known, but is discussed below. Note that the slickenlines for most of these fractures plunge gently to the southeast, close to the bedding-fracture intersection (Figure 61). If one uses the argument, as was implied at the Union Furnace outcrop, that the regional maximum (compressive) stress remained essentially horizontal throughout the Alleghanian deformation, then these slickenlines indicate movement while the beds were horizontal. That is, the movements were early, before the major folding began.

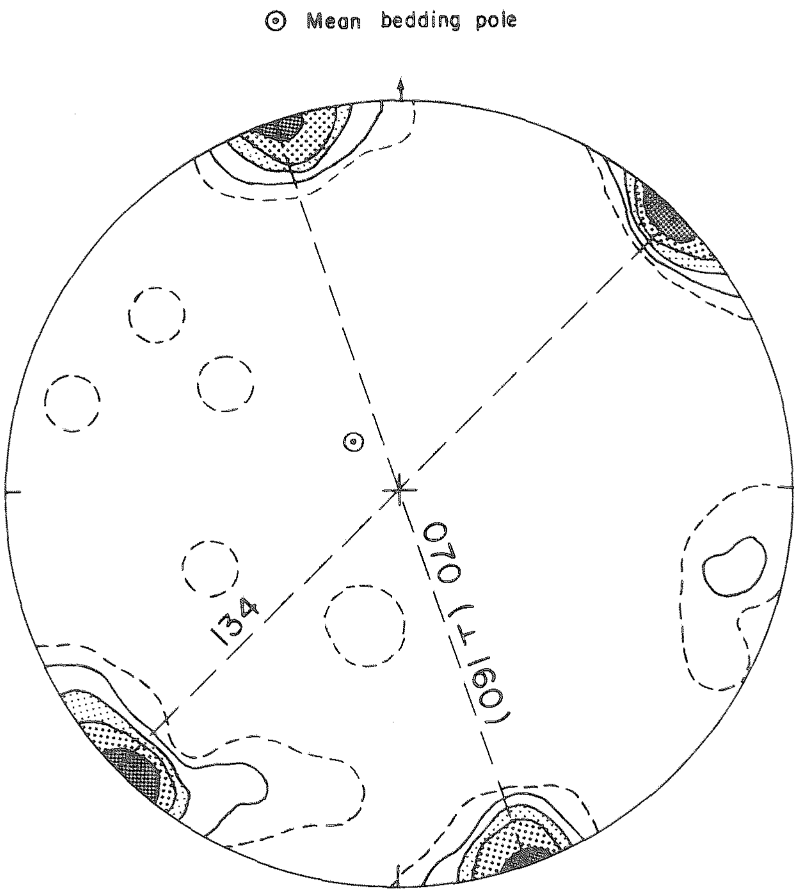


Figure 60. Stereogram of measured planar fractures. Many of the master (dip) fractures (which trend 134 degrees azimuth) contain slickensides. The strike fractures (trending 070 degrees), possess far fewer slickensides. See Figure 61. Contour intervals are 1, 2, 5, 10, and 20 percent.

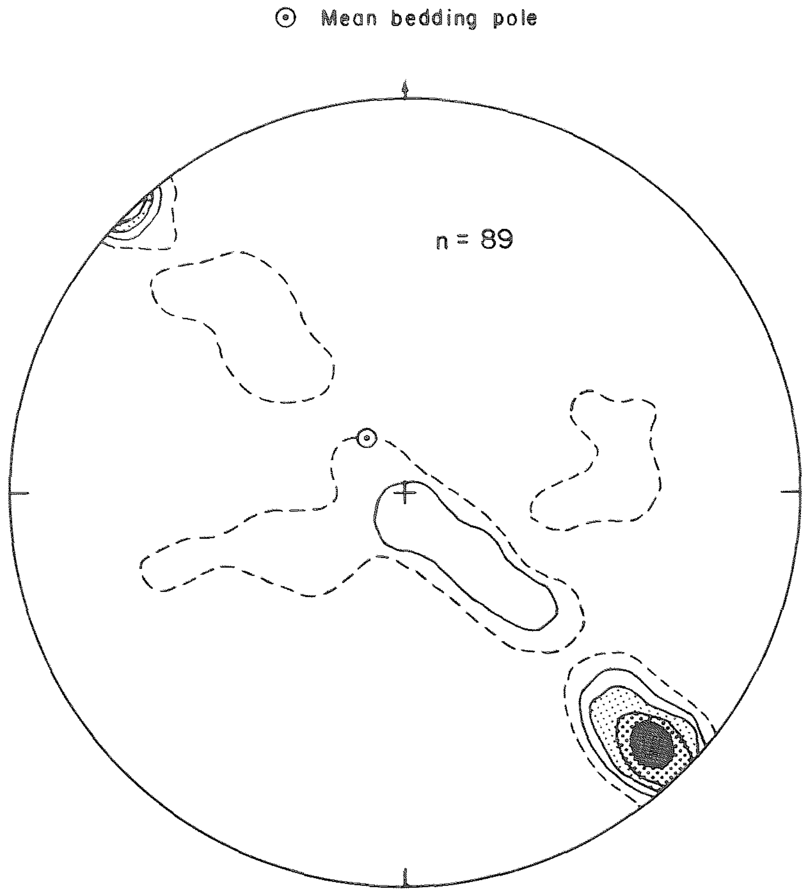


Figure 61. Stereogram of measured slickenlines on planar fractures. The vast majority lie close to the bedding-master fracture intersection; the remainder weakly define two girdles. Contour intervals are 2, 5, 10, 15, and 20 percent.

For a smaller fraction of the master fractures, the slickenlines are moderately to steeply plunging (Figure 61). Their origin must be different from those parallel to the bedding, because the difference in orientation indicates they formed under a differently oriented stress system. However, no clear evidence of the relative ages of the two groups was found in the roadcut. That is, it is not known which orientation was earlier, but if forced to choose, I would say, more from bias than conviction, that the steeply plunging slickenlines formed later than the bed-parallel ones, but still during the Alleghanian, perhaps representing space adjustment in the later stages of the regional folding. There is more to discuss about slicksides on fractures, but first we must turn to a different, yet related subject: cleavage.

SOME WORDS ABOUT CLEAVAGE

Cleavage is present in these rocks, not as a pervasive slaty cleavage, nor even as a cleavage restricted to certain lithologies (e.g., the shale interbeds in the Salona) as was true at Union Furnace (STOP 1). Perhaps this is not entirely true. A steeply southeast-dipping rough surface in the northwest end of the roadcut parallels a faint fabric that may represent an incipient shaly cleavage. Be that as it may, the obvious cleavages here at Huntingdon are spatially very restricted, appearing only adjacent to and in conjuncion with some of the larger slickensided master fractures. This cleavage consists of a closely spaced fracture set forming a small dihedral angle with the master fracture. Although this fracture cleavage does not contain vein filling as at Union Furnace, they appear as arrays of en echelon extension fractures bounded by the major fracture. They do not occur adjacent to every slickensided master fracture; and they are restricted to only a few beds, suggesting some lithic control on their development. But it is their orientation that is of interest. This fracture cleavage is perpendicular to bedding, and thus the cleavage-master fracture intersections are close to the bedding poles (Figure 62). No slickensides are on any of the cleavage surfaces, implying that each surface was formed as an extension fracture (no movement parallel to the surface). If so, the maximum principal stress direction lay in that cleavage. Now note that the cleavages form a 20° to 35° angle (total range is 9° to 42°) with the master fractures (Figure 62). This range of angles between the stress and the surface is usual where shear movement occurs on the surface. Thus the fracture cleavage arrays and the movements on the master fractures appear to be dynamically related. That is, the same stress orientation that produced the fracture cleavage also produced the shear movements at the same time (Figure 63). Furthermore, because the cleavage-fracture intersection parallels the intermediate principal stress, the related shear movements must also have been parallel to bedding, as is indicated by the bed-parallel slickenlines. An additional bit of evidence can be gleaned from the fracture cleavage. The relative orientation of the cleavage vis-a-vis the master fracture enable us to determine whether the shear movement was right- or left-lateral. Given the northwest trending master fractures, if the cleavage is more northerly trending, the movement on the master fracture was right lateral; a more easterly trend would indicate left lateral displacement. Returning to Figure 62, we find that both left lateral and right lateral movements can be inferred for the master fractures, and in equal frequency. This means that not just one, but two differently oriented stress systems produced the cleavage structures in this outcrop. The one that produced the 'right lateral' cleavage was directed (on the average) horizontally at 335° azimuth; the average 'left lateral' orientation was also horizontal, at 279° azimuth. Which system was developed first is not known. Both utilized the

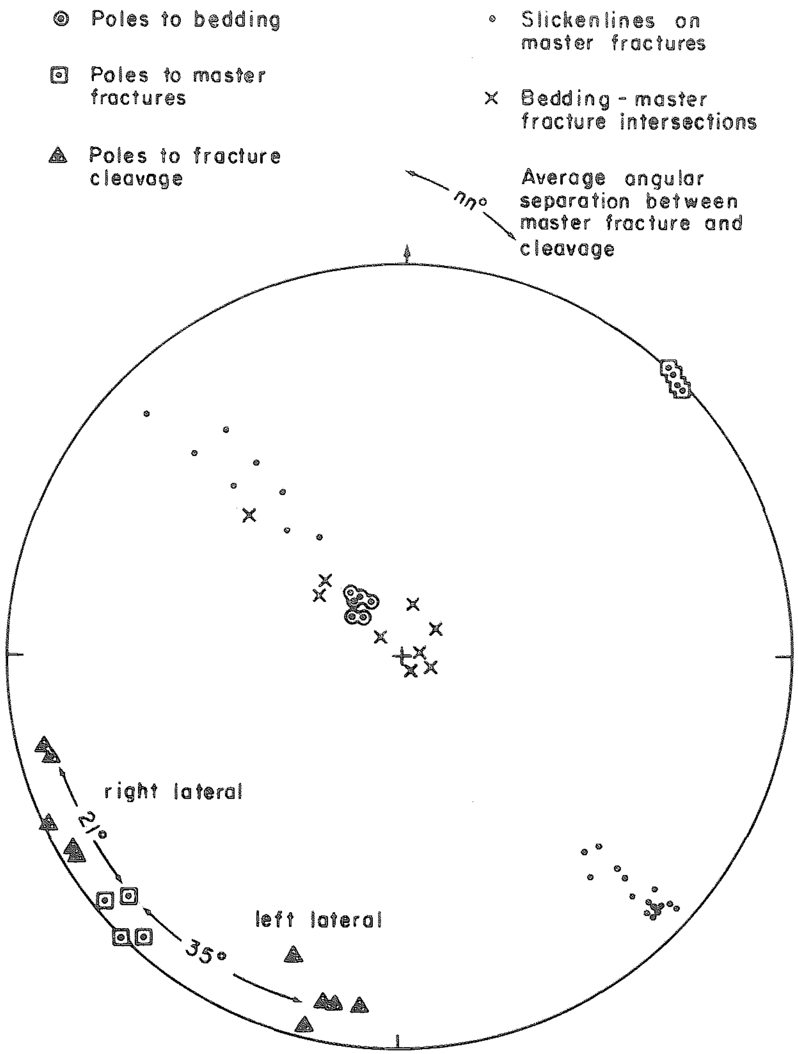


Figure 62. Stereogram of measured data associated with the fracture cleavage. Note that the mean angular difference from the master fracture for the "right lateral" fracture cleavage is significantly less than for the "left lateral" cleavage.

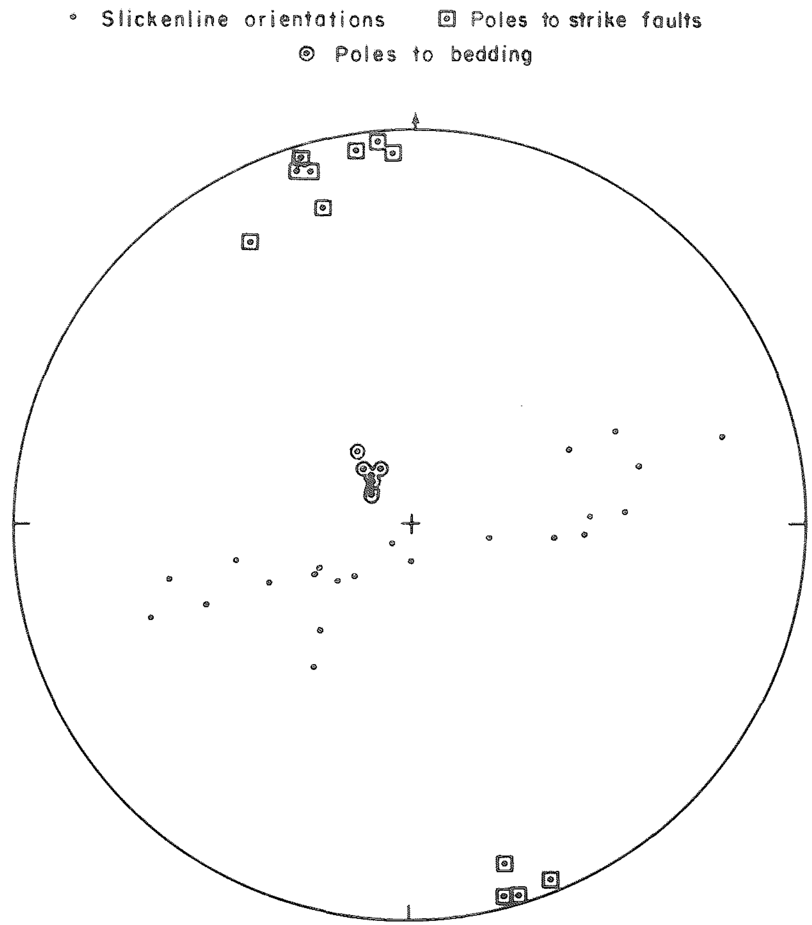


Figure 64. Stereogram of measured strike fractures and the slickenlines thereon, which define a broad east-northeast girdle.

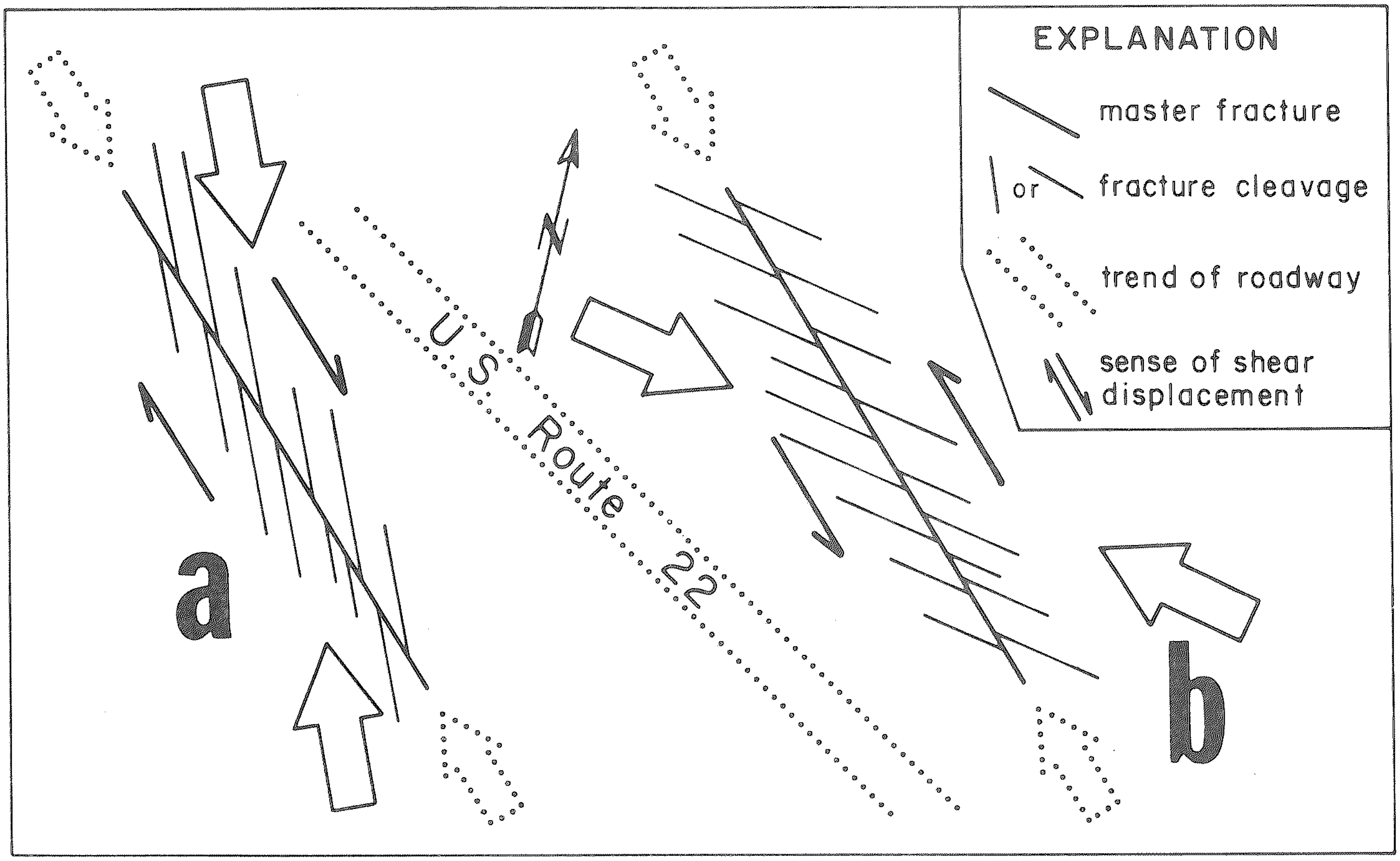


Figure 63. Dotted open arrows show maximum stress directions for master fractures (317 degrees mean azimuth); solid open arrows for fracture cleavage. a: 'right lateral' fracture cleavage, 338 degrees mean azimuth. b: 'left lateral' cleavage, 282 degrees mean azimuth. Road trends 303 degrees.

same master fractures, which suggests that the master fractures may have preceeded both stress systems. If so, and presuming that the master fractures were formed as extension fractures (which is not an outlandish presumption because some of the master fractures lack any slickensides--which itself is also not conclusive evidence), then a third even earlier stress system must have formed those. And all of this occurred before the major regional folding began. Well, not exactly, for now comes the sticky wicket. Figure 62 shows that on the majority of the master fractures the slickenlines lie near the bedding-fracture intersection, which is consistent with the preceeding analysis. But on a few of the master fractures with the associated fracture cleavage arrays, the slickenlines plunge moderately to steeply northwest. These orientations are not consistent with the inferred stress fields, and so these more vertical movements must have occurred either before the inception of the cleavage arrays, or after. Again, no hard evidence as to relative age has been found. Whenever these slickenlines developed, they required a stress system with a steep (in the range of 50° to 70°, but not vertical) maximum principal stress. If they preceeded the fracture cleavage, then such a stress system would need to occur between the formation of the master fractures and the cleavage. This unduly complicates the early deformational history of these rocks, and no other evidence supports such an event. It is more likely that the steep slickenlines were created following the cleavage formation, perhaps when the regional stresses were localy reoriented during the late stages of folding.

BACK TO SLICKENSIDES ON FRACTURES

Having deduced the role of the fracture cleavage, we can now return to Figure 61 and more slickensides on fractures. First, consider the northwest trending girdle. It contains both the southeast plunging maximum that represents the bed-parallel movement on the master fractures and the above-mentioned moderately to steeply northwest plunging slickenlines associated with the fracture cleavage. This girdle also contains a moderately to steeply southeast plunging cluster. As it turns out, only the master fractures with adjacent cleavage have slickenlines plunging to the northwest. All the moderately to steeply southeast plunging slickenlines occur on fractures lacking cleavage. Is this correlation real, or is it only an artifact of the small sample size? All the northwest slickenlines occur on only 2 master fractures, so I suspect an artifact. Regardless, I would guess that whatever the cause was for the northwest slickenlines, it was also the cause of the southeast plunging slickenlines.

Interestingly, in the master fractures with bed-parallel slickenlines, only that orientation is present. In contrast, the fractures with the steeper slickenlines all contain several orientations, mostly from moderate to rather steep. Apparently, movement in the latter group was occurring episodically, as if the driving stress system were continually changing orientation. This complicated movement picture is more appropriate for late stages of folding, when local inhomogeneities influence the deformation to a greater extent.

One other group of slickenlines is present on Figure 61, in a nearly east-west girdle. These are developed on the strike fractures that form the prominent cluster in Figure 60. Nearly all the slickenlines are moderately to steeply plunging, with a fairly even distribution along the girdle (Figure 64). The notable gap in the distribution is near the bedding-fracture intersection. Because of their moderate to steep inclination, they were probably formed during the same period that the steeply plunging slickenlines on the master fractures were formed, late in the folding.

NOW FOR SOME DEMONSTRABLE FAULTS

A few faults with measurable offsets (in contrast to the simple slickensided surfaces discussed above) are present in this roadcut, albeit they are minor ones. Displacement on them is relatively small, on the order of a few centimeters to a meter or so. They possess a variety of orientations with no apparent systematic relation among them.

The most prominent fault in this outcrop is on the north side of the road, above the highway paddle 8-90 on the northeast side of the road. It offsets a siltstone bed some 9 m above road level. This fault actually consists of a 3 m wide zone containing at least 6 individual faults subparallel to one another. Displacement is down on the southeast, and the steeply southwest plunging slickenslines on the faults indicates that the movement was primarly normal. The total displacement was on the order of a meter, but this was distributed among the several faults, each with an offset of a decimeter or so.

A conjugate pair of faults is exposed on one of the more prominent master fractures on the southwest side of the road, some 60 m northwest of the 'DO NOT PASS' traffic sign. Both are strike faults, and their intersection plunges gently to the east. The offset of bedding on the vertical fault is down on the north, whereas the moderately south dipping fault has an offset of down on the south, which together constitutes a graben structure. The amount of offset is small, on the order of 5 to 8 cm. The inferred maximum principal stress direction (the acute bisectrix between the faults, perpendicular to the fault intersection) is steeply to the southwest. This stress direction is not consistent with the early bed-parallel movements, but rather is a subhorizontal extension, perhaps late in the folding.

SYNOPSIS OF THE OUTCROP

This outcrop in the Middle Devonian Mahantango Formation (the Cadent series of Rogers, 1858) along U.S. Route 22 at Huntingdon appears at first glance to offer little of structural significance, given the rather constant and gentle southeast dip of bedding, and the relatively uniform lithology. Yet perhaps it is because of this lithological and structural uniformity that some of the subtler aspects of the Alleghanian deformation can be seen here.

The most prominent structures, the master (dip) fractures, and the less dramatic strike fractures were probably the earliest structures formed, before any folding began. Unlike so many fracture sets elsewhere in the Valley and Ridge province, these 2 sets are not orthogonal--the master fractures trend 314° azimuth and the strike fractures trend 070°. The acute angle between them is 64°. Why this should be is not known.

The next structural event was the utilization of the master (dip) fractures for bed-parallel movements, as indicated by the numerous slickenlines parallel to the fracture-bedding intersections. Associated with this movement was the development of arrays of fracture cleavage in the rock adjacent to the master fractures. The presence of both 'left lateral' and 'right lateral' cleavages indicate that this event consisted of 2 phases, with a shift of stress field orientation between the phases.

The regional folding was the next event. The gentle dip in this part of the Broad Top syncline indicates that the folding was not intense here, and that this area was a relatively simple 'structural island' surrounded by large, complex anticlinoria, the Nittany to the northwest, and the Jacks Mountain to the southeast.

The last event recorded in these rocks comprises the various faults and movements on pre-existing fractures, as indicated by the moderately to steeply plunging slickenlines. These movements are not as coherent as the earlier structures, but despite their various attitudes, the strong vertical component suggests that these movements occurred late in the folding, perhaps reflecting space adjustments at depth. Or they may be part of a post-Alleghanian deformation, possibly related to the Tyrone-Mount Union lineament.

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		LEAVE STOP 3. PROCEED STRAIGHT AHEAD.
0.2	29.6	Borrow area on left in Mahantango Formation. Note that modern weathering is producing a shale-chip rubble deposit. Similar deposits of periglacial origin are common on the Mahantango and similar lithologies.
0.6	30.2	BEAR RIGHT to PA Route 26.
0.1	30.3	BEAR RIGHT onto PA Route 26 South. CONTINUE TO BEAR RIGHT at Stop Sign. Road travels down Woodcock Valley. The valley is underlain by limestone and is underdrained. Crooked Creek has captured Woodcock Valley surface drainage at several points.
1.8	32.1	High ridge to left is Piney Ridge which is underlain by Harrell and Brallier Formations.
0.4	32.5	Lovely restored stone house on right was once occupied by T. Kaktins grandparents.
1.7	34.2	Quarries on left and right at McConnellstown are in carbonates of the Keyser-Tonoloway Formations and are operated by the New Enterprise Stone and Lime Company, Inc.
1.2	35.4	Redstone Ridge on right and Warrior Ridge on left. Outcrops ahead are of Keyser-Tonoloway carbonates.
1.4	36.8	TURN LEFT to Seven Points Recreation Area.
0.4	37.2	Gap in Warrior Ridge. Outcrop of Keyser Formation on left.
0.2	37.4	Town of Hesston on left.
0.3	37.7	Pass through Backbone Ridge. Outcrop on left of Mahantango Formation.
0.4	38.1	View to right of Tussey Mountain on skyline, Hesston and Warrior Ridge in foreground. Road climbs to crest of Piney Ridge.
0.4	38.5	Crest of Middle Ridge is underlain by Scherr Formation.
0.7	39.2	Crest of Allegrippus Ridge is underlain by Foreknobs Formation.
0.5	39.7	Entrance to Seven Points Recreation Area.
0.2	39.9	Information center on right.
2.2	42.1	TURN RIGHT into Oak Picnic and shelter area.
0.2	42.3	STOP 4. LUNCH.

RAYSTOWN LAKE

Thirty-mile-long Raystown Lake was completed in 1976 by the U. S. Army Corps of Engineers at a cost of about $68 million. It is estimated that since its completion the dam has prevented an amount of flood damage almost equal to its cost. The lake has 110 miles of shoreline, 514,000 acre feet of recreational storage, 248,000 acre feet of flood control storage, 11,625 acres of public use land, and 2470 acres of wild life management land. The recreation pool level is 786.0 feet msl and the maximum flood pool level is 812.0 feet msl.

As attractive as the lake may seem during our visit, it is not without its problems. Raystown Lake attracts about 1.5 million visitors each year for boating, fishing, and camping. With as many as an estimated 1,400 boats on the water on Saturdays and Sundays during the summer season, the lake becomes hazardous at times even though the safety record on the lake is very good. How many people can be accommodated by the lake remains to be determined. Some feel that it is already overpopulated.

If one looks to the north down the lake from the vicinity of the Oak Picnic area, one is rewarded with a view of the relatively flat crests of ridges projecting into the lake from either side. These are cores of meander bends of the now flooded Raystown Branch Juniata River. The very sinuous meanders of the river are still reflected by the outline of the lake, (Figure 00, p. 000) and also still shown on the 7 1/2' topographic maps. The crests of these ridges have some remnant fluvial materials up to an elevation of about 200 feet above the bed of the drowned river. A comparable meander core with fluvial gravels exists at Warrior Path State Park, the site of Stop 11, Day 2 of this trip.

I. C. White (1885, p. 32) mentioned the occurrence of boulder deposits on the Raystown Branch, but he did not recognize them at elevations more than 60 feet above the river bed. It is interesting to note how poorly fluvial mechanics were understood when White did his work in Huntingdon County. White comments on the occurrence of boulder deposits along the Juniata River near Huntingdon, Petersburg, and Alexandria at heights up to 100 feet above the river. He also mentions an unusual occurrence at an elevation of 950 feet A. T. (200 feet above river) on the western slope of Warrior Ridge. These boulder deposits have rounded and polished sandstone boulders up to 4 feet in diameter, but more commonly 3 to 5 inches in diamter.

In an effort to explain the occurrence of these deposits White offers 5 possible explanations (1885, p. 32-33):

1. A heavier ancient rainfall caused a flood of exceptional magnitude.
2. The melting of snows of the glacial age might have raised the level of the rivers in the area. White was aware that the area had not been glaciated.
3. The deepening of the present river channels. White seems vaguely inclined in this direction, but if so viewed the downcutting as having occurred since the end of the glacial age.
4. J. P. Lesley suggested that a dam may have once existed at Jack's Narrows high enough to make a large lake in which boulder deposits, deltas, and etc., would be created.
5. "Ocean submergence.--If, however, the abnormal deposit of rounded iron sandstone boulders, at 950' A. T., be taken into consideration, it leads to the inevitable conclusion that the Juniata country has been in comparatively recent times covered by the ocean 1000' or more above present seal level." (White, 1885, p. 33) White points out that the absence of any marine deposits associated with such a submergence is a problem, but says that the idea cannot be dismissed without further work.

Keep some of these topics in mind as you travel through the area. Be particulary aware of them at Stop 9, Day 2 of the trip.

0.2	42.5	LEAVE parking area. TURN RIGHT at main road and continue past the marina.
2.3	44.8	Information center on left.
3.0	47.8	TURN LEFT onto PA Route 26 South.
1.3	49.1	Quarry to left on Warrior Ridge is in Keyser Formation. There is an old kiln at the south end of the quarry.
1.5	50.6	St. Mathews Lutheran Church on left was built in 1838. Oldest monuments dated 1843 and 1845.
1.5	52.1	Center of Marklesburg.
0.5	52.6	Zion Reformed Church on left was built in 1847 and rebuilt in 1887.
1.0	53.6	Shultz cemetary historical monument on right. Oldest monument

dated 1830.

		dated 1830.
2.1	55.7	TURN LEFT onto PA 994 East to Entriken.
0.2	55.9	Village of Entriken and kiln on left.
0.4	56.3	TURN LEFT following PA Route 994 East.
0.4	56.8	Outcrop of Brallier Formation on left.
1.0	57.8	STOP 5. ENTRIKEN SECTION. Stop buses before long section of guard rail with no outcrop on right side of road.

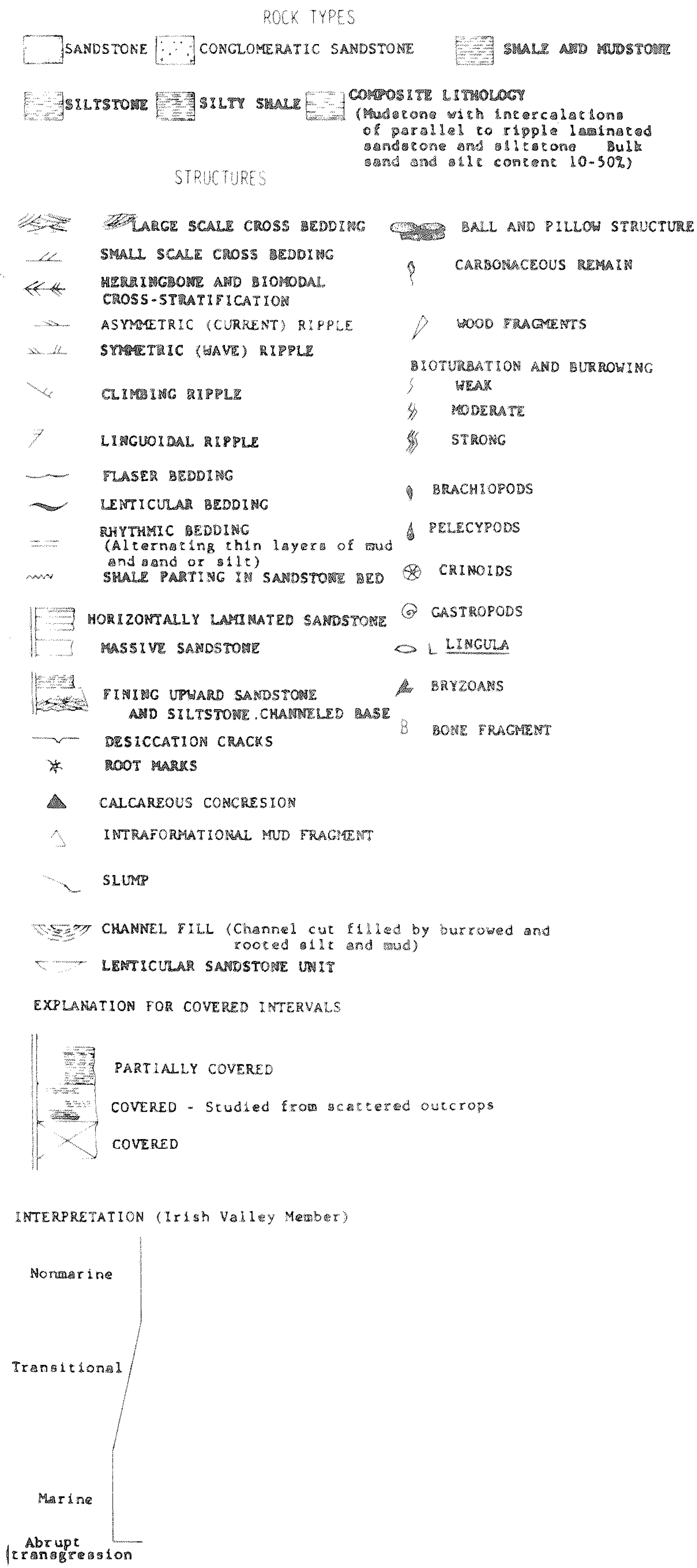
DISCUSSANT: EUGENE G. WILLIAMS

At this locality, we will examine the nature of the transitional rocks between the marine rocks of the Trimmers Rock Formation below and the non-marine rocks of the Sherman Creek Member of the Catskill Formation above. The transitional rocks, exhibiting well defined cycles or motifs, comprise the Irish Valley Member, the interpretation of which is critical in the concept of the "Catskill Delta." We use the older rock-stratigraphic terms for consistency with Rahmanian's work. The present subdivisions are in ascending order: Scherr (Trimmers Rock), Foreknobs (uppermost Trimmers Rock and Irish Valley Member), and Catskill (Sherman Creek and Duncannon Member). The Entriken section contains the most complete sequence of the motifs in central Pennsylvania. Contacts between formations and cycles within the Irish Valley lithology are illustrated in Figure 65. Reference to Figure 38 (p. 78) shows that to the north at Port Matilda, the Irish Valley is dominantly an alluvial-deltaic sequence whereas to the south at Saxton it is mainly a barrier island one, neither of which exhibit notable cyclicity.

The upper part of the Trimmers Rock Formation, consisting of a silty-shale and sandstone-shale facies occupies the lower 360 ft (108 m) of the measured section (Figure 65). The lithologic characteristics and the inferred environments are summarized in Figure 66. Sandstones are frequently wavy- and cross-laminated and rippled on upper surfaces, generally fine-grained, and may exhibit groove and flute casts along bottom contacts. Gray siltstone and shale beds are extensively bioturbated; burrows are usually solitary, oriented both parallel and perpendicular to bedding. Marine fossils occur throughout the interval. Brachiopods dominate but there are also pelecypods, crinoid columnals, bryozoan fragments and encrustations, fish plates, and plant fragments. Shells occur as solitary forms in shales and as coquina layers at the top of some sandstone beds.

The Trimmers Rock facies are inferred to have formed within a shallow marine shelf environment. The presence of hummocky cross lamination and symmetric ripples in conjunction with small-scale cross lamination suggests a position above wave base in the shelf environment where both storm waves and tidal currents operate. Petrographically, the sandstones of the Trimmers Rock resemble those of the alluvial Sherman Creek, suggesting that they were rapidly emplaced without much subsequent reworking.

The Irish Valley Member at this section is organized into well-defined cycles or motifs, the general character of which has been discussed in the accompanying paper on Catskill sedimentation (see Figure 37, p. 76). Two types of variation on this cyclic theme are exhibited at the Entricken section and are illustrated in Figures 67 and 68; the silty-muddy motif facies occurs in the interval 360 to 850 ft. (108 to 225 m) and the sandy-silty-motif facies in the



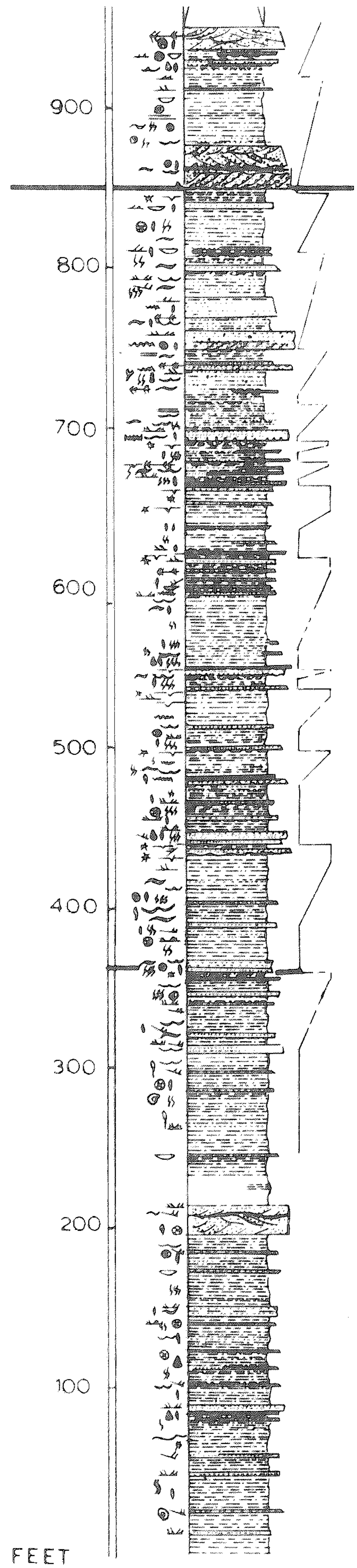
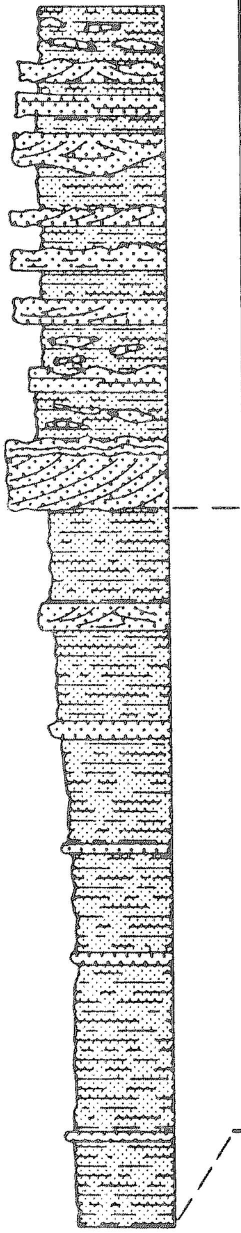


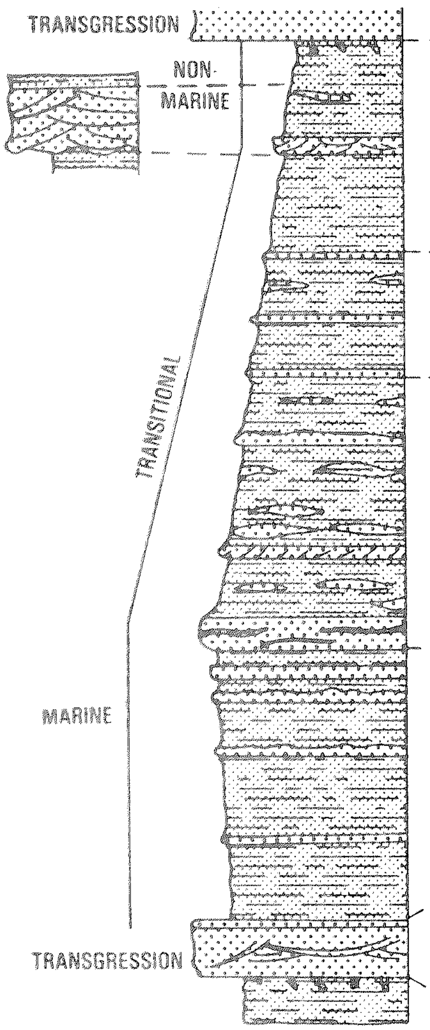
Figure 65. Measured section along PA Route 994 at Entriken.



Facies	*Sedimentary structures*	*Interpretation*
Sandstone-shale facies Light- to olive-gray interbeds of fossiliferous sandstone and silty shale	– Sandstones: Large-scale and solitary to small-scale crossbedding; linear (symmetric and asymmetric) and interference ripples; horizontal wavy (hummocky) and flaser bedding; beds 5-20 ft thick; quartz-pebble bases; many with 4-ft-thick solitary planar cross-strata dipping northeast – Silty shale: Horizontal, wavy bedding – Bioturbated horizons common	Shallow marine subtidal shelf (tidal sand waves and ridges)
Silty shale facies Gray olive-gray, fossiliferous silty shale and siltstone with thin sandstone layers interspersed	– Siltstones: Horizontal, wavy, and/or ripple lamination – Sandstones: Small- to micro-scale crossbedding; linear and interference ripples; wavy and horizontal lamination (hummocky cross-stratification) – Bioturbated horizons common	Shallow marine shelf

Figure 66. Idealized vertical facies sequence of the uppermost 75 to 150 m of the Trimmers Rock Formation (modified from Rahmanian, 1979).

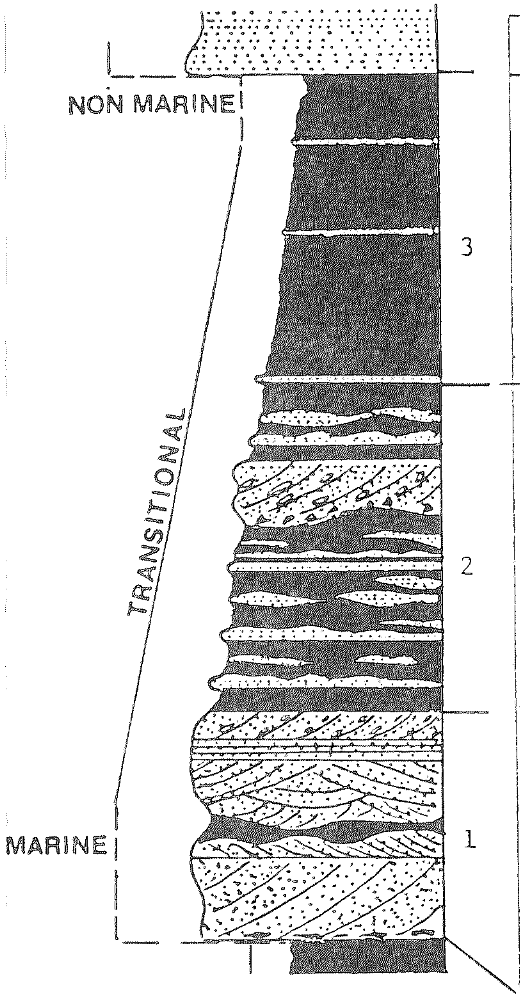
interval 850 to 1350 ft (255 to 305 m) (Figure 65). Five subfacies are recognized in the silty-muddy motifs, namely: 1) basal, bioturbated sandstone, 2) green shale and silty shale, 3) green sandstone-mudstone, 4) red, laminated siltstone, and 5) red massive mudstone and siltstone. The cycles range in thickness from 5 to 64 ft (1.5 to 19.5 m). Each motif has a planar, sharp basal contact which separates the basal, green marine sediments from the red mudstone of the underlying motif. Evidence suggests that each motif started with an initial transgressive event, now represented by the basal sandstone and the overlying green, fossiliferous, silty-shale facies. The presence of



Facies	Sedimentary structures	Interpretation
Red massive mudstone	Massive; desiccation cracks; abundant root traces; occasional interbedded red, lenticular, fining-upward sandstone bodies	High-tide to supratidal mudflat
Red laminated siltstone	Desiccation cracks; horizontal (rhythmic), and wavy siltstone beds	
Green sandstone-mudstone facies (dominantly mudstone)	Flaser, wavy and lenticular bedding; blocky and massive in places; small-scale solitary, interference, and linear, clay-draped ripples; burrowing and bioturbation common	Low-mid tidal flat
Green fissile shale and silty shale (fossiliferous)	– Silty shales: Finely laminated – Sandstones: Rippled to micro-crossbedded – Bioturbated intervals common	Low-energy shallow marine shelf-shoreface
Basal, bioturbated sandstone	– Extensive bioturbation – Horizontal to low-angle crossbedded	– Transgressive sand (beach)

Figure 67. Idealized vertical facies sequence of the silty-muddy motif of the Irish Valley Member (modified from Rahmanian, 1979).

brachiopods and crinoidal debris and burrows of marine affinity implies a normal marine environment for this facies. Absence of thick and winnowed sand bodies in the transgressive phase reflects a rapid transgression coupled with a high rate of mud and silt supply. The transgression was followed by a stage of slow sedimentation during which time extensive biological reworking of the deposited sediments, including the transgressive beaches, took place. Finally, marine deposition of mud gradually changed to deposition of thin, well sorted, quartzitic sandstone with symmetric ripples (probably wave generated) as the sea shoaled. Above the shoaling phase occurs a fining upward, regressive tidal flat sequence. The complexly bedded, thin quartzitic sandstone and the interbedded, burrowed and flaser-bedded, green siltstone and shale are inferred to represent low to middle tidal flat facies. The overlying red, laminated siltstone and red, massive mudstone are thought to occur in the high to supratidal range. The



Facies	Interpretation	Sedimentary Structures
Red Mud-stone	Upper muddy flat to supratidal flat.	Dessication cracks; root marks; horizontal siltstone lamination; starved silt-stone ripples.
Green Quartzitic sand-stone - mudstone	Mid-tidal flat.	Small-scale, solitary cross-bedding; flaser lenticular, wavy bedding; mud-draped ripples and shale partings; common bioturb-ation structures; unimodal and bimodal cross-bedding; herringbone structures.
Quartzitic	Low tide terrace, tidal channels.	Regularly-bedded; horizon-tal and cross-bedded, rip-ple and lenticular bedding; shale parting.
Sandstone	Subtidal or intertidal sand bars.	Large-scale solitary cross-beds; capped by opposite-dipping small-scale cross-beds and large-scale rip-ples; unimodal cross-bedding.

sandstone

silty shale and mudstone

Figure 68. Idealized facies sequence and depositional environment of sandy-silt motifs (modified from Rahmanian, 1979).

presence of root marks, desiccation and mud cracks, and carbonate nodules supports the concept of at least temporary subaerial exposure. The sandstone units which cut through some of the high-tide mudflat sediments may represent meandering tidal channels.

The sandy-silt motifs, diagrametically illustrated in Figure 68, are characterized by 3 facies: 1) quartzitic-sandstone facies, 2) green quartzitic sandstone-mudstone facies, and 3) red mudstone facies. Facies 2 and 3 resemble those described in the silty muddy motifs, but facies 1 is quite different. In all sand-silt motifs it consists entirely of a basal sandstone body ranging in thickness from 6.6 to 13 ft (2 to 4 m). The sandstones are fine- to medium-grained, moderately well-sorted quartzites. Spherical and discoidal quartz pebbles and cobbles up to 3 inches (7.5 cm) in diameter, mud clasts, brachiopods, and bone fragments occur as basal lag deposits in some beds. These sandstones bodies exhibit well defined crossbedding, both planar and trough types.

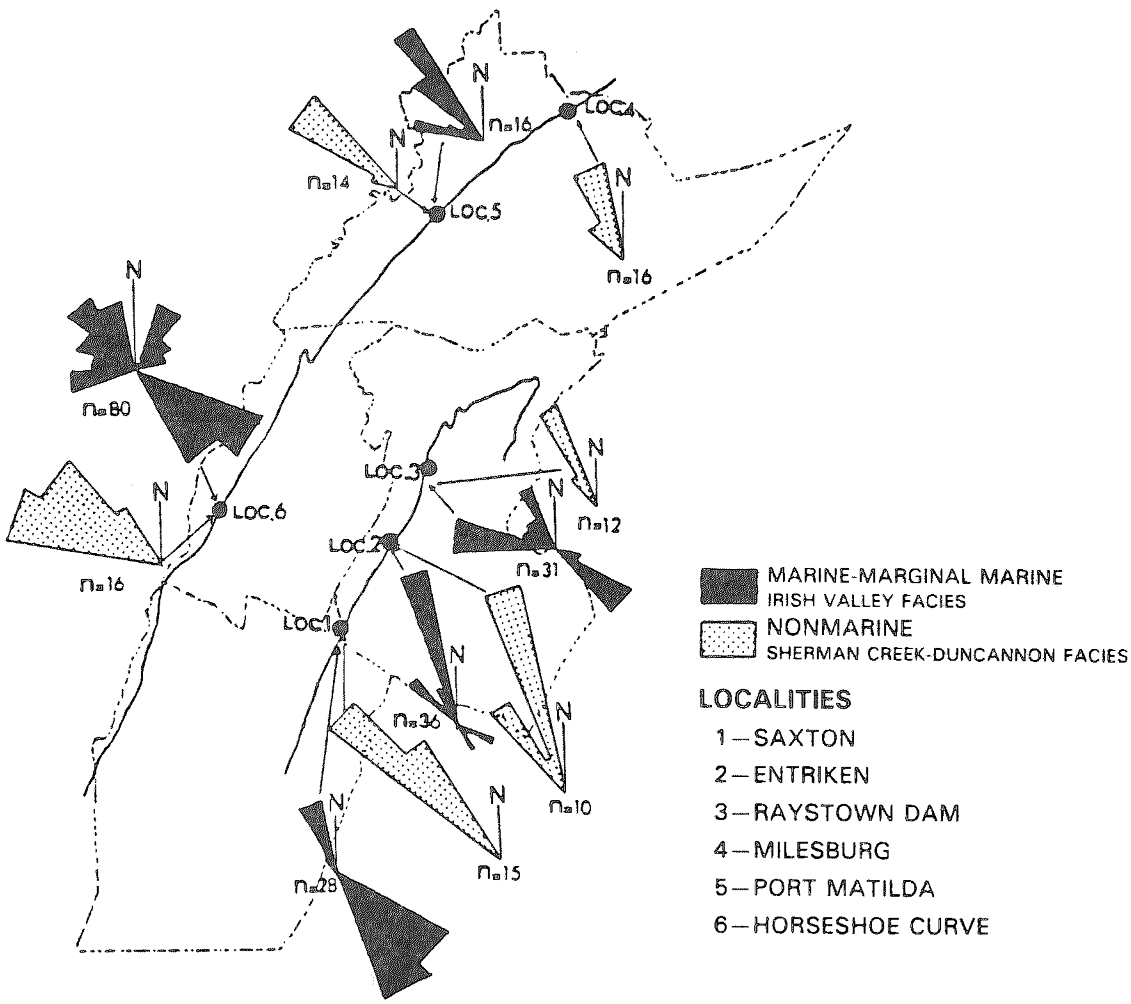


Figure 69. Paleocurrent directional data for the Catskill Formation in central and south-central Pennsylvania (modified from Rahmanian, 1979).

In one sandstone body a single set is over 9.8 ft (3 m) thick. Cross-bed dip directions (Figure 69) exhibit a bipolarity to the northwest and southeast, which probably represents the ebb and flood tidal flows on tidal deltas, bars, or channels. These sandstone bodies are overlain successively by deposits of low, middle, and upper tidal flats.

The varying thickness and limited lateral extent of the individual motifs lead to the conclusion that they were produced by variation in sediment supply which itself may have resulted from changes in shelf circulation, decline of sediment to the basin, or lateral shifts in the position of the delta geometry. In the last case, transgression occurred when delta sediments from the Port Matilda area (see Figures 39 and 40, p. 79) were diverted away from a particular part of the shoreline and regional subsidence and compaction overwhelmed sedimentation. Regression occurred when influx of sediments by longshore drift caused building of tidal flats.

The non-marine Sherman Creek Member of the Catskill Formation overlies the Irish Valley Member; the contact occurs just to the south of the bridge abutment. The Sherman Creek is composed of fining upward alluvial cycles consisting of thick, red mudstone, siltstone, and to a lesser degree, red, fine- to very fine-grained sandstone. The cycles start with dominantly red, lenticular to sigmoidly bedded sandstone units which possess basal erosional contacts and gradational tops. The basal sandstone units grade upward to a relatively thick sequence of interbedded red siltstone with dominantly red mudstone at the top of the cycle. Cycles range in thickness from 5 to more than 30 ft (1.5 to 9 m). The inferred environments for the Sherman Creek are those associated with shallow meandering rivers. The general paleogeographic setting for the fining upward cycles of the Sherman Creek is that of the distal parts of a broad and inactive coastal plain, bordered in the seaward direction by extensive tidal flats now represented by the Irish Valley motifs.

The Sherman Creek Member is best exposed in the slopes on the east side of Raystown Lake. The fact that it underlies the valley now covered by the lake testifies to its lack of erosional resistance in this area.

The third member of the Catskill Formation, the Duncannon, is thin or absent in the Entricken area. In general, in central Pennsylvania, the thick alluvial cycles of the Duncannon are best developed in areas where the cycles of the Irish Valley are absent or poorly formed, a relation which leads to the paleogeographic interpretation illustrated in Figure 40 (p. 79), namely that the Catskill exhibits both alluvial-deltaic and tidal-coastal plain facies, which were confined to definite areas as progradation continued from southeast to northwest. The nature of the coastal plain facies depends upon the distance from the depocenters and the configuration of the coast. The Entriken section is inferred to represent the progradation of a shallow shelf, muddy shoreline, and inactive coastal plain in contrast to delta progradation to the north at Port Matilda sections.

LEAVE STOP 5. PROCEED STRAIGHT AHEAD.

0.5 58.3 Bridge. End of section.

0.9 59.2 Second bridge. Good view of Terrace Mountain and lake. Road proceeds up Tatman Run.

0.6 59.8 A 10-20 foot high bank exposure of unstratified alluvium occurs at the entrance to the Lake Raystown Resort on the right. The deposits are approximately 115 feet above the modern Raystown Branch of the Juniata River (pre-dam water levels) and may be distinguished from colluvial deposits by the presence of smooth, waterworn pebbles, cobbles, and boulders derived from geologic units which do not outcrop on Terrace Mountain upslope from the site. Though the surface of the outcrop has been graded and the upper 3-6 feet are not stratified, other sites at similar heights above the river probably have stratified river sand and gravel under a cover of cryoturbated, mass-wasted colluvial material which was emplaced during the Wisconsinan by periglacial action. The soil and rock-weathering characteristics of the exposure are similar to those on T_4 along the main Juniata River (Table 5, p. 107).

1.2 61.0 PROCEED STRAIGHT AHEAD at road intersection. Road to Trough Creek State Park on right.

1.3 62.3 Excellent view ahead of local landscape.

1.4 63.7 Note colluvium on Mauch Chunk rock in roadcuts along next mile.

2.7 66.4 Road to Todd on left. Village of Eagle Foundary ahead.

2.0	68.4	BEAR SLIGHT LEFT following PA Route 994 East at road intersection in Cooks.
1.0	69.4	Crest of Rays Hill. Outcrop of Pottsville Formation.
0.6	70.0	Very sharp turn to left with outcrop of Pottsville Formation on the left.
0.7	70.7	TURN LEFT at T-intersection.
0.1	70.8	TURN RIGHT. Cross Cole Valley.
0.4	71.2	Cross narrow gauge railroad line.
0.2	71.4	Crest of Sideling Hill.
0.3	71.7	Cross narrow gauge railroad near base of hill.
3.1	74.8	TURN RIGHT at T-intersection following PA Route 994 East and PA 655 South.
0.1	74.9	TURN LEFT following PA 994 East.
1.3	76.2	STOP SIGN AND BLINKER LIGHT. TURN RIGHT following PA Route 994 East in center of Three Springs.
6.4	82.6	STOP SIGN. BEAR RIGHT following PA Route 994 East in Rockhill.
0.1	82.7	East Broad Top Railroad on right and left.
0.4	83.1	STOP LIGHT. TURN LEFT onto US Route 522 North in Orbisonia.
0.8	83.9	Outcrop with Tioga ash bed in the Onondaga-Marcellus Formation rocks on right. East Broad Top Railroad line on left.
2.9	86.8	Village of Shirleysburg boundary.
0.4	87.2	Shirleysburg United Methodist Church on right.
0.2	87.4	TURN RIGHT in center of Shirleysburg at store on corner a block beyond the red brick Shirleysburg United Methodist church on the right. Travel up Fort Run valley.
1.2	88.6	Pass through gap in Pine Ridge. Quarry in sandstone of Oriskany Formation on right on first curve.
0.4	89.0	BEAR LEFT at Y-intersection. Road to right go to Stone Church.
0.3	89.3	Bethel Cemetary on left has monuments dating back to 1859.
3.5	92.8	STOP SIGN. TURN RIGHT onto PA Route 103 North.
0.6	93.4	End of section for Stop 6-A. Note landslide in colluvium.
0.2	93.6	STOP 6-A. ALLENPORT SILURIAN SECTION. Park buses on right side in wide berm for off-loading. Buses will turn around at wide pull-off on left 0.2 mile ahead. Buses should wait until called for on-loading. Across the Juniata River is the Newton Hamilton meander where terrace levels T_0-T_4 occur.

DISCUSSANTS: EDWARD COTTER AND J. D. INNERS

INTRODUCTION

Two sections along the Juniata River east of the village of Allenport comprise a nearly uninterrupted stratigraphic sequence from the medial part of the Lower Silurian Rose Hill Formation to the medial part of the Upper Silurian-Lower Devonian Keyser Formation. Total thickness of the included strata is approximately 565 m, of which 87 percent is exposed. The rocks dip rather uniformly toward N65W at 45 to 65 degrees on the west limb of the second-order Blue Mountain anticline. Blue Mountain itself, a breached doubly-plunging anticlinal mountain, has its southwest termination about 2 km south of here.

The stop is divided into 2 parts (Figure 70):

A includes the middle and upper Rose Hill, Keefer, and lowermost

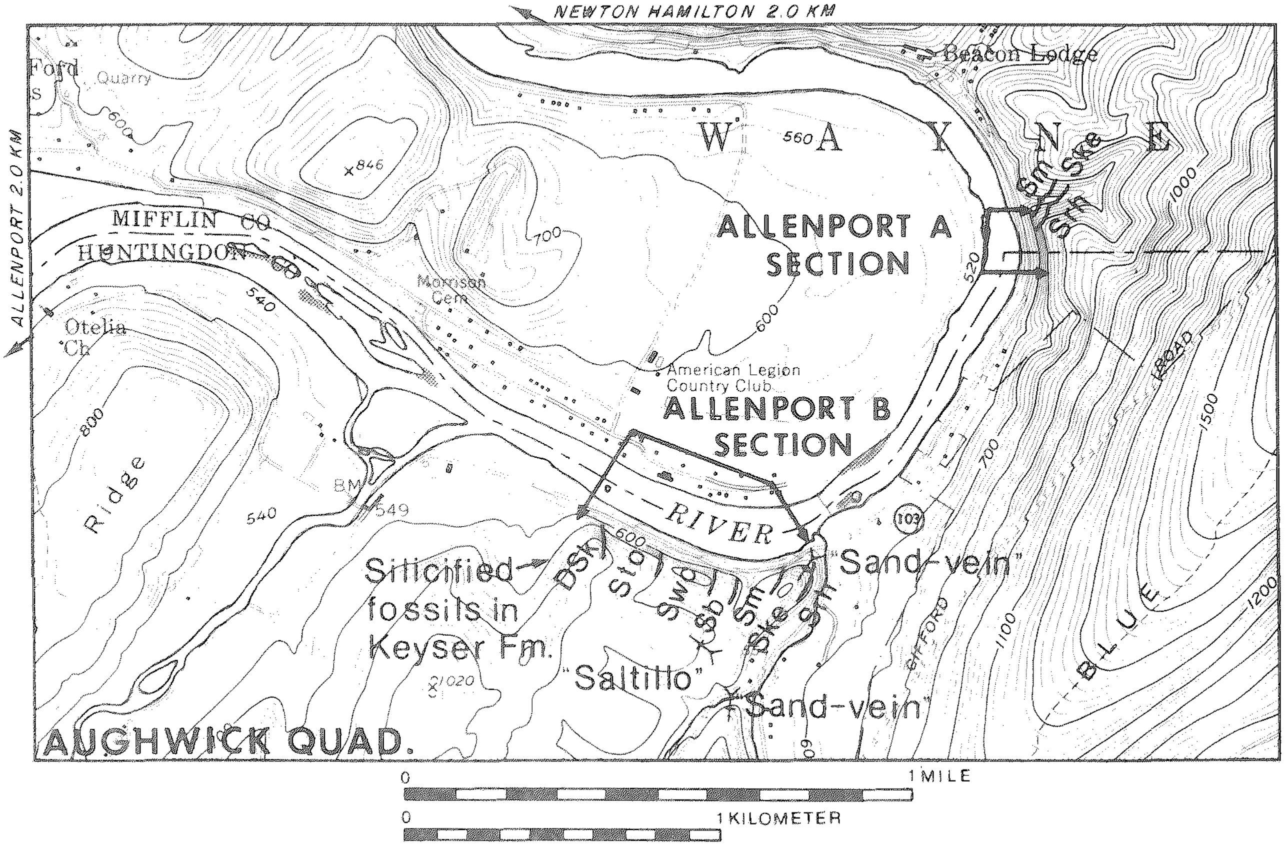


Figure 70. Map location for Stop 6. Note the old iron mines near B section.

Mifflintown Formations that crop out just north of the Huntington-Mifflin county line in Wayne Township, Mifflin County.

B includes the Keefer, Mifflintown, Bloomsburg, Wills Creek, Tonoloway, and lower Keyser Formations that are exposed in deep roadcuts at the north end of Mine Bank Ridge and its foothills in Shirley Township, Huntingdon County.

Cotter will deal with sedimentologic interpretations of the Rose Hill to Mifflintown interval, and Inners will consider some stratigraphic and sedimentologic aspects of the upper Mifflintown to Keyser strata. References cited are given on pages 36-39.

STOP 6A. ROSE HILL (upper part) AND KEEFER FORMATIONS

Much of the Rose Hill Formation here is fissile mudrock with only thin distal storm beds. The hematite-cemented sandstone units (Cabin Hill and Centre Members) have wedged out before reaching this relatively distal position. Rogers (1858, p. 132) recognized this, noting that at Jack's Narrows (near Mount Union) the Surgent Iron Sandstone was absent and the Lower Slate was not sepaable from the Upper Slate.

The Rose Hill here becomes more interesting as the Keefer Formation is approached, for storm beds become thicker, more common, and largely composed of skeletal limestone (coquinites) (Figure 71). Most storm beds have flat bases and either rippled or wavy, hummocklike tops. The only diagnostic biogenic structure is Chondrites (called Buthotrephis gracilis by Rogers, 1858), a form

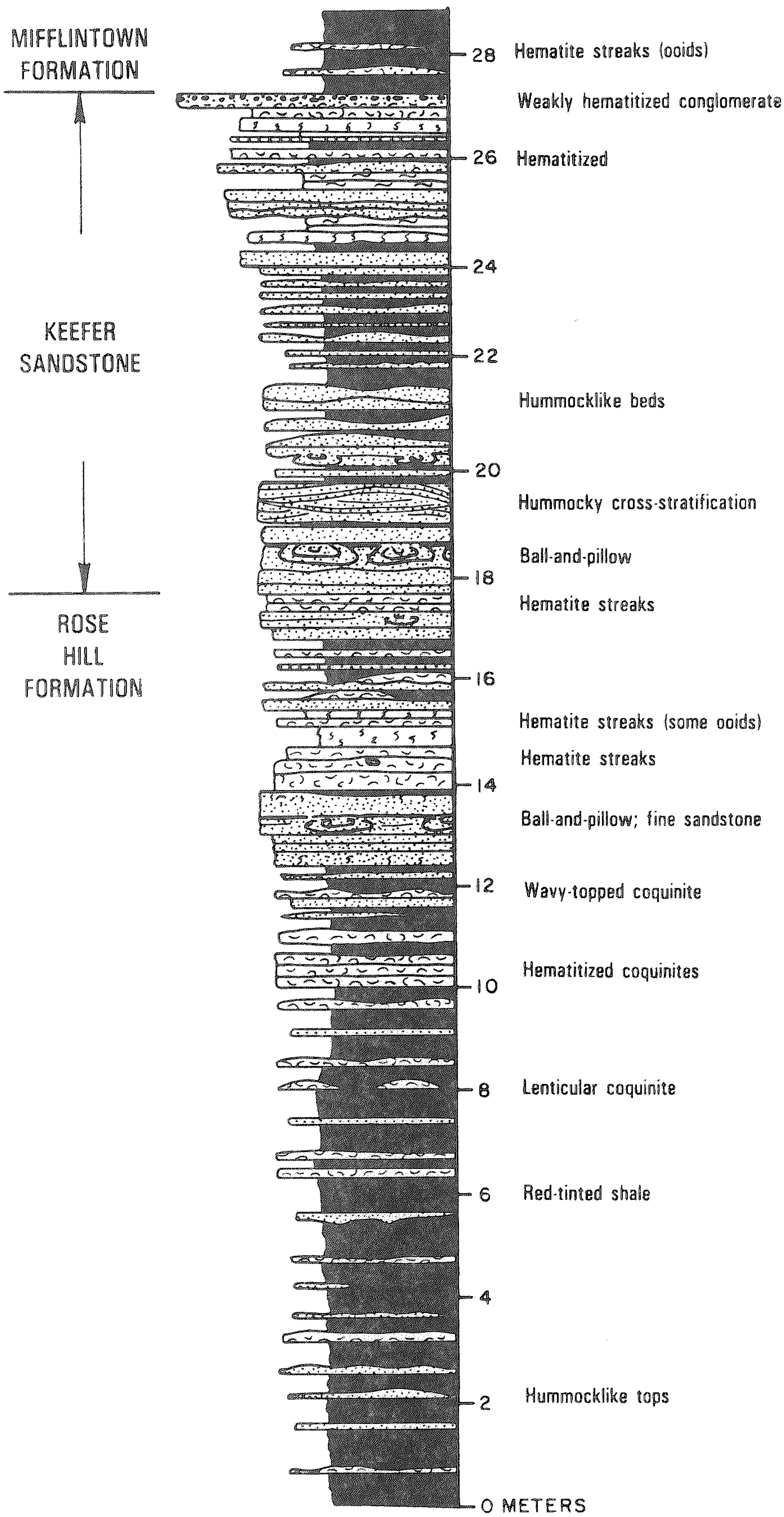


Figure 71. Stratigraphic column of Rose Hill and Keefer Formations at Stop 6A.

made by organisms able to tolerate extremely low levels of oxygen (Bromley and Ekdale, 1984). Some of the coquinite beds have been hematitized (Figure 71).

I judged the thin coarsening-upward sandstone sequence between 12 and 14 m (Figure 71) to be insufficient, and placed the lower boundary of the Keefer Formation at the base of a thicker quartz arenite sequence (just below 18 m on Figure 71). As at other Keefer exposures, the unit is not all quartz arenite, but comprises alternating heterolithic and monolithic subdivisions. The heterolithic parts are made of alternating mudrock and storm beds (sandstone or coquinites), and the monolithic parts contain structures indicating rapid deposition under shallower, storm-dominated conditions. These structures include ball and pillow (more common here than at any other Keefer exposure I have seen) and HCS (internal stratification between 19 and 20 m on Figure 71, and hummocky bed geometries at various levels).

The alternation of the slightly deeper heterolithic parts and the slightly shallower monolithic parts represents the fifth-order cycles within the overall generally shallower third-order cycle represented by the Keefer as a whole. The positions of these fifth-order cycles are not marked on Figure 71 because of the lack of clear demarcation between them. Some coarsening- and shallowing-upward sequences are more clearly defined (such as from 12-14 m and from 17-20 m on Figure 71), but others are more complex and may contain several superimposed cycles. I leave the decision about how many coarsening and shallowing-upward sequences there are to your judgement.

LEAVE STOP 6-A. RETURN SAME WAY CAME on PA Route 913 South.

0.9 94.5 STOP 6-B. ALLENPORT SILURIAN SECTION.
Park buses and offload in wide area at T-intersection at east end of section. Buses will remain there and pick up at end of section when called to proceed.

STOP 6B. PART I. KEEFER AND MIFFLINTOWN FORMATIONS

In central Pennsylvania, the Mifflintown Formation was defined by Miller (1961) chiefly because the Keefer, Rochester and McKenzie Formations (see Figure 13, p.28) cannot be differentiated for mapping purposes in some parts of central Pennsylvania. Where the Keefer Formation is separately distinquishable (as here), the Mifflintown Formation consists of the strata above the Keefer and below the Bloomsburg Formation (Faill and Wells, 1974, p. 42; Berg and others, 1983).

Because the bedding sequence in the Keefer Formation here is virtually identical to that at Stop 6A, the previous discussion applies to these rocks as well. Of special interest, however, are the old iron mine workings on the hillside just above the roadcut. Oliver Etnier opened an ore bed at this spot in 1870(?), abandoning the project a year later (Dewees, 1878). He reportedly shipped about 100 tons of hard "fossil ore" that contained 22 to 25 percent metallic iron. The marginal quality of the ore - even for those days - readily accounts for the short life of the operation. Examination of the workings suggests that most of the ore was taken from a drift into the medial Keefer at the end of the ridge. A small amount of soft ore was also stripped along the outcrop to the south, and a second, smaller drift, was dug out at a slightly higher altitude than the first. You can judge for yourself exactly where the ore bed(s) lie in the outcrop. Farther to the south, several mines exploited the Keefer ores on Lick Ridge at the nose of Blue Mountain. One of these is evident as a caved drift on the stream bank next to the Shirleysburg Road (Legislative Route 31030) 500 m south of Etnier's mine (see Figure 70). Ores in this immediate area were mined as early as the 1830's for Bell's furnace on West Licking Creek (Rogers, 1858), located about 1.4 km south-southeast of here.

The lower Mifflintown Formation stratigraphic succession at this locality is presented in the column of Figure 72. Major aspects of this succession are considered below in units identified by position (meters) above the base of the formation. (A more generalized view of the upper Mifflintown - above the concealed Rabble Run Member - is shown in Figure 74).

0-9.5 m

The granular conglomerate with weak hematite development establishes a clear correlation with the top of the Keefer seen at Stop 6A. The lowest 9.5 m of the Mifflintown consists of mudrock and thin to medium storm beds, a few of which are faintly hematitized. Storm bed geometries (flat bases, domal hummocklike tops) are similar to those in underlying formations. Granules in the lowest storm beds suggest that these units were derived from the offshore bars (shoal complexes) represented by the top of the Keefer. Toward the top of this unit the storm beds are composed largely of ostracode coquinites, a lithology very characteristic of the Mifflintown Formation.

9.5-21 m

This unit is characterized by the repetitious alternation of fissile mudrock and irregularly lenticular micrite that commonly contains flat-pebble intraclasts. The irregular lenticularity appears to result from a number of factors. Foremost among these is that storm wave processes have generated domal, hummocklike bed tops (seen more clearly on solitary micrite beds rather than where superimposed). In other cases, irregularity of bed bases has resulted from a gutterlike fluting of underlying sediment. Later beds draped over any of these primary irregularities conform to the underlying form. During compaction and diagenesis the primary irregularities were enhanced. For example, it appears that the clusters of intraclasts, which in many cases were associated with hummocklike thicker parts of beds, were not as compactible as adjacent parts of the same bed, thereby accentuating the differential thickness.

The intraclast-bearing micrites are another variety of storm bed. To develop the flat intraclasts requires a situation in which burrowing organisms are absent and the muds have sufficient submarine cementation to be partly lithified (Sepkoski, 1982; Tucker, 1982). Subsequent storms rip up flat clasts, resedimenting them in either sheetlike beds or gutterlike scours as the shallow sea floor is degraded (Kazmierczak and Goldring, 1978; Sepkoski, 1982; Tucker, 1982; Whisonant and others, 1985). A suggestion has been made that to get the vertically packed ("edgewise") arrangement of the flat clasts (Figure 73), a moderate degree of wave energy during accumulation is required (Donovan and others, 1985).

Cyclicity is apparent in the repetitious alternation of mudrock and lenticularly bedded micrite. Nine 1 to 2 m-thick cycles have been labelled on Figure 74. These are the Mifflintown Formation equivalent of the fifth-order cycles present in the Rose Hill and Keefer Formations at other localities.

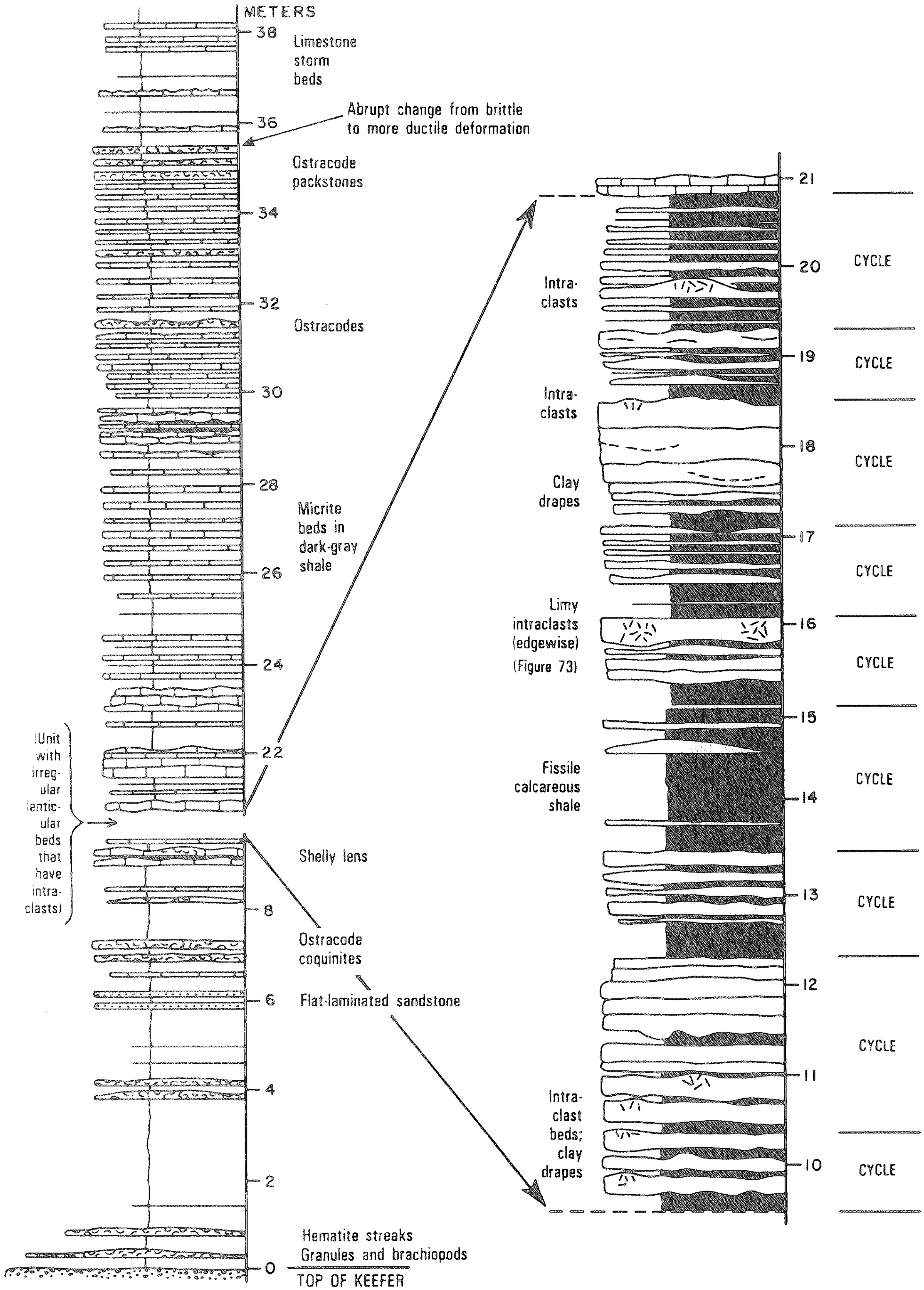


Figure 72. Stratigraphic column of Mifflintown Formation at Stop 6B.

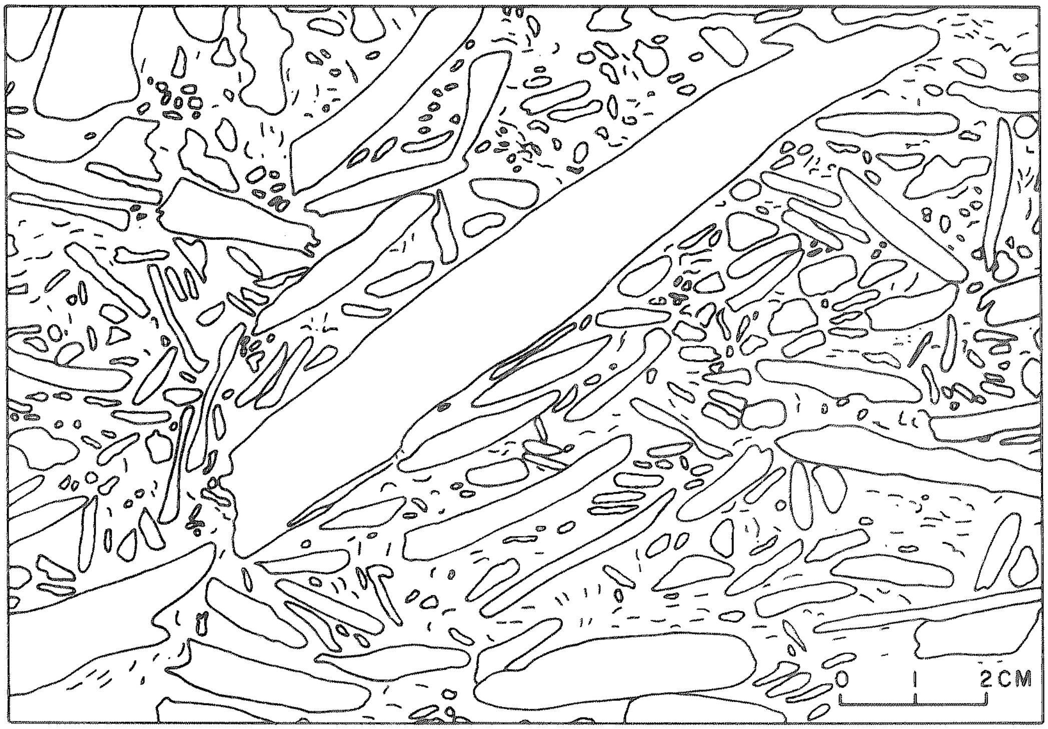


Figure 73. Sketch of "edgewise" conglomerate at 16 m (Mifflintown Formation).

Development of these cycles required that conditions alternated between the aggradation of mud under anaerobic, low-energy conditions and the degradation and resedimentation of micrite under higher-energy, storm-generated processes. Such an alternation was accomplished by changes in relative depth of the sea floor. The presence of similar fith-order cycles in a variety of depositional settings (coastal, mid-shelf, more distal shelf) in these medial Silurian formations indicates that depth changes result from allogenic causes.

21-35.5 m

The Mifflintown Formation continues largely as micritic storm beds intercalated within dark gray shale. Ostracodes appear in storm beds in the upper part of this unit, and are concentrated into packstones just below the unit top. Variations in the proportions of shale and storm beds hint at a vague cyclicity, but there is too little evidence to state that a cyclicity definitely is present.

Above 35.5 m

This unit begins with an abrupt change to shale-dominated lithologies, accompanied by a change in the style of tectonic strain. Within the dominant shale the thin limestone beds have the flat bases and rippled tops that reveal their origin as storm beds. Many of the storm beds, especially those in the poorly exposed part well above the unit base consist of ostracode packstone. The change of depositional style that begins this unit (at 35.5 m) reflects a relatively abrupt deepening of the marginal ramp. This deepening was probably of somewhat larger scale than occurred to make the fifth-order cycles noted in underlying units, however there is insufficient information here to identify the level of significance. It is possible that this deepening is related to the exceptionally higher stand of sea level seen regionally in the middle part of the Mifflintown Formation.

STOP 6B. PART II. MIFFLINTOWN (upper part), BLOOMSBURG, WILLS CREEK, TONOLOWAY, AND KEYSER (lower part) FORMATIONS

The uppermost Mifflintown to medial Keyser stratigraphic succession at Allenport is shown in Figure 74. According to Pennsylvania Department of Transportation (District 9-0) personnel, the existing cut on PA Route 103 was excavated in 1972. Local residents claim that the cut face has weathered back 2 to 3 m since construction, an assertion that is supported by the profuse rubble at the base of the slope and the extremely fractured nature of much of the rock.

MIFFLINTOWN FORMATION (upper part)

The valley between the two roadcuts conceals most of the approximately 30 m thickness of the red Rabble Run Member, a progradational tongue of the Bloomsburg facies which is recognizable over much of the Juniata Valley from Mount Union to the southwest (Hoskins, 1961). About 2 m of grayish-red, calcareous claystone, including the shaly and oolitic "Saltillo" iron ore bed (0.5 m thick), crops out at the extreme east end of the second cut. (The Saltillo ore was apparently mined from an open cross-cut behind the old stone house belonging to William Crownover on L. R. 31030, a few hundred meters to the south). The uppermost Mifflintown consists of 25 m of olive-gray, calcareous clay shale containing thin to medium interbeds of silty, micritic limestone, and brachiopod-coquinite limestone (storm beds). The contact with the overlying Bloomsburg Formation is abrupt but conformable.

BLOOMSBURG FORMATION

The Bloomsburg Formation is 32 m thick here, the same thickness noted by Hoskins (1961) in the cut along U. S. Routes 22-522 at Mount Union 6 km to the northwest.

0 to 13 m

The lower part of the formations consists of grayish-red, slightly calcareous mudstone containing a few yellowish-green splotches. F. Swartz (1955) observed several siltstone dikes 0.3 to 2 cm wide and up to 1.2 m long at the top of this unit at Mount Union. Such dikes, evidently fillings of deep mudcracks, are known to be associated with the Moyer Ridge siltstones and sandstones at several other localities in central Pennsylvania (see Nickelsen, 1983). A diligent examination of the faulted and intensely cleaved mudstone interval noted on the columnar section of Figure 74 might reveal their presence here as well.

Although these beds are quite fossiliferous (ostracodes, forams, etc.) at Mount Union (Hoskins, 1961), they appear to be barren at Allenport.

13 to 22.5 m (Moyer Ridge Member)

The medial 9.5 m is interbedded sandy siltstone and silty mudstone, the siltstones occurring mainly in packets of 5 to 30 cm-thick beds at the base and

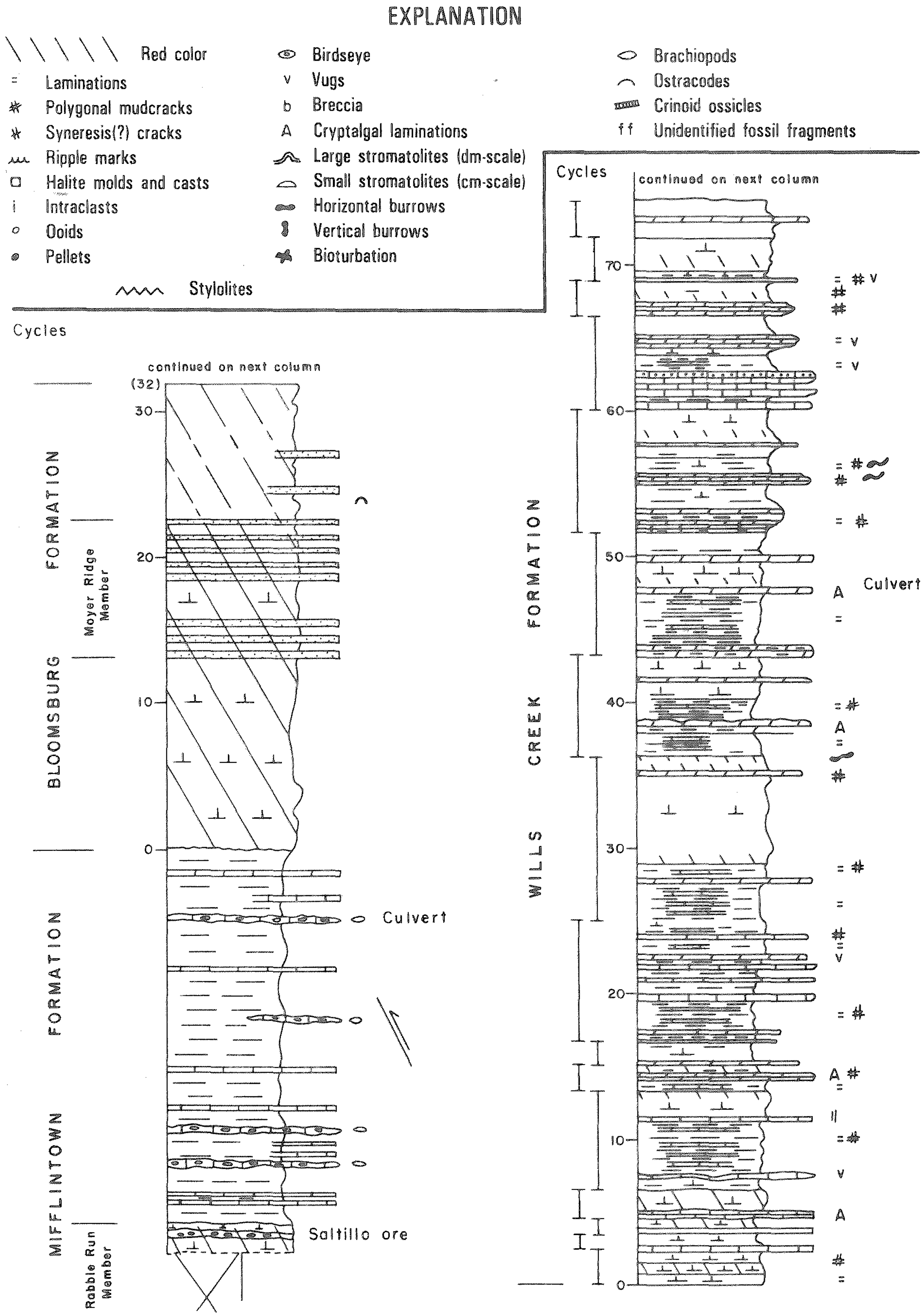


Figure 74. Stratigraphic column of upper Mifflintown, Bloomsburg, Wills Creek, Tonoloway, and lower Keyser Formations at Stop 6B.

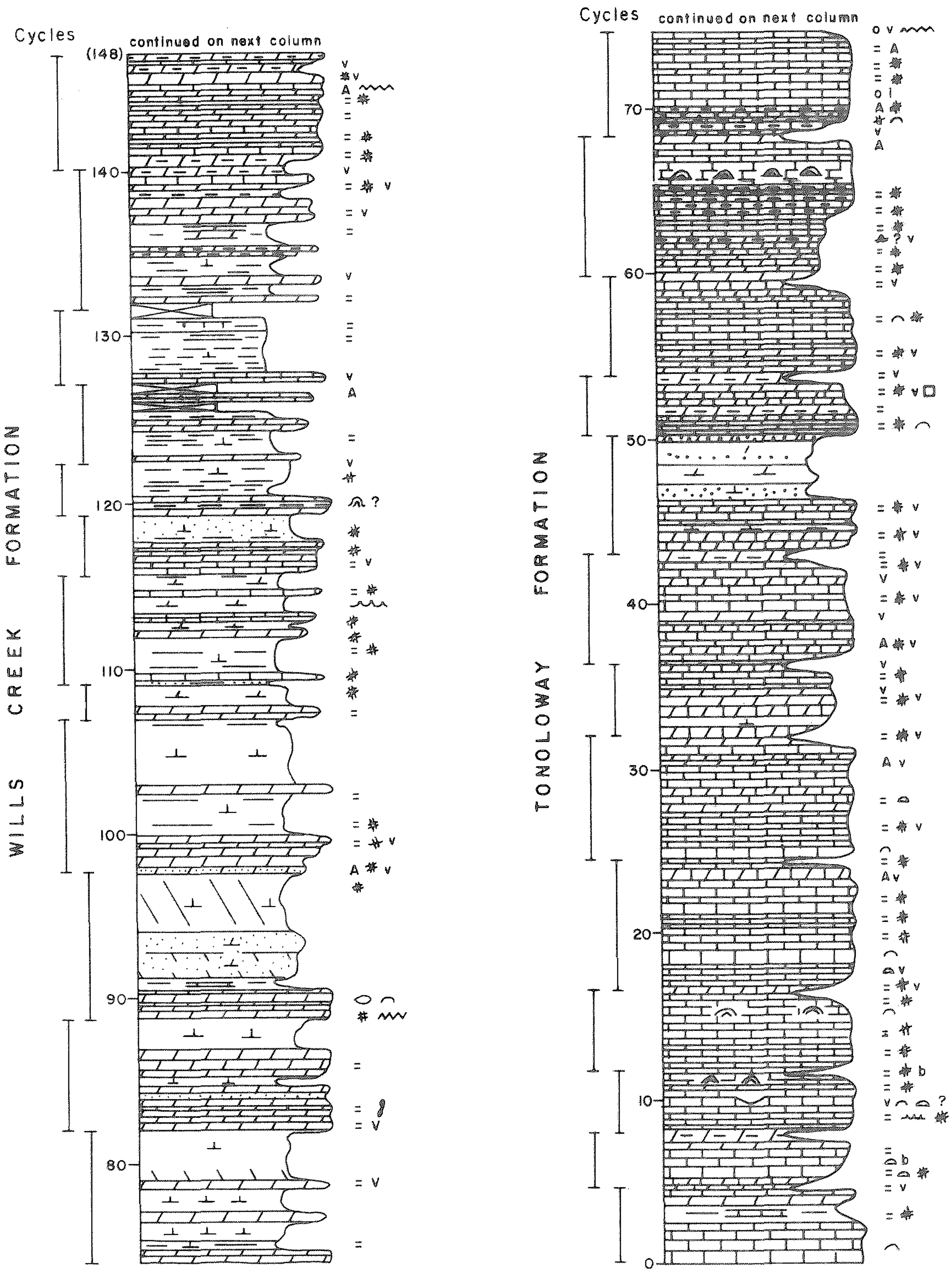


Figure 74. (continued)

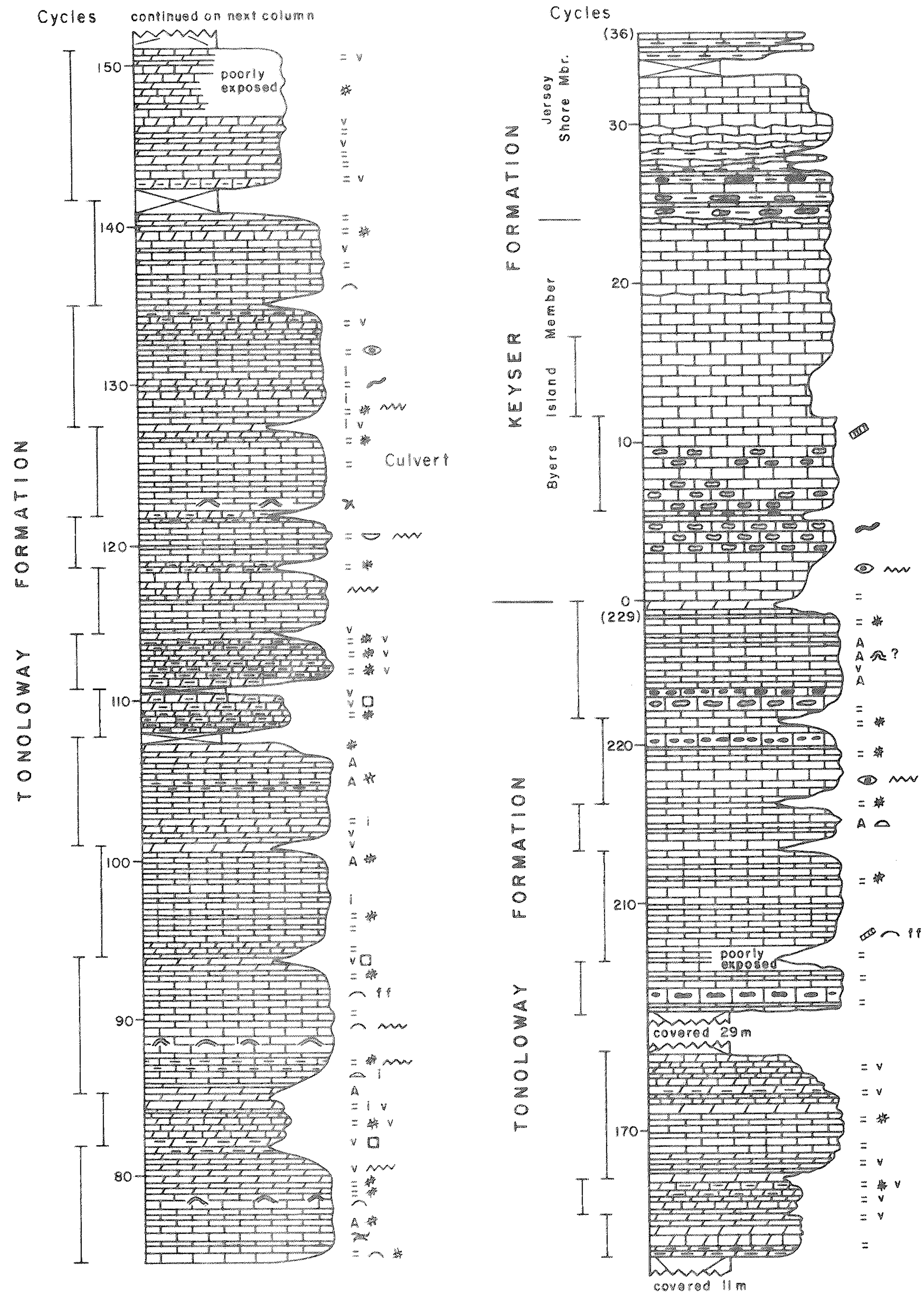


Figure 74. (continued)

top of the interval. The 2.5 m of slightly calcareous mudstone in the middle contains subspherical calcareous nodules, 1 to 2 cm in diameter. Such nodules are locally very common in the Bloomsburg of central Pennsylvania (Hoskins, 1961). They are similar to those found in other red bed successions (e.g. Catskill and Mauch Chunk Formations) and apparently owe their origin to soil-forming processes (Sevon, 1985).

Ostracodes are fairly common in 0.35 m of interlaminated medium-gray gray limestone and light-olive-gray, calcareous clay shale about 3 m from the top of member.

According to Hoskins (1961), the most significant faunal change in the Bloomsburg Formation occurs just below the Moyer Ridge Member. Most of the ostracodes found below the Moyer Ridge are not found above it (p. 107). This is evidently the basis for placing the Niagaran-Cayugan series boundary at approximately this position (Berg and others, 1983).

22.5 to 32 m

In the upper part of the Bloomsburg several thin light-olive-gray, fossiliferous (ostracodes), calcareous siltstone and clay shale intervals are intercalated in the dominant grayish-red, slightly calcareous mudstone. The uppermost 2 m, below the conformable contact with the overlying Wills Creek Formation, has a profusion of light-olive-gray mottles.

WILLS CREEK FORMATION

The Wills Creek is 148 m thick and 99 percent exposed along PA Route 103. F. Swartz (1934, 1955) measured a thickness of 140 m at Mount Union, apparently picking the same horizons as noted on Figure 74 as the top and bottom.

0 to 7 m

The lower few meters of the Wills Creek consists of interbedded yellow-brown weathered, cryptalgal-laminated micritic limestone and grayish-red to light-olive gray, mudcracked, calcareous mudstone that forms a transition zone with the underlying Bloomsburg Formation. These beds are organized into crude 2 m-thick cycles.

7 to 138 m

The bulk of the formation consists of cyclically interbedded yellow-brown weathered dolostone and dolomitic limestone; laminated, medium-dark-gray, light-olive-gray weathered, clay shale and micritic limestone; and massive, light-olive-gray to grayish-red, calcareous to dolomitic mudstone (see Figure 74). Red beds are absent from the upper 38 m of this interval.

The vuggy dolomitic beds at the base of the cycles are probably shallow subtidal to low-intertidal beds that have been dolomitized by reflux-solutions from the sabkha (Lucia, 1972). While several beds have a few horizontal burrows and many may contain ostracodes, the only fairly abundant fossils (ostracodes and rhynchonellid brachiopods) occur in the basal, oolitic carbonates of the cycle betweem 89 and 97.5 m. These beds are apparently the most marine in the formation and may correlate with marine limestone observed by Inners (in preparation) in the medial Wills Creek of the West Branch Susquehanna Valley, 110 km to the northeast. Subtidal micritic limestone and limy sandstone beds at 60 to 63 m correlate with identical beds exposed in the lower part of the Wills Creek at Mount Union. Cryptalgal laminites occur as yellowish-brown carbonate beds at 14, 37, 98, and 145 m. A few of these algal beds exhibit shallow polygonal mudcracks indicative of a low intertidal origin. Small stromatolites may be present in an interbedded micritic dolostone and clay shale interval at 120 m above the base.

Thinly laminated clay shale and limestone intervals in the middle of the cycles probably represent low to high intertidal deposition. These beds contain both complete polygonal mudcracks and incomplete, syneresis(?) cracks (e.g. at 98 m). The latter may not indicate subaerial desiccation, but rather either the contraction of clays in an aqueous, hypersaline environment (Burst, 1965) or small-scale fracturing of clay-rich sediments due to compaction or foundering (Plummer and Gostin, 1981).

The massive claystones at the top of the cycles formed on the supratidal evaporative flats (sabkha). Bedding in these units has been nearly destroyed by repeated periods of mudcracking and evaporite growth and resolution (Tourek, 1970). In some cases disruption of these beds is so complete that individual mudcrack polygons are not discernible. Tourek (1970) also speculates that portions of the massive beds may have been deposited as loess. The occurrence of well-rounded sand grains in this lithology as well as in discrete sandstone beds at other localities in the central Appalachians indicates that eolian deposition was locally important during accumulation of the Wills Creek sediments (DeWitt and Colton, 1964; Tourek, 1970; Inners, in preparation).

138 to 148 m

The uppermost part of the Wills Creek is predominantly laminated dolostone and dolomitic limestone that has a pronounced Tolonoway aspect. These beds apparently represent one full cycle and part of another one (see Figure 74). Like those in the Tonoloway the cycles are capped by vuggy, yellow-brown weathered dolomite that typically forms a deep recess in the cut. Because mud crack polygons are visible in nearly every bed, it appears that this portion of the formation is almost entirely high(?) intertidal to supratidal.

TONOLOWAY FORMATION

The Tonoloway is 229 m thick at the Allenport section, 81 percent of which is exposed. F. Swartz (1934, 1955) measured between 237 and 250 m at Mount Union.

0 to 174 m

The bulk of the formation consists of 3 to 8 m-thick sabkha-type cycles capped with vuggy, probably evaporite-bearing, dolostone (see Figure 74). Two of the best cycles are shown in Figures 75 and 76.

Diagnostic elements of each part of the typical Tonoloway cycle are given in Figure 16 (p. 33). The most notable features that relate to this cyclicity in the lower and middle portions of the formation are mentioned below.

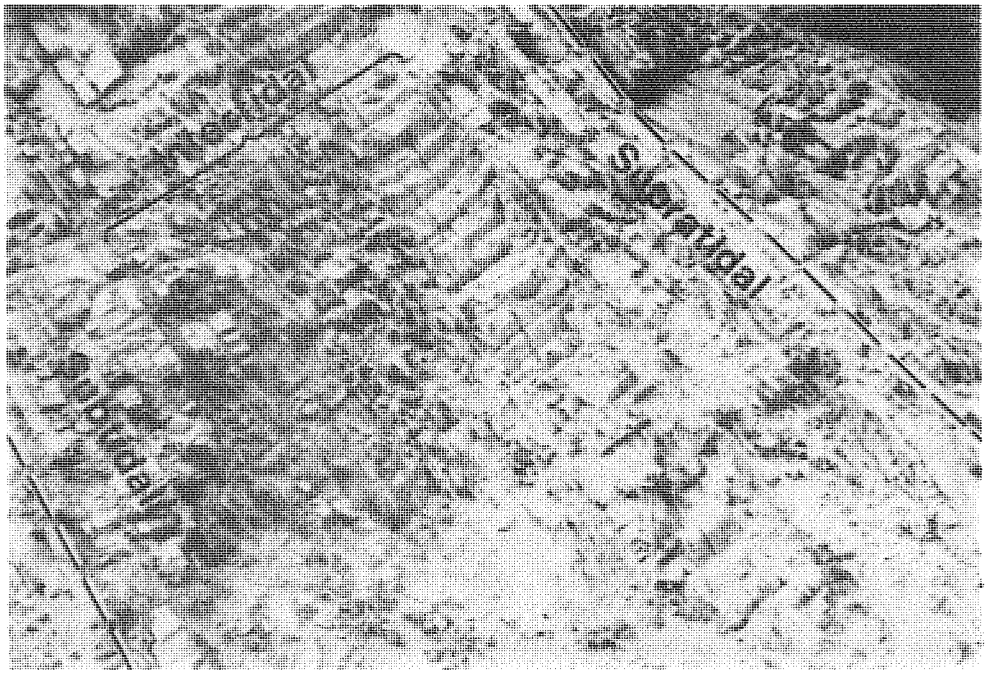


Figure 75. Cycle between 94 and 101 m in Tonoloway Formation. Note deep mudcracks in high-intertidal part of cycle.

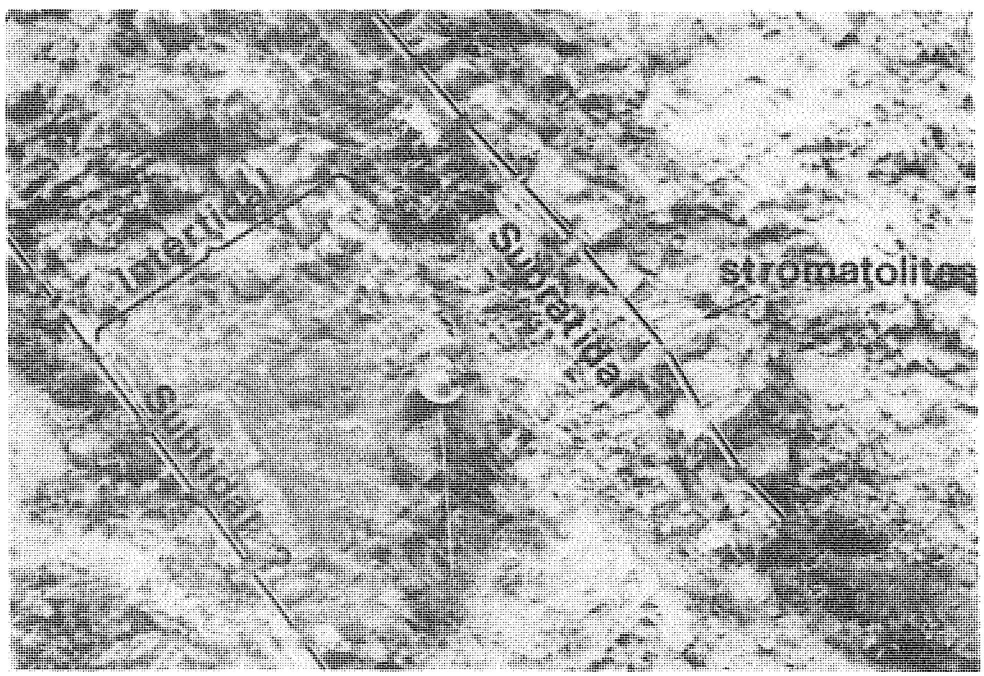


Figure 76. Cycle between 119 and 122 m in Tonoloway Formation. Note stromatolites in low-intertidal portion of overlying cycle.

SUBTIDAL. The most prominent marine bed occurs at the very base, where an ostracode calcarenite 1 m thick abruptly overlies thin bedded to laminated dolomitic limestone at the top of the Wills Creek. A similar calcarenite bed forms the base of the Tonoloway at Mount Union (see F. Swartz, 1934, 1955). Although both F. Swartz (1955) and Lacey (1961) noted abundant oolites in presumed basal subtidal limestones of many cycles at Mount Union (especially between 44 and 117 m), I observed oolites only in presumably subtidal calcarenites at 71 and 75 m. Anyone making a more rigorous investigation of this exposure, might find many more such beds. Subtidal intraclastic beds occur at 71, 98, 128, and 130 m. Syneresis (?) cracks are best seen at 45 m.

INTERTIDAL. Stromatolites of the lower intertidal zone are well exposed at 11, 15, 66, 79, 88.5, and 122.5 m. These are mostly isolated, domal, laminated hemispheroids 0.3 to 0.5 m in diameter and 0.1 to 0.2 m in height (Figure 77). Four such algal heads spaced 2 to 3 m apart on a single bedding plane are visible between the top and the bottom of the rock cut at 66 m. At least one head in this group has the club-shape characteristic of intertidal stromatolites at Shark Bay, Australia (Logan, 1961). Judging by the size of the structures and the lack of well-defined intermound clastic debris, average tidal range in this portion of the Tonoloway "lagoon" must have been quite low - probably on the order of 0.6 m or less (see Logan, 1961). In addition to the many large stromatolites, domed algal structures 2.5 to 5 cm in diameter and height are also common.

Polygonal mudcracks, particularly characteristic of the high intertidal zone, occur in profusion throughout this part of the Tonoloway section. In some cases the cracks extend 1.5 to 2 m vertically (see Figure 75), suggesting long periods of intense desiccation.

SUPRATIDAL. The vuggy, supratidal dolostones and dolomitic limestones almost invariably erode back to a deep recess on the cut, making identification of the cycles considerably easier. These beds have a distinctive yellow-brown weathering color that probably results from small percentages of iron in the dolomite crystal structure. Halite molds and casts 0.5 to 2 cm on a side occur in vuggy carbonate units at 53, 94, and 111 m. The profuse calcite-lined vugs in the dolomitic beds probably represent anhydrite nodules that formed early in diagensis of the sabkha sediments (Tourek, 1970, p. 60). Although no evaporite beds are known to occur at Allenport or nearby sections, a healed breccia bed at 11.5 m and a disturbed zone of mesoscopic folds at 83 to 85 m, both within the "sabkha" interval, strongly suggest (1) penecontemporaneous evaporite dissolution (see Tourek, 1970), and (2) stratal expansion upon recrystallization of anhydrite to gypsum, probably under relatively near surface conditions. Other beds that may initially have had a very high percentage of anhydrite or gypsum are at 54.5 and 59.5 m. (A 12 cm thick, almost open-work breccia bed from which evaporites may have been dissolved in the ground water zone occurs in the Tonoloway at Mount Union 25 m east of the culvert at Station 45+00 on U. S. Route 22-522).

203 to 229 m

Except for an 8 cm thick, massive, dense dolostone bed at the very top, the upper 26 m of the Tonoloway exposed at Allenport consists entirely of laminated to medium bedded, frequently mudcracked micritic limestone. Subtidal to high-intertidal(?) cycles are well developed, but no supratidal beds are present

Figure 77. Domal stromatolite at 88.5 m in Tonoloway Formation.

(with the possible exception of the non-vuggy dolostone at the top). Courses of concretionary dark-gray chert occur at 204, 221, and 223 m. At 222 m is a 1 m-thick bed of nodular, Keyser-like limestone. The uppermost Tonoloway contrasts sharply with the dolomitic beds exposed below the covered interval and probably originated in a more distal portion of the tidal flat complex.

KEYSER FORMATION

Only the lower 36 m of the Keyser Formation crops out here. Total thickness of the formation in the area is approximately 48 m (Reeside, 1918; Swartz, 1934, 1955).

0-24 m above base (Byers Island Member)

The Byers Island consists of three main divisions. At the base are 3 m of very thin to medium bedded, medium-dark-gray, stylolitic, micritic limestone containing abundant calcite "birdseyes". These beds apparently correlate with the high-calcium "calico rock" of the Altoona-Hollidaysburg area (Butts, 1945). The middle portion (3-9.5 m) is nodular, argillaceous, fossiliferous, micritic limestone typical of the member throughout central Pennsylvania. The upper

14.5 m consists of medium- to thick-bedded, fossiliferous, in part bioskeletal, micritic limestone that contains 2 or 3 coarsening-upward sequences (PACs ?) 3 to 5 m thick.

Head (1969) interprets the diagnostic nodular bedding of the Byers Island as sedimentary boudinage. He notes that the nodules are somewhat "cleaner" and more bioclastic than the surrounding argillaceous, micritic matrix. Prior to disruption of the original bedding, these nodular units consisted of interbedded argillaceous to very argillaceous, biomicrites and non-argillaceous biomicrites. Compaction subsequent to deposition caused vertical compression, and sedimentary boudinage was initiated because of the higher plasticity of the argillaceous beds (Head, 1969 p. 124).

Identifiable invertebrate fossils are not particularly abundant in the Byers Island. Approximately 2 m above the base of the typical nodular beds is a thin band of micritic limestone containing many rhynchonellid brachiopods, all apparently of the same genus (Cupulorostrum or Machaeraria). The only other fossils observed by the author were ostracodes and fragmental crinoid columnals. A few vermiform burrows up to 1 cm long occur in the nodular beds between 3 and 6 m above the base.

Above 24 m (Jersey Shore Member)

The exposed portion of the Jersey Shore Member of approximately 12 m of thin to medium bedded, micritic to bioskeletal limestone and calcareous clay shale. Shale interbeds occur in the lower 4.5 m and upper 2 m, but are absent in the medial part. The lower shaly beds contain discrete biomicrite lenses to 5 cm in thickness and 10 cm in length.

Although the portion of the Jersey Shore exposed along PA Route 103 is quite fossiliferous (brachiopods, crinoid ossicles, etc.), few forms can be readily identified. On the back side of the ridge, however, along the power line 200 m south-southwest of the road, silicified atrypid brachiopods ("Atrypa" reticularis), rugose and tabulate corals, and small stromatoporoids weather out of sparsely bioclastic micrite that lies near the top of the member. Many of the brachiopods specimens exhibit the diagnostic "upright" spiralia of atrypids.

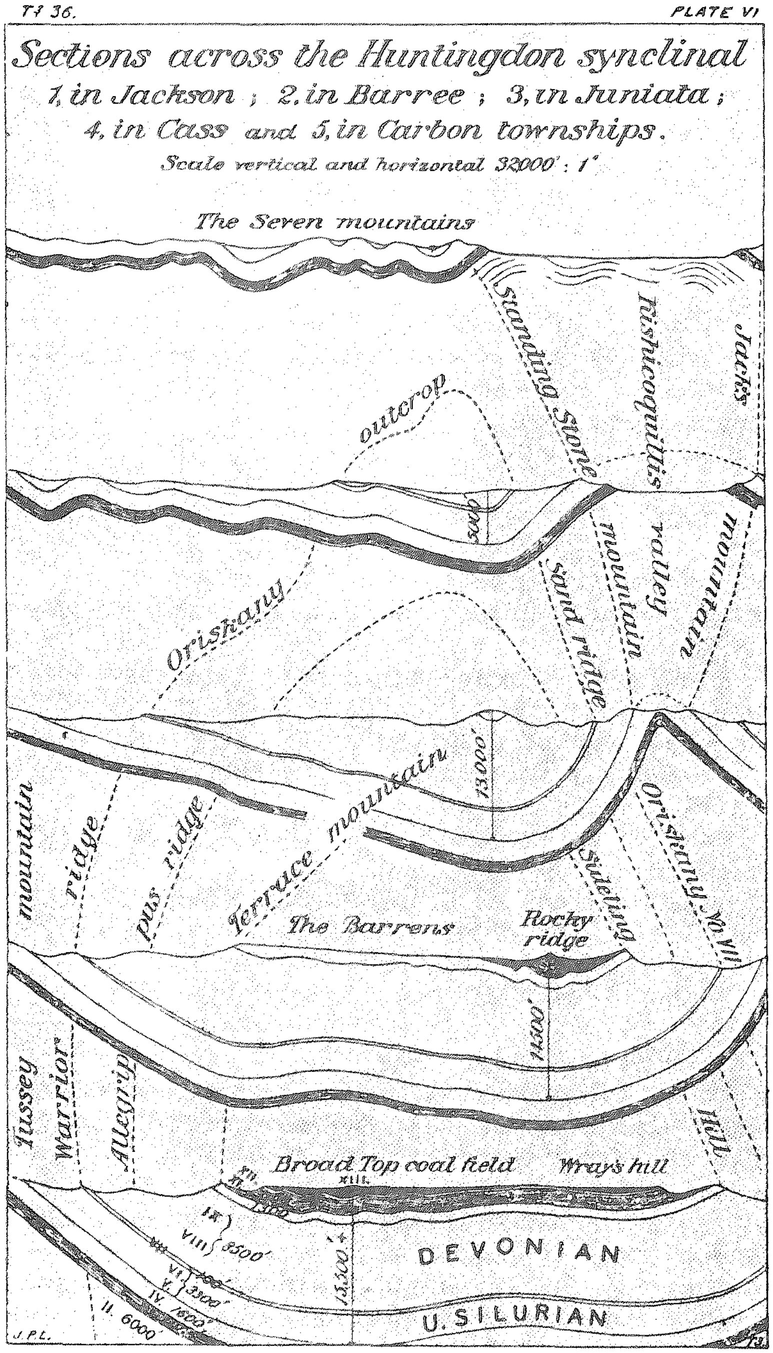
		LEAVE STOP 6-B. PROCEED STRAIGHT AHEAD on PA Route 103 South.
0.5	95.0	End of Allenport section.
0.5	95.5	Bridge over Aughwick Creek. Ahead is a terrace bar complex built by interaction of Aughwick Creek and the Juniata River.
2.4	97.9	STOP SIGN. TURN RIGHT onto US Route 522 North in Allenport.
1.2	99.1	TURN RIGHT AT SECOND STOP LIGHT in Mount Union following US Route 522 North. Mount Union is built on a series of 4 Juniata River terraces and the river floodplain.
0.6	99.7	Cross bridge over the Juniata River. Exposures to right ahead are in Bloomsburg and Wills Creek Formations.
0.2	99.9	STOP LIGHT. TURN LEFT onto US 22 West.
0.5	100.4	Huntingdon County line.
1.9	102.3	PA Route 655 South to Mapleton on left. Route 655 North.
1.8	104.1	View ahead on right of steeply dipping Oriskany sandstone in Pennsylvania Glass Sand quarry as pass over bridge.
0.2	104.3	PA Route 655 South on left. A high fluvial terrace remnant about 180 feet above the river, now blanketed and churned into over-

lying colluvium from Jack's Mountain, occurs in a bank exposure ahead to the right.

5.6 109.9 Brallier-Chemung outcrop on right.

0.3 110.2 Brallier-Chemung outcrop along exit road to right at curve to left before bridge over Juniata River. Excellent outcrop also along railroad below road level.

1.0 111.2 **TURN RIGHT** into parking lot of Raystown Country Inn. **END OF DAY 1 TRIP!! SEE YOU AT THE BANQUET!!**



Sections across the Huntingdon synclinal, from White, 1885, p. 36.

ROAD LOG - DAY 2

Mileage Inc	Mileage Cum	
0.0	0.0	START. Leave back parking lot of Raystown Country Inn, Huntingdon, PA. TURN RIGHT onto US Route 22 West.
0.7	0.7	Site of Stop 3, Day 1.
0.8	1.5	BEAR RIGHT to PA Route 26.
0.2	1.7	STOP SIGN. TURN RIGHT onto PA Route 26 South.
2.2	3.9	Kaktins house on right (Day 1, Mileage 32.5).
3.8	5.5	New Enterprise quarries (Day 1, Mileage 34.2).
2.6	8.1	Road on left to Seven Points Recreation Area.
2.8	10.9	St. Mathews Lutheran Church on left was built in 1838. Oldest monuments dated 1843 and 1845.
2.0	12.9	Zion Reformed Church on left was built in 1847 and rebuilt in 1887.
1.0	13.9	Historical marker for Shultz cemetary on right. Oldest monument dated 1830.
2.0	15.9	PA Route 994 on left.
4.4	20.3	Note crest of Tussey Mountain ahead on right. Very irregular crest line results from deeper weathering and erosion at zones of structural weakness.
0.7	21.0	Bedford County line.
0.8	21.8	PA Route 164 on right.
0.4	22.2	Historical marker for Phillips Rangers on left. Road to memorial on right. Ten men were killed by Indians near here on July 16, 1780. Captain Phillips and his son were held prisoner until the end of the Revolution.
3.0	25.2	Henrietta Mountain Road on right at start of curve at Homans Corner.
0.1	25.3	TURN RIGHT onto unnamed paved road just past Sport Shop on left and road guard on right. Warrior Ridge is now on the right and is the east limb of a southward plunging anticline. Tussey Mountain split away by folding and is farther west. Outcrops ahead are of Hamilton Group shales.
1.1	26.4	Note boulder colluvium derived from Tuscarora Formation on Warrior Ridge occurs on right and left.
0.8	27.2	Low ridge on right is Oriskany sandstone.
0.1	27.3	Ravers Gap to the right. Note coarse alluvium in stream bed.
0.3	27.7	Good view ahead of landscape of area.
2.8	30.5	STOP SIGN. TURN RIGHT onto PA Route 26 South. Buses need to swing wide.
1.0	31.5	Cross end of Oriskany ridge.
0.4	31.9	Road to left leads to St. Pauls Reformed Church which was built in 1885. Cemetary has many monuments dating back to the early decades of 1800 with the oldest dated 1812.
0.2	32.1	View to left of St. Pauls church and cemetary.
0.4	32.5	Road to left crosses Yellow Creek along which the original First Survey traverse was made.
0.1	32.6	Note outcrops on left along Yellow Creek. These rocks were presumably examined by Frazer.
1.1	33.7	TURN RIGHT onto PA Route 36 to Loysburg.
2.0	35.7	Excellent exposures of scree derived from the Tuscarora Formation on both sides of Loysburg Gap.

0.8 36.5 STOP 7. LOYSBURG GAP.

Large pull-off at west end of outcrop for bus parking and turn around. Broad valley to west is Morrison Cove, a breached anticlinal valley. Buses will move to old road on south side of road for onloading.

DISCUSSANT: ALLAN M. THOMPSON

This outcrop exposes Upper Ordovician clastic rocks in the notch through Tussey Mountain called Loysburg Gap, carved by Yellow Creek, Hopewell 7.5' quadrangle, Bedford County. The outcrops are primarily road cuts along the north side of PA Route 36.

The purposes of this stop are:

1. To examine a regressive, marine-to-continental transition;
2. To infer depositional environments of clastic sedimentary rocks based on lithologies, fossils, and primary sedimentary structures;
3. To examine different methods of defining stratigraphic units.

AREAS

Rocks at this location are exposed in 3 distinct AREAS, which are numbered west to east on the location map (Figure TA). Area 1 comprises roadcut exposures along PA Route 36 across from the parking area. Area 2 comprises limited exposures along the highway 200 m east of Area 1. Area 3 includes outcrops along the VERY DANGEROUS blind curve 100 m east of Area 2.

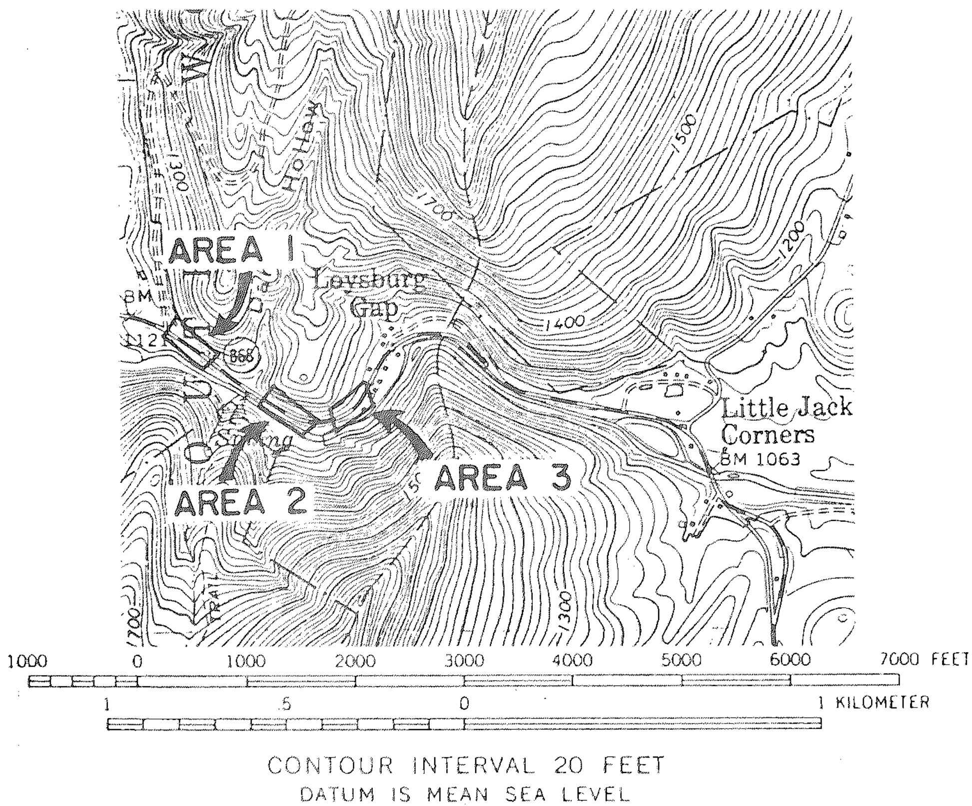


Figure 78. Location map of the Loysburg Gap area, showing positions of outcrop Areas 1, 2, and 3.

PROCEDURE

The story here is best deciphered by noting the changes in the rocks that occur up-section. The optimal format is thus a self-paced walk east along the outcrop. For your positional convenience, the outcrop is measured along the highway; the zero point is the intersection of the ground surface with the major coquina bed at the top of the Reedsville Formation. Negative distances are west, positive distances are east from zero. These are road distances, not stratigraphic distances.

As you work you way along the outcrop, you should pay attention to these points:

1. The amount of matrix in the sandstones;
2. The amounts and distribution of shales relative to sandstones;
3. The types of primary sedimentary structures, their mutual associations, and their relation to types of sandstones;
4. The implications of those primary structures for depth of water, flow, regime, current strength, directions and constancy of flow;
5. Traction or suspension deposition;
6. Organization of beds and bedding types into systematic vertical sequences;
7. Types of trace fossils, and their environmental implications.

STRUCTURAL GEOLOGY

The rocks strike 010 and dip 50 SE on the east side of the Morrisons Cove anticline. Features associated with flexural-slip folding are common, including small drag or kink folds as well as bedding-plane slip surfaces. These structures often inhabit grassy areas of poor exposure in Area 1, and are indicated on the columnar sections. Slickensided surfaces both parallel to and across bedding are common. Incipient wedge thrusts indicate the possibility of layer-parallel shortening prior to major folding, but offset is difficult to detect.

The rocks contain no penetrative fabric elements. A nearly vertical, presumably axial-planar cleavage is barely visible in the shales. A southwest-dipping parting or spaced cleavage, apparently normal to bedding, affects the mudstones and some siltstones, giving a blocky-splitting character. This spaced cleavage is not parallel to axial plane orientations of either major or minor folds, and its origin is not well understood. Burrow structures in sandstones of Areas 1 and 3 were presumably originally normal to bedding, and may have been rotated slightly in the direction of bedding-plane slip.

Look for these structural features:

1. Cleavage, and its origins;
2. Fault and slickenside orientations;
3. Evidence of layer-parallel shortening;
4. Relations of minor to major structures.

SEDIMENTARY ROCKS

AREA 1

Figure 79 is a columnar section of the rocks exposed at Area 1. Figure 80 is a key to the symbols used in Figures 79, 81, and 82.

The rocks in Area 1 expose the transition from marine to continental deposition, and give an excellent exercise in interpretation of primary sedimentary structures. Skeletal fossils have not been found above +9 m (as of 1986). The average grain size increases steadily up-section; the rocks here are predominantly sandy, although the mud is strategically located.

The marine rocks constitute the Reedsville Formation (Lithofacies B, p. 22); the continental rocks comprise the lower Bald Eagle Formation (Lithofacies C, p. 24).

REEDSVILLE FORMATION

The uppermost 22 m of the Reedsville Formation are exposed at the west end of the outcrop. The rocks are bioturbated, fine-grained quartz wackes with abundant small skeletal fossils and fossil fragments. Gastropods, Lingula, Orthorhynchula, crinoids, and pelecypod taxa are scattered through the rocks, and are concentrated into brown-weathering coquina layers and lenses (e.g., -6 m, -0.5 m). Intense bioturbation has destroyed all but the largest-scale bedding, and the coquinas are lensoid and discontinuous (e.g., -4 m). The coquinas rest on scoured surfaces, and are themselves eroded. Chalcedonic, oncolitic structures of possible algal origin are exposed at STATION 1 (-12 m).

The contact with the Bald Eagle is gradational by interbedding of contrasting lithologies, and may be placed at several points depending on the criteria selected. I have placed the contact at the top of the major coquina, the base of the dominantly unfossiliferous section (STATION 2: 0 m). The Reedsville contains two thin, clean quartz arenites typical of overlying Bald Eagle sandstones, and several fossiliferous Reedsville-like lithologies occur above that level (although they are nearly covered by grass in the structurally disturbed zone near the spring).

BALD EAGLE FORMATION

The rest of Area 1 exposes the lower Bald Eagle Formation, the Centennial School Member of Swartz (1955), Lithofacies C in its entirety. Most of the sedimentologic diversity and lithologic successions is generated by the recurrence of 4 distinct rock types:

1. Olive-gray to black shale/mudstone and siltstone; unfossiliferous, possibly bioturabated, and generally devoid of internal primary sedimentary structures;
2. Olive-gray to greenish gray, fine-grained quartz wacke sandstone, with well-sorted grain fraction but significant matrix;
3. Medium to light gray and occasionally bluish-gray, fine- to medium-grained quartz arenite; well sorted with little to no matrix;
4. Red-gray to maroon mudstone and siltstone, with fine-grained lithic arenite to wacke sandstones.

Each of these lithologies anchors a sedimentologic association in the outcrop. These are numbered 1 through 4, and are indicated in Figure 79.

ASSOCIATION 1. This association consists of thinly interbedded black shale and minor olive-gray quartz wacke. Sandstone beds average 2 to 4 cm thick, and contain ripple-generated bedding structures, including individual mud-draped

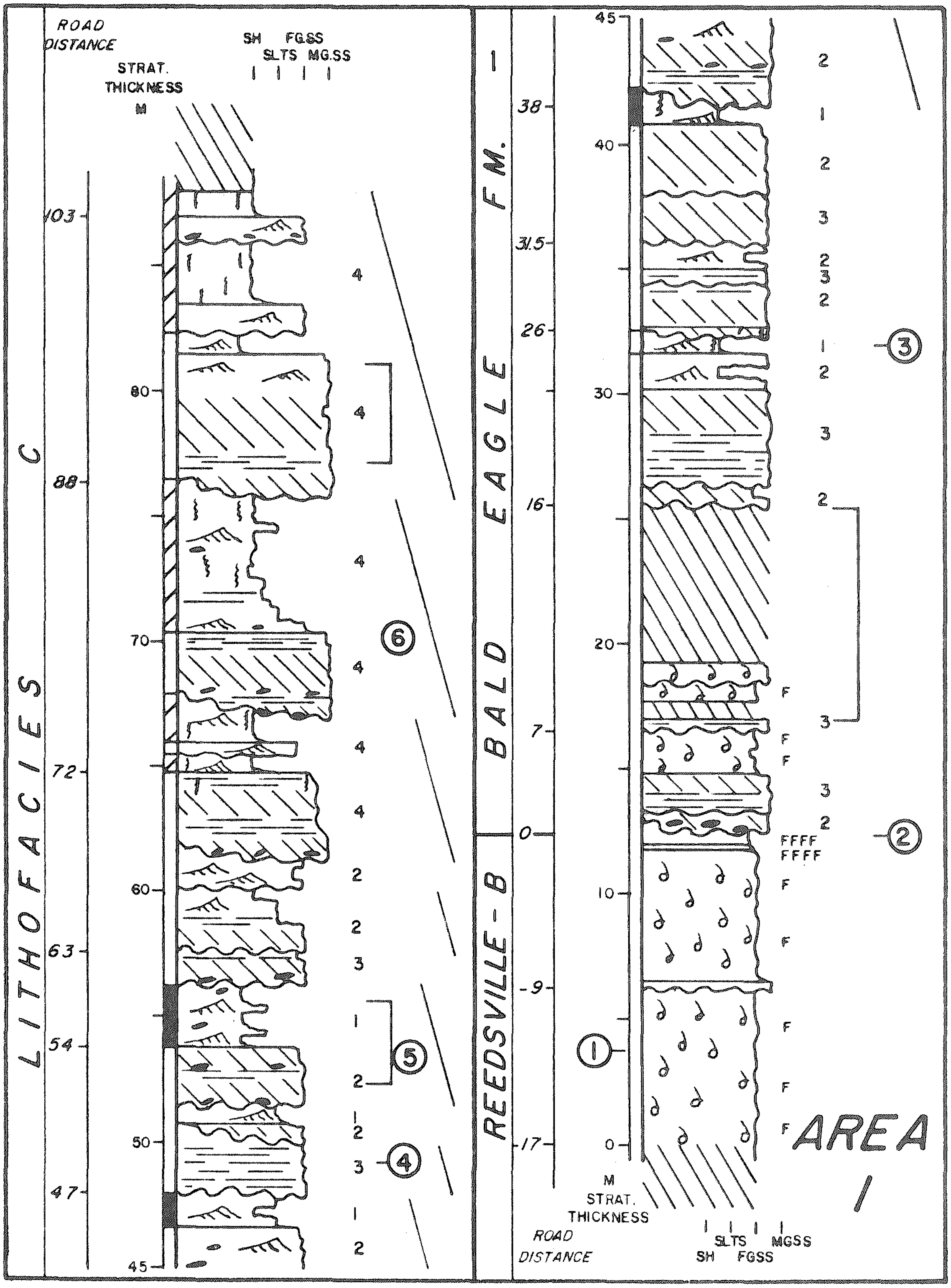


Figure 79. Columnar section for Area 1, Loysburg Gap. See Figure 80 for key to symbols.

ripple trains (STATION 3, +24 m and +47 m). Small-scale trough crossbedding is abundant, and grades into ripple-bedding and parallel lamination. Foreset azimuths are often nearly bipolar, suggesting reversing currents (e.g., +55 m). Intrabed erosion surfaces suggestive of reactivation surfaces occur. Bases of sandstones are frequently load-casted down into mudstones. The mudstones are nearly structureless, but may be burrowed (+24 m) and possibly bioturbated (+38 m).

In examining Association 1, pay attention to:

1. Ripple structures and ripple-generated bedding;
2. Evidence for subaerial exposure of mudstone beds;
3. Evidence for trace-fossil activity and/or bioturbation;
4. Skeletal fossils.

ASSOCIATION 2. This association consists of olive-gray quartz wacke in thin to thick beds, with minor shale. These sandstones comprise thicker beds than Association-1 sandstones, reaching 50 to 100 cm (at +41 m and +63 m). They are large-scale crossbedded, with occasional planar-base and common trough-base cosets. Both NW and SE transport directions are indicated, and bipolar, herringbone cross-strata are present (+42 m). Crossbed sets and cosets are typically topped abruptly by thin (mm-thick) clay drapes (+63 m and +68 m), indicating rapid declines in current strength. Low-angle channel cut-and-fill struc-

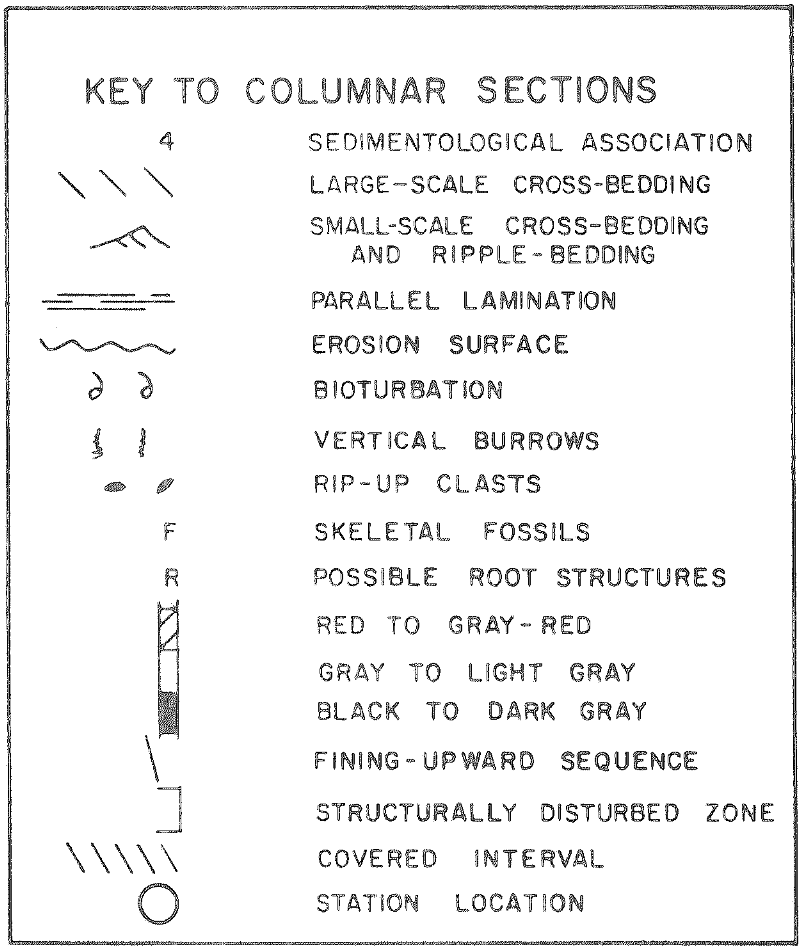


Figure 80. Key to columnar sections for Loysburg Gap.

tures are common. Small-scale crossbedding and ripple-bedding are frequent also.

Association 2 lithologies are organized into sequences up to 3 m thick. Lower parts are large-scale crossbedded, with rip-up clast conglomerates in the basal cosets. Higher parts are small-scale trough crossbedded and ripple-bedded in thinner cosets, and contain more shale beds. A good example is seen at +38 to +47 m.

Association 2 sequences grade upward into Association 1 by upward increase in shale abundance. An example is shown at STATION 5, beginning at +51 m. These combined sequences reflect steadily declining current velocities, and suggest deposition in shallowing channel/point-bar arrays.

In Association 2, look for:

1. Clay drapes on sandstone beds;
2. Vertical organization of bedding and lithology;
3. Scour surfaces truncating bedding below, and overlying rip-up-clast layers;
4. Evidence for reversing or undirectional current flow.

ASSOCIATION 3. This association consists of light gray to white or bluish-gray quartz arenite, with little to no interbedded shale. Sandstones are fine to medium grained, clean, and well sorted.

Two types of primary structures dominate these sandstones. Most dramatic is widespread parallel lamination, in "sets" averaging 50 cm thick (STATION 4, at +48 m; also at +2 m, +19 m, and +30 m). Parting lineation, primary current lineation, and current-crescent casts characterize bedding planes in parallel-laminated zones. These sequences are erosionally interbedded with other rocks.

The remaining rocks of Association 3 are trough crossbedded, in cosets reaching 2 m thick (at +32 m and +62 m). Some foresets are undulatory and may resemble hummocky bedding or reactivation surfaces. Foresets consistently dip W or NW, indicating essentially unidirectional flow. Bases of crossbedded sequences cut erosionally downward into underlying rocks. Clay drapes are not noted in Association 3.

In Association 3, look for these features:

1. Bedding types, and associated bedding-plane features;
2. Evidence for depth of water, either direct or indirect;
3. Evidence for unidirectional or reversing current flow;
4. Fossils and/or trace fossils;
5. Relation of parallel-laminated sandstones to other associations.

ASSOCIATION 4. This association consists of gray to red-gray, medium-grained lithic arenite and red-gray siltstone and shale, in sequences reaching 10 m thick. The sandstones are large-scale crossbedded and are scoured downward into underlying rocks with rip-up clast conglomerates above the erosion surfaces. These are often "spotted" with brown-weathering micro-concretions of diagenetic ankerite. They lack clay drapes and bidirectional crossbeds.

The siltstones and mudstones are dark red, wavy- and flaser-bedded (at +73 m and +84 m), and contain small calcareous concretions and tubular burrow structures normal to bedding. Small, irregular clay-lined septae transverse to bedding (+100 m) resemble root structures in younger rocks and may indicate the presence of paleosols.

The rocks are organized into fining-upward cycles in which bed thickness, average grain size, and size of primary structures all decrease upward. The best-developed cycle occurs at STATION 6 (beginning at +74 m and proceeding 9.8 stratigraphic m to the east). The lowest rocks are channeled and trough cross-bedded sandstones. These are succeeded upward by small-scale crossbedded, fine-grained sandstones, and those by red siltstones and mudstones. The upward sequence suggests declining current velocities, and is consistent with models of deposition on shallowing channel-point bar arrays traversing a region above sea level, where wetting of overbank deposits was intermittent enough to permit oxidation of iron compounds to generate red beds.

In Association 3, look for the following:

1. Vertical facies organization and upward fining;
2. Evidence for subaerial exposure, specifically mud cracks and soil development;
3. Burrows and bioturbation.

INTERPRETATION

The data you have collected so far provide the basis for your interpretation of depositional environments. A number of reasonable interpretations is possible and the one presented here is no more inherently correct than any other; it is based on a regional integration of about 25 measured sections. Use this model as one to shoot at, to alter as your data dictate.

The possible environments of deposition are constrained by the presence of fossils below and red beds above. The disappearance of fossils must be compatible with any model accepted. In the absence of incontrovertible evidence to the contrary, the presence of red beds is taken to indicate nonmarine conditions. Remember also that it is Late Ordovician time; land plants are theoretically not present (but see Area 3 below), and the sedimentological effects of macerated and comminuted plant debris, acting as sediment-binding agents, are absent.

Association-1 and -2 rocks are interpreted together, because of their gradational nature and relationship in sequences. They are interpreted to represent channel (Association 2) and overbank/tidal flat (Association 1) deposition in coastal creeks traversing a broad sandy intertidal zone. Reversing flow in the channels generated bidirectional cross-strata and reactivation surfaces. Lower flow velocities higher on the point bars and on the interchannel flats generated smaller-scale sand waves and ripple trains. Mud deposition from slack-tide water created thin drapes over all bedforms in both channels and flats.

The key to understanding Association-3 rocks is the correct interpretation of the parallel-laminated sandstones. Parallel lamination in sandstones generally requires upper-flow-regime conditions, with relatively high flow velocity and shallow depth, or both. Possible common environments where these conditions are realized include swash zones of beach foreshores, and zones of accelerated flow over the tops of shallow sand bars. Paleocurrent azimuths in these sandstones are consistently to the W and NW. In addition, the local hydrodynamics prevented mud from being deposited, even though the associated rocks indicate that it was clearly in the water mass and available for deposition. Finally, to date no skeletal fossils have been found in Association 3 sandstones.

These constraints are most consistent with unidirectional flow over thin sand bars in shallow, possibly braided distributary channels feeding an open shelf (see Figure 12, p. 25). In the absence of plant material, these channels may have been wide and shallow, with many bars both exposed and subaqueous. The result was a sheet sand composed of many distributary mouth bar sandstones. The ripple-bedded channel/flat sequences of Associations 2 and 1 represent tidal-zone creeks that traversed the interdistributary sandy coastal flats; occasional shallow bays allowed for considerable mud deposition. The distributary sheets sands and coastal flats graded seaward into brackish marine bays and open shelf colonized by skeletal organisms and bioturbated by infaunal elements. The rocks of Association 4 are interpreted to represent nonmarine channel and overbank deposition in shallow distributary rivers on a nearshore coastal plain complex. Landward from the distributaries overbank deposition on the subaerial delta plain led to red-bed formation in muds that spent prolonged times above the water table.

AREA 2

Area 2 comprises roadcut exposures beginning +289 m east of zero (Figure 78), and exposes 47 m of coarse-grained lithic arenite and lithic wacke of the Spring Mount Member of the Bald Eagle Formation and the East Waterford Member of the Juniata Formation (Swartz, 1955). Together these make up the middle portions of Lithofacies D. The columnar section is given in Figure 81.

The relations between rock color and sedimentologic properties are well demonstrated in this exposure. The gray-red color transition that marks the traditional Bald Eagle-Juniata formation boundary is exposed at STATION 7 (+300 m). Here the color change in sandstones occurs over a 2-m interval, from gray green (typically 5Y6/1, 5GY5/2 to 10Y4/1) through neutral dark gray (N3 and N4) to dull red-gray (5YR6/1, 5R4/2 to 10R4/2). Here the change broadly coincides with the base of a channel-filling sandstone, but that is not true everywhere; the color change is usually irrespective of primary sedimentologic boundaries.

Rock color is variable through a zone about 35 stratigraphic m thick above the formation boundary. Above +300 m the color of sandstones is predominantly red, although there are several gray zones in the next 30 m, notably at +303 m where the color changes occur over an interval 1 to 2 cm thick. The colors of siltstones and mudstones in this variable interval are unpredictable and not consistently related to neighboring sandstone color.

Now compare the sedimentologic properties of red and gray sandstones and note the similarities. They show no discernible petrographic or sedimentologic differences and are not consistently separable locally or regionally. Both are medium- and coarse-grained, and both have the same grain composition. Both contain large-scale trough crossbedding, with set thickness often exceeding 1 m (290 m, +338 m). Both contain rip-up clasts at the bases of sets (+303 m and elsewhere); clast colors generally, but not always, match host sandstone colors. Paleocurrent azimuths are the same within the error, to the NW with considerable

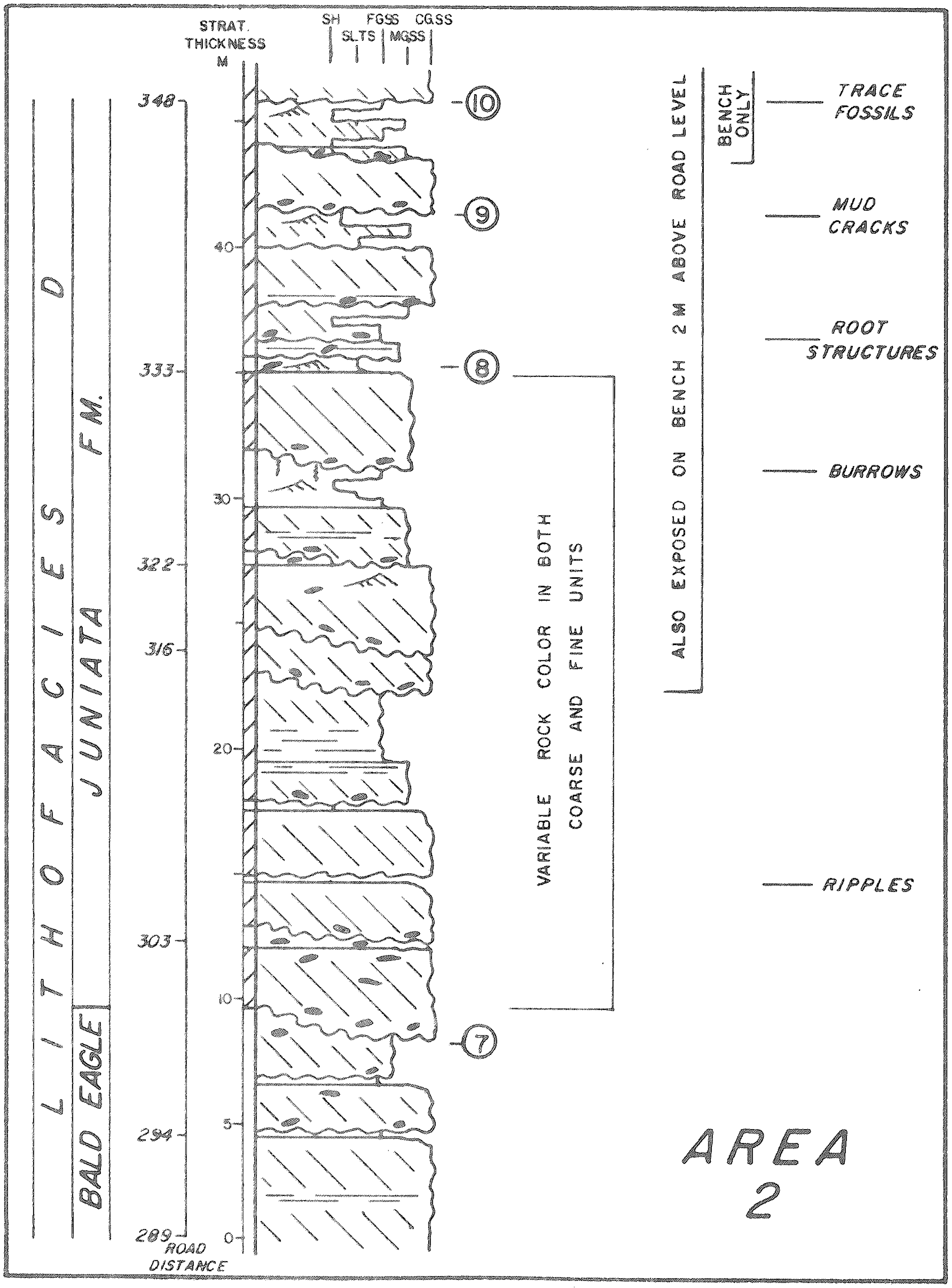


Figure 81. Columnar section for Area 2, Loysburg Gap. See Figure 80 for key to symbols.

scatter. Low-angle channel structures are common in both (+303 m, +320 m). Parallel-laminated sandstones are frequent (+294 m).

Siltstone and mudstone beds are rare but significant in both gray and red rocks, and are irregularly distributed. They comprise less than 3 percent of the section, are less than 1 m thick, and usually are less than 10 cm thick. They are usually lenticular, and often pinch out within the outcrop. They are often highly distorted by load-casting of overlying sandstones, and may be seen in the process of giving birth to rip-up clasts (+303 m). They are bounded below and above by erosion surfaces; they were probably deposited from low-velocity to standing water that immediately followed high-velocity, erosive currents. The siltstones are ripple-bedded to wavy-bedded, and may contain burrows and bioturbation. They may be red or gray, and need not match the color of the surrounding rocks.

At STATION 8 (+338 m) the mudstones contain questionable rootlet structures. At STATION 9 on the elevated bench (+343 m) the mudstone-sandstone contact contains mud cracks. These data suggest that the mudstones accumulated above sea level, and were able to dry out periodically. At STATION 10 large mining-type trace fossils inhabit a sandstone-mudstone contact. This suggests that critters were making a living extracting organic nutrients from the muds, which were therefore not barren of organic material.

An example of the relation between sedimentology and color boundary is afforded by the Morrisons Cove anticline. Here on Tussey Mountain the combined thickness of gray (Bald Eagle Formation, 135 m) and red (Juniata Formation, 61 m) portions of Lithofacies D is 196 m. In contrast, on Dunning Mountain 8 km to the west (visible through the gap), Lithofacies D is at least 169 m thick (top not exposed); all 169 m and the top 14 m of underlying Lithofacies C are red. While Lithofacies D thickness has changed little, the position of the color change has dropped 149 m. This behavior typifies the irregular and unpredictable nature of the relation between stratigraphy and this color boundary throughout central Pennsylvania. Details are given by Thompson (1970).

Lithofacies D grades upward into Lithofacies E by increase in both thickness and relative abundance of mudstone beds.

In Area 2, look for these features:

1. Evidence that rock colors are primary and depositional;
2. Evidence that one or both rock colors are secondary;
3. Which came first, the gray or the red?
4. Evidence that rock color is genetically correlated with bedding structures;
5. Evidence for velocity fluctuations in water flow.

INTERPRETATION

Again, there are probably several reasonable models for the origin of the rocks of Lithofacies D. One is offered here. Take potshots at it, and point out where it is wrong.

The proposed model tries to account for the great predominance of sand over finer sediment, the great pedominance of trough cross-bedding over other bedforms, the unidirectional nature of the paleocurrent azimuths, the peculiar distribution and rarity of the siltstone/mudstone beds, and the evidence for subaerial exposure. It tries to ignore rock colors as environmental indicators, for reasons given above.

The above constraints are most compatible with deposition of these rocks as bars in a complex of low-sinuosity, braided rivers that flowed NW down a fairly steep regional paleoslope. The sandstones represent subaqueous channel and channel-margin bars that grew downstream and laterally. High flow velocities, or lack of binder in the fine fraction, or both, contributed to noncohesiveness and easy erodibility of bank sediment, and a resulting anastomosing channel pattern that spread over wide areas. Consistently high flow velocities prevented deposition of significant amounts of fine sediment. Rapid channel avulsion led to temporary ponding of water in abandoned anabranches and deposition of small amounts of fine sediment. Reoccupation of those channels led to erosion and rapid covering of fine sediment by new migrating sand bars.

The alluvial plain thus generated was distal to the fan complex that probably developed near the orogenic front to the east and southeast. It graded downslope into low-gradient, high-sinuosity alluvial plains represented by the cyclic deposits of Lithofacies C. The inferred paleogeography is shown diagrammatically in Figure 12 (p. 25).

AREA 3

Area 3 comprises roadcut outcrops on the west side of PA Route 36 on the blind side of the cure, beginning +441 m east of zero (Figure 78). The columnar section is given in Figure 82.

CLEAR AND PRESENT DANGER - This is a BLIND CURVE, with high-speed truck traffic approaching UNSEEN IN THE INSIDE LANE of a narrow road: BE CAREFUL - The life you lose may be your own.

Lithologies

The sandstones are fine-grained lithic wackes, with significant amounts of matrix. Hematite constitutes up to 6 percent of the total rock, but is a minor constituent of the illite-chlorite matrix.

Trough-crossbedding of both large and small scale dominates the sandstones. Lower coset boundaries often are scoured downward into underlying shales (+488 m), and rip-up clast conglomerate layers frequently occupy the lower portions of sets (+457 m). Cosets rarely exceed 1 m in thickness, and grade down in size to less than 10 cm. Foreset azimuths are generally unidirectional, with wide scatter. Parallel lamination occasionally occurs in the upper parts of large-scale trough cosets, and rippled sandstone surfaces are common (STATION 13, +500 m).

Siltstones and mudstones are blocky-splitting, dark red to maroon, and difficult to separate. Significant shale is present. They exhibit ripple-bedding, wavy bedding, and lenticular bedding. They contain isolated ripple trains of very fine-grained sandstone (+473 m), often in single ripples in sand-starved trains. The mudstones contain buff-weathering calcareous concretions, suggesting an origin by evaporation. Desiccation cracks occur at STATION 14 (+513 m). Bioturbation may have destroyed much bedding.

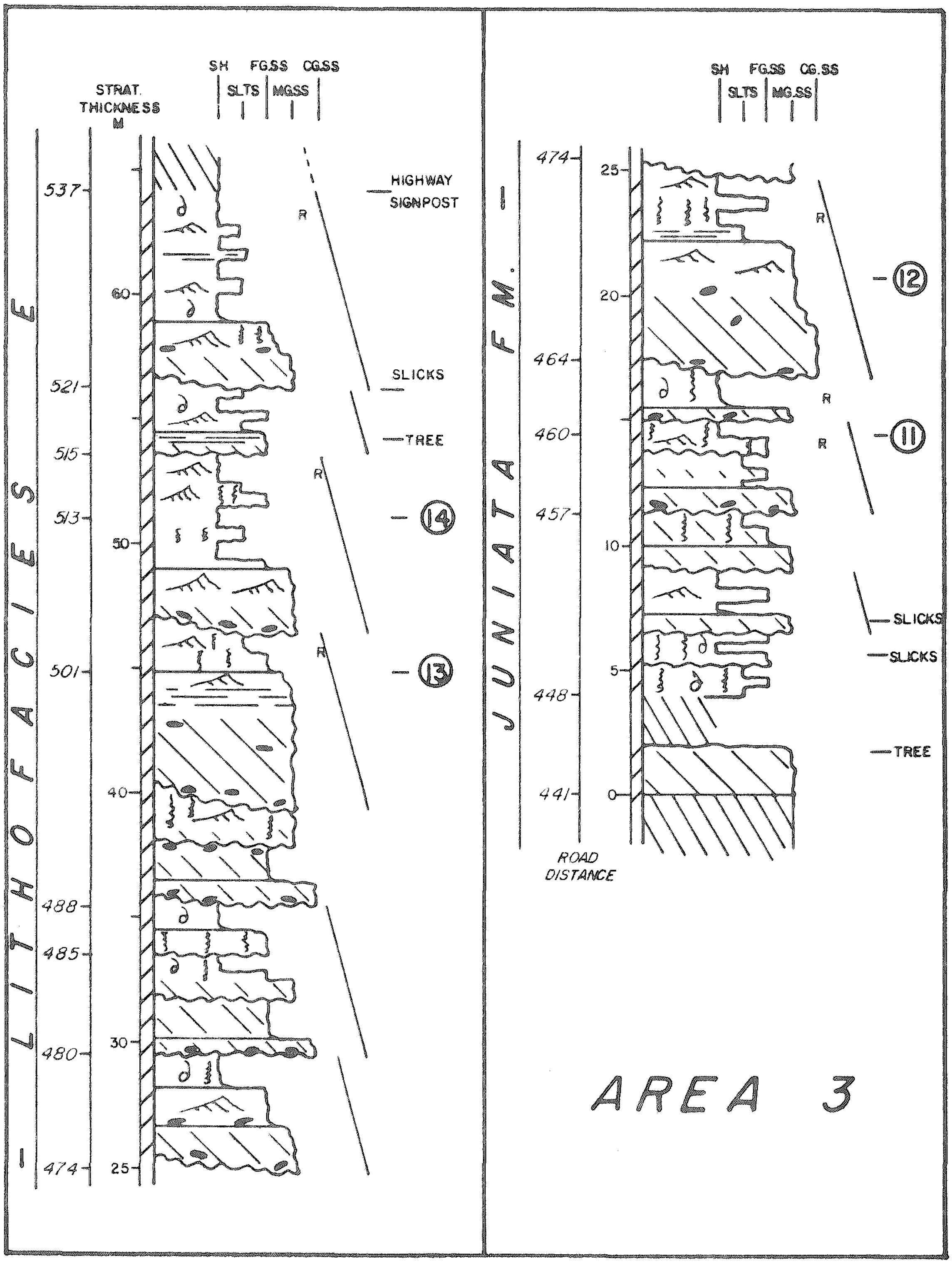


Figure 82. Columnar section for Area 3, Loysburg Gap. See Figure 80 for key to symbols.

Trace fossils are prominently displayed. Many fine-grained sandstones contain isolated one-dimensional, tubular, clay-filled structures, oriented normal to bedding. These are probably organic burrows and reach 50 to 60 cm in length. They occur at STATION 11 (+460 m) and elsewhere. They appear to be domiciles rather than escape burrows. They are apparently restricted to fine-grained sandstones, but show no consistent association with particular bedding types. They resemble Skolithos burrows, and it is worth looking for remains of the occupants. However, the structures dip consistently southwest in the plane of the spaced cleavage, and the possibility exists that they may be structural, or structurally accentuated features, perhaps related to pressure solution in layer-parallel-shortening situations.

Several fine-grained beds contain small, irregular, clay-lined structures transverse to bedding that resemble root structures (+463 m, +472 m, +535 m, and elsewhere). Examine these with the knowledge that, at present, the onset of significant colonization by land plants is dated as Early Silurian, and form an opinion. These are potentially significant structures. Retallack (1985) and Feakes and Retallack (in press) have described fossil soils from equivalent rocks of Lithofacies E near Reedsville.

Organization

The lithologies are organized in several fining-upward sequences (Figure 82). A prominent sequence is shown at STATION 12 (beginning at +464 m). Basal sandstones with rip-up clasts are eroded downward into shales and mudstones. They are overlain by smaller-scale trough crossbedded sandstones, interbedded siltstones, and mudstones. Grain size, bed thickness, coset thickness, and scale of current-generated structures all decrease generally upward (with numerous exceptions) within a sequence. The Skolithos-like burrows consistently occur in the middle portions of the sequence. The proportions of siltstone and shale are high, suggesting generally low-energy sedimentation.

In Area 4, look for these features:

1. Vertical organization of rock types and primary structures;
2. Evidence for subaerial exposure;
3. Biogenic versus structural origin of tubular clay plugs;
4. Fossil soils and criteria for their identification;
5. Evidence for steady or intermittent current flow.

INTERPRETATION

The current best guess is that these rocks represent channel and overbank deposition from both traction currents and from suspension on aggrading point bars in shallow alluvial rivers traversing a broad, coastal, delta plain of low regional paleoslope. The scoured basal sandstones represent channel-bottom erosion and deposition low on the laterally prograding point bar. The higher, smaller-scale crossbedded sandstones and siltstones represent upper point-bar deposition. This paleoenvironmental position was inhabited by infaunal, Skolithos-like critters. The irregular transition from sandstone to mudstone may represent variations associated with the channel margins, including levees and crevasse splays. The absence of organic binding agent from the fine-sediment fraction probably rendered the channel banks less cohesive and more prone to breaching during floods; crevasse-splay sandstones would then be a normal part of floodplain makeup, and floodplains would be quite sandy. The floodplain muds and silts developed calcareous concretions by precipitation from evaporating water during dry periods.

The red color is probably essentially primary, although the sediment was probably not deposited as red. The present color probably developed by progressive aging and irreversible dehydration of precursor ferric hydroxy- and oxyhydrates to hematite shortly after deposition. The red color of both channel and overbank facies argues for a fluctuating water table. This suggests that this floodplain was set inland from the coastal zone farther west. However, the effects of the absence of plant material on the oxidizing potential of ground water are not fully known, and the above may have to be modified in the light of new information.

Test the above interpretation against what you see and know, and modify it as you see fit. The interpretation hinges to a significant degree on the eventual identity of the suspected burrow structures: if they are in fact Skolithos burrows, the interpretations of sedimentologic orgin of the rocks and of Skolithos paleoecology must be, or must become, compatible. If Skolithos is restricted to shallow-marine environments, then we have marine red beds and marine fining cycles. If the burrows are not Skolithos, there is potentially no problem. If the burrows are Skolithos, and the sedimentologic interpretation of nonmarine conditions is correct, then the paleoecologic range of Skolithos may have to be revised. Which evidence is stronger: sedimentologic or paleontologic? How far from the coast did these rocks form? You decide.

		LEAVE Stop 7. **TURN AROUND AND RETURN** via PA Route 36 to PA Route 26.
2.8	39.3	**STOP SIGN. TURN LEFT** onto PA Route 26 North.
1.4	40.7	View of St. Pauls church ahead on right.
0.5	41.2	Outcrops of Oriskany Formation ahead on right and left.
1.5	42.7	Outcrop of Scherr Formation on left. Yellow Creek on right.
1.0	43.7	Hopewell cemetary on left.
0.3	44.0	Outcrop of Pocono Formation on left.
0.2	44.2	PA Route 915 on right to Hopewell. Route 26 parallels Raystown Branch Juniata River. River Mountain on left, Riddlesburg Mountain on right.
1.9	46.1	**TURN RIGHT** to Riddlesburg.
0.3	46.4	Note coking kilns and large slag dumps on right. Note the yellow boy in Sixmile Run ahead on the left.
1.1	47.5	Center of Defiance. Post office on left.
0.7	48.2	Borough of Coaldale limit.
0.4	48.6	Coaldale post office on right.
0.8	49.4	**BEAR LEFT** at Y intersection to Wood.
0.5	49.9	**TURN LEFT** at T-intersection to Dudley. Moderate grade up to the Broad Top upland is underlain by the Pennsylvanian age Conemaugh Group.
1.2	51.1	Historical marker on left for Thomas White, a participant in the Boston Tea Party on December 16, 1773.
0.3	51.4	Colluvium with deep red weathering on right.
0.8	52.2	Huntingdon-Bedford County line.
0.3	52.5	Note architecture of Immaculate Conception Catholic Church on right and country estate ahead on left.
0.2	52.7	**STOP 8. DUDLEY SECTION.**
		TURN LEFT onto mine road.

Buses will drive to strip area, unload, turn around, and park.

DASH COAL COMPANY STRIP MINE.
DISCUSSANTS: WILLIAM E. EDMUNDS AND ALBERT D. GLOVER

PLEASE NOTE: Because of mining regulations, and especially for safety reasons, no one is permitted near the highwall. Everyone must stay where group is assembled.

This stop visits a recently reactivated strip mine on the upper of 2 coal beds which have been worked intermittently on this mountain for the last 25 years or more. The 2 coals appear to be separated stratigraphically by about 50 feet. The general structural dip averages about 4° or 5° NW, although the dip is not uniform and there are some superimposed lower-order folds. Dips up to 27° were measured near the southeastern end of the mine.

One of the two coals mined here was mapped as Kelly by Gardner (Gardner shows the Kelly-Barnett interval as 286 feet in his general section, but 94 feet in his Six Mile Run section). The seam being mined is identified by the operator as "Big Pittsburgh," and the lower seam is referred to as "Little Pittsburgh." A recent examination of elevations in the deep mine on the Fulton coal which lies 600-700 feet directly below this strip mine shows that neither of these 2 coals can be Gardner's "Kelly." In the Survey drill hole (Figure 45), the coal named "Rogers" lies 650 feet above the Fulton bed. Based on stratigraphic interval, it appears that the "Big Pittsburgh" seam in this strip mine may be equivalent to the "Rogers" coal in the Survey drill hole. It is interesting that White (1885) noted that miners then referred to this bed as "Pittsburgh." Both White and Gardner stated that this was a gross correlation error.

The rocks exposed in this strip mine highwall are shown in columnar section in Figure 83. The mined coal is shipped to power plants to generate electricity.

The mine coal is about 52 inches thick and is separated into three distinct benches. The 18-inch upper bench is actually a bone coal (high content of detrital matter) with 36.9 percent ash and 1.82 percent sulfur. The 22 inch middle bench is very good quality coal with 11.8 percent ash and only 0.59 percent sulfur. Ash content of the 12 inch lower bench is 21.7 percent and the sulfur is low at 0.52 percent. The sulfur content of the 2 lower coals is almost entirely inherent organic sulfur. Three fourths of the sulfur of the upper bench is pyritic, introduced by chemical interaction between the swamp water and the water in which the overlying shale was deposited.

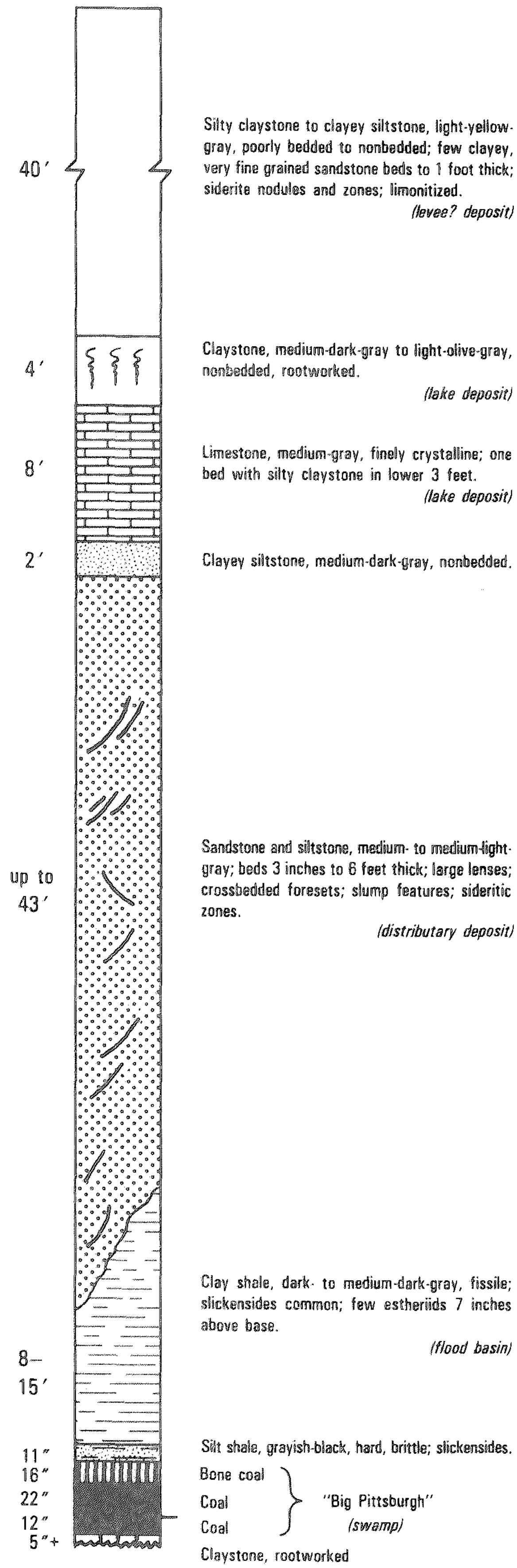
On a dry, ash-free basis, this coal has a fixed carbon content of 77.57 percent and is classified as medium volatile bituminous coal. However, most Broad Top coal analyses fall between 78 and 83 percent fixed carbon and the coals are classified as low volatile bituminous coals. This discrepency can be accounted for if we are correct in believing that this seam is not Kelly, but actually much higher stratigraphically. Also, most of the mined coals in Broad Top, and therefore most of the analyses, are 300 to 600 feet lower in the section. Because fixed carbon content increases at about 1 percent for every 100 feet of depth (Hilt's law), the lower rank of this higher coal seems reasonable.

The section exposed in this stripping is a fairly common Pennsylvanian coastal plain sequence showing the typical cyclic alternations between very low energy environments (coal and fresh-water limestone) and high energy settings (sandstone and siltstone).

The coal, representing the usual coal swamp, probably formed in a secure interfluvial area protected by stable levees. The high-ash benches at the top and bottom of the seam are common and reflect a transition from clastic accumulation to peat formation at the base and the reverse at the top. The coal swamp was terminated by the introduction of fine clastics into the area. These clastics buried and rapidly compressed the peat. The exact nature of the depositional environment of the shale overlying the coal is not clear. The simplest interpretation is that this influx of fine clastics into an upper delta plain flood basin resulted from a distant breach in the protecting levees. The presence of fresh-water estheriids in the shale supports this hypothesis.

The overlying crossbedded sandstone and siltstone unit very likely represents a fluvial distributary building its way out into the flood-basin and souring out the fine clastics of its own sediment apron. The distributary deposition ends fairly abruptly, presumably indicating its abandonment or diversion.

Following abandonment of the distributary, the area once again was bypassed by the main streams and became a coastal plain fresh-water lake where clayey lime mud was precipitated. Later, an unbedded fine claystone, similar to a conventional underclay, was deposited. It is very common to find a coal developed at this horizon, but there is no evidence here of even an abortive try at a peat swamp.



SCALE: 1 inch = 10 feet

Figure 83. Highwall section at Dash Coal Company strip mine, Dudley, PA.

The long sequence of silty claystone to clayey siltstone at the top of the stripping exposure does not lend itself to an easy environmental interpretation. The light color indicates low carbon content and either low input of macerated plant debris or, more likely, strong oxidizing conditions. The significance of the weak bedding and poor fissility is not clear. It may reflect bioturbation, including root-working, although there are few direct signs of this. Perhaps outer levee or levee-flood-basin transition may be the best explanation.

		LEAVE Stop 8. RETURN to main road. TURN LEFT to Dudley. Proceed through Dudley and down moderately steep grade.
0.6	53.3	STOP SIGN. TURN LEFT onto PA Route 913 West. Small railroad museum on right. Road proceeds down Shoups Run.
0.5	53.8	Outcrop of Pottsville Formation on both sides of the road.
1.1	54.9	Borough of Coalmont boundary.
1.5	56.4	Bible Deliverance Church on left.
0.2	56.6	TURN RIGHT to Trough Creek State Park at T-intersection. PA Route 913 goes left.
6.4	63.0	STOP SIGN. Intersection with PA Route 994. PROCEED STRAIGHT AHEAD to Trough Creek State Park.
1.6	64.6	STOP SIGN at T-intersection. TURN LEFT. Park office and visitors center are on road to the right. The visitors-center building was constructed in 1732.
0.3	64.9	Outcrops along the road between here and lunch stop are all in the Pocono Formation. Note the gabions used along Trough Creek as flood protection for the road.
1.1	66.0	Copperas Rock picnic area on right. Rhododendron, Copperas Rock, Ledges, and Balanced Rock trails on left before the bridge.
0.4	66.4	Rhododendron, Abbot Run, Swinging Bridge, Rainbow Falls, and Balanced Rock trails are to the left.
0.3	66.7	Campground on right is situated in an abandoned meander channel of Trough Creek. The floor of the channel is approximately 60 feet above the present creek level.
0.1	66.8	Terrace Mountain Road on right leads to an upland area called The Barrens where some very old residual soils are preserved in relatively flat areas. At present there is no means of determining the age of the soils. Because of resistance and structure, the Pocono sandstone underlying the Barrens may constitute a relatively stable geomorphic surface as well as a structural and modern topographic surface. The deep, red soils developed in this area, and elsewhere in the Broad Top Basin on sandstones of Pennsylvanian age, contrast sharply with thin, blonde soils on steeper slopes adjacent to streams. Exposures in some drainageways show blonde, sandy soils overlying deep, red, more clayey soil. Because flat surfaces are inherently more resistant to mass movement and surface erosion, soils on such surfaces may preserve a longer, more complex record of climatic change than many other locales.
0.2	67.0	Road on left marked One Way Do Not Enter should be used by buses to enter parking lot for picnic area.
0.1	67.1	STOP 9. FLUVIAL TERRACES AND LUNCH.

DISCUSSANT: TERESA KAKTINS

FLUVIAL GEMORPHOLOGY

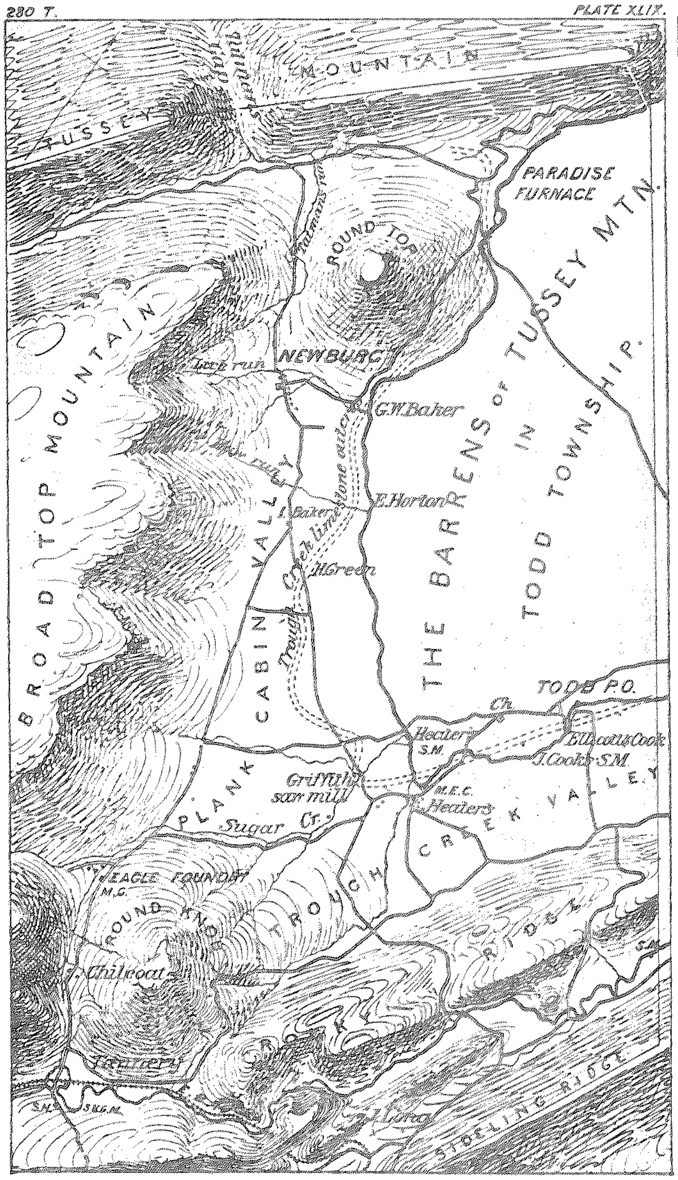
Great Trough Creek has unusually well developed terraces compared to most similar-sized streams in the Folded Appalachians. This is at least partly, perhaps primarily, controlled by the geology and structure of the Broad Top syncline in addition to climatic events. Though locally severely folded, resistant rocks (Pocono and Pottsville sandstones) of the Broad Top Basin generally dip gently on the western limb toward the axis of the basin. Fluvial deposits are preserved on structural dip slopes to much higher elevations than on comparably-sized streams in steep-dipping, less resistant rocks. At Todd (Figure 48, p. 110), Great Trough Creek and Little Trough Creek merge and turn sharply from flowing along strike. Great Trough Creek then crosses structure for about 13 stream miles to join the Raystown Branch Juniata River. The stream course changes from gently meandering in a relatively open valley to strongly meandering in a gorge with valley walls from 100 feet high at the upstream end to 400 feet high where Great Trough Creek breaches Terrace Mountain and joins the Raystown Branch. Within the gorge are a number of cutoff and abandoned meanders and terraces upon which campsites and picnic areas are located within Trough Creek State Park.

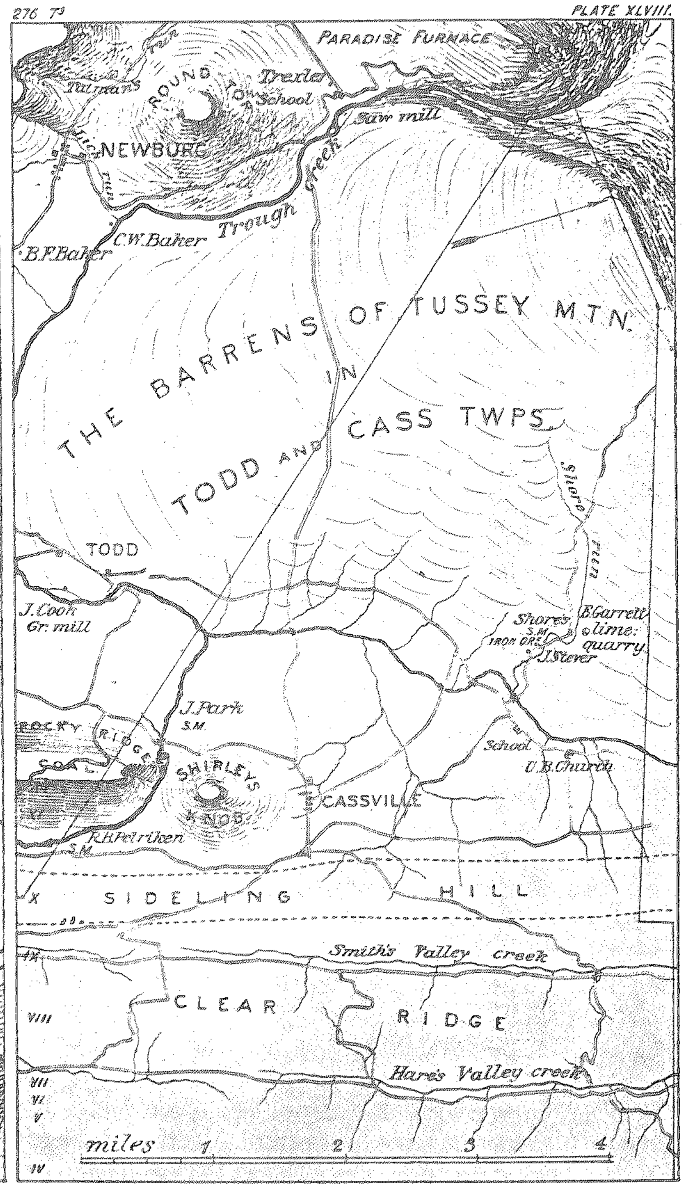
The meandering gorge and surrounding (relatively flat) uplands might be interpreted as rejuvenation (tectonic uplift?) and superposition of a formerly graded, highly meandering stream. However, the top of the gorge corresponds to the top of the Pocono Formation (on which adjacent gentle slopes are developed) and the depth of the gorge increases toward the mouth as the elevation, structural and topographic, of the top of the Pocono increases. There is no gorge present where less resistant Mauch Chunk shale forms the floor and wall of the valley. Tortuous meanders are the result of stream exploitation of whatever zones of weakness occur in the Pocono sandstone: jonts, fracture traces, and minor faults. Meandering and incision are much less pronounced on the Mauch Chunk Formation. Fluvial terrace deposits occur high on valley side slopes due to their structural orientation (essentially flat-lying for some distance) and the resistance of the underlying surface to dissection. Terrace deposits do occur along both branches of Trough Creek upstream from the gorge. Rocks underlying these terraces are less resistant than the Pocono sandstone, remnants at equivalent heights are more dissected, and terraces are destroyed more rapidly by erosion.

Three strath terrace levels are preserved at the ice mine picnic area. These surfaces have not been correlated with those on the Juniata. The surfaces are topographically and materially well defined. The materials comprise sandy matrix and clasts up to boulder size. The matrix consists of a mixture of quartz sand (Pocono) and red rock fragments (Mauch Chunk). The clasts observable at the surface are Pocono sandstones. Some of the clasts are well rounded and some are relatively angular. This is common for fluvial deposits of this type and for a stream of this size. Take a good look at the material presently being transported by Great Trough Creek at this locality. The variation in degree of rounding which occurs is presumed comparable to that in the terrace deposits. Indeed, in some cases the present is the key to the past!

ICE MINE

The ice mine occurs in a short opening at the base of the hillside. The opening serves as an air duct for the release of cold air trapped in the porous





Todd township map. Cass township map.

Maps from White, 1885, p. 280 and 276 respectively.

and permeable slope cover during the winter. The hillside is covered with a mantle of colluvium of unknown thickness which was produced by physical disintegration of the Pocono sandstone followed by downslope movement and accumulation of the sandstone debris. Cold winter air accumulates in pore space within the colluvium and moves slowly downslope during the summer. When the cold air encounters warmer, more humid air in the ice mine opening, ice forms. The formation of ice ceases when the air within the colluvium is warmed by summer circulation.

BALANCED ROCK

Balanced Rock is a large block of Pocono sandstone which has moved slowly downslope by mass wasting to reach its present, apparently precarious position on a ridge above the west side of Trough Creek.

LEAVE PARKING LOT AND RETURN SAME ROUTE.

1.2	68.3	Copperas Rock on left.
1.2	69.5	TURN RIGHT onto exit road to PA Route 994.
0.3	69.8	Outcrops of Mauch Chunk Formation on both sides.
1.2	71.0	STOP 10. TROUGH CREEK LIMESTONE. Park buses along road before outcrop.

DISCUSSANTS: LEONARD J. LENTZ, CLIFFORD H. DODGE, AND THOMAS M. BERG

OVERVIEW

The Trough Creek limestone member of the lower Mauch Chunk Formation was first described and discussed by Rogers (1858) who named the unit "Umbral limestone" as part of the Umbral Formation in the Broad Top region. He characterized it as a mixed red and grey, impure limestone which was locally quarried for use in the furnaces of the area. He noted that a few fossils were present in the limestone, mostly corals and bivalve shells. Ashburner (1878) referred to the unit as "Mountain limestone," and White (White and others, 1885) named it the Trough Creek limestone for the many exposures along Trough Creek.

Early workers dealing with the Trough Creek "limestone" stratigraphy apparently thought that this unit was correlative with the Loyalhanna Limestone of southwestern Pennsylvania and the Greenbrier Limestone of West Virginia as well as a siliceous limestone unit in the Lycoming County area (Lesley and others, 1895). Butts (1945) considered this limestone a northeastward extension of the Greenbrier Limestone. Most recent work has focused on the petrologic and sedimentologic makeup of the limestone and has continued to address regional stratigraphic relationships. Adams (1970) examined the Loyalhanna in great detail, and Hoque (1965) examined the Mauch Chunk in detail, which includes the petrography of the Trough Creek Member; both studies included the Broad Top area. Geologic mapping in the southern part of the basin by Brink (1984) inferred that the Trough Creek Limestone might be laterally equivalent to the Deer Valley Limestone of Somerset County. The petrographic studies led to two different conclusions. Hoque (1965) thought the Trough Creek might be laterally equivalent to the Loyalhanna limestone. Adams (1970, p. 87) believed that, although there was no direct physical connection between the Trough Creek Member and the Loyalhanna, they both probably occupied the same stratigraphic position. In any case, the Trough Creek Member apparently is the eastern extension of a more marine limestone (Loyalhanna) situated to the west and south. In the Broad Top "sub-basin" it appears to be just such a shore facies.

Paleocurrents from the Loyalhanna Limestone (Adams, 1970) in southwestern Pennsylvania suggest an east-southeastward sediment transport direction which became more northerly near the eastern edge of the Appalachian Basin. Trough Creek Limestone paleocurrents (Hoque, 1965) depict a somewhat more northerly and southeasterly component of sediment transport resulting in a mean of N53°E. The southeasterly component is strongest in the Broad Top "sub-basin."

The probable source for these sediments was determined from heavy mineral analysis by both Adams (1970) and Hoque (1965). Probably two source areas existed. One from the north provided reworked sediments; a second from the east provided sediment derived from metamorphic terrane. The red coloring of these two units probably came from this second easterly source (Adams, 1970). The source or parent material for the northerly-derived, reworked sediments is not generally known. Obviously the older Burgoon sandstone would appear to be the most likely candidate, however Hoque (1965) tended to discount this based in part on the sediment make-up of the Burgoon and the mechanical effects of transport of such a relatively mature sandstone. The matter has yet to be satisfactorily resolved.

The contact of the Trough Creek Member with the underlying Burgoon Sandstone is sharp and generally found to be conformable. However some skepticism exists. Reger (1927), Chase (1955), and to some extent, Adams (1970) considered the contact between the Burgoon and the overlying strata unconformable. Upon first glance this might appear so because of the vastly different sediment types and the abrupt color change. The usual criteria used in identifying disconformities are not present here. The outcrops seen on this Field Conference show only an abrupt color change, a change in cement, and a change in grain size across the contact. There is no evidence for an erosional boundary, and beds do not seem to be missing from the known stratigraphic column. On the other hand, lithic grains (metamorphic rock fragments) present in the Burgoon Sandstone are not found incorporated into the basal Trough Creek Member as might be expected if deposition was continuous. Were the phyllitic framework grains simply winnowed away? Whatever processes were involved, the change from the Burgoon depositional environment to the Trough Creek depositional environment was abrupt and widespread. Can you suggest a modern analog?

In the field, the Trough Creek is difficult to locate because it is easily eroded and often covered. Generally it is found by association with the more resistant underlying Burgoon Sandstone. The first occurrence of red siltstone or calcareous sandstone marks the basal Mauch Chunk and/or Trough Creek Member.

STOP DESCRIPTION

This outcrop locality exposes the basal, red-colored calcareous siltstones, and very fine to fine-grained sandstones and sandy limestones of the Trough Creek Member of the Mauch Chunk Formation as well as the underlying Burgoon Sandstone. Probable individual sedimentary packages are set out from each other by noncalcareous clay shale partings. Participants in the Field Conference should note the variety of sedimentary structures present and the lack of megafossils. Local strike and dip is N42°E, 8°SE.

Hoque (1965, p.335) described the Mauch Chunk Formation with the Trough Creek Limestone Member at the base for a nearby location. The Trough Creek is but one of 3 limestone horizons he noted for this area. The other 2 which he referred to as "Deer Valley" and "Greenbrier of Pennsylvania" (Wymps Gap?) occur higher in the section, but only the latter was the more recognizable in the field. The Deer Valley horizon probably was evident only as a thin calcareous zone at approximately 25 m above the Burgoon Sandstone. This succession of carbonate units, becoming more fossiliferous going upward in the Mauch Chunk section, is important to the overall depositional picture presented below. The Trough Creek Member is the primary interest at this stop.

The 2 outcrops seen here will be viewed in reverse order, starting with the younger strata and working our way down-section to the older strata. Outcrop "B" will be examined first (Figures 84, and 85).

The upper portion of outcrop B is characterized by a vaguely coarsening-upward sequence of calcareous, thin-bedded, grayish-red siltstone and light

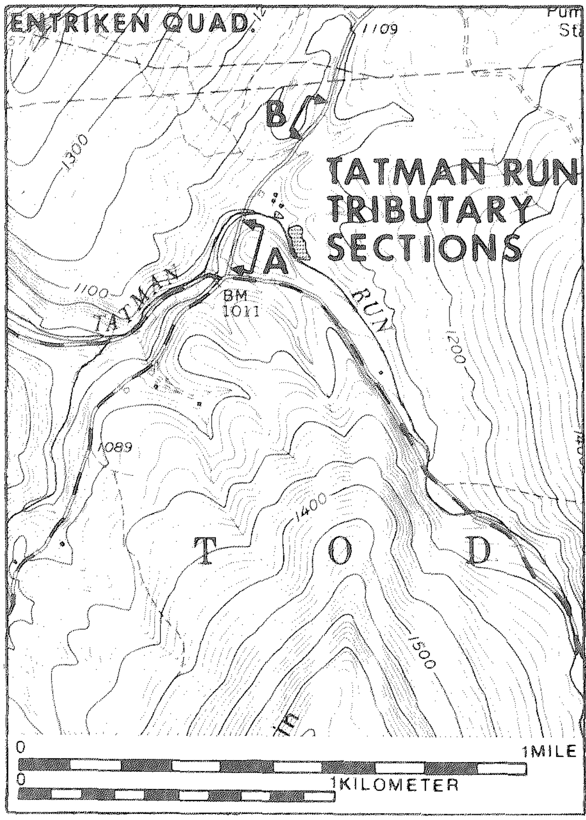


Figure 84. Map showing location of the Tatman Run Tributary section, Stop 10.

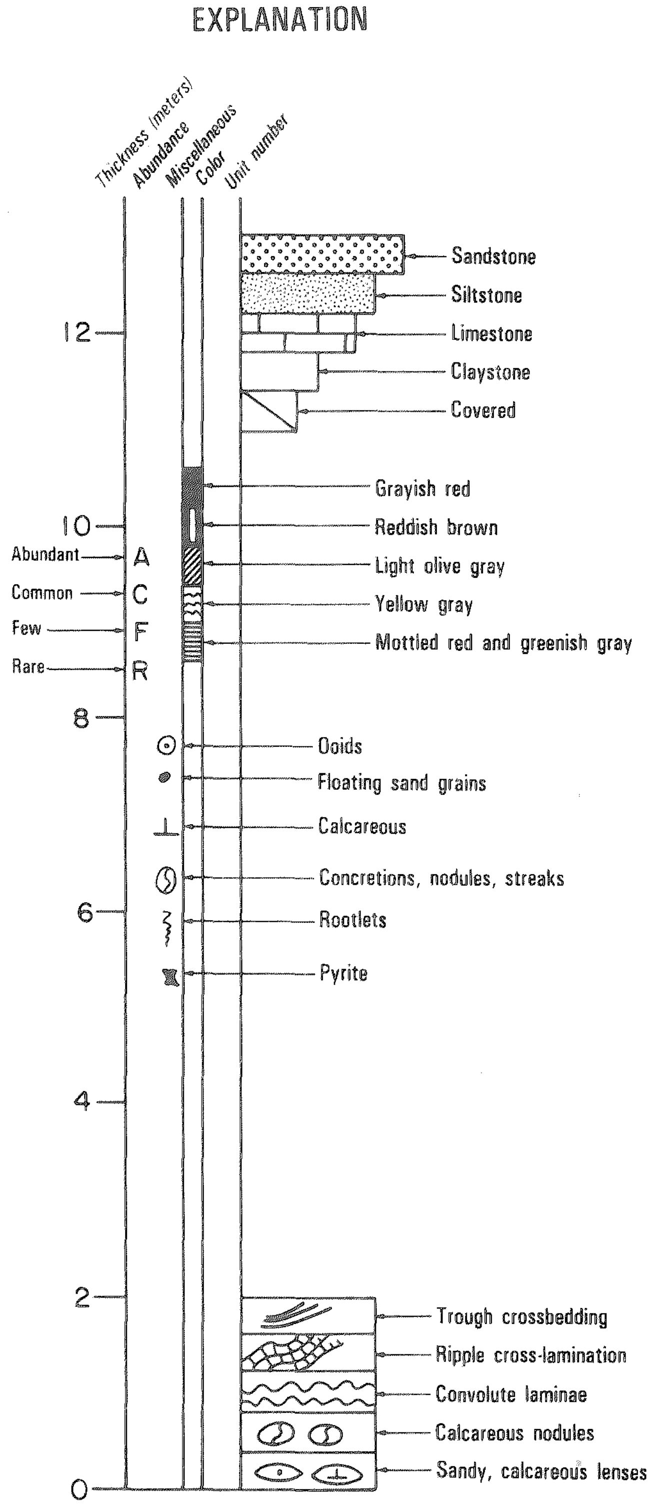


Figure 85. Columnar section of Mississippian rocks (Burgoon Sandstone and Trough Creek Member of Mauch Chunk Formation) exposed at Tatman Run Tributary section, Stop 10.

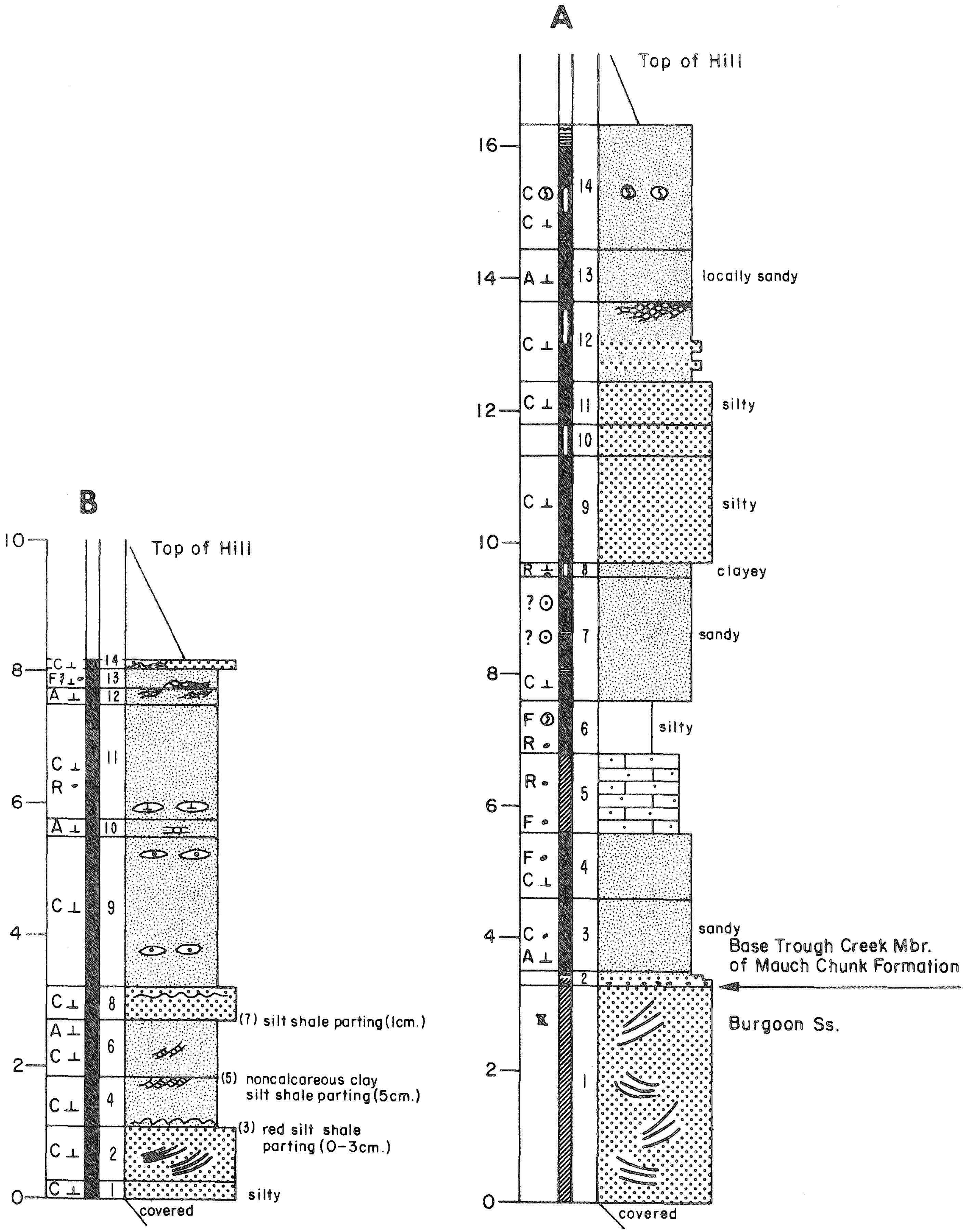


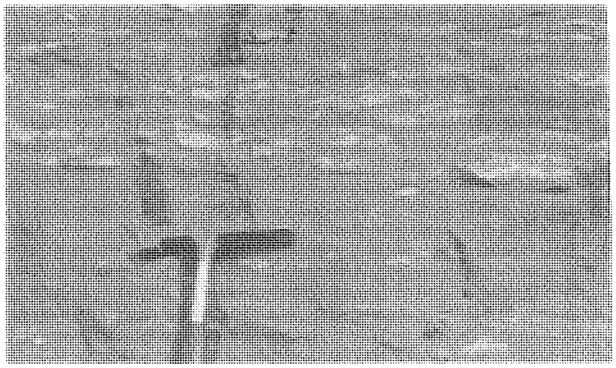
Figure 85. continued.

grayish-red, calcareous, very fine-grained sandstones exhibiting ripple lamination, occasional rootworking, and thin gray calcareous lenses. Note that some lenses are internally laminated, and often occur as small, discrete "pods" with the laminations sharply truncated at the edges. They occur mainly in unit B11 (Figure 85B). About 1 km north along this road, these laminated lenses and pods are much more prevalent. Another type of thin lens or stringer occurs lower in the section in unit B9. The lenses are composed of light gray to olive-green, calcareous, very fine grained sandstone. Their relative geometry can be seen in drill borings left in the face of the roadcut (Figure 86a). Note their relative abundance in the top and bottom part of the unit B9. Prominent sedimentary structures include cross bedding, ripple laminations, planar laminations, and convolute laminations (units B2, B4, and B8). Unit B8 is particularly interesting because of the contorted and convolute bedding (Figure 86b). The red, very fine grained, calcareous sandstone of unit B4 is the same as the reddish lithology described at the top of the Warriors Path section and illustrated in Figures D3f, D3g, and D3h. The calcareous sandstone of unit B2 (Figures 86c and 86d), exhibits a distinctive trough crossbedding. Notice the tangential contact of the cross-strata with the underlying horizontal laminations. The troughs themselves are truncated by horizontal laminations (Figure 86c). The lower flow regime crossbedded unit contrasts with the higher flow regime horizontally-laminated beds above and below. The basal contact of unit B2 with the underlying grayish-red, structureless, calcareous silty sandstone of unit B1 is sharp. The Trough Creek Member calcareous sandstones commonly weather to a distinctive "ribbed" appearance as shown in Figure 86d. This is similar to weathering patterns observable in the Loyalhanna Formation along the Allegheny Front.

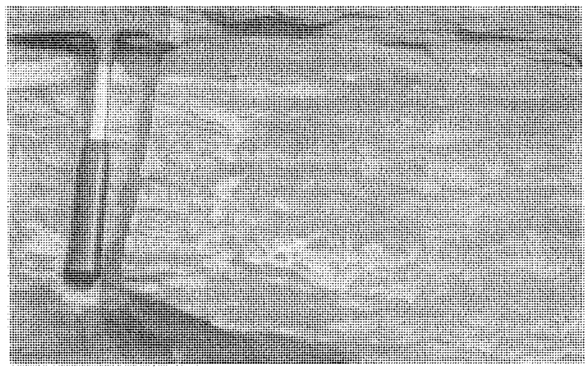
Down the road, at outcrop A (Figure 84), observe the overall section and note that the units again are crudely separated out by shale partings. Again, these tend to be noncalcareous but sometimes rippled. There is a tendency for repetition of siltstone beds throughout Section A, punctuated by thicker-bedded sandstones or thin clayey units. Lateral gradations to beds of different grain size are also apparent. Signs of probable bioturbation also occur in this outcrop, effectively destroying some sedimentary structures.

Within units A8 through A10 (Figure 85A) near the top of the roadcut, a gross coarsening-upward from siltstone to sandstone is discernible. These then tend to fine-upward into siltstone (units A11 through A14). This is in contrast to the sandstones and siltstones and sandy limestones found near road level. These lower units crudely fine-upward into sandy limestone or calcareous sandstone (unit A5). As observed in outcrop, the sediments usually exhibit little

Figure 86. Sedimentary structures in the Trough Creek Member of the Mauch Chunk formation Formation and in the Burgoon Sandstone: a, Ripple-laminated calcareous lenses within unit B9 of the section at Stop 10; b, or contorted bedding within unit B8 which may be due to bioturbation or periodic drying; c, Trough-style crossbedding typical of Trough Creek Member calcareous sandstone, exposed in unit B2 (note truncation of cross-strata by horizontally-laminated beds above hammer); d, Exposure of crossbedding in unit B2, weathering to distinctive "ribbed" appearance typical of Trough Creek Member calcareous sandstones; e, Burgoon Sandstone exposed at Stop 10, section A, showing sharp upper contact with overlying Trough Creek Member of Mauch Chunk Formation (L. J. Lentz for scale); f, Detail of outcrop of Burgoon Sandstone showing trough crossbedding (looking perpendicular to trough axes).



a



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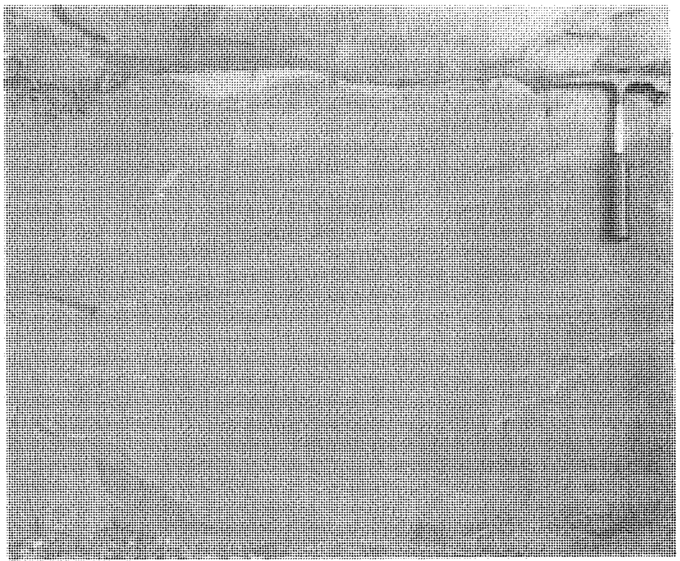

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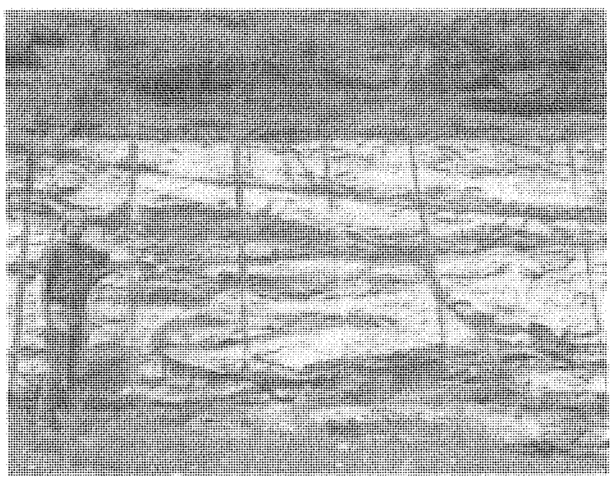

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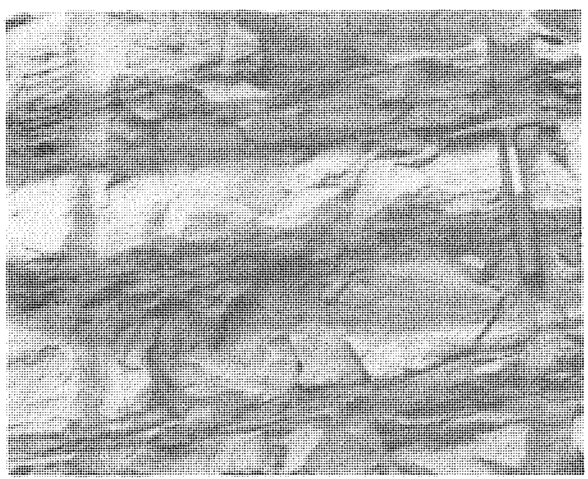

f

(readily) apparent gradation in grain size other than what can be inferred from sedimentary structures. The fine clastics (calcareous and noncalcareous siltstones) included in the "Trough Creek Member" as used here contrast with the Trough Creek descriptions given by Hoque (1965) or White and others, (1885). They described Trough Creek rocks as dominantly limestone with lesser amounts of siltstone and sandstone occurring as a discrete stratigraphic horizon in the basal 5 to 15 m of the Mauch Chunk Formation. This suggests that a great amount of lateral variation exists within the Trough Creek Member and should be expected when looking for "limestone" in other areas. Perhaps those areas of more pure limestone are where some of the megafossils noted in the literature were found (Hoque, 1965, Adams, 1970, White and others, 1885, Rogers, 1858, Ashburner, 1878). Microfossils (foraminiferids, Figure D3e) are seen in thin section and probably do exist in all Trough Creek calcareous units. Unit A5 is the same as the calcareous sandstone described at the top of the Warriors Path section, and is shown in thin section in Figures D3a, D3b, D3c, and D3d.

One final item to consider here at outcrop A is the contact between the Burgoon Sandstone (unit A1) and Trough Creek Member (units A2 and above). This contact can be seen near road level on the west side of the road. Observe the contact (Figure 86e) between the light-colored, crossbedded (Figure 86f), medium-grained sandstone of the Burgoon, and the reddish Trough Creek Member siltstones and fine-grained sandstones. Can you tell if an unconformity exists here? The contrast between the light greenish-gray, well-sorted, fine- to medium-grained, subangular to subrounded, quartz arenite of the Burgoon with the grayish-red, very fine to fine-grained, subangular to well-rounded, sandy calcarenite to calcareous sandstone of the Trough Creek Member is perplexing when interpreting depositional environments. Would you interpret a disconformity here?

ENVIRONMENTS OF DEPOSITION

An inferred depositional environment and sedimentary history may be along the lines that follow. The alluvial Burgoon sediment source died out abruptly (see Stop 11, p.212-214). As the area continued to subside, marine conditions began to return from the west. This marine transgressive event is now evident as the Loyalhanna and Trough Creek carbonate units. The lower to middle Mauch Chunk Formation as a whole probably reflects such a deepening event in the Appalachian Basin and Broad Top "sub-basin," as evidenced by the greater marine affinities of limestones occurring successively higher in the section. After the final transgressive event (Greenbrier of Pennsylvania/Wymps Gap), fluvial-deltaic deposits (upper Mauch Chunk) from the east once again returned to cover the area.

For the Trough Creek carbonates here, and the Loyalhanna carbonates to the west, the depositional environments are not well understood. They have been interpreted as eolian (Butts, 1924), and as nearshore marine (Adams, 1970). The more detailed petrographic work of Adams (1970) and Hoque (1965) tend to support a marine shoreline environment for deposition of these units. The authors envisioned a similar mode of deposition for the Trough Creek Member and suggest the following scenario.

The Trough Creek probably represents a very complex set of conditions with a depositional setting ranging from shoreface to below wave base where sand waves carried by littoral currents moved across the bottom. Additional sediment input, particularly the micrite pellets, ooids, fossil fragments, etc. (Figures D3b, D3c, D3d, and D3e), was probably derived from nearby carbonate sand shoals which were exposed to wind erosion and transport during low tide.

Other mechanisms probably existed which contributed to the mixed quartz grain sizes and rounding (or lack of rounding). One possible mechanism is the combination of the reworking of dune and beach sands in a shallow marine environment to provide the coarser, well-rounded, frosted (?) quartz grains, and the wind transport of a finer-grained, more angular, silt-sized fraction carried in from an upwind land source (Wilson, 1975). These finer particles settled out in the quieter waters away from wave action, perhaps behind swash bars.

Constant movement of sand waves across the area apparently resulted in an environment inhospitable for organisms. This may explain the apparent lack of megafossils and burrowing in the Trough Creek lithologies. Some shoaling probably occurred on this very shallow shelf. As it did, shallowing-upward, disturbed sequences such as unit B8 (Figure 86b) resulted.

Imagine a beach and shallow sea stretching out before you. Realize a major change in your shoreline is occurring. The old coast is slowly being drowned as the sea encroaches. The winds are blowing in from the west and the climate may be changing to more arid. All the sediments will become red within the Broad Top area as minute quantities of hematite are added. This is the lower Mauch Chunk of Broad Top.

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LEAVE STOP 10. PROCEED STRAIGHT AHEAD across PA Route 994. Outcrops of Burgoon ahead.

1.9 73.0 Road traverses Little Valley. Road is approximately at the contact between the Burgoon and Mauch Chunk Formations. Little valley developed in Mauch Chunk Formation. Area where valley widens has limited Trough Creek Member exposures.

4.2 77.2 Village of Middleton boundary.

0.2 77.4 STOP SIGN. TURN RIGHT onto PA Route 913 West to Saxton. Road follows Shoup Run through water gap in Terrace Mountain.

1.5 78.9 Bedford County line.

0.7 79.6 STOP SIGN. TURN RIGHT following PA Route 913 West.

0.2 79.8 STOP LIGHT. TURN LEFT onto 8th Street in Saxton. Ahead on the left is the local fire department. Exposures adjacent to the parking lot contain fluvial gravels and are 120-140 feet above the Raystown Branch.

0.5 80.3 STOP SIGN. PROCEED STRAIGHT AHEAD to Warrior Path State Park.

1.3 81.6 STOP 11. WARRIOR PATH SECTION.
Park, unload, and turn buses at guard rail fence at sharp right turn at former railroad cut.
The Raystown Branch has 3 well-defined terrace levels developed on the meander bend on which Warrior Path State Park is built. Thin boulder lags occur as much as 180 feet above the river along Warrior Path Trail which traverses the crest of the meander bend. Rounded cobbles and boulders may be excavated in the woods along the trail. These fluvial remnants are smooth and well-rounded, and some cannot be derived upslope from the Burgoon Formation.

DISCUSSANTS: CLIFFORD H. DODGE AND THOMAS M. BERG

This stop involves a nonstrenuous 1.1 km walk along the old Huntingdon and Broad Top Mountain Railroad grade. To simplify logistics, we will begin at the top (southern end) of the sequence and then work our way down section (northward) back towards the buses. When examining the outcrops, WATCH OUT for poison ivy and uneven footing in the underbrush.

INTRODUCTION

This locality has traditionally been called the Riddlesburg section, but to minimize confusion, we have renamed it the Warriors Path section because of its location within and adjacent to the state park having the same name. Interestingly, Warriors Path State Park was named for its proximity to the famous path used by the Iroquois Indians during their raids and wars with the Cherokee and other tribes of southern Pennsylvania (Pennsylvania Department of Environmental Resources, 1980).

The Warriors Path section is a classic field locality. Because of the easy access and relative completeness of the exposures here, geologists have periodically examined these rocks for more than a century. The principal objective of most previous studies has been to better understand the relationship between this section and the regional stratigraphy of the "Pocono" Formation (Rockwell Formation and Burgoon Sandstone in the Broad Top region) in central Pennsylvania. Yet, these outcrops still hold surprises, and their geologic significance has not diminished. The Warriors Path section is especially noteworthy for its Upper Devonian and Mississippian transgressive-regressive sequence and variety of interpreted fluvial styles. In keeping with the theme of this year's Field Conference, we will reexamine the work of the "old boys" in light of modern concepts of sedimentology and stratigraphy.

The Warriors Path section is a homoclinal sequence of rocks (average strike and dip = N23°E, 43°SE) located along the western flank of the Broad Top synclinorium on the east side of the Raystown Branch of the Juniata River about 2.3 km south of Saxton in Bedford County (see Figure 87; and Appendix 3, p. 225). The section consists of a series of Upper Devonian and Mississippian (Conewangoan through Meramecian Stages) outcrops that were first exposed around 1855 during the construction of the Huntingdon and Broad Top Mountain Railroad (Africa, 1883, p. 37-38). The rocks discussed here (from oldest to youngest) include the upper 150.9 m of the Catskill Formation, all of the Rockwell Formation and Burgoon Sandstone, and the lower 17 m of the Mauch Chunk Formation (Trough Creek Member). The section also includes the type section of the marine Riddlesburg Shale Member of the Rockwell Formation (Reger, 1927a, p. 400, 405; 1927b, p. 156-157). The description of the Warriors Path section is summarized in Figure 88 and is given in detail in Appendix 3 (p. 225). The stratigraphic relationships of these rocks are shown in Figure 41 (p. 82).

PREVIOUS INVESTIGATIONS

The exposures of the Warriors Path section did not exist until more than a decade after the First Geological Survey of Pennsylvania (1836-1842) had completed most of its field investigations. The nearest published section of the First Survey was measured about 0.8 km south of Riddlesburg along Riddlesburg Mountain above the east side of the Raystown Branch of the Juniata River. This section consisted of rocks that are stratigraphically higher than those found at Warriors Path and include perhaps the upper 100 m of the Mauch Chunk Formation and the lower 25 m of the Pottsville Formation (Rogers, 1858, p. 531). Most of the work of the First Survey in the Broad Top region was conducted by Alexander McKinley in 1839 to 1841 (Rogers, 1840, 1841, and 1842).

The Warriors Path section has previously been measured in part by Stevenson (1882, p. 69-70, 234) and Laird (1942, p. 70-72), and more completely by White (White and others, 1885, p. 79, 81) and Reger (1927a, p. 399-400). Butts (1945, p. 13) also examined these exposures but only made a brief comment about them. White (White and others, 1885, p. 81) first recognized the marine invertebrate fossil fauna at Warriors Path (i.e., in the Riddlesburg Shale Member of the Rockwell Formation). Girty (1928) later described the invertebrate fossils in detail and published faunal lists for this locality (see Appendix 3, p. 226) and three others throughout the Broad Top region. Laird (1942) also examined the marine shale at Warriors Path but only published a list of the dominant species. He also presented a composite faunal list for the Riddlesburg Shale Member based on his regional studies. Reger (1927a) merely noted the fauna that was identified by Girty. Little work has been done on the paleobotany of this locality. Reger (1927a) collected a few plant fossils from the Catskill Formation and forwarded them to David White for identification. Read (1955) identified fossil flora in the Burgoon Sandstone that most probably came from the Warriors Path section (see Appendix 3, p. 225). Some aspects of the paleontology will be further discussed later on.

STRATIGRAPHY

The Pennsylvania Geological Survey subdivides the rocks of the Warriors Path section, on the basis of lithostratigraphy, into the Catskill Formation (units 1-13), Rockwell Formation (units 14-46), Burgoon Sandstone (units 47-55), and Mauch Chunk Formation (units 56-57) (Figure 88). Only the Burgoon Sandstone is the lithostratigraphic equivalent of the Pocono Formation of northeastern Pennsylvania (Berg and others, 1980). The contact between the Catskill and Rockwell Formations is placed at the top of the last thick red-bed sequence, marking the top of the "major body of red beds." Although the overlying Rockwell contains some fine-grained red beds, it is predominantly grayish olive to olive gray. Moreover, the base of the formation reflects a change in depositional environment from the underlying Catskill. The boundary between the Rockwell Formation and the Burgoon Sandstone is placed at the base of the continuous sandstone outcrops that contain no significant shale interbeds and that have larger scale and higher angle trough cross-strata than do the underlying units. Similarly, the upper contact of the Burgoon is placed at the top of the sandstone sequence having the same characteristics, above which are the grayish-red calcareous siltstones and limestones of the Mauch Chunk Formation (Trough Creek Member).

Berg and Edmunds (1979, p. 3-16) have discussed in detail the historical development of thought concerning the nomenclature and correlation of the Upper Devonian and Mississippian rocks in Pennsylvania. By the early twentieth century, there was widespread usage of the stratigraphic nomenclature in a chronostratigraphic sense and a lack of full appreciation of lateral facies changes. In particular, the base of the "Pocono" Formation (now equivalent to the Rockwell Formation and Burgoon Sandstone of the Broad Top region) was thought to mark the Devonian-Mississippian systemic boundary. With regard to the Warriors Path section, earlier workers (e.g., Reger, 1927a; Laird, 1942) attempted to define the base of the "Pocono" using a combination of paleontology and lithostratigraphy.

On the basis of paleobotany, Reger (1927a, p. 406-408) believed that he had discovered an important key bed near the top of the Catskill at Warriors Path that could probably be traced laterally through Pennsylvania, Maryland, West Virginia, and northern Virginia and that would be useful for correlation. He went so far as to erect a type section here for a green, fossil plant-bearing shale and to name the unit the "Saxton shale" (presumably unit 2 of our section). Reger had collected fossil plant fragments from the shale and forwarded them to David White, who identified the material as *Archaeopteris* of probable upper Catskill age (Reger, 1927a, p. 407). Ignoring lateral facies changes, Reger believed that all green, plant-bearing shales at about this position in the Catskill were correlative and Late Devonian in age. Thus, he concluded that the "Saxton shale" was of "evident value in the determination of the Catskill-Pocono, and therefore the Devonian-Mississippian, boundary" (Reger, 1927a, p. 407-408). However, because of lateral facies changes and the multiplicity of "green shales" in the Catskill, we are unable to trace the "Saxton shale" beyond its outcrop! Chronostratigraphic thought prevailed.

Laird (1942, p. 37, 70-72) fell into the same paleontological trap. Whereas the base of the "Pocono" of White (White and others, 1885) and Reger (1927a) coincides with that of the Rockwell Formation at Warriors Path, Laird placed the contact significantly higher, just below the base of the Riddlesburg Shale Member. Laird (1942, p. 37) believed that "the boundary between the 'Pocono' and the 'Catskill' is a rather difficult one to determine on the basis of lithology alone. ...where the Riddlesburg [marine] fauna can be found, the boundary can be located with near certainty. It seems highly probable that heretofore the boundary of the Devonian-Mississippian has been placed too low." The systemic boundary was unswervingly linked to a presumed formation boundary.

SEDIMENTOLOGY AND PALEONTOLOGY

Mauch Chunk Formation

The uppermost part of the Warriors Path section that we measured consists of the lower 17 m of the Trough Creek Member of the Mauch Chunk Formation (units 56-57 of Figure 88). The upper contact of the underlying Burgoon Sandstone is visible along the ridge above the path (the top 3 m are missing at path level); the contact is sharp and planar. The Mauch Chunk continues southward beyond the area to be examined and appears as a series of discontinuous outcrops along the east side of the old railroad grade.

Although the Trough Creek Member has been discussed in detail at Stop 10, the samples that were analyzed in thin section were taken from Stop 11. Much of this interval is covered, but it is characterized by grayish-red calcareous siltstones and calcareous clayey siltstones with highly calcareous zones and lenses. Rare floating quartz sand grains were observed in the siltstone.

A minor amount of light-olive-gray, fine-grained, very calcareous sandstone float is present in the ravine to the east of the path. This very calcareous sandstone is lithologically equivalent to unit A5 of Stop 10. Thin-section analysis of this sandstone shows that it comprises a framework of angular to subrounded quartz grains, micrite pellets, and ooids, along with foraminifers and other fossil fragments, set in sparry calcite cement (Figure 89a). The quartz grains are monocrystalline and polycrystalline (Figure 89b). The ooids, micrite pellets, and fossil fragments are squeezed or penetrated in many cases by the quartz grains (Figures 89b, 89c, and 89d). The endothyroid foraminifers are abraded and fragmental (Figure 89e).

Some grayish-red, highly calcareous, very fine grained sandstone to coarse siltstone was observed cropping out about 26 m (stratigraphically) above the base of the Mauch Chunk along the ridge above the path on the northeastern side of the ravine. This fine, red calcareous unit is lithologically equivalent to unit B4 of Stop 10. In thin section, this very fine grained sandstone has a framework of very angular to subangular quartz grains and micrite pellets (10 to 15 percent of the framework) set in sparry calcite cement (Figure 89f). Some of the pellets may be recrystallized ooids (Figure 89g). The quartz is mostly monocrystalline, and rare plagioclase grains are present (Figure 89h). Many of the quartz grains are partly embayed and replaced by calcite (Figure 89g). The micrite pellets and ooids are commonly coated with hematite (Figures 89g and 89h).

These last two rock types are considered to be typical Trough Creek "limestones" of White (White and others, 1885). Because the Trough Creek lithologies at Warriors Path are nearly identical to those at Stop 10, they are believed to reflect the same high-energy, nearshore depositional environments.

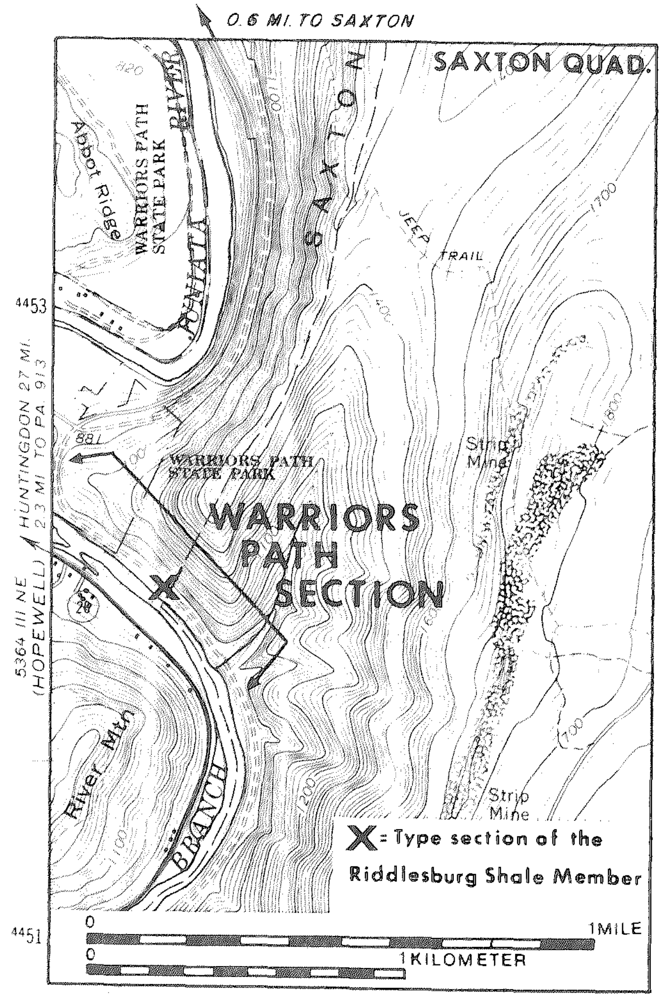


Figure 87. Map showing location of the Warriors Path section, Stop 11.

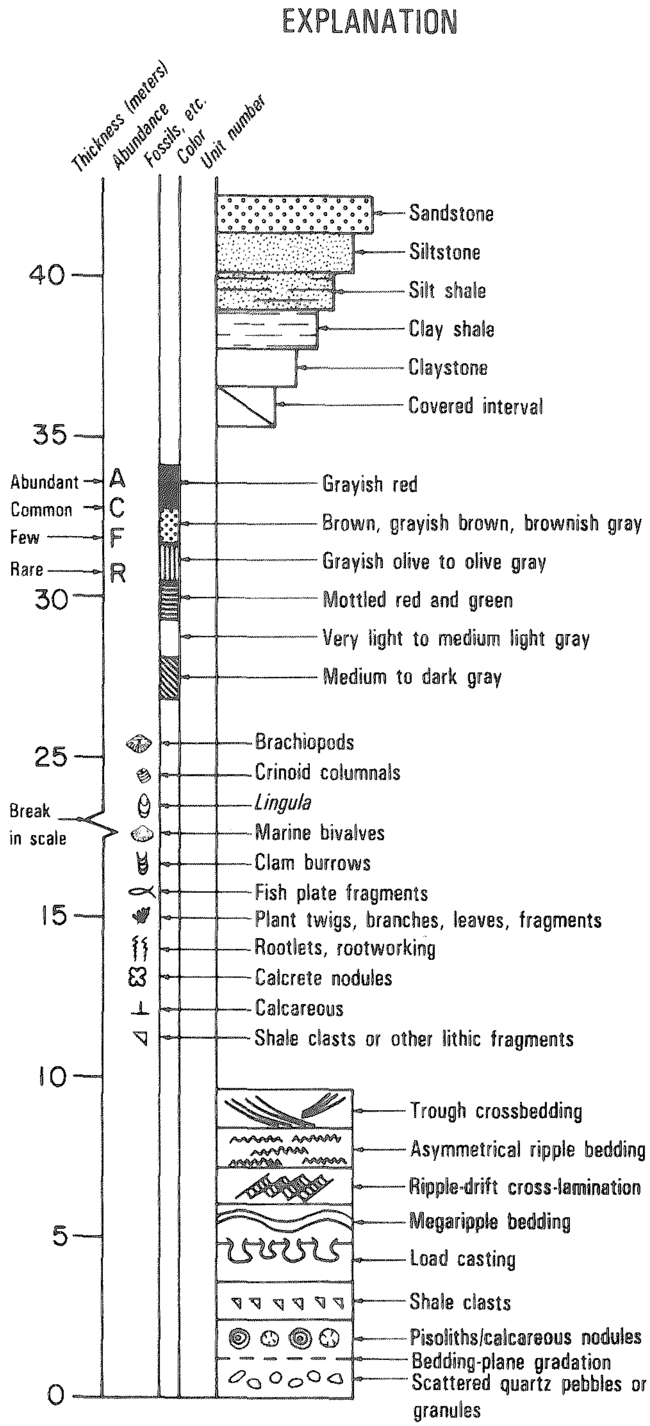
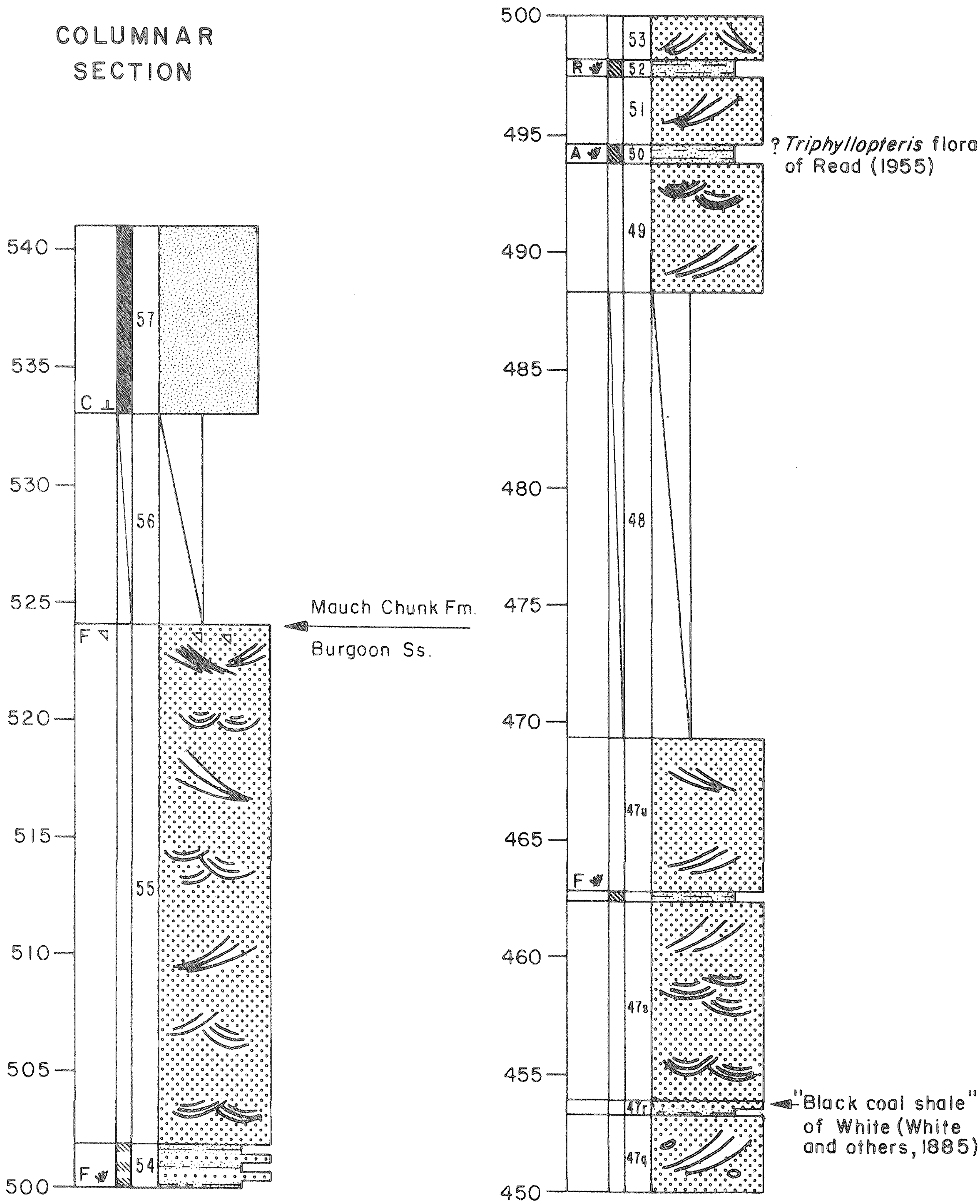


Figure 88. Columnar section of the Upper Devonian and Mississippian rocks exposed at the Warriors Path section.



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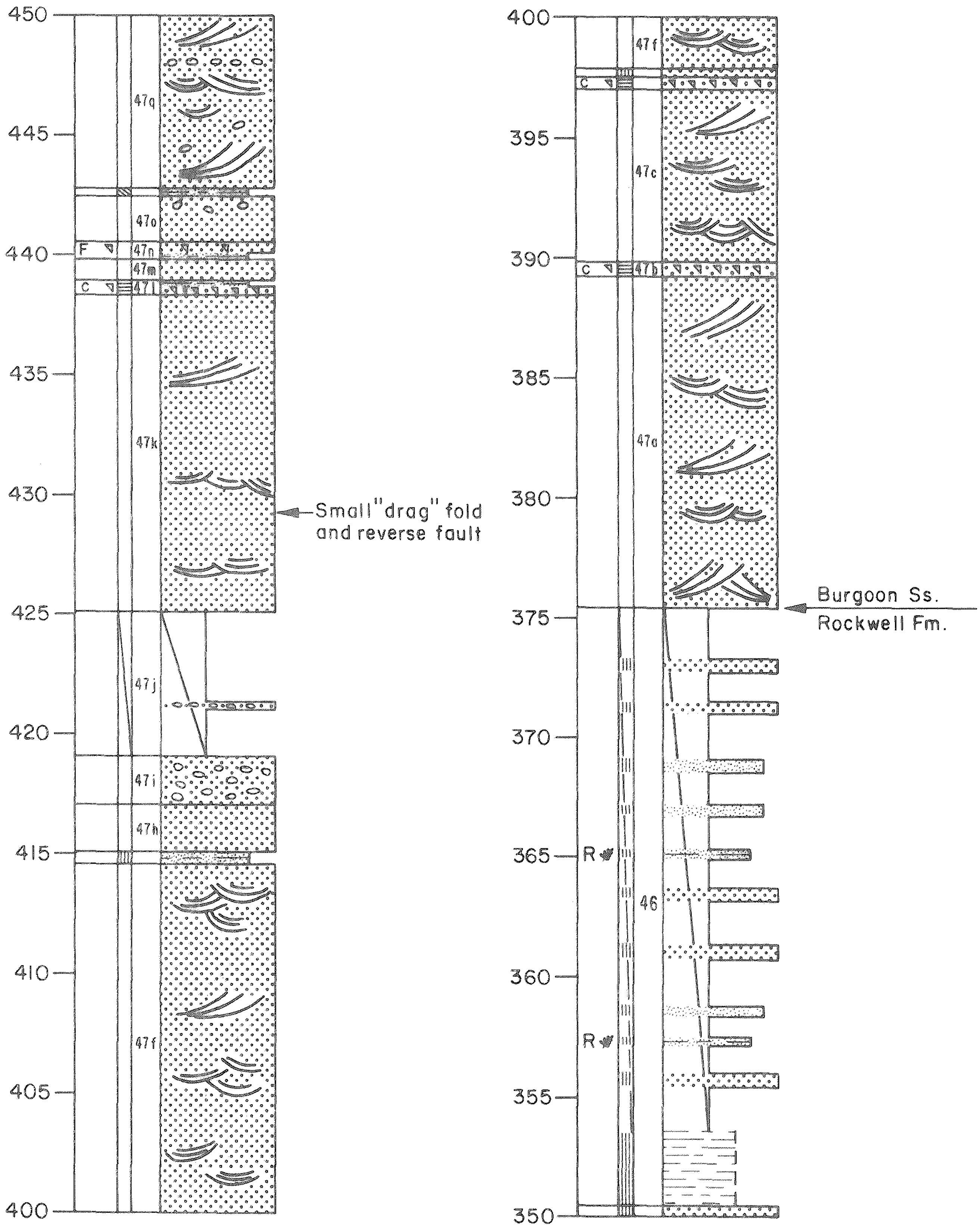

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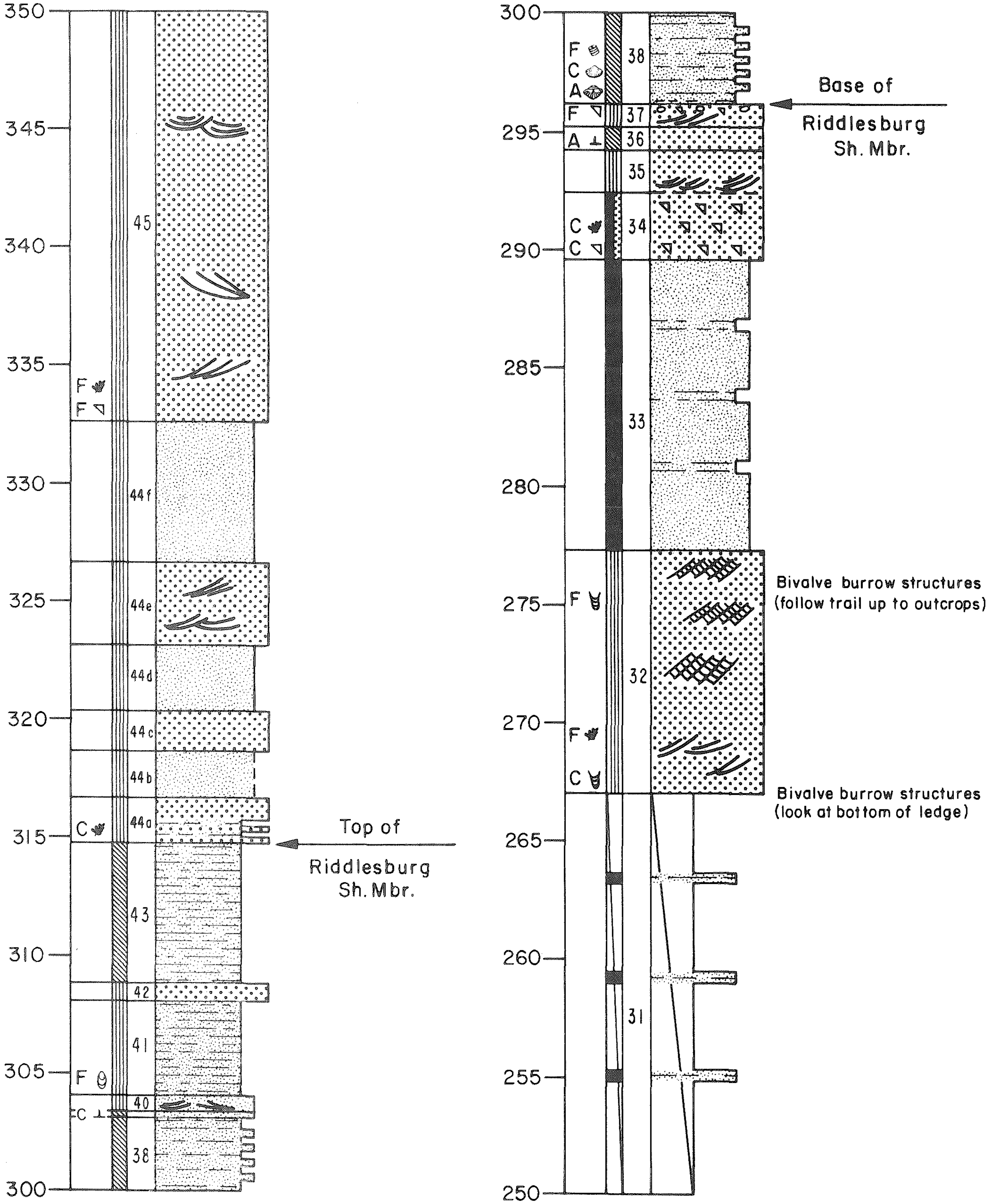

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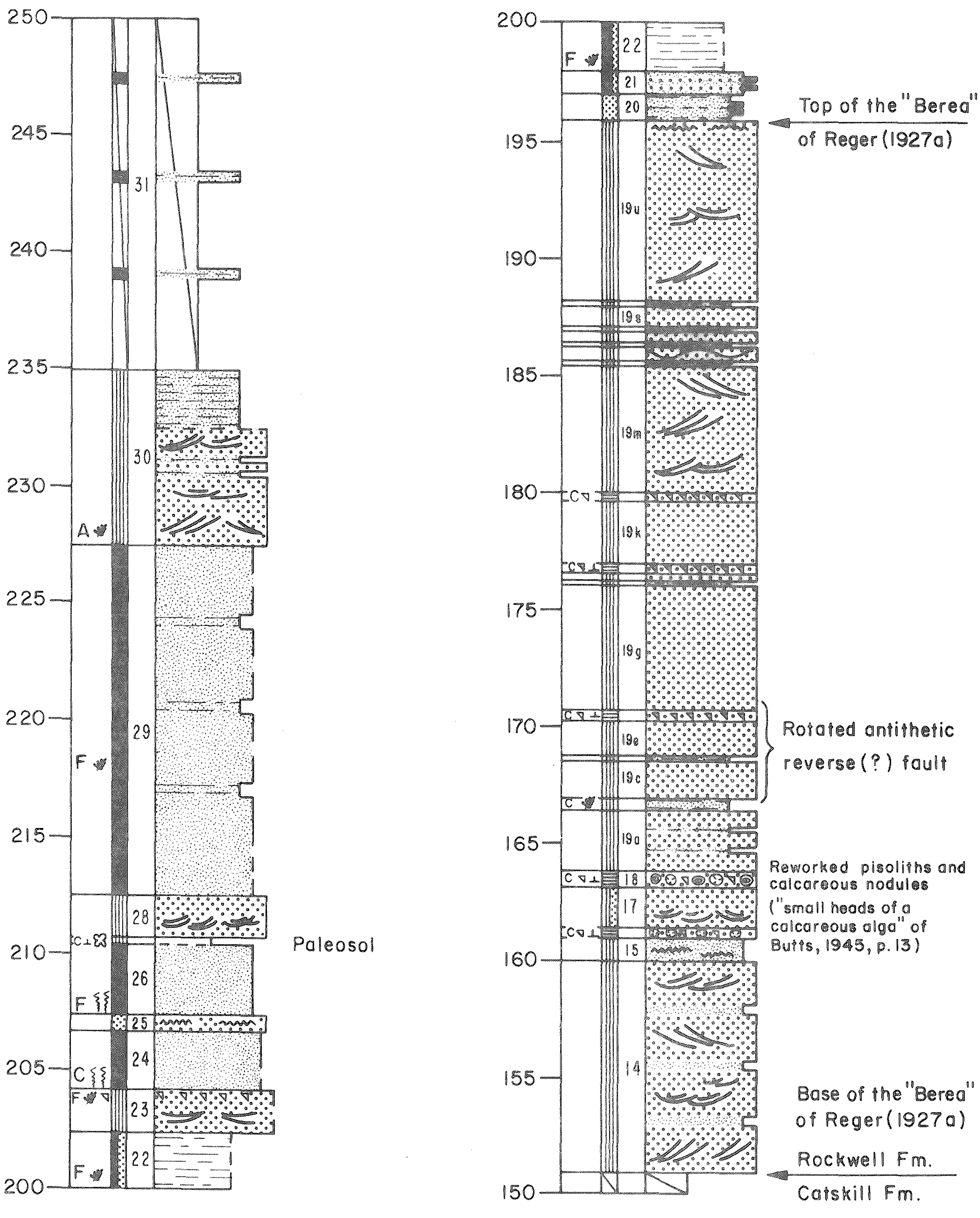

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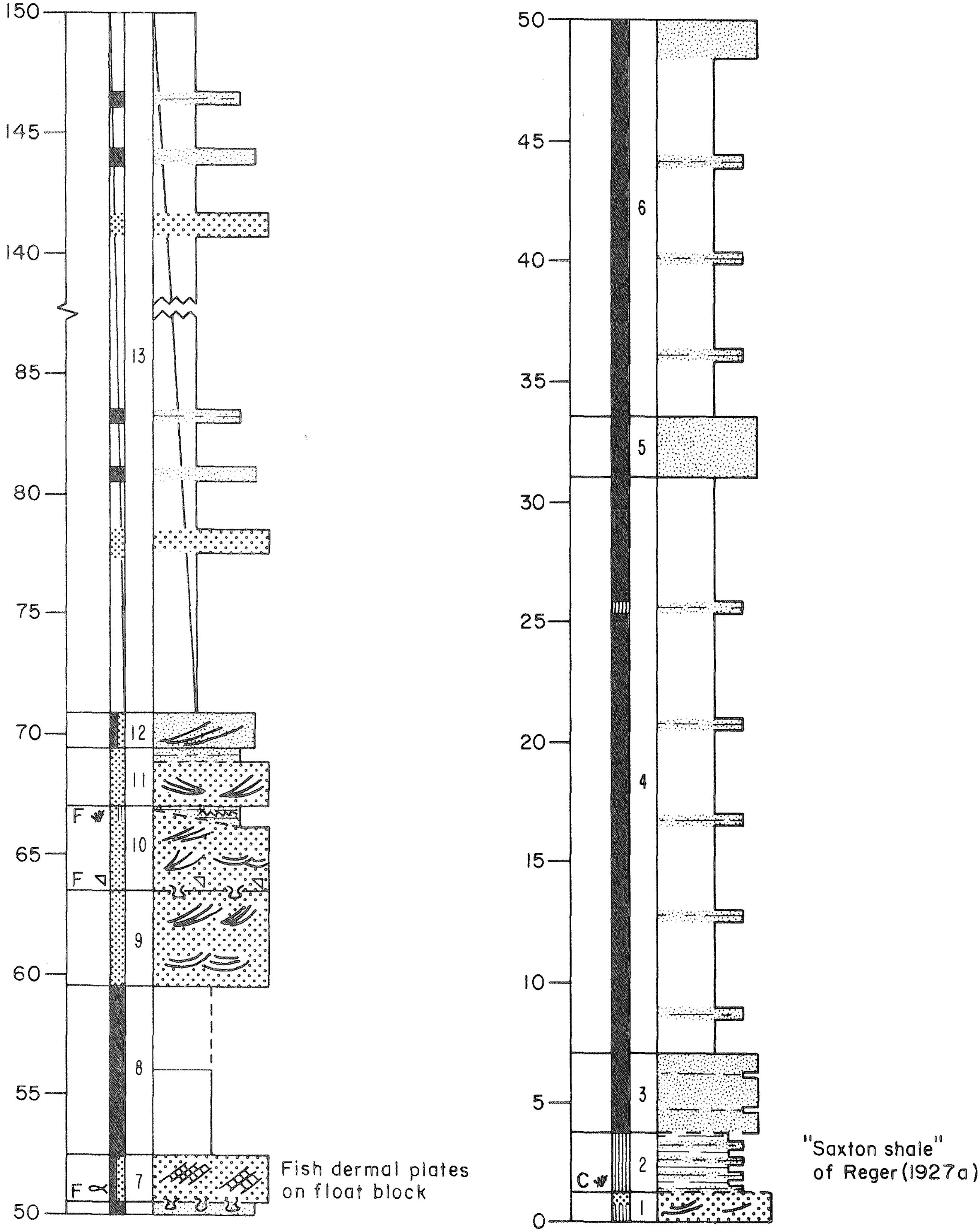


Figure 88. continued.

Figure 89. Photomicrographs of thin sections of:

a. Trough Creek Member calcareous sandstone showing angular to subangular quartz grains (Q), micrite pellets (m), ooid (o), and foraminifer (f) set in sparry calcite cement (s). Crossed nicols.

b. Trough Creek Member calcareous sandstone showing subangular grains of monocrystalline quartz (Q) and polycrystalline quartz (P), and micrite pellets (m) squeezed between quartz grains. Framework is cemented by sparry calcite (s). Crossed nicols.

c. Trough Creek Member calcareous sandstone showing ooid (o) with angular quartz nucleus, micrite pellet (m), and quartz grains (Q) set in sparry calcite cement (s). Note that some quartz is embayed and partially replaced by calcite. Crossed nicols.

d. Trough Creek Member calcareous sandstone showing quartz grain (Q) penetrating fossil fragment (F). Sparry calcite (s) fills center of fossil and other areas. Micrite pellets (m) at left. Plane-polarized light.

e. Trough Creek Member calcareous sandstone showing partially abraded endothyroid foraminifers (f), micrite pellet (m), and quartz grains (Q) set in sparry calcite cement (s). Foraminifer at right is same one shown in Figure 89a. Plane-polarized light.

f. Trough Creek Member very fine grained, calcareous sandstone showing very angular to subangular quartz grains (Q) and micrite pellets (m) set in sparry calcite cement (s). Plane-polarized light.

g. Trough Creek Member very fine grained, calcareous sandstone showing hematite-coated, partially-recrystallized ooid (o), micrite pellet (m), and partially-embayed and replaced quartz grains (Q), set in sparry calcite cement (s). Crossed nicols.

h. Trough Creek Member very fine grained, calcareous sandstone showing angular to subangular monocrystalline quartz grains (Q), hematite-coated micrite pellets (m), and rare plagioclase grain (p) set in sparry calcite (s) cement. Crossed nicols.

i. Burgoon Sandstone (unit 55) showing monocrystalline quartz (Q), polycrystalline quartz (P), microcrystalline quartz (x), metamorphic rock fragment (M), and rare plagioclase (p), cemented by authigenic quartz, which produces interlocking overgrowth grain boundaries. Very small quantities of illite (i) are present. Crossed nicols.

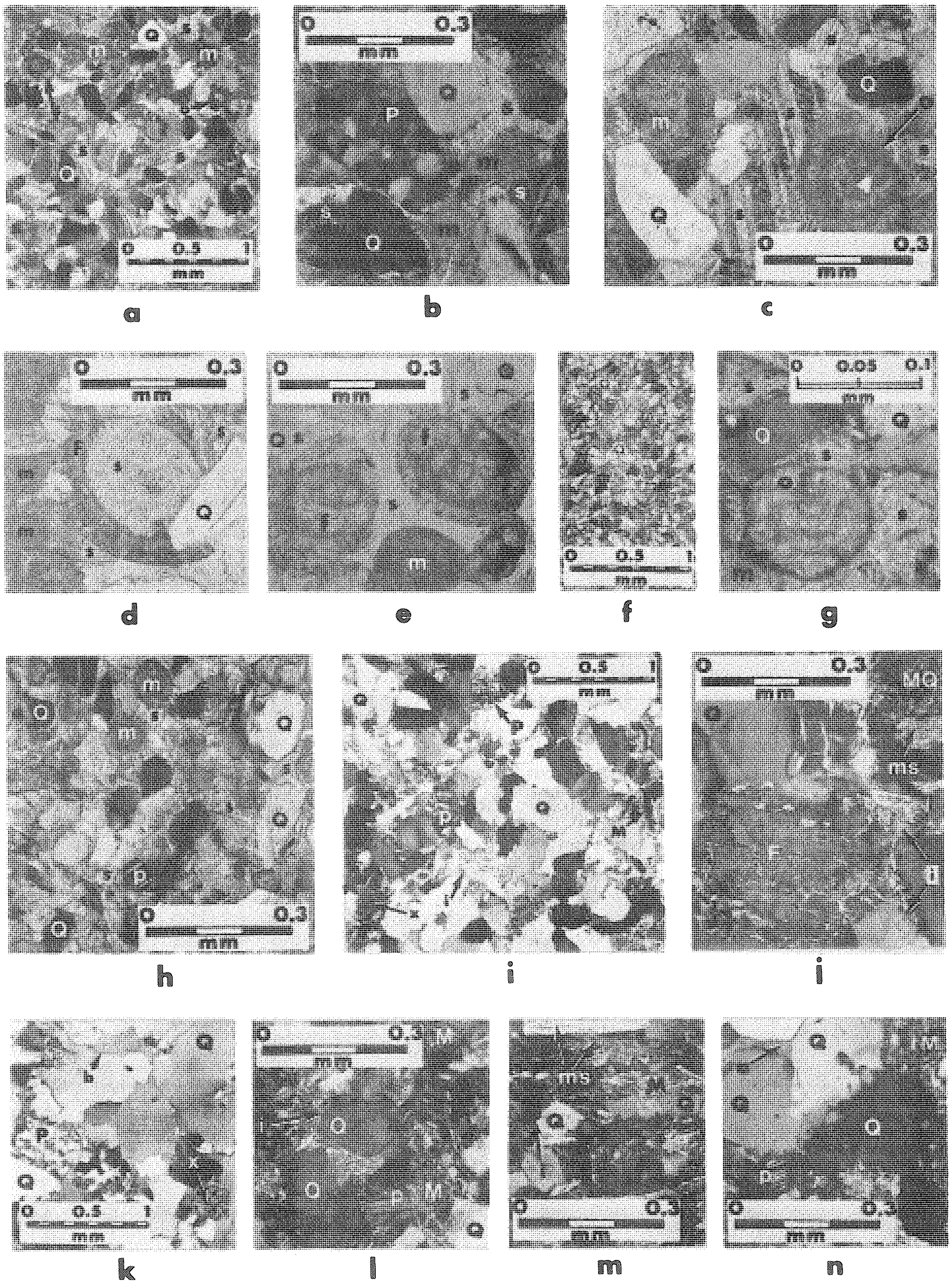
j. Burgoon Sandstone (unit 55) showing feldspar grain (F) partly replaced by illite. Monocrystalline quartz (Q), metaquartz (MQ), and some detrital muscovite (ms) comprise most of the framework. Illite matrix (i) is present in small amounts. Crossed nicols.

k. Coarse-grained Burgoon Sandstone (unit 47i) showing monocrystalline quartz (Q), polycrystalline quartz (P), and microcrystalline quartz (x) cemented by authigenic quartz overgrowths which produce interlocking, euhedral grain boundaries (b). Crossed nicols.

l. Rockwell Formation sandstone (unit 14) showing common quartz (Q), rare plagioclase feldspar (p), and common metamorphic rock fragments (M), set in illite matrix (i). Crossed nicols.

m. Rockwell Formation sandstone (upper part of unit 32) showing quartz (Q), metamorphic rock fragments (M), and detrital muscovite (ms), set in illite matrix (i). Crossed nicols.

n. Catskill Formation sandstone (unit 1) showing quartz (Q), plagioclase feldspar (p), and metamorphic rock fragment (M), set in illite matrix and authigenic quartz cement (a). Crossed nicols.


a
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Burgoon Sandstone

The next major subdivision to be observed is the Burgoon Sandstone (units 47-55 in Figure 88). As one of the major ridge-forming units of the region, the Burgoon Sandstone, or No. X of Rogers (1838), was confused with the much older Tuscarora Formation, or No. IV of Rogers (1838), until distinguished by the geologists of the First Geological Survey of Pennsylvania during their pioneer stratigraphic studies in 1836. Before this time, the No. X of Terrace (Saxton) Mountain was thought to be equivalent to the No. IV of Tussey Mountain to the west. Among other things, this conclusion incorrectly implied that the Broad Top coal measures were much older than their counterparts in western Pennsylvania (Lesley, 1876, p. 53-55). Fortunately for us, however, this was all clarified yesterday by "members" of the First Geological Survey at Stop 2.

The Burgoon Sandstone is about 148 m thick here and is generally well exposed. The Burgoon is dominantly trough crossbedded, very light gray to medium-light-gray, fine- to medium-grained sandstones with minor medium-dark-gray silt shales and variegated intraformational conglomerates. The sandstones are locally coarse to very coarse grained with scattered zones or layers of extraformational quartz-pebble and quartz-granule conglomerate. The sandstones would generally be classified as quartz arenites and sublitharenites. The sandstone framework is monocrystalline (dominant), polycrystalline, and microcrystalline quartz, some stretched metaquartz and metamorphic rock fragments, few feldspars and micas, and some heavy minerals. The framework is cemented predominantly by authigenic quartz, producing interlocking overgrowth grain boundaries (Figure 89i). There are few pockets of illite, and some feldspars are partly replaced by illite (Figure 89j). Even some of the coarser, less well sorted beds in the Burgoon have very little clay matrix, and are dominantly quartz with authigenic overgrowths as cement (Figure 89k). Well-developed, medium- to large-scale, moderate- to high-angle trough cross-strata are common. Bottom contacts of beds are sharp. The silt shale interbeds do not exceed 1 m and are commonly less than 0.5 m. They generally occur in the upper half of the unit and are commonly discontinuous. The total shale fraction (thickness) of the exposed interval is only about 3 percent. The intraformational conglomerates contain shale chips set in a sandy, muddy, iron-rich matrix. They are noncalcareous and are mostly confined to several relatively thin (≤0.6 m) interbeds in the lower half of the unit. Fining-upward cycles are absent. Coal is virtually nonexistent, with only one very thin (1 cm) coaly, carbonaceous zone (part of unit 47r) observed. Laird (1942, p. 71) apparently mistook some of the trough crossbedding for significant folding and thrust faulting and thought that some of the discontinuous silt shale interbeds had been tectonically squeezed. What do you think?

Of the relatively few plant fossils and carbonaceous fragments observed throughout the Burgoon, most are confined to the upper silt shale interbeds. In this regard, unit 50 is especially noteworthy. This carbonaceous silt shale contains an abundance of well-preserved fossil plant leaves (pinnules of ?Triphyllopteris) and twig fragments. Unit 50 is most probably collection locality 16 of Read (1955, p. 14-15), which was erroneously described as situated 2 miles north of Riddlesburg in Tussey Mountain rather than Terrace (Saxton) Mountain and where he identified Triphyllopteris latilobata Read. If our identification of the plant fossils is correct, unit 50 would fall within floral zone 2 of Read and Mamay (1964) and thus be Osagean to early Meramecian in age (Edmunds and others, 1979).

The Burgoon Sandstone is interpreted as the result of deposition by sandy braided-river systems on an alluvial plain. The terrestrial origin of this unit is suggested by the trough-style crossbedding, the locally well preserved plant fragments in the silt shales, and the lack of both marine and trace fossils. The observed features of the Burgoon are most compatible with braided-river models (see Walker, 1979) and include high sand content; dominantly coarse grained material; thin, scattered, laterally discontinuous, fine-grained material; and an absence of fining-upward cycles. The medium- to large-scale trough cross-strata were probably produced by sinuous-crested dunes that migrated within the major channels. The discontinuous silt shales are interpreted as partially preserved braid bars. The intraformational conglomerates represent lag gravels that formed in the deepest parts of channels following lateral erosion of braid bars.

The extensive, composite, laterally continuous sand sheets that can be produced by braided-river systems are consistent with the regional characteristics of the Burgoon. Cotter (1978, p. 367) has interpreted the fluvial style of the Burgoon Sandstone (Pocono Formation) in central Pennsylvania as channeled braided (i.e., composed of genetic units that are more channelized with low width-to-thickness ratios). Edmunds and others (1979, p. B13; B21, figure D) have suggested deposition of the Burgoon in a vast anastomosing alluvial sand plain or braided alluvial-deltaic sand plain.

Rockwell Formation

The Rockwell Formation at Warriors Path is around 224 m thick (units 14-46 in Figure 88). It is perhaps the most interesting unit of the section and certainly the most complex. The Rockwell consists of a heterogeneous assemblage of lithologic units that can be subdivided into 4 sequences: (1) a sequence at the base composed of dominantly light-olive-gray sandstones with minor silt shales and intraformational conglomerates (units 14-19); (2) a partly covered sequence of interbedded light-olive-gray sandstones, grayish-red siltstones and silt shales, and subordinate grayish-red clay shales arranged in fining-upward cycles (units 20-37); (3) a sequence of medium-dark-gray siltstones and silt shales with marine fossils towards the base (units 38-43); and (4) a sequence of interbedded light-olive-gray sandstones and olive-gray siltstones organized in fining-upward cycles (units 44-46). The thicknesses of sequences 1 to 4 are 44.9 m, 100.3 m, 18.6 m, and 60.7 m, respectively. The contact between the Rockwell and the underlying Catskill Formation is covered but probably sharp. Our interpretations of the depositional environments of the Rockwell are preliminary and based mostly on the Warriors Path section.

Sequence 1 (units 14 to 19)

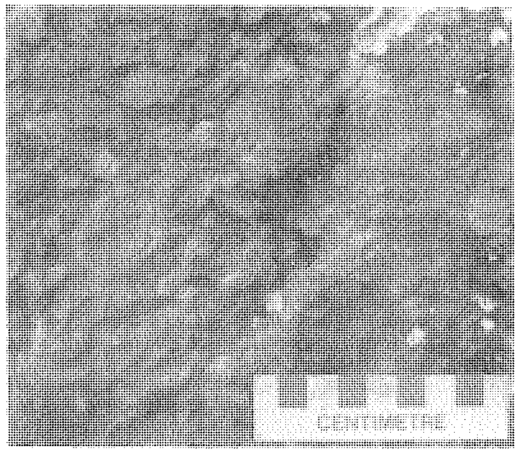
The sandstones of the sequence at the base of the Rockwell are light olive gray to grayish olive, very fine to mostly fine grained, generally well sorted, medium to thick bedded, and commonly planar bedded with some small- to large-scale, low-angle trough crossbedding. A few sandstones also exhibit sinuous ripple bedding (unit 19u) or megaripple bedding (unit 19o). Fining-upward cycles are very poorly developed or absent. Bottom contacts of the sandstones are sharp and planar. Petrographically, the sandstones are lithic graywackes (Figure 89I).

The few, thin (generally <0.2 m) silt shales contain abundant fossil plant debris and twigs on some surfaces and have sharp bottom contacts. They are somewhat discontinuous. The silty beds only make up about 1 percent of this sequence.

Two types of intraformational conglomerate are present. The first type occurs as several thin (0.4 m) interbeds in the upper two-thirds of the sequence and consists of poorly bedded masses of shale chips and clay galls set in a sandy, silty, muddy, calcareous to noncalcareous matrix. A few streaks of carbonaceous debris were observed. The bottom contacts of these beds are sharp. The second type of intraformational conglomerate (units 16 and 18) is situated in the lower third of the sequence and should be a good topic for discussion. Unit 16 consists of calcareous nodules and shale clasts set in a poorly sorted, sandy, silty, muddy, slightly calcareous matrix. In addition to these lithologies, unit 18 (Figure 90a) contains pisoliths and thin, laterally discontinuous, wedge-shaped sandstone beds. The pisoliths are entirely calcareous. Many contain obvious concentric internal structures, whereas others exhibit a radiating pattern. The pisoliths in this bed were examined by Butts (1945, p. 13), who astutely described them as "small heads of a calcareous alga." Unit 18 also represents one of the "calcareous breccias" of White (White and others, 1885, p. 81). These 2 units thin laterally and have sharp bottom contacts.

Although some of the gross aspects of this sequence suggest deposition by braided-stream systems, we believe that these rocks reflect sedimentation by sandy, low-sinuosity streams that wandered freely across a lower alluvial plain to upper delta plain. A key to our interpretation is the presence of reworked pisoliths and calcareous nodules in units 16 and 18. This suggests that stabilized, nearby overbank deposits existed long enough for the development of caliche or carbonate-rich soil and perhaps small, ephemeral lakes or ponds. As the streams migrated laterally and eroded their banks, the interfluvial deposits were generally reworked and occasionally preserved in the channel fill. Thus, evidence of former floodplain or vertical accretion deposits implies meandering systems; the lack of fining-upward cycles suggests low sinuosity rather than high. Moreover, in contrast to the Burgoon Sandstone, this sequence is predominantly planar bedded with some less well developed, lower angle trough cross-bedding and is composed of finer grained sandstones. As another interpretation, could we be looking at a single major channel belt of a high-sinuosity meander system? The lateral variability of this sequence is poorly known, but some data (Reger, 1927a) suggest that the interval is nearly all sandstone between Saxton and Hopewell, a distance of about 10 km.

Figure 90. Sedimentary and biogenic structures at Stop 11: a, Calcareous intraformational conglomerate in the Rockwell Formation (unit 18) with pisoliths, calcareous nodules, and shale clasts; b, Lower bedding surface of unit 32 in the Rockwell Formation showing protrusions which are interpreted to be the bottoms of escape burrows of freshwater clams; c, Vertical cross-section of an escape burrow of a freshwater clam in the upper part of unit 32 in the Rockwell Formation (note downward bending of sandstone laminae adjacent to burrow, and internal downward crescentic structure within the burrow); d, Ripple-drift laminations in sandstone of upper part of unit 32 in the Rockwell Formation; e and f, Dermal plates of Late Devonian fish in red coarse siltstone of unit 7 in the Catskill Formation (note variation in shape and ornamentation).



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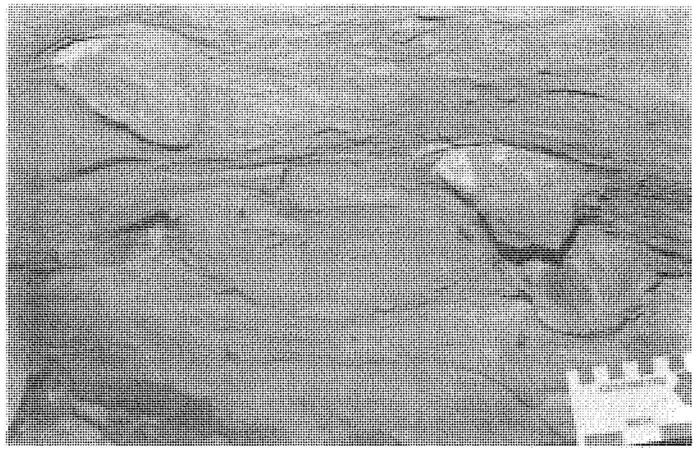

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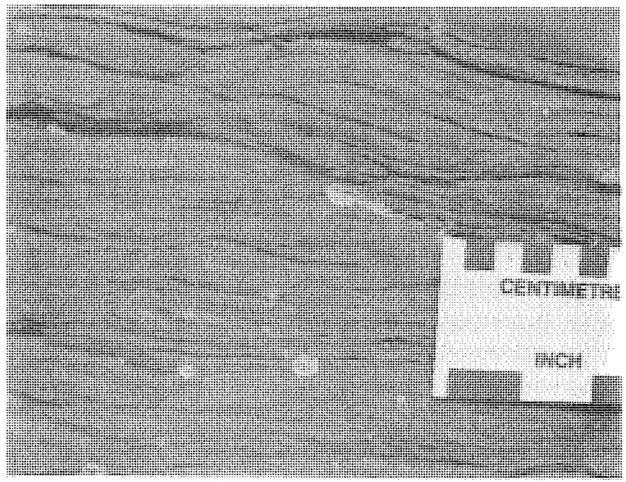

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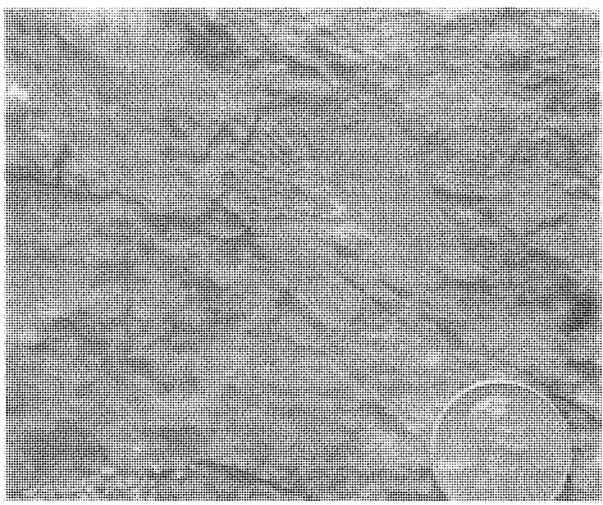

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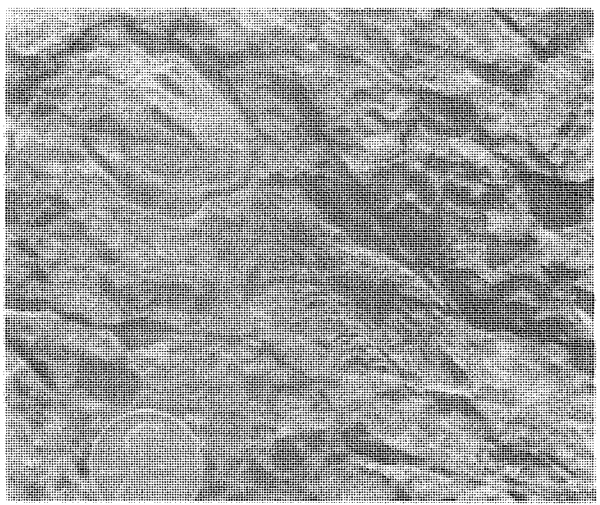

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Sequence 2 (units 20 to 37)

The sandstones are mostly light olive gray, very fine to fine grained, and thin to medium bedded. The sandstones are probably lithic graywackes for the most part (Figure 89m). A few shale chips and plant fragments are present except locally where they are common to abundant. Variegated intraformational conglomerate (unit 34) is present near the top of the interval. It consists of a poorly sorted mixture of shale and siltstone clasts set in an iron-rich, sandy, muddy, clayey matrix. Fossil plant fragments, twigs, and branches are common. Several pebbles of quartz and chert occur in the uppermost bed of this sequence (unit 37). The unit below (unit 36) is very calcareous but apparently unfossiliferous. The sandstones contain both parallel laminations and medium- to large-scale, low-angle trough crossbeds. Some ripple bedding was observed and will be discussed later. Bottom contacts of beds are generally sharp, except for unit 35 which is gradational.

The finer grained rocks are mostly grayish red and dominantly siltstones and silt shales. Some of the beds are rootworked and contain plant fragments. One light-olive-gray claystone (unit 27) contains calcrete nodules that are locally common and up to 2 cm long.

This sequence is characterized by fining-upward cycles. Although the interval is partly covered, cycles appear to range from about 8 to 40 m in thickness. At least 5 cycles are present. The grayish-red silt and clay fractions comprise 48 to 81 percent of each cycle and are greatest towards the middle of the sequence.

One sandstone (unit 32) is particularly interesting, and contains bivalve escape burrows and very well developed ripple-drift cross-laminations. Several of the burrows are exposed at the base of the unit as protrusions on the bottom of the overlying ledge (Figure 90b) (visible at path level), and a few can be seen in vertical cross section (Figure 90c) about 2 m below the top of the unit in the ripple-drift beds (follow trail up to outcrops). The burrows are up to 10 cm in diameter, exhibit internal crescentic structures, and show downward-curving laminae along the outside walls. They were produced as the result of upward movement by clams following rapid burial. Some aspects of the burrow morphology are similar to those described by Thoms and Berg (1985) and Bridge and others (1986) for bivalve escape burrows of the Upper Devonian Catskill Formation in northeastern Pennsylvania, southeastern New York, and northern New Jersey. They interpreted the clams as nonmarine, non-siphonate, epifaunal to shallow infaunal suspension feeders. The escape burrows at Warriors Path are believed to be the first known occurrence above the Catskill in Pennsylvania.

The ripple-drift cross-laminations (Figure 90d) have high amplitude, are highly sinuous to almost linguoid, and are a product of unidirectional flow. They are the dominant sedimentary structure in the upper two-thirds of the sandstone, whereas the lower third is mostly planar bedded with some medium- to large-scale trough cross-strata. This sandstone is interpreted as a point-bar deposit in a meandering stream that aggraded in response to a rapid supply of sediment from suspension.

This sequence is believed to represent sediments that were deposited by high-sinuosity meandering streams on a subsiding upper delta plain that was ultimately inundated by a marine transgression. Unit 19u can be interpreted as marking the base of the first fining-upward cycle, and thus genetically could be included in this sequence rather than the preceding one. As vertical accretion occurred, levees were occasionally breached by small floods, resulting in crevasse deposits (unit 25). Caliche soils developed on the floodplains and were sometimes preserved beneath the base of a fining-upward cycle (unit 27). As a result of subaerial exposure, oxidation of the overbank sediments produced the red color. In the distal parts of the upper delta plain, communities of freshwater clams dwelled on the point bars of streams (unit 32). As this stream channel migrated laterally, vertical accretion deposits resulted from periodic overbank flooding (unit 33). This was eventually interrupted by a crevasse splay (?) (units 34 and 35) whose deposits were subsequently reworked (units 36 and 37) during the rapid marine transgression of the Riddlesburg. The short stratigraphic interval between the last fining-upward cycle (units 32 and 33) and the marine silt shale (unit 38) implies a relatively short distance between upper delta plain and marine depositional environments. This may suggest that units 32 and 33 represent deposition by a small meandering stream system along the flank of a delta lobe away from major distributary-mouth processes.

Sequence 3 (units 38 to 43)

This interval corresponds exactly to the type section of the Riddlesburg Shale Member (Reger, 1927a, p. 400, unit 10). We do not understand or agree with Laird's (1942, p. 72) subsequent modification of the type section that would also include our units 44a to 44d. The Riddlesburg marine shale was first recognized here by White (White and others, 1885, p. 81).

The Riddlesburg Shale Member consists mostly of medium-dark-gray to dark-gray and medium-olive-gray to olive-gray, pure to clayey siltstones and silt shales. These lithologies display well-developed exfoliation and cleavage that yield hackly and splintery fragments ("pencil" forms). Minor very fine grained, light-olive-gray to olive-gray sandstone is present in the upper third of the sequence. One thin (0.2 m) calcareous siltstone was observed and contains no macrofossils.

Unit 38 contains a low-diversity, open-marine fossil fauna (see Appendix 3, p. 225). Invertebrate fossils are present throughout this unit but are more common to abundant in the bottom 2 to 3 m. The most common genera appear to be _Rhipidomella_, _?Camarotoechia_, and _Chonetes_ (brachiopods) and _Cypricardinia_ (bivalve). The predominantly articulate brachiopod fauna is commonly iron stained. Most fossils are deformed and are preserved as internal and external molds.

The Riddlesburg Shale Member is probably Early Mississippian (Kinderhookian) in age (Berg and others, 1983), but the evidence is equivocal. Girty (1928, p. 112) accepted a Mississippian age for the Riddlesburg but pointed out that "the [Early] Carboniferous age of this [Riddlesburg] fauna, though it is very probable on broader grounds, is but slenderly supported by the evidence of the fauna itself." Caster (1934, p. 38) noted that the Riddlesburg lacked critical Mississippian forms. Chadwick (1935, p. 141) concurred and asserted that Girty studied the Riddlesburg fauna with the preconception that it was Mississippian. Willard (1939, p. 303) accepted the Pocono (Mississippian) age of the Riddlesburg without comment. Laird (1942, p. 71-72) concluded that the Riddlesburg at Warriors Path (and elsewhere) was of Early(?) Mississippian (Kinderhookian?) age. At some other exposures of the Riddlesburg, Laird (1942) identified the brachiopod _Syringothyris_, which was later considered a diagnostic Lower

Mississippian (Kinderhookian) form in northwestern Pennsylvania (Holland, 1958). Weller and others (1948, p. 170) acknowledged the uncertainty of the Mississippian age of the Riddlesburg Shale Member, but nevertheless showed (chart 5, column 102) the Riddlesburg as Lower Mississippian (Osagean). Their reason for not accepting Laird's Kinderhookian(?) age was not explained. Edmunds and others (1979, p. B15-B17) have discussed the lack of adequate paleontological studies of the Mississippian of Pennsylvania and the need for a biostratigraphic zonation of the Lower Mississippian marine sequence. Clearly, much research remains to be done on the Riddlesburg Shale, including studies in regional stratigraphy, micropaleontology, and paleoecology.

The Riddlesburg is interpreted as interdistributary bay-fill deposits. Unit 38 represents the most open-marine facies of this low-energy, nearshore environment. The number of invertebrates decreased upward in unit 38 as the bay became more restricted. Eventually, the open-marine fauna was replaced by brackish-water forms, particularly Lingula (unit 41). Circulation finally ceased, and the former bay became a lake or swamp on the lower delta plain.

Sequence 4 (units 44 to 46)

The uppermost sequence of the Rockwell Formation is characterized by fining-upward cycles. Although the top half (unit 46) is partly covered, interbedded sandstones and siltstones comprise the bulk of this interval.

The sandstone beds thicken and coarsen upward. They are mostly light olive gray, and range from very fine grained at the base (units 44a and 44c) to fine to medium grained at the top (unit 45) of the well-exposed interval. The sandstones are mostly planar bedded but exhibit some low-angle trough crossbedding. Some plant fragments are present in unit 45. Bottom contacts of beds are sharp.

The siltstones are olive gray and contain common plant fragments at the base (unit 44a) of the sequence. Unlike sequence 2, red beds are absent. Bottom contacts of beds are also sharp.

The partly covered interval includes sandstones, predominantly siltstones, and some silt shales, with silty clay shale at the base. The rocks are light olive gray to olive gray. The sandstones are very fine to almost fine grained and appear to be mostly parallel bedded. They contain a few plant fossils. The whole succession appears to coarsen upward grossly and probably consists of fining-upward cycles that become increasingly silty and sandy.

This interval suggests a return to deposition of sediments by high-sinuosity meandering streams on an upper delta plain. The base of the sequence is believed to reflect the growth of a new delta lobe (delta switching). Units 44a to 44d are interpreted as an alternating series of crevasse and floodplain deposits. This was followed by sedimentation produced by a small meandering stream system (units 44e and 44f). A larger channel system (unit 45 and part of 46) eventually developed further up on the delta plain. Progradation continued, and the meadering streams finally gave way to the braided style of the Burgoon Sandstone.

Catskill Formation

The upper 150 m of the Catskill Formation (units 1 to 13) constitutes the last interval to be examined. The Catskill consists of mostly grayish-red silt shales, silty claystones, and claystones with subordinate grayish-red siltstones and brownish-gray to moderate-yellowish-brown, very fine to fine-grained sandstones. The sandstones are locally light olive gray to grayish olive and are somewhat trough crossbedded. These Catskill sandstones are mostly lithic arenites (Figure 89n). Locally, they also contain a few clay chips, plant fragments, and load features. Several well-preserved fish plates (Figures 90e and 90f) are present on one sandstone float block (unit 7). (Please DO NOT disturb; leave the collecting to the specialists!) Unit 7 is also ripple-drift cross-laminated in places. Units 9 to 12 comprise a well-developed point-bar sequence consisting of interbedded trough crossbedding and horizontal (parallel) laminations with occasional ripple bedding. Where plant fragments are locally common, such as in unit 2 (the presumed "Saxton shale" of Reger, 1927a), the organic material has reduced the iron pigmentation of the rock, thus changing the color from grayish red to grayish olive. Can you follow this color change laterally?

The rocks are characterized by fining-upward cycles that range in thickness from 4 to 28 m. Fine-grained material dominates and comprises about 68 to 88 percent of each cycle. The upper half of the interval is mostly covered but appears to contain 2 or 3 (?) additional fining-upward cycles. The sandstones or siltstones at the base of the cycles are generally separated from the underlying units by a sharp to slightly erosional contact. The sandstones and siltstones usually grade upward to much thicker claystones and silt shales that mark the top of the cycles. The Catskill at Warriors Path contains some clastics that are finer grained than those found in any other part of the section.

This part of the Catskill Formation is interpreted as having been deposited as sediments by high-sinuosity meandering streams in a muddy, low-gradient alluvial plain. The thickness of the preserved vertical accretion (floodplain) deposits and fine grain size of the channel fill suggest a low regional slope and slowly migrating channels. Rahmanian (1979) has interpreted the upper Catskill of the Broad Top region as representing a low-relief, inactive "coastal" plain or intradeltaic area having channel belts of small, highly sinuous meandering streams and broad flood basins. The lack of extensive and thickly developed sandstone sequences suggests that large stream channels were absent.

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		LEAVE STOP 11. RETURN via route came.
1.3	82.9	STOP SIGN. TURN LEFT onto Liberty Street.
0.9	83.8	STOP SIGN. TURN LEFT onto PA Route 913 West.
0.1	83.9	Floodplain of Juniata River and view ahead of Piney Ridge (low) and Warrior Ridge (high).
0.5	84.4	STOP SIGN. TURN RIGHT onto US Route 26 North at gap in Piney Ridge.
3.2	87.6	Philips Rangers historical sign on right.
1.2	88.8	Huntingdon County line. Good view ahead on left of Tussey Mountain.
2.0	90.8	St. Mathews Lutheran Church on right.
2.9	93.7	Seven Points Recreation Area to right.
6.2	99.9	TURN RIGHT to US Route 22 East.
0.2	100.1	STOP SIGN. TURN RIGHT onto US Route 22 East.
1.3	101.4	TURN LEFT into parking lot of Raystown Country Inn. **END OF 1986 FIELD CONFERENCE!! HAVE A SAFE TRIP HOME!! SEE YOU NEXT YEAR!!**

APPENDIX 1

MEASURED SECTION OF ORDOVICIAN CARBONATES

Described section of the Loysburg through Nealmont Formations in roadcut (lat. 40°37'28"N, long. 78°10'25"W) located about 0.8 mile northwest of Union Furnace. Section begins on the west side of the road at the northern end of the roadcut at road level approximately 460 feet south of the first intersection of a macadam road on the west side of PA Route 453 and ends on the east side of the road near the southern end of the road cut. Measured and described by S. W. Berkheiser, Jr. See Thompson (1963) for a description of the Salona through Coburn Formations measured in the nearby Warner Company quarries.

Unit	Lithologic description	Thickness (in feet)

Loysburg Formation (56.3 feet thick)

-04 Mudstone (limestone), olive black, containing very faint horizontal burrowing and mottling, occasionally faint laminations present, basal contact slightly irregular but sharp....1.1
Mudstone (dolomitic), olive gray, sharp flat basal contact....0.6
Mudstone (dolomitic), olive gray, containing thin dolomite laminations at upper contact, burrowed and mottled, contacts undulatory....1.2
[Subtotal 2.9]

-03 Mudstone (limestone), olive gray, containing distinct bands and laminations especially at base, horizontal burrowing, pyrite spheres and cubes up to 1 cm in diameter, local wedge faulting may repeat small portions of the section....6.4
Mudstone (limestone), olive black, containing very faint laminations towards top, minor stylolites, both contacts obscured by cover....1.8
Covered (might be finely laminated or travertine zone)....1.0
Mudstone (dolomitic), olive black to olive gray, containing distinct bands and laminations, at 1.0' above base occurs 0.2' thick dolomitic band above which bands and laminations become less distinct, at 1.7' from base occurs an undulatory and channel-like skeletal wackstone bed <0.1' thick con taining pyrite, both contacts undulatory....2.4
Mudstone (limestone), olive black, containing faint mottling, horizontal burrowing, upper contact slickenlined, minor stylolites....2.2
[Subtotal 13.8]

Section projected and moved to upper bench on the same side of the road (west) due to covered, faulted, and travertine area.

-02 Covered....1.0
Cryptalgal mudstone, olive gray to olive black, containing convex stromatolites, rare shaley lenses, minor burrowing and mottling, 1.8' thick intraclastic zone 2.2' from top composed algal mats, fluorite in calcite veins at 3.5' from base, both contacts obscure....6.6
Mudstone (dolomitic), olive black, containing faint laminae locally convoluted, abundant micro-calcite veinlets....2.8
Mudstone, olive black, containing distinct planar laminae, minor stylolites, horizontal burrowing pyrite cubes and blebs....5.4
Intraclastic mudstone, brownish gray to olive black, containing clasts up to 0.1' in diameter, basal contact obscure upper contact undulatory.1.1
Mudstone, brownish black, containing very faint laminae....0.7
[Subtotal 17.6]

-01 Mudstone (dolomitic), brownish black, containing distinct closely spaced planar laminae, flaggy bedded....7.1
[Subtotal 7.1]

0 Mudstone, olive black, containing distinct laminae at the base becomes mottled in the middle and less distinct towards the top, abundant horizontal worm burrows, minor small shelly fragments locally, planar basal contact....6.4
Mudstone (dolomitic), pale yellowish brown to olive gray, containing very faint laminae, locally minor small shelly fragments, pellets at 3.6' from base, slightly undulatory basal contact....7.8
Mudstone (dolomitic), light olive gray, containing distinct planar laminae....0.7
[Subtotal 14.9]

Total thickness of the Loysburg Formation 56.3

Hatter Formation (99.7 feet thick)

Section projected back to road level on the same side of the road (west).

1 Mudstone, olive gray to olive black, containing wavey faint laminae locally, minor stylolites, trace pyrite near top, basal contact sharp and planar....4.3
Mudstone-wackstone, dark gray, containing minor discontinuous laminae, locally small articulate brachiopods, at 0.8' from base a 0.2' thick intraclastic zone, a 0.1' thick undulatory shaley parting at top, basal contact planar....1.7
Mudstone, medium dark gray, containing disarticulate shell fragments and common calcite replacement of fossil debris, 0.1' thick shale parting at top....0.5
Mudstone, dark gray, containing a 0.4' thick wackstone at the top, wavey laminae common at base, minor calcite replace skeletal debris throughout....1.4
Mudstone, olive black, containing a 0.5' thick undulatory laminae zone at base, minor to rare calcite replaced skeletal fragments, basal contact slightly undulatory....1.4
Mudstone, dark gray, containing very faint bands and laminae, rare calcite replaced brachiopod fragments, slightly undulatory basal contact..0.8
Mudstone, medium dark gray, containing laminae, 0.08' thick intraclastic zone at top....0.2
[Subtotal 10.3]

2 Packstone, dark gray, containing small intraclasts, rare mudstone intraclasts up to 1 cm in diameter at top, undulatory laminae, brachiopod fragments, basal contact planar....1.05
Mudstone-wackstone, dark gray to grayish black, containing distinct laminae, small intraclasts and brachiopod fragments, clay-carbon stylolite-like upper contact....0.75
Mudstone, dark gray to grayish black, containing minor wackstone, locally very faint laminae....0.7
Packstone, dark gray to grayish black, containing minor undulatory laminae near middle, basal contact locally stylolitic....1.05
Mudstone-wackstone, dark gray to grayish black, containing undulatory laminae, calcite replaced skeletal debris....0.35
Packstone, dark gray to grayish black, containing brachiopod fragments, very faint undulatory laminae, basal contact slightly undulatory....0.7
Mudstone-wackstone, dark gray to grayish black, containing undulatory laminae, minor calcite replaced skeletal debris, 0.1' thick light brownish gray bentonitic (?) parting (0) at top....0.5

Unit	Lithologic description	Thickness (in feet)

Mudstone, grayish black, containing minor wackstone near top, undulatory laminae grade into 0.15' thick planar shaley zone at top, minor calcite replaced skeletal debris throughout....1.55
Mudstone, olive black, containing minor undulatory laminae at base, minor calcite replaced skeletal debris, planar basal contact....1.2
Packstone, grayish black to dark gray, containing intraclasts, pellets brachiopod fragments, minor stylolites....2.0
Wackstone-mudstone, grayish black to dark gray, containing abundant skeletal debris (especially brachiopod fragments) very faint undulatory laminae, slightly undulatory basal contact....1.3
[Subtotal 11.2]

Section projected to east side of road at road level.

3 Mudstone-wackstone, grayish black to dark gray, containing distinct mottled laminae many of which are discontinuous, locally fenestral-like, skeletal debris common some of which are replaced with a dark yellowish orange calcite, burrowing locally common, 0.5' thick nodular like argillaceous zone at 3.5' from the top....40.8
[Subtotal 40.8]

4 Mudstone-wackstone, grayish black to brownish black, containing mottled discontinuous undulatory laminae and bands, disarticulate and articulate brachiopods, horizontal worm burrows, pellets, quartz sand (?), slightly undulatory basal contact....1.5
Wackstone, grayish black, containing distinct bands and discontinuous laminae, similar to above unit but more intensely mottled, skeletal debris common, horizontal worm burrows, pellets, trace pyrite, slightly undulatory basal contact....3.0
Wackstone-mudstone, grayish black to brownish black, containing mottled discontinuous laminae, brachiopod fragments, pellets, quartz sand (?), horizontal worm burrows, slightly undulatory basal contact....1.4
Packstone-wackstone, grayish black to dark gray, containing indistinct discontinuous undulatory laminae some of which are mottled; abundant brachiopod, bryozoa, and skeletal debris; hardgrounds; common pyrite...1.0
Mudstone-wackstone; grayish black to brownish black; containing indistinct, discontinuous, undulatory, laminae some of which are mottled; horizontal worm burrows; small brachiopod fragments; pellets; quartz sand (?), common pyrite....1.0
Packstone, grayish black to brownish black, containing abundant large brachiopod fragments, a 0.05' thick pelletal zone in the middle, pyrite, horizontal burrows, whole unit is discontinuous and pod-like....0.25
Mudstone-wackstone, grayish black, containing distinct coarse mottled banding, disarticulate and articulate brachiopods, horizontal burrowing, pellets, quartz sand (?), basal contact gradational....2.1
Wackstone, brownish black, containing mottled banding, discontinuous undulatory laminae, horizontal burrows, common small brachiopod fragments, pellets, basal contact gradational....1.3
[Subtotal 11.6]

5 Wackstone-packstone, brownish black, containing very distinct mottling similar to above only here mottling is light gray color where above it is dark gray, abundant brachiopod and bryozoa fragments, pellets, horizontal burrows, trace pyrite, quartz sand, gradational basal contact...7.1
[Subtotal 7.1]

6 Banded packstone-wackstone, dark gray to grayish black, containing cycles comprising of <0.1' thick basal skeletal lag followed by <0.35' thick burrowed laminae zone having minor brachiopod fragments, quartz sand, common pyrite....3.6
Packstone, medium dark gray to brownish black, containing laminae, cross-stratification, quartz sand and silt, minor pockets of small brachiopod fragments, pyrite....4.2
[Subtotal 7.8]

7 Packstone-wackstone, dark gray to olive gray, containing distinct laminae and bands that locally are wavey and nodular-like, quartz sand, locally disarticulate brachiopod fragments, minor horizontal burrowing, basal contact gradational....2.3
Packstone-grainstone, brownish black, containing skeletal debris, agrillaceous undulatory laminae in middle of unit, undulatory basal contact....2.0
Wackstone-packstone, dark gray to brownish gray, containing undulatory discontinuous mottled laminae, disarticulate brachiopod fragments, horizontal burrows, slightly undulatory basal contact....3.1
Wackstone, grayish black, containing indistinct laminae, disarticulate brachiopod fragments, argillaceous bands at 1.9' from base, minor horizontal burrows, shaley parting at top....3.5
[Subtotal 10.9]

Total thickness of the Hatter Formation 99.7

Snyder Formation (95.5 feet thick)

8 Mudstone (dolomitic), grayish black to black, containing horizontal burrows, some laminae and bands, minor brachiopod fragments, quartz sand and silt, 0.15' thick grayish black shaley parting at top....1.1
Silty wackstone (dolomitic), grayish black, containing distinct bands and laminae, minor ripple cross-stratification, horizontal and vertical burrows, minor brachiopod fragments, minor pyrite, minor calcite and dolomite filled vugs up to 0.2' in diameter locally, 0.3' thick collapse (?) breccia at base, dusky yellowish brown shaley parting at top....3.9
[Subtotal 5.0]

9 Skeletal packstone (dolomitic), dark gray to brownish black, containing brachiopods, bryozoa, crinoids (?), horizontal burrows, birdseye or fenestral textures, thin clay-carbon shaley residue at top....0.35
Mudstone-wackstone (dolomitic), medium dark gray to olive gray, containing laminae, vertical and horizontal burrows, minor skeletal debris; laminae draped around calcite, dolomite, and quartz filled vugs up to 0.15' thick....3.6
Wackstone-packstone (dolomitic), dark gray to grayish black, containing very faint laminae and bands, faintly mottled with horizontal (?) burrows, some brachiopods fragments especially towards top....1.8
Lensoidal mudstone-wackstone, brownish black to grayish black, containing abundant brachiopod fragments especially towards top, horizontal burrows, small intraclasts....0.55
Mudstone-wackstone (dolomitic), brownish black to grayish black, containing horizontal (?) burrows, mottling, very faint laminae towards base....0.45
Wackstone-packstone (dolomitic), brownish black to grayish black, containing very faint laminae, pellets (?), slightly undulatory basal contact....0.75
Wackstone-packstone (dolomitic), brownish black to grayish black, containing abundant horizontal burrows and mottling, minor brachiopod fragments, basal contact slightly undulatory....1.2

Unit	Lithologic description	Thickness (in feet)
	Oolitic packstone, grayish black, containing undulatory laminae	0.9
	Oolitic grainstone, brownish black, containing 0.15' thick laminated mudstone cap	0.35
		[Subtotal 10.0]
10	Oolitic mudstone-wackstone, grayish black, containing horizontal burrows and mottling	0.45
	Wackstone-packstone, grayish black, containing laminae, pellets (?)	0.65
	Mudstone-wackstone, grayish black, containing very faint laminae and streaks, brachiopod fragments at base, horizontal burrows locally, common stylolites	5.1
	Mudstone-wackstone, grayish black, containing large scale pelloidal cross-stratified structures, ooliths, brachiopod fragments	1.8
	Mudstone-wackstone, grayish black, containing faint laminae and bands, common brachiopod fragments	2.4
	Skeletal packstone, dark gray to grayish black, containing abundant brachiopod and crinoid fragments, thin shaley laminae at top	0.65
	Wackstone, grayish black, containing laminae, brachiopod fragments, pellets, common micro-stylolites	4.7
	Wackstone-mudstone, grayish black, containing laminae having agrillaceous partings and bands	0.35
		[Subtotal 16.1]
11	Mudstone-wackstone, grayish black, containing faint discontinuous bands and laminae, minor brachiopod fragments, 0.3' thick zone of abundant horizontal burrows at top	1.8
	Argillaceous parting, dusky yellowish brown	0.05
	Wackstone (dolomitic), dark gray	0.2
	Argillaceous parting, dusky yellowish brown	0.05
	Wackstone, olive gray, containing limonite staining, mottling, 0.05' thick pale yellowish brown bentonite (1) at top	0.35
	Intraclastic wackstone-mudstone, dark gray, containing mostly mudstone clasts < 0.5' in length and <0.05' thick, intensly mottled at base, horizontal burrows, brachiopod fragments, pellets, dusky yellowish brown shaley parting at top	2.35
		[Subtotal 4.8]
12	Mudstone, grayish black, containing undulatory discontinuous laminae, abundant calcite replaced skeletal debris, minor pyrite, 0.5' thick horizontally burrowed intraclastic zone at top	2.6
	Intraclastic packstone-grainstone, dark gray to olive black, containing mudstone clasts up to 0.1' in diameter, articulate and disarticulate brachiopods, pellets, crinoid fragments	5.7
	Mudstone-wackstone, dark gray to olive black, containing argillaceous and undulatory laminae, horizontal burrows, bryozoa (?) fragments, gastropods, rare brachiopod fragments	0.5
		[Subtotal 8.8]
13	Mudstone, olive black, containing adundant articulate and disarticulate brachiopods, bryozoa, crinoids, small intraclasts, horizontal burrows	1.3
	Skeletal packstone, grayish black to olive black, containing abundant articulate and disarticulate brachiopods, bryozoa, crinoids, coral (?) towards top, undulatory bedding	1.9
	Mudstone, olive black, containing near living position (?) corals and bryozoa locally draped by argillaceous mudstone, minor articulate and disarticulate brachiopods	2.7
	Banded intraclastic mudstone-wackstone, olive black to olive gray, containing cycles of intraclastic packstone overlain by planar laminated mudstone typically 0.2' to 1.4' thick, cryptalgal (?) laminae, mudcracks (?), brachiopod fragments, gastropods	12.8
		[Subtotal 18.7]
14	Mudstone, grayish black, containing undulatory laminae typically spaced 0.1' to 0.2' apart, at 0.15' from base a 0.05' to 0.075' thick undulatory argillaceous parting, disarticulate brachiopods	2.6
	Intraclastic mudstone-wackstone (dolomitic), olive black, containing flat pebble conglomerate, vertical burrows, mudcracks, minor fossil debris	0.75
		[Subtotal 3.4]
15	Intraclastic wackstone-mudstone, olive black to olive gray, containing cycles up to 1' thick of intraclastic wackstone having mudstone and wackstone clasts up to 0.2' in diameter overlain by skeletal faintly laminated wackstone; within the intraclastic zone abundant brachiopods, corals, and gastropods; some cross-stratified wackstone bands; locally silica sand; locally inverse bedding where larger diameter intraclasts overlie smaller diameter intraclasts, occasionally thin mudstone cap at top of cycles, 0.5" thick light brownish gray bentonitic parting (1A) at 10.7' from top 0.9" thick grayish orange bentonitic parting (1B) at 3.4' from top	22.4
		[Subtotal 22.4]
16	Mudstone-wackstone, olive black, containing abundant bryozoa some of which might be in growth position near top, brachiopods, undulatory shaley parting at top	1.1
	Intraclastic mudstone-packstone, olive black, containing cycles typically 0.3' to 0.5' thick having intraclastic packstones overlain by horizontal and vertical burrowed mudstones, abundant skeletal debris in intraclastic zones, intraclastics typically <0.5" in diameter, cross-stratified packstone at top	4.15
	Mudstone-wackstone, brownish black, containing horizontal burrows, mottling, minor crinoids and brachiopods, planar upper contact	1.0
		[Subtotal 6.25]
	Total thickness of the Snyder Formation 95.5	

Linden Hall Formation (150.5 feet thick)

Unit	Lithologic description	Thickness (in feet)
17	Wackstone-mudstone, olive black, containing undulatory discontinuous laminae, horizontal burrows, mottling, minor articulate and disarticulate brachiopods, undulatory shaley parting at top	0.65
	Burrowed mudstone-wackstone, olive black, containing abundant horizontal - burrows, mottling, disarticulate brachiopods, gastropods, corals	1.7
	Burrowed mudstone and intraclastic packstone, brownish black to olive black, containing cycles of 0.1' to 0.3' thick discontinuous and channel like skeletal packstone overlain by 0.5' to 0.8' thick burrowed mudstone having undulatory discontinuous laminae, mottling, horizontal with minor vertical burrows, stratibound irregular shaped chert nodules in upper 14.2', 0.6" thick yellowish gray bentonite (2) at top	38.7
		[Subtotal 41.1]
18	Burrowed mudstone and lensoidal intraclastic wackstone-packstone, brownish black to olive black, containing cycles of 1.3' to 0.2' thick burrowed mudstone having discontinuous undulatory laminae, mostly horizontal burrows terminating in short vertical tops; interbedded lensoidal intraclastic wackstone-packstone from 0.2' to 0.5' thick having common brachiopods, corals, minor edgewise conglomerate; elongate irregular chert nodules in upper 1.6' up to 0.2' long; 0.6" thick yellowish gray bentonite (3) at 3.7' from top; 0.2" thick medium dark argillaceous laminae, horizontal worm burrows, trace pyrite, minor skeletal fragment	3.6
	Mudstone-wackstone, brownish black, containing horizontal burrows, minor calcite replaced skeletal fragment, undulatory discontinous laminae towards base, 0.75' thick dusky brown clay at top	2.0
	Wackstone-mudstone, brownish black, containing horizontal and vertical burrows, mottling, disarticulate brachiopods, echinoderm fragments (?), undulatory upper contact	3.0
	Mudstone, brownish black, containing discontinuous shaley laminae, oblique burrows, minor brachiopods and bryozoa, trace pyrite, shaley parting at top	4.7
		[Subtotal 13.3]
22	Burrowed wackstone-mudstone, olive black, containing abundant horizontal and minor vertical burrows, crinoids, brachiopods, corals, bryozoa, 0.2' thick intraclastic zone 7.5' from base, shaley parting at top	13.2
	Mudstone, brownish black, containing minor wackstone, undulatory thin discontinuous laminae, horizontal burrows, corals, brachiopods, bryozoa	1.5
	Mudstone-wackstone, brownish black, containing horizontal burrows with vertical burrows at base, brachiopods, bryozoa, echinoderms, gastrops, undulatory shaley parting at top	3.5
	Mudstone, brownish black to olive black, containing minor wackstone and thin discontinuous skeletal intraclastic zones <0.2' thick having rounded clasts about 0.4" in diameter, horizontal and minor vertical burrows, mottling, brachiopods, coral, crinoids, trace pyrite	12.7
		[Subtotal 30.9]
23	Mudstone-wackstone, brownish black, containing <0.2' thick and bands that become less distinct in upper 1.5', horizontal with minor vertical burrows, articulate brachiopods, corals, gastropods, pellets (?), 3.1' from base a 0.4' thick interval of hummocky-like cross-stratification	7.8
		[Subtotal 7.8]
	Total thickness of the Linden Hall Formation 150.5	

Nealmont Formation (76.3 feet thick)

Unit	Lithologic description	Thickness (in feet)
24	Mudstone-wackstone, brownish black, containing undulatory and anastomosing laminae, horizontal burrows; brachiopods, gastropods, and corals concentrated in thin discontinuous zones, gradational upper contact, 0.2" thick bentonite (6) at top	4.1
	Wackstone, grayish black, containing distinct horizontal burrows and laminae, minute echinoderm (?) debris, 0.2' thick discontinuous skeletal zones	1.5
	Mudstone, brownish black, containing minor <0.2' thick skeletal wackstone zones having brachiopods and gastropods, distinct discontinuous undulatory banding up to 0.05' thick, horizontal burrows especially in argillaceous bands, 0.2" thick bentonite (7) 8.4' from base	17.1
	Mudstone, olive black to brownish black, containing discontinuous and undulatory laminae, horizontal and vertical worm burrows, diminsihing laminae and increasing burrows in upper 1.0', gastropods and disarticulate brachiopods commonly concentrated in thin <0.1' thick wackstone zones	4.2
		[Subtotal 26.9]
25	Mudstone-wackstone, olive black to brownish black, containing thin discontinuous zones of skeletal wackstone, discontinuous undulatory laminae, horizontal burrows, gastropods, disarticulate brachiopods, significant dissolutioning along laminae	5.7
	Mudstone-wackstone, brownish black, containing burrow mottling, minor discontinuous laminae in lower 5.5', corals, brachiopods, echinoderm fragments	8.4
	Mudstone, brownish black, containing undulatory laminae, burrow mottling, brachiopods, gastropods, echinoderm fragments, shaly partings up to 0.4" thick throughout, flaggy to blocky bedding	2.5
	Mudstone-wackstone, brownish black, containing burrow mottling, indistinct laminae towards top, disarticulate brachiopods, gastropods, echinoderm fragments (?), undulatory shaly parting at top	10.3
		[Subtotal 26.9]
26	Wackstone-mudstone, brownish black, containing undulatory and anastomosing laminae (pseudo-nodular), brachiopods, echinoderm fragments, minor horizontal burrows, 0.3" thick bentonite (8) 1.6' from base	3.5
	Nodular wackstone, brownish black, containing skeletal wackstone nodules about 0.1' thick in 0.4" thick argillaceous matrix (laminae), 0.6" thick bentonite (9) 1.5' above base	4.4
	Argillaceous wackstone, grayish black, containing 0.5' thick nodular zone in the middle, nodules <0.1' thick, minor brachiopods and echinoderm fragements, pyrite	2.0
		[Subtotal 9.9]
27	Nodular wackstone, grayish black, containing nodules up to 0.15' thick having minute skeletal fragments, black shale matrix	3.1
	Argillaceous mudstone, grayish black, containing minute skeletal fragments, 0.7" thick bentonite (10) at top	0.75
	Nodular mudstone, grayish black, containing nodules up to 0.3' thick having articulate and disarticulate brachiopods, minute skeletal debris; <0.2' thick shale beds at 1.3', 2.0', 3.5', and top	4.7
	Argillaceous mudstone, grayish black, containing bands of shale up to 0.1' thick, minor brachiopods and gastropods, 0.2' thick shale at top	3.1
	Mudstone, grayish black, containing minor minute skeletal fragments, 1.6" thick bentonite (11) at top	0.9
		[Subtotal 12.6]
	Total thickness of the Nealmont Formation 76.3	

APPENDIX 2

DESCRIPTION OF SECTIONS MEASURED AT TATMAN RUN TRIBUTARY, NEAR TROUGH CREEK STATE PARK AND NEWBURG, HUNTINGDON COUNTY, PENNSYLVANIA

The Mississippian (Osagean and Meramecian Stages) exposures at this locality are referred to as the Tatman Run tributary sections. Section A consists of the upper 3.5 m of the Burgoon Sandstone and the lower 12.85 m of the overlying Trough Creek Member of the Mauch Chunk Formation. Section B comprises over 8.2 m of the Trough Creek Member. (See Figure 85, p. 194.) The base of section B is believed to be several meters stratigraphically above the top of section A.

The Tatman Run tributary sections are situated between Tatman Run and several small tributaries along Township Route T 381 just north of the intersection with State Route 994 (Legislative Route LR 31013) in the Entriken 7-1/2-minute quadrangle. (See Figure 84, p. 194.) Section A consists of exposures along the east and west sides of Route T 381 between 40°18'11"N/78°09'12"W (north end) and 40°18'06"N/78°09'14"W (south end) about 2.7 km northwest of Newburg. Section B is located on the west side of Route T 381 about 0.6 km north of State Route 994 between 40°18'23"N/78°09'01"W (north end) and 40°18'21"N/78°09'03"W (south end) about 2.9 km northwest of Newburg.

The sections were measured by L. J. Lentz, C. H. Dodge, and T. M. Berg on August 4 (section A) and August 5 (section B), 1986.

TATMAN RUN TRIBUTARY SECTION A

UNIT	THICKNESS METERS	DESCRIPTION
		Top of measured section TROUGH CREEK MEMBER OF MAUCH CHUNK FORMATION (PART)
14	1.9	Calcareous siltstone, grayish-red (10R4/2) to reddish-brown (10R4/4), mottled with greenish-gray (5GY6/1) especially towards base of unit but very subtly towards top; vaguely bedded; nonfissile; small nodules that appear to have been calcareous have weathered out leaving hollow shapes that are about 1 to 1.5 cm thick; nodules more common in middle of unit; some white (carbonate?) coarse silt grains locally; hackly to rubbly. Bottom contact gradational. Interval above this unit to top of hill mostly covered.
13	0.8	Calcareous siltstone, grayish-red (5R4/2); locally where it has very fine grained sand and rarely fine-grained sand can be called calcareous sandy siltstone; medium bedded; slabby. Bottom contact gradational.
12	1.2	Interbedded calcareous sandy siltstone and calcareous siltstone to siltstone, grayish-red (10R4/2) to reddish-brown (10R4/4); sand is very fine grained with minor fine grained locally; thickly laminated; subfissile to nonfissile; thin calcareous laminae and lenses locally; somewhat vaguely ripple laminated; hackly and rubbly. Bottom contact gradational.
11	0.65	Calcareous silty sandstone, grayish-red (10R4/2); very fine grained; massive; blocky. Bottom contact sharp.
10	0.5	Sandstone, reddish-brown (10R4/4); very fine grained; porous; friable; "punky"; few small white (carbonate?) grains locally; grades laterally to calcareous silty sandstone, grayish-red (10R4/2) on fresh surfaces to pale red (10R6/2) on weathered surfaces; also grades laterally to siltstone, reddish-brown (10R4/4); noncalcareous; all lithologies may represent differential weathering along joint planes; somewhat hackly. Bottom contact sharp.
9	1.6	Calcareous silty sandstone, light-grayish-red (10R5/2) with minor grayish-red (10R4/2); very fine grained; subrounded; weathers by exfoliation; massive; blocky. Bottom contact sharp.
8	0.2	Siltstone to clayey siltstone, reddish-brown (10R4/4); slightly calcareous but noncalcareous in clayey zones; nonfissile; sparse, rounded, very fine sand grains throughout; few small unidentifiable dark specks; mostly hackly but some rubbly. Bottom contact sharp.
7	1.9	Calcareous sandy siltstone, grayish-red (10R4/2) to reddish-brown (10R4/4), locally mottled light-olive-gray (5Y6/1); sand is very fine to fine grained with rare medium grained, rounded to well rounded; all of unit calcareous; thickly laminated discontinuously; mottling of unit due to bioturbation(?); commonly a center in many carbonate sand grains (ooids?); rubbly to blocky. Bottom contact sharp.
6	0.8	Mostly covered. Silty claystone, grayish-red (10R4/2) to reddish-brown (10R4/4); nonfissile; sparse, floating, subrounded to rounded, very fine to fine quartz sand grains throughout; few small calcareous nodules; noncalcareous matrix; few compaction slickensides; in bottom 5 cm of unit observed predominantly siltstone with common floating sand grains; hackly to rubbly. Bottom contact sharp.
5	1.2	Sandy calcarenite to very calcareous sandstone, light-olive-gray (5Y6/1) with medium-olive-gray (5Y5/1) near base; vaguely thin bedded but stands out as a single unit; floating, fine quartz sand grains throughout but more common towards base of unit; blocky. Bottom contact sharp.
4	1.0	Siltstone, grayish-red (10R4/2); slightly calcareous throughout; nonfissile; floating quartz sand grains throughout with less towards top; rubbly to hackly. Bottom contact sharp.
3	1.1	Very calcareous sandy siltstone to silty limestone, medium-dark-gray (N4) to medium-gray (N5) grading upward at about 0.45 m to grayish-red (5R4/2); vaguely undulatory surfaces or thin beds but dominantly structureless to "massive"; floating, frosted(?), rounded to well-rounded with some angular, fine to medium quartz sand grains throughout; rubbly to blocky. Bottom contact sharp but somewhat undulatory. TOTAL MEASURED TROUGH CREEK MEMBER = 12.85 m.
		BURGOON SANDSTONE
2	0.20	Sandstone, light-olive-gray (5Y5/2) to dark-yellowish-gray (5Y6/2); mostly fine grained with some medium grained; subrounded; very thin bedded; platy to flaggy; grading upward to calcareous sandy silt shale, medium-olive-gray (5Y5/1) to olive-gray (5Y4/1); thickly laminated to almost thinly laminated; hackly; upper half of unit is fissile to subfissile. Bedding attitude on contact between units 2 and 3 is N42°E, 8°SE. Bottom contact gradational.
1	3.3	Sandstone, light-gray (N7) with light-greenish-gray (5GY8/1) tint, weathered light-olive-gray (5Y5/2); fine grained to dominantly medium grained; well sorted; subangular; micaceous on some bedding planes; very broad, medium to thick crossbed sets consisting of very thin to thin cross-strata; slabby to almost blocky. Outcrop begins at road level. Bottom contact covered. TOTAL MEASURED BURGOON SANDSTONE = 3.5 m.

TATMAN RUN TRIBUTARY SECTION B

UNIT	THICKNESS METERS	DESCRIPTION
		Top of measured section TROUGH CREEK MEMBER OF MAUCH CHUNK FORMATION (PART)
14	0.1	Calcareous sandstone, light-grayish-red (10R5/2), weathers to pale-red (10R6/2) internally with some light-olive-gray (5Y6/1) on external surfaces; very fine grained; thin bedded; obviously ripple bedded with 0.3 m between crests; rubbly. Bottom contact sharp.
13	0.3	Calcareous siltstone, grayish-red (10R4/2); few scattered, thin, very fine grained sand laminae; few floating, very fine sand grains locally; obvious ripple bedding on bottom surfaces of unit with 15 to 20 cm between crests, and vague throughout rest of unit; few rootlets locally on some surfaces; mostly hackly. Bottom contact sharp.
12	0.25	Highly calcareous siltstone to very silty limestone, grayish-red (10R4/2); thin bedded; internally ripple bedded with beds up to 4 cm thick that are very broad with 0.25 to 0.5 m between crests; weathers to a recess; slabby to rubbly. Bottom contact sharp.
11	1.75	Calcareous siltstone, grayish-red (10R4/2); vaguely thin bedded; nonfissile; lower 0.75 m of unit has isolated, somewhat rounded, lighter colored, cross-laminated calcareous siltstone lenses; these cross-laminated lenses have truncated internal structures, and a few are up to 4 cm thick; rare, floating, fine quartz grains; hackly to rubbly. Bottom contact sharp.
10	0.25	Silty limestone to highly calcareous siltstone, mostly light-grayish-red (10R5/2) with some grayish-red (10R4/2); thin bedded; basal part of unit grades laterally to light-olive-gray (5Y6/1), subangular to mostly rounded, fine-grained calcareous sandstone; rubbly to slabby. Bottom contact sharp.
9	2.3	Calcareous siltstone, grayish-red (10R4/2) to reddish-brown (10R4/4); moderately calcareous; very thin to thin bedded but poorly bedded in middle of unit; nonfissile; common lenses, up to 2 cm thick, of lighter gray, very fine grained calcareous sandstone (lenses appear to be calcareous quartz sandstone and/or calcarenite); lenticular bedding very well developed in upper 0.5 m of unit, present in rest of unit, but poorly developed in middle of unit; hackly to rubbly. Bottom contact sharp.
8	0.5	Calcareous sandstone, light-grayish-red (10R5/2) and medium-olive-gray (5Y5/1) in a somewhat interbedded appearance; thickly laminated to very thin bedded; vague ripple bedding to contorted bedding; bedding becomes thinner and more contorted upward; blocky to rubbly. Bottom contact sharp.
7	0.01	Silt shale, grayish-red (10R4/2); thinly laminated; subfissile; poorly exposed. Bottom contact sharp.
6	0.85	Calcareous siltstone, mostly grayish-red (10R4/2) but upper 0.2 m becoming light-grayish-red (10R5/2); thinly laminated with vague ripple bedding throughout; unit locally has some fine-grained sand laminae. Upper 0.2 m is highly calcareous silty sandstone, light-grayish-red (10R5/2), weathered to more of a gray; very fine to fine grained; subrounded to angular grains; common quartz grains. Unit blocky to rubbly. Bottom contact sharp.
5	0.05	Clayey silt shale, grayish-red (10R4/2); thinly laminated; subfissile; noncalcareous; chippy to hackly. Bottom contact sharp.
4	0.75	Calcareous siltstone, light-grayish-red (10R5/2) grading upward to grayish-red (10R4/2); some zones contain very fine grained sand; appears to be thickly laminated to very thin bedded based on weathered surfaces; nonfissile; towards central and northern end of outcrop there is vague ripple bedding throughout most of unit, with good sinuous, asymmetrical ripple-bedded surfaces at top of unit and somewhat contorted bedding at base of unit; towards southern end of outcrop there is well-developed ripple bedding with very small troughs; rubbly and blocky to hackly. Bottom contact sharp.
3	0 - 0.03	Silt shale, grayish-red (10R4/2); thickly laminated; subfissile; chippy. Bottom contact sharp.
2	0.85	Calcareous sandstone, light-grayish-red (10R5/2) with tint of medium-olive-gray (5Y5/1); fine grained with a little medium grained; irregular ripple bedding with horizontal laminae at base of unit, grading upward to cross-strata in thin to medium bed sets with some sets becoming thick bedded laterally; individual bed sets composed of thin cross-laminae; blocky to rubbly. Bottom contact relatively sharp.
1	0.25	Calcareous silty sandstone, light-grayish-red (10R5/2) to dominantly grayish-red (10R4/2); dominantly fine grained; moderately sorted; subrounded to rounded; vaguely laminated but basically structureless; blocky to hackly. Bottom contact covered. Outcrop begins at road level. TOTAL MEASURED TROUGH CREEK MEMBER = 8.21 - 8.24 m.

APPENDIX 3

DESCRIPTION OF SECTION MEASURED NEAR WARRIORS PATH STATE PARK BETWEEN SAXTON AND RIDDLESBURG, BEDFORD COUNTY, PENNSYLVANIA

The Upper Devonian and Mississippian (Conewangoan through Meramecian Stages) exposures at this locality have traditionally been called the Riddlesburg section. However, because of their proximity to Warriors Path State Park, we believe that it is more appropriate to refer to the exposures as the Warriors Path section. The exposures have previously been measured in part by Stevenson (1882, p. 69-70, 234) and Laird (1942, p. 70-72), and more completely by White (White and others, 1885, p. 79, 81) and Reger (1927a, p. 399-401). (See p. 219-221 in this guidebook for complete reference citations.) The section as described herein comprises the upper 150.9 m of the Catskill Formation, all of the Rockwell Formation and Burgoon Sandstone, and the lower 17 m of the Trough Creek Member of the Mauch Chunk Formation. It also includes the type section of the marine Riddlesburg Shale Member of the Rockwell Formation (Reger, 1927a, p. 400, 405; 1927b, p. 156-157). (See Figure 88, p. 204.)

The Warriors Path section is situated along the abandoned Huntingdon and Broad Top Mountain Railroad grade on the east side of the Raystown Branch of the Juniata River in the Saxton 7-1/2-minute quadrangle between 40°11'31"N/78°14'59"W (base) and 40°11'08"N/78°14'34"W (top). The base of the type section of the Riddlesburg Shale Member of the Rockwell Formation is located at 40°11'18"N/78°14'45"W. (See Figure 87, p. 204.) The northern end (base) of the Warriors Path section is 350 m inside the southeastern corner of Warriors Path State Park about 2.3 km south of Saxton and 3.4 km north of Riddlesburg.

The section was remeasured by T. M. Berg and C. H. Dodge on June 9-12, 1986.

UNIT	THICKNESS METERS	DESCRIPTION
		Top of measured section
		TROUGH CREEK MEMBER OF MAUCH CHUNK FORMATION (PART)
57	8	Calcareous siltstone to calcareous clayey siltstone, grayish-red (10R4/2); contains highly calcareous zones and lenses; nonfissile; hackly to rubbly. Only upper 2 m visible at path level along southeastern side of ravine; other 6 m covered here, but observed along ridge above path on northeastern side of ravine. Bottom contact covered.
56	9	Covered. Colluvium in ravine consists mostly of siltstone to clayey siltstone, grayish-red (10R4/2), hackly to rubbly; subordinate, fine- to medium-grained sandstone, light-gray (N7), slabby; and minor fine-grained, very calcareous sandstone, light-olive-gray (5Y6/1), slabby, one of the Trough Creek "limestones" of White (White and others, 1885). TOTAL MEASURED TROUGH CREEK MEMBER = 17 m
		BURGOON SANDSTONE
55	22.2	Sandstone, light-gray (N7) to very pale orange (10YR8/2); fine to medium grained; medium to thick bedded; slabby and blocky; discontinuous silt shale stringers in bottom third of unit; well-developed trough cross-strata; upper 3 m covered at path level, but observed along ridge above path on northeastern side of ravine where sandstone locally contains a few shale chips. Bottom contact sharp.
54	1.8	Interbedded sandstone and silt shale. Sandstone is tan, fine grained, thin to medium bedded, and iron stained. Silt shale is medium dark gray (N4) and micaceous; contains a few fossil plant fragments. Unit is irregularly bedded. Bottom contact sharp.
53	1.9	Sandstone, medium-light-gray (N6), weathered light-brown (5YR6/4); medium grained; medium bedded; trough cross-strata; slabby and blocky. Bottom contact sharp.
52	0.7	Silt shale, medium-dark-gray (N4); coarser silt than unit 50; fissile; iron stained; rare carbonaceous fragments; chippy and platy. Bottom contact sharp.
51	2.9	Sandstone, medium-light-gray (N6), weathered light-brown (5YR6/4); medium grained; medium bedded; well-developed trough cross-strata; slabby and blocky. Bottom contact sharp.
50	0.8	Carbonaceous silt shale, dark-gray (N3) to dark-olive (10Y2/2) or grayish-black (N2); micaceous; thinly laminated; fissile; well-preserved fossil plant leaves (pinnules of ?*Triphyllopteris*) and twig fragments; chippy, flaky, and platy. This is unit 40 of White described as "shale, dark, with broken plants" (White and others, 1885, p. 79). Moreover, this is very likely collection locality 16 of Read (1955, p. 14-15), which was erroneously described as situated 2 miles north of Riddlesburg in Tussey Mountain rather than Terrace (Saxton) Mountain and where he identified *Triphyllopteris latilobata* Read. Bottom contact sharp.
49	5.5	Sandstone, medium-light-gray (N6), weathered light-brown (5YR6/4); mostly medium grained with some fine grained; thin to medium bedded; large-scale trough cross-strata; slabby and blocky. Somewhat broken and bent in tight fold where ochre staining abundant along fractures. Bedding attitude is N27°E, 48°SE. Bottom contact covered.
48	19	Covered.
47u	6.5	Sandstone, very light gray (N8); mostly fine grained with some medium grained; mostly thin bedded with some medium bedded; few scattered pyrite nodules; poorly developed trough cross-strata; few large plant impressions along bottom contact; slabby, blocky, and some flaggy. Bedding attitude is N17°E, 41°SE. Bottom contact sharp.
47t	0.4	Silt shale, medium-dark-gray (N4); hackly. Bottom contact sharp.
47s	8.5	Sandstone, medium-light-gray (N6); mostly medium grained; medium to thick bedded, upper 1 m thin bedded; few scattered pyrite nodules; large-scale trough cross-strata; slabby and blocky. Bottom contact sharp.
47r	0.6	Silt shale, medium-dark-gray (N4). Overlain by sandstone, light-olive-gray (5Y5/2); fine grained. Overlain by sandstone, light-olive-gray (5Y5/2), weathered moderate-yellowish-brown (10YR5/4); very fine grained; "punky." Topped with a 1-cm-thick, coaly, carbonaceous zone, grayish-black (N2) to black (N1). This includes unit 36 of White described as "black coal shale" (White and others, 1885, p. 79). Bottom contact sharp.
47q	10.5	Sandstone, very light gray (N8); medium grained with some zones that are coarse grained to nearly very coarse grained; granules rare except in a quartz-pebble sandstone bed that is 0.4 m thick and is near middle of unit; medium to thick bedded; few scattered pyrite nodules; very well developed trough cross-strata; few thin silt-shale stringers occur but pinch out; slabby and blocky. Bottom contact sharp.
47p	0.3	Silt shale, medium-gray (N5). Bottom contact sharp.
47o	1.9	Sandstone, very light gray (N8); medium grained to almost coarse grained with rare granules; medium to thick bedded; slabby and blocky. Bottom contact sharp.
47n	0.7	Interbedded silt shale and sandstone. Silt shale is medium dark gray (N4). Sandstone is light olive gray (5Y5/2), fine grained, and thin bedded. Some discontinuous intraformational conglomerate at top of unit. Intraformational conglomerate is variegated olive gray (5Y4/1), brownish gray (5YR4/1), grayish red (10R4/2), and dusky yellow (5Y6/4), and contains shale clasts set in a sandy, muddy, iron-rich matrix. Bottom contact sharp.
47m	0.9	Sandstone, very light gray (N8); fine to medium grained; medium to thick bedded; slabby and blocky. Bottom contact sharp.
47l	0.6	Interbedded intraformational conglomerate and silt shale. Intraformational conglomerate is variegated olive gray (5Y4/1), brownish gray (5YR4/1), grayish red (10R4/2), and dusky yellow (5Y6/4), and contains very small shale clasts set in a sandy, muddy, iron-rich matrix. The silt shale is medium dark gray (N4) and hackly. Each lithology makes up half the unit. Bottom contact sharp.
47k	13.3	Sandstone, very light gray (N8), weathered moderate-yellowish-brown (10YR5/4); fine to medium grained; medium to thick bedded; planar bedded with lower angle trough cross-strata; slabby and blocky. Lower half of unit contains small "drag" fold and reverse fault. Bedding attitude to the north of fold is N15°E, 46°SE and to the south of fold is N22°E, 42°SE. Bottom contact covered.
47j	6	Covered. Contains quartz-granule conglomerate float.
47i	2	Conglomeratic sandstone, very light gray (N8), weathered moderate-yellowish-brown (10YR5/4); coarse to very coarse grained with zones of quartz-pebble and quartz-granule (extraformational) conglomerate; medium to thick bedded; slabby and blocky. Bottom contact sharp.
47h	2	Sandstone, very light gray (N8), weathered moderate-yellowish-brown (10YR5/4); fine to medium grained; medium to thick bedded; slabby and blocky. Bottom contact sharp.
47g	0.1-0.5	Clayey silt shale, olive-gray (5Y4/1) to medium-dark-gray (N4); hackly. Bottom contact sharp.
47f	16.7	Sandstone, very light gray (N8), weathered moderate-yellowish-brown (10YR5/4); fine to medium grained; medium to thick bedded; trough cross-strata; slabby and blocky. Bottom contact sharp.
47e	0.3	Sandstone, light-olive-gray (5Y5/2), weathered moderate-yellowish-brown (10YR5/4); fine grained; micaceous; fissile; very thinly to thinly laminated. Bottom contact sharp.
47d	0.5	Intraformational conglomerate, variegated olive-gray (5Y4/1), brownish-gray (5YR4/1), grayish-red (10R4/2), and dusky-yellow (5Y6/4); contains shale clasts set in a sandy, muddy, iron-rich matrix. Bottom contact sharp.
47c	7.2	Sandstone, very light gray (N8), weathered moderate-yellowish-brown (10YR5/4); fine to medium grained; medium to thick bedded; trough cross-strata; slabby and blocky. Bottom contact sharp.
47b	0.6	Intraformational conglomerate, variegated olive-gray (5Y4/1), brownish-gray (5YR4/1), grayish-red (10R4/2), and dusky-yellow (5Y6/4); contains shale clasts set in a sandy, muddy, iron-rich matrix. Bottom contact sharp.
47a	13.8	Sandstone, very light gray (N8), weathered moderate-yellowish-brown (10YR5/4); fine to medium grained; medium to thick bedded; trough cross-strata; slabby, blocky, and some flaggy. Bedding attitude is N22°E, 63°SE. Bottom contact covered. The contact between the Burgoon Sandstone and Rockwell Formation is placed here because this is the base of the continuous sandstone outcrops that contain no significant shale interbeds and that have more well defined, larger scale, higher angle trough cross-strata than do the underlying units. TOTAL BURGOON SANDSTONE = 148.2 - 148.6 m
		ROCKWELL FORMATION
46	25	Partly covered. Interval includes sandstone, predominantly siltstone, and some silt shale, with silty clay shale at base of unit. Whole succession appears to coarsen upward grossly. Sandstone, olive-gray (5Y4/1) to dusky-yellow (5Y6/4); very fine to almost fine grained; micaceous; thin bedded; one outcrop mostly parallel bedded; few fossil plant fragments; slabby. Siltstone, dusky-yellow (5Y6/4) to light-olive-gray

UNIT	THICKNESS METERS	DESCRIPTION
		(5Y5/2); fine to very coarse silt (coarsening upward); micaceous; subfissile to nonfissile; hackly to rubbly. Silt shale and silty clay shale, olive-gray (5Y4/1) to light-olive-gray (5Y5/2); fissile to subfissile; rare carbonaceous fragments (no other evidence of fossils observed); hackly and chippy.
45	17.8	Sandstone, olive-gray (5Y4/1) to dusky-yellow (5Y6/4); mostly fine grained with some medium grained; well-sorted, subangular grains; some shale clasts locally; dominantly planar bedded but with some well-developed trough cross-strata; fissile zones contain fossil plant debris; slabby and blocky. Bedding attitude is N23°E, 56°SE. Bottom contact sharp.
44f	6.0	Siltstone, olive-gray (5Y3/2); very thin to thin bedded; subfissile; hackly to platy. Bottom contact sharp.
44e	3.5	Sandstone, light-olive-gray (5Y5/2); very fine to fine grained; medium bedded; mostly parallel bedded but with some subtle trough cross-strata; slabby to flaggy. Bottom contact sharp.
44d	2.8	Siltstone, olive-gray (5Y3/2); very thin to thin bedded; subfissile; hackly to platy. Bottom contact sharp.
44c	1.7	Sandstone, light-olive-gray (5Y5/2); very fine grained; thin bedded; exfoliates to a degree; mostly parallel bedded but with some low-angle trough cross-strata; slabby to flaggy. Bottom contact sharp.
44b	2.0	Partly covered. Mostly siltstone, olive-gray (5Y3/2); very thin to thin bedded; subfissile; hackly to platy.
44a	1.9	Interbedded sandstone and siltstone. Sandstone, light-olive-gray (5Y5/2); silt sized to very fine grained; thin bedded; mostly parallel bedded but with some low-angle trough cross-strata; slabby to flaggy. Silt shale, olive-gray (5Y3/2); thickly laminated; fissile to subfissile; common fossil plant fragments; chippy to hackly. Upper half of unit is all sandstone. Bottom contact sharp.
43	6.0	Clayey silt shale, olive-gray (5Y3/2) to medium-dark-gray (N4) to dark-gray (N3); thinly laminated; fissile to subfissile; no invertebrate fossils observed; chippy and hackly. Bottom contact sharp. This is the uppermost unit of the type section of the Riddlesburg Shale Member (Reger, 1927a, p. 400, unit 10). It is also the top of unit 20 of White described as "shales, dark, very fossiliferous; (in the bottom 10' Spirifer, Rhinchonella, &c.)" (White and others, 1885, p. 81).
42	0.7	Sandstone, light-olive-gray (5Y5/2) to olive-gray (5Y4/1); silt sized to very fine grained; thin to almost medium bedded; mostly parallel bedded but with some surface irregularities; platy, flaggy, and slabby. Bottom contact sharp.
41	4.0	Silt shale, olive-gray (5Y3/2); subfissile; well-developed exfoliation weathering pattern; few Lingula; hackly to rubbly. Bottom contact sharp.
40	0.7	Siltstone, medium-olive-gray (5Y4/2); slightly micaceous; thickly laminated; irregularly bedded; small-scale, low-angle trough cross-strata; hackly and platy. Bottom contact sharp.
39	0.2	Calcareous siltstone, medium-dark-gray (N4); effervesces easily; medium-bedded; nonfissile; hackly to rubbly. Bottom contact sharp.
38	7.0	Siltstone and clayey siltstone to silt shale, medium-dark-gray (N4) to dark-gray (N3); subfissile to nonfissile; bedding indistinct; strong exfoliation and cleavage yield hackly and splintery fragments ("pencil" forms). Marine invertebrate fossils, predominantly an articulate brachiopod fauna, are present throughout unit but are most common to abundant in bottom 2-3 m. Most brachiopod fossils are iron stained. Most fossils are deformed and are preserved as internal and external molds. Invertebrate fossils include abundant Rhipidomella; fewer Schuchertella, ?Camarotoechia, ?Orbiculoidea, Chonetes, and Cypricardinia; and far fewer crinoid ossicles and fragments. These abundances are qualitative. Fossils collected from this unit were examined by Girty (1928, p. 111, 123; collection locality 3548), who identified the following 14 genera (using modern nomenclature): Rhipidomella, Schuchertella, Chonetes, and ?Camarotoechia (articulate brachiopods, abundant); ?Orbiculoidea (inarticulate brachiopod, abundant); Palaeoneilo and Cypricardinia (bivalves, abundant); ?Nuculoidea (bivalve, few); ?Glabrocingulum (eotomariid gastropod, few); Graphiocrinus (crinoid, few); Spirorbis (worm, few); Spirifer (articulate brachiopod, rare); ?Glossites (bivalve, rare); and ?Stenopora (bryozoan, rare). The estimated abundances by Girty are considered semiquantitative and are based on at least nine collections made by three workers at four collection localities, including this one, throughout the Broad Top region (Girty, 1928, p. 111). Laird (1942, p. 72) also examined this interval and identified the following genera that he considered dominant (using modern nomenclature): Rhipidomella, ?Camarotoechia, Chonetes, and Cypricardinia. This is the lowest unit of the type section of the Riddlesburg Shale Member (Reger, 1927a, p. 400, unit 10). It is also the bottom of unit 20 of White (White and others, 1885, p. 81). Bottom contact sharp.
37	0.7-1.0	Sandstone, light-olive-gray (5Y5/2); fine grained; several pebbles of quartz and chert along with a few shale clasts in upper 0.2 m of unit; medium bedded; low-angle trough cross-strata; slabby. Bedding attitude is N29°E, 41°SE. Bottom contact very irregular and diffuse.
36	0.5-1.0	Calcareous sandstone, medium-dark-gray (N4); fine grained; very calcareous; almost a limestone; medium bedded; planar bedded; blocky and rubbly. Bottom contact sharp and somewhat irregular.
35	1.8	Sandstone, light-olive-gray (5Y5/2); fine grained; medium bedded; strongly trough crossbedded at base, grading upward to parallel laminated; slabby grading upward to flaggy. Bottom contact somewhat gradational and undulatory.
34	2.3-2.8	Intraformational conglomerate, variegated olive-gray (5Y4/1), brownish-gray (5YR4/1), grayish-red (10R4/2), and dusky yellow (5Y6/4); poorly sorted mixture of shale and siltstone clasts in an iron-rich, sandy, muddy, clayey matrix; common pockets of limonite and hematite; common fossil plant fragments, twigs, and branches. Bottom contact sharp.
33	12.3	Interbedded siltstone and silt shale, grayish-red (10R4/2); dominantly siltstone; thin to almost medium bedded; subfissile; thin yellow streak about two-thirds of the way above base; hackly to rubbly. Bottom contact sharp.
32	10.3	Sandstone, light-olive-gray (5Y5/2); very fine to fine grained; micaceous; medium to thick bedded; some medium- to large-scale trough cross-strata in lowest third of unit, but mostly planar bedded grading upward to very well developed ripple-drift cross-lamination (only visible much above path level); ripples are high amplitude, highly sinuous to almost linguoid; blocky and slabby. Common fossil clam burrows exposed at base of unit as protrusions on bottom of overhanging ledge (visible at path level); few well-developed, vertical cross sections of fossil clam burrows exposed about 2 m beneath top of unit in ripple-drift beds (only visible much above path level); escape burrows are up to 10 cm in diameter, exhibit internal crescentic structures, and show downward-curving laminae along the outside walls. Some aspects of the burrow morphology are similar to those described by Thoms and Berg (1985) and Bridge and others (1986) for bivalve burrows of the Upper Devonian Catskill Formation in northeastern Pennsylvania and portions of adjacent states. Bedding attitudes are N10°E, 27°SE; N35°E, 32°SE; and N26°E, 27°SE. Bottom contact covered but probably sharp.
31	32	Covered. Mostly grayish-red (10R4/2) silt shale float.
30	7.5	Sandstone and silt shale. Sandstone is light olive gray (5Y5/2), fine grained, micaceous, mostly medium bedded, and trough crossbedded; contains abundant fossil plant fragments near base of unit; and has a few thin silt shale interbeds in middle of unit. Sandstone grades evenly upward to fissile, light-olive-gray (5Y5/2) silt shale in upper third of unit. Bottom contact covered.
29	15	Partly covered. Interbedded siltstone and silt shale, mostly grayish-red (10R4/2) but with streaks of light-olive-gray (5Y5/2) or dusky-yellow (5Y6/4); dominantly siltstone; some indistinct fossil plant fragments; bottom 2.1 m mostly covered (includes interval equivalent to unit 17, the "fireclay shale, gray," of Reger, 1927a, p. 400).
28	1.8	Sandstone, light-olive-gray (5Y5/2); mostly very fine grained with some fine grained; micaceous; thin to medium bedded; trough cross-strata in sets of approximately 0.4 m thick; slabby. Bottom contact sharp.
27	0.3	Claystone, light-olive-brown (5Y5/6) to dusky-yellow (5Y6/4); slightly silty; nonfissile; few to common calcrete nodules up to 2 cm across near top of unit; hackly and crumbly. This is unit 19 of Reger (1927a, p. 400) described as "shale, yellow." Bottom contact gradational.
26	3.0	Siltstone, grayish-red (10R4/2); thinly bedded but obscure in part owing to dominant cleavage; subfissile to nonfissile; some fossil rootlets; hackly. Bedding attitude is N25°E, 40°SE. Bottom contact sharp.
25	0.7	Sandstone, grayish-brown (5YR3/2) to brownish-gray (5YR4/1); silt sized to very fine grained; very thin bedded; some ripple bedding; hackly, rubbly, and platy. Bottom contact sharp.
24	2.5	Partly covered, especially near base. Siltstone, grayish-red (10R4/2); subfissile; well cleaved; commonly fossil rootlets on cleavage faces; hackly to rubbly. Bottom contact covered.
23	1.8	Partly covered. Sandstone, light-olive-gray (5Y5/2) to dusky-yellow (5Y6/4); very fine grained; medium bedded; shale clasts and fossil plant fragments at top of unit; subtle, low-angle trough cross-strata; slabby. Bottom contact partly covered but probably sharp.
22	4.5	Partly covered. Silty clay shale and clay shale, brownish-gray (5YR4/1) to grayish-red (10R4/2); very thinly laminated; fissile; few fossil plant fragments; chippy and platy. Bottom contact covered.
21	0.9	Interbedded siltstone and sandstone with minor silt shale, predominantly grayish-red (10R4/2) with some grayish-brown (5YR3/2) and brownish-gray (5YR4/1); very micaceous; thin bedded; wavy bedded; platy, chippy, and slabby. Bottom contact sharp.
20	1.1	Silt shale to siltstone, grayish-brown (5YR3/2); slightly micaceous; thickly laminated; fissile to subfissile; bottom 0.4 m partly covered; hackly. Bottom contact partly covered but sharp.
19u	7.7	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); fine grained; well sorted; medium to thick bedded; dominantly planar bedded with few low-angle trough cross-strata; sinuous ripple bedding at top of unit; fossil plant debris on some surfaces; slabby to blocky. Top of the "Berea" of Reger (1927a, p. 400, unit 21). Bottom contact sharp.
19t	0.2	Silt shale, light-olive-gray (5Y5/2) to dusky-yellow (5Y6/4); micaceous; thinly to thickly laminated; fissile to subfissile; abundant plant debris and twigs on some surfaces; chippy, platy, and hackly. Bottom contact sharp.

UNIT	THICKNESS METERS	DESCRIPTION
19s	0.85	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); fine grained; well sorted; medium bedded; planar bedded; slabby to blocky. Bottom contact sharp.
19r	0.1-0.2	Silt shale, light-olive-gray (5Y5/2) to dusky-yellow (5Y6/4); micaceous; thinly to thickly laminated; fissile to subfissile; abundant fossil plant debris and twigs on some surfaces; chippy, platy, and hackly. Bottom contact sharp.
19q	0.5	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); fine grained; well sorted; medium bedded; planar bedded; slabby to blocky. Bottom contact sharp.
19p	0.15	Silt shale, light-olive-gray (5Y5/2) to dusky-yellow (5Y6/4); micaceous; thinly to thickly laminated; fissile to subfissile; abundant fossil plant debris and twigs on some surfaces; chippy, platy, and hackly. Bottom contact sharp.
19o	0.6	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); fine grained; well sorted; medium bedded; megaripple bedded; slabby to blocky. Bottom contact sharp.
19n	0.2-0.25	Silt shale, light-olive-gray (5Y5/2) to dusky-yellow (5Y6/4); micaceous; thinly to thickly laminated; fissile to subfissile; abundant fossil plant debris and twigs on some surfaces; chippy, platy, and hackly. Bottom contact sharp.
19m	5.4	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); fine grained; well sorted; medium to thick bedded; planar bedded with low-angle, broad trough cross-strata; fossil plant debris on some surfaces; slabby to blocky. Bottom contact sharp.
19l	0.4	Intraformational conglomerate, mottled greenish-gray (5GY6/1) to light-olive-gray (5Y5/2) with light-grayish-olive (10Y5/2) and brownish-gray (5YR4/1); poorly bedded masses of shale chips and clay galls set in sandy, silty, muddy, noncalcareous matrix; few streaks of carbonaceous debris; hackly and rubbly. Bottom contact sharp.
19k	2.7	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); fine grained with some very fine grained; well sorted; medium to thick bedded; planar bedded; fossil plant debris on some surfaces; slabby to blocky. Bottom contact sharp.
19j	0.4	Calcareous intraformational conglomerate, mottled greenish-gray (5GY6/1) to light-olive-gray (5Y5/2) with light-grayish-olive (10Y5/2) and brownish-gray (5YR4/1); poorly bedded masses of shale chips and clay galls set in sandy, silty, muddy, calcareous matrix; few streaks of carbonaceous debris; hackly and rubbly. Bottom contact sharp.
19i	0.2-0.3	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); fine grained with some very fine grained; medium bedded; planar bedded; slabby to blocky. Bottom contact sharp.
19h	0.1-0.2	Silt shale, light-olive-gray (5Y5/2) to dusky-yellow (5Y6/4); micaceous; thinly to thickly laminated; fissile to subfissile; abundant fossil plant debris and twigs on some surfaces; hackly. Bottom contact sharp.
19g	5.4	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); fine grained with some very fine grained; well sorted; medium to thick bedded; planar bedded with subtle, low-angle trough cross-strata; fossil plant debris on some surfaces; slabby to blocky. Rotated antithetic reverse (?) fault near base of unit; fault also cuts through units 19c to 19f; maximum displacement of about 0.5 m. Bottom contact sharp.
19f	0.1-0.4	Calcareous intraformational conglomerate, mottled greenish-gray (5GY6/1) to light-olive-gray (5Y5/2) with light-grayish-olive (10Y5/2) and brownish-gray (5YR4/1); poorly bedded masses of shale chips and clay galls set in a sandy, silty, muddy, calcareous matrix; few streaks of carbonaceous debris; hackly and rubbly. Bottom contact sharp.
19e	1.5	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); very fine to fine grained; well sorted; medium to thick bedded; planar bedded with subtle, low-angle trough cross-strata; fossil plant debris on some surfaces; slabby to blocky. Bottom contact sharp.
19d	0.2	Silt shale, light-olive-gray (5Y5/2) to dusky-yellow (5Y6/4); micaceous; thinly to thickly laminated; fissile to subfissile; abundant fossil plant debris and twigs on some surfaces; chippy, platy, and hackly. Bottom contact sharp.
19c	1.6	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); very fine to fine grained; well sorted; medium to thick bedded; planar bedded with subtle, low-angle trough cross-strata; fossil plant debris on some surfaces; slabby to blocky. Bottom contact sharp.
19b	0.2-0.5	Silt shale, light-olive-gray (5Y5/2) to dusky-yellow (5Y6/4); micaceous; thinly to thickly laminated; fissile to subfissile; abundant fossil plant debris and twigs on some surfaces; chippy, platy, and hackly. Bottom contact sharp.
19a	2.6	Sandstone, light-olive-gray (5Y5/2) to grayish-olive (10Y4/2); very fine to fine grained; well sorted; medium to thick bedded; planar bedded with subtle, low-angle trough cross-strata; contains two thin silt-shale interbeds; fossil plant debris on some surfaces; slabby to blocky. Bottom contact sharp.
18	0.2-0.7	Intraformational conglomerate, mottled mostly olive, brown, and grayish-red (10R4/2); pisoliths and shale clasts set in a poorly sorted, sandy, silty, muddy, slightly calcareous matrix; pisoliths are mostly medium gray (N5) on fresh surfaces, and many have obvious concentric internal structure; pisoliths are all calcareous and generally are less than 4 cm by 2 cm although one measured 6 cm by 4 cm. No fossils observed. Unit contains laterally discontinuous, poorly indurated sandstone beds up to 18 cm thick that rapidly thin to 0 cm and form wedge-shaped bodies. Unit weathers to a recess; rubbly. Bottom contact sharp.
17	1.8	Sandstone, olive-gray (5Y4/1) to yellowish-brown (10YR5/2), pieces weathered brown and "punky"; very fine grained; thin bedded; planar bedded and small-scale trough cross-strata. Bottom contact sharp.
16	0-0.4	Intraformational conglomerate, mottled greenish-gray (5GY6/1) to light-olive-gray (5Y5/2) with light-greenish-olive (10Y5/2) and brownish-gray (5YR4/1); calcareous nodules and shale clasts set in a poorly sorted, sandy, silty, muddy, slightly calcareous matrix; calcareous nodules up to 7 cm across and 3 cm thick; some very thin siltstone beds less than 2 cm thick; no obvious internal bedding; weathers to a recess; unit is laterally discontinuous. Bottom contact sharp.
15	1	Siltstone, greenish-gray (5GY6/1), weathered yellowish-brown (10YR5/2); coarse silt; micaceous; very thin bedded; ripple bedded; platy, chippy, and hackly. Bottom contact sharp.
14	9	Sandstone, medium-olive-gray (5Y4/2) to light-olive-gray (5Y5/2); very fine to fine grained; medium to thick bedded; well-developed trough cross-strata in sets up to 1.2 m thick; contains some thin (less than 0.5 m) siltstone beds composed of very coarse silt; slabby to blocky. Bedding attitudes are N36°E, 33°SE; N12°E, 38°SE; N15°E, 40°SE. Base of the "Berea" of Reger (1927a, p. 400, unit 21). Bottom contact mostly covered but probably sharp. TOTAL ROCKWELL FORMATION = 221.4 - 224.55 m
		CATSKILL FORMATION (PART)
13	80	Covered. Few scattered outcrops of sandstone, siltstone, and silt shale. Sandstone is yellowish brown (10YR5/2) and very fine grained. Siltstone and silt shale are grayish red (10R4/2). Appear to be two or three (?) fining-upward cycles in this interval.
12	1.5	Sandy siltstone, brownish-gray (5YR4/1) to grayish-red (10R4/2); trough(?) cross-strata. Bottom contact partly covered but sharp.
11	2.4	Sandstone, moderate-yellowish-brown (10YR5/4) with orange cast; fine grained; medium to thick bedded; trough cross-strata; blocky to rubbly. Grades upward to silt shale, light-yellowish-brown (10YR6/4) to olive-gray (5Y4/1); parallel bedded. Bottom contact sharp.
10	3.5	Sandstone, moderate-yellowish-brown (10YR5/4) with orange cast; fine grained; small clay chips at base of unit; medium to thick bedded; trough cross-strata; slabby to rubbly. Grades upward to silt shale, light-yellowish-brown (10YR6/4) to olive-gray (5Y3/2); fossil plant fragments; ripple bedded at top of unit. Bedding attitude is N13°E, 54°SE. Sandstone cuts into or is loaded into underlying unit; bottom contact is sharp with less than 0.3 m of relief.
9	4	Sandstone, weathered moderate-yellow-brown (10YR5/6); mostly very fine with some fine grained; small- to medium-scale trough cross-strata. Grades upward to sandstone, moderate-yellow-brown (10YR5/6); very fine grained; thin bedded. Grades upward to fissile sandstone or to silt shale composed of coarse silt; very thinly laminated; parallel laminated; cut out by overlying unit. Bottom contact covered.
8	7	Silty claystone, grayish-red (10R4/2); crumbly and hackly. Upper half of unit covered. Bottom contact covered.
7	2	Sandstone, grayish-red (10R4/2) to brownish-gray (5YR4/1); coarse silt to very fine grained; very micaceous; thickly laminated to very thin bedded; ripple-drift cross-lamination; small (2-4 cm) load casts at base of unit; several well-preserved, fossil dermal fish plates on one bedding surface of float block at path level; some bedding surfaces have slickenlines running in several directions; slabby, flaggy, and blocky. Bedding attitude is N33°E, 43°SE. Bottom contact sharp.
6	17	Claystone, grayish-red (10R4/2); slightly silty; subfissile; few grayish-red (10R4/2) silt shale interbeds; hackly. Well-developed hackly to equant claystone to siltstone in upper 2 m of unit. Bottom contact sharp.
5	2.5	Siltstone, grayish-red (10R4/2); undulatory bedding; slabby, blocky, and rubbly. Bottom contact sharp.
4	24	Claystone, grayish-red (10R4/2); slightly silty; subfissile; few grayish-red (10R4/2) silt shale interbeds; hackly. In upper third of unit is 0.5 m thick, very light olive gray (5Y6/2), coarse silt shale. Bedding attitude is N12°E, 50°SE. Bottom contact sharp.
3	3.3	Siltstone, grayish-red (10R4/2); very micaceous; thin bedded; some thin silt shale interbeds; blocky, rubbly, and slabby. Bottom contact gradational.
2	2.5	Clayey silt shale to silty clay shale, grayish-olive (10Y4/2 to 10Y5/2); common fossil plant fragments and carbonaceous fragments but not identifiable; chippy and platy. This is the presumed "Saxton shale" of Reger (1927a, 1927b). Unit grades laterally to interbedded silt shale, siltstone, and silty clay shale, grayish-red (10R4/2); some siltstone beds up to 0.3 m thick towards top of unit. Bedding attitudes are N27°E, 52°SE and N36°E, 46°SE. Bottom contact gradational.
1	1.2	Sandstone, light-olive-gray (5Y5/2) grading upward to brownish-gray (5YR4/2); medium grained grading upward to very fine grained; very micaceous; thin bedded grading upward to very thin bedded; most of unit parallel bedded; bottom surface of some beds irregularly and vaguely (trough?) crossbedded; slabby to flaggy. Bottom contact sharp. Small exposure (about 0.3 m) of grayish-red (10R4/2) silt shale below unit to path level. TOTAL CATSKILL FORMATION MEASURED = 150.9 m

MISSING UNITS IN APPENDIX 1, ORDOVICIAN-AGE CARBONATES AT UNION FURNACE, PAGE 223, 51st GUIDEBOOK

19 Mudstone-wackstone, brownish black, containing undulatory and anastomosing laminae, horizontal burrows, minor disarticulate and articulate brachiopods, pyrite, 0.2' thick intraclastic pods near top................2.1
Bentonite (5), medium gray, re-entrant....................................0.4
Mudstone, brownish black, containing minor skeletal wackstone especially at base, vertical and horizontal burrows, minor undulatory laminae throughout..1.6
Skeletal intraclastic wackstone-packstone, brownish black, hardground at base, thin irregular chert nodules at base..............................0.3
Mudstone, brownish black, containing minor intraclastic wackstone, undulatory and slightly anastomosing laminae, vertical and horizontal burrows some with vertical escape-like tops, minor irregular chert nodules..1.0
Mudstone, brownish black, containing laminae and bands, hummocky cross-stratification, <0.1' thick chert bed, scoured base, transitional top....0.5
Mudstone-wackstone, brownish black, containing horizontal and vertical burrows, mottling, skeletal debris, pyrite..................................2.8
Burrowed-mudstone and intraclastic wackstone-packstone, brownish black to olive black, containing mudstone cycles 0.2' to 1.5' thick having vertical and horizontal burrows or undulatory laminae, brachiopod fragments, irregular and scoured hardground contacts with overlying skeletal wackstones, trace pyrite; wackstone-packstone cycles 0.1' to 0.2' thick having lensoidal shape, intraclasts <0.2" in diameter, possible hummocky cross-stratification, calcite replaced crinoid or echinoderm fragments, iregular and undulatory contacts...9.0
Mudstone, olive black, containing <0.2' thick minor discontinuous intraclastic wackstone-packstone beds having rounded clasts <1" in diameter; argillaceous undulatory to anastomosing laminae and bands, horizontal burrows with minor vertical burrows, abundant skeletal debris................4.4
[Subtotal 22.1]

20 Wackstone, brownish black, containing faint mottling, horizontal and vertical burrows, minor calcite replaced articulate and disarticulate brachiopods, shaly parting at top..3.5
Mudstone, olive black, containing undulatory and anastomosing argillaceous laminae, vertical and horizontal burrows, minor intraclastic wackstone-packstone lenses typically <0.1' thick..............................4.2
Skeletal wackstone-packstone, olive black, containing mostly brachiopod fragments, indistinct laminae..0.6
Skeletal grainstone, olive gray to medium dark gray, containing abundant fossil hash, minor to rare mudstone clast <0.2" in diameter..............0.6
Wackstone-packstone, brownish black, containing <0.2' thick discontinuous intraclastic zones, indistinct undulatory laminae, horizontal worm burrows, disarticulate and articulate brachiopods, crinoids, hardgrounds....4.4
[Subtotal 13.3]

21 Mudstone, olive black, containing undulatory and anastomosing argillaceous laminae, horizontal worm burrows, trace pyrite, minor skeletal fragment..3.6
Mudstone-wackstone, brownish black, containing horizontal burrows, minor calcite replaced skeletal fragment, undulatory discontinuous laminae towards base, 0.75' thick dusky brown clay at top...........................2.0
Wackstone-mudstone, brownish black, containing horizontal and vertical burrows, mottling, disarticulate brachiopods, echinoderm fragments (?), undulatory upper contact..3.0
Mudstone, brownish black, containing discontinuous shaly laminae, oblique burrows, minor brachiopods and bryozoa, trace pyrite, shaly parting at top...4.7
[Subtotal 13.3]

PLEASE SEE ERRATA SHEET FOR ARTICLES ON PAGES 7 AND 111