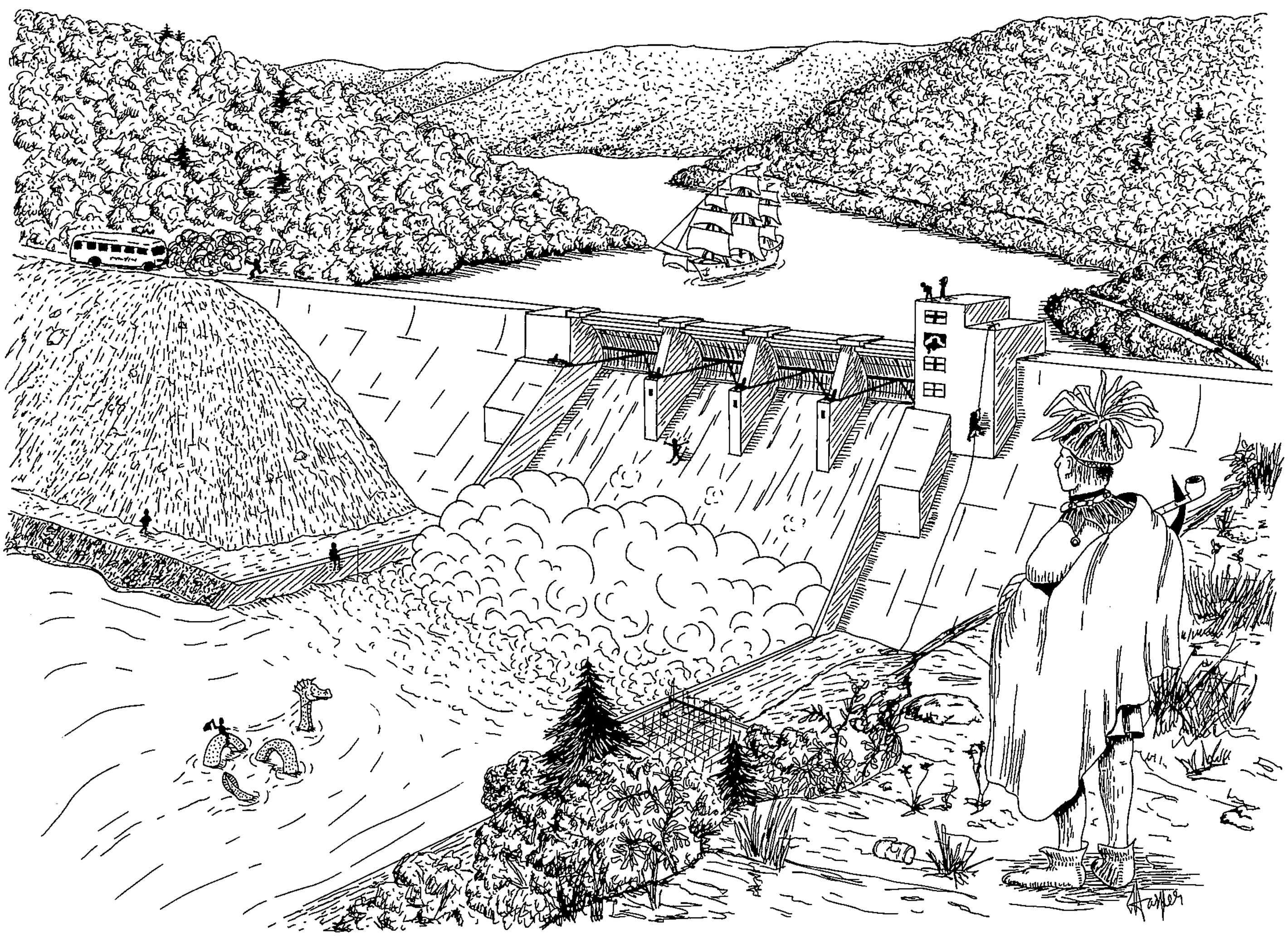
GUIDEBOOK

57th Annual Field Conference of Pennsylvania Geologists

GEOLOGY OF THE UPPER ALLEGHENY RIVER REGION IN WARREN COUNTY, NORTHWESTERN PENNSYLVANIA



Hosts: Pennsylvania Geological Survey
University of Pittsburgh at Bradford

October 1, 2, and 3, 1992
Warren, Pa.

ADDENDUM AND ERRATA
for
Guidebook for 57th Annual Field Conference of PA Geologists

ADDENDUM

Page 186.
Editor's Note. The 24 deformed crinoid ossicles had a mean axial ratio of 1.11 (standard deviation = 0.07). Orientation of the long axes grouped as follows: 50 percent were within a 17° spread; 62.5 percent, 24° spread; 83 percent, 53° spread; and 100 percent, 89° spread. These data are in good agreement with Hudak (1992, Northeastern Geology, v. 14, p. 108-112). An additional 180 ossicles had no detectable deformation.

ERRATA

p= page; P= paragraph; L= line; [means remove]; *means add*.

p	P	L	Correction
2	3	2	were *mostly* derived
4	2	3	Olean Conglomerate *Member*
7	5	3	Conewa*n*go
8	1	1	[River] *Creek*
9	Figure 5, Solid circles on map:		[8] *9*, [9] *8*
12	3	6	198[3]*6*
18	3	5	Rocks (Stop [9] *8*)
18	4	1	Ashburner (1880) *formally* named
19	1	2	very light[-]gray
23	1	3	[)]
24	1	2	[c]*C*ommonwealth
28	3	7	[Z]*z*onal-scale
29	1	6	sea*-*level
64		26	in*-*situ
65	Figure 20, near top:		PIN[E]K ROCK
75	3	2	a[n] long
79	1	2	as[s]ym*m*etry
87	3	24	gel[u]*i*fluction
90	1	9	[may] *can*
95	1	1	ice*-*
96	4	1	well[-]developed
98	4	2	cat*e*gories
110	4	7	isolate[d]
113	1	14	storm*s*
113	4	7	(100-[feet]*foot*)
115	2	2	influx of *reworked*
125	2	6	gel[u]*i*fluction? Does gel[u]*i*fluction
126	1	5	gel[u]*i*fluction?
126	1	9	gel[u]*i*flucted
130	2	7	(Figure [03]*39*).
132	Photograph identification numbers:		[C]*D* [D]*C*
143	1	2	Lithofacies [I]*II*
143	2	2	Lithofacies [I]*II*
144	4	3	g*r*ay

148	2	15	do<u>es</u> igneous
148	3	9	unk<u>n</u>own
174	1	7	lea[a]ving

Guidebook for the

57th ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

GEOLOGY OF THE UPPER ALLEGHENY RIVER REGION IN WARREN COUNTY, NORTHWESTERN PENNSYLVANIA

W. D. Sevon, editor

Contributors and field trip leaders:

Clifford H. Dodge
Edgar M. Hopkins
Assad A. Panah
John A. Harper
Michael E. Moore
Jon D. Inners
Thomas M. Berg
Douglas A. Stewart
Joseph M. Tarantino
Donald L. Woodrow
Samuel W. Berkheiser
William E. Kochanov
Helen L. Delano
L. R. Auchmoody

October 1-3, 1992

Hosts: Pennsylvania Geological Survey
University of Pittsburgh at Bradford

Headquarters Motel: The Holiday Inn, Warren, PA

Cover: The spirit of Chief Cornplanter keeps watch over the 57th Annual Field Conference of Pennsylvania Geologists at Kinzua Dam, Warren County.
Art work by John A. Harper

Guidebooks distributed by:

Field Conference of Pennsylvania Geologists, Inc.
P. O. Box 1124
Harrisburg, PA 17108

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

BEDROCK LITHOSTRATIGRAPHY OF WARREN COUNTY, PENNSYLVANIA

Clifford H. Dodge
Pennsylvania Geological Survey
Harrisburg, PA 17105-2357

INTRODUCTION

Recent work on the groundwater resources of Warren County by the Pennsylvania Geological Survey, in cooperation with the U.S. Geological Survey, Water Resources Division, has led to renewed interest in the bedrock geology of the area. Except as reconnaissance for the 1980 *Geologic Map of Pennsylvania* (Berg and others, 1980) or incidental to various oil and gas investigations, little new work had been accomplished on rocks exposed at the surface in Warren County since the pioneering studies by Carll (1883), Butts (1910), and Caster (1934). Understanding the geology is essential for identification and characterization of aquifers and for determination of regional groundwater flow paths.

As an important aspect of the groundwater investigation, the Pennsylvania Geological Survey compiled a new geologic map (scale 1:50,000) for the county. Prior to this undertaking, however, it was necessary to review our existing knowledge of the regional bedrock lithostratigraphy, test its validity, and make changes or modifications where necessary. This analysis was facilitated through the use of full-hole, natural gamma-ray logs and sample descriptions (cuttings) from oil and gas wells, which provided the key to much improved resolution, correlation, and quantification of bedrock units. Consequently, a far greater understanding of the lithostratigraphic framework has emerged. Nevertheless, there is much more to learn, and as demonstrated by this year's Field Conference, Warren County is a fertile area for future sedimentological, paleontological, and stratigraphic research.

Preparation of the following summary of the bedrock geology relied on and built upon a number of noteworthy previous investigations, including Ashburner (1880), Butts (1910), Carll (1883), Caster (1934), Cathcart and others (1938), Dickey (1941), Dickey and others (1943), Ingham and others (1956), Kelley (1967), Kelley and Wagner (1972), Lytle (1965), Lytle and Goth (1970), McGlade (1964), Sass(1960), Ward and others (1979), and White (1881).

GENERAL GEOLOGY

Lithostratigraphy

Upper Devonian (uppermost Cassadagan and Conewangoan), Lower Mississippian, and Pennsylvanian rocks are exposed in Warren County and comprise a mixed siliciclastic sequence of sandstone, siltstone, shale, subordinate conglomerate, a few calcareous beds, and minor coal. The sedimentary rocks exposed total about 1,350 feet (410 m). In ascending order, the bedrock is divided into the Chadakoin Formation, Venango Formation and laterally equivalent Catskill Formation, Riceville Formation and laterally equivalent Oswayo Formation, Knapp Formation and laterally equivalent unnamed mixed terrigenous clastics, Corry Sandstone, Cuyahoga Formation, Shenango Formation, and Pottsville Formation. For the most part, this nomenclature conforms with usage on the 1980 *Geologic Map of Pennsylvania* (Berg and others, 1980), or on the statewide correlation chart of Berg and others (1986). Minor changes in rock-stratigraphic rank were made to better reflect the mappability of certain geologic units. The historical development of stratigraphic nomenclature for Warren County is given in Figure 1.

A recent (1992) unpublished correlation study by the author confirmed the validity of the existing lithostratigraphic nomenclature for the county. Locations of wells used to construct two representative geologic cross sections for Warren County and vicinity are shown in Figure 2. The two geologic sections, using gamma-ray logs, are shown in Figures 3 and 4.

Sedimentary Controls and Environments

The exposed Upper Devonian and Lower Mississippian sequence represents sediments that were derived from areas of orogenic (Acadian) uplift to the southeast and deposited in shallow-marine-shelf to lower-delta-plain environments (Edmunds and others, 1979). The rocks are basically an alternating series of finer and coarser grained, marine terrigenous clastics, mostly shales and sandstones, that reflect sedimentological responses to multiple cycles (third through fifth order) of transgression and regression/progradation (see Harper and Laughrey, 1987, p. 24-26). Alluvial Pennsylvanian (Pottsville) sediments resulted from the reworking of earlier Paleozoic rocks in New York and southern Canada that underwent epeirogenic uplift along the margin of the North American craton. The sediments were subsequently deposited in alluvial- or delta-plain environments bordering an encroaching, shallow east-west embayment (Meckel, 1967; Edmunds and others, 1979). The Pennsylvanian strata are separated from the underlying rocks by a major regional disconformity, which is discussed below. For a more comprehensive overview, the reader is referred to Edmunds and others (1979), who have summarized the regional paleogeography, depositional environments, and depositional history of the Mississippian and Pennsylvanian rocks in Pennsylvania.

Structure

The geologic structure of the surface rocks in Warren County is characterized by broad, open folds in the east that diminish in amplitude westward, resulting in a gentle, south-southwest regional tilt to the beds. Local warping of the strata in the western part of the county appears to be related primarily to differential compaction (Cathcart and others, 1938; McGlade, 1964). Flexures in southeastern Warren County are irregular to asymmetrical. They typically have wavelengths of approximately 4

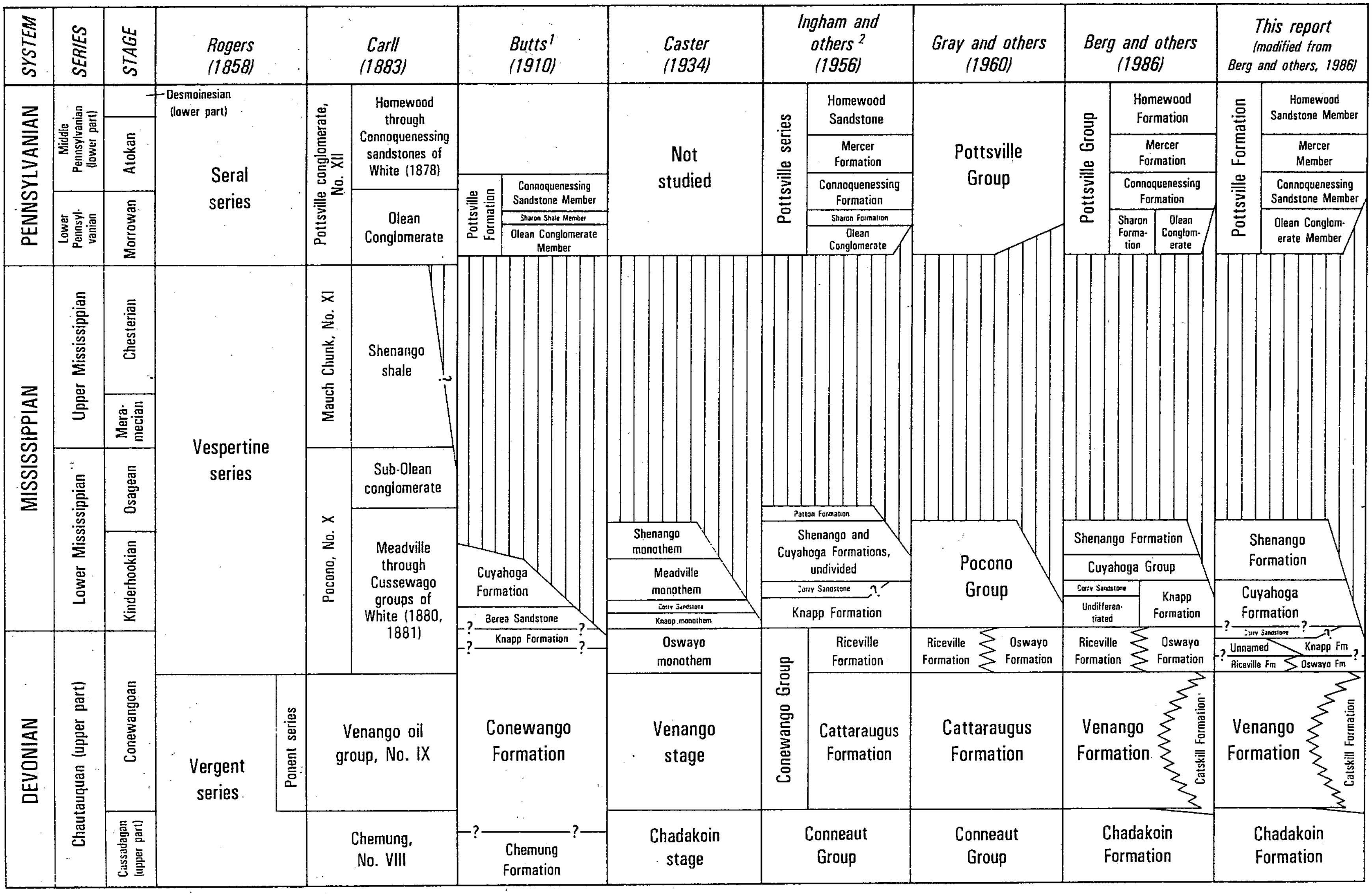


Figure 1. Historical development of stratigraphic nomenclature applied to the bedrock of Warren County. Closely ruled vertical lines indicate disconformity. ([1]Valid for northern Warren County. [2]Valid for southern Warren County.)

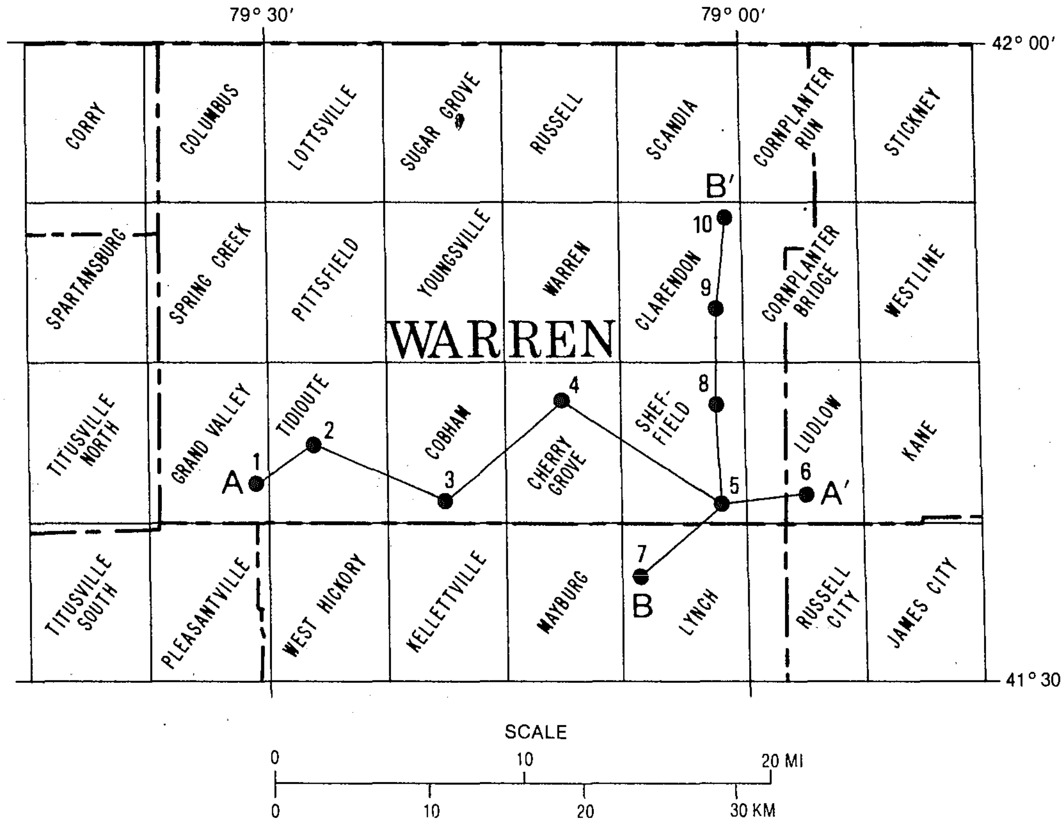


Figure 2. Location map of numbered wells used in geologic sections A-A' and B-B' (Figures 3 and 4), Warren County and vicinity. Diagonal names refer to 7.5-minute topographic quadrangles.

miles (6.5 km), heights (structural relief) of nearly 50 feet (15 m), and plunges of about 30 feet per mile (6 m/km) to the southwest. The regional dip of the strata in western Warren County is about 20 to 30 feet per mile (4 to 6 m/km) to the south-southwest. No surface faults (tectonic) have been reported.

Mississippian-Pennsylvanian Disconformity

The earliest known suggestion of a pre-Pottsville disconformity in Warren County came from Carll (1883, p. 326), who recognized the irregular contact between the Olean Conglomerate (Lower Pennsylvanian) and subjacent Knapp Formation (Upper Devonian or Lower Mississippian) in Glade Township. Using oil-well records, Ashburner (1879, 1880) demonstrated the southward thickening of the rocks between the Pottsville and Catskill Formations to the east of Warren County but did not attribute it to a disconformity. White (1891) originally proposed a regional Mississippian-Pennsylvanian disconformity in Pennsylvania, West Virginia, and Ohio to account for the absence of floral assemblages that otherwise occur in the Southern Anthracite field of eastern Pennsylvania. Since that time, numerous workers have documented the existence of the disconformity.

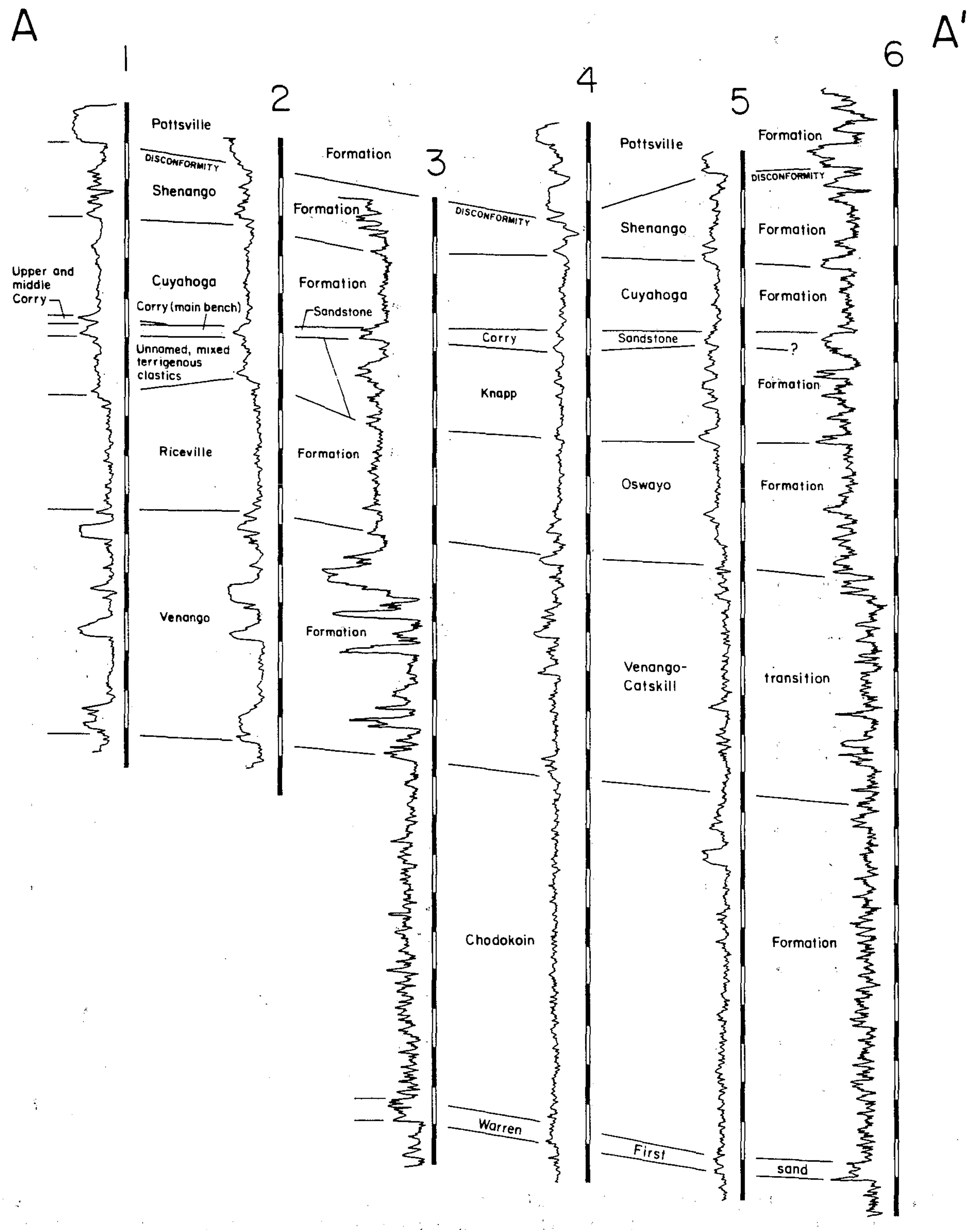


Figure 3. Diagrammatic west-to-east (A-A') geologic section showing correlation of gamma-ray logs in southern Warren County and vicinity. Datum is top of Corry (main bench) or Corry-Knapp. Vertical scale of logs indicated by adjacent graduated bars; each increment equals 50 feet (15.2 m). No horizontal scale implied. See Figure 2 for location of section.

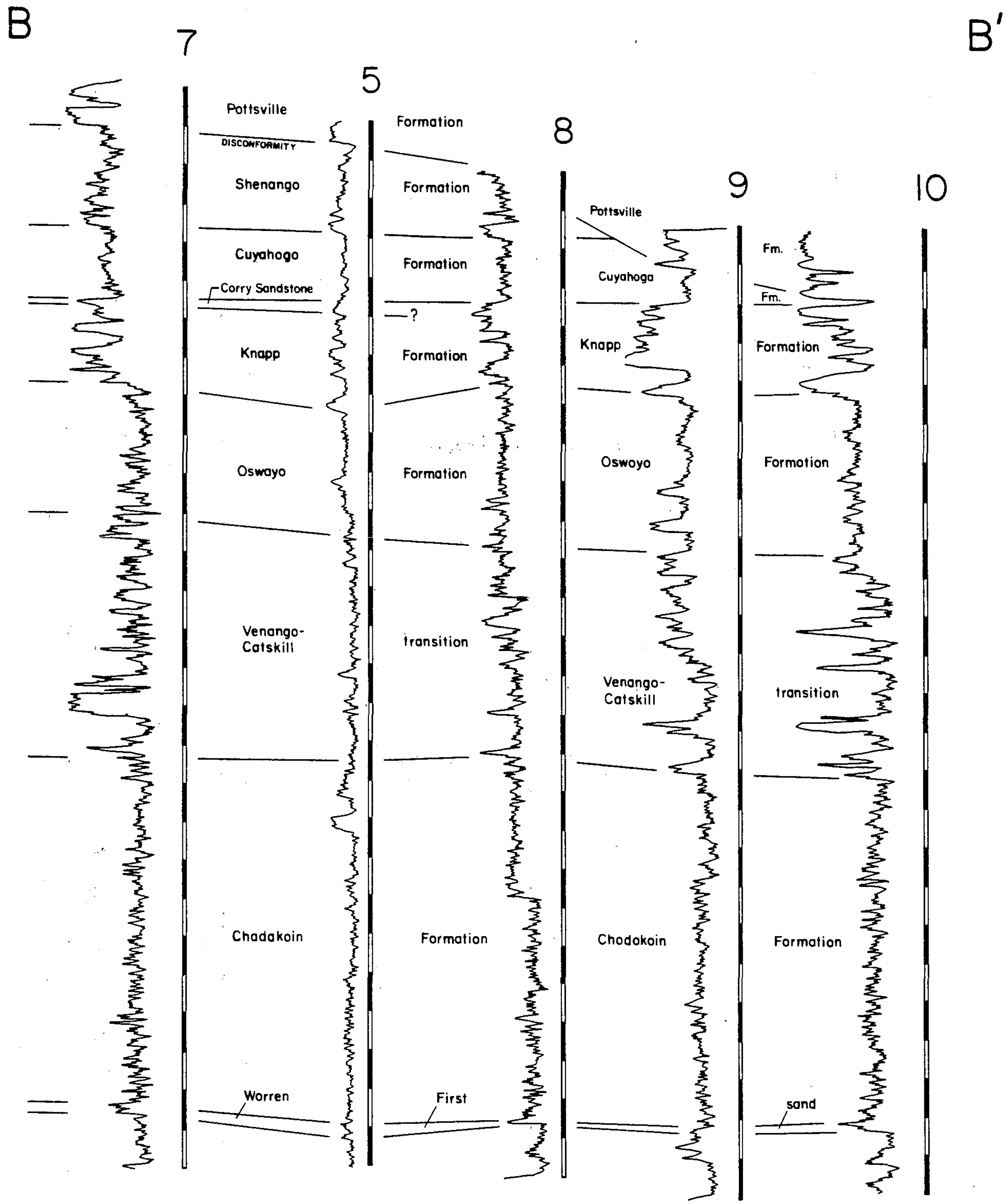


Figure 4. Diagrammatic south-to-north (B-B') geologic section showing correlation of gamma-ray logs in eastern Warren County and vicinity. Northward thinning of the Shenango and Cuyahoga Formations is due to erosion on the Mississippian-Pennsylvanian disconformity. Datum is top of Corry (main bench) or Corry-Knapp. Vertical scale of logs indicated by adjacent graduated bars; each increment equals 50 feet (15.2 m). No horizontal scale implied. See Figure 2 for location of section.

Prior to deposition of the Pottsville in Warren County and elsewhere, the underlying rocks were subjected to mild epeirogenic uplift and folding, tilted southward, and truncated by erosion. Consequently, the pre-Pennsylvanian rocks thin northward in the county, resulting in a net loss of section, from south to north, of about 250 feet (75 m)(see Figure 4). Local relief on the erosional surface of the disconformity may reach 50 feet (15 m)(Ingham and others, 1956). In the Warren County area, erosion probably continued from the Late Mississippian (Meramecian) into the Early Pennsylvanian (Morrowan) (Edmunds and others, 1979).

BEDROCK LITHOSTRATIGRAPHIC UNITS

Upper Devonian

Chadakoin Formation

Named by Chadwick (1923) for a sequence of interbedded siltstones and reddish to chocolate-colored shales exposed along the Chadakoin River near Jamestown, New York, the formation was first used formally in Pennsylvania on the 1980 state geologic map (Berg and others, 1980). The Upper Devonian Chadakoin Formation averages about 450 feet (135 m) thick in Warren County and consists of interbedded greenish-gray to light-gray or reddish-purple-gray siltstone and medium-gray to medium-dark-gray or reddish-purple-gray shale, with some very fine- to fine-grained, light-greenish-gray to light-gray sandstone. Marine fossils, especially brachiopods and ichnofossils, are common. A persistent zone of dominantly reddish-purple-gray siltstones and shales commences about 110 feet (33 m) below the top of the formation and extends downward to its base. This zone is remarkably uniform in thickness and is the characteristic "pink rock" of drillers. Overlying the "pink rock" are mostly greenish-gray to medium-gray siltstones and shales.

The top of the Warren First sand marks the base of the Chadakoin. The Warren First is composed of interbedded very fine grained greenish-gray sandstone, olive-gray to dark-gray siltstone, and some greenish-gray to medium-gray shale. The unit is persistent throughout the region and is an excellent key bed. The base of the Warren First sand is particularly distinctive on gamma-ray logs. The contact between the top of the Warren First and overlying "pink rock" is conformable and generally sharp.

The top of the Chadakoin Formation is also sharp and occurs at the base of the Knox Fifth sand (or its equivalent). This contact is discussed further under the Venango Formation. In the eastern third or more of Warren County, the Tanners Hill red beds, a tongue of the Catskill Formation, represent the upper member of the Chadakoin and immediately underlie the Knox Fifth. The Tanners Hill is about 15 to 40 feet (4.5 to 12 m) thick and is composed of dominantly grayish-red siltstones and shales.

In Warren County, the Chadakoin crops out along the lower parts of the Allegheny River valley to as far west as the Youngsville area and northward along the length of the Conewago

River valley, which includes the Warren Mall section of this Field Conference (Stop 10). It is also exposed in some of the deeper river valleys near the New York border.

Rocks of the Chadakoin Formation were deposited as sediments in a shallow-marine-shelf (offshore) environment.

Venango Formation

Credit for naming the Venango Formation rightly belongs to Carll (1880), who called it the Venango oil sand group for a series of petroleum-producing sandstones and conglomerates in the Venango County area (see Harper and Laughrey, 1987, p. 27). The Venango Formation includes all of the strata from the top of its upper bounding key bed, the Woodcock Sandstone Member (Venango First sand or its equivalent), to the base of its lower key bed, the Panama Conglomerate Member (Venango Third sand or its equivalent). The formation is about 280 to 330 feet (85 to 100 m) thick in Warren County. The Venango consists of varying amounts of light-gray conglomerate, conglomeratic sandstone, and sandstone; gray and greenish-gray siltstone; and dark-gray to brownish-gray and minor grayish-red shale. Grayish-red shale may be more common where the Venango interfingers with the Catskill Formation. The sandstones and conglomerates are generally lenticular. Sandstones are commonly very fine to medium grained but range up to very coarse grained. Conglomeratic beds commonly contain discoidal-shaped (flat) quartz pebbles. Thin calcareous sandstones and sandy limestones occur locally. Marine fossils are present and include brachiopods, trace fossils, some bivalves, and a few dermal fish plates and related material (Carll, 1883). Rare, more exotic forms have been found, such as phyllocarid (leaf shrimp) crustaceans (Beecher, 1884) and eurypterid ("sea scorpion") arthropods (Hall, 1884). Scattered plant fossil fragments also occur locally.

Defining the contacts of the Venango Formation is difficult where the bounding key beds are absent. In Warren County, the base of the Venango is generally well marked by the Knox Fifth sand or its equivalent. However, the upper contact becomes ill-defined eastward beyond the limits of the type Venango First sand. In its place are scattered lenticular sandstones that occur anywhere within an interval of perhaps 40 feet (12 m) both above and below the horizon of Venango First. Where marker beds are not recognized, it is common practice to map the contacts by projection of interval thickness. Some workers contend, however, that these lenticular sandstones are genetically linked to the Venango sands and should be included in the Venango Formation. Moreover, there is some opinion that the overlying Oswayo Formation by definition should not contain appreciable or thick sandstone (Harper, 1992, personal communication).

Towards the southeastern part of the county, the Venango Formation intertongues with red beds of the Catskill Formation. The stratigraphic position and thickness of the two formations are nearly the same. The percentage of red beds in the stratigraphic interval increases gradually at first and then abruptly near the southeast corner of the county (Figure 5). The

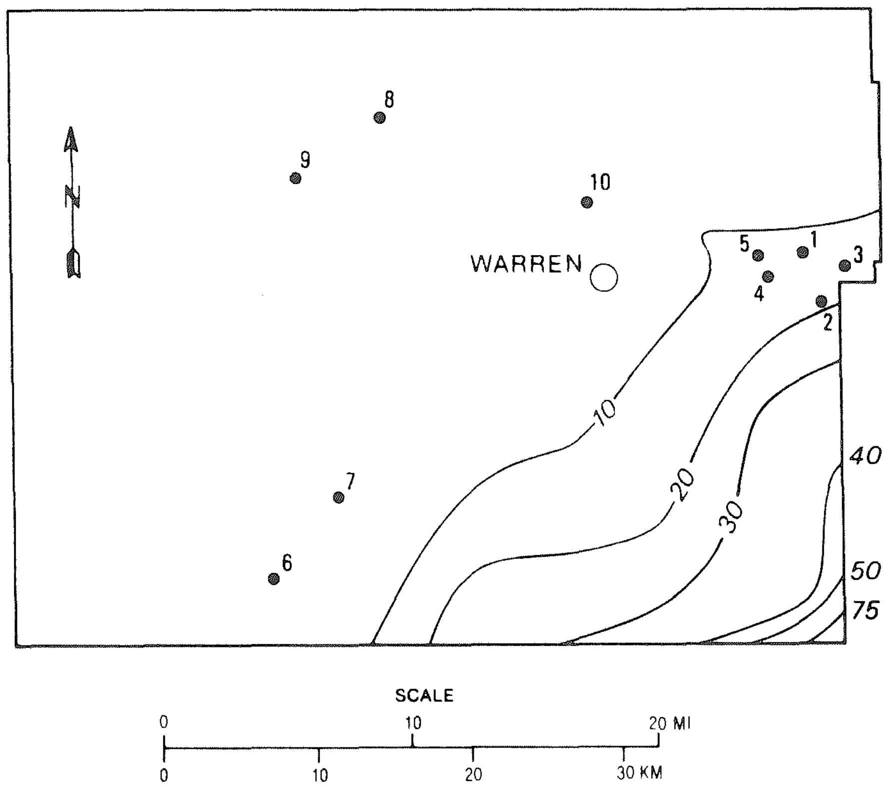


Figure 5. Map showing the transition zone between the Upper Devonian Venango and Catskill Formations, Warren County. Numbered isopleths represent the percentage of stratigraphic interval occupied by red beds. Locations of Field Conference stops indicated by numbered solid circles. Larger open circle denotes county seat. Modified from unpublished work map of Berg (1985).

red beds never occupy the entire interval in the county, but some generally occur at or near the top of the stratigraphic interval in the transition zone and southeastward. Where more than half the interval is red beds, the name Catskill is assigned. The contours (isopleths) in Figure 5 indicate the relative dominance of red Catskill (dominantly nonmarine) sedimentation, and their shape reflects the general configuration of the paleoshoreline. Thus, the paleoslope (assuming orthogonality) appears to shift from an overall northwesterly direction for most of southeastern Warren County to a northerly trend along the east-central border area. As a result of averaging, however, the map does not portray the orientation of the paleoshoreline at any given time, and individual features, such as delta lobes, cannot be resolved.

The Venango Formation crops out within the deeper river valleys throughout much of the county. It is well exposed in several roadcuts near Big Bend and Kinzua Dam (Stops 1, 2, and 4). Other outcrops occur along the Allegheny River near Cobham (Stop 7) and vicinity.

Depositional environments of the oil-producing sandstones of the Venango Formation are offshore bar and beach, tidal channels, and subaqueous dunes (Dickey, 1943; Kelley, 1967). Other associated lithologies represent lagoonal, intertidal, and lower-delta-plain deposits. Harper and Laughrey (1987) noted that the Venango oil sands record fifth-order transgressive-regressive cycles in which repetitive series of sand-forming facies migrated back and forth in response to successive rises and falls in sea level.

In Warren County, petroleum production from the Venango Formation is confined to the southwest. Various aspects of the oil and gas geology of the formation are presented by Harper (1992, this guidebook).

Catskill Formation

Regional relationships of the Catskill Formation are given in Woodrow and Sevon (1985). The Catskill of western Pennsylvania is characterized by interbedded grayish-red siltstone and shale and light-gray to tan and grayish-red sandstone that are generally arranged in fining-upward cycles. These rocks resulted from mostly nonmarine sediments deposited by meandering stream systems on alluvial or upper-delta plains.

In Warren County, the Catskill is confined to the southeast corner where it intertongues with the Venango Formation. Here, the Catskill red beds, or drillers' "red rock," are mostly grayish-red siltstones and shales that represent lower-delta-plain or coastal-margin deposits. Some of the red beds contain burrows, root traces, or scattered *Lingula*. Sandstones associated with the red beds are commonly very fine to fine grained and gray to olive gray. They may represent distributary channels, distributary mouth bars, or tidal channels.

By convention, the Catskill is differentiated from the Venango-Catskill transition zone if the red beds exceed 50 percent of the stratigraphic thickness of the interval. Where the thick mass of red strata occurs in Warren County, the base of the Catskill is defined by the Tanners Hill red beds. The top of the formation is placed at the highest red bed, which appears to occur at about the stratigraphic horizon of the Venango First sand. However, the base of the overlying unit shifts up or down somewhat according to the position of the highest red bed.

Catskill red beds are exposed in the deeper river valleys in southeastern Warren County.

Riceville Formation

I.C. White (1881) named this formation for exposures of shale along Oil Creek at Riceville, Crawford County. The Riceville Formation in Warren County comprises fissile, medium-gray, bluish-gray, dark-brown, and purplish-red shales; thin, scattered medium-gray siltstones; and minor, thin, scattered, very fine grained, light-gray sandstones that are locally calcareous. Few to common marine fossils are present. The formation ranges in thickness from about 125 to 170 feet (38 to 52 m). The Riceville grades laterally eastward to the Oswayo Formation near Warren. Upper and lower contacts are conformable and sharp to gradational. However, the lower contact is not always clearly defined, as was discussed under the Venango Formation.

The Riceville is seldom exposed. It is situated along the valley slopes in the southern part of the county and caps much of the uplands north of the Allegheny River.

Riceville sediments were deposited in an offshore shelf environment during a period of marine transgression.

Oswayo Formation

The Oswayo Formation was originally described by Glenn (1903, p. 978-980) for exposures of olive-green and rusty-brown sandy shales that contain thin, scattered sandstone interbeds. Thin, lenticular, impure, highly fossiliferous "limestones" also were observed locally. The type area of the formation is along Oswayo Creek near Olean, New York. Caster (1934, p. 96) later remarked that the Oswayo Formation was "laterally extraordinarily homogeneous" westward from its type area and into Warren County. He described the Oswayo as "everywhere a coarse arenaceous shale, brownish green to olivaceous in color, highly micaceous with thin sandstone lenses, for the most part calcareous cemented..." (Caster, 1934, p. 96). However, despite his assertion that sandstones are always thin and a minor component of the Oswayo, Caster (1934, p. 100-102) proceeded to describe a measured section of the Oswayo along PA Route 546 in northern McKean County in which thick crossbedded sandstones occur! It seems clear that the intent of Glenn (1903) was to define the Oswayo as extending from the highest red bed of the Catskill Formation to the base of the overlying Knapp Formation, regardless of the composition of the Oswayo interval or the presence of sandstone. One of the difficulties faced by these early workers was the lack of long, continuous exposures, thus precluding a full understanding of the vertical and lateral variability (not to mention correct lithostratigraphic correlations) of the named units.

Where the Catskill Formation is present, the lower contact of the Oswayo Formation is well defined. However, westward into Warren County, the Oswayo generally overlies the Venango Formation or Venango-Catskill transition zone. In these circumstances, the contact between the Oswayo and the underlying formation may be arbitrary and determined by interval thickness if the Venango First sand or its equivalent is absent. Thus, thicker sandstones may be present locally in the Oswayo Formation.

In Warren County, the Oswayo is characterized by dark-greenish-gray to medium-greenish-gray and olive shales and silty shales; medium-greenish-gray to greenish-gray and light-olive siltstones; and much subordinate very fine to fine-grained, light-greenish-gray to pale-olive sandstones. Marine fossils are common, particularly trace fossils and brachiopods. Scattered plant fragments are present locally. The formation is about 150 to 200 feet (45 to 60 m) thick.

As is the case for the Riceville, the Oswayo Formation seldom crops out and is studied mostly from well samples or float. The Oswayo is situated along the higher valley slopes or in the upland areas in the eastern part of the county.

The Oswayo grades laterally westward to the Riceville Formation and represents transgressive sediments that were deposited in nearer shore, shallow-marine environments relative to the Riceville.

Upper Devonian or Lower Mississippian

The position of the Devonian-Mississippian boundary in northwestern Pennsylvania was much debated earlier in this century. The main arguments have been reviewed by Edmunds and others (1979). Relying mainly on the faunal analysis of Holland (1958), current thinking places the systemic boundary at the base of the Knapp Formation or its equivalent (Berg and others, 1983). In studying the brachiopods of the Oswayo and Knapp Formations, Holland (1958) placed the Devonian-Mississippian boundary at the stratigraphic horizon having the greatest number of new forms, but he acknowledged that different species may be facies controlled. Central to his thesis is the first occurrence of the brachiopod *Syringothyris*, which is present in the Knapp but absent in the underlying Oswayo Formation. This genus was believed to be restricted to the Early Mississippian. *Syringothyris* also occurs in the Corry Sandstone (Sass, 1960).

Recent work has cast doubt on Holland's interpretation. Carter and Kammer's (1990) study of brachiopods from the Price Formation (Upper Devonian and Lower Mississippian) of West Virginia and adjacent areas in Pennsylvania and Maryland suggests that the last occurrence of *Cyrtospirifer* (Late Devonian) and not the first occurrence of *Syringothyris angulata* Simpson (now considered latest Devonian and Early Mississippian) should be used to define the Devonian-Mississippian boundary. Because both fauna occur in the Knapp Formation and Corry Sandstone (Holland, 1958; Sass, 1960), Carter and Kammer (1990) concluded that the two formations are latest Devonian in age. Using a different approach, Eames (1974) reached a similar conclusion. Based on his investigation of the palynology of the Berea Sandstone (temporal equivalent of the Corry) and superjacent Cuyahoga Group in northeastern Ohio, Eames placed the Mississippian-Devonian boundary at the bottom of the Cuyahoga.

Because of renewed uncertainty as to the position of the systemic boundary, the Corry-Knapp interval is considered Late Devonian or Early Mississippian in this paper.

Knapp Formation

Glenn (1903) named the Knapp Formation for a sequence of interbedded flat-pebble conglomerates and shales exposed at Knapp Creek, New York, just north of McKean County, Pennsylvania. The Knapp in Warren County consists of interbedded extraformational conglomerate, pebbly sandstone, sandstone, some siltstone, and shale. Conglomerates and conglomeratic sandstones are light gray and commonly ferruginous, and contain rounded, discoidal quartz pebbles that locally may exceed 0.6 inch (15 mm). Rounded rock fragments are present locally in the conglomerates. The pebbly sandstones may contain scattered lenses of conglomerate. In some places, the conglomeratic units display graded bedding and crudely to well-defined planar or trough crossbedding. Planar-tabular crossbed sets locally exceed 6.5 to 13 feet (2 to 4 m). Sandstones are light gray to light greenish gray, locally argillaceous or calcareous, and commonly ferruginous. They are typically very fine to medium grained but are coarse to very coarse grained in some places. Crossbedding and ripple bedding occur locally. Siltstones are gray to greenish gray, and shales are dark gray to dark greenish gray. Few to common marine fossils are present and include brachiopods and crinoids. Plant fragments occur locally as well. Knapp fauna have been discussed in detail by Holland (1958) and Caster (1934).

The Knapp Formation is present in the eastern two-thirds of Warren County, where it ranges in thickness from 0 to 140 feet (0 to 42 m). It thins westward and grades laterally to a finer grained, unnamed, marine mixed-clastic sequence. The Knapp thickens downward to the east at the expense of the underlying Riceville or Oswayo Formation. Upper and lower contacts are generally sharp and conformable.

The Knapp Formation crops out along the valley sides in the southern part of the county and in the upland areas or ridge tops to the northeast. It is locally a cliff former, and large float blocks can be found well below the outcrop belt. This is clearly evident at the Dixon Gully section at Stop 5. Near the Allegheny River and northward, the uppermost Knapp is locally removed by erosion on the Mississippian-Pennsylvanian disconformity. Where this occurs, such as its superb illustration at Rimrock Overlook (Stop 3), the Knapp is unconformably overlain by rocks of the Pennsylvanian Pottsville Formation.

The Knapp Formation comprises sediments that were deposited in offshore, regressive bar and beach systems, and associated environments.

Unnamed marine mixed clastics

In western Warren County, the lateral equivalent of the Knapp Formation is an unnamed marine sequence of thin, impure, locally calcareous, mostly very fine grained, light-gray sandstone; gray siltstone; and subordinate dark-gray shale. The sequence is about 60 to 100 feet (18 to 30 m) thick, recognizable on gamma-ray logs and in the field, and mappable. It should be formally named. Its upper contact with the overlying Corry Sandstone is sharp and conformable, whereas its base is generally gradational though conformable.

The unnamed mixed terrigenous clastics have been misidentified in earlier reports as the Cussewago Sandstone (e.g., Dickey, 1941; Dickey and others, 1943; Ward and others, 1979). The Cussewago is absent in this region (Demarest, 1946; Pepper and others, 1954).

The unnamed sequence is poorly exposed along the valley flanks or upland areas in western Warren County.

The clastics are interpreted as offshore or lower shoreface deposits that are seaward from the Knapp bar/beach systems.

Corry Sandstone

The Corry Sandstone is an excellent key bed that is readily identified in the field and subsurface, particularly where the Knapp Formation is absent. It is distinctive on gamma-ray logs and the best marker bed in western Warren County. White (1881) named the Corry Sandstone for exposures in the now-abandoned Colegrove quarries, south of Corry in southeastern Erie County.

The Corry Sandstone generally ranges from 10 to 35 feet (3 to 10 m) thick but becomes thinner where it overlies the Knapp Formation. At its thickest, the Corry occurs as two sandstones separated by shale--the tripartite Corry of Dickey (1941)--but the lower sandstone is much more persistent and widespread. In Warren County, the tripartite Corry is mostly confined to southwest.

The lower or main bench of the Corry is about 8 to 20 feet (2.5 to 6 m) thick and consists of well-indurated, flaggy to slabby, locally crossbedded, clean, slightly calcareous to calcareous, subangular to well-rounded, silt to very fine grained, light-gray to very light gray or yellowish-gray fossiliferous sandstone that contains some shale chips or quartz pebbles toward its base. Quartz grains are locally frosted and bimodal (very fine and medium grained). The base of the unit is mostly sharp and conformable; it may be gradational where it overlies the Knapp Formation. Marine fossils are common to abundant and have been studied in detail by Sass (1960) and Caster (1934).

The medial subdivision of the Corry, where present, is about 5 to 10 feet (1.5 to 3 m) thick. It is composed of gray to greenish-gray, thin-bedded siltstone, silt shale, and much subordinate clay shale. Upper and lower contacts are gradational to sharp and conformable. Marine body fossils are rare, but trace fossils are present locally.

Where it occurs, the upper bench of the Corry consists of well-indurated, slabby, locally crossbedded, clean, locally pebbly (quartz), very fine to medium-grained, light-gray to very light gray or yellowish-gray sandstone. Although ichnofossils are present in places, body fossils appear to be absent. The thickness of the upper unit is about 5 to 15 feet (1.5 to 4.5 m).

Geologists have long debated the stratigraphic relationships between the Corry Sandstone and the Knapp Formation. The Corry was thought to immediately overlie the Knapp or grade laterally to the upper part of it (Butts, 1910; Caster, 1934; Ingham and others, 1956; Sass, 1960; Lytle, 1965). Resolution of the problem has been hampered by widely scattered exposures and inadequate subsurface control. The most compelling arguments favored a superjacent Corry but were based largely on biostratigraphic reasoning. Sass (1960) identified a distinctive brachiopod suite associated with the Corry (main bench) and absent from the Knapp. In tracing the faunal suite eastward across Warren County and into McKean County, he noted that his

Corry thins to a foot or less and contains pebbles that are indistinguishable from the Knapp. A recent unpublished lithostratigraphic correlation study by Dodge (1992), using gamma-ray logs and sample descriptions, supports a superjacent Corry at least through the western two-thirds of northern Forest and Warren Counties. If the Corry does in fact merge eastward into the Knapp, it nevertheless appears that the top of the Knapp does not extend any higher than the stratigraphic position of the Corry. Thus, the top of the Corry (main bench) or Corry-Knapp is a reliable datum (key horizon) for lithostratigraphic correlation and structure contouring (Figures 3 and 4).

The Corry Sandstone crops out locally along the hillsides and valley slopes in western Warren County but generally is observed only as float.

The Corry is believed to represent shoreface and foreshore environments that developed during a time of maximum regression/progradation. The lenticular nature of the upper Corry Sandstone and the locally observed occurrence of bipolar cross-stratification in it (e.g., Ward and others, 1976, p. 23) suggest that the upper Corry may be, in part, tidal-channel deposits.

Lower Mississippian

Cuyahoga Formation

Although defined somewhat differently from present usage, Newberry (1871) applied the name Cuyahoga to shales exposed along the Cuyahoga River near Cleveland, Ohio. In Pennsylvania, the Cuyahoga is traditionally given group ranking and subdivided into three formations, in ascending order, the Orangeville Shale, Sharpsville Sandstone, and Meadville Shale. However, even where these subdivisions are apparently well developed, such as in Mercer County near the type areas, it has been noted that "the Cuyahoga Group might almost be considered a formation consisting of shale and silty shale containing widespread lenses of sandstone near the middle part" (Schiner and Kimmel, 1972, p. A17). Because of their limited mappability, the subdivisions are herein regarded as members and the Cuyahoga, which is much more laterally persistent and mappable, a formation. This view is further strengthened by recent geologic mapping, which has demonstrated that the Cuyahoga is traceable across Warren County and is practically all shale there.

In Warren County, the Cuyahoga Formation consists of fissile to subfissile, dark-gray to medium-dark-gray shale and silty shale; scattered, thin gray siltstone interbeds; and minor, local, thin, very fine grained, light-gray sandstone interbeds. Trace fossils are present. Although reported by others (e.g., Ingham and others, 1956; Lytle, 1965), there is no evidence of thin beds or lenses of flat-pebble conglomerate in the Cuyahoga Formation. Earlier suggestions to the contrary can be attributed to lithostratigraphic miscorrelations.

Where overlain by the Shenango Formation (Lower Mississippian), the Cuyahoga thins eastward from about 130 to 80 feet (40 to 24 m) as the Shenango thickens downward. Where overlain by the Pottsville Formation (Pennsylvanian), it thins northward due to erosion on the Mississippian-Pennsylvanian disconformity and is absent in the northern third of the county. Contacts with adjacent units are sharp and conformable. The Cuyahoga Formation has a characteristically uniform "shale" response on gamma-ray logs that makes it easily recognizable.

The Cuyahoga occurs along the valley slopes in the southern part of Warren County and in the upland areas farther north. It is very poorly exposed.

Rocks of the Cuyahoga Formation were deposited as sediments during a marine transgression, probably in a bay or on a shallow-marine muddy shelf.

Shenango Formation

White (1880) originally applied the name Shenango to some sandstone and shale exposed in the Shenango River valley in Mercer County. Later workers (e.g., Dickey, 1941; Dickey and others, 1943; Poth, 1963; Carswell and Bennett, 1963) expanded the definition to include a thicker, more complex sequence of sandstones and shales. As recognized today, Kimmel and Schiner (1970) divided the Shenango Formation into two informal members: a lower member composed mostly of interbedded sandstone and shale and an upper member, formerly misnamed the Hempfield Shale of Caster (1934), consisting chiefly of shale and siltstone. Edmunds and others (1979, p. B8) have rightfully suggested that the upper member be formally renamed as a separate unit.

The maximum thickness of the Shenango Formation in Warren County is about 130 feet (40 m). The formation is present only in the southern third to half of the county, having been removed to the north by the pre-Pottsville disconformity.

The lower member of the Shenango Formation comprises slabby to flaggy, very fine- to medium-grained, light-gray, pinkish-gray, and yellow-gray sandstone; dark-gray to medium-dark-gray shale; and subordinate gray to greenish-gray siltstone. The sandstones contain scattered, discoidal quartz pebbles up to 0.6 inch (15 mm) or more in length, and lenses of flat-pebble conglomerate. Low-angle crossbedding, ripple bedding, and shale chips occur locally. In some areas, the sandstones fine upward. Plant stems and fragments, including *Lepidodendropsis*, are a few to common locally in the sandstones. Some marine fossils are present in the lower member, particularly lebensspuren and brachiopods. Busch (1943) prepared a faunal list for part of the Shenango in Venango County, which may have some relevancy here. The basal sandstones of the lower member interfinger with the underlying Cuyahoga Formation and thicken downward to the east. The contact between the lower member of the Shenango Formation and the Cuyahoga Formation is sharp and mostly conformable. The upper contact of the lower member is sharp to gradational and conformable. The thickness of the lower member varies from 0 to 70 feet (0 to 21 m). The lower member is truncated northward by the regional disconformity. It is exposed locally in its outcrop belt along the upper valley sides and ridge tops in the southern part of the county.

The upper member consists of fissile to subfissile, dark-gray to medium-dark-gray and greenish-gray shale and silty shale; thin-bedded, medium-gray to light-greenish-gray siltstone; and subordinate very fine- to fine-grained, light-gray sandstone. Some trace fossils and a few body fossils occur in places. The member is 0 to 90 feet (0 to 27 m) thick and confined to the southern edge of the county, where it is very poorly exposed along the ridge flanks. It is unconformably overlain by rocks of the Pennsylvanian Pottsville Formation.

The lower member of the Shenango Formation represents regressive, lower-delta-plain deposits consisting of distributary channels, distributary mouth bars, crevasse splays, subaqueous levees, and interdistributary bays. Depositional environments of the upper member reflect a more transgressive phase and include bay and prodelta/shallow-marine muddy-shelf facies.

Lower and Middle Pennsylvanian

Pottsville Formation

Lesley (1876) introduced the name Pottsville as a synonym for the older term "lower barren coal measures." The Pottsville Formation (Lower and Middle Pennsylvanian) in this part of northwestern Pennsylvania consists of four members. In ascending order, they are the Olean Conglomerate, Connoquenessing Sandstone, Mercer, and Homewood Sandstone. The Pottsville is a complex, heterolithic, essentially nonmarine sequence of extraformational conglomerate, sandstone, some siltstone, subordinate shale, and minor coal that are commonly lenticular and variable in thickness. The Pottsville members are not readily mappable in Warren County, owing to vertical and lateral variability and to lack of exposures and subsurface control.

The maximum thickness of the Pottsville Formation in Warren County is about 240 feet (75 m), in the vicinity of Coal Knob near the McKean County border. The Pottsville underlies the upland areas and ridge tops south of the Allegheny River and generally occurs as small, isolated remnants capping several of the higher hilltops farther to the north. The formation unconformably overlies successively older rocks northward. Only the more resistant Pottsville units are well exposed locally. Generally, however, the sandstones and conglomerates are present as float or boulder colluvium.

Rocks of the lower Pottsville Formation (i.e., Olean Conglomerate and Connoquenessing Sandstone Members) were deposited as sediments by gravelly or sandy braided streams crossing an alluvial plain. Upper Pottsville strata represent depositional environments chiefly characterized by high-sinuosity meandering-stream systems on an upper delta plain. Meckel (1967) has discussed the origin and sedimentology of the Pottsville conglomerates and sandstones in detail.

Olean Conglomerate Member

The Olean Conglomerate (Lower Pennsylvanian) is very conspicuous in appearance and consists of ferruginous, trough-crossbedded, well-cemented, light-gray quartz-pebble conglomerate and conglomeratic sandstone (quartz arenites). The pebbles are mostly milky vein quartz and are commonly rounded to well rounded and subspherical to spherical. The quartz clasts are typically medium to very large pebbles but locally may include small cobbles (greater than about 2.5 inches, or 6 cm). Some discoidal quartz pebbles occur locally, particularly in the northern part of the county, and are interpreted as reworked from the Knapp Formation. Except locally near the base, the Olean Conglomerate is matrix supported, having a matrix composed of poorly sorted, medium- to very coarse grained quartz sand and in places quartz granules. Overall, the member fines upward. Toward the base of the unit, the Olean may be massive or crudely trough crossbedded. Plant compressions are present in places. Coal occurs very locally at the base of the member in northeastern Warren County and was formerly mined (Carll, 1883; Butts, 1910). The maximum thickness of the Olean is about 60 feet (20 m).

The lower contact of the Olean Conglomerate is sharp but irregular, scoured, and disconformable. The Olean is not laterally continuous, although it may appear so at outcrop scale. Its distribution and deposition are controlled by the paleotopography on the pre-Pottsville regional disconformity (Meckel, 1967). Local paleorelief on the disconformity is probably about 50 feet (15 m) (Ingham and others, 1956).

Well-developed rock cities and tors are present in the Olean Conglomerate in the northern part of the county. Bold escarpments and cliffs also occur. Popular tourist spots in the Olean include Rimrock Overlook (Stop 3), Jakes Rocks, and Nuttles Rocks (Stop 9). Huge float blocks, up to 30 feet (9 m) high or so, may be common locally and situated well below the outcrop belt of the member. The Olean is clearly evident in the northern two-thirds of the county but occurs as scattered float elsewhere.

Ashburner (1880) named the member for its spectacular development at Rock City near Olean, New York. The Olean Conglomerate was an important key bed for nineteenth-century well drillers, who used it to calculate depths to the oil-producing sands. However, there was much confusion for a time in identifying the Olean and in distinguishing it from other subjacent conglomerates. Ashburner (1880, p. 57) resolved this problem when he observed that "the pebbles in the upper [Olean] conglomerate are invariably round or prolate spheroids (egg shaped); consequently this rock cannot be mistaken for the lower or Sub-Olean [Knapp] conglomerate in which the pebbles are flat or oblate spheroids having the shape of a flattened orange."

Connoquenessing Sandstone Member

The Connoquenessing Sandstone (Lower and Middle Pennsylvanian) comprises mostly ferruginous, slabby, trough-crossbedded, well-indurated, fine- to coarse-grained, light-gray to very light-gray sandstone and pebbly sandstone (quartz arenites); much subordinate gray siltstone; and minor dark-gray to medium-dark-gray shale. Quartz granules and small quartz pebbles are present locally in layers, lenses, or zones. Sandstones tend to fine upward. Thin carbonaceous shale and discontinuous impure coal occur in places. Scattered plant compressions are present, especially *Lepidodendron*. Although individual beds are commonly lenticular, the overall sequence is laterally persistent. The base of the member is mostly gradational but conformable where underlain by the Olean Conglomerate. If the Olean is absent, the base of the Connoquenessing is sharp and disconformable.

The Connoquenessing Sandstone is the most important ridge-forming unit in Warren County. Huge float blocks and rock cities also occur in these sandstones and are up to 30 feet (9 m) high or so. The Connoquenessing is around 60 to 100 feet (20 to 30 m) thick.

Mercer Member

The member consists of fissile to subfissile, dark-gray to medium-dark-gray shale to silty shale; some grayish-black to dark-gray carbonaceous shale; gray siltstone; lenticular, impure coal; some olive-gray rooted underclay; and subordinate, thin, light-gray sandstone. Carbonized plant fragments are a few to common locally. Some of the Mercer coals, particularly in the southern part of the county, were mined in the past for domestic use (Carll, 1883). The lower contact of the member is probably sharp to gradational and conformable. Laterally, the Mercer may change gradually or abruptly to sandstone. The member is very poorly exposed but probably ranges in thickness from about 20 to 60 feet (6 to 20 m).

It is not known if the Mercer Member in Warren County was subject to marine influence as occurred in nearby Elk and McKean Counties, where I have identified brackish or marine invertebrate fossils in the upper Pottsville.

Homewood Sandstone Member

The Homewood Sandstone (Middle Pennsylvanian) is the highest member of the Pottsville Formation. It is difficult to distinguish from Connoquenessing sandstones and is recognized chiefly through the identification of underlying Mercer coals, if present, or by interval difference from the base of the Pottsville Formation. Relatively little information is available on the Homewood Sandstone. It is composed mostly of ferruginous, slabby, trough-crossbedded, well-cemented, locally pebbly (quartz), fine- to coarse-grained, light-gray sandstone (quartz arenite). Subordinate gray siltstone and dark-gray shale are also present. Plant compressions and fragments occur. The lower contact is believed to be sharp to gradational and conformable or disconformable. As is the case in surrounding counties, the Homewood Sandstone is probably lenticular (fluvial channel fills) and grades or abruptly changes laterally to shales and siltstones (flood-plain deposits) comparable to those of the Mercer Member.

The Homewood is believed to vary from about 0 to 50 feet (0 to 15 m) thick. It caps some of the higher ridges in the southern and eastern parts of the county.

ACKNOWLEDGMENTS

Several oil and gas producers generously provided geophysical logs and well records that greatly enhanced my understanding of the bedrock lithostratigraphy in Warren County. In particular, I wish to thank David A. Lind, General Manager, and Douglas E. Kuntz, Geologist, of Pennsylvania General Energy Corporation, Warren, PA; Darryl E. Pierce of PAPCO, Warren, PA; and Lamont Beers, Chief Geologist, of National Fuel Gas Supply Corporation, Buffalo, NY. John A. Harper, Pennsylvania Geological Survey, shared valuable insights and useful references concerning present ideas on the position of the Mississippian-Devonian boundary in northwestern Pennsylvania.

PALEOGEOMORPHIC AND SEDIMENTOLOGIC FRAMEWORK OF BRADFORD AND VENANGO GROUP SHORELINES IN NORTHERN PENNSYLVANIA

Edgar M. Hopkins
University of Pitsburgh at Bradford
Bradford, PA 16701

INTRODUCTION

This paper is a regional interpretation of the 400 m-thick, marginal-marine portion of the Upper Devonian clastic wedge in the northern part of the Central Appalachian Basin. Knowledge of petroleum geology and stratigraphy are combined to reconstruct paleodepositional setting along a portion of the Catskill Sea. The following questions pertaining to this area are entertained:

1. In what directions did the basin margin and its shorelines trend?
2. What coastal geomorphic forms existed, and which generated reservoir facies?
3. How did the type of shoreline vary along the coast and through time?
4. How did syndepositional intrabasinal tectonism influence paleogeography and facies patterns?
5. What stratigraphic relationships exist between reservoir zones and overlying and underlying strata?
6. How do the observed facies patterns relate to the instantaneous cross-sectional configuration of the basin margin and might this configuration have been controlled by sediment accumulation, subsidence rate, and/or structural elements?

METHODS

Repeated review of the oil field literature, especially the Pennsylvania Geological Survey quadrangle-scale atlases and reports, yielded a wealth of general information. Well data from unpublished consulting studies were integrated into a conceptual model of regional patterns of reservoir sand deposition (Hopkins, 1987; 1988).

On-strike exposures of reservoir units in northern Pennsylvania and western New York allowed verification of the various paleoenvironmental settings in the subsurface, notwithstanding the anticipated along-shore variations of environments and coastal energy.

Surface exposures were studied during several years in Allegany County, New York (Hopkins, 1988) and McKean and Warren Counties, Pennsylvania (Hopkins, in preparation). Outcrops included roadcuts and other vertical sections, and creeks, which in this region expose long stretches of bedding planes (Hopkins, 1988). Over 15 key exposures were studied (Table 1). Surface outcrop studies provided details of paleoenvironments for a given location through time, but generally could not provide areal trends of synchronous deposition due to the sparseness of exposures in this region. Remarks by Woodrow (1985) on the

TABLE 1. Key Outcrop Localities--Famenian Coastal and Marine Strata Chautauqua/Cattaraugus/Allegany Counties, New York, and Warren/McKean Counties, Pennsylvania

Stratigraphic Position	Location	County	Description	Source
Venango Group Upper	Bear Lake RR Cut	W. Warren Cty.	Burrowed, conglomeratic sandstone (in creek) overlain by dark gray shale, overlain by heterolithic sandstone/shale with abundant *Rhizocordium*	
Middle	Hanley Brick Quarry	S. Central McKean Cty.	Distributary mouth bar, delta platform	Fettke, 1938
	Salamanca/Rock City	W. Cattaraugus Cty.	Tidal inlet conglomerate	Unknown, 1 mile north of Salamanca
Lower	Panama Rock City	W. Chautauqua Cty.	Tidal inlet conglomerate	Unknown, ½ mile west of Panama (fee)
	Magee Hollow Rd. Cut	S.W. Warren Cty.	Barrier/backbarrier intertidal	Stop 7
	Hwy. 59 Kinzua Rd. Cuts	E. Warren Cty.	Shelf tempestites and shales overlain by distributary channel (see Dodge, this field guidebook)	Stop 1
	Wolf Creek Quarries	S.E. Cattaraugus Cty.	Massive sandstones with intertidal redbeds	Kriedler, 1957
Chadakoin Formation	N. Warren Rd. Cut	N. Central Warren Cty.	Mid-offshore tempestites	Stop 10
	Kendall Refinery Rd. Cut	N. Central McKean Cty.	Mid-offshore tempestites	Jackson Ave., Bradford, PA
	Ceres Hwy. 417 Rd. Cut	S.W. Allegany Cty.	Proximal tempestites	1 mile west of Ceres, NY
	Olean Industrial Park	S.E. Cattaraugus Cty.	Distal tempestites	North of Route. 17
	Eldred Bridge Rd. Cuts	N.E. McKean Cty.	Intertidal/subtidal delta platform	½ mile north of Eldred, both sides of bridge
Bradford Group Upper	Kinney Hollow Rd. Cut	E. Cattaraugus Cty.	Thin bedded Cuba Sandstone, delta-front, overlain by tempestites, possible disconformity at base Cuba	Manspeizer, 1963a
	Scio-Vandermark Crk.	S.E. Allegany Cty.	Shelf muds with rare storm sheet sandstones overlain by packed tempestites, overlain by dark gray shale overlain by Cuba delta-front sandstones	Manspeizer, 1963; also Kriedler, 1957
Middle	Angelica Gorge	Central Allegany Cty.	"Scholes Sandstone"--tidal channel/beach overlain by inner shelf muds, overlain by delta-front thin bedded sandstone	Manspeizer, 1963a
Lower	Rushford Dam	N.W. Allegany Cty.	Thick dark gray to black shale section below dam overlain by Rushford sandstone, cross shelf channel fill, overlain by Scholes shoreline sandstone	Manspeizer, 1963a
	Alfred Station Quarry	N.E. Allegany Cty.	Dark gray shelf shale overlain by Alfred Station coquinite (massive, shelfal coquinitic sandstone) overlain by dark gray shelf shales	Manspeizer, 1963a

probable futility of achieving precise mapping of shorelines in the Upper Devonian are echoed by this writer for the outcrop belt, but do not apply in the heavily drilled oil field belt.)

Oil field shape and sand isopachs proved to be as valuable in reconstructing coastal geomorphology as the outcrop data was in reflecting environments of deposition. Surface and subsurface analysis both involved a "distillation process" of excluding local variability to capture "environmental essence", as described for paleoenvironmental modeling from vertical stratigraphic sections by Walker (1984).

Paleoshoreline mapping establishes the timing and nature of Catskill deposition. Regional-dip cross sections were constructed to ascertain temporal relationships between sand bodies so that contemporaneous shorelines could be mapped.

A key to success in paleogeomorphic interpretation via sand body geometry is that, within the Catskill wedge, the individual high-energy environmental milieus responsible for reservoir development were often "frozen in time" rather than forming blanket deposits.

Presumably, relative sea level fluctuations were pulsational and geologically frequent. Many of the subsurface-derived paleogeomorphologic interpretations were made from large scale maps, the details of which are crucial to interpretation. These details cannot be adequately portrayed on the small scale maps reproducible here. Subsurface lithologic data (gamma ray log shape, FMS and dipmeter logs, cutting and core descriptions) were used, where available, to support the more inductive interpretation of sand body geometry.

The mapping of lineaments from Landsat imagery and high altitude aircraft photography and registration of these lineaments with published geophysical and structural maps also applies to this study, but is not discussed here due to space limitations (Iranpanah and Hopkins, 1987; Hopkins, 1988).

ACKNOWLEDGEMENTS

Thanks are extended to Jackie Streb, Natural Sciences Division Secretary, for typing, and to the many students who assisted in the field, especially Robert Kuntz, Doug Kuntz, David McCoy, and Bruce West. Log and other subsurface data was kindly provided by Messrs. Lamont Beers of Empire Exploration, Carl Burgchardt of Carl Burgchardt and Associates, Doug and Robert Kuntz of Pennsylvania General Energy, and Terry Pegula of East Resources. Finally, thanks go to the University of Pittsburgh at Bradford for Faculty Development Grants in partial support of this research.

DESCRIPTION OF OIL FIELD BELT

The informally named Bradford and Venango groups of Late Devonian (Famenian) age contain some 15 to 20 regional sandy zones. Within these zones, hundreds of discrete sandbodies form shallow stratigraphic oil reservoirs along a 20-mile-wide, northeast-trending belt across western Pennsylvania. These sandbodies account for close to 1.5 billion barrels of past oil production in the commonwealth.

The oil fields of this belt define a time-series of ancient coastlines which formed along the most basinward reaches of land during progradational pulses within the longer term progradations which formed the two highest wedges of the "Catskill" delta complex (Figure 6). This study focuses on reconstruction of these shorelines in the northern part of the belt.

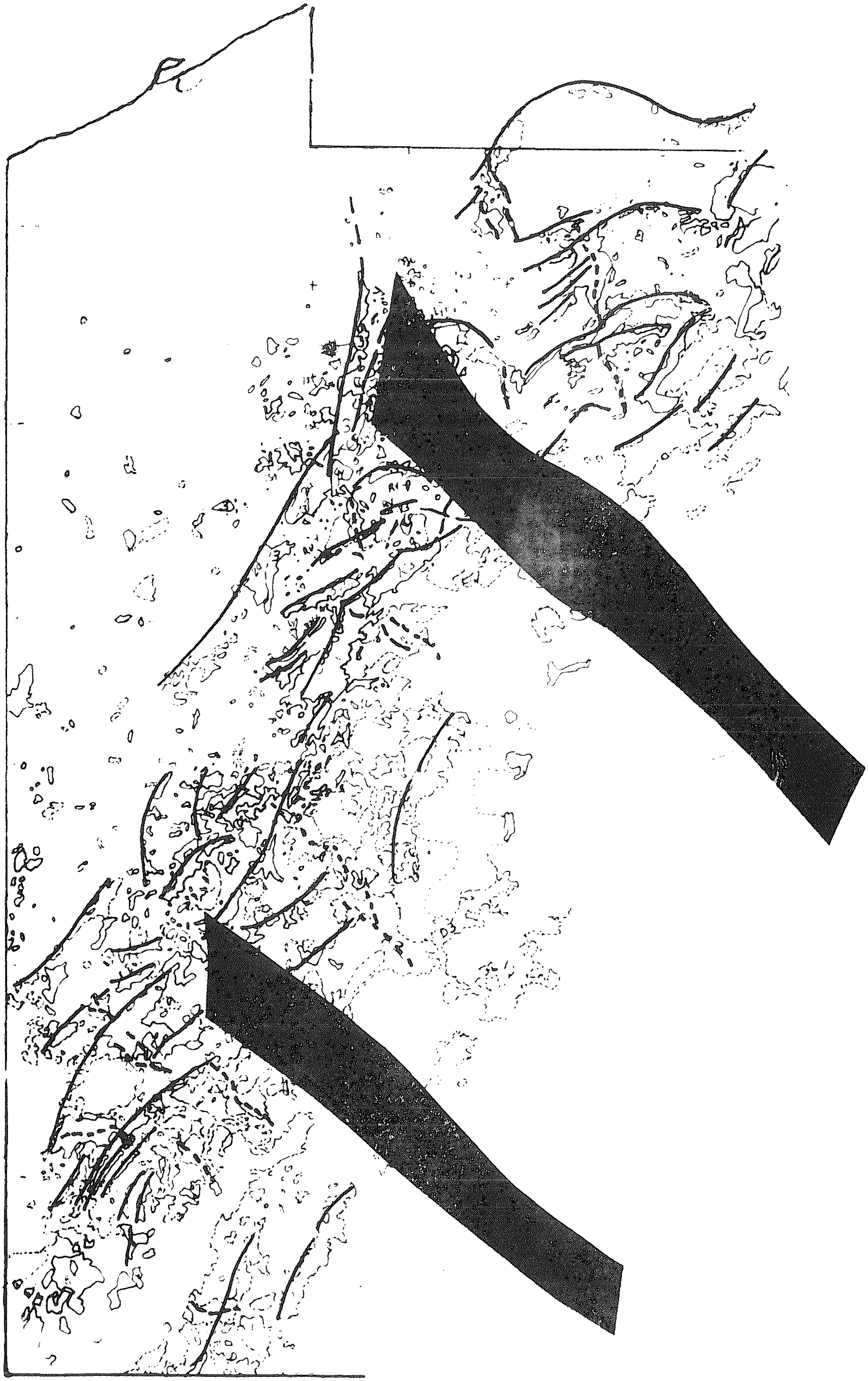
Because the distal coastal facies of the two regressive/transgressive wedges are located entirely within the little-deformed western portion of the Appalachian Plateau, the strata are buried across most of the state. They can be extensively studied on outcrop only in the northern tier of counties along the upwarped end of the Central Appalachian Basin. This area, which has numerous outcrops within a few miles of oil production from the same strata, is ripe for detailed stratigraphic/sedimentologic study. New pools, small but lucrative, are still being discovered within this 100-year-old oil-field belt. The strata may also serve as models for undiscovered gas fields in lower wedges located between the area of established gas production east of the oil field belt and recent field discovery and development near the Allegheny Structural Front.

STRATIGRAPHY

Establishment of Facies

There is a 100-year history to the stratigraphic study of these rocks. Early classical studies introduced important new stratigraphic concepts of the day (Hall, 1839; Butts, 1903; Barrell, 1913; Chadwick, 1924; Caster, 1934; Willard, 1939). Early on, it was recognized that, in ascending order, the Elk, Bradford, and Venango Groups of the subsurface oil belt included the distal sandy facies of three progradational pulsations of the sequentially west-building Catskill "delta" wedge across western Pennsylvania and western New York (Carll, 1883). These three east-thinning wedges were separated by tongues of marine shale deposited during transgressions across the previously deposited sandy apron. Caster (1934) organized the internal stratigraphy of the wedges into time-transgressive environmental lithofacies, each termed a magnafacies, to give us the classic land-to-basin lithofacies series; "Catskill, Chemung, Portage, and Cleveland." Modern refinements allow additional distinct lithofacies to be identified, and to the degree that each records a separate

Figure 6. Upper Devonian paleoshorelines and drainage thalwegs corresponding to oil and gas fields in western Pennsylvania. Oil fields are shown with solid lines, gas fields with dashed lines. Bold solid lines show paleoshorelines; bold dashed lines, paleodrainageways. Note segmentation of shorelines, related to lineament zones (patterned). Also note change to NNW drainage and ENE shoreline trends in northern Pennsylvania.



environmental setting, continuing through time, subdivision of these classical facies types would seem to be a fruitful construct in better understanding the Catskill "seascape."

Coastal sandstones ("Cattaraugus" magnafacies of Rickard, 1975) separated marine "Chemung and Portage" beds from nonmarine, red "Catskill" sandstones and shales. Generally, the marine strata were either shelfal coquinitic mudstone/shales or slope/basin shales. The coquinitic mudstones signified the "Chemung" magnafacies. They were viewed as indicating proximity to the coast. The deeper marine shales represented the "Portage" magnafacies deposited basinward, far from shore.

Stratigraphic Terminology

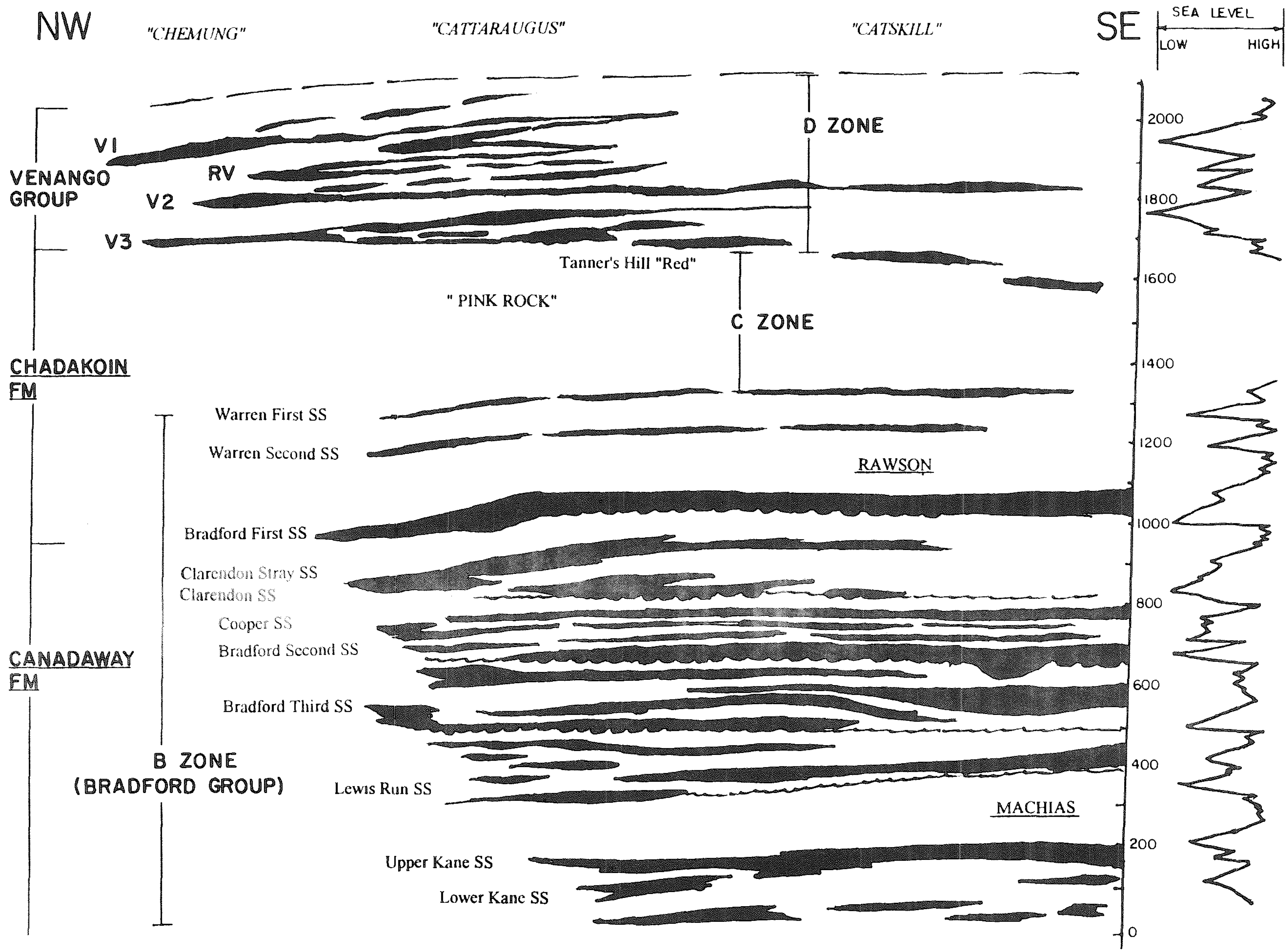
A mix of names from both New York and Pennsylvania is utilized for the Upper Devonian reservoir-bearing strata along the counties bracketing the state line. Stratigraphic nomenclature in western New York stresses surface outcrops and concentrates on more distal facies, while that of northern Pennsylvania stresses well data, and concentrates on more proximal (reservoir) facies. The nomenclature also reflects differing philosophies (see Sevon and Woodrow, 1981; Manspeizer, 1963a,b).

Formal Groups in the Upper Devonian of New York were generally defined as a set of synchronous "parvafacies": several lateral facies isolated from overlying and underlying strata by isochronous marker beds. Whereas the older Catskill wedges contain nearly isochronous, transgressive black shales, the younger wedges were subdivided on the basis of less isochronous, regressive coastal sandstones, because black shales are lacking. In areas beyond the limits of the sandstones, which do not persist basinward, biostratigraphic zones were used to subdivide the section (Tesmer, 1963).

In northern Pennsylvania, subsurface terminology is informal. For outcropping strata, major lithologic changes are used as boundaries, rather than marker beds (for discussions see Sevon, 1981; Sevon and Woodrow, 1981; Harper and Laughrey, 1987). A summary of nomenclatural relationships is given in Figure 7.

The subsurface Bradford Group of Pennsylvania is approximately equivalent to the Canadaway Formation of New York (Rickard, 1975). The subsurface Venango Group of Pennsylvania, along with the overlying Oswayo Formation, is equivalent to the

Figure 7. Diagrammatic regional dip cross section showing stratigraphic nomenclature. Bradford Group strata taken from a regional (20-log) dip cross section; Venango Group strata taken from Kelly (1967). Chadakoin strata from various sources. Italicized names show magnafacies at Venango stratigraphic level. These magnafacies (lithosomes) descend toward the southeast. Outcropping formation and group names are underlined, subsurface units shown in plain type--name changes along strike are not given. Bradford Group unconformities (scalloped lines) are inferred from stratigraphic discordances seen on logs.


NW
"CHEMUNG"
"CATTARAUGUS"
"CATSKILL"
SE
SEA LEVEL
LOW
HIGH
D ZONE
V1
RV
V2
V3
VENANGO GROUP
Tanner's Hill "Red"
" PINK ROCK"
C ZONE
CHADAKOIN FM
Warren First SS
Warren Second SS
RAWSON
Bradford First SS
Clarendon Stray SS
Clarendon SS
Cooper SS
Bradford Second SS
CANADAWAY FM
Bradford Third SS
B ZONE (BRADFORD GROUP)
Lewis Run SS
MACHIAS
Upper Kane SS
Lower Kane SS
2000
1800
1600
1400
1200
1000
800
600
400
200
0

Conewango Group of New York (Tesmer, 1963). The shaly rocks separating the two sandy wedges, although several hundred feet thick, are not given even informal group status in the subsurface of Pennsylvania; the bulk of this strata is simply known as the "Pink Rock." It is somewhat equivalent to the Chadakoin Formation of western New York or Conneaut Group of western Pennsylvania.

Stratigraphic Cyclicity

Zones

The Upper Devonian oil sands of Pennsylvania occur within the upper 500 m of the 1000-m-thick Upper Devonian section. Across Warren County, the lower 200 m of the sand-rich strata comprise the Bradford Group, also designated as Zone B (Piotrowski and Harper, 1979). The still lower Elk Group [Zone B0] pinches out before reaching Warren County. Some distance above the Bradford Group yet another sand rich interval, the 100-m-thick Venango Group of subsurface terminology, is designated as Zone D. Lying between these two sandy intervals, Zone C is a pervasive marine siltstone and shale unit including the "Pink Rock" of the driller. Zone C is approximately 120 m thick, but thins eastward because of thickening of the sandy wedges (Harper and Laughrey, 1987).

These groups appear to extend into West Virginia (Dennison, 1985). The establishment of the correlative age, by fossils, of the Red Lick Member of the Foreknobs Formation of West Virginia and the Caneadea Shale of western New York (just below the Bradford Group sands) (McGhee and Dennison, 1980) as well as the apparent persistence of the "Pink Rock," the shalier interval dividing the two groups, indicate of synchronicity of Zonal-scale sea-level fluctuations.

Sub Zones

Correlation of individual oil- and gas-productive Upper Devonian sands of western Pennsylvania is notoriously difficult due to the discontinuous nature of sand development within a given zone and the frequent vertical repetition of oil-bearing sands through the sandy wedges. Tremendous nomenclatural problems were also introduced by early miscorrelations and overextensions of sands by drillers.

This state of affairs led to the lumping of "bundles" of sands (subzones) averaging some 50 m thick, as an operational mapping method (Kelley and Wagner, 1972; Piotrowski and Harper, 1979). Much insight into the regional stratigraphic architecture of these rocks was gained by the isopachous mapping of these sand "bundles" by Piotrowski and Harper (1979). Hopkins (1987) relied heavily on the regional subsurface mapping efforts of these workers in interpreting Late Devonian paleogeography along the oil field belt in northern Pennsylvania. Boswell and Donaldson (1988) have performed similar analyses on more vertically restricted intervals in West Virginia, and have demonstrated how paleotectonic elements have influenced regional deposystems.

Sand "Zones"

Sand "zones" ("belts of sand and silt lenses," see Piotrowski and Harper, 1979) on the order of 10 m thick, can generally be correlated in paleo-dip cross sections (Lytle, 1965; Hopkins, 1988; and others). Limited statewide paleostrike correlation of individual sand zones has been claimed, suggesting possible depositional control by eustatic sea level changes (see Boswell, 1988; Harper and Laughrey, 1989).

Vertical repetition of these sand "zones," at an average of every 25 m or less, is attributed to small scale, regressive/transgressive cyclicity (Dickey and others, 1943; Kelley, 1967; Piotrowski and Harper, 1979; Hopkins, 1988). Harper and Laughrey (1987) suggest that, while each of the three sandstone-rich groups (zones) spans a third-order, regressive/transgressive cycle, fourth and fifth order regressive/transgressive cycles subdivide these groups.

Isolated "clean" sandbodies developing within the sand zones reflect instantaneous along-shore changes and paleodip/time changes in environmental energy. Regional correlation of the slightly time-transgressive sandy "zones" which contain these sandbodies is surprisingly good. For example, the "Glade Rocks" of the Bradford Group are widely correlated, as opposed to the "Glade Sand," which develops locally within the zone, as discrete bodies along narrow (shoreline) bands (Lytle, 1965). I have noted paleodip direction continuity of sand zones for 33 km or more in log cross sections (Hopkins, 1988; and in preparation). Only occasionally can some individual sand bodies be carried this far, and atypical facies show up in some wells. Some of the sandy zones clearly transect time-transgressive magnafacies, and thus have time stratigraphic value, though they do not appear to be as isochronous as the stratigraphically lower black shale units of the deeper basin (Boswell, 1988).

Sequence Stratigraphy

The lack of extensive outcrops along strike, and the lack of modern log suites in the bulk of wells in the Appalachian Basin accounts for the fact that stratigraphic analysis is not as developed as for more recently drilled foreland basins such as the Cretaceous Western Interior Seaway. Also, seismic stratigraphy has seen little application in these rocks despite the practicality of such methods (R. Kuntz and D. Kuntz, personal communication, 1991). The eventual recognition of hiatal surfaces and other time-markers related to some of these zones may allow sequence stratigraphy to be successfully applied to these rocks. Baird and Lash (1991) describe condensation zones and hiatal surfaces in more basinal strata of the Catskill Sea in extreme northwestern Pennsylvania and western New York.

I recognize many small scale disconformities in log cross sections across the oil field belt. Also of possible regional significance are the thin conglomeratic layers of apparent transgressive nature above some of the main Venango sands (Kelley, 1967). To the east, Rahmanian (1979) found green to gray, transgressive, marine shales directly overlying red regressive nonmarine shales in the older Frasnian marginal marine "Catskill" rocks. Such hiatal surfaces arguably attributable to either low energy coasts or ravinement of shoreline sands, complicate the subsurface geologist's task of assigning regressive or transgressive origins to each sand zone so that regressive/transgressive wedge geometry can be unravelled.

DEPOSYSTEMS

Basin History Effects

In general, the successively younger sandy zone wedges of the Upper Devonian strata extend slightly farther west and northwest as a result of the overall long-term progradational nature of the Catskill wedge (Figure 7).

The largest time scale of change in Late Devonian coastal facies may be a subtle decrease in geomorphic relief at the coast upward through the three wedges, with offshore sandy facies being more common in the Elk Group and backshore sandy facies becoming more common in the Venango Group. Only the lowest (Elk Group) contains numerous basin-edge fan reservoirs. Cross-shelf sandy channel fills described by Manspeizer (1963) have been noted only below the middle Bradford Group.

Slope/basin-floor black shales (Cleveland facies) also penetrate the Elk Group from the west, but are not found in the Bradford or Venango Group wedges. This indicates that slope/basin dysaerobic/anaerobic environments no longer reached the area during transgressive pulses.

The reverse may be true with respect to coastal plain facies within the wedges. Nonmarine strata separating regressive and transgressive sands are unreported in the Elk and lower Bradford Group, occasionally present in the middle and upper Bradford Group and thin but common in the Venango Group. Thin redbeds, mostly shales, and varicolored sands and shales representing subaerial delta platform and fluvial environments are typical only within reservoir zones of the Venango Group (Kelley, 1967). I have also observed that transported paleosol horizons are fairly common in the Venango Group.

The Elk Group will not be discussed further, because most of its reservoir facies are located well to the east in the shallow gas field belt rather than in the shallow oil field belt, and published data concerning the exact stratigraphic horizons producing in individual gas fields is generally unavailable. The Elk Group (B0 zone) is visible on outcrop in north-central Pennsylvania, over 160 km east of Warren County (Woodrow, 1968).

The cause of the inferred subtle but pervasive shallowing-upward of depositional environments of sands through the upper Catskill wedges is not known. I suggest that either the basin subsidence rate decreased through the Famenian, or that the wedge merely prograded west into an area of the more stable basin forebulge, or perhaps onto slightly positive tectonic elements (see Harper and Laughrey, 1989).

Intrabasinal Structural Effects

The regional shoreline patterns also changed through time due to differential tilting and subsidence rates of basement blocks, perhaps related to localization of Acadian thrust-loading upon individual blocks. The overprinting of regressive/transgressive history upon spatial/temporal changes in basin depth and slope resulted in crossing paleoshorelines at different stratigraphic levels (Figure 6).

Regressive-Transgressive Effects

Sand body geometry reflects deposystem variations even at the 50-m-thick "sand bundle" scale at which mapping was done by Piotrowski and Harper (1979). The "bundles" are based upon empirical picking of a widely correlative shale between sand units, and not upon recognition of genetic groupings of regressive/transgressive wedges. By happenstance, several of the bundles reflect transgressive phases while others represent regressive or lowstand phases; the transgression-dominated bundles are characterized by a predominance of shore-normal sands, presumably trapped along estuarine axes during flooding, whereas the regression dominated bundles show greater longshore transport in the form of elongate shore-parallel sandbodies (Hopkins, 1987).

TECTONISM

I believe that the regional geomorphic setting during the Acadian Orogeny may have been affected by as many as five orders of intrabasinal tectonic elements; from largest to smallest these are: (1) the Rome Trough, trending north (to east-northeast in New York?); (2) cross-basin basement blocks and bounding fault zones, trending northwest; (3) faults caused by intra-basement block break-up, trending north-northwest; (4) basement "uplifts"; and (possibly) (5) small syndepositional folds, generally trending northeast but changing trend near basement block edges (Figure 8).

Basin Shape

The Upper Devonian Appalachian foreland basin-fill fans across central Pennsylvania and southwestern New York in a convex to the northwest pattern (Ayrton, 1963) which is parallel to the Pennsylvania Recess of the Appalachian fold belt. A palinspastic reconstruction for post-Devonian folding (Faill, 1985) fails to remove this convexity. Furthermore, erosion of Upper Devonian strata along the northern edge of the Central Basin, affects, but is not responsible for the convex pattern, as the bisectrix of the convexity is located in northwestern Pennsylvania, south of the limits of eroded Upper Devonian strata.

Unfortunately, due to upwarping and erosion along the north end of the Central Basin, the continuation of this trend to the east and the configuration of the entire opposite side of the basin can only be inferred.

It is concluded that the Catskill sedimentary wedge fanned out from its southeastern source and that the shape of the Appalachian Basin itself affected the sediment pile thickness; that is, regional depositional strike, as defined by the basin trend, changed from north-northeast in Pennsylvania to east-northeast across western New York.

There is much evidence that such a bend in the basin was present throughout most of the Paleozoic (Iranpanah and Hopkins, 1987; Hopkins, 1987; 1988). The Upper Devonian oil-field belt follows the inferred basin curvature, from north-northeasterly across most of Pennsylvania to east-northeasterly across western New York.

Upon close inspection, the belt exhibits several segments having distinct oil field trends and dominated by pools of different age (Figure 6). Rather than being a mundane observation, this pattern probably reflects varying strike of the coastal plain and shelf surface across each of several recurrently active basement-blocks (Iranpanah and Hopkins, 1987, Hopkins, 1987). Only when large-scale curvatures of the paleo-coast are recognized is it possible to account for the complex pattern of oil fields in western Pennsylvania. As noted for similar intrabasinal structures in West Virginia (Donaldson and Boswell, 1986), each block in western Pennsylvania may have experienced a unique history of syndepositional tectonism and hence a unique history of sedimentation. This probably included somewhat different subsidence and sediment supply rates and sediment dispersal patterns. The latter varied according to differences in oceanographic setting (prevailing wind orientation to the coast, wave attenuation ratio, tidal amplification, etc.).

Previous models of regional stratigraphy and basin shape include the "rowboat" model of Dennison (1984), emphasizing definition of a straight keel line, but also the transom shape of the northern end of the basin versus the bow shape of the southern end. Dennison mentions and illustrates a "42nd Parallel" basement fracture zone trending east-northeast across western New York, but does not incorporate this feature into his basin shape-model, preferring to show the basin keel line as continuing straight across this feature towards the north-northeast. On the other hand, I am impressed with the often ignored evidence for an east-northeast strike to this part

Figure 8. Syndepositional structural elements of the northern oil field belt. Oil fields are darker outlines; gas fields, lighter outlines. Aeromagnetic contours numbered in hundreds of gammas. Note correspondence of distal sands of lower Bradford (B1) and Venango (V) Groups over aeromagnetic highs (axes shown by intermediate black lines. Lineaments (bold black lines) disrupt structures and oil field patterns due to early formation and long term reactivation of basement faults. Inferred small syndepositional fold axes are shown by dashed lines.


UPPER DEVONIAN OIL FIELD *
UPPER DEVONIAN GAS FIELD *
AXIS OF MAGNETIC POSITIVE
(CONTOURS IN 100'S OF GAMMAS) *
NORTHWEST TRENDING LINEAMENT
* FROM DATA PUBLISHED BY STATE GEOLOGICAL SURVEYS
N
NEW YORK
B1
B1
V
V
V
V
TMU

of the basin during most of the Paleozoic, including Ordovician paleogeologic setting in western New York (Rickard, 1973), Silurian salt basin elongation (Alling and Briggs, 1961), distribution of Tully limestone thickness and facies (Oliver and others, 1971), Upper Devonian black shale thickness (Kamakaris and Van Tyne, 1980a,b), and finally, the paleocurrent directions and thickness trends of Upper Devonian sandstones in western New York (Woodrow, 1968; Manspeizer, 1963; Hopkins, 1988). Despite such evidence for a "boomerang" shape to the basin, most Upper Devonian (Famenian) paleoshoreline reconstructions adhere to the straight basin model, continuing the north to northeast trend of paleoshoreline mapped across West Virginia and western Pennsylvania (Dennison, 1984; Boswell and Donaldson, 1988; Tesmer, 1963; and others).

The major trend changes in Late Devonian paleoshorelines occur just north of the northwestward extension of the Tyrone-Mount Union cross-structural discontinuity (CSD) (Hopkins, 1987, 1988) (Figure 8). Evidence for extensive Taconic (?) strike-slip motion along this inferred basement fault zone is given by Muller and others (1980). Later strike-slip motion has not been established, but this feature influenced deposition intermittently through Paleozoic time, whenever its bordering blocks experienced different relative motions allowed by vertical reactivation of the fault (Williams and Bragonier, 1974; Famy, 1979; Lavin and others, 1982; Johnson, 1984; Sevon, 1985; Smith and Rose, 1985; Hopkins, 1987, 1988).

Late Precambrian Rome Trough influence on the Devonian Appalachian Basin axis extends into Pennsylvania from the south (Harper, 1989; Famy, 1979; Boswell, 1989), but this feature has not been traced, in published reports, into northern Pennsylvania. The so-called Olin Basin of Potter County makes speculation on a possible change in direction of the Rome Trough north of the Tyrone Mount-Union lineament compelling to me as a reason for the noted directional change in the basin, but a discussion of this is beyond the scope of this paper.

Smaller Scale Intrabasinal Structures

There is much disagreement regarding the extent of tectonism within the Appalachian Basin proper during the Acadian Orogeny. Many workers question its existence (see Faill, 1985) while others record syndepositional folds or uplifts which affected facies and thickness changes (Woodrow, 1968; Piotrowski and Harper, 1979; Harper, 1988; Manspeizer, 1963a; Scholten, 1959; Sevon, 1981). Daniels (1986) and Prouty (1986) attribute northwesterly structural elements (faults and folds) in the southeast portion of the Michigan Basin to forces emanating from the Appalachian Basin during both the Taconic and the Acadian orogenies. It is suggested that the Tyrone-Mount Union CSD could have localized Paleozoic folding and faulting within both these basins.

In addition to northwest offsets of shorelines across this basement block boundary, one or more secondary, north-northwesterly trending faults may have controlled the delivery of sediments down the paleoslope. I have mapped several north-northwest trending lineaments and subsurface faults in northwestern Pennsylvania which may represent intra-block segmentation by secondary shear stresses. Many Upper Devonian deposystems north of the Tyrone-Mt. Union Lineament extension have a northwest to north-northwest paleo-thalweg trend and northeast to east-northeast paleoshoreline trends (Figure 8).

In addition to the major bend in the basin, several smaller syndepositional uplifts are thought to have forced directional changes upon those shorelines which reached them during sea level changes associated with eustacy or thrust-loading. Two such features are inferred from two north-northeast elongated aeromagnetic positive anomalies in Warren and McKean Counties (Figure 8). The more southwesterly of these was noted by Piotrowski and Harper (1979) to have localized the multistory shoreline sands of the Venango Group through the Bullion-Clintonville, Foster-Reno, and the numerous smaller oil fields around the southwest corner of Warren County. The more northeasterly underlies the huge Bradford and Kane oil fields. A possible third aeromagnetic high/oil field pairing is located along the New York continuation of the lower Bradford Group sand productive belt. Northwest-trending lineaments offset these three aeromagnetically identified features (Figure 8). Either Grenville or Rome Trough structures might have caused the aeromagnetic highs. An original single feature could have been displaced by Taconic wrench faulting (see Lavin and others, 1982). These structures were effective in localizing distal stillstand shorelines only if the regression (progradation) for each of the wedges just reached their location. The Bradford Group wedge did not prograde as far as the younger Venango Group wedge, accounting for the locus of sand deposition of each.

Despite the commonly held opinion that the anticlines of the Allegheny Plateau formed during the Alleghanian Orogeny, many petroleum geologists have noted the "cleaning-up" of Upper Devonian sands across many of these anticlinal axes. (See Fettke, 1938; Dennison, 1985a). This writer notes reservoir-quality sands concentrated along the axes of numerous "Alleghanian anticlines." On one, a series of several small en echelon sand bodies oblique to the axis of the structure suggests that a subtle high was present to locally concentrate sand, but that the regional paleostrike was not parallel to the structural axis, resulting in diachronous sandy deposystems along the crest by localization of high energy environments through time.

REGIONAL PALEOGEOGRAPHIC FRAMEWORK

Slope Elements

Reconstruction of the regional physiography of the Catskill Sea is beset with uncertainties. The problem of finding an actualistic model in a modern time of limited epeiric seas and the uncertainty of isochronicity of lateral facies, may render this issue unanswerable. It is one of the thornier problems in accounting for basin margin deposits, particularly the nearshore to offshore transitions recognized in the "Chemung" magnafacies (Goldring and Langenstrassen, 1979).

Woodrow and Isley (1983) recognize the basin margin, clinoform, and basin floor as the major topographic subdivisions of the Catskill Sea. Woodrow (1985) identifies various facies corresponding to the basin margin, attributes a sedimentary (delta-edge) origin to the break between the nearly horizontal, shallow basin margin and the sloping clinoform, but also suggests the possible causal effect of internal waves between stratified water masses, storm-wave base, and tectonic features (minor).

The idea of a drowned (marine) "delta platform" as a major physiographic entity is employed in many lithofacies and biofacies interpretations (Bowen and others, 1974; Thayer, 1974; and others). Such a model relies on a continuous deltaic coast, as suggested by Boswell and Donaldson (1988), rather than a more varied shoreline with non-contiguous deltas, as inferred by me. Reservoir geometry of distal sand bodies indicates spacing of deltas which may preclude the idea of a universal delta platform (Figure 6). It is argued that delta platforms were not contiguous; thus, widespread lateral occurrence and vertical presence (in regressive as well as transgressive sections) of the "Chemung" facies can not have been confined to drowned delta platforms. To answer this question the frequency, size, and persistence of deltas along the ancient coast must be established. There is little agreement regarding the number or constancy of drainageways across the Catskill alluvial plain. From three to over eight river systems are inferred for Pennsylvania (Dennison, 1985; Bjerstedt and Kammer, 1988; Boswell and Donaldson, 1988; Harper and Laughrey, 1989).

It is suggested that structural features of the basin (hinge lines, intrabasin uplifts, etc.) or merely different subsidence rates in the basin may have controlled changes in water depth and bottom slope critical to facies, rather than depositionally constructed topographic features. Late Devonian syndepositional structures have been fairly well documented in West Virginia (Donaldson and Boswell, 1986), and noted as well in Pennsylvania (Piotrowski and Harper, 1979; Dennison, 1985; Hopkins, 1988).

COASTAL PALEOENVIRONMENTS

Paleoenvironmental Setting

The exact nature of depositional environments along the Acadian margin of the Late Devonian Catskill Seaway has long been debated. Many local coastal paleoenvironments have been recognized in vertical section (see Sevon and Woodrow, 1981; Sevon, 1985; Woodrow, 1985; Slingerland and Loule, 1988). Boswell and Jewell (1988) used depositional trends inferred from different sandbody geometry to catalogue coast to basin reservoir facies in West Virginia.

Hopkins (1988) identified shoreline paleoenvironments of reservoir sands of the Bradford and Venango Groups in northern Pennsylvania and mapped paleoshorelines. Inferred paleoenvironments include shore-tied shoal, ebb tidal delta, inlet fill, interdeltaic barrier, delta-rim barrier, distributary bar, and various backshore paleosettings, including backbarrier tidal flat/channel, and river/estuary channel (Figure 9). Some of these paleoenvironmental settings are documented at key outcrop localities (Table 1). Deltaic and interdeltaic shorelines existed side by side, and oceanographic settings varied from wave- to tide-dominant along the coast. Continued debate as to the overall energy type/level of the basin margin may be ignoring variations expected along an irregular coast.

Paleoenvironmental Energy Spectrum

The subject of depositional energy levels along the Late Devonian Catskill shoreline has been much debated. Some workers have argued for low energy conditions along the coast (Rahmanian, 1979; Walker and Harms, 1975). Others have assumed high energy conditions (Slingerland and Loule, 1988). Studies of Late Devonian coastal deposits have been concentrated along the Allegheny Front outcrop belt. Extension of results from these eastern Frasnian-aged deposits to western Famenian-aged shorelines may not be valid, because distance to source and basin slope varied significantly (Boswell, 1988). More importantly, the argument for either a high or low energy coast may itself be flawed, because curves and bends in the coastline resulted in along-shore variations in paleo-energy levels due to wave enhancement along coastal promontories, and tidal enhancement along coastal embayments (see Hayes, 1979).

I believe that the coastal marine energy level did indeed vary considerably along Famenian shorelines; some moderate to high energy barriers and wave-dominated delta rim beaches extended unbroken for over 50 km. Longshore distribution of sand by waves was greatest on promontory coasts, where wave dominated deltas and/or straight barrier systems resulted. In larger embayments, strike-limited, tide-dominated sandy shorelines formed at river mouths as tidally dominated deltas and estuaries. Several sites of ebb-tidal deltaic deposition of Bradford Group reservoir sands have been mapped by me. Sandy shorelines here were separated by stretches of low to "zero" energy coasts, where deposits were muddy. Because longshore sand transport did not extend across these lower energy coastal segments, identification of sandy sediment debouchment points and effective downdrift direction and distance is crucial to exploration for petroleum reservoirs here.

Some of the promontories and embayments along the Catskill Sea were structurally controlled whereas others were depositionally controlled by deltaic promontories and estuaries of larger drowned river valleys. There may have been feedback between syndepositional structures and rivermouth location (Hopkins, 1987). Variation in sand transport dynamics (increasing tidal action and decreasing wave action) from the Carolina Capes into the Carolina "Bays" and Georgia Bight, noted by Hayes (1979), may provide a modern example of such feedback leading to a promontory coast. The Carolina Capes promontory may represent the edge of a large Pleistocene delta (Hopkins, 1971), but also may be structurally upwarped as part of the Cape Fear Arch. A modern example of structural feedback leading to a (narrow) coastal embayment is Mobile Bay, Alabama, which is a graben. The significance of compartmentalization of sand deposystems by drowned river valleys, whether structurally controlled or not, is shown by Halsey (1979) for the Virginia to New Jersey coastal compartments.

Structure-related coastal irregularities of the Catskill Sea included primary bends across basement block boundaries and secondary bends around syndepositional structural uplifts. Both tended to set up promontories which fed back to higher wave energy sedimentation. Third order shoreline curvature was caused by progradation of small deltas with decreasing sediment supply into delta-margin embayments (see Donaldson and Boswell, 1988).

As shorelines moved landward or seaward through time, sandy sediment trapped along river thalwegs produced a series of strike-perpendicular sand bodies. Long shore transport produced

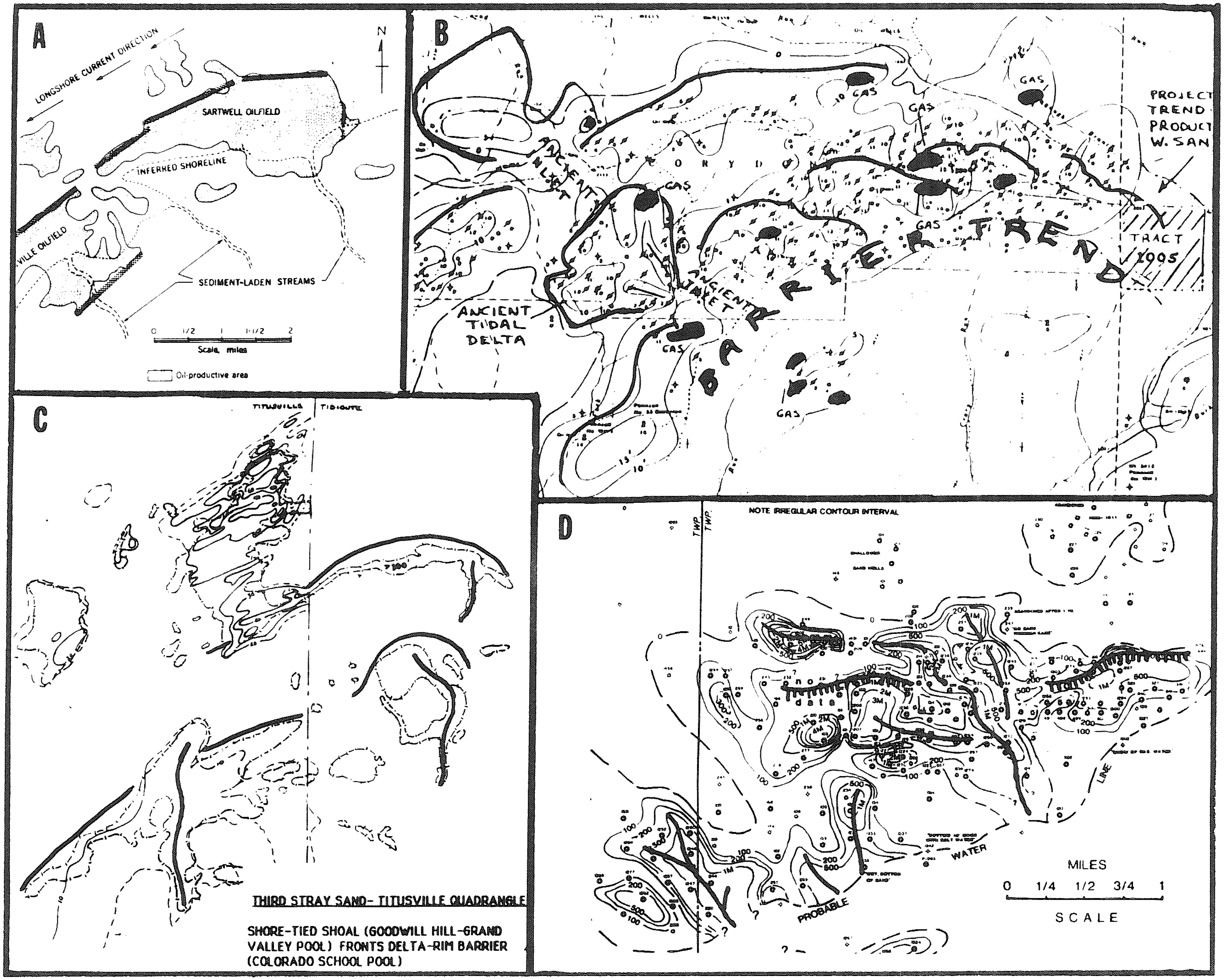
Figure 9. Examples of paleogeomorphic form displayed by Famenian shoreline oil and gas fields.

A. Interpretation by Bureau of Mines geologists of Sartwell Oil Field (lower Bradford Group). Typical level of data where oil field outline is the major clue to origin. Subsurface data would probably show an asymmetric wedge-shaped sand body typical of this oil field form. It is thought to represent a migratory estuarine channel.

B. Watsonville field from lower Bradford Group sand. This field lies along the rim of a subdelta of the Clarendon Delta, hence the curvature of the paired delta-rim barriers. Sand isopach data shows accretionary crescentic spit/dune bodies which form local gas traps. Also shown are two ebb deltas as an inlet maintained a straight path through successive barriers.

C. Shore-tied sandbodies often lie off the front of productive barrier trends. Some have a digitate form, others are overlapping lobes. Here a third type shows shore-parallel "fenestration" into bars suggestive of tidal current reworking of a shoal sandbody. This feature developed off the "Triumph Delta"-rim barrier, which exhibits a distributary body and which loses pebble content from the distributary, downdrift along the barrier. (Data is from Cathcart and others, 1938.)

D. Contour map showing initial daily potential (I.P.) in millions of cubic feet of gas (M=1 million, here) in a turn of the century, lower Bradford Group sand pool. Clean sandbody geometry is very well portrayed by accurate I.P. maps. Here a coastal sandbody with shore-normal and shore parallel (hachured) trends formed athwart an anticlinal axis. It is inferred to be a tide-dominated barrier/ebb-tidal delta deposit. Two similarly shaped, en echelon sandbodies of slightly different age, also lay along the northeast axis of this anticline, suggesting localization, along an obliquely oriented incipient structure, of high energy environments during sea level passage.


A
LONGSHORE CURRENT DIRECTION
N
SARTWELL OILFIELD
INFERRED SHORELINE
VILLE OILFIELD
SEDIMENT-LADEN STREAMS
0 1/2 1 1-1/2 2
Scale, miles
Oil-productive area
B
GAS
PROJECT
TREND
PRODUCT
W. SAN
ANCIENT INLET
ANCIENT INLET
ANCIENT TIDAL DELTA
BARRIER TREND
TRACT 1005
C
TITUSVILLE
TIDIOUTE
THIRD STRAY SAND- TITUSVILLE QUADRANGLE
SHORE-TIED SHOAL (GOODWILL HILL-GRAND VALLEY POOL) FRONTS DELTA-RIM BARRIER (COLORADO SCHOOL POOL)
D
TWP.
TWP.
NOTE IRREGULAR CONTOUR INTERVAL
no data
WATER
PROBABLE
LINE
MILES
0 1/4 1/2 3/4 1
SCALE

associated sandbodies trending at near-right angles. The paleoslope may also have varied slightly across small, incipient anticlines. As mentioned, a time-series of local, en echelon, sand deposystems obliquely along an anticlinal axis has been mapped by me. The sandbodies do not extend off structure (Figure 9D). Thus, isochronous shorelines cannot be mapped by merely extending "chains" of oil pools, because this may link discontinuous, diachronous deposystems. Rather, paleoshorelines are continuous along high energy coastal segments, but these are separated by intervening sparser and narrower oil fields, only some of which are isochronous, across embayed low energy segments.

Major bends in the basin created shelf segments with different oceanographic setting as well as compartmentalizing coastal dispersal systems (Hopkins, 1988). Wave height and direction, tidal amplitude, shelf currents, etc. may have varied significantly on different shelf segments. The greatest bend in the basin is thought to have been located in northern Pennsylvania, so that the New York shelf, with its more easterly trend (in the modern directional sense) may have differed dynamically from the more northerly trending Pennsylvania part of the basin.

Geologic History

The inferred regional shoreline patterns changed through time due to differential subsidence of blocks, as well as changes in sediment debouchment points and sediment influx rate. This writer notes that most of the Bradford Group shoreline oil fields are situated at the distal or climactic point of a regression, i.e., a marine shale directly overlies most reservoir sands. Only occasionally are sequential fields developed along the basal part of a regressive wedge and they are even less common along the transgressive top of the wedge (probably due to ravinement). Thus the pattern noted by Kelley (1967) for each of the Venango sand trends is thought to apply as well to the Bradford Group reservoirs. The distance of the transgression to the southeast above each reservoir sand varied, as several scales of relative sea level change, both allocyclic and autocyclic, were involved (see Boswell and Donaldson, 1988).

Despite the discussed difficulty of correlation of individual sandbodies, and the fact that opposing processes can result in opposite relative sea-level changes along shore, one can get some idea of regressive/transgressive history of the Famenian Catskill Sea by plotting the stratigraphic position of a paleoshoreline against its areal location along the paleoslope (Figure 7).

Bradford Group

Four regional log cross sections (not included) suggest that seven specific sand zones lying near the bottom of as many regressive/transgressive wedges, represent the major regressions of the Catskill Sea during depositon of the Bradford Group (Hopkins, 1988). There is some evidence (from changing intervals between sands) of unconformities below some of these sand zones

(Figure 7). These zones include, from oldest to youngest:

1. The lower Kane zone
2. The Lewis Run zone
3. The Bradford Third/Richburg/Rushford/Alfred Station Coquinite zone
4. The Bradford Second/Cooper(?)/Scholes zone
5. The Clarendon/Chipmunk zone
6. The Queen/Glade/Bradford First/Cuba zone
7. The Warren Second zone

The details of this history are beyond the space available, but the general sequence was: 1. Establishment of a northern (shoal-sand?) deposystem across the "Bradford Dome" (Figure 10). 2. After transgression, the building further south of a north-northwest prograding "Cooper Delta" system. 3. After transgression, progradation along the same (structurally controlled?) north-northwest axis to build the "Clarendon Delta." 4. A transgression followed; the Clarendon Stray climbs the section to the southwest changing from a barrier sand in contact with the progradational delta-rim Clarendon Sand to a marine sand in the manner described by Penland and others (1988). Renewed progradation formed the Glade Bars off the rim of the buried Clarendon Delta, and then established the "Glade Delta" 25 km north-northwest. 5. A major transgression began but may have been partly reversed during deposition of the Warren Second Sand.

C-Shale

The transgression renewed, resulting in a more basinward Chemung facies, the "Pink Rock" storm-laid coquinites. The extent of this transgression is unknown. The 107-m-thick "Pink Rock" can be well documented by its log characteristics, but it has largely been ignored as a topic for subsurface study, because it bears no reservoir facies. Several cycles of shallowing are suggested by the internal stratigraphy of this unit (see Stop 10).

Venango Group

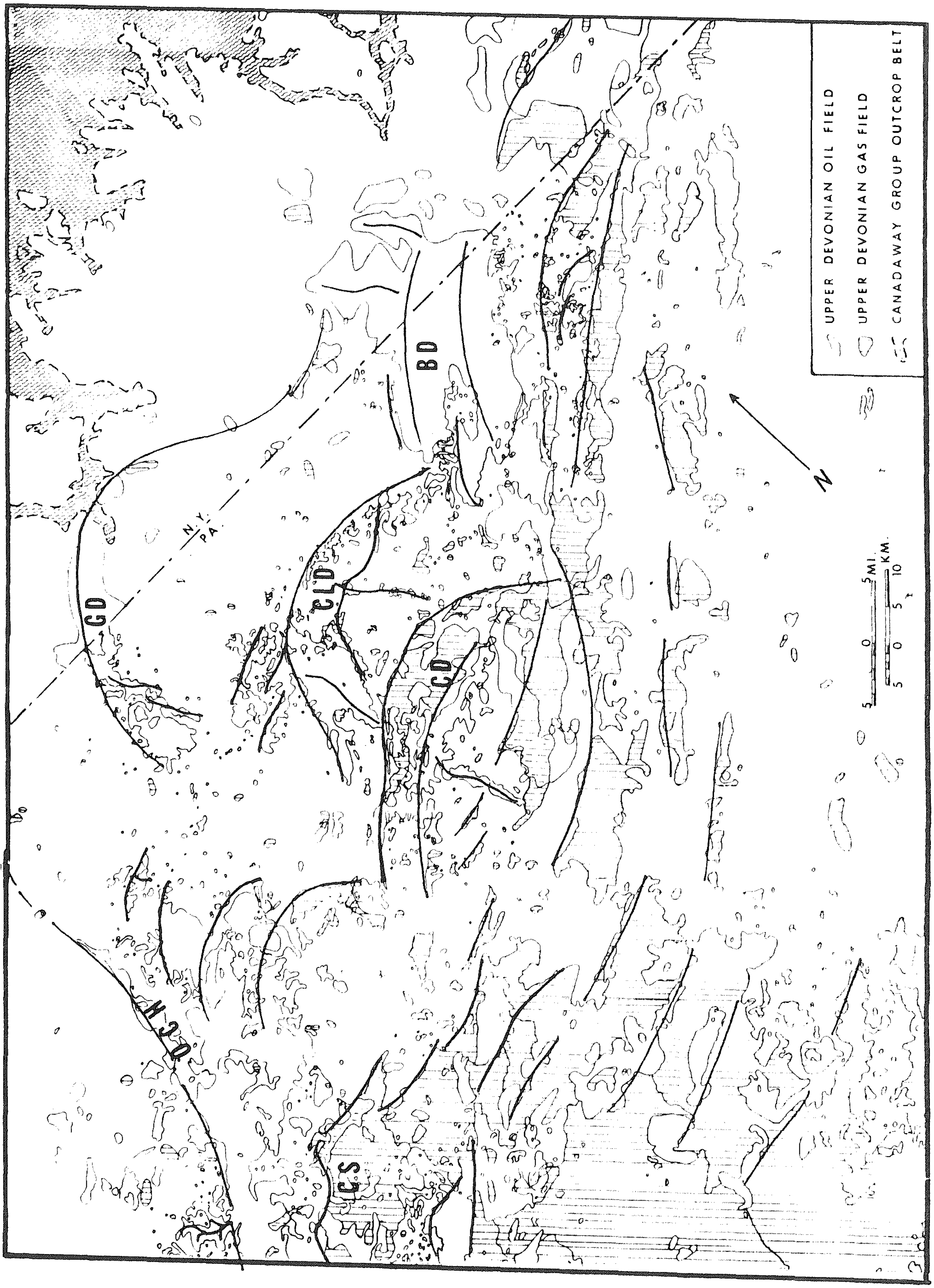
The Venango Group has not been extensively studied by me. It appears to be somewhat less complex than the Bradford Group, having more clearly defined major sand zones (see Stop 7). It has been studied by Dickey and others (1943), Kelley (1967), and Harper and Laughrey (1987).

The Third, Gray, and Second sands were deposited during regressive barrier shoreline reoccupation of a north-northeast trending basement high across eastern Venango County (Piotrowski and Harper, 1979). Four Third Stray reservoirs were deposited during stillstands within a transgression, and the Knox Third on another transgressive pulse. The latter three fields, located off the paleohigh mentioned, all have a more easterly trend, demonstrating the influence of local tectonic features on paleostrike of the shoreline (Figure 11).

SUMMARY AND CONCLUSIONS

1. The basin margin took a major bend toward the east near the Pennsylvania-New York state line. A broad coastal promontory at the bend migrated progressively but intermittently toward the northwest through time, from central McKean County, Pennsylvania during the early Famenian to central Warren County, Pennsylvania by the middle Famenian and, perhaps, to central Chautauqua County, New York by the late Famenian. Smaller changes in coastline orientation related to coastal promontories of both structural and depositional origin.
2. Barrier island systems, estuary mouth ebb-deltas/shoals, and fluvial-dominated and wave-dominated river deltas all existed along the Catskill coastline, and accumulated reservoir sand facies. Low or "zero" energy coastal segments, accumulating

Figure 10. Famenian Shoreline Patterns--Northern Oil Field Belt. Three well separated coastal depocenters formed through the Famenian. The Bradford Third and similar age sands were deposited along a WNW drainage thalweg onto the Bradford Dome (BD), which is associated with a northeast-elongated aeromagnetic positive anomaly. This formed a distal stillstand promontory coast; the shoreline trended ENE into New York, as shown by Manspeizer (1963a,b). Southward into Pennsylvania, the coastline was deflected sourceward south of the Tyrone-Mt. Union Lineament Zone, onto a more subsiding basement block where a different river system shed sand southward. Low energy coasts lay between the major rivers. The Bradford Second/Cooper/Scholes Sands formed on a subsequent regressive pulse. A large delta system, the Cooper Delta (CD), was build along a structurally controlled NNW axis. During the next progressively greater regression, the Clarendon Delta (CLD) of the middle Bradford Group formed along the same NNW axis. The transgression of this delta is chronicled by the Clarendon Stray Sand. A final regression within the Bradford Group, still farther to the NNW, built the Glade Delta (GD). The edge of this delta can be traced into western New York along an arc of small productive Glade reservoirs. At the same general time a promontory cape, Cape Speechley (CS), formed just south of the Tyrone-Mt. Union Lineament Zone (TMU). The Chadakoin (C-Shale) transgression followed. This was large enough to separate the two oil sand groups. Eventually, sourced from the south, a series of small deltas and a large barrier system was built off the southern cape. The distal stillstands were focused over yet another NE structural trend, the Oil City High (OCH) associated with an aeromagnetic positive, as noted by Piotrowski and Harper (1979). The barrier system may have extended in an arc parallel to the earlier Glade Delta Front, but erosion has partially removed the Venango Group in New York. A westerly change from conglomerate to (LeBoeuf) Sand in western Chautauqua County (Baird and Lash, 1991) may be associated with the front of this hypothetical delta.


UPPER DEVONIAN OIL FIELD
UPPER DEVONIAN GAS FIELD
CANADAWAY GROUP OUTCROP BELT
N
5 0 5 MI.
5 0 5 10 KM.
N.Y.
PA.
GD
BD
CLD
CD
CS

silts and muds separated some of the higher energy shoreline types. Many of the reservoir bodies exhibit both a shore-parallel and a shore-normal portion, reflecting the subequal deposition by riverflow/tides and waves, and the local nature of sand dispersal systems.

3. Twenty five-km-long deltaic shorelines, spaced on approximately 41-km centers, were separated by barriered and non-barriered interdeltaic shorelines. Offshore slopes may have been different off these two types of shorelines, but tectonic elements could have overridden depositional effects in setting up shelf depth, basin edge slopes, etc.

4. Intrabasinal tectonism compartmentalized deposystems and determined local strike of shorelines. The tectonic elements ranged from large-scale faults, both basin-parallel and basin-normal, to broad uplifts, to small incipient fold structures, so that tectonic influence was pervasive.

5. Erosion surfaces bound certain of the reservoir zones. Both regressive and transgressive sands formed, but regressive sands were better preserved. Marine shales overlay most of the reservoir sands indicating at least limited transgression after shoreline establishment. Pure shales tend to be in contact with the reservoir units, but sand filled gutter-cast-bearing shales and coquinites reflect slightly deeper water. The marine facies may vary off deltaic and interdeltaic coastal segments, but more study of this is needed.

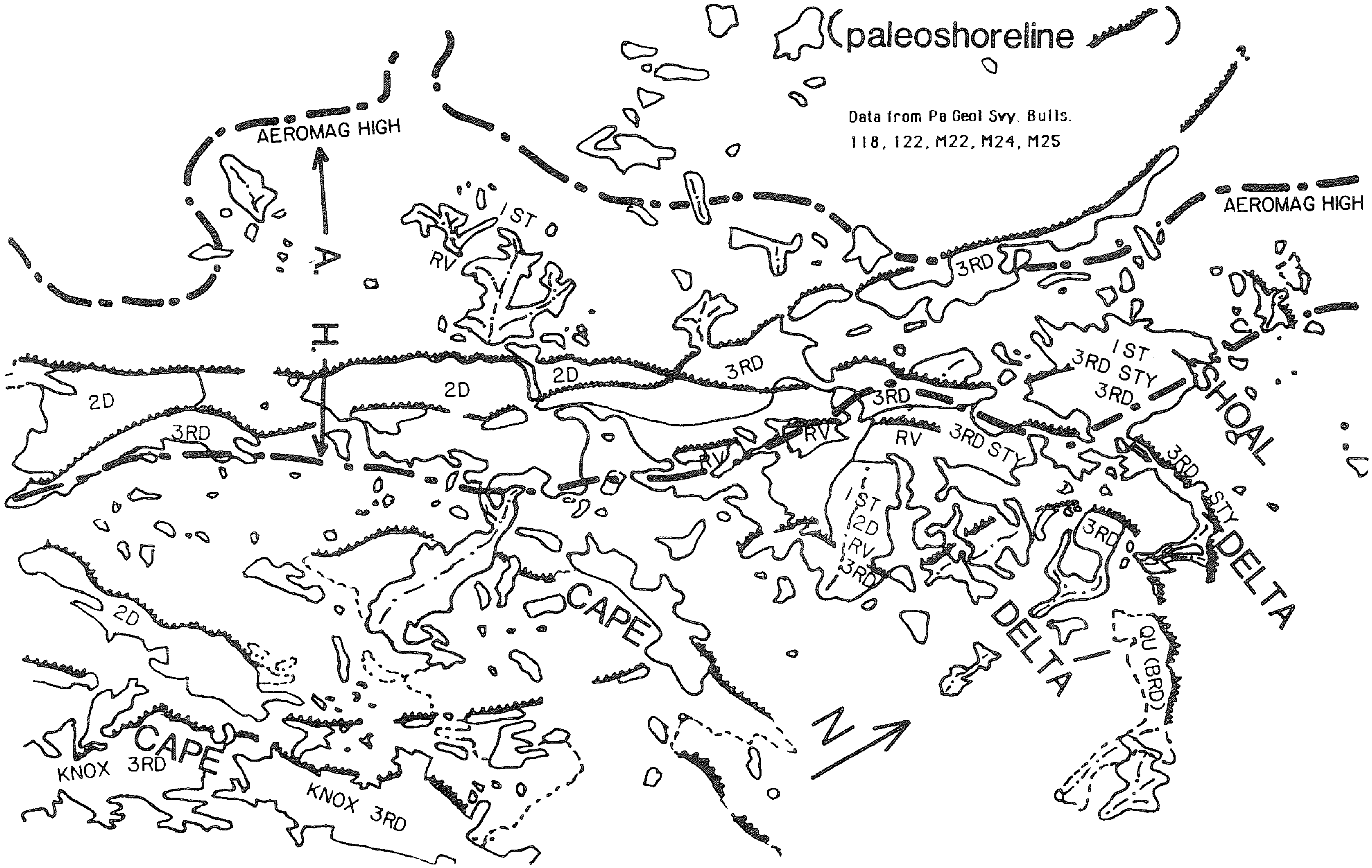
6. The syndepositional, cross-sectional configuration of the basin is poorly known. It is believed that both tectonic and depositional factors were locally important in controlling offshore slopes and facies.

FUTURE STUDIES

Much remains to be learned about the tectonic/sedimentologic framework of these important strata. The above mentioned debates concerning the nature of shelf/slope elements and coastal types must be resolved. Yet to be determined is the importance of eustatic sea level changes versus uplift periodicity/basin subsidence rates on the various scales of depositional cyclicity evident. More mapping of regional shorelines is desirable, not just for the distal turn-around points as presented in this paper, but along the regressive bottoms and transgressive tops of wedges as far east as the Allegheny Front!

Obviously, impediments exist; the bulk of drilling data

Figure 11. Venango Group shoreline history. The Venango regressive climax shorelines are multistoried along a reoccupied structure, the "Oil City High." They had a more westerly paleodip direction, and may have swung in an arc toward the northwest before turning back to the east, just as did the older Bradford Group "triple delta" trend. This is the "Big Bend" hypothesized in this study. Intermediate Venango sands show the change in paleoslope near the Tyrone-Mt. Union lineament, toward the north-northeast, as seen by the orientation of the paleodrainageway, and shoreline trends.


(paleoshoreline)
Data from Pa Geol Svy. Bulls.
118, 122, M22, M24, M25
AEROMAG HIGH
AEROMAG HIGH
A. H.
1ST
RV
2D
3RD
3RD STY
SHOAL
DELTA
DELTA
CAPE
CAPE
KNOX 3RD
KNOX 3RD
QU (BRD?)
N

available is primitive, and surface exposures, compared for example to similar Cretaceous-aged rocks of the Rocky Mountain Foreland Basin, are poor.

Sequence-bounding unconformities have not been identified, so that analysis utilizing the newer concepts of sequence stratigraphy has only recently begun (Baird and Lash, 1991).

OIL AND GAS GEOLOGY OF WARREN COUNTY

John A. Harper
Pennsylvania Geological Survey
Pittsburgh, PA

INTRODUCTION

Knowledge of oil in Warren County preceded drilling by many years. Oil seeps were common occurrences in some streams, particularly in the western part of Warren County where the Venango oil sandstones were fairly close to the surface (Carll, 1880; 1883). When the early European settlers arrived in northwestern Pennsylvania in the 17th century, they found groups of pits where oil seeps occurred, for example along Hosmer Run west of Garland in Spring Creek Township. The Native Americans of the region knew nothing about these pits, and it has been speculated that an ancestral tribe was responsible.

The first oil well in Warren County was drilled early in 1860 near Tidioute, not long after "Colonel" Edwin L. Drake's successful venture near Titusville (Carll, 1883). Word of Drake's success using standard salt-well drilling technology spread rapidly throughout the Appalachian basin, spurring many individuals and partnerships to purchase leases from willing landowners. During the first flurry of activity, whole forests disappeared, only to be replaced by forests of wooden derricks and engine houses such as shown in Figure 12. Now, 132 years later, drilling for oil and natural gas has touched virtually all

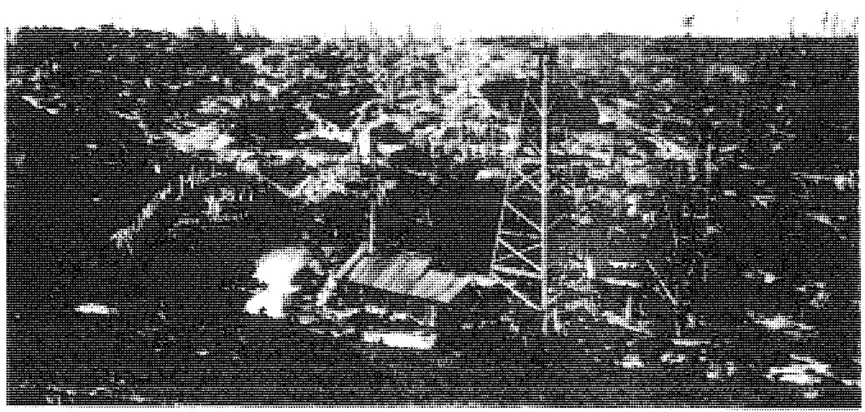


Figure 12. Historical photo by John Mather of the Triumph oil field in 1871, showing the "forest" of oil wells typical of of that period. Such "forests" were especially susceptible to fires, and a stray spark or a carelessly thrown match was all it took to start a conflagration that could lay bare the countryside.

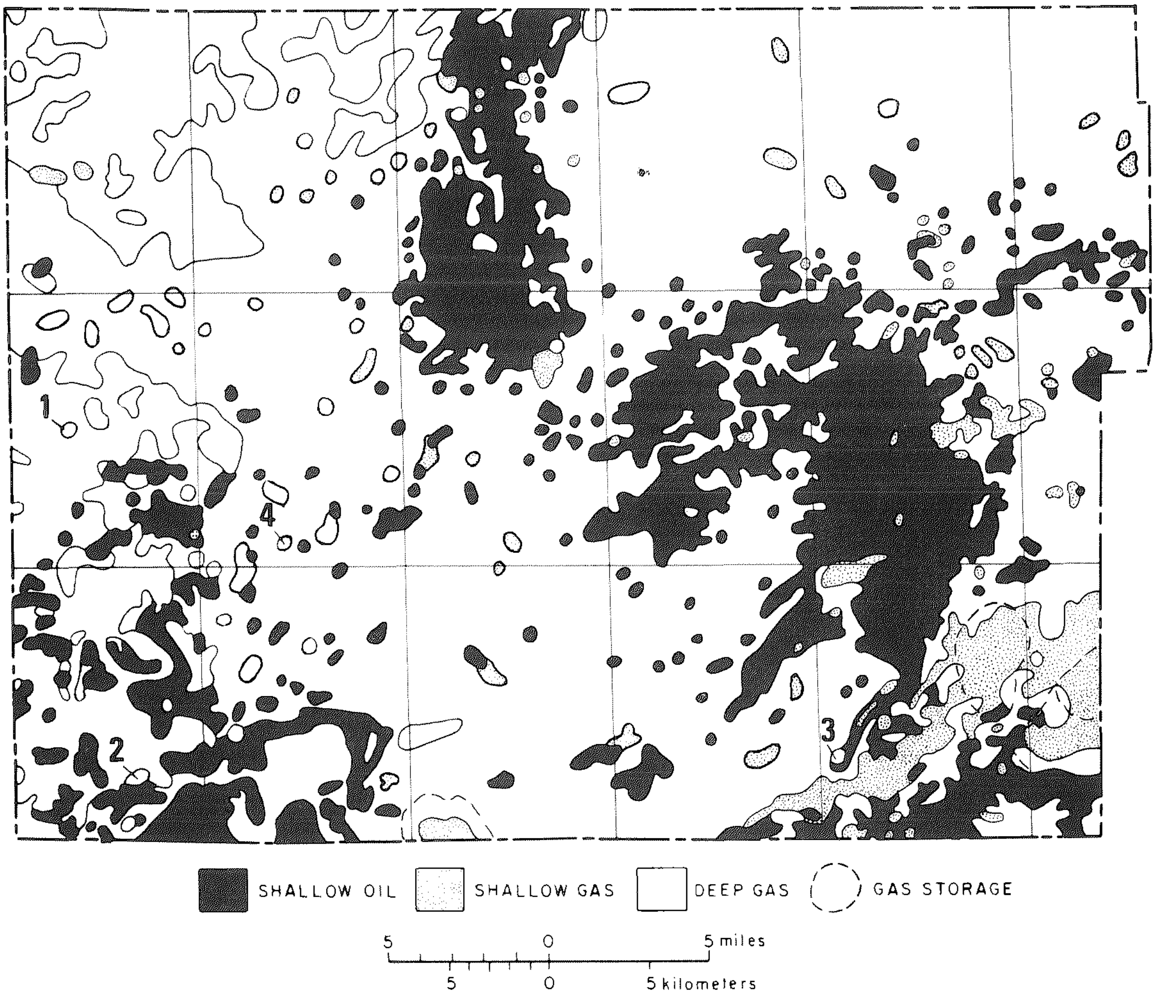


Figure 13. Oil and gas fields map of Warren County as of May, 1992. Deep gas fields mostly represent Medina Group production. Numbered exceptions include: 1 - Cobb Corners oil pool (Onondaga Limestone), County Line field; 2 - McCarthy oil and gas pool (Onondaga Limestone), Colorado field; 3 - Kinley gas pool (Helderberg Group), Bull Hill field; 4 - Ross Hill gas pool (Beekmantown Group), Davy Hill field.

of Warren County. Not all areas have been productive, however, as shown by the limits of production in Figure 13.

Natural gas was a minor hydrocarbon commodity in Warren County until the late 1970's when the Natural Gas Policy Act of 1978 set higher prices for unconventional gas resources. In 1982 the Federal Energy Regulatory Commission designated the Lower Silurian Medina Group as a "tight" (low permeability) formation in Crawford, Erie, Mercer, Venango, and Warren Counties. This designation allowed operators to request significantly higher prices for Medina gas, resulting in thousands of new wells during the 1980's. Today the Medina Group is the most important reservoir in the county in terms of total annual drilling and production. The deep gas fields of Figure 13 show the present distribution of Medina production.

SOURCE ROCKS

According to Laughrey, the number of potential source rocks for the oil and natural gas found in Warren County are limited (Laughrey, 1991). Black, organic-rich mudrocks of the Upper and Middle Devonian and Upper Ordovician are the only reliable source rocks for all known Pennsylvania hydrocarbons. There has been much speculation in the literature about the value of the Cabot Head Shale, a formation within the Medina Group, as a source of gas in that unit. However, geochemical studies point to very low total organic carbon (TOC) contents in those rocks (Cole and others, 1987; Laughrey, in preparation), indicating that the Cabot Head would be a very minor source at best.

TRAPS

Traps typically are stratigraphic, consisting of lateral pinchouts, diagenetic changes (porosity and permeability barriers), and mudrock seals. During his tenure as State Geologist in the late 1800's, J. P. Lesley tried to impress upon the oil industry that oil production in northwestern Pennsylvania occurs as a result of stratigraphy and regional dip, without benefit of anticlinal control (Lesley, in Carll, 1886). However, structural traps are important locally where subtle folds and minor faults occur. Subtle structures have been mapped at most shallow horizons by Cathcart and others (1938), Dickey (1941), Ingham and others (1956), McGlade (1964), Lytle (1965), and Lytle and Goth (1970), and others. In addition, Laughrey (1984) and Ensign (1991) report that structures are subtle but important in the Lower Silurian Medina Group sandstone reservoirs of Crawford and Warren Counties.

Although Medina Group reservoirs produce primarily as a result of stratigraphic traps, regional fracture patterns may also be important. As these become better known, the use of lineament studies may benefit Medina operators in Warren County as they have benefitted certain operators in Crawford and Venango Counties (Zagorski, 1991).

In contrast to the shallower (less than 6,000 feet) reservoir rocks, at least one large domal structure occurs in the Lower Paleozoic dolostones of southwestern Warren County as mapped during a recent study of the Upper Cambrian Gatesburg Formation in Pennsylvania and Ohio (AONGRC, 1991). The structure, which can be mapped on the Lower Ordovician Beekmantown Formation as well as the Gatesburg, has been the target of several deep (greater than 8,000 feet) exploratory wells drilled in the Tidioute area since 1957. All the wells had shows of gas in the Beekmantown, and the most recent, drilled in 1984, looked productive enough to designate a pool. However, it is not certain if this well ever actually produced.

MAJOR RESERVOIR ROCKS

Venango Group

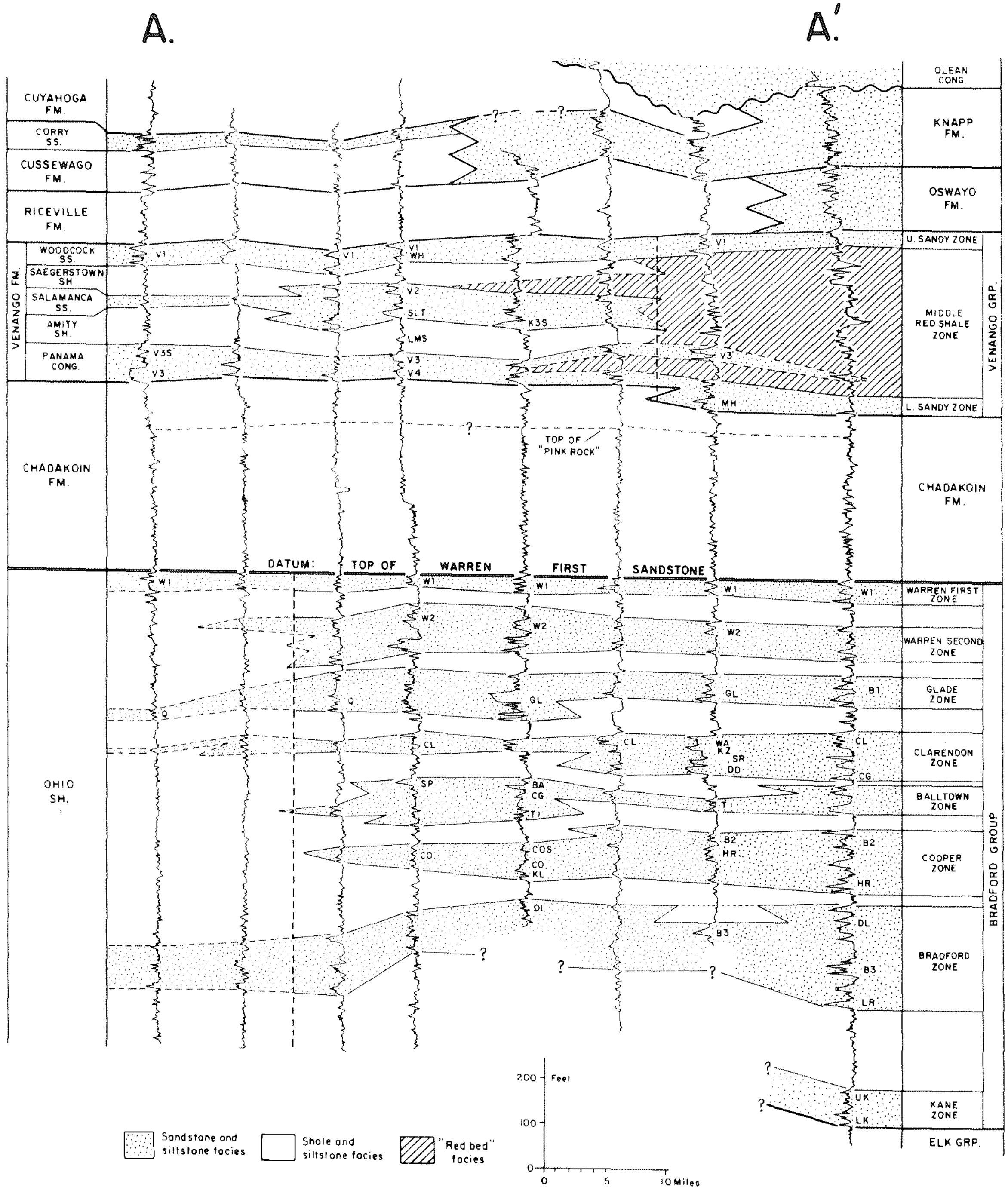
In outcrop in northwestern Pennsylvania, the Upper Devonian Venango Formation consists, in decending order, of the Woodcock Sandstone, Saegerstown Shale, Salamanca Sandstone, Amity Shale, and Panama Sandstone. In the subsurface of most of western Pennylvania, however, the equivalent strata have been given group status. The reader is referred to Harper and Laughrey (1987 and 1989) for more complete discussion of the Venango Group.

In Warren County the Venango Group consists of a variable amount of interbedded sandstone, siltstone, and shale sandwiched between two fairly persistent zones of sandstone called the Venango First and Venango Third sandstones (the Woodcock and Panama equivalents) (Figure 14). The group as a whole can be traced across the county, but specific identification of the reservoir sandstones within it becomes increasingly difficult toward the east where Catskill "red bed" lithologies (the Cattaraugus Formation of earlier authors) tend to dominate the section between the upper and lower sandstones. To complicate matters further, to the south and east additional Venango facies sandstone units develop below the Venango Third. These sandstones act to extend the group downward into the subjacent Chadakoin Formation. In this same area the distinction between the upper beds of the Venango Group and the beds of the superjacent Oswayo Formation begins to break down. Field geologists prefer to call to the entire section between the Knapp (Corry and Cussewago equivalent) sequence and the red Catskill facies the Oswayo Formation. In Figure 14, however, the distinction is preserved in deference to the definition of the Venango Group in southwestern Pennsylvania (Harper and Laughrey, 1987; 1989).

Lithology and Reservoir Characteristics

Typical Venango Group reservoir rocks consist of relatively thick sequences of interbedded sandstones, siltstones, and shales

Figure 14. Venango and Bradford Group cross section A-A'. See Figure 17 for location. Drillers' sand names are abbreviated as follows: B1 - Bradford First; B2 - Bradford Second; B3 - Bradford Third; BA - Balltown; CG - Cherry Grove; CL - Clarendon; CLS - Clarendon Stray; CO - Cooper; COS - Cooper Stray; DD - Dew Drop; DL - Deerlick; GL - Glade; HR - Harrisburg Run; KL - Klondike; LK - Lower Kane; LMS - Little Minister Stray; LR - Lewis Run; MH - Magee Hollow; Q - Queen; SLT - Salt: SP - Speechley; SR - Sugar Run; TI - Tiona; UK - Upper Kane; V1 - Venango First; V2 - Venango Second; V3 - Venango Third; V3S - Venango Third Stray; V4 - Venango Fourth; W1 - Warren First; W2 - Warren Second; WA - Washingtonville; WH - White.


A.
A'.
CUYAHOGA FM.
CORRY SS.
CUSSEWAGO FM.
RICEVILLE FM.
VENANGO FM.
WOODCOCK SS.
SAEGERSTOWN SH.
SALAMANCA SS.
AMITY SH.
PANAMA CONG.
CHADAKOIN FM.
OHIO SH.
OLEAN CONG.
KNAPP FM.
OSWAYO FM.
U. SANDY ZONE
MIDDLE RED SHALE ZONE
L. SANDY ZONE
VENANGO GRP.
CHADAKOIN FM.
WARREN FIRST ZONE
WARREN SECOND ZONE
GLADE ZONE
CLARENDON ZONE
BALLTOWN ZONE
COOPER ZONE
BRADFORD ZONE
KANE ZONE
BRADFORD GROUP
ELK GRP.
TOP OF "PINK ROCK"
DATUM: TOP OF WARREN FIRST SANDSTONE
Sandstone and siltstone facies
Shale and siltstone facies
"Red bed" facies
200 Feet
100
0
0 5 10 Miles

with the pay section restricted to the sandstones. These rocks consist of fine-grained quartz sand thoroughly cemented by authigenic silica, but lenses of coarse-grained sandstones and pebble conglomerates are common, especially near the tops of the beds. There seems to be a direct relationship between grain size and amount of cement, such that the finer the grain size the more cementation; the pebbly beds commonly are friable (Dickey, 1941). Constituent grains consist mostly of white quartz, but yellow quartz is common. Feldspars, rock fragments, and heavy minerals are rare to absent, but ilmenite, magnetite, and authigenic iron minerals are common. Sandstone geometries suggest that these rocks developed in very nearshore conditions that may be interpreted as beaches, barrier bars, and tidal channels (Dickey, 1941; Dickey and others, 1943; Kelley, 1967).

Venango Group sandstones have exceedingly variable porosities and permeabilities (Figure 15). Porosities range from less than 5 to 25 percent, averaging 15 percent in the pay zones. Permeabilities range from less than 0.1 to 4,000 millidarcies, with a range of 10 to 500 millidarcies in the best reservoirs. Oil saturations range from 10 to 50 percent, averaging less than 30 percent, whereas water saturations typically range from 40 to 60 percent. Of course, these data were derived from the more productive portions of the reservoirs, most of which were drilled prior to World War II. Since that time much of the Venango Group drilling in Warren County has been relegated to the more marginal parts of the reservoirs where porosities, permeabilities, and oil saturations are lower and water saturations are higher.

Producing Areas and Methods

Hydrocarbon production from the Venango Group reservoir sandstones is almost entirely restricted to the southwestern quarter of the county (Figure 16). North and east of this area much of the equivalent section either crops out or grades laterally into shale- and "red bed"-dominated lithologies (Figure 14). Although all of the Venango Group sandstones produce oil or gas in the county, production occurs mostly from the Venango First and Venango Third sandstones.

Venango Group sandstones traditionally have been produced naturally by flush production, and by secondary recovery methods, including vacuum pumping and air-gas injection (Dickey, 1941; Lytle, 1955; 1959). In the latter method, air or natural gas is pumped into the reservoir rock to drive the oil toward one or more producing wells. Waterflooding, steam injection, and *in situ* combustion techniques also have been tried (Caspero and others, 1963; Lytle, 1966) but with little success. The highly variable nature of the rock, including broad ranges in permeability and fluid saturations, undoubtedly had a great effect on these methods, helping to channel fluids into the more permeable, already depleted portions of the reservoir.

Bradford Group

Upper Devonian Bradford Group stratigraphy is shown in

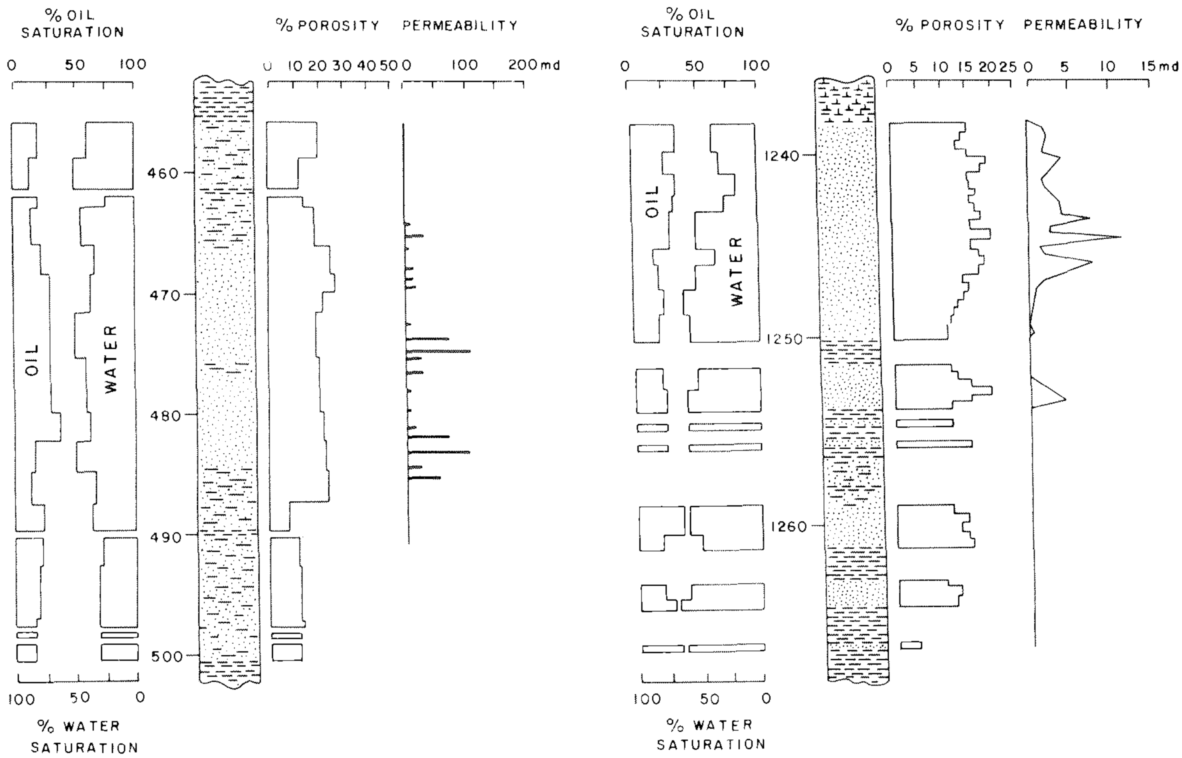


Figure 15. Representative core analyses from Upper Devonian reservoirs in Warren County. Left, Venango Group, Venango First sandstone, Goodwill Hill-Grand Valley field, Southwest Township (modified from Dickey, 1941). Right, Bradford Group, Clarendon sandstone, Clarendon field, Meade Township (modified from Lytle, 1965).

Figure 14. Like the Venango Group, the Bradford consists of numerous reservoir sandstones interbedded with non-productive sandstones, siltstones, and shales. Based on cores recovered in McKean County and interpretation of lithology from geophysical logs in the Indiana-Westmoreland County area, the Bradford Group also contains a few thin marine limestones and numerous marine shale and siltstone zones. Future study of this group in the subsurface of western Pennsylvania may determine that these marine zones are regional in nature, thus providing ideal datums for stratigraphic correlation.

The top of the Bradford Group has traditionally been placed at the top of the Warren First (or First Warren) sandstone. Although this is typically an excellent marker horizon throughout western Pennsylvania, it can be difficult to distinguish on geophysical logs in certain areas. West of central Warren County the sandstones defining the group become less distinct in the section. The Bradford Group gradually merges westward into the Ohio Shale, and an arbitrary cutoff is drawn at the approximate position of the Allegheny River valley (Figure 14).

The primary oil-producing strata within the Bradford Group

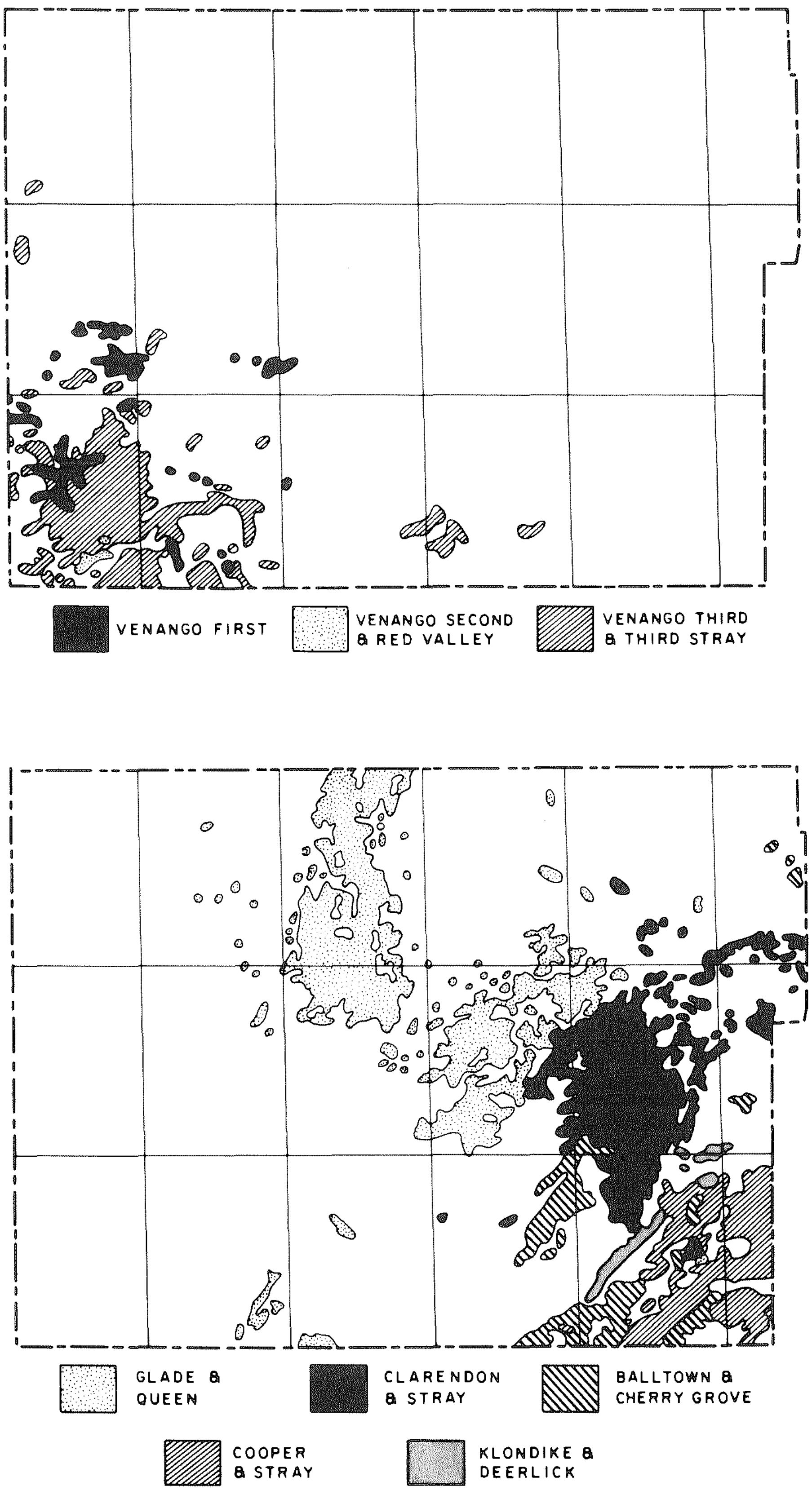


Figure 16. Shallow oil and gas fields of Warren County A. fields producing from Venango Group reservoirs. B. fields producing from Bradford Group reservoirs.

of Warren County include the Glade (or Queen), Clarendon (including Gartland, Kinzua, Sugar Run, and Washingtonville), Balltown, Cherry Grove, Cooper, Klondike, and Deerlick sandstones. Other sandstones approximately correlative with, or stratigraphically lower in the section, than these rocks are important Bradford Group reservoirs to the east and south.

Lithology and Reservoir Characteristics

Most Bradford Group reservoir sandstones consist of light-colored to reddish- or chocolate-brown, very fine- to coarse-grained sublitharenites. The dominant grain size is very fine to fine, but several of the reservoir sandstones contain abundant quartz pebbles near the tops of the units. The reservoir sandstones of the Bradford Group appear to have been deposited in a series of nearshore and shallow marine shelf environments. Distinctive beach/bar forms appear throughout the group in the reservoir sand map of Ingham and others (1956), and McGlade (1964) described the Glade sandstone in Sugar Grove field (north-central Warren County) as a barrier bar sequence. Undoubtedly, other depositional systems will be delineated when these rocks are studied more fully.

Although Bradford Group reservoirs exhibit variable porosities and permeabilities (Figure 15), they are not nearly so variable as those of the Venango Group sandstones. Porosities generally range from about 5 to 25 percent, averaging 10 percent in the pay zones. Permeabilities range from less than 0.1 to more than 10,000 millidarcies in at least one field, but most reservoirs average about 0.3 millidarcy. Oil saturations range from 5 to 45 percent, averaging about 20 to 25 percent. Water saturations typically are higher than oil saturations.

Producing Areas and Methods

The Bradford Group sandstones produce oil in large areas of north-central, central, and southeastern Warren County (Figure 16). West and north of these areas the reservoir sandstones grade into siltstones and very fine-grained sandstones that may produce gas in limited areas. The patterns of historical production are interesting from the standpoint of the nearly complete separation of Venango and Bradford production areas. This separation is curious in that it cannot be interpreted simply as the result of regional dip (where the Venango Group would be at the surface or missing entirely in the area where the Bradford Group produces). These two areas appear to be separated by a zone running northwest-southeast through the county between Watson and Spring Creek Townships. Earlier studies by Harper (1989; 1992) suggest that this zone may be part of a cross-strike structural discontinuity (CSD), a zone of fracturing inherited from faulting or fracturing in the basement. Harper's work suggests that CSD's may affect reservoir sedimentation patterns, fluid migration pathways, and diagenetic changes that govern the occurrence of oil and gas. Further study will be necessary to determine if this is a valid concept in this case, or if the separation of

Venango and Bradford producing reservoirs is simply coincidence.

Following the initial depletion of oil by flush production in Warren County Bradford Group reservoirs, the oil industry tried a number of secondary recovery techniques, including vacuum pumping, hydraulic fracturing, air-gas injection, and waterflooding (Lytle, 1955; 1959). All have been successful to some degree wherever they were applied, although some reservoir rocks are more amenable to one technique than another. For example, drilling and production in the Glade sandstone of the Sugar Grove and Youngsville fields increased dramatically following the introduction of hydraulic fracturing in 1962 (Rough and Eckard, 1963; 1964; McGlade, 1964). Air-gas injection has been successful in the Glade sand in Warren and Glade fields, whereas waterflooding has been applied extensively in the Clarendon sand in Clarendon field (Fettke, 1950; Lytle, 1965). Traditionally, waterflooding has been more successful in the Bradford Group reservoirs than in the Venango Group because of the more homogeneous reservoir characteristics of the rocks.

Medina Group

The Medina Group in Pennsylvania consists of three formations, an upper Grimsby Formation comprised of interbedded sandstones and shales, a middle Cabot Head Shale, and a lower Whirlpool Sandstone. A cross section of the Medina Group across Warren County (Figure 17) illustrates the relationship among these formations and demonstrates that, in the eastern third of the county the Whirlpool and Cabot Head pinch out. This pinch out apparently is a result of erosion over a regional high. The Pennsylvania Geological Survey uses this as an arbitrary cut-off, restricting the Medina Group to the west and the Tuscarora Sandstone to the east. It appears that at least the upper portion of the Grimsby Formation is correlative with the Castanea Member of the Tuscarora (Laughrey, 1984),

Lithology and Reservoir Characteristics

Grimsby sandstones typically consist of light gray to reddish-colored, very fine- to fine-grained quartz arenites, wackes, subarkoses, and sublitharenites interbedded with siltstones and mudstones of varying colors and compositions. Whirlpool sandstones typically are composed of light gray, very fine-grained, glauconitic, quartz arenites and subarkoses with light colored mudstone interlaminae. Medina sandstone geometries are reminiscent of fluvial-deltaic deposits, and commonly are so described as far west as Ohio. Laughrey (1984), however, interpreted the Medina as mixed fluvial and paralic to marine deposits. Most authors describe the Whirlpool as a basal transgressive sandstone deposited on a low, eroded coastal plain developed on the Upper Ordovician Queenston Formation. The Grimsby sandstones apparently developed in mixed fluvial and nearshore settings, with individual sandstones representing ephemeral braided fluvial and paralic deposits (Laughrey, 1984)

The Medina Group sandstones have been characterized as

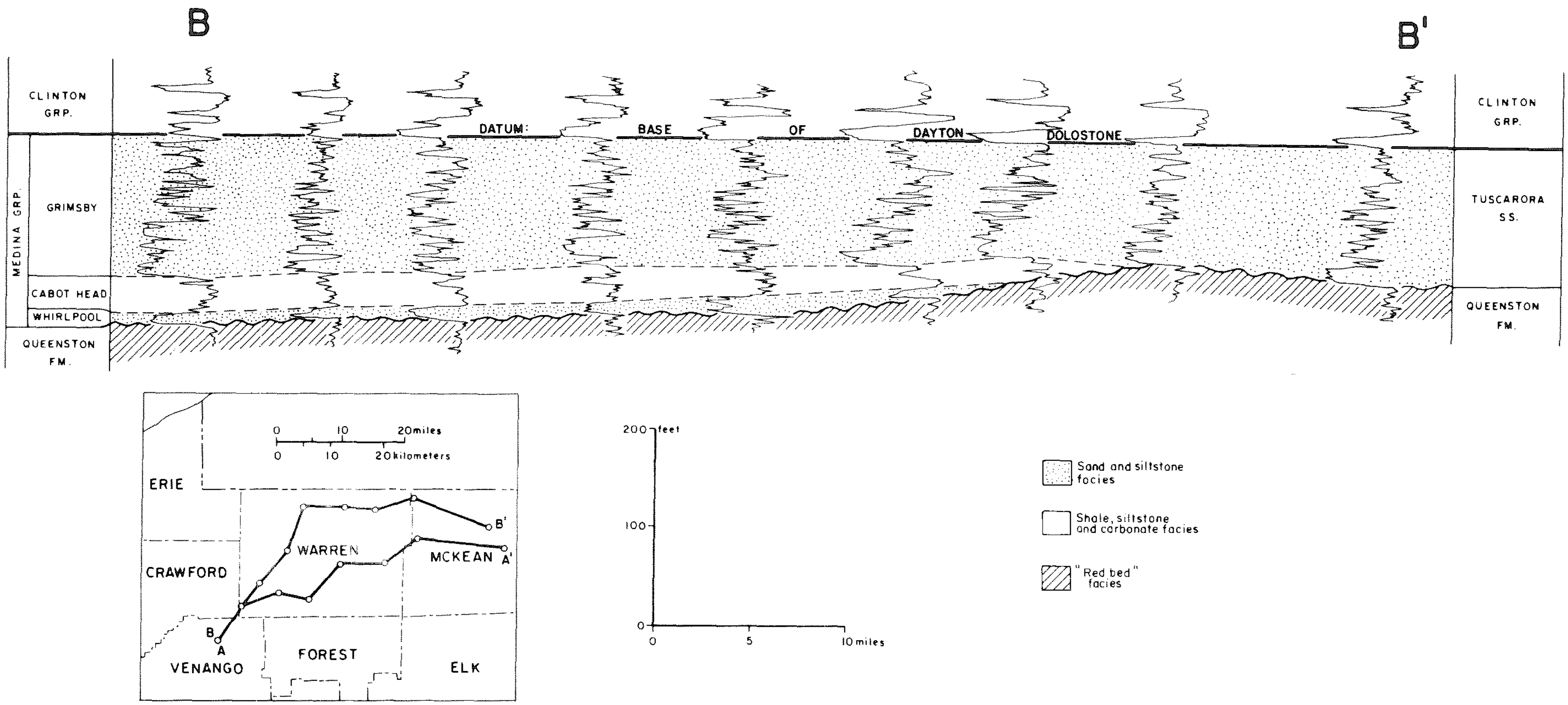


Figure 17. Cross section B-B' illustrating the relationship of the Lower Silurian Medina Group to the Tuscarora Sandstone and adjacent formations.

"tight", that is, having very low porosities and permeabilities, throughout most of northwestern Pennsylvania. Exceptions include areas of intense fracturing. Average measured and calculated permeabilities are less than 0.1 millidarcy throughout the section, but fracture permeabilities as high as 117 millidarcies have been measured by core analysis (Laughrey, 1984). Medina porosity ranges from less than 2 to almost 12 percent, but average about 5 percent (Laughrey and Harper, 1986). Water saturations as measured by core analysis range from 20 to more than 80 percent.

Producing Areas and Methods

As of May, 1992 Medina gas in producible economic quantities is almost restricted to the western third of Warren County (Figure 13). Only a few of the limited number of wells drilled east of Sugar Grove Township in north-central Warren County have been productive. Most Medina operators tend to be very conservative. Since 1985 most of the activity has been infill drilling in developed fields. A few outpost/extension wells (wells drilled two or more locations away from established production) are reported every year, and these generally define the limits of risk in the Medina of Warren County.

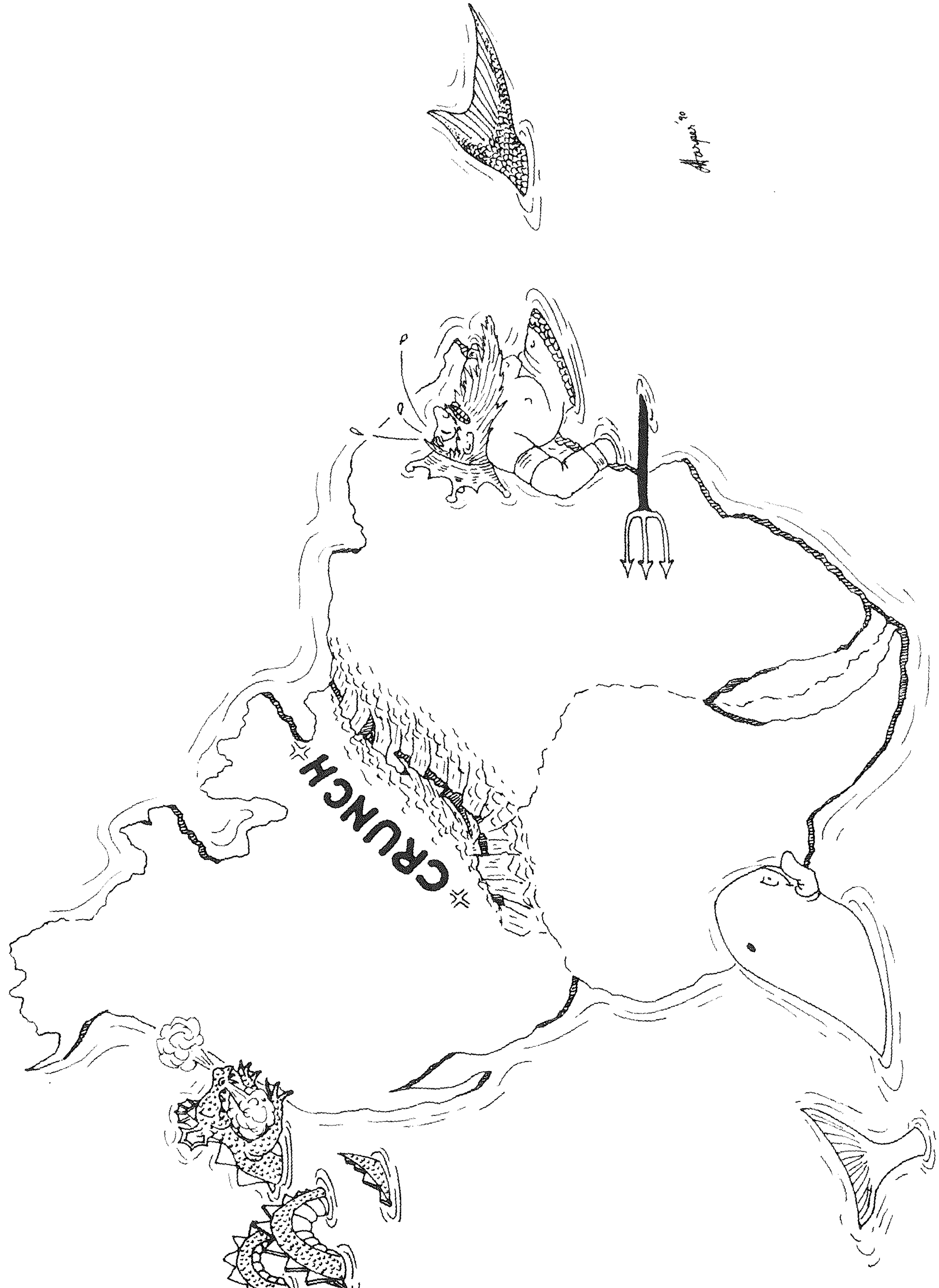
Because the Medina Group sandstones are "tight" they require hydraulic fracturing to induce economic gas flow. Operators have been cautioned in designing stimulation procedures, however. Laughrey (1984) pointed out that there are a number of potential problems inherent in the composition of Medina sandstones that may be induced with the wrong type of stimulation material. Porosity and permeability reduction may occur as a result of: 1) acid-sensitive authigenic chlorite releasing iron as a gelatinous ferric hydroxide; 2) authigenic illite occurring as delicate fibers that tend to accumulate in the presence of fresh water; and 3) water-sensitive and acid-sensitive mixed-layer illite-chlorite clays that have properties of both. The mixed-layer clays are even more important as false indicators of high water saturation. Geophysical logs indicating high water saturations may be reading irreducible water locked up in clay micropores. Laughrey (1984) cautioned Medina operators to carefully evaluate their wells before abandoning them.

SECONDARY RESERVOIR ROCKS

Secondary reservoirs in Warren County include carbonates of the Middle Devonian Onondaga Limestone, Lower Devonian Helderberg Group, and Lower Ordovician Beekmantown Group. Producing pools in these rocks are indicated by number designations in Figure 13. Not a great deal is known at present about any of these reservoirs, although at least one Onondaga Limestone pool (#2 on Figure 13) may be a patch reef developed above a sand bar in the Lower Devonian Oriskany Sandstone. High gas production and substantial oil production from the three wells in this pool, plus high porosities and low water saturations calculated from geophysical logs in nearby wells, point to a possible reef facies.

It may be purely coincidental that Kinley pool, the Helderberg producer in southeastern Warren County (#3 in Figure 13), occurs beneath the elongate bar of Klondike sandstone in Bull Hill field, Cherry Grove and Sheffield Townships (see Figure 14). It is also possible that the Klondike bar was influenced by structural control at depth, and that at least part of that control may be present at the level of the Helderberg in Kinley pool. There is very little well control in this area below the Upper Devonian, and without seismic information it is especially difficult to develop a reasonable explanation. Perhaps further light will be shed on this problem in the future.

The Beekmantown pool in central western Warren County (#4 in Figure 13) is the only producing area from this carbonate unit in Pennsylvania. It is also somewhat enigmatic in that it appears to have been drilled on structural closure that can be mapped to at least the level of the Late Cambrian Gatesburg Formation. Without cores, well cuttings, logs, or seismic information, it is difficult to characterize the Beekmantown in this area.


CRUNCH

THE IPSCO DEEP WELL: A COOPERATIVE PROJECT TO ASSIST PENNSYLVANIA'S PETROLEUM INDUSTRY

Douglas A. Stewart and Joseph M. Tarantino
DER Bureau of Mining and Reclamation

INTRODUCTION

Exploration and development of Pennsylvania's Appalachian Basin for oil and natural gas has continued since Colonel Edwin Drake drilled the first oil well in 1859. In 1992, drilling rig activity is at its lowest rate in memory. Today's oil and gas producer must be able to provide adequate supplies of natural gas and oil at the current market prices and still turn a profit. To stay competitive in such a tight market, the oil and gas producer must find new ways to increase the recovery of oil and gas in new and existing fields and improve benefit/cost ratios. The producer must also develop new or refine current drilling techniques so they are more efficient and environmentally responsible. To meet these needs, IPSCO (International Petroleum Services Co.) and the Pennsylvania State University initiated a joint venture to drill a sterile deep well to be used solely for training and research purposes (Figure 18). The main objective of this cooperative effort is to establish a research center and training facility at IPSCO's headquarters in Sheffield, Pennsylvania.

ESTABLISHMENT OF THE FACILITY

Terry L. Pope, president of IPSCO, introduced the idea of having a dedicated drilling rig, permanently mounted on a test well location. A permanently mounted drilling rig would allow drilling crews to be properly trained in rig operations and safety procedures in a controlled setting, replacing the unpredictable dangers associated with on the job training during active drilling operations.

In October of 1990, Pope contacted Dr. Robert W. Watson of the Petroleum and Natural Gas Section of the College of Earth and Mineral Sciences at the Pennsylvania State University. Pope wanted to find out if Penn State would be interested in this project, with the idea that Penn State could also utilize the site for its own research purposes. Penn State accepted the proposal, and in November 1991, Dr. John A. Dutton, Dean of the College of Earth and Mineral Sciences at Penn State, created the Drilling-Hydraulics Research Center at the Sheffield site, with Watson as Director (Curtin, 1992).

DRILLING THE WELL

Drilling of the research well commenced on March 6, 1992 (Figure 19). To insure that the well remain sterile and free of any oil, gas, and water produced from the various geologic formations, the following drilling procedure was utilized:

Forty feet of 20-inch-diameter conductor casing was installed in the initial section of the well. Then after

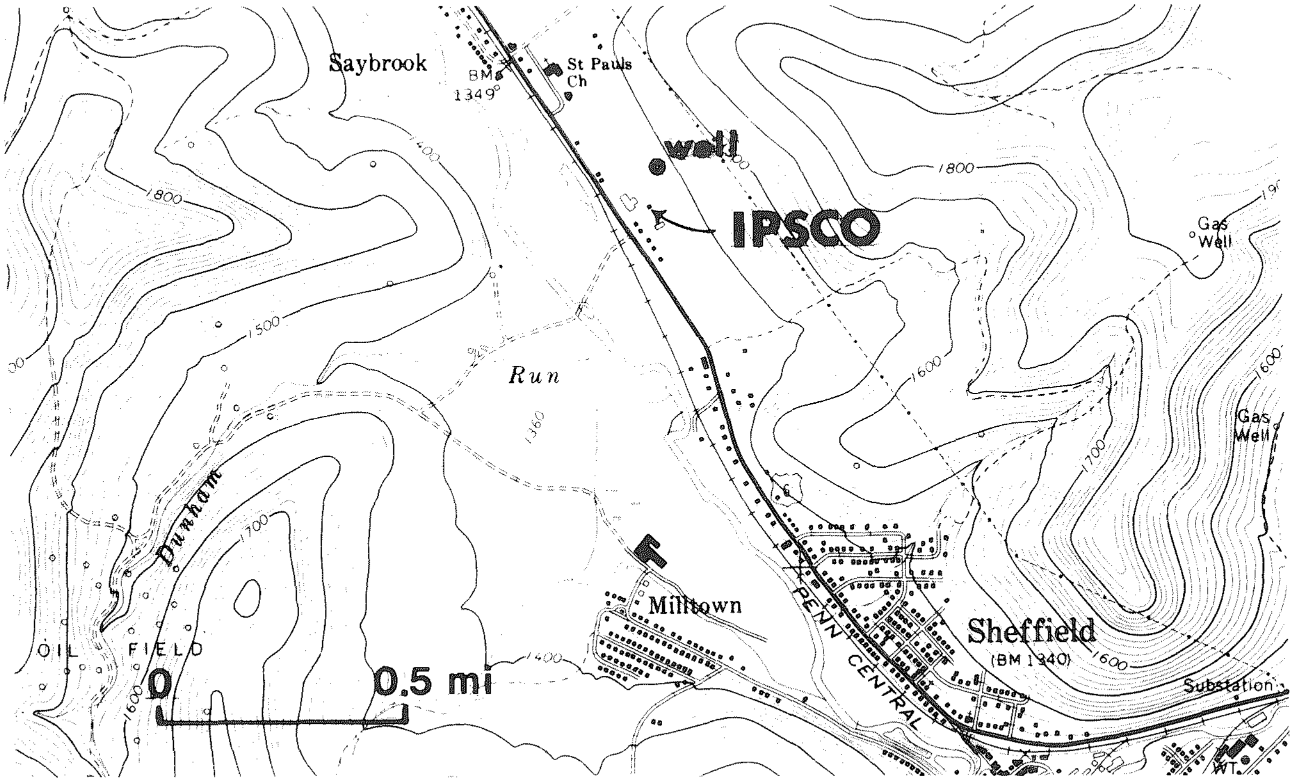


Figure 18. Location map of IPSCO's headquarters at Sheffield, Warren County, Pennsylvania, showing the site of the IPSCO training/research well.

drilling a 17.5-inch hole through 120 feet of gravel and 290 feet of bedrock, 410 feet of 13-3/8-inch casing was run inside the 20-in casing and cemented in place. Cementing the casing in place is accomplished by pumping the cement slurry down inside the casing, forcing it out the bottom, and up between the casing and the wellbore. A wiper plug is pumped down the casing forcing all the cement out the bottom, so only the wiper plug must be drilled out when drilling resumes. The remaining 12-1/4-inch hole was drilled to a depth of 4100 feet. A string of 9-5/8-inch casing was run all the way to the bottom of the well. This casing was then cemented in place from the bottom (T.D.) to the top with 850 sacks of cement leaving a 200-foot cement plug remaining in the bottom of the casing. These actions will effectively prevent any water, oil or natural gas from entering the well bore unless introduced from the top. The well was completed on March 18, 1992.

The IPSCO research well could not have been drilled without significant industry donations. To date, industry has either provided and/or committed $3,500,000 of support in materials, equipment, services, and land. In order to start the project, one (1) acre of mineral rights below IPSCO's Sheffield headquarters was deeded over from National Fuel Gas with the stipulation that no oil or gas ever be produced from the well. The 20-inch conductor casing and the pit liner were donated by

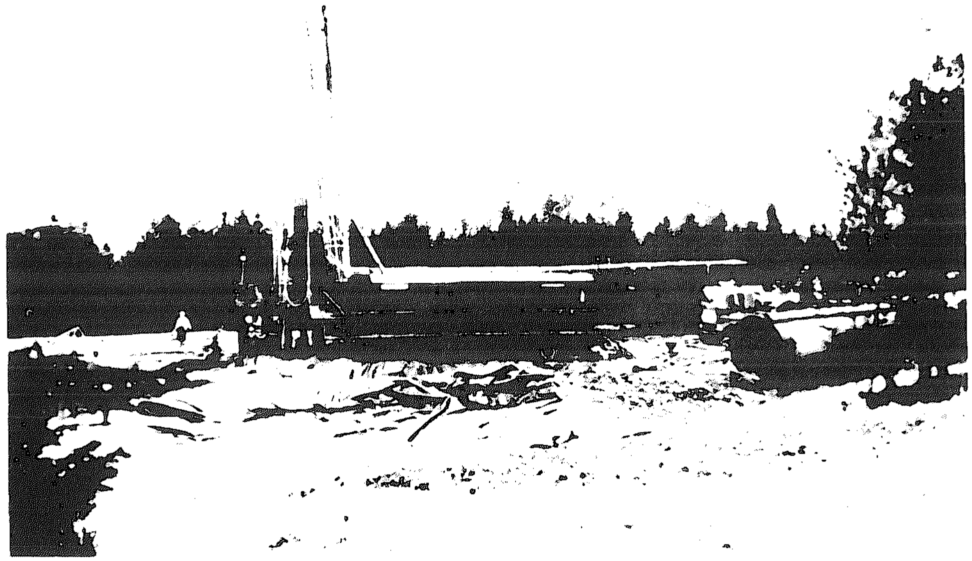


Figure 19. Drilling of the IPSCO well, using a Mac 4 rotary drilling rig, March 1992.

North Penn Pipe and Supply Co. of Warren. The remaining casing valued at $100,000 was donated by the USX Corporation of Pittsburgh. The drilling of the well, the land for the center, and the Mac 4 rotary rig dedicated to the research center were all donated by IPSCO. Pennzoil provided the diesel fuel to drill the well, and Kendall donated the lubricating products for the life of the project. Schlumberger of Bradford contributed the wireline well logging services. Universal, IPSCO's sister company, donated all well-cementing services.

GEOLOGY OF THE WELL

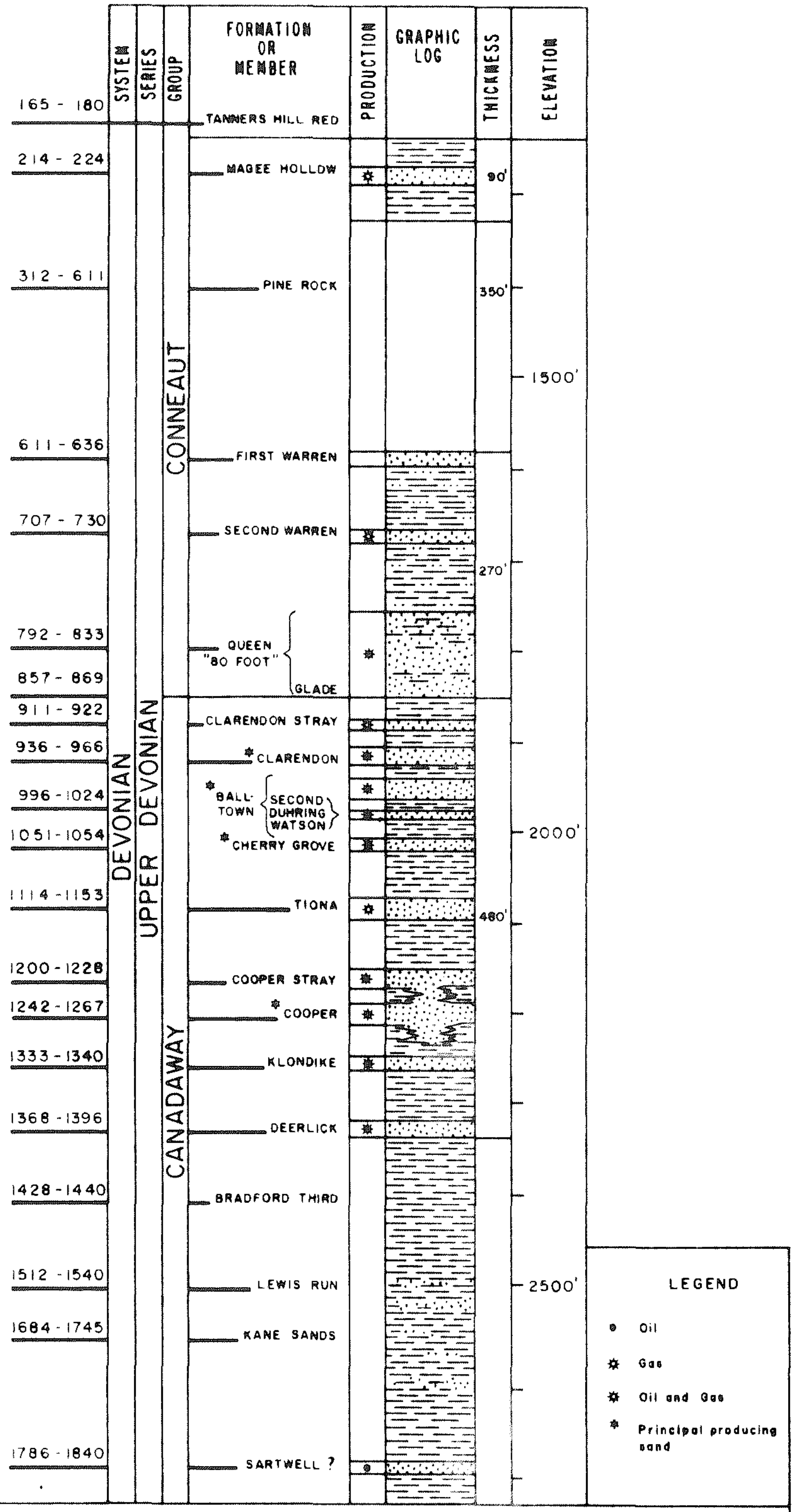
The research well was spudded in Holocene/Pleistocene colluvial and terrace deposits, penetrated bedrock (Upper Devonian Venango Formation) at 120 feet, and bottomed in the Tully Limestone at a total depth of 4084 feet (Figure 20). Shows of oil and gas were encountered in all of the principal and secondary "producing sands" from the Second Warren (707-foot depth) down to the Deerlick (1368-foot depth). The most important of these sands in the Sheffield quadrangle are the Clarendon Stray, the "upper and lower" Balltown, the Cherry Grove, and the Deerlick (Ingham and others, 1956). Also of considerable local significance is the Sartwell sand, penetrated in the IPSCO well about 400 feet below the Deerlick and accounting for one of the numerous oil shows. The Sartwell is the lowest producing sand in the Sheffield quadrangle (Ingham and others, 1956).

AIR DRILLING RESEARCH

The thrust of this research project is to promote the use of compressed air as a drilling fluid for drilling and circulation, where practical, in place of mud-based drilling fluid systems. Some of the impacts and benefits of the proposed project are summarized below (Adewumi and Watson, 1992):

1. Drilling with air instead of mud reduces drilling costs and therefore decreases the cost of producing oil and gas. Also, air drilling does not cause the problems associated with drilling with mud; i.e., formation damage, lost circulation, etc., avoiding post-drilling operations. Air drilling provides better formation reservoir data acquisition, because the formation is not contaminated by the muds used in conventional drilling.
2. Drilling muds often use different chemicals, some of which may be harmful to the environment and require special disposal at considerable expense. Should research at this facility indicate that air drilling can satisfactorily replace mud drilling in some circumstances, the threat of environmental harm may be effectively reduced.
3. The development of economical air-drilled horizontal well technology will encourage production of tight oil and gas reservoirs common to the Appalachian Basin. Improvement in horizontal well technology will open previously restricted areas for oil-and-gas production.
4. Developing technology for the in-situ treatment of subsurface hazardous waste may replace the current practice of excavating this material. The in situ treatment of buried hazardous waste using air drilling will reduce costs both in drilling and in the later remediation.
5. Some of the research to be conducted will be on gas and solids flow rates. This will be used to develop profiles of gas and particulate velocity, pressure drop profiles, and solids volumetric concentration at various operating conditions. The pressure and pressure drop will be measured using pressure transducers placed at various intervals in the well bore.
6. A multi-phase hydrodynamic model will be developed. This model will represent wellbore hydraulics encountered in hole-cleaning while air drilling and techniques for solving the resulting system of partial differential equations. Further, a better understanding of the dynamics of pneumatic transport of solid cuttings during air drilling and the associated well bore hydraulics will be gained from developing this model.

The technology developed at this facility will be shared with industry and academia through PC-based programs. The facility will provide a place for on-site safety training for any improved air drilling technology, blowout preventor operation and testing, and well control classes. It is estimated that the research facility, when in full operation, will have an annual budget of several hundred thousand dollars.



SERIES	GROUP	FORMATION	DEPTH
U. Devonian	Canadaway	No other formations recognizable	1840 - 2500
U. Devonian	Canadaway	Base Canadaway	2500
U. Devonian		Upper Devonian shales	2500 - 4050
M. Devonian		Tully Limestone	4050 - T. D. (4084)

Figure 20. Log of the IPSCO well. (Stratigraphic picks by Burgchardt (1992).


RRRRRIIPP

SURFICIAL GEOLOGY AND GEOMORPHOLOGY OF WARREN COUNTY, PA.

W. D. Sevon
Pennsylvania Geological Survey
Harrisburg, PA 17105-2357

PHYSIOGRAPHY

Warren County lies athwart the Glaciated Pittsburgh Plateau and the High Plateau Sections of the Appalachian Plateaus Physiographic Province. A small portion of the Pittsburgh Low Plateau Section of the same province occurs in the southwestern part of the county but there is little topographic distinction between that area and the High Plateaus Section and the two areas will be discussed as a single entity.

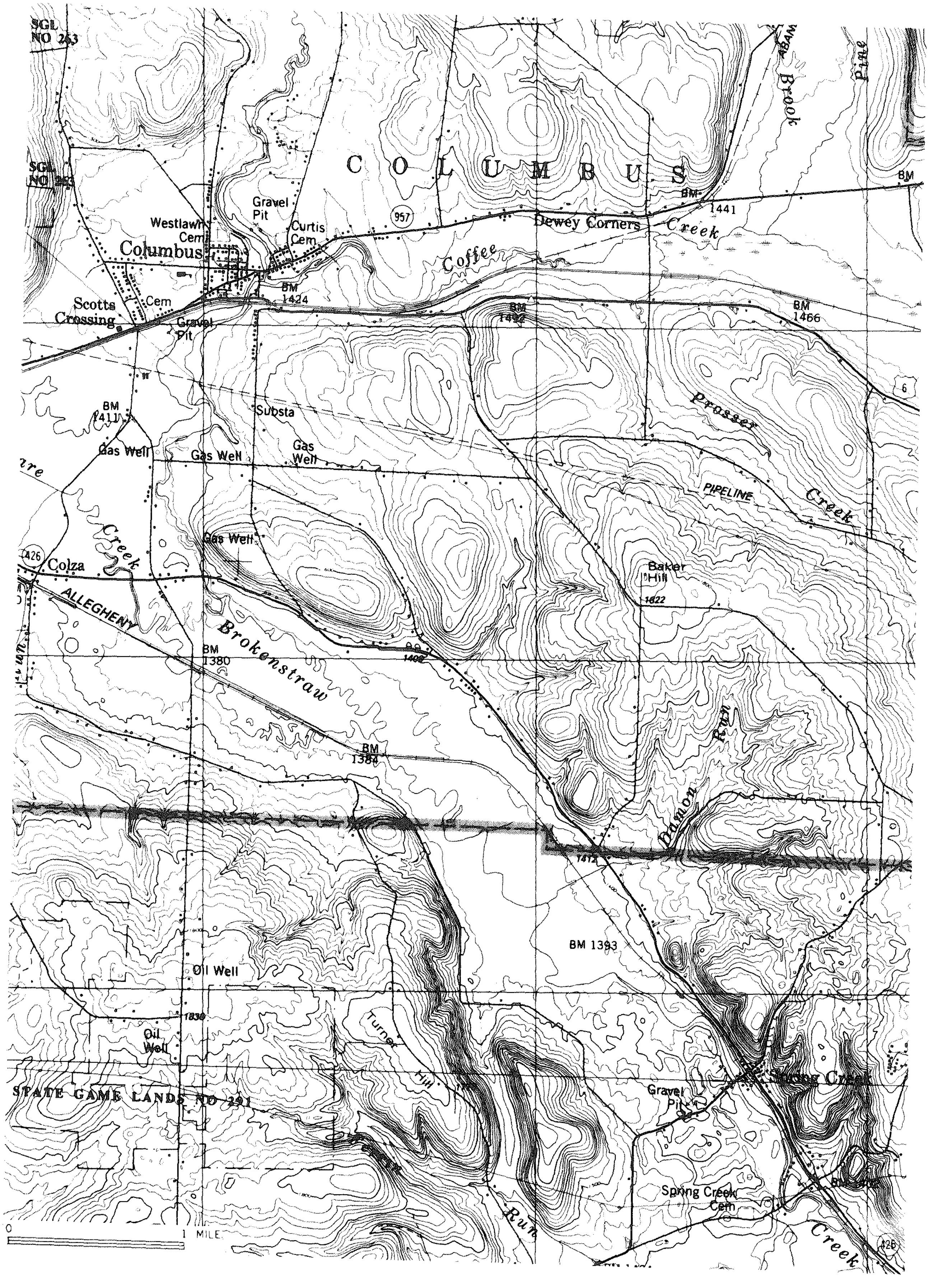
Glaciated Pittsburgh Plateau Section

The glaciated area is characterized by narrow, rounded uplands separated by broad, flat-floored valleys (Figure 21). Local relief between valley floors and adjacent upland surfaces is generally greater than 300 feet. The topography has a strong NW-SE orientation which Harper (1992) suggests is related to fracturing associated with cross-strike structural discontinuities. Harper also suggests that the several NE-SW trending glacial borders which are nearly coincident in terminal position may be controlled by the western edge of the Rome trough, a basement rift complex which was intermittently active throughout the Phanerozoic. His reasoning is that the trough may have acted "as a crustal pivot to slow ice flow" and may have conducted "more heat to the surface where increased ambient temperatures could have impaired ice movement." These ideas warrant serious consideration and further investigation.

Cultivation in Warren County is restricted almost exclusively to the glaciated area where the relief is less and slopes are gentler than in the rest of the county. The topographic boundary between the glaciated section and the High Plateaus Section is well defined and corresponds closely to the maximum extent of Late Wisconsinan glaciation. It should be noted that an area 1 to 10 miles wide south and southeast of the Late Wisconsinan glacial border has been glaciated by earlier ice sheets. However, erosion subsequent to those glaciations has removed much of the older glacial material and colluviation associated with later glaciations has either covered the materials or mixed them with local bedrock-derived debris. Incision of the landscape makes it topographically more similar to the plateaus section than the glaciated one.

High Plateau Section

The High Plateau Section is characterized by a dendritic to subdendritic complex of narrow ridges separated by narrow valleys (Figure 22). Local relief between the valley floor and an adjacent ridge is frequently 400-500 feet. Some of the visually


SGL
NO 263
COLUMBUS
Gravel
Pit
Westlawn
Cem
Curtis
Cem
Columbus
957
Dewey Corners
Creek
1441
Coffee
BM
1424
Scotts
Crossing
Cem
Gravel
Pit
BM
1432
BM
1466
Brook
Pine
BM
1411
Substa
Prosser
Creek
Gas Well
Gas Well
Gas
Well
PIPELINE
Creek
Gas Well
426
Colza
Baker
Hill
1622
ALLEGHENY
Brokenstraw
BM
1380
1402
BM
1384
Run
Damon
1412
BM 1393
Oil Well
1830
Oil
Well
Turner
Hill
STATE GAME LANDS NO 291
Gravel
Pit
Spring Creek
Spring Creek
Cem
Run
Creek
426
0
1 MILE

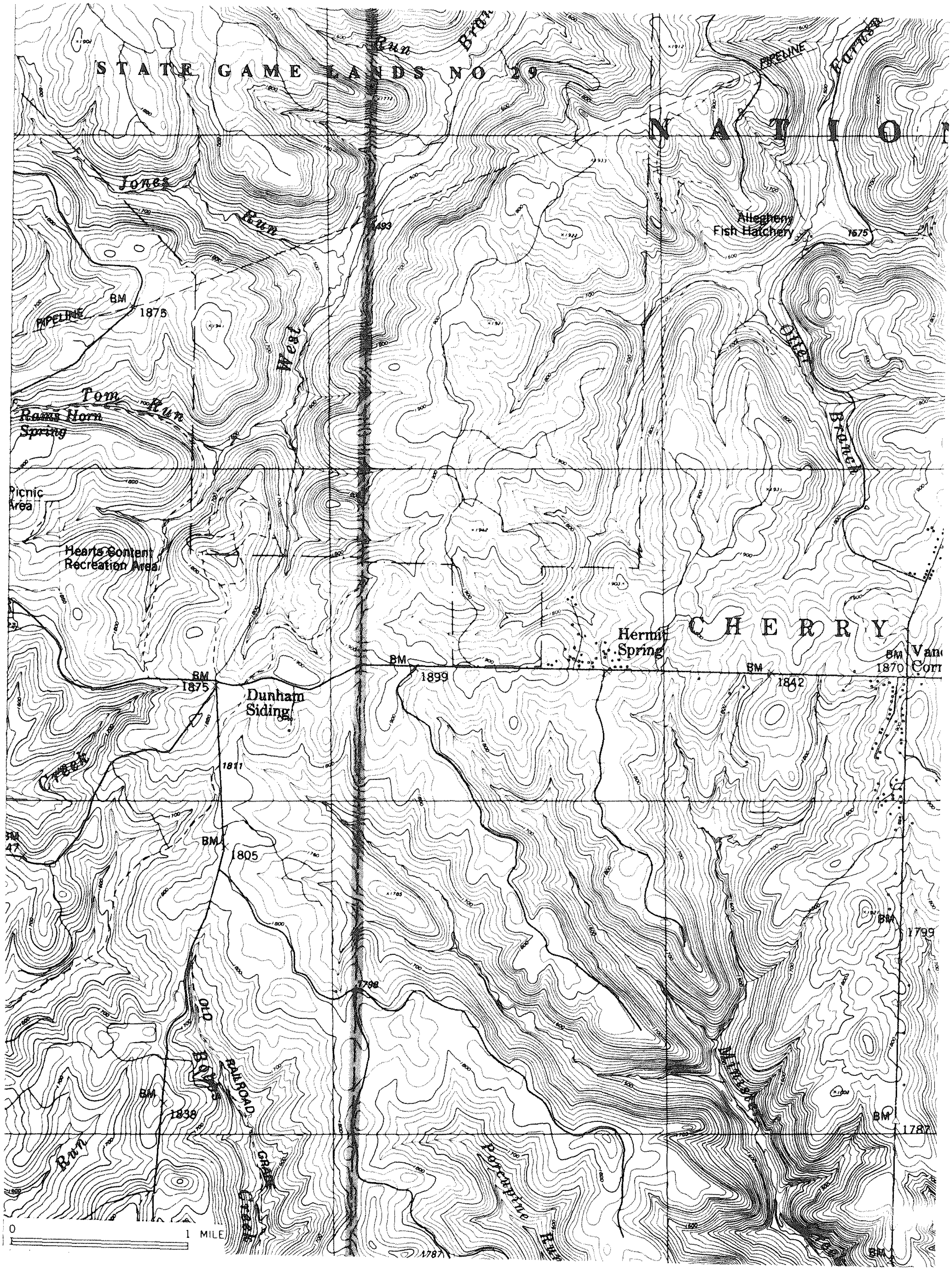
accordant uplands were considered peneplain remnants by Butts (1910, p. 2) and were used as contouring control for the Harrisburg peneplain by Campbell (1903). However, current ideas on Appalachian erosional history (Sevon, 1985; 1989) discount any peneplain remnants in Warren County. The section is traversed in its western part by the deep and narrow gorge of the Allegheny River and in its eastern part by the less dramatic valley of Dutchman Run and Tionesta Creek. Except for a few cleared areas on privately owned land, the section is almost exclusively forest and within the boundaries of the Allegheny National Forest.

CLIMATE

Warren County is within the area of humid continental warm summer climate. This climate occurs in the area of conflict between polar and tropical air masses. During the winter, polar air masses dominate with much colder weather interrupted occasionally by surges of tropical maritime air. Winter temperatures in Warren County are among the coldest in the Commonwealth. Frosts can occur quite late in the spring and very early in the fall. During the summer, maritime and continental air masses bring higher temperatures and slightly increased rainfall. Warren County is affected by air masses crossing Lake Erie and has a relatively uniform annual rainfall distribution. The area generally has more cloudy days than much of the rest of the Commonwealth and this, combined the cooler temperatures makes soil moisture deficits a rarity. Table 2 presents a summary of climatic data for Warren.

In an area which has maximum relief of over 1100 feet, local relief commonly exceeding 400 feet, maximum elevation over 2200 feet, much of the area with elevations greater than 1500 feet, and virtually all possible combinations of slope and aspect, multitudes of microclimates are present. Unfortunately, there is little data to indicate the variations. However, a few generalities can be made. Table 2 indicates that at least 100 freeze/thaw cycles may be expected each year and some areas will experience many more while some places--a steep, north-facing slope, for example--may experience many less. Sunlight on north- and south-facing slopes may differ by as much as 46 units (in g $cal/cm^2\ hr^{-1}$), assuming the slope gradients are the same. The influence of sunlight on slopes with the same aspect will vary with the gradient of the slope, the higher the gradient the greater the influence. During the winter, cleared and open land may freeze to a depth of up to 3 feet while snow-covered forest land will not freeze at all because of the insulating blanket of snow and forest litter.

Figure 21. Topographic form of the Glaciated Pittsburgh Plateau Section in northwestern Warren County. Map from the Warren County 1:50,000-scale topographic map. Area is mainly in the Columbus 7.5-minute quadrangle. Note the morainic topography in Brokenstraw Creek valley at Spring Creek and the 200-feet deep, dry, meltwater channel on the west side of the valley.


STATE GAME LANDS NO 29
N A T I O
PIPELINE
Allegheny Fish Hatchery
Jones Run
West
Tom Run
Rains Horn Spring
Picnic Area
Hearts Content Recreation Area
Otter Branch
C H E R R Y
Hermit Spring
Dunham Siding
BM 1875
BM 1899
BM 1842
1811
BM 1805
1798
BM 1799
BM 1787
BM 1838
OLD RAILROAD GRADE
Creek
Run
Porcupine Run
0 1 MILE

WEATHERING

No work has been done on the rate and type of weathering which is occuring in Warren County at the present time but some speculation is appropriate. The effectiveness of chemical weathering since the end of the last glaciation is shown at Stops 6 and 9 where igneous, metamorphic, and carbonate pebbles and cobbles in porous and permeable outwash deposits have been weathered to different degrees depending on the age of the deposit: the older the deposit, the greater the depth of oxidation and leaching.

The amount and distribution of rainfall in Warren County is adequate to generate considerable chemical weathering under certain circumstances. In the forested area (and prior to cultivation all of the county was forested) there is a considerable amount of leaf litter which contributes organic acids to infiltering rainwater already somewhat acidified by its contact with CO_2 in the air. The organic acids have an affinity for leaching alumina and iron. This leaching, part of the process of spodsolization, is effective primarily in sandy materials and produces a surface layer of nearly white sand. The leached alumina and iron may be redeposited at lower levels in the soil or may be carried out of the area in the groundwater. Spodzolic soils do occur in Warren County in areas underlain by sandy bedrock such as at Stop 3, but there has been no quantification of the process in Warren County.

The effect of chemical weathering on the non-sandy rocks of Warren County is very uncertain. Relatively little work has been done on weathering rates of siltstones and shales, particularly in the northeastern United States. Affifi and Bricker (1983) established rates of chemical denudation of 2 m/Ma for sandstone and 10 m/Ma for shale in Virginia. However, if we use Richmond, VA as an example for comparison with Warren, the mean annual temperature there is 9.8^{o} F higher, the mean annual rainfall is 1.3 inches higher, and the groundwater temperature is 6.8^{o} F higher. Each of these factors contributes to a more rapid rate of chemical denudation in Virginia than in Warren County.

In addition, the rocks in Warren County are essentially horizontal, a factor which impedes downward migration of chemically-active water and slows the areal extent of chemical weathering. Water infiltration occurs along fractures and thus chemical weathering is concentrated along the joints.

Joints and Weathering

Mechanical weathering is locally active in Warren County.

Figure 22. Topographic form of the High Plateau Section in part of south central Warren County. Map from Warren County 1:50,000-scale topographic map. Area is within the Cherry Grove 7.5-minute quadrangle. Drainage of Minister Creek has had only periglacial effects during the Pleistocene. Drainage in north half of map was dammed by ice during the Illinoian glaciation.

Table 2. Summary of climatic data for Warren, Pennsylvania. Data from: 1889-1930, Climatic summary of the United States, Section 87. - Pennsylvania; 1931-1952, Climatic summary of the United States - Supplement for 1931 through 1952, Pennsylvania; 1951-1980, Climatography of the United States No. 20, Pennsylvania.

Month	Monthly Prec.[1] Mean	Monthly Prec. High	Monthly Prec. Low[2]	Daily Prec. Max.[3]	Monthly Snowfall Mean[1]	Monthly Temp.[4] Mean	Monthly Temp. Mean Max.	Monthly Temp. Mean Min.	Record Temp. High	Record Temp. Low	Days Temp. Crosses Freeze Line[3]
Jan	2.87	7.51	1.11	1.36	15.1	25.9	34.3	17.5	74	-26	14
Feb	2.54	5.88	0.58	1.30	13.5	25.7	35.1	16.3	70	-34	16
Mar	3.35	7.25	0.77	1.58	11.0	35.0	44.6	24.8	90	-24	19
Apr	3.55	7.27	1.03	1.63	3.5	45.7	57.3	34.0	92	0	14
May	4.08	9.96	0.57	2.37	0.2	57.0	69.8	43.9	95	21	4
Jun	4.52	9.24	1.40	3.47	0.0	65.9	78.6	53.2	98	29	0
Jul	4.30	12.54	1.10	3.67	0.0	70.0	82.3	57.6	98	36	0
Aug	3.72	9.80	0.68	3.29	0.0	68.3	80.5	56.2	100	35	0
Sep	3.73	8.70	0.89	2.81	T	62.0	74.1	50.0	100	26	1
Oct	3.37	8.37	0.13	4.66	1.0	51.1	62.8	39.7	90	14	7
Nov	3.59	9.44	1.21	1.81	8.5	39.6	48.0	31.1	84	1	16
Dec	3.15	6.46	1.53	1.55	15.4	29.1	36.6	21.7	69	-22	15
Annual	42.77				68.3	47.9					106

1 = in inches; 2 = 1889-1952 data only; 3 = 1951-1980 data only; 4 = in degrees F.

Much of the exposed bedrock comprises interbedded shales, siltstones, and sandstones which in unvegetated artificial exposures disintegrate rapidly to create outcrop-bottom rubble piles (e.g., the large outcrop along the south side of PA Route 59 at Kinzua Dam, at Stop 1, Stop 2, Stop 7, and Stop 10). This process is aided by joints which can be examined at Stops 1-5, 7, 8, and 10. On casual inspection, most roadcuts appear to have joints which parallel the roadcut face, suggesting that they are stress relief joints (Ferguson, 1967).

A quantity of joint data was collected from shales and thin sandstones in the eastern part of Warren County (Table 3). In general the data indicate that appearances are deceiving and that despite the presence of joints with orientations similar to the trend of the roadcut face, a direct correspondence is generally lacking although a subparallelism of joints and roadcuts is present. This could result from the artificiality of the roadcut face relative to the pre-roadcut topographic orientation which would have controlled development of stress relief joints. More credence to the effect of stress relief is provided by data set 7 in Table 3.

Data set 7 comprises joint readings taken at intervals of 100 feet around the curve on PA Route 59 immediately west of Stop 1. Data collection started near the west end of the outcrop where the road orientation is N7E. The data show that the northeast oriented joints show a rotation of orientation around the curve. Observation indicates that the joints are subparallel to the roadcut face. A N18E joint appears persistent throughout

Table 3. Joint data from Stop 1 (1), Stop 2 (2), selected outcrops along PA Route 59 between Stops 1 and 4 (3 and 4), Stop 5 (5), Stop 10 (6), and along curve on PA Route 59 immediately west of Stop 1 (7). First number is the strike; second number, north dip except for bold numbers which are south dips. Column for road gives the orientation of road adjacent to the outcrop which approximates the orientation of the outcrop.

	NORTHEAST									NORTHWEST									
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	Road
1			26/**85**	37/90	49/87	51/80	61/74		90/85			22/90		46/81	60/81	61/80	79/79		N68E
			30/83	37/**86**	50/73	57/87								43/85			73/81		
			30/**81**	35/**84**													77/90		
2	8/**79**	16/79	27/87	38/78		59/75	66/75	74/77	90/80		16/85	26/87	39/90	47/75	51/77	66/85		84/72	N73E
			26/80			56/75	65/90	75/75				21/90	34/90		57/85	67/74			
			25/85			55/86	65/81					30/90				67/87			
						59/84	65/86					23/90				62/85			
						57/**85**	61/80					28/90				61/90			
																68/90			
3	5/80								90/90									85/85	N5E
	3/75																		
4					44/77								37/87						N47E
5			25/90												60/85		75/80		N70W
															60/72				
															60/78				
6						56/**86**						22/85	34/80	43/90					N20W
													35/75						
													35/78						
7	2/83	17/81								7/85							72/86		N7E
		20/79													54/80				
		14/84														68/**85**			
	5/90															65/**86**			
		14/74			47/87						12/87				55/72				
	9/83		30/81												52/90				
		19/78	27/85		45/88								40/90			64/**85**			
			27/84	35/76	47/**86**							25/90			54/90				
			24/84	40/73															
				38/88		55/90								50/90					
		20/80				53/77													
						56/69									60/80				
		18/65				57/77		71/82								66/**85**			
		20/90	30/87			60/77						30/90							
				35/**83**	50/75											61/90			N65E
	5/82	18/79	27/84	37/82	47/82	56/80	64/81					25/89	36/84		57/81	65/85	75/83		

and may be complementary to the N65E tectonic joint. Data in the 51-70^{o} range from all sets suggest the possibility that three joint sets, N54E, N61E, and N66E, may be present and masked by the artificial arrangement of the data.

Observation at all of the roadcuts indicates that the joints are better developed and more open higher in the cut, closer to the original surface. This is particularly true in the higher roadcuts such as at Stops 1, 4, and 10. At Stop 1 it appears that there is a northwestward rotation of joint orientation upwards in progressively thicker sandstone beds. Spacing of the northeast joints in shales and siltstones is generally less than an inch to a few inches; in the sandstones, unknown but probably a few feet. Spacing of northwest joints in the shales and siltstones is irregular but generally several inches to a few feet; in the sandstones, one to several feet. Physical weathering along these variably spaced joints generates small pieces of shale and siltstone and small to large slabs and blocks of sandstone in the roadcut debris piles.

Additional data (collected by M. Moore) from massive, ledge-forming sandstones and conglomerates at Stops 3 and 5 (Table 4), shows a wide diversity of joint orientations, but suggests that 2 orientations, N20W and N60W, may be persistent. The N60W orientation is probably related to tectonics. These joints are widely spaced, in terms of a few to 10's of feet. Physical weathering of these rocks, particularly at Stop 3 where there are few bedding-plane partings, gives rise to some very large blocks.

Table 4. Joint data from Stop 3 (1) and Stop 5 (2). First number is strike; second number, north dip except bold numbers which are south dips.

	NORTHEAST									NORTHWEST								
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90
1	2/90	14/90				52/90	68/90		85/90	4/90	19/90	24/90	32/90	44/90	58/90	68/90	72/90	84/90
	9/90	14/90				55/90	62/90		82/90	4/90	20/90	26/90	39/90		60/90			
		11/90							85/90		20/90	22/90			59/90			
												30/90						
2			25/90	32/90		56/90		80/90			19/90			49/90	60/90	61/90		
						56/90		74/90		4/90	18/90				60/90			
								71/90							54/90			
		13/90				55/90			84/90	4/90	20/90				60/90			

Mechanical weathering presumably proceeds at a much slower rate where the bedrock is protected by surficial material and not as much broken material is produced because of the decreasing importance of joints with depth. The outcrops of thick, massive sandstone and conglomerate, Stops 3, 5, and 8, appear to be very resistant to mechanical weathering under present climate and their breakdown is going on at a very slow rate involving grain-by-grain disintegration rather than large-scale separation along joint planes.

GEOMORPHIC HISTORY

Alleghanian orogeny to the Pleistocene.

The Permian Alleghanian orogeny produced a large mountain area, the Alleghanian Mountains, in eastern Pennsylvania. Westward draining streams eroded these mountains during their formation, throughout the remainder of the Permian, and all of the Triassic. All of the sediment eroded was deposited on a vast alluvial plain which extended from the mountain front to somewhere in the west and northwest. Some of the sediment may have been transported as far as the Sverdrup Basin in the Arctic or the Rocky Mountains, but data from vitrinite reflection and apatite fission tracks indicate that much of the sediment eroded from these mountains was deposited in Pennsylvania and subsequently eroded at a later time (Sevon, 1989). Possibly as much as 2000 to 3000 feet of sediment may once have existed above the Pennsylvanian rocks of Warren County.

Sometime during the latest Triassic or early in the Jurassic, eastward flowing drainage developed in eastern Pennsylvania and headward erosion gradually beheaded the westward drainage of the eroded Alleghanian Mountains and thus eliminated them as an eastern source of sediment. Although there is no record of what happened, we must assume that western Pennsylvania then changed from an area of deposition to an area of erosion. Because that erosion was developing on a relatively flat alluvial plain which had low gradient streams, we will assume that erosion proceeded at a very slow rate for a long period of time, possibly throughout the remainder of the Mesozoic. Presumably, material eroded from western Pennsylvania was transported to depositional sites farther west or northwest. The eastward-flowing drainage worked its way farther and farther west by continued headward erosion and stream piracy. Such drainage-change processes operate today as the West Branch Susquehanna River continues to enlarge its drainage network westward.

During the early part of the Cenozoic, the eastward-draining part of Pennsylvania underwent an long period of chemical weathering accompanied by minimal physical weathering (Poag and Sevon, 1989). The climate throughout the period was warmer and wetter than at present. There is no reason to suspect that western Pennsylvania was subject to different conditions. The result of this extended period of weathering was the development of a thick zone of weathered material which mantled a surface of unkown relief and configuration.

Something happened about 16 million years ago which caused the start of vigorous physical erosion in eastern Pennsylvania. The reason may be (1) climate change, for which there is little evidence, (2) tectonic uplift, which is difficult to account for on a passive margin, or (3) both 1 and 2. Whatever happened, the offshore record indicates that one of the largest pulses of sediment input in the record occurred during the Middle Miocene and continued with declining quantity through the rest of the

Miocene and the Pliocene (Poag and Sevon, 1989). We must assume that western Pennsylvania was subject to a similar period of erosion and that, as is the case in eastern Pennsylvania, the basic elements of the present topography were formed during this interval of time.

At the start of the Pleistocene, drainage in Warren County as well as the rest of northwestern Pennsylvania and adjacent New York was to the northwest (Figures 23 and 24). Development of present drainage will be considered both here and later.

Drainage and Drainage Change

The story of drainage and drainage change in Warren County and the rest of northwestern Pennsylvania is complex and far from being complete. Traditionally the story has involved two main aspects: the integration of several segments into the present Allegheny River and the reversal of flow direction for many streams. There is not total agreement about what happened or when, but the basics of the story are similar.

Carll (1880) did the original work in the area and noted that the rock floors of many streams dipped in directions opposite from the present direction of stream flow which occurs on fill material. He constructed his interpretation of the preglacial drainage (Figure 24) based on subsurface data obtained from many oil wells. He hypothesized that the Allegheny River breached cols at Kinzua and Thompsons Island when the north flowing streams were dammed by glacial ice. He also recognized a reversal of Tionesta Creek through the col near Barnes and the reversal of all of those streams heading in glaciated areas.

Carll's pioneering work was followed by that of Chamberlin and Leverett (1894), Leverett (1902), Butts (1910), Williams (1917), Leverett (1934), and Philbrick (1976). All of these works were confined to the where and when of reorientation of stream-flow direction and were similar in overall interpretation.

Problems of dating and correlation of glacial deposits as well as uncertainty about ice borders of the older glaciations make it difficult to determine the more recent detail of drainage change in northwestern Pennsylvania. Perhaps much more important is the larger, long-term aspect of drainage change which has been previously overlooked: Warren County is part of the battle ground of drainage reorientation from formerly northwest to present southwest which was occurring before glaciation.

Note some of the details of the preglacial drainage shown in Figure 23: in particular, the lower Allegheny River at Pittsburgh and the old middle Allegheny River at Franklin. These preglacial streams make pronounced changes in direction from northwest to northeast. Harper (1989) suggests that the segments of the Monongahela and Allegheny south and northeast of Pittsburgh flow above the axis of the Rome trough and that the trough has been offset by movement along a lineament which controls the course of the Ohio River after the two rivers are joined in offset position. No similar explanation exists for Franklin. Instead, this latter directional change may be related to regional dip.

The initial drainage in northwestern Pennsylvania was to the

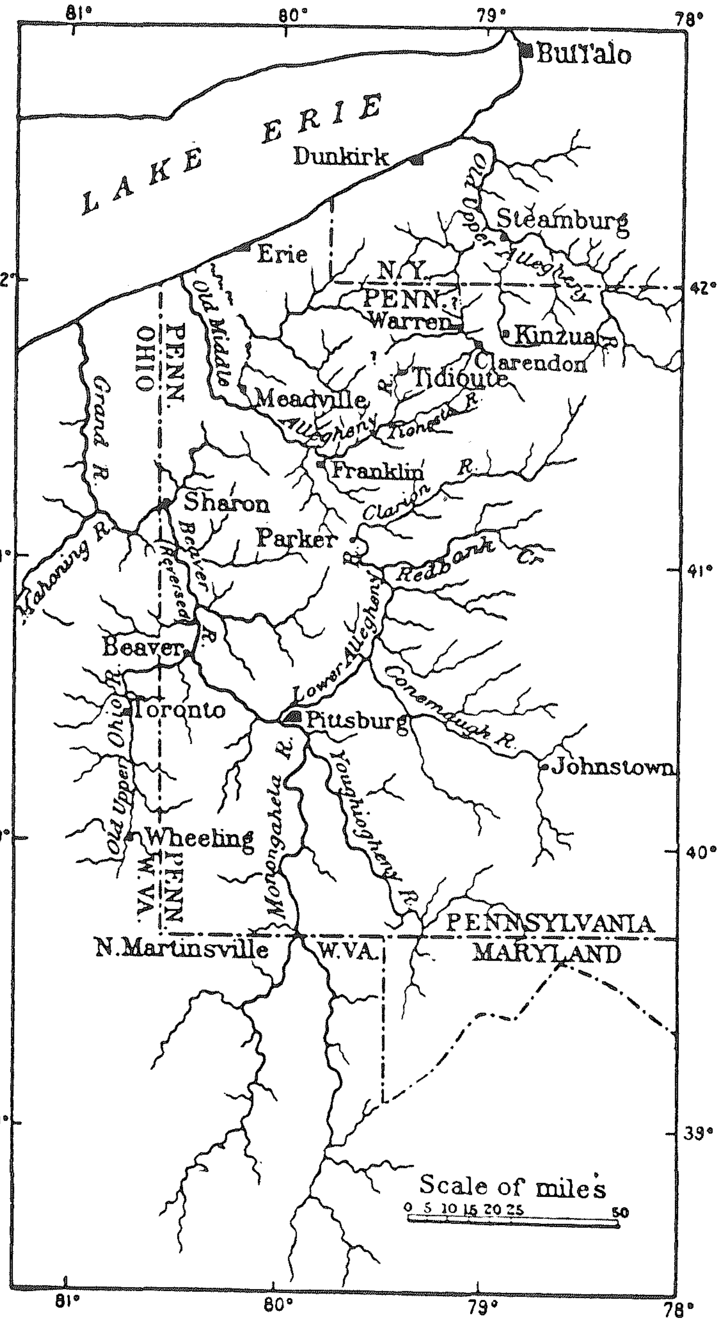
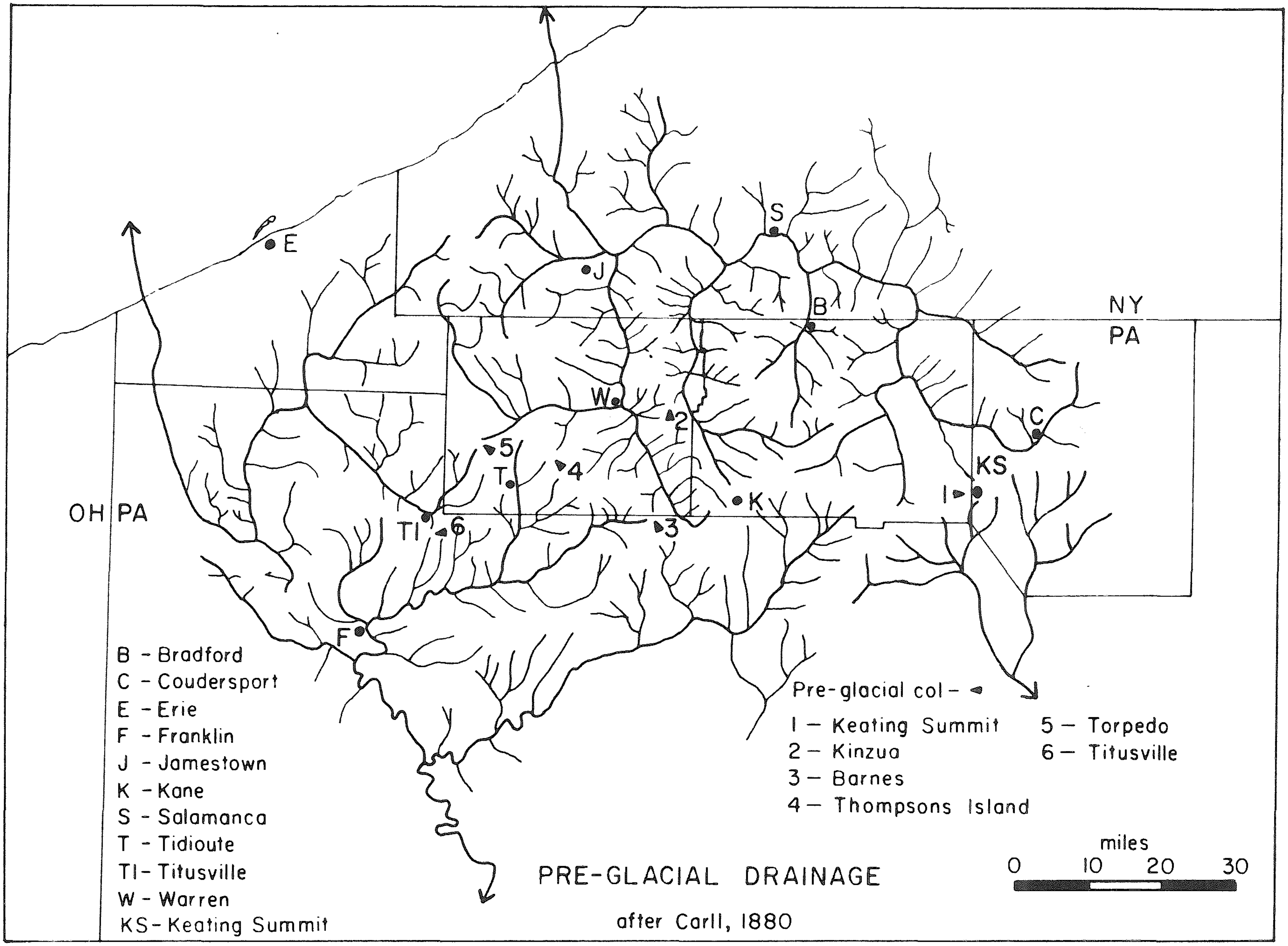


Figure 23. Pre-glacial drainage in northwestern Pennsylvania and adjacent New York and Ohio (from Leverett, 1902).

northwest, developed on the Permian alluvial plain which sloped in that direction. As the streams eroded deeper they encountered older and older strata. The stream channel positions probably changed little as long as the material being eroded was essentially the same hardness. However, eventually more resistant beds were encountered which had a different regional dip than the overlying Permian beds. The known regional dips of the Pennsylvanian and Mississippian strata in northwestern Pennsylvania is to the southwest. Lattman (1954) points out that in rocks with low regional dips and in cases with a resistant



PRE-GLACIAL DRAINAGE

after Carll, 1880

rock above weaker rocks, tributaries will erode faster up the dip and create a tributary-length assymetry. I suggest that this is what happened in the Franklin area and probably much of the rest of northwestern Pennsylvania. Thus, the long term regional process of changing the drainage direction from northwest to southwest was merely aided by glaciation, not initiated by it.

Illustration of this process is found in Forest County and the southern extremes of Warren County where all of the streams are part of a southwest draining network which appears to be eroding its way up the regional dip (Figure 25). The Allegheny River is part of this network and is the most advanced segment, probably because of glacial assistance. Many stream segments throughout the county seem to have good agreement with regional and local structure.

Nor is that the end of the story. Given enough time, quite a few millions of years, the drainage may eventually shift to the southeast. Subsurface structure contour maps indicate that with increasing depth there is a shift in regional dip to nearly south (Harper and Abel, 1980a,b) and from the Onondaga down through the Queenston shale (Cate, 1962; Harper and Piotrowski, 1979; Piotrowski, 1981) regional dip is around 50 feet/mile to S40E. Thus, when these lower units are encountered further shifts in drainage can be expected, particularly if the Susquehanna River has reached into the area by then.

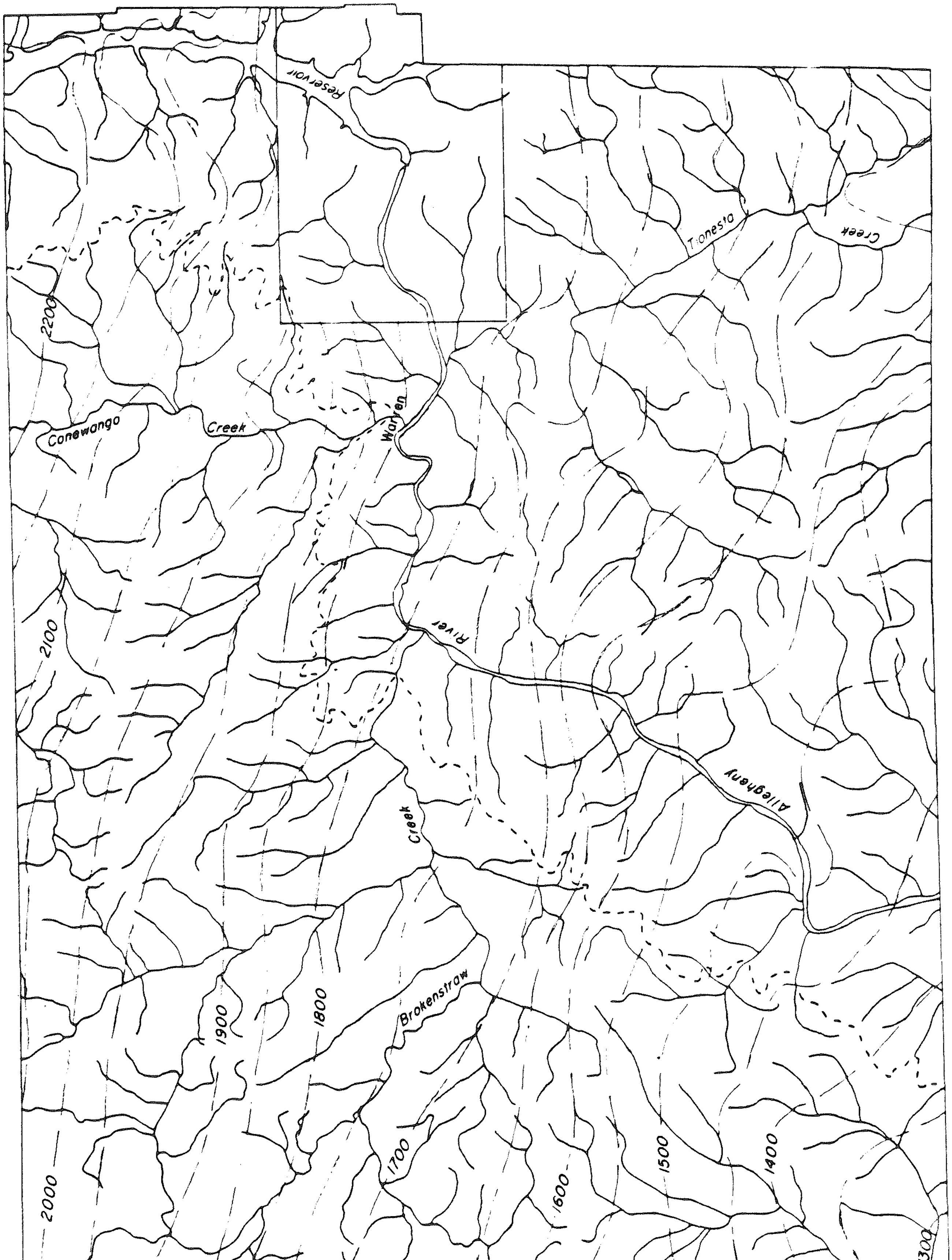
Beyond the regional picture we can note some local details. The drainage network of Warren County (Figure 25) gives a subtle impression that many streams have preferred alignments. To test this possibility, the Warren County 1:50,000 scale topographic map was surveyed for straight stream segments longer than 0.5 mile in length and the bearings of 65 such segments were measured. The measurements yielded two mean orientations: N50E (n = 26; SD = 11) and N47W (n = 39; SD = 16). These orientations do not agree precisely with those of the measured joints (see **Joints and Weathering**), but the spread of the standard deviation (SD) and the general inaccuracy inherent in the measurement process is enough to suggest that the position of at least some of the drainage is controlled by the joint system. In addition, the N47W orientation approximates that of cross-strike structural discontinuities which occur in the subsurface of the area (Harper, 1992; personal communication).

Pleistocene

The Glaciations

Northwestern Pennsylvania has been subject to 4 known major glaciations (White and others, 1969). The extent and age of the oldest glaciation, the Slippery Rock, is unknown and no deposits of this glaciation are known in Warren County. However, reports of isolated erratics beyond the defined limits of pre-Wisconsinan glaciation (Leverett, 1934, p. 96; White and others, 1969, p. 15)

Figure 24. Pre-glacial drainage in northwestern Pennsylvania and adjacent New York and Ohio (from Carll, 1880).


Reservoir
Tionesta
Creek
Conewango
Creek
Warren
River
Allegheny
Creek
Brokenstraw
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300

may be remnants of the former extent of this glaciation. The general lack of deep excavations in Warren County limits knowledge of the extent of Slippery Rock material buried beneath younger deposits.

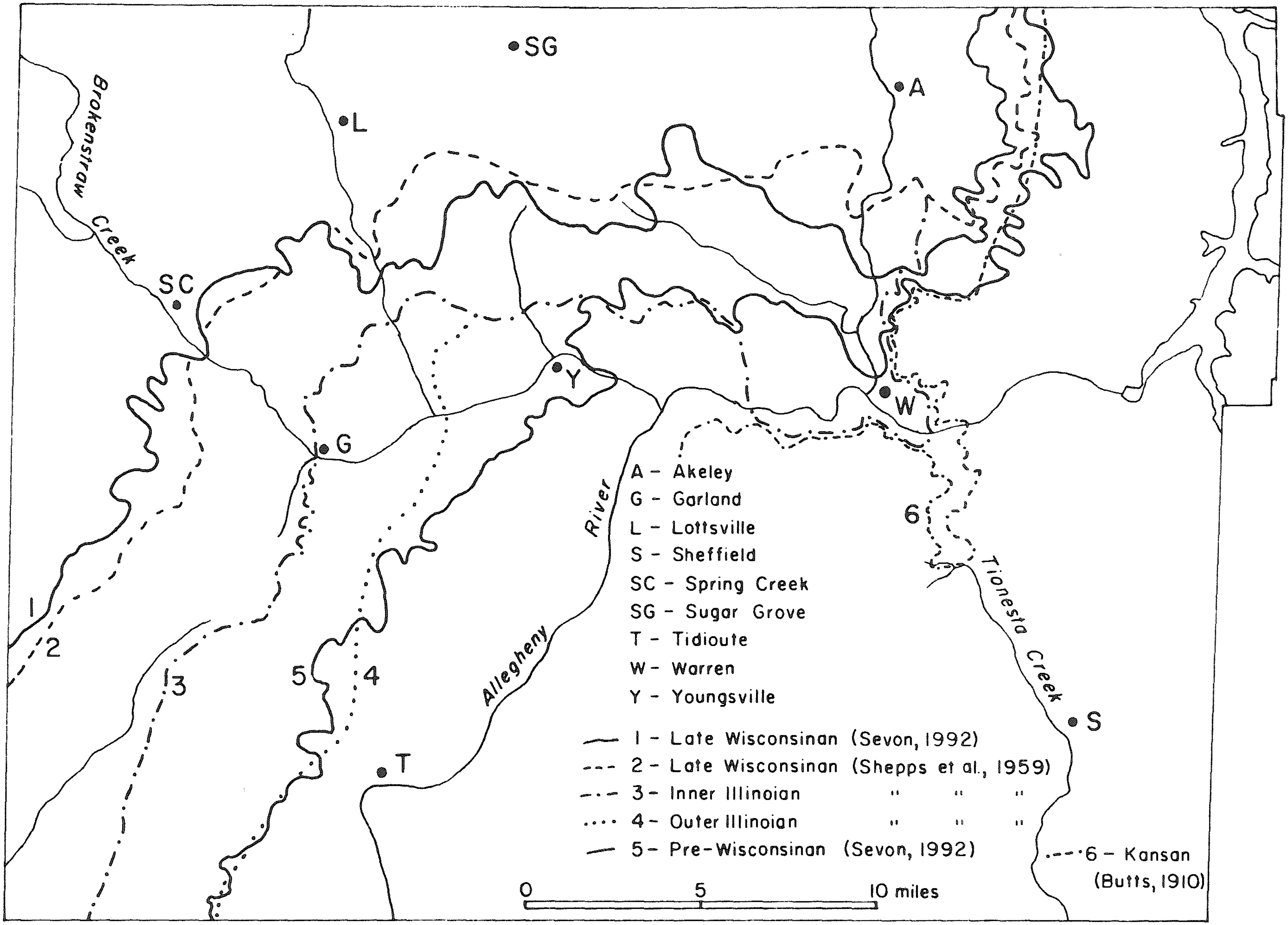
The next youngest glaciation, the Mapledale, was previously interpreted to be Illinoian (?) in age (White and others, 1969), but here is considered to be pre-Illinoian because of the lack of evidence for an early Wisconsinan glaciation (Braun, 1988; Ridge and others, 1990). A few deposits with sufficient weathering to be of Mapledale age occur in southwestern Warren County, but for the most part deposits of this glaciation have been either incorporated into the colluvium created by two subsequent glaciations or covered by colluvium. The boundary for this glaciation, the Outer Illinoian of Shepps and others (1959), is shown on Figure 26. It is at this point that some of the problems of glacial geology in Warren County begin to appear.

Note that the border of the Outer Illinoian (Figure 26, #4) or the Inner Illinoian, where it cuts out the Outer Illinoian, does not correspond to the pre-Wisconsinan border as drawn by me (Figure 26, #5). The pre-Wisconsinan border drawn by me is based on the Warren County soil maps (Cerutti, 1985) and seems to be a reasonable interpretation considering the amount of colluviation which has occurred. No work has been done to resolve this discrepency.

The next youngest glaciation is the Titusville, formerly considered to be Early Wisconsinan in age, but which must be now assigned an Illinoian age because of the absence of an early Wisconsin glaciation in Pennsylvania (Braun, 1988; Ridge and others, 1990). Till and sand and gravel deposits of this glaciation do occur although much of the material was colluviated during the Late Wisconsinan and in many cases mixed with freshly eroded bedrock. The boundary for this glaciation, the Inner Illinoian of Shepps and others (1959), is shown on Figure 26. No attempt has been made to retrace and redefine this border, but evidence suggests that such an effort is necessary to properly understand the glacial history of Warren County.

The Inner Illinoian border (Figure 26) protrudes southward to the south side of the Allegheny River valley in the area of Warren. This places it beyond the pre-Wisconsinan border as defined by soils information. More importantly, there are sand and gravel deposits 6 miles southeast of Warren on the valley bottom at Clarendon and Weldbank that are almost certainly ice-contact stratified drift deposits of Illinoian age. These deposits were given considerable importance by Williams (1917)

Figure 25. Drainage network of Warren County. Network was taken from the Warren County 1:100,000 scale topographic map tracing only the blue-line drainage. Irregular short-dashed line is the pre-Wisconsinan glacial boundary from Figure 26. Long-dashed lines are structure contours of the top of the Corry supplemented by data from the top of the Venango and the "pink rock". Data generalized from unpublished Pennsylvania Geological Survey maps. Revision ongoing in the northeastern quarter of the county.


SG
A
L
Brokenstraw
Creek
SC
Y
W
G
River
Allegheny
Tionesta Creek
S
T
1
2
3
4
5
6
A - Akeley
G - Garland
L - Lottsville
S - Sheffield
SC - Spring Creek
SG - Sugar Grove
T - Tidioute
W - Warren
Y - Youngsville
1 - Late Wisconsinan (Sevon, 1992)
2 - Late Wisconsinan (Shepps et al., 1959)
3 - Inner Illinoian " " "
4 - Outer Illinoian " " "
5 - Pre-Wisconsinan (Sevon, 1992)
6 - Kansan (Butts, 1910)
0
5
10 miles

who considered them as evidence for the Conewango drainage change. Williams had the advantage of seeing many exposures no longer available, but his sequential reconstruction is difficult to follow because he attributes everything to different phases of the same glaciation. Wright (1914) also discusses the deposits at Clarendon and indicates that they are 308 feet thick. Butts (1910) drew a border for the ice which extended to Clarendon (Figure 26, #6), but his border is not mechanically realistic and no work has been done to determine a better border.

The youngest glaciation in Warren County, the Kent, is Late Wisconsinan in age and its deposits make a well-defined band across the northwestern part of the county. The discrepency in border definition between Shepps and others (1959) and me (Figure 26) probably derives from my use of 1:24,000-scale topographic maps and aerial photographs not available to Shepps and others. The landscape contains abundant deposits of till, ice-contact stratified sand and gravel, outwash sand and gravel, and some lake deposits. Constructional topography both at the position of maximum ice advance and at recessional positions (Stop 9) is well developed. The general distribution of the deposits is shown in Figure 27.

Most of the materials incorporated within the Late Wisconsinan deposits, and presumably the same is true for the older deposits, is locally derived and comprises clay, silt, sand, gravel, plate-shaped clasts of siltstone and sandstone. Boulders occur, but are not abundant. A variety of igneous and metamorphic rock types comprise a few percent of the gravel and cobble fraction as does some limestone and some originally calcareous, fossiliferous claystones. White and others (1969, Table 2, p. 44) give the following data for till samples collected in northwestern Pennsylvania:

Table 2. *Mean texture and composition of tills*
(Number of samples used to determine mean shown in parentheses)

UNIT	*% Sand*	*% Silt*	*% Clay*	*% Quartz*	*% Feldspar*	*% K Feldspar*	*% Heavy Minerals*	*% Calcite*	*% Dolomite*	*% Total Carbonate*
Lavery Till	32.7 (15)	47.0 (15)	20.3 (15)	68.9 (11)	31.1 (11)	31.9 (11)	3.7 (11)			
Kent Till	43.0 (43)	38.5 (43)	18.5 (43)	86.9 (22)	13.1 (22)	44.7 (22)	2.2 (18)	1.4 (3)	1.8 (3)	3.2 (3)
Titusville Till	45.4 (155)	36.9 (155)	17.7 (155)	87.9 (100)	12.1 (100)	52.9 (100)	2.9 (96)	1.1 (9)	1.3 (9)	2.4 (9)
Mapledale Till	44.0 (24)	36.0 (24)	20.0 (24)	94.6 (24)	5.4 (24)	53.1 (24)	2.1 (21)	0.7 (9)	0.6 (9)	1.3 (9)

They indicate that there is wide variation in both the texture and composition, that the carbonate is leached to a depth of 60 to 80 inches, and that the till is oxidized to a depth of 10 feet. They also indicate (p. 32-33) that the Kent Till is

Figure 26. Various interpretations of the positions of glacial ice borders in Warren County.

generally less than 10 feet thick and is underlain by Titusville Till. Thus the depth of leaching and oxidization extends through the Kent Till into variably weathered Titusville.

Additional data on composition of glacial materials is provided by Craft (1979, Table 8, p. 22) as follows:

Table 8. *Lithologic Composition of Gravel Deposits, Warren County Area*
(Numbers represent weight percents)

	LAND BASE					RIVER				
	1674-1 Brokenstraw Sand and Gravel, unscreened	1674 Brokenstraw Sand and Gravel, sieved, crushed and washed	1574-A Emlenton Limestone, Pittsfield, crush pile includes weathered material	Emlenton Limestone, Pittsfield, lower 10' of working face	Tionesta Sand and Gravel, Garland Plant, crush pile	Warren River Dredge, crush pile	Warren River Dredge, crush pile	Warren River Dredge, crush pile, 1 year old	Warren River Dredge, barge	General Concrete, Warren, crush pile
Gray siltstone	51.3	60.0	15.7	70.8	53.8	50.2	46.3	7.1	49.9	36.2
Gray calcareous siltstone	13.4	16.8	3.3	4.3	11.7	28.3	18.6	2.3	5.4	7.9
Brown siltstone	17.3	9.4	77.5	- -	22.6	4.3	8.9	81.6	17.1	6.8
Brown calcareous siltstone	5.3	1.1	- -	10.3	--	2.3	5.3	- -	5.6	- -
Crystalline rock	0.6	4.4	2.0	4.2	2.0	9.6	9.3	6.2	14.9	9.0
Chert	0.4	0.8	1.5	2.3	2.0	3.8	7.3	1.6	5.0	2.3
Limestone	11.7	4.2	- -	- -	3.9	- -	- -	- -	3.1	8.5
Sandstone	0.4	2.9	- -	8.1	3.8	1.5	2.7	7.0	- -	29.4

These data indicate that there is a large contribution of foreign material to the glacial materials in Warren County. The crystalline rocks obviously came from the Canadian Shield. The calcareous siltstones may be derived from the Northeast and Girard Formations (Gresley, 1894; Gilman and Metzger, 1967) which are exposed along the south margin of Lake Erie. The limestones are presumably from somewhere in New York.

The Side Effects of Glaciation

GLACIAL LAKES. One of the side effects of the glaciation was the damming of pre-glacial drainages by glacial ice. This damming caused development of ice-marginal lakes which filled the valleys to a height of an outlet at the lowest available col. In Warren County this applies to the drainage area of the Allegheny River now dammed by Kinzua Dam and all of the former Conewango drainage

Figure 27. Map of the surficial deposits of Warren County (from unpublished mapping by W. D. Sevon).

Alluvium

Colluvium

Colluvium and pre-Wisconsinan glacial

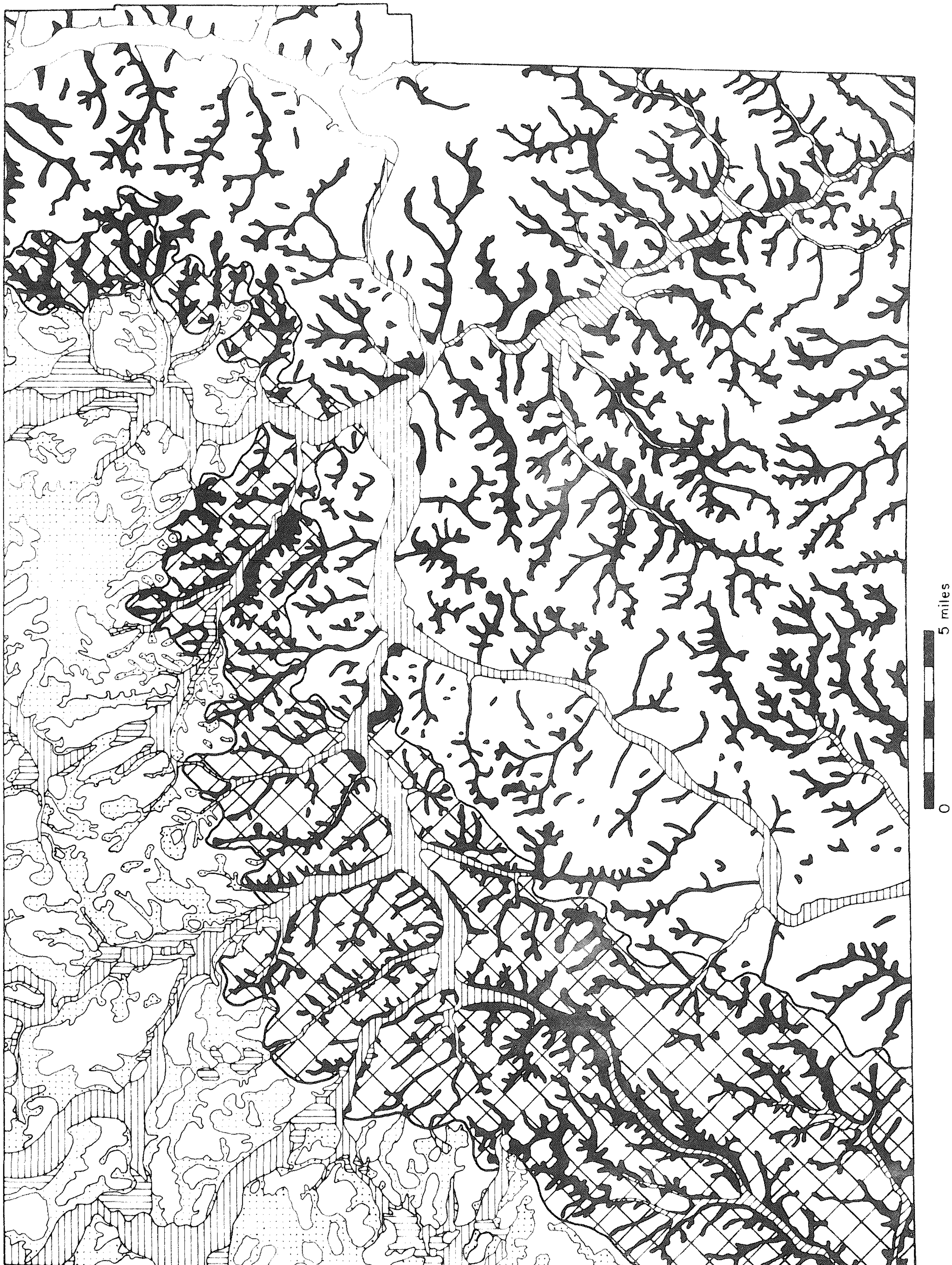
Alluvium, colluvium, and lake sediments

Outwash sand and gravel

Ice-contact sand and gravel

Glacial till

Bedrock and thin colluvium


0
5 miles

between Warren and the former col at Barnes. Blue silts and clays were deposited in these lakes (Carll, 1880) and are 10's of feet thick in places. Wright (1914) indicates 100 feet of clay at Clarendon overlain by 208 feet of sand and gravel. Following the draining of the lakes because of removal of the ice dam or lowering of the outlet, the lacustrine deposits were covered with outwash and/or alluvium.

PERIGLACIATION. Because of its proximity to the borders of the several glacial ice sheets and its relatively high elevation, the unglaciated part of Warren County was subjected to severe periglacial activity during the Pleistocene. As cold climate conditions intensified with the onset of each ice age, the freezing front deepened and presumably wreaked havoc on the bedrock because of the existing joint and bedding planes. Budel (1982) and Washburn (1980) have described very well the disintegration of bedrock as the result of the advance of the freezing front. This activity created an abundance of particulate rock material, especially that derived from the sub-Knapp rock units.

We assume that continuous or nearly continuous permafrost existed in Warren County during several thousand years of ice advance and melting. During the summer months, those parts of the landscape which had an aspect favorable for maximum sunlight would have thawed to some depth. Once thawed the more or less water-saturated, unconsolidated, surface material would have moved downslope by gelifluction (slow flowage of water saturated waste downslope over frozen ground) on a surface with almost any gradient other than perfectly flat. Gradient, water content, and texture of material are factors controlling the rate and amount of movement, but water content is probably the most important. Frost creep (the ratchetlike downslope movement of particles as a result of frost heave followed by thaw) also plays a part in the process, but the extent of its importance is unknown. As a result of the extensive amount of gelifluction (and frost creep) in Warren County, most of the landscape beyond the Late Wisconsinan border is mantled with gelifluction deposits of some thickness.

The thicker (>6 feet) gelifluction deposits, called colluvium, are shown on Figure 27. The thickest deposits are on the lower part of sideslopes and in the bottoms of valleys not dominated by alluvial processes. Most of the rest of the landscape has colluvium cover less than 6 feet thick except in places where bedrock is at the surface. Almost all of this colluvium comprises relatively small materials and only occasionally are boulder-size clasts present.

Because periglaciation in the area occurred during 4 glacial episodes, there should be some evidence of different colluvial events. To date no such evidence is known for Warren County. However, Snyder and Bryant (1992) describe repeated colluvial episodes near Steamsburg, NY, about 22 miles northeast of Warren. They ascribe the colluviation to periglacial origin and address the difficulties of dating multiple colluvial events. In addition, Waltman and others (1990) have studied buried pre-Wisconsinan paleosols developed in colluvium and residuum elsewhere in the unglaciated Allegheny Plateau. These multiple colluvial deposits indicate that prior to the first colluvial event, at least in the nonglaciated part of the county, slopes were steeper and valleys deeper than at present.

Despite the widespread occurrence of colluvial deposits in Warren County, the deposits are generally poorly exposed and rather uninspiring to the viewer when exposed. The large blocks of sandstone and conglomerate which locally litter hillslopes (Stop 3) and gully bottoms (Stop 5) are much more dramatic in visual impact, but are related to the same basic processes. The large ledges of massive and resistant rock of the Knapp and Olean Formations differ from the finer-grained underlying units in that they do not possess closely spaced joint sets or bedding planes. Consequently, when freeze-thaw activity worked on these units, the result was the production of large blocks rather than small particles.

Once separated from the source outcrop, a block was dependent upon the underlying material for movement downslope. As the debris under the block moved by gelifluction, the block responded in any of several ways: (1) remained upright and moved away from the source outcrop maintaining its original orientation, (2) toppled forward to assume a new, probably more stable, position and proceeded farther downslope, and (3) rotated backwards in the manner of a slump block and again assumed a new position from which to proceed downslope. In all cases any motion downslope depended on movement of underlying material because there is no mechanism for movement of the blocks by themselves, other than free fall. The rate of movement was probably slow unless a block encountered a very steep slope in which case its momentum, once in motion, would tend to carry it a considerable distance downslope. The presence of large blocks hundreds of feet downslope from their source outcrop in Warren County could be the result of either a few long movements or many short movements during several periglacial episodes. In some cases the source ledge occurs at the head of a gully and downslope movement of the blocks results in their concentration in the gully. Both ploughing blocks and braking blocks (Washburn, 1980, p. 223-224) occur and are discussed at the descriptions for Stops 3 and 5 which provide excellent examples of the movement of large blocks by the process of gelufluction.

DRAINAGE CHANGES. The following items are deemed very relevant to the probable recent drainage history in Warren County.

1. The pre-glacial topography was inherited from erosion which probably commenced in the Middle Miocene. The drainage network was presumably much older, but changing.

2. The rock floors of the northwest-draining valleys were cut to elevations considerably below present fill levels prior to the earliest glaciation.

3. Colluvium of probable pre-Illinoian age occurs on slopes of these early cut valleys and is now covered with younger colluvium.

4. Outwash deposits at Tidioute, Grunderville, and Oakland

Cemetary (South Warren) are interpreted to be Illinoian in age and appear to rest on the rock floor of the valley.

As a consequence of the above, I would suggest the following history.

1. The integration of the Allegheny River below Warren was accomplished prior to the onset of glaciation as suggested by Chamberlin and Leverett (1894) or during the Slippery Rock glaciation. If the integration occurred during Slippery Rock time, then I suggest that the segment of river from Irvine to Tidioute may have been ice marginal which enhanced its entrenchment. Drainage probably was reversed in those streams which were glaciated. Integration of the Allegheny River at Kinzua may or may not have occurred during Slippery Rock glaciation, but advance of the Slippery Rock ice to or across the Kinzua col would have enhanced erosion of the col.

2. Following the melting of the Slippery Rock glacier, the area was subjected to a long period of weathering and erosion.

3. The pre-Illinoian Mapledale glaciation occurred and the associated periglaciation destroyed most of the evidence of the Slippery Rock glaciation beyond the Mapledale border. Reversals of drainage in the glaciated area were completed. If the Allegheny River had not been previously integrated across the Kinzua col, it was during this glaciation. The rock floor of the Allegheny River was cut to near its present level.

4. Mapledale glaciation was followed by a long period of weathering during which a deep soil was developed on both Mapledale glacial deposits and colluvium generated during the glaciation.

5. The Titusville glaciation extended across the Allegheny River at Warren and into the valley of Dutchman Run all the way to Clarendon and Weldbank. This caused the reversal of the South Branch Tionesta Creek into its present course and creation of glacial lakes in which lake sediments were deposited. A substantial amount of outwash was deposited in the Allegheny River valley which was subsequently eroded, possibly aided by catastrophic failure of the ice dam at Warren.

6. No major drainage changes are known from Late Wisconsinan time, but local readjustments in the glaciated area are common.

Holocene

The Holocene has been relatively quiet in Warren County. Probably the main thing which has happened is the development of soil, which is discussed elsewhere, and revegetation following the end of Kent glaciation.

The landscape immediately following the melting of Late Wisconsinan ice comprised tundra vegetation in the non-glaciated area and barren ground in the glaciated area although development of vegetation on debris-mantled dead ice is possible. As the climate warmed, a gradual succession of forest vegetation occurred in Warren County. The details of this succession are not known for this area and even the generalities are complex. There has been no study of a site in Warren County which has a record of the vegetational history. The interested reader is referred to the following review articles for northeastern United States: Bernabo and Webb (1977), Wright (1981), and Watts (1983).

The result of the vegetational succession at the time of European settlement was a white pine-hemlock-hardwoods forest. There is virtually no evidence of this forest in existence today except at the National Forest's Hearts Content Scenic Area and even this stand is changing. The forests of Warren County have undergone a complex history of forest fires and logging since the mid 1600's. The forest succession today is so affected by excessive deer browsing that the future of the Allegheny National Forest is not to be a climax forest of hemlock, beech, and maple, but rather nearly pure beech (Auchmoody and others, 1983).

ENVIRONMENTAL IMPACT

General

The geomorphological history of Warren County, particularly the Pleistocene interval, has considerable impact on the surface of the area. Most of the county is covered by a thin to thick cover of unconsolidated surface materials attributable directly or indirectly to glaciation. The rock floors of some valleys are deeply buried and do not slope in the same direction as the surface. The topography is somewhat rugged and moderately steep to steep slopes are common. The soils are all young and frequently have fragipans. Each of these items has some environmental impact.

The many valleys filled with glacial outwash are potential sources of water, but at the same time can be easily contaminated because of their permeable nature.

Landslides

Helen L. Delano
Pennsylvania Geological Survey
Harrisburg, PA 17105-2357

Landslides and other slope movements are well documented as both engineering geologic hazards and geomorphic agents in the Appalachian Plateaus. Most of the literature citations (and most of the problems) for Pennsylvania involve the southwestern part of the state, especially the urbanized area around Pittsburgh. The High Plateau Section, including Warren, has a much lower incidence of recent landsliding, but there is enough activity to warrant attention.

Warren County is at the northern end of the project area for a USGS reconnaissance study of mass movement in the Appalachian Plateaus. The resultant open-file 7.5-minute quadrangle maps show landslides and related features (Pomeroy 1981). Pomeroy built on this data for later, more detailed work on landslides near Warren and the Allegheny Reservoir (1983, 1986) (Figure 28). He describes two major types of slope movement: large prehistoric (Pleistocene?) debris flows, and recent slumps and earthflows related to human modification of slopes.

The ancient debris flows occur most commonly in non-glaciated areas close to the glacial border. The debris deposits include boulders and rocks up to 10 feet long in a silty to clayey sand matrix. Typical dimensions for the debris flows are 2,000 to 4,000 feet long, 600 to 1500 feet wide and less than 30 feet thick (although some may be locally up to 100 feet thick). The flows occupy old drainageways on 20 to 50 percent slopes. These features are not presently active, although small slides may occur within the deposits if disturbed by construction or other activity. Pomeroy attributes the formation of the flows to periglacial climate near the glacial border and associated frost and moisture conditions.

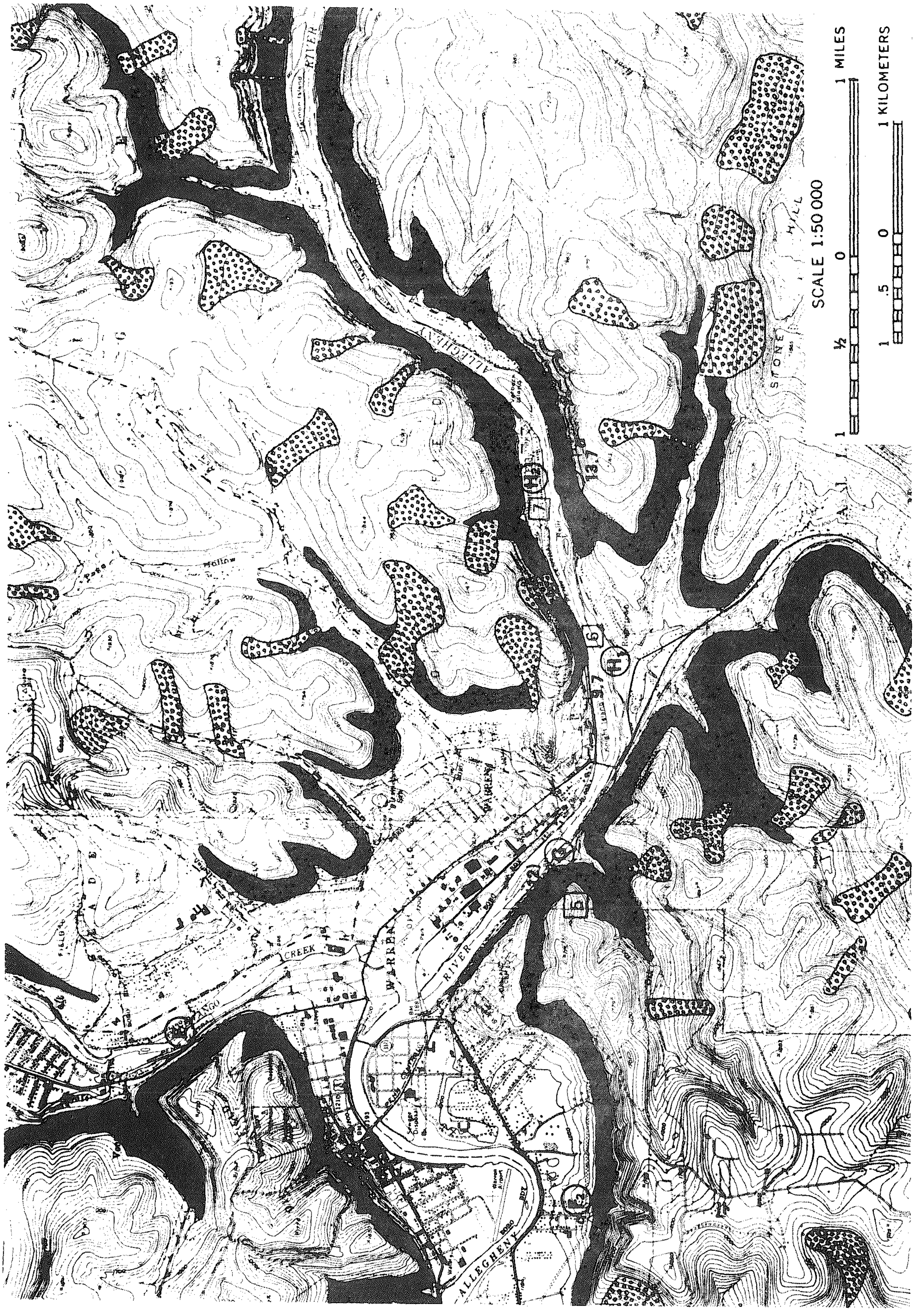
Both Pomeroy (1986) and Philbrick (1976) describe recent slumps and debris slides associated with construction activity on the lower one-fourth to one-third of the slopes in the Warren area. These involve accumulations of colluvium which are known to be up to 35 feet thick. Sliding along layers of blue-gray clay was reported in many of the slides. Pomeroy (1986) found potassium-deficient illite as the dominant clay in all 12 of the samples of slope movement materials he had analyzed. Potassium-deficient illite has been associated with slope stability problems in other parts of the Appalachian Plateau (Fisher and others, 1968; Pomeroy, 1982) as well.

Philbrick (1976) describes both old and recent slides associated with construction of Kinzua Dam and attendant highway relocations. A large old landslide was removed at the south abutment of the present dam. Slumps and slides which developed during road and railroad relocation near the north end of the reservoir were attributed to glacial lake clays below outwash and colluvial sediments. Philbrick suggests that many of these are reactivations of older slides. A recent debris-avalanche slide can be seen at Stop 5.

Although some of the recent landslides occur along the banks of the Allegheny reservoir, Pomeroy does not believe that water-level fluctuations in the reservoir are a significant factor in triggering landslides or reactivating old ones.

Thus, the landslide situation in the Warren area is: there are numerous old landslides, presumably developed under Late Pleistocene periglacial conditions. These are fairly stable under present conditions until they are disturbed by construction activities such as cutting, filling, road building and drainage changes. Highway and railroad relocations associated with dam construction and later improvements have provided numerous examples. Newman and Gower (1987) describe construction of the highway bypass south of Warren over slopes with both recent and

Figure 28. Part of map showing areas of slope movements in the Warren area (from Pomeroy, 1986, Plate 1). Solid black shading and "a" with pointer - active or recently active slope movement; Small circle pattern - old slope movement; Gray shading - slopes with moderate to severe susceptibility to movement; Circled letters, boxed letters, and numbers relate to items in Pomeroy's text.


SCALE 1:50 000
1 MILES
1 KILOMETERS
STONE HILL
ALLEGHENY
RIVER
CREEK

prehistoric landslides. They found as much as 60 feet of unconsolidated sediments along the lower slopes of the Allegheny River valley, in investigations for retaining walls along the Warren Bypass. The Field Conference will pass through this area on the first day as we travel from Warren to Kinzua Dam.

SOILS OF WARREN COUNTY

W. D. Sevon
Pennsylvania Geological Survey
Harrisburg, PA

INTRODUCTION

The information on soils of Warren County provided here is taken from the Warren and Forest Counties soil survey (Cerutti, 1985) and supplemented by information from Ciolkosz and others (1989), Cunningham and Ciolkosz (1984), Cronce and Ciolkosz (1983), and Carter and Ciolkosz (1980). The accompanying general soil map (Figure 29) shows broad areas that have a distinctive pattern of soils, relief, and drainage. Each map unit is a unique natural landscape consisting of several major soils and some minor (unmentioned here) soils. The map and accompanying descriptions are provided for general information only. Any need for specific information should be directed to the soils report itself which provides detailed information on the nature of the soils, their uses, and their limitations as well as detailed soil maps.

SOIL FORMATION

Soil is a natural, three-dimensional body of material at the earth's surface which has specific characteristics resulting from the integrated effect of the soil forming factors. There are 5 soil-forming factors which operate on unconsolidated surface material to produce soil:

Soil = Time + Parent Material + Climate + Vegetation + Topography

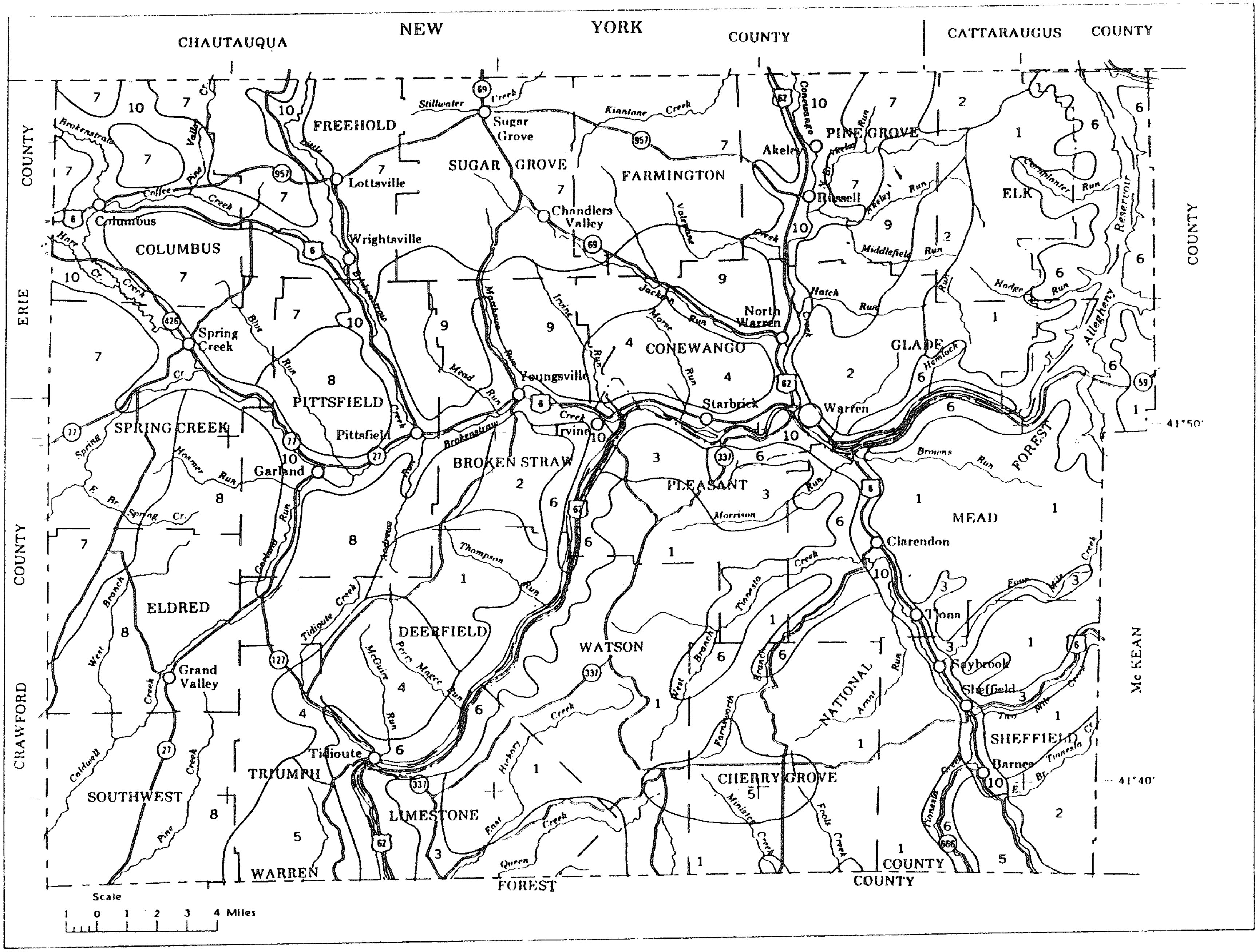
The relative importance of each of these factors varies from site to site, but all are important. Only a few generalities will be presented here about soil genesis in Warren County.

Time

Virtually all, if not all, of the soils in Warren County have formed in the past 20,000 years or less. This is because the soils are developed on parent materials affected by the Late Wisconsinan glaciation. The Late Wisconsinan glacier eroded bedrock to expose fresh rock, deposited new material, and influenced the climate so that periglaciation either destroyed older soils or mixed them with fresh material. A few protected sites may still preserve pre-Late Wisconsinan soils and colluvium and Late Wisconsinan sediments do cover some paleosols, but such are not in general evidence.

Parent Material

There are 3 general categories of material from which soils have developed in Warren County: recent glacial, colluviated


CHAUTAUQUA
NEW YORK COUNTY
CATTARAUGUS COUNTY
ERIE COUNTY
CRAWFORD COUNTY
McKEAN COUNTY
FOREST COUNTY
FOREST COUNTY
41°50'
41°40'
FREEHOLD
SUGAR GROVE
FARMINGTON
PINE GROVE
ELK
COLUMBUS
CONEWANGO
GLADE
PITTSFIELD
SPRING CREEK
BROKEN STRAW
PLEASANT
MEAD
ELDRED
DEERFIELD
WATSON
NATIONAL
SOUTHWEST
TRIUMPH
LIMESTONE
CHERRY GROVE
SHEFFIELD
WARREN
Sugar Grove
Lottsville
Wrightsville
Columbus
Chandlers Valley
Akeley
Russell
North Warren
Spring Creek
Youngsville
Starbrick
Warren
Irvine
Pittsfield
Garland
Clarendon
Tiona
Saybrook
Sheffield
Barnes
Grand Valley
Tidioute
Stillwater Creek
Kiantone Creek
Brokenstraw
Coffee Creek
Pine Valley Cr.
Hare Cr.
Blue Run
Conewango
Jackson Run
Morse Run
Irvine Run
Matthews Run
Mead Run
Hosmer Run
E. Br. Spring Cr.
Thompson Run
Andrews
Tidioute Creek
McGuire Run
Perry Magee Run
West Branch
Caldwell Creek
Pine Creek
Hickory Creek
East Creek
Queen
Minister Creek
Fools Creek
Farnsworth
Tionesta Creek
Arnot Run
Morrison
Browns Run
Hatch Run
Hemlock
Middlefield Run
Akeley Run
Cornplanter Run
Hodge Run
Allegheny Reservoir
Four Mile Creek
Two Mile Creek
E. Br. Tionesta Cr.
Scale
1 0 1 2 3 4 Miles

older glacial, and colluviated bedrock residual. Till, ice contact sand and gravel, and outwash were products of the Late Wisconsinan glaciation. Beyond the limits of Late Wisconsinan glaciation is a fringe area several miles wide which contains pre-Wisconsinan glacial deposits, mainly till, but with some sand and gravel. These materials were colluviated during the Late Wisconsinan and are generally mixed with local bedrock materials. The unglaciated part of the county was colluviated during each of the glaciations and colluvium of some thickness covers most of the landscape although undisturbed bedrock does occur.

Many of the soils in Warren County outside the Late Wisconsinan boundary have a notable contrast in texture between the upper 20-30 inches and below. The upper zone generally has more than 50 percent silt and less than 10 percent coarse fragments which is often considerably different than the underlying material. Cronce and Ciolkosz (1983, p. 16) have suggested that the upper zone contains a large addition of windblown material, loess, which has been partially mixed with the local parent material by frost action and tree throw. The large area of Late Wisconsinan outwash plain which could have served as a source for the loess adds credance to this idea.

The basic soil properties of color, texture, structure, and consistence are largely determined by the parent materials. These properties, in turn, affect other soil characteristics such as drainage conditions and the development of fragipans.

Climate

The present climate of Warren County was discussed earlier and the soils are generally related to it. The soils are all classified as having a mesic temperature regime, but Carter and Ciolkosz (1980) indicate that in Warren County, soils above 1875 feet elevation have a frigid temperature regime. The effect of climatic departures from the present norm during the past 15,000 years is unknown.

Vegetation

The climate of Warren County favors growth of hardwood trees and many of the soils have developed under forests. Considerable vegetable debris accumulates on the forest floor. This litter contributes organic acids to infiltering water, is decomposed by the action of micro-organisms, earthworms, etc., and adds organic matter to soil. Tree throw (uprooting of trees) mixes the soil and loosens the underlying material.

Topography

The topography affects both surface runoff and internal drainage. Surface runoff influences the degree of erosion which

Figure 29. General soil map of Warren County, Pennsylvania. The map is from Cerutti, 1985. Numbers are the key for the general soil map units which are discussed in the text.

affects soil depth. Soil on steep and very steep slopes is lost almost as fast as it is formed. Gentler slopes farther downslope receive this material and are increased in thickness. Internal drainage affects the weathering of soil material and bedrock. Topographic position in terms of slope and aspect affect soil microclimate.

SOILS OF WARREN COUNTY

Figure 29 is the general soil map of Warren County. This map shows broad areas that have a distinctive pattern of soils, relief, and drainage. Each unit on the soil map represents a unique natural landscape. It is named for the major soils present. The minor soils are not discussed here.

The soil series utilized in the general soil map comprise about 75 percent of the soils in Warren County and are classified in one of three soil orders: Ultisols, Inceptisols, and Alfisols.

Ultisols are moderately well to very well developed soils with light-colored surface horizons, a B horizon of illuvial clay accumulation (argillic horizon), and low subsoil base saturation status (<35 percent of the cation base exchange capacity). They can also have a fragipan B horizon. This order comprises about 35 percent of the soils of Warren County and includes the soil series Alvira, Cavode, Cookport, Ernest, Gilpin, Hanover, Shelmadine, and Wharton.

Inceptisols are weak to moderately well-developed soils with a color and/or structural B horizon (cambic) or a fragipan B horizon. They are relatively young eluvial soils which have lost constituents by leaching, but have no horizons in which significant amounts of these constituents have accumulated. This order comprises about 30 percent of the soils of Warren County and includes the soil series Braceville, Chenango, Hazleton, Lordstown, and Mardin.

Alfisols are moderately well developed soils with light-colored surface horizons, a B horizon of illuvial clay accumulation (argillic horizon), and relatively high subsoil base (Ca+Mg+Na+K) saturation status (>35 percent of the cation exchange capacity). They can also have a fragipan B horizon. This order includes the Venango soil series which comprises about 10 percent of the soils of Warren County.

One of the primary characteristics of many of the soils in Warren County is the presence of a fragipan. A fragipan is a loamy, brittle subsurface horizon low in permeability and content of organic matter; low to moderate in clay; and high in silt or very fine sand. A fragipan appears cemented and restricts root penetration. When dry, it is hard or very hard and has a higher bulk density than the horizon or horizons above. When moist, it tends to rupture suddenly under pressure rather than to deform slowly. The very slow permeability of fragipans causes perching of water, particularly in spring and early summer. This condition generally ends by late summer when roots have extracted most of the water during leaf-on conditions.

Soil Descriptions

A. Dominantly deep and moderately deep soils that formed in residual and colluvial materials.

1. Hazleton-Cookport-Cavode

Deep, well drained through somewhat poorly drained, mainly sloping and moderately steep soils that formed in materials weathered dominantly from acid sandstone and shale. The map unit consists of broad plateaus that are dissected by major drainageways.

2. Cavode-Ernest-Gilpin

Deep and moderately deep, somewhat poorly drained through well drained, mainly sloping and moderately steep soils that formed in materials weathered dominantly from acid shale and sandstone. The map unit consists of hilly areas that are strongly dissected by minor drainageways.

3. Ernest-Wharton-Gilpin

Deep and moderately deep, moderately well drained and well drained, mainly sloping to moderately steep soils that formed in materials weathered from acid shale, siltstone, and sandstone. The map unit consists of hilly areas that are dissected by minor drainageways.

4. Gilpin-Cavode-Ernest

Moderately deep and deep, well drained through somewhat poorly drained, mainly sloping to very steep soils that formed in materials weathered from acid shale and sandstone. The map unit consists of hilly areas that are strongly dissected by minor drainageways.

5. Cookport-Hazleton-Ernest

Deep, moderately well drained and well drained, mainly gently sloping and sloping soils that formed in materials weathered from acid sandstone and shale. The map unit consists of broad plateaus dissected by small drainageways.

6. Hazleton-Gilpin-Ernest

Moderately deep and deep, well drained and moderately well drained, mainly sloping, steep, and very steep soils that formed in materials weathered from acid shale and sandstone. The map unit consists dominantly of valley sides along major rivers and creeks.

B. Dominantly deep soils that formed in glacial till.

7. Venango-Mardin-Lordstown

Deep and moderately deep, somewhat poorly drained through well drained, mainly gently sloping soils that formed in Wisconsinan glacial till. The map unit consists of broad upland plateaus, hilltops, and hillsides dissected by minor drainageways and separated by major drainageways.

8. Hanover-Alvira-Shelmadine

Deep, well drained through poorly drained, mainly gently sloping and sloping soils that formed in pre-Wisconsinan glacial till. The map unit consists of broad plateaus and undulating to rolling, low hills with a few major drainageways.

9. Alvira-Lordstown-Shelmadine

Deep and moderately deep, poorly drained, somewhat poorly drained, and well drained, mainly gently sloping to moderately steep soils that formed in pre-Wisconsinan glacial till. The map unit consists of high hills that have relatively narrow, convex tops and long, uniform sides with few drainageways.

C. Soils that formed in glacial outwash and alluvial materials.

10. Wayland-Chenango-Braceville

Deep, very poorly drained through well drained, mainly nearly level and gently sloping soils that formed in water-deposited materials derived from acid sandstone and shale as well as some igneous, metamorphic, and carbonate erratics. The map unit is in valleys on floodplains and terraces adjacent to major streams.

ENVIRONMENTAL IMPACT

In general, most of the soils of Warren County have limitations on their use, primarily because of their slope or the character of the soil. Tables presented in the soils report (Cerutti, 1985, p. 105-135) detail these limitations and only a partial review is presented here.

The fragipans tend to perch water, particularly in the spring of the year, which in turn creates real or marginal wetlands. These wetland areas are now the subject of much environmental concern and law. Marginal wetlands can cause large differences in interpretation.

The evaluation for building site development (Cerutti, 1985, Table 10, p. 119-122) for 6 building catgories indicates that 67 percent of the surface of the county has severe soil-based problems for construction. Likewise, 97 percent of the surface area of the county presents problems for 5 categories of sanitary facilities (Cerutti, 1985, Table 11, p. 123-127). Perhaps suprisingly, 67 percent of the surface area of the county has problems for 5 categories of recreational development (Cerutti, 1985, Table 8, p. 110-114). In contrast, 95 percent of the area of the county is very suitable for woodland management and productivity (Cerutti, 1985, Table 7, p. 105-109). Because 84 percent of Warren County is woodland, it would appear that the land is being used appropriately.

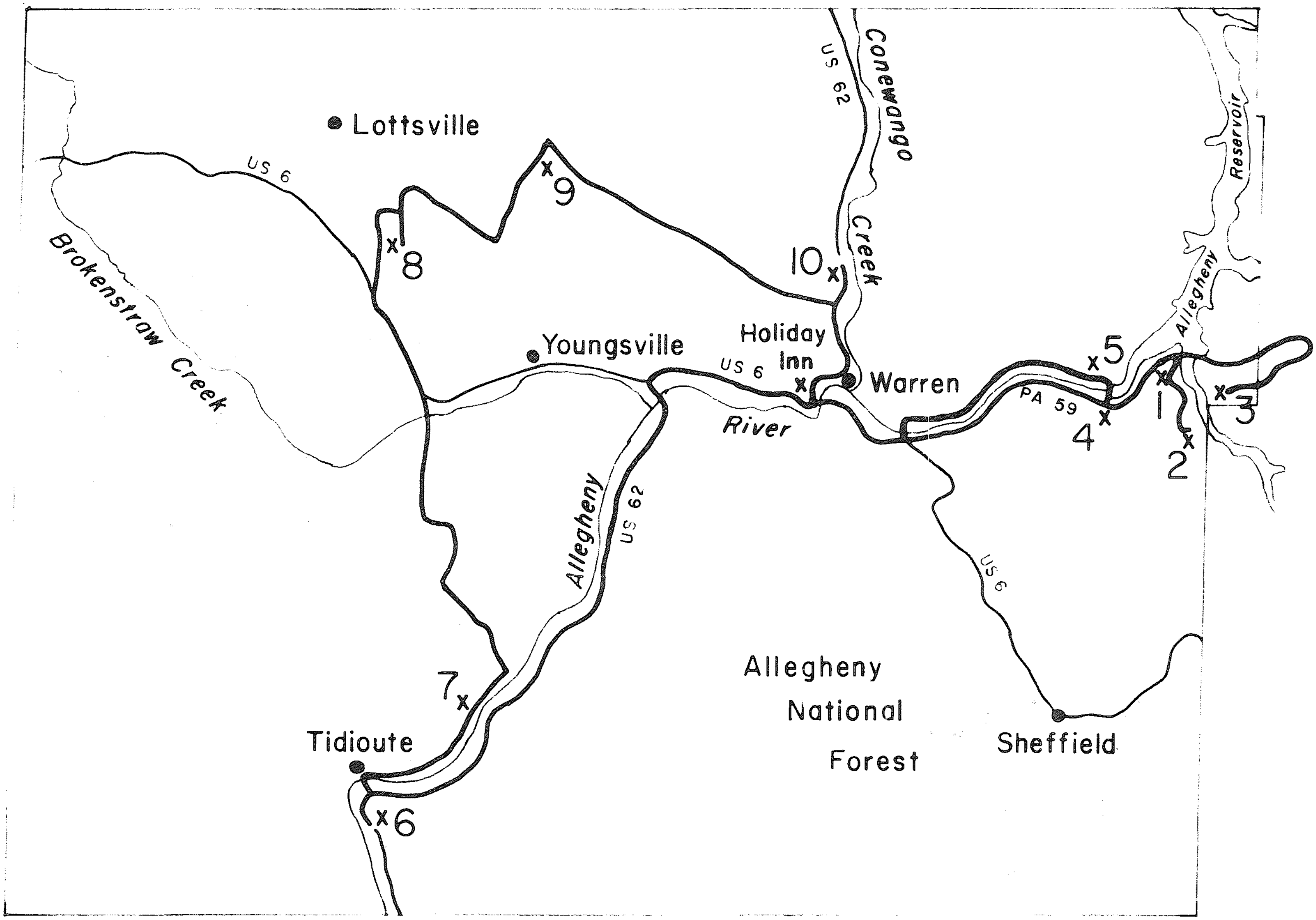
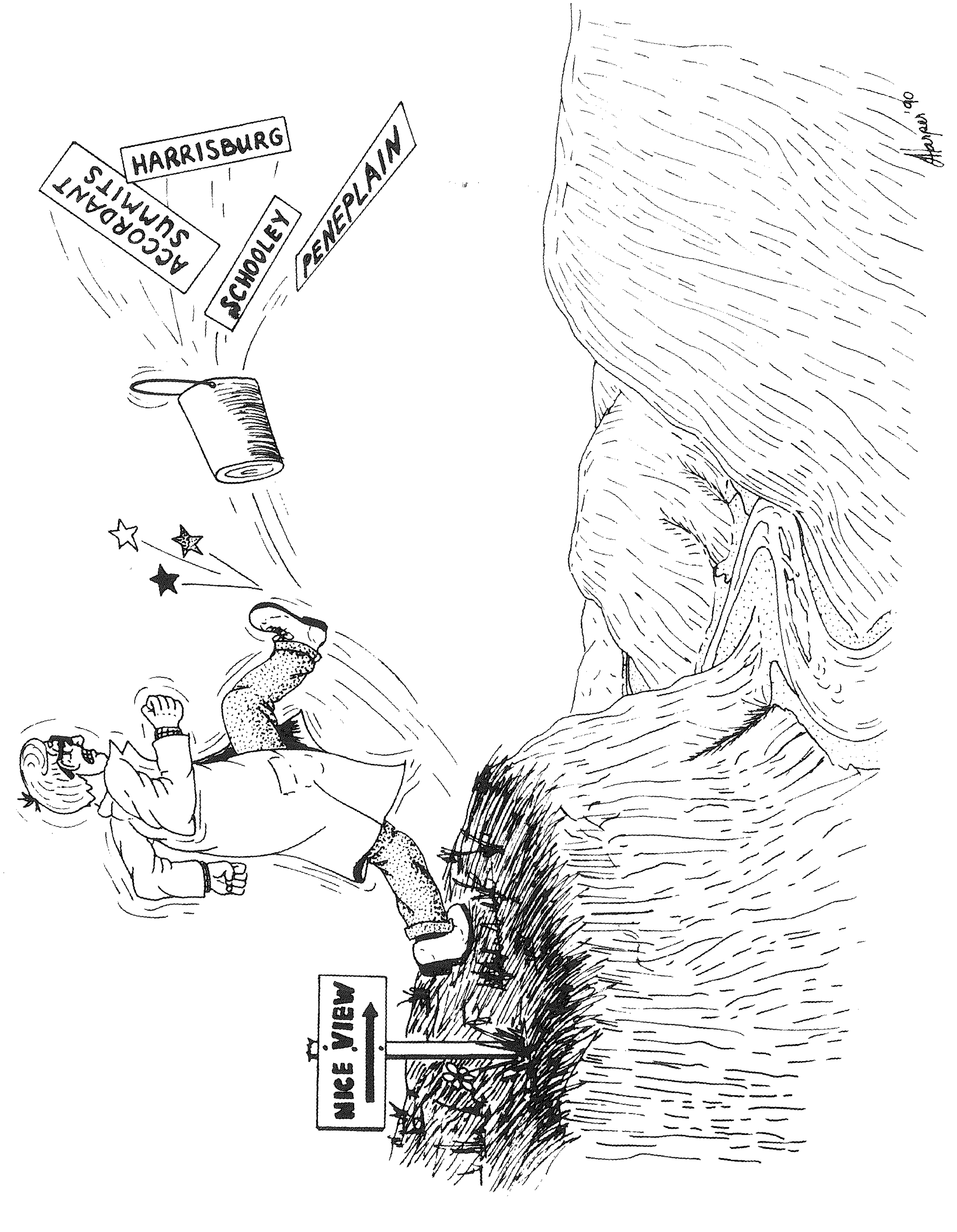


Figure 30. Route map for 1992 Field Conference in Warren County.


HARRISBURG
ACCORDANT SUMMITS
SCHOOLEY
PENEPLAIN
NICE VIEW
Harper '90

ROAD LOG AND STOP DESCRIPTIONS - DAY 1

Mileage Inc	Mileage Cum	
0.0	0.0	Leave parking lot of the Holiday Inn. **TURN RIGHT** onto Ludlow Street.
0.2	0.2	**TURN RIGHT** onto US Route 6 East entrance ramp.
0.2	0.4	Join US Route 6 East.
0.3	0.7	Cross Allegheny River.
0.8	1.5	**STOP LIGHT. CONTINUE STRAIGHT AHEAD.** Ahead on right is Oakland Cemetary which is built on glacial sand and gravel of probable Illinoian age.
0.7	2.2	Old oil well on left. It produced from the Glade sand, South Warren pool, at a depth of about 750 feet (Lytle, 1965).
0.1	2.3	Outcrop of Devonian Venango Formation on right. View of oil refinery on left. Oil used comes from Saudi Arabia via the west coast and Canada.
1.0	3.3	**STOP LIGHT. CONTINUE STRAIGHT AHEAD.** US Business Route 6 goes to left.
0.2	3.5	**STOP LIGHT. TURN LEFT** onto PA Route 59 East.
0.4	3.9	**BEAR LEFT** following PA Route 59 East.
3.6	7.5	Enter Allegheny National Forest.
2.0	9.5	Kinzua Dam visitors center on left. View across Allegheny River valley to Dixon Gully, site of Stop 5.
0.7	10.2	Kinzua Dam on left. Outcrop of Devonian Venango Formation on right.
0.4	10.6	Views of Allegheny Reservoir to left here and ahead.
1.9	12.5	**STOP 1. JAKES RUN SECTION, MIDDLE VENANGO FORMATION.** Discussant: Clifford H. Dodge

For your safety, **PLEASE** stay well off the roadway! **PA ROUTE 59 IS WELL TRAVELED.** Use caution along the roadcut. Rock debris frequently sloughs off the outcrop. Do not be fooled by the relative lack of large float blocks; this is a very popular spot for "scavengers."

INTRODUCTION

This stop is located along the south side of PA Route 59 just west of Jakes Run near the western edge of the Cornplanter Bridge 7.5-minute quadrangle (Figure 31). The Jakes Run section (Figures 32 and 33) represents one of the more complete, continuous exposures in eastern Warren County and includes the oldest rocks that we will examine in detail on the first day of the Field Conference. The interbedded sequence of flat-lying marine to marginal-marine shales and sandstones exposed here comprises most of the Upper Devonian (Conewangoan) middle Venango Formation, or Zone D2b of Kelley and Wagner (1972). The Jakes Run section is near the western edge of the intertonguing transition zone between the marine Venango Formation and eastern laterally equivalent, nonmarine Catskill Formation (see Dodge, 1992, this guidebook).

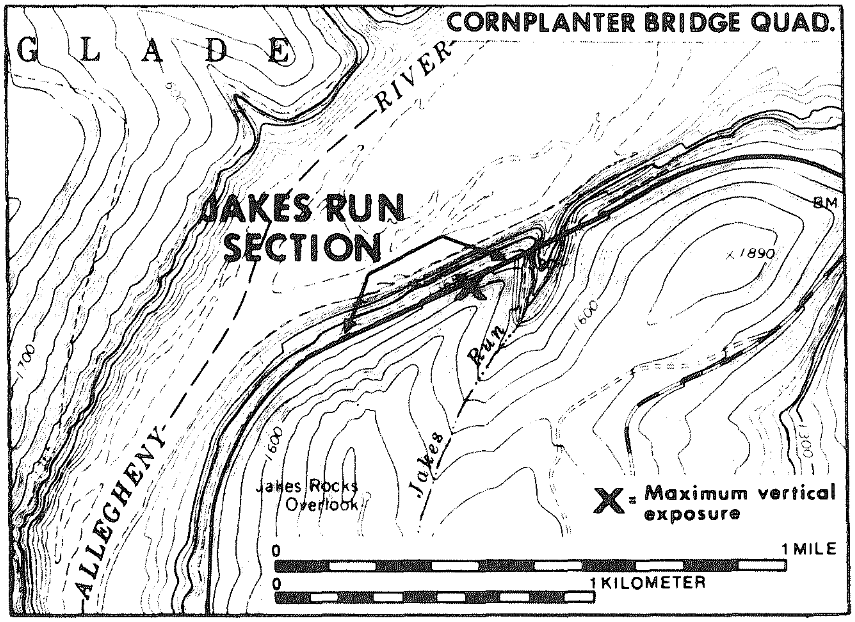


Figure 31. Map showing location of the Jakes Run section.

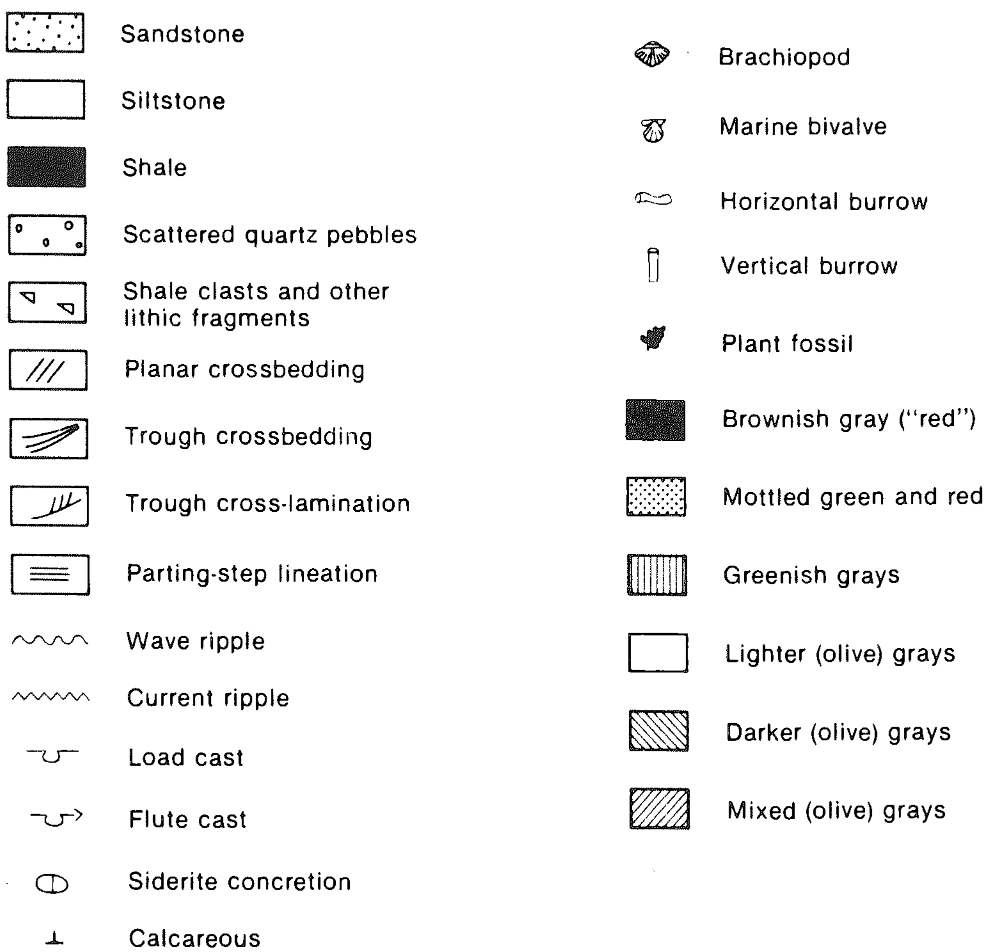


Figure 32. Explanation of symbols used in Figure 33.

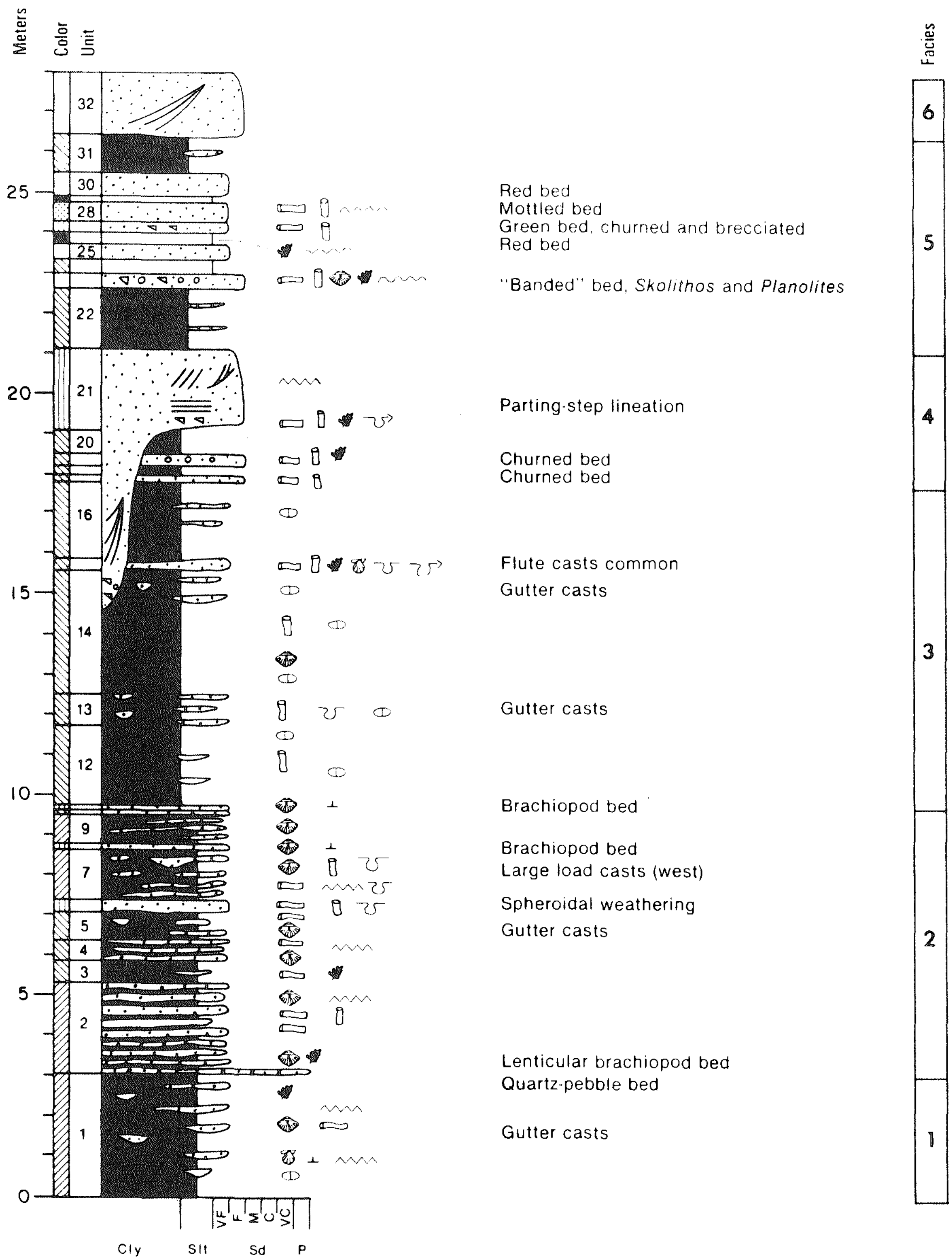


Figure 33. Columnar section of Upper Devonian rocks (middle Venango Formation) exposed at the Jakes Run section.

The roadcut is situated along the western flank of a small unnamed syncline. The fold axis, where it crosses PA Route 59, is about 275 m (900 feet) east of Jakes Run (stream) and plunges approximately S30°W at nearly 5.7 m/km (30 feet/mile). In the vicinity of the section, the average strike and dip of the beds are N60°E, 7.6 m/km (40 feet/mile) to the southeast (see Lytle and Goth, 1970, Plate 2). Along the face of the exposure, the apparent dip measures only 1.5 m (5 feet) to the westsouthwest over a distance of about 460 m (1,500 feet), or 3.3 m/km (17.6 feet/mile). Two principal joint sets were observed here, and their orientations average N60°W, 82°NE and N44°E, 88°NW. See pages 71-74 and Stop 7 for a discussion of jointing in Warren County.

The maximum vertical exposure (41°51'20"N/41°58'41"W, NAD 27) is about 28 m (90 feet). The upper 12 m (40 feet) is largely inaccessible, and its examination was based on float and the use of binoculars. The altitude at the base of the roadcut at the east end is 424 m (1,391 feet).

At the Jakes Run section, we have the opportunity to study a prograding terrigenous clastic sequence that represents storm-influenced-nearshore and lower-delta-plain environments of deposition. Conferees are encouraged to examine and discuss the evidence that does or does not support this interpretation. Consider the importance and implications of such factors as:

1. Composition and texture of sandstones;
2. Bed thickness, geometry, and lateral continuity;
3. Ratio of sandstone to shale as a function of position in the vertical sequence;
4. Relative dominance of traction- versus suspension-load sedimentation;
5. Primary sedimentary structures and their mutual associations;
6. Distribution, type, and abundance of fossils and biogenic structures.

The rocks of the section are subdivided into six facies on the basis of lithologic associations, bed thickness, and sedimentary structures.

DESCRIPTION

Facies 1

Facies 1 (unit 1) can be observed only towards the east and west ends of the roadcut where it is not covered with shale colluvium. The better exposures occur at the west end, however.

The facies consists of shale with sandstone gutter casts and other lenticular beds. The shale comprises fissile to subfissile, dark-olive-gray clay shale and silty clay shale, which locally contain a few siderite lenticular laminae. The sandstones are light olive gray, silt to very fine grained, impure, and lenticular. They range in size from laminae a few centimeters across to medium- to thick-bedded lenses several meters wide. Most of the sandstone lenses are elongate and protrude (long axes) from the face of the outcrop at an oblique angle.

Gutter casts (Plate 1A) are common and are characteristically much longer (perhaps a meter or more) than they are wide or high (a few centimeters to several decimeters). They have scoured, concave-upward bases, sharp but curving sides, and flat to undulatory and locally current-rippled tops. Narrow tool marks (casts) occur in places along the soles of the gutter sandstones. Crests of observed current ripples trend subparallel to somewhat oblique to the gutter axes. Gutter-cast axes throughout the unit are consistently aligned NW-SE between 65° and 85°.

Larger lenticular sandstones are similar to the gutter casts in cross section but have more irregular sides. Many of the lenticular beds appear structureless (though laboratory analysis may prove otherwise), but some are internally cross-laminated. Dip directions of the cross-laminations suggest that at least some of the infilling of the gutters was from the sides. A few of the smaller sandstone lenses are calcareous.

Shell fragments of bivalves and more common brachiopods are present locally at the bases of some lenticular beds. Horizontal ichnofossils in convex hyporelief occur in places on the soles of the sandstones. A few carbonized plant fragments were observed locally.

Facies 2

These rocks are mostly interbedded sandstones, lenticular sandstones, and shales in various proportions, and several discrete, laterally continuous, thin to medium sandstone beds. Noteworthy features include planar, wavy, lenticular, and minor ripple bedding; various cut-and-fill structures; brachiopod-shell (coquinites) and quartz-pebble lag deposits; marine trace fossils; and load casts. Facies 2 is also best seen at the east and west ends of the outcrop.

The most persistent bed observed in the area occurs at the base of facies 2 (unit 2) and has been traced for a distance of about 1.5 km (0.9 mile). It consists of clean, mostly very thin to thin-bedded, very fine to fine- and locally medium-grained, light-gray sandstone that contains scattered, milky-white quartz granules to small discoidal quartz pebbles in the bottom 1-3 cm (0.4-1.2 inches). A few larger discoidal pebbles occur locally. The bed is wavy, pinches and swells, and represents a basal lag. Upper and lower contacts are sharp. No other pebbly beds were observed in this facies.

About 5-10 cm (2-4 inches) above the pebbly sandstone is another thin, rather persistent sandstone that contains scattered lenses or discontinuous zones of randomly oriented brachiopod fragments, representing a shelly lag.

Two sheetlike coquinites (units 8 and 11) occur at or near the top of facies 2. Unit 8 is a very persistent, slightly wavy, medium-bedded, locally calcareous (owing to primary shell material), very fine grained, medium-dark-greenish-gray fossiliferous sandstone (Plate 1B). It contains common to abundant, randomly oriented, broken and unbroken brachiopod shells in the lower half of the bed. Unit 11 is similar but thinner, more fossiliferous, and perhaps less persistent. Unit 8 is traceable across the outcrop (and even to the east of Jakes Run bridge) and maintains an almost constant interval above the base of unit 2. Thus, facies 2 is essentially bounded by key beds.

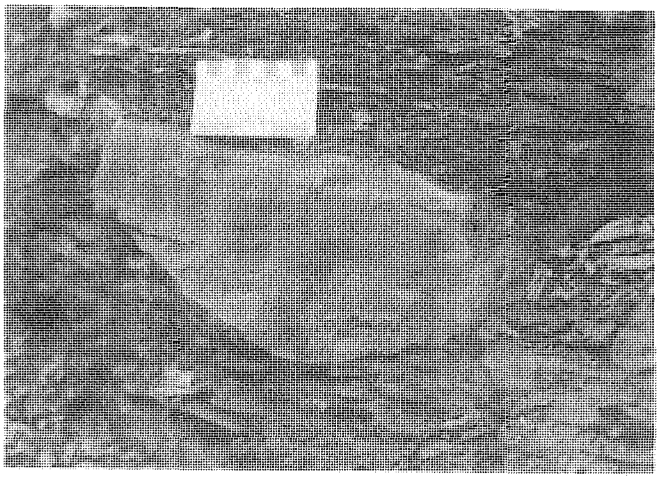
Very thin to medium sandstone and shale interbeds characterize units 2, 4, 7 and 9. Except for the pebbly bed at the base of unit 2, the sandstones are medium olive gray to light olive gray, silt to very fine grained, and impure. The beds have planar or slightly wavy to wavy tops and bottoms, and pinch and swell in places. Contacts are sharp. Some elongate scour features or gutter casts occur locally along the bases of sandstones. Current ripples are present in places along the upper surfaces but are generally not well developed. Sandstones appear mostly structureless but locally are planar- to cross-laminated. Many of the beds are discontinuous or lenticular. The more persistent sandstone interbeds are in the lower two units.

Brachiopod shells are few to common locally at the bases of some sandstones. The most common brachiopod identified is the robust *Cyrtospirifer*. Rare to few strophomenid brachiopods are present in unit 2. Vertical and horizontal burrows occur in convex hyporelief on the soles of some sandstone beds. *Planolites* is the ubiquitous horizontal trace fossil found here and represents the actively backfilled ephemeral burrow of a mobile deposit feeder, possibly a polychaete (Pemberton and Frey, 1982).

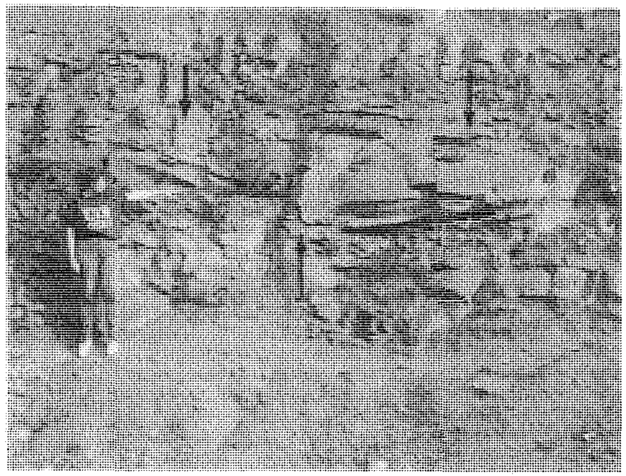
Sandstones tend to thicken up-section, particularly in units 6 and 7. Unit 6 is thick bedded, fairly persistent (continuing to the next roadcut to the east), mostly structureless, and characterized by spheroidal to bulbous weathering. Load casts are present.

Unit 7 is a more complex unit, having thicker, discontinuous beds generally in the upper half. Towards the east end of the

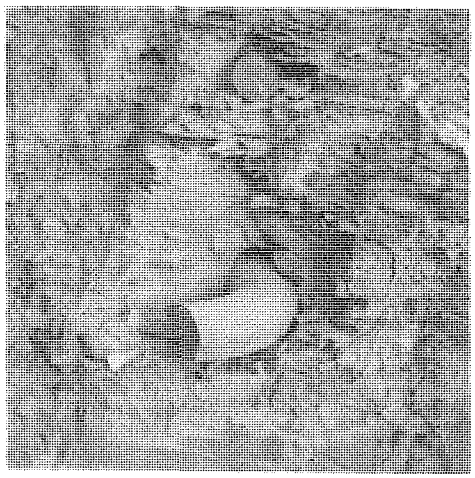
Plate 1. Sedimentary and biogenic features at Stop 1:
A. Ripple-topped gutter cast composed of very fine grained sandstone, within unit 1 at west end of roadcut. Scale divided into centimeters and inches; B. Lenticular sandstone channel fill within unit 7, towards east end of outcrop. "Up" arrow points to thalweg. "Down" arrows show position of overlying, persistent coquinite bed, unit 8; C. Curving, sideritized intrastratal trace of *Palaeophycus* within shale of unit 3; D. Simple-parabolic flute casts on sole of ledge-forming sandstone, unit 15. Height of sandstone bed is 0.3 m (1 foot); E. Looking south at the Jakes Run section, towards the west end of roadcut. Discordant channel sandstone (unit 21) near top of view thickens to the west. Vertical distance from road level to top of thick sandstone is about 15 m (50 feet); F. Vertical *Skolithos* burrows (S) and horizontal *Planolites* traces (P) in full relief in "banded," iron-stained sandstone, unit 23. Scale divided into centimeters and inches.



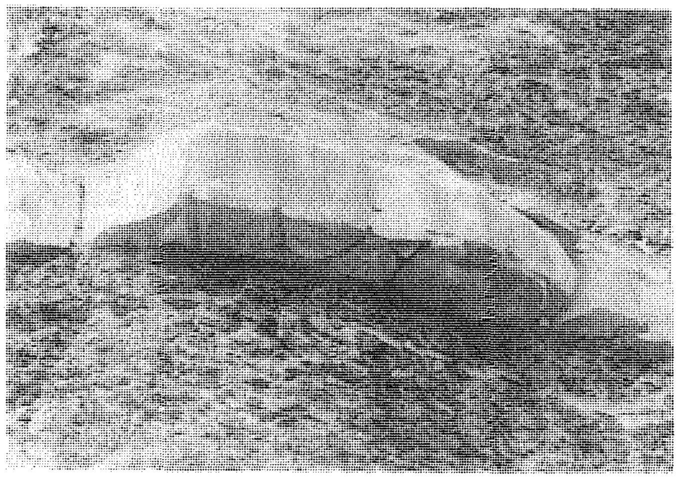
A



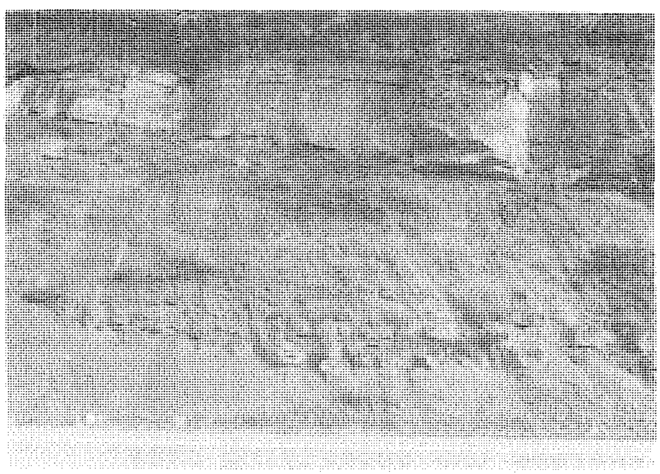
B



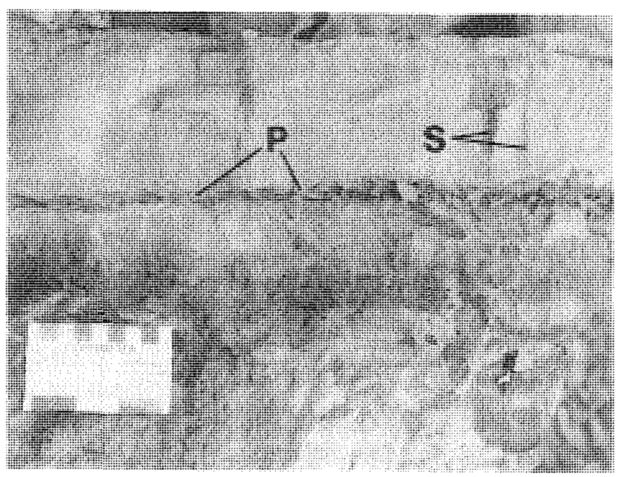
C



D



E



F

roadcut is an asymmetrical sandstone channel fill, which measures up to 0.5 m (1.6 feet) thick by about 10 m (33 feet) wide (Plate 1B). Overlying the sandstone but along the thalweg is a thin, lenticular, highly fossiliferous sandstone (coquinite) containing abundant, randomly oriented, disarticulated and articulated *Cyrtospirifer* shells, mostly as external molds. Cross-cutting relationships within the channel sandstone suggest at least two stages of infilling (though not necessarily multiple events), followed by late-stage emplacement of the shelly lag. The articulated brachiopod shells suggest that they may not have been transported far from their place of origin.

At the same stratigraphic position near the west end of the exposure is a fairly continuous, thick-bedded sandstone that contains numerous load casts, resulting in a sharp but irregular base with up to 20 cm (8 inches) of local relief. The load casts suggest relatively rapid deposition of sand on underconsolidated or waterlogged mud (reverse density gradient). Could this sandstone have been deposited during the same event as infilling of the asymmetrical channel?

The shale interbeds (units 2, 4, 7, and 9) are fissile to subfissile, chippy to platy, mostly dark-olive-gray silty clay shale to silt shale. A few horizontal burrows and rhynchonellid brachiopods are present locally.

The thicker shales (units 3 and 5) are compositionally the same as the previously described interbeds but also contain sandstone and siltstone lenses. Unit 5, especially, has gutter casts and thin lenticular beds. The sandstones have planar to slightly wavy tops and locally contain a few brachiopod shell fragments. A few horizontal burrows and scattered, carbonized plant debris also occur in places in the sandstones.

One curving, sideritized, full-relief trace of *Palaeophycus* was found in the shale in unit 3 (Plate 1C). The trace measures 2.5 cm (1.0 inch) in diameter and more than 10 cm (4 inches) long. *Palaeophycus* is interpreted as the passively infilled dwelling burrow of a predaceous or suspension-feeding organism, probably a polychaete (Pemberton and Frey, 1982).

Facies 3

Facies 3 (units 12-16) is dominantly shale, with some discontinuous or lenticular sandstones, gutter casts, and one persistent sandstone.

The shales (units 12, 14, and 16) are mostly subfissile, chippy to platy, olive-gray to medium-dark-gray clay shales that contain few to common flat siderite concretions and lenticular laminae. A few horizontal burrows and rhynchonellid brachipods were observed in places.

In the upper 1.2 m (3.9 feet) of unit 14, the clay shale is more resistant to weathering; contains more abundant and somewhat larger siderite concretions, generally in zones or bands; is white-sulfur stained in places (pyrite dissolution); and appears locally "siltier" (probably due to siderite). It also contrasts with the rest of the unit in that it is medium dark gray and weathers to about the same color, whereas the underlying clay shale is mostly olive gray with a brownish-gray tint and weathers to medium grayish brown.

The sandstones are medium gray, silt to very fine grained, and impure. Contacts are sharp, and bases are commonly scoured. *Planolites* is present locally in convex hyporelief. Scattered gutter casts or small lenticular beds occur in units 12 and 16. Larger, more common gutter casts and lenticular sandstones are present in the upper 1 m (3 feet) or so of unit 14. Unit 13 contains several mostly thin, discontinuous to lenticular sandstone interbeds. To the west, these give way to a zone of scattered gutter casts. Only a few gutter-cast axes were measured in facies 3, and they trend NW-SE between 56^{o} and 68^{o}.

Unit 15 is distinctive and consists of medium- to thick-bedded, locally micaceous, impure, very fine grained medium-gray sandstone. Though it thins laterally to the east and west, it is present across the face of the outcrop, except where it is truncated to the west by unit 21. The sandstone is ledge forming and distinguished by the presence of common to abundant large sole marks (Plate 1D). The sole marks consist of simple-parabolic flute casts and elongate, symmetrical to asymmetrical, straight to sinuous scour casts. Some of these features are hybrids. Loading effects appear to have distorted some of the sole marks. Individual flute and scour casts generally range up to 0.1-0.2 m (0.3-0.6 foot) across and typically are 3-5 cm (1-2 inches) deep. Fossils were observed locally at the base of the sandstone and include common to abundant small nuculid bivalves, few to common horizontal (*Planolites*) and vertical burrows, and some carbonized plant fragments.

The presence of flute casts suggests unidirectional, turbulent flow of suspended sediment-laden material (sand) that differentially eroded a cohesive substrate (mud). What conditions could account for the occurrence of this bed here?

The flutes are excellent indicators of paleocurrent directions and measure N5^{o}W-N25^{o}W. These paleocurrent readings deviate significantly from the gutter-cast bearings.

A float block was observed to the west of the main exposure, which is believed to come from unit 15. It contains more complicated flute morphologies that are classified as conjugate bulbous-parabolic and conjugate asymmetrical forms (see Allen, 1984, p. 254-256).

Facies 4

The rocks (units 17-21) comprise persistent medium to thick sandstone and shale interbeds and an overlying thick- to very thick bedded sandstone that is partly discordant at its base. The interbedded shales (units 18 and 20) are similar in appearance to those of facies 3, but are inaccessible for examination.

Units 17 and 19 seem to be the same texturally and compositionally, but only the latter was examined in detail (from float). Unit 19 consists of medium- to thick-bedded, hackly to rubbly and lumpy, intensely bioturbated (churned), very fine to fine-grained, medium-gray to medium-olive-gray argillaceous sandstone. It characteristically weathers to yellowish gray on the outcrop. Scattered grains of coarse quartz sand to quartz granules occur locally. Unit 19 is laterally continuous except where cut out by unit 21 and is also found in the next roadcut to the east of Jakes Run bridge.

A few to locally common carbonized plant stems and fragments were observed in unit 19, up to 1 cm (0.4 inch) wide by 8 cm (3 inches) long. Ichnofossils are also present and include a few to common vertical burrows and horizontal *Planolites* traces, and several observed *Palaeophycus* in convex hyporelief(?). *Palaeophycus* is locally crosscut by vertical burrows. Preferential bioturbation of beds is controlled by several factors including sedimentation rates, salinity, availability of nutrients, and sedimentary textures (Weimer and others, 1982).

Unit 21 is the most conspicuous interval in the section (Plate 1E). It maintains a fairly uniform thickness of about 1.5-2 m (5-6.5 feet) over the eastern two-thirds of the outcrop and cuts out several of the underlying units to the west, where it thickens downward another 4 m (13 feet) or so. The unit appears to thin again some distance farther to the west of the main roadcut and pinches out to the east of Jakes Run bridge. Unit 21 is composed of thick- to very thick bedded, slabby to blocky, very fine to fine-grained, greenish-gray micaceous sandstone. It appears to fine upward.

Towards the east end of the exposure, unit 21 displays parting-step lineation (planar laminations), suggesting traction currents and some deposition under upper flow-regime conditions (Harms, Southard, and Walker, 1982). The sandstone is also trough cross-laminated (rib-and-furrow structure in plan view) or planar crossbedded in places and locally has scattered shale chips near its base. Several isolated simple-parabolic flute casts and scour features were observed on the sole of the bed. A few to common vertical and horizontal fossil traces occur locally near the base of the sandstone.

Where thickest near the west end of the section, unit 21 is trough crossbedded. The base of the unit here is scoured and contains a siderite-pebble lag deposit up to 0.2 m (0.6 foot) thick. This is interpreted as a channel lag, the entire contents of which appears to have been transported. The shape and composition of the clasts suggest that most are siderite concretions, probably derived from facies 3 (units 14 and 16). Scattered quartz granules, small quartz pebbles, and medium-dark-gray shale chips also occur. Fragments of thin, cylindrical, sideritized fossil traces are present in the lag (generally less than 3 cm, or 1.2 inches, long). Several siderite-filled burrows were observed that are teardrop shaped and have a small depression in their tapered ends. These are morphologically similar to certain nonmarine traces (Hopkins, 1992, personal communication).

Carbonized plant stems and fragments are few to common and locally abundant in the thick sandstone of unit 21. Several large coalified plant compressions were observed about 1 m (3 feet) above the base of the unit near the channel lag.

Facies 5

Facies 5 (units 22-31) consists of thin- to thick-bedded sandstones, red and green siltstones, and shales. Float from several of the units (23, 26, 27 and 28) was examined.

Prominent in the outcrop and as float is unit 23, a slabby to blocky, clean, well-rounded, very fine to fine-grained light-gray sandstone. It is commonly iron stained in bands (Plate 1F). The sandstone contains scattered, well-rounded, coarse-grained quartz sand to elongate quartz granules and locally a few well-rounded, elongate to discoidal, small quartz pebbles. Some brownish-gray to grayish-red shale chips also occur in places, though generally associated with the coarser grained quartz sand and pebbles. Shallow wave ripples are present locally. Several brachiopod shells, including *Cyrtospirifer*, were observed. A few scattered carbonized plant stems and fragments are present, up to 1 cm (0.4 inch) wide by 12 cm (4.7 inches) long.

Trace fossils are common to abundant in unit 23, particularly suspension-feeding *Skolithos* and deposit-feeding *Planolites* (Plate 1F). A few *Monocraterion* and rare *Rhizocorallium* were also observed. *Planolites* is abundant in convex epirelief and convex hyporelief on upper and lower bounding surfaces, respectively, and in full relief on several internal bedding surfaces. Vertical *Skolithos* shafts are up to 1 cm (0.4 inch) in diameter and 9 cm (3.5 inches) long. To the west of the main roadcut, slabs of typical "pipe rock" occur, containing numerous larger *Skolithos*. These float blocks also have common to abundant, large carbonized plant compressions along the bounding bedding planes.

Skolithos is interpreted as the vertical dwelling burrow of a suspension-feeding polychaete or phoronid (Pemberton and Frey, 1984). *Monocraterion* is similar to *Skolithos* except for its "golf tee" appearance or downward-pointing nested cone structure at its upper end. This feature is believed to be an escape structure resulting from the upward migration of the *Skolithos* organism (Hallam and Swett, 1965). *Rhizocorallium* is a subhorizontal "U"-shaped burrow with protrusive spreiten that may be the dwelling burrow of a suspension-feeding animal (Fürish, 1974).

Unit 26 is the "major" red bed of the section. It is composed of fissile, brownish-gray micaceous silt shale to siltstone that contains horizontal and vertical burrows. Small to large plant compressions occur locally, with stems observed up to 1 cm (0.4 inch) wide and more than 17 cm (6.7 inches) long. Shallow wave ripples were observed in places.

Unit 27 is mostly intensely bioturbated, burrowed, very fine to fine-grained, medium-light-greenish-gray sandstone. Vertical and horizontal burrows are common to locally abundant. Elsewhere, this unit contains brecciated medium-dark-greenish-gray to greenish-gray silty claystone that is infilled with sandstone, forming a mosaic pattern.

Unit 28 consists of silt to very fine grained sandy siltstone to silty sandstone that is mostly greenish gray but partly mottled in places with brownish gray and grayish red. Vertical and horizontal burrows are few to common. Shallow wave ripples occur locally.

Facies 6

This facies (unit 32) caps the section but is visible only locally. The rock is composed of slabby to blocky, thick- to very thick bedded, trough-crossbedded sandstone. It cuts down slightly into the underlying unit. Although inaccessible, the sandstone appears similar to unit 21.

ENVIRONMENTS OF DEPOSITION

Overview

In a broad, regional context, the rocks exposed at the Jakes Run section were deposited as sediments in a basin-margin setting along a cratonic seaway during the time of maximum regression/progradation of the Late Devonian Catskill Delta (Woodrow, 1985; Dennison, 1985). It appears that the Catskill Delta complex in Pennsylvania was the result of coalescing, smoothly arcuate or lobate deltas; no distinctly elongate deltas have been documented (Dennison, 1985). The alluvial plain adjacent to the shoreline was widely developed and dissected mainly by relatively small, sinuous streams that were separated by broad, muddy interfluves (Woodrow, 1985). Evidence suggests that Catskill shorelines were subject to microtidal (astronomical) activity (Woodrow and Isley, 1983; Walker and Harms, 1975) and normally small wave heights (i.e., 2 m or less) (Woodrow and others, 1973). The inferred paleoclimate was wet-dry seasonal (Woodrow, 1985).

Considerable work needs to be done on the Venango-Catskill transition zone in order to determine the paleoshoreline configuration and associated facies patterns (paleobathymetry) through time and space. Nevertheless, lacking information to the contrary, it is believed that for Warren County and vicinity the Catskill Delta was arcuate shaped and bordered by a gently sloping delta platform (subaqueous delta plain). With this in mind, the Jakes Run section is interpreted as a progradational sequence of storm-influenced-nearshore and lower-delta-plain environments that were supplied with mostly fine-grained sediments from the Catskill Delta.

Lower Facies Association

For purposes of discussion and interpretation, facies 1, 2, and 3 are viewed as a lower facies association. The three facies are believed to represent shallow-subtidal deposits, resulting from both storm (sand) and fair-weather (mud) sedimentation. Sand was transported either as traction load or suspension load, whereas finer grained clastics moved in suspension.

Interpretation of the lower facies association relies heavily on the bypass-zone tempestite model of Myrow (1992), which was developed for storm-influenced, coastal to inner-shelf areas having muddy (fine-grained) shorelines subject to deltaic sedimentation. According to the model, sediments entrained along the shoreline are carried seaward by storm-generated relaxation (e.g., seaward-directed storm-surge ebb) currents that erode the shallow-subtidal zone, creating shore-normal elongated scours or runnels (gutter casts). The shallow-subtidal environment is a zone of sediment transport in which little sand is deposited outside of the scours. In deeper water, storm-generated currents weaken, erode progressively less of the seafloor, and deposit thicker and more continuous sand beds. Still farther offshore, bed thickness reaches a maximum, and hummocky cross-stratification may be common. More distally yet, bed thickness decreases again. However, changes in bed thickness can be attributed to variations in strength of the depositing storm as well as the distance from shoreline (proximality trends).

A storm-influenced shallow-subtidal environment of deposition is suggested for facies 1, 2, and 3 by the presence or absence of various sedimentary structures and by the vertical and lateral relationships. Features attributed to storm processes include the gutter casts, scoured bases of sandstone interbeds, pinch-and-swell and wavy bedding, and bioclastic and pebbly lags.

An intertidal environment is ruled out by the lack of bidirectional cross-stratification, reactivation surfaces, flaser bedding, flat-topped ripples, desiccation cracks (and other evidence of subaerial exposure), and other features, such as fining-upward sequences, indicative of tidal channel fills. Furthermore, characteristics of gutter casts (runnels) that are typical of a tidal-flat environment, such as bifurcation (branching) and highly variable axial trends, are not present.

The stratigraphic position of the three lower facies in relation to the overlying shallower water (lower-delta-plain) facies suggests a shallow-subtidal environment (i.e., Walther's Law). Lateral relationships also indicate relatively close proximity to the shoreline. About 2.4 km (1.5 miles) to the east of the Jakes Run section, Sevon (Thompson and Sevon, 1982, p. 58-60) measured a 30-m (100-feet) section near Kinzua Beach (41°51'11"N/78°56'57"W, NAD 27) that represents mostly the same stratigraphic interval. Nearly 40 percent of the Kinzua Beach section comprises red shales and siltstones of the Catskill Formation. The red beds become thicker and more common upward. Those occurring about 9 m (30 feet) above the base of the section are burrowed and contain root traces, thus indicating deposition of sediments in environments that were probably intermittently subaerially exposed (Thompson and Sevon, 1982).

Other factors lend support for a shallow-subtidal origin. For example, the absence of hummocky cross-stratification suggests deposition above fair-weather wave base. The commonly occurring brachiopod *Cyrtospirifer* is a nearshore form (Greiner, 1957; McGhee and Sutton, 1981), and the presence of some articulated shells in the storm lags indicates that transport probably was not far.

According to Myrow's (1992) model, facies 2 may represent a somewhat deeper nearshore environment relative to facies 1 and 3 (resulting from transgression/subsidence in excess of sedimentation), but more likely reflects differences in storm-current strength (weaker), storm frequency (greater), and sand supply. Proximality trends of Myrow (1992) suggest that the transitions between facies 2 and adjacent facies should be gradational. This, however, is not the case.

Subaqueous channels (e.g., unit 7, Plate 1B) in facies 2 helped to funnel sand away from the shore by traction. However, some of the very fine grained sandstones appear structureless, suggesting at least partial deposition (or *in situ* redeposition?) from suspension.

The flute-casted sandstone of unit 15 (facies 3) represents sediments that were subject to turbulent, unidirectional flow and were deposited from suspension. Paleocurrent directions for unit 15 vary considerably from the gutter-cast trends, which are presumed to be perpendicular to the paleoshoreline. This deviation and the absence of flutes in subjacent storm beds suggest that the sandstone was probably not the result of relaxation currents, but rather a strong flooding event (river flood underflow).

Crests of current ripples trend subparallel or somewhat oblique to the gutter-cast axes and suggest some flow subparallel to the paleoshoreline (longshore currents?). Examination of ripples was hampered by the uniform orientation of the roadcut and the paucity of well-exposed bedding-plane surfaces. This may explain the lack of observed wave ripples, or perhaps normal wave activity was weak here, as has been noted elsewhere (Woodrow and others, 1973).

Upper Facies Association

Facies 4, 5, and 6 constitute an upper facies association. The upper three facies represent a lower-delta-plain environment that is characterized by distributary-channel, crevasse-splay, and shoaling-upward intertidal deposits. Larger and more abundant plant material in the upper facies association reflects the growing encroachment of land. The absence of tidal indicators suggests that tidal activity was weak.

Unit 21 dominates facies 4 and is interpreted as distributary-channel (thicker, discordant) and crevasse-splay (thinner, more uniform) sandstones. This interpretation is supported by the gross geometry of the unit, the scoured base of the thick sandstone, the sedimentary structures, the overall uniform grain size, the characteristic basal channel-lag deposit, and the abundance of plant material. The channel thalweg trends roughly north-south, or oblique to the paleoshoreline. The crevasse-splay deposit thins laterally to the east and pinches out a short distance beyond Jakes Run bridge.

Units 17 and 19 are persistent and interpreted as "precursor beds" that are genetically related (major flooding events?) to the overlying distributary system.

Unit 23 (facies 5) represents a shoreline sandstone and preserves a *Skolithos* Ichnofacies characterized by a *Skolithos-Planolites* assemblage. The *Skolithos* Ichnofacies is indicative of moderate- to relatively high-energy conditions and typically developed in clean, shifting particulate (sandy) substrates (Seilacher, 1967). Such environments are favored by infaunal suspension feeders that generally lived in long, vertical burrows. The *Skolithos* Ichnofacies most commonly occurs in intertidal to high-energy subtidal settings, though bathymetric displacement has been recognized and interpretation of depositional environments should be based on other criteria as well (Frey and Pemberton, 1984). *Planolites* probably indicates a quiet-water environment (Pemberton and Risk, 1982; Frey and Pemberton, 1984), and its occurrence in unit 23 as full-relief traces on several bedding planes is interpreted as evidence of omission surfaces. Sediments of the *Skolithos* Ichnofacies were subject to abrupt and frequent changes in the rate of deposition, erosion, and physical reworking (Frey and Pemberton, 1984). Bjerstadt (1987, p. 885) recognized foreshore-beach and tidal-flat deposits in the Oswayo Member (Upper Devonian) of the Price Formation in West Virginia that preserve a *Skolithos* Ichnofacies dominated by a *Skolithos-Planolites* assemblage.

Red shale chips in the sandstone of unit 23 attest to the growing influx of land-derived Catskill sediments, possibly interfluve material from within the alluvial plain.

Other units in facies 5 also suggest shallow- to very shallow water environments. Red (unit 26) and mottled green and red (unit 28) siltstones are believed to be intertidal deposits. They are burrowed and preserve some shallow wave ripples. Unit 26 also contains scattered plant fragments, some of which are large. Furthermore, it may reflect brackish-water conditions. Although not observed here, *Lingula* was found in similar red beds at about the same stratigraphic position only 1 km (0.6 mile) to the east of the Jakes Run section (Road log, Day 1, mileage 13.7). Unit 27 commonly consists of intensely burrowed sandstone, but locally contains brecciated silty claystone, which suggests possible desiccation and subaerial exposure. This is believed to be the shallowest water deposit exposed in the section. Units 22 and 31 were inaccessible but may represent shallow distributary-bay fills.

Facies 6 occurs at the top of the Jakes Run section and is interpreted as another distributary-channel deposit.

Keep in mind that the ideas presented herein are based mostly on one exposure. Systematic collection and analysis of subsurface and outcrop data are needed to validate or modify the interpretations. Proximality-distality trends should be established for the lower facies association.

ACKNOWLEDGEMENTS

My thanks to Dr. Edgar M. Hopkins, University of Pittsburgh at Bradford, for valuable discussions, both in and out of the field, concerning the Jakes Run section and Upper Devonion stratigraphy and sedimentology in northwestern Pennsylvania. Teresa A. Sholley, summer intern and senior at Indiana University of Pennsylvania, provided important logistical support and an essential extra pair of "eyes" in the field and office. The assistance of Dr. Jon D. Inners, Pennsylvania Geological Survey,

in identifying some of the body fossils is much appreciated. James H. Dolimpio and Jack G. Kuchinski, Pennsylvania Geological Survey, expertly drafted the illustrations.

		Leave Stop 1. **CONTINUE STRAIGHT AHEAD** on PA Route 59 East.
0.2	12.7	Bridge over Jakes Run.
0.5	13.2	Good view on left of Allegheny Reservoir.
0.2	13.4	**TURN RIGHT** onto National Forest Road 262 just before Cornplanter Bridge.
0.3	13.7	Outcrop on the right, mapped as Venango, has sandstones and some thin red beds with *Lingula*.
2.5	16.2	Road to Dewdrop Campground on left.
0.2	16.6	**STOP 2. CATSKILL FORMATION AT DEWDROP RUN.** Discussants: Donald L. Woodrow and W. D. Sevon

The purpose of this stop is to examine rocks which are mapped as part of the Catskill Formation. The Catskill is shown on the 1980 Geologic Map of Pennsylvania (Berg and others, 1980) as having its base at the approximate base of this outcrop and its top somewhere in the forest higher on the slope. The Catskill is extended westward along Dewdrop Run for less than a mile and then cut off. That mapping was influenced by this outcrop which was known to reconnaissance mappers, principally T. Berg, in the mid-1970's. Sevon (Thompson and Sevon, 1982) described a section at Kinzua Beach, 2.1 miles north at the east end of Cornplanter Bridge, in rocks which are mapped as Venango, but which bear some similarity to the rocks at Stop 2.

As indicated in Dodge's discussion of the Upper Devonian rocks of Warren County (this guidebook, p. 1-11), southeastern Warren County is the western extreme of Catskill alluvial plain progradation. As a consequence, an appropriate question is "What is Catskill, particularly at the western edge of its occurrence?" As Figure 5 and text discussion of page 10 indicate, mapping of Catskill in this area of interfingering with the Venango is based on the presence of red beds. The red beds being separated as Catskill are in the correct stratigraphic position and, where exposed, generally show characteristics typical of Catskill rocks of alluvial origin farther to the east. Thus, it is Catskill because it is a nonmarine unit containing red beds.

However, Epstein and others (1974) in northeastern Pennsylvania and Walker (1972) and Hoskins (1976) in east central Pennsylvania have shown that a little to a lot of the Catskill can be nonred and marine. Therefore, as you examine this outcrop, consider how much more or less rock in the area might be Catskill and for what reasons.

The rocks exposed at Stop 2 (Figure 34) comprise almost 30 m of mixed lithologies, colors, and depositional environments. Red colors are not bold and make up only about 9 percent of the exposed sequence. Body fossils, brachiopods and possibly pelecypods, are uncommon and known definitely only from Units 1 and 13. Float of sandstone containing brachiopod casts and fish scale fragments occurs but its source is uncertain although the base of Unit 11 is a possibility.

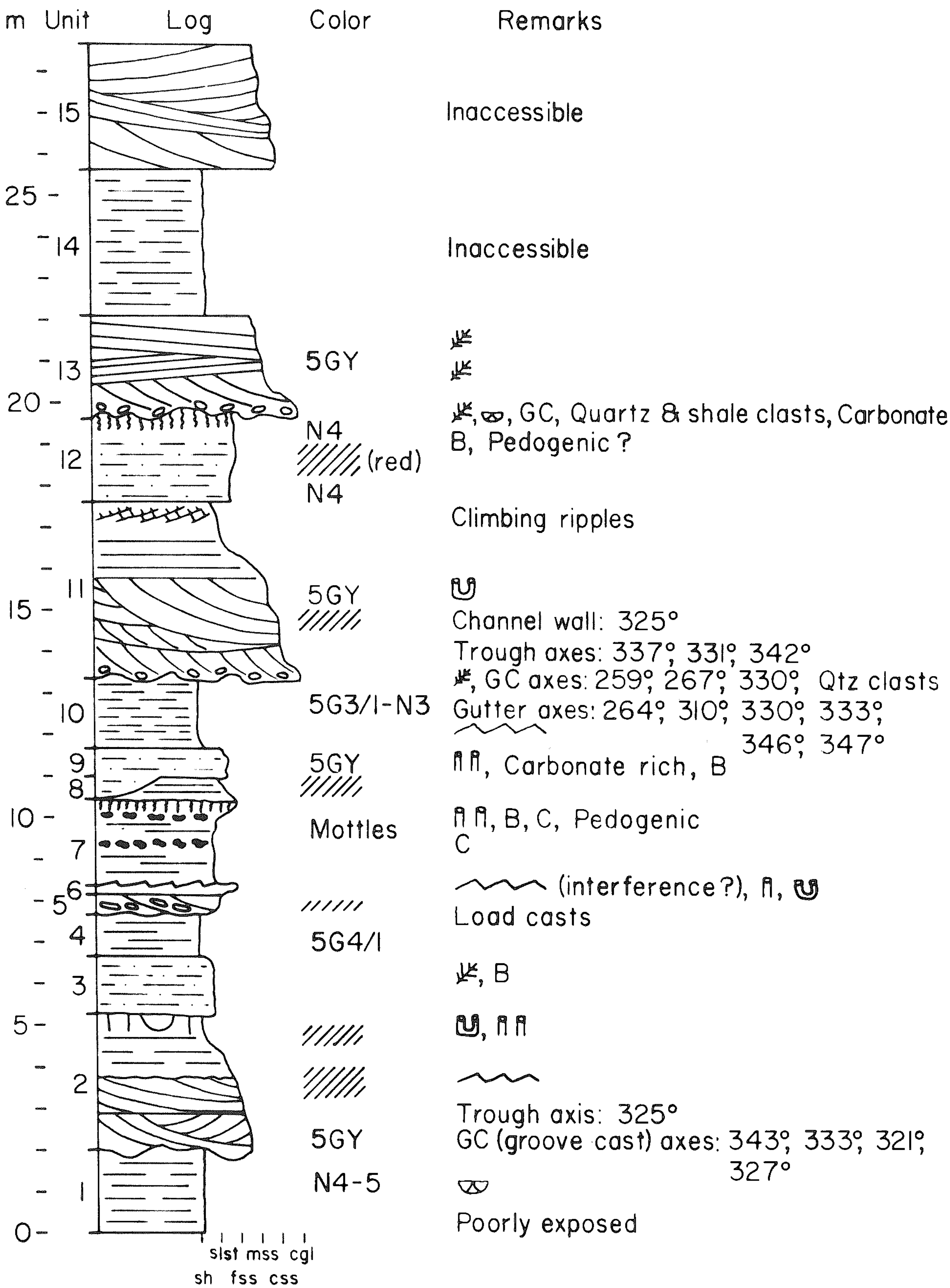


Figure 34. Columnar section of Catskill Formation rocks exposed at the Dewdrop Run section. Key: = plant remains; = u-shaped burrows; = vertical burrows; = ripples; = body fossils; C = carbonate nodules; B = bioturbation.

Orientations taken from gutter axes, groove casts, axes of trough crossbeds, and one channel wall are adequate to verify a northwest transport direction with a mean orientation of 321^o (standard deviation = 27^o).

Carbonate nodules, mottled colors, bioturbation, and probable paleopeds occur in the upper part of Unit 17. These features seem to be positive evidence that the original sediments were weathered subaerially to produce a soil.

Plant remains (Units 3, 11, 13) and vertical burrows (Units 2, 7, 9) are nondiagnostic, but can be associated with marginal marine environments on both sides of the strand line. Carbonate, sometimes a characteristic of Catskill rocks, occurs in various places in Units 7 through 13.

When viewed as a whole, a pattern is apparent in the form of four distinct packages. The packages are: Units 2-4; 5-10; 11-12; 13-14(?). Each of these packages starts with an erosional base, coarser-grained rock, and crossbeds. These rocks fine upward into shales. Pedogenic horizons occur definitely in Unit 7 and possibly in Unit 12. Although fossils are not known from the bases of Units 2, 5, and 11, we would not be suprised to find them there.

These packages resemble fluvial, fining-upward cycles and it is tempting to call them that without further evaluation. However, fluvial cycles should not have marine fossils as are known to occur in Unit 13 and may occur elsewhere. There are other features within the packages, such as vertical and U-shaped burrows, plant remains, gutters, and bioturbation, which suggest the possibility of considerable marine influence. These packages are very reminiscent of the Irish Valley motifs defined in east central Pennsylvania by Walker (1971; 1972; Walker and Harms, 1971). Today such packages are usually termed cyclic sequences in which the base of each cycle represents a transgression and the upper part of the cycle a regression. Each cycle can range from a few centimeters to many meters in thickness and a given sequence of rocks may possess many or few cycles. The cycles represent a complex interplay beween sediment supply and subsidence along a muddy coastline. Warren County at the western edge of Catskill progradation seems ideally suited for this cyclic sedimentation pattern. The text discussion for Stop 1 covers adequately the details of the presumed coastline and nothing further is added here.

Figure 34 is a composite of the Dewdrop Run exposure and not all units are present at all places. Units 1 and 2 occur only at the west end (downgrade) of the outcrop and Units 13-15, which are generally inaccessible, are best accessed at the east (upgrade) end of the outcrop. When viewed face-on in the central third of the outcrop, the protruding sandstone units and the recessed finer-grained units are obvious and make locating specific units within the sequence fairly easy. The pedogenic zone, Unit 7, is readily located between the two lower protruding sandstones. Less obvious in the lower half of Unit 11 is a channel-fill sequence which cuts out all of the previously deposited sandstone. The east margin of the channel is clear.

The west margin is less certain, but the channel extends 100 feet or more across the cliff. Is this a tidal channel on a muddy coastline or a fluvial channel which was just inland beyond tidal influence?

After examining the exposure, consider the reality and the ease of mapping a unit called Catskill in Warren County and adjacent areas. Are the criteria really firm? Is Catskill a mappable unit in this area of depositional limit and minimal outcrop?

		Leave Stop 2. **TURN AROUND AND RETURN THE WAY CAME.**
3.0	19.6	**STOP SIGN. TURN RIGHT** onto PA Route 59 East. Cross Cornplanter Bridge which crosses the Kinzua Creek branch of Allegheny Reservoir.
0.6	23.2	Outcrop on right at Kinzua Beach of Devonian Venango and Catskill Formations. See Thompson and Sevon (1982) for description.
2.0	25.2	McKean County line.
0.3	25.5	**TURN RIGHT** onto road to Rimrock picnic area and overlook. Road is bordered with abundant mountain laurel which blooms beautifully at the end of June.
2.5	28.0	**STOP 3. RIMROCK OVERLOOK AND LUNCH.** Discussants: Michael E. Moore, W. D. Sevon, and L. R. Auchmoody.

In addition to lunch, this stop will offer the rare opportunity to examine an extended exposure of the Pennsylvanian-Mississippian unconformity and to ponder some enigmatic questions on the processes of colluviation and mass wasting. Figure 35 is a generalized map of the overlook area with suggested points of interest. Please use common sense and avoid the temptation to hammer on the outcrop.

GEOLOGY

Rimrock Overlook provides the only confirmed location in Warren County (and perhaps the whole state) where the unconformity at the base of the Pennsylvanian is extensively exposed in outcrop.

Post-Missippippian deformation imparted a gentle south-southwest dip to the strata. Erosion prior to deposition in the Pennsylvanian resulted in deposition on progressively older units from south to north across the county. At this location approximately 130 feet of sandstone, granule conglomerate, and quartz pebble conglomerate of the Pottsville Formation was deposited on the pebbly to conglomeratic quartz sandstones of the Mississippian Knapp Formation. Figure 36 is a composite stratigraphic section for the overlook.

The Knapp Formation at this locality is represented by a maximum exposure of 11.5 feet (near station 360) of cross-bedded medium-grained, thin- to thick-bedded, pebbly, quartz sandstone with minor flat-quartz-pebble conglomerate and granule conglomerate. Although the Knapp contains abundant marine fossils at other locations in the county, they are very rare in

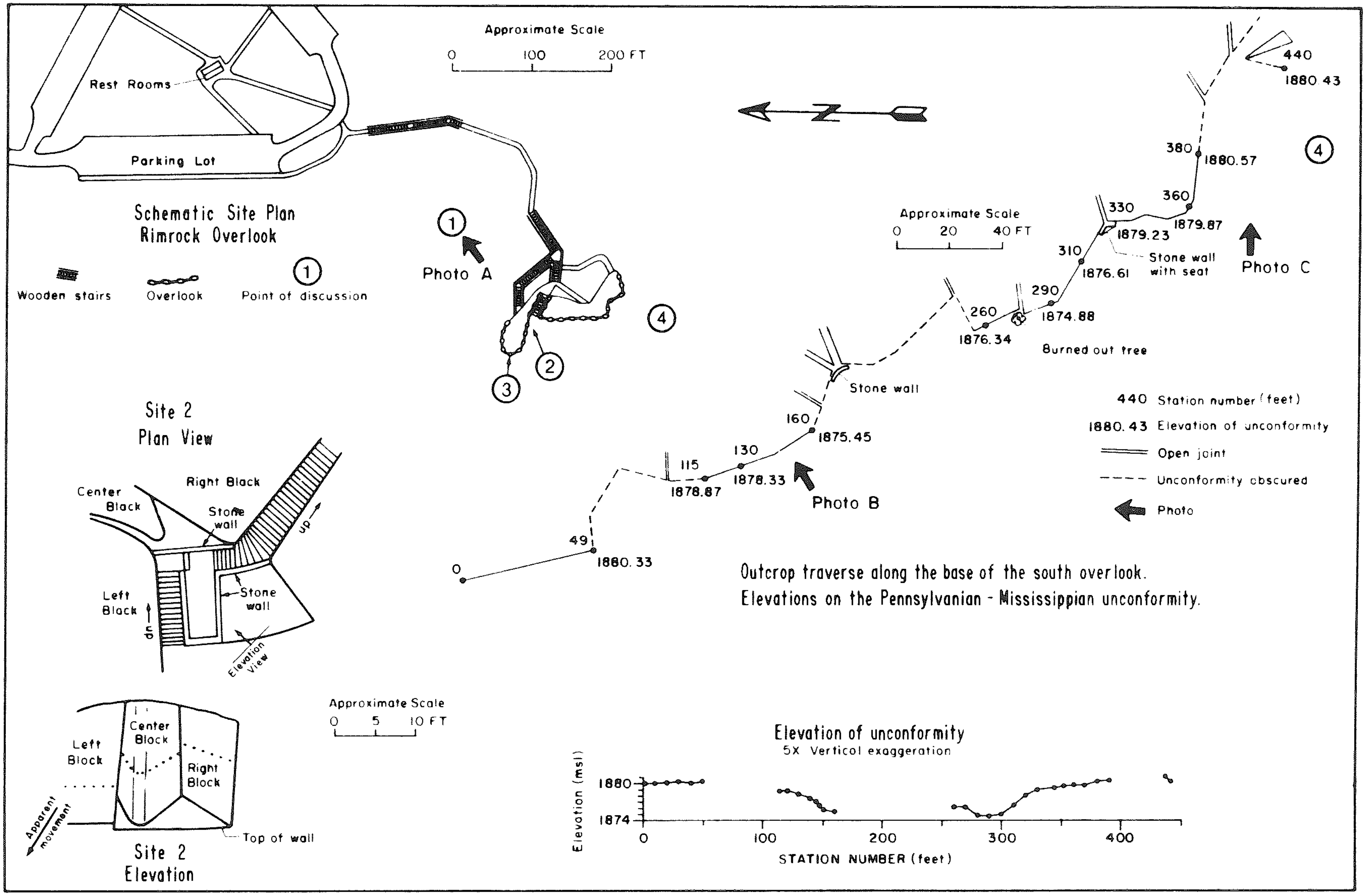


Figure 35. Map of the Rimrock Overlook area, a traverse of the southern overlook and a cross section relating elevation of the Mississippian-Pennsylvanian unconformity to the traverse.

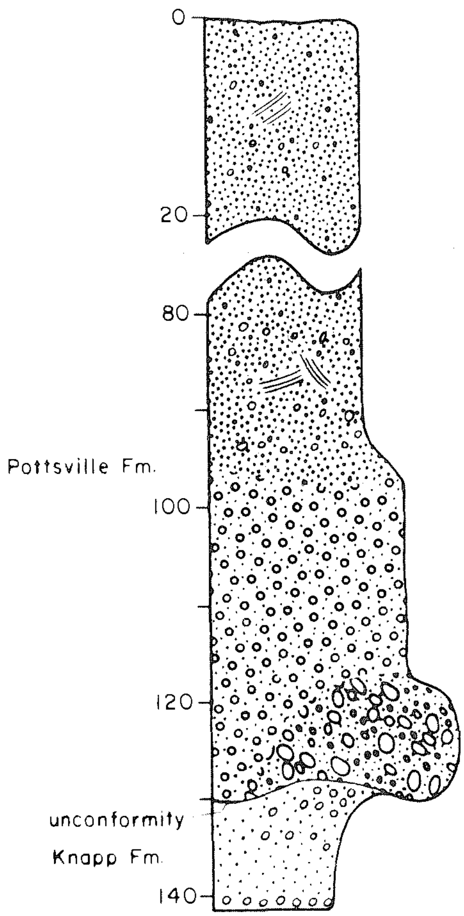


Figure 36. Composite section of the Knapp and Pottsville Formations at Rimrock Overlook.

this outcrop - only fragments have been found, mostly near station 350.

In one sense the Pottsville Formation exposed at this site can be described as a single, fining-upward sequence consisting of up to 10 feet of massive Olean-like quartz-pebble conglomerate (best exposed near station 5) that grades upward into approximately 22 feet of massive clast-supported fine quartz-pebble conglomerate (best seen near Site 3). Finally the section is capped with nearly 100 feet of coarse-grained, massive to very thick bedded sandstone and pebbly sandstone.

THE UNCONFORMITY

Figure 35 contains both a 440-foot outcrop traverse of the base of the southern overlook and a graph relating the elevation of the unconformity to the traverse. As you examine the unconformity, look for evidence of scour and fill structures. The high energy regime that resulted in deposition of the Pottsville must have entrained flat pebbles from the Knapp. How thick is the zone of mixed pebble geometries? Was the Knapp lithified prior to deposition of the Pottsville? What evidence supports your conclusion?

Perhaps more interesting than the 5.7 feet of maximum relief is that the geometry seems to indicate a low channel-like area between stations 150 and 200. Plate 2B (station 145-150) shows a zone where complex intermixing of flat Knapp pebbles with more spherical Pottsville pebbles may best be explained as a lag gravel on the edge of a channel. Interpreting the cross section, maximum relief would be expected near station 200.

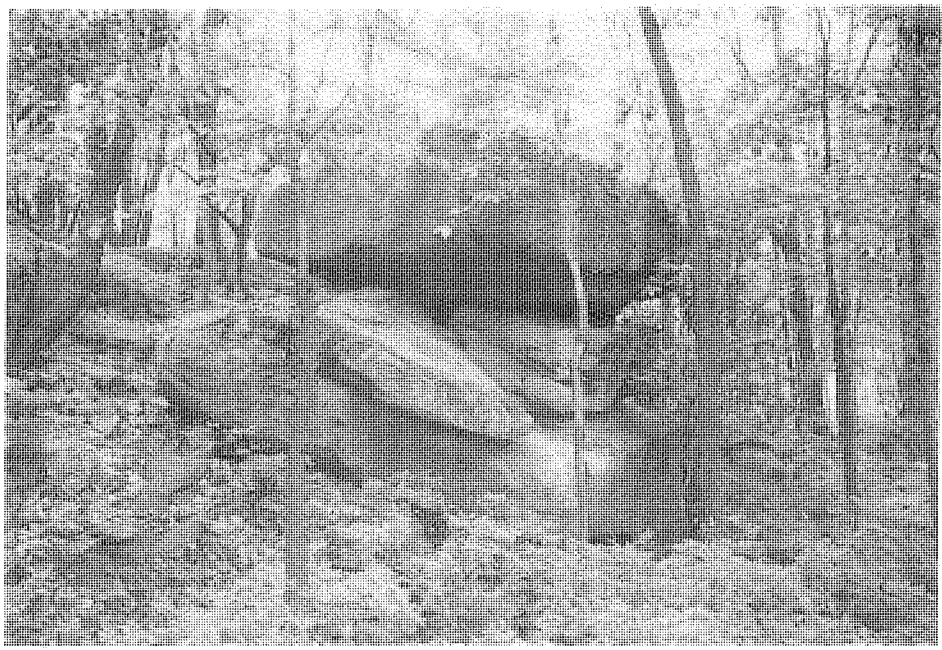
SITE 2

As you descend the stairs from the overlooks note the coarsening of the Pottsville Formation. After exiting the tight confines of the partially covered joint opening, briefly stop and look at the Pottsville that surrounds this opening in the outcrop. Referring to Figure 35, Site 2, the open joint between the left and middle blocks and the offset in the 4-inch pebble horizon indicate that the left block has moved both out and down approximately 1.5 feet relative to the middle block. That movement may have been associated with the same event that resulted in both the toppling of the blocks that previously filled this break in the outcrop and the opening of the joint you just passed through. The missing piece may actually be one of the several huge blocks that lie just downslope from the stairs. The massive to irregularly bedded nature of the Pottsville makes determination of the "tops" of the blocks unusually difficult. This is not a problem for one of the largest blocks situated just downslope from the bottom of the stairs. That block measures tens of feet on a side and is the only one of this magnitude with the Knapp still attached to the base. From that stratigraphy we learn that the block rotated about 135 degrees downslope. The present position provides exceptional three dimensional access to both the Knapp and its overlying unconformity.

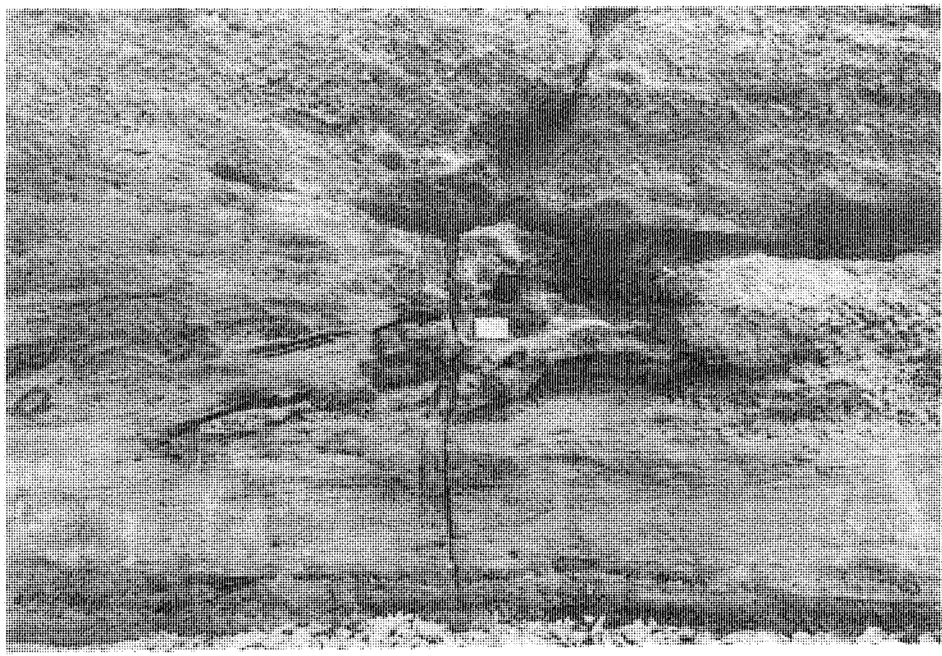
SITE 3

About 200 feet to the right of the bottom of the stairs the Pottsville is a beautifully sculpted conglomerate. Examination reveals a moderately well sorted, clast-supported, massive, fine-pebble conglomerate. Further observation reveals an apparent positive correlation between pebble size and degree of rounding. That is, the smaller pebbles appear less rounded than the larger ones. Two obvious explanations come to mind. The different sized pebbles come from different source areas and/or the mechanical breakdown of larger pebbles shortly before deposition. Meckel (1967) and other researchers have not proposed dual source areas for conglomerates in this area. Additionally, examination of the larger pebbles reveals that most are severely weakened by fracturing and can be fragmented with minimal force, so the latter mechanism appears most logical. Just below this exposure is an outcrop of the Knapp Formation. A large spring emenates from its base. The spring has been developed and is apparently still in use, presumably by the U.S. Forest Service. A fence around the outfall limits access to the estimated 40 gallons per minute that discharges from the overflow pipe.

A



B



C

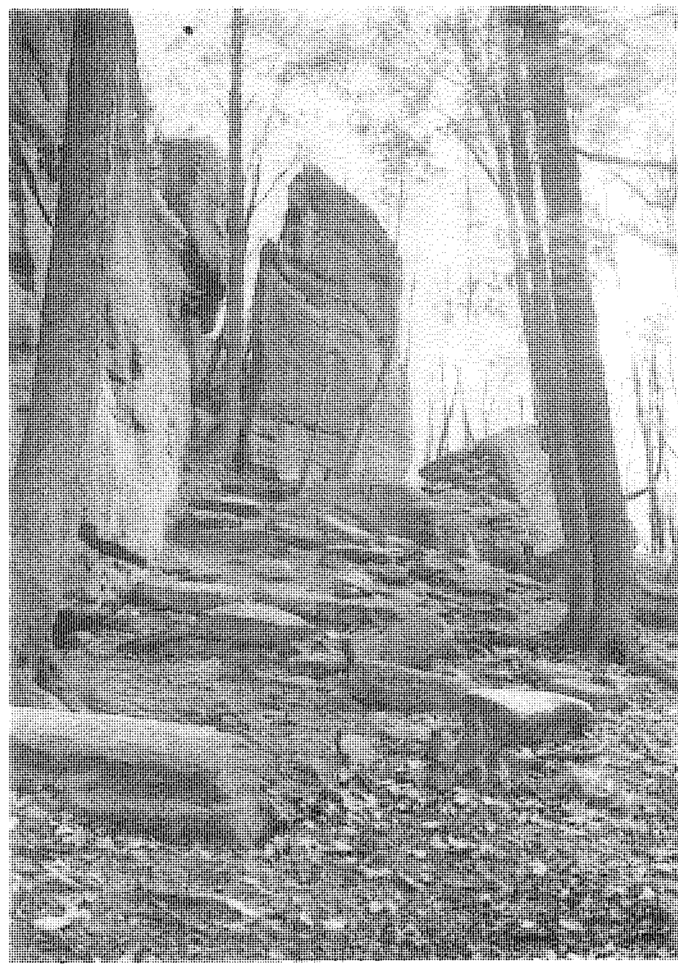


Plate 2. Photographs from Rimrock Overlook. A. Stacked blocks of Pottsville sandstone. B. Irregular nature of the unconformity between the Pottsville and Knapp Formation near Station 150. C. Thirty-foot pinnacle of the Pottsville Formation separated from the outcrop. Note toppled block in the center right. The unconformity is about half way up the face at the left.

SITES 1 AND 4

Plate 2A and 2C are included to stimulate discussion on the processes involved in the formation and movement of the large colluvial blocks of Pottsville that are present both above and below the overlooks. Unfortunately, work for this conference has provided more questions than answers. For example, what conceivable process is responsible for the arrangement of the blocks in Plate 2A? Cursory examination will eliminate differential weathering - the blocks are obviously not stratigraphically conformable. That being the case, then there should be some evidence, such as striations or sheared pebbles, to indicate the movement of one block over the other. We could find no such evidence. Most probably they result from some aspect of periglacial activity, the specifics of which are highly speculative.

GEOMORPHOLOGY

Rimrock provides an excellent opportunity to view and ponder the production of large blocks (Plate 2A) from a ledge and their subsequent downslope transport. The general aspects of this process are discussed earlier in the guidebook (p. 86-87). The ledge at Rimrock exposes a relatively uniform, massive rock which has no bedding-plane separations in the main face. Rock above the main face has bedding-plane separations spaced a few to several feet apart. Joints are widely and apparently irregularly spaced in the cliff, but are probably closer spaced and more regular in the overlying sandstones.

To fully appreciate the forces which have been active here in the past, a pleasant and not rigorous tour is recommended. From the top of the ledge **proceed down** the stone steps between the separated rocks near the north end of the ledge. At the narrow point of the passage note the aligned pebble zones on either side of the walkway. Are the pebble zones offset or merely separated? Which block has moved?

Go left at the bottom of the steps. Follow the trail to a recess in the cliff just beyond the end of the iron railing. Here is a good view of the ledge, joints, and separation of blocks from the main ledge. Note the debris coming out of one of the joints.

Continue on to the stone wall next to the ledge. A cool breeze should be flowing from the joint behind the wall. The air is cooled as it flows down along the cold rock (and possibly through open interstices of unseen rock rubble in the upper part of the open joint). The rate of flow will depend on the temperature contrasts. Stand at the right end of the wall facing the ledge and look to the left. Note the separated outer block and that it has moved down 2-3 feet. This is not obvious when walking past the block.

Continue along the trail to a stone wall and seat. As you face the ledge, note that the block on the left has moved away and down from the main body of rock. You may want to go back along the trail to see how large this moved block is and what the separation looks like at the other end. Note also the rock debris which has fallen into the separation crack. Where did it come from?

Just beyond the stone seat, the trail encounters a large mass of rock rubble and continues upwards along the ledge. Note the many different orientations of the blocks. Did all of the blocks come from the ledge face? Probably not. Note the tree growing against one of the blocks at trail level. Is the tree growing into the rock or is the rock moving and pressing into the tree? I favor the former concept.

This is a good place to contemplate the forces of freeze and thaw which have created the rock rubble. It may be easy to visualize forcing apart the large blocks when the joint is essentially a hairline fracture, but what happens when the crack is an inch wide? When does the process of freeze-thaw get replaced with gelufluction? Does gelufluction play a part in the actual separation of the blocks from the main body of rock?

Before continuing on the trail past the large rotated block on the right side, **turn downhill** off the trail. After leaving the trail, walk slightly to the left toward the two large blocks which have bedding oriented approximately horizontal. Are the blocks right side up or upside down? Walk between the two blocks and appreciate their size. Just in front of the blocks the slope flattens for a short distance before steepening again. Note that there are lots more blocks on the downslope. They are present all the way to lake level and probably to the original valley bottom now beneath the lake.

Turn right in front of the blocks and walk toward a very large block which has the bedding rotated backwards into the slope. Note the size of this block. **Continue walking** on the downslope side of the large block toward an even larger block also with bedding rotated backwards into the slope. Here is a block the height of the whole ledge measured in 10's of feet in every dimension. Contemplate movement of this block. What is the orientation of bedding relative to the cliff face? Has the block toppled forward or slumped backwards? **Continue walking** on the downslope side of this block. Note at the north end of the block that it abuts a much smaller block with different bedding orientation. Note that this block rests on a jumble of rock rubble. Note again that the slope below these blocks is littered with blocks and boulders.

Continue around and to the right and come up to the uphill end of the very large block. (If one continues ahead instead of turning uphill, another large block is encountered which is downslope from the steps. That block has definitely toppled forward.) Look at the bedding surface which comprises the upslope end of the block and note the pile of rocks debris at the base of the bedding plane. This debris presumably represents weathering of the rock since it came to rest. Note that you are on a mound of rock rubble which has jammed up behind the very large block. The very large block is a braking block which either moved slower or came to a stop causing still moving debris behind it to pile up. Ploughing blocks normally build a mound of material in front of them and leave a linear scar behind them.

Such features are not obvious here.

Note also that the rock rubble between the two large blocks continues without being impeded but diminishes in apparent extent before the flat in front of the large blocks. Does the rubble represent a late phase of gelifluction or the extent of Late Wisconsinan geluflucton? When were the large blocks moved? Is the smaller rubble from the ledge? Probably not. Some or most of it probably arrived at the top of the ledge by gelifluction of material above the ledge, toppled over the ledge to the base, and then gelufluoted on down the slope.

Walk back up the slope to the trail and continue in the former direction past the large block on the right and up along the ledge face past the still upright separated block (Plate 2C). Continue up the the surface above the ledge. Note the source rock and moved blocks on the upper surface. Remember that the periglacial processes operated everywhere, not just on the ledge itself.

		Leave Stop 3. **RETURN THE WAY CAME.**
2.5	30.5	**STOP SIGN. TURN LEFT** onto PA Route 59 West.
0.3	30.8	Warren County line.
1.3	32.1	Large block of cross-bedded rock on left is float block from Rimrock area. Is it Olean or Knapp?
1.4	33.5	On right is Kinzua Point Allegheny National Forest information center.
0.9	34.4	Site of Stop 1 on left.
2.3	36.7	**STOP 4. KINZUA DAM, ALLEGHENY RESERVOIR, AND SENECA POWER STATION: HISTORY, GEOLOGY, AND INFRASTRUCTURE.** Discussant: Jon D. Inners (with additional comments by Brian Greene and Steve Lauser, U. S. Army Corps of Engineers, Pittsburgh District).

Kinzua Dam is situated on the upper Allegheny River about 7 miles west of Warren in Kinzua and Glade Townships, Warren County (Figure 37). Upstream of the dam is the Allegheny Reservoir, a huge impoundment that at normal pool extends northward nearly to Salamanca, New York, a distance of more than 20 miles. Downstream is the Seneca Pumped-Storage Hydroelectric Generating Station of Pennsylvania Electric Co. (Penelec), which uses the Allegheny Reservoir as its lower storage reservoir.

Kinzua Dam and Allegheny Reservoir are operated by the U. S. Army Corps of Engineers, Pittsburgh District, mainly for the purposes of flood control, recreation, and low-flow augmentation. To maintain river-flow requirements, Penelec coordinates water releases from its Seneca Power Station with the Corps.

Kinzua is a Seneca word which reportedly means "land of many and big fishes." In keeping with this Indian parlance, the Allegheny National Fish Hatchery, located on the north bank just below the dam, raises lake trout for placement in Lakes Erie and Ontario. Also apropos of the name, trophy-size muskellunge, walleye, and bass inhabit the deep waters of the Allegheny Reservoir, and "monster" carp prowl the surface waters on the upstream side of the dam.

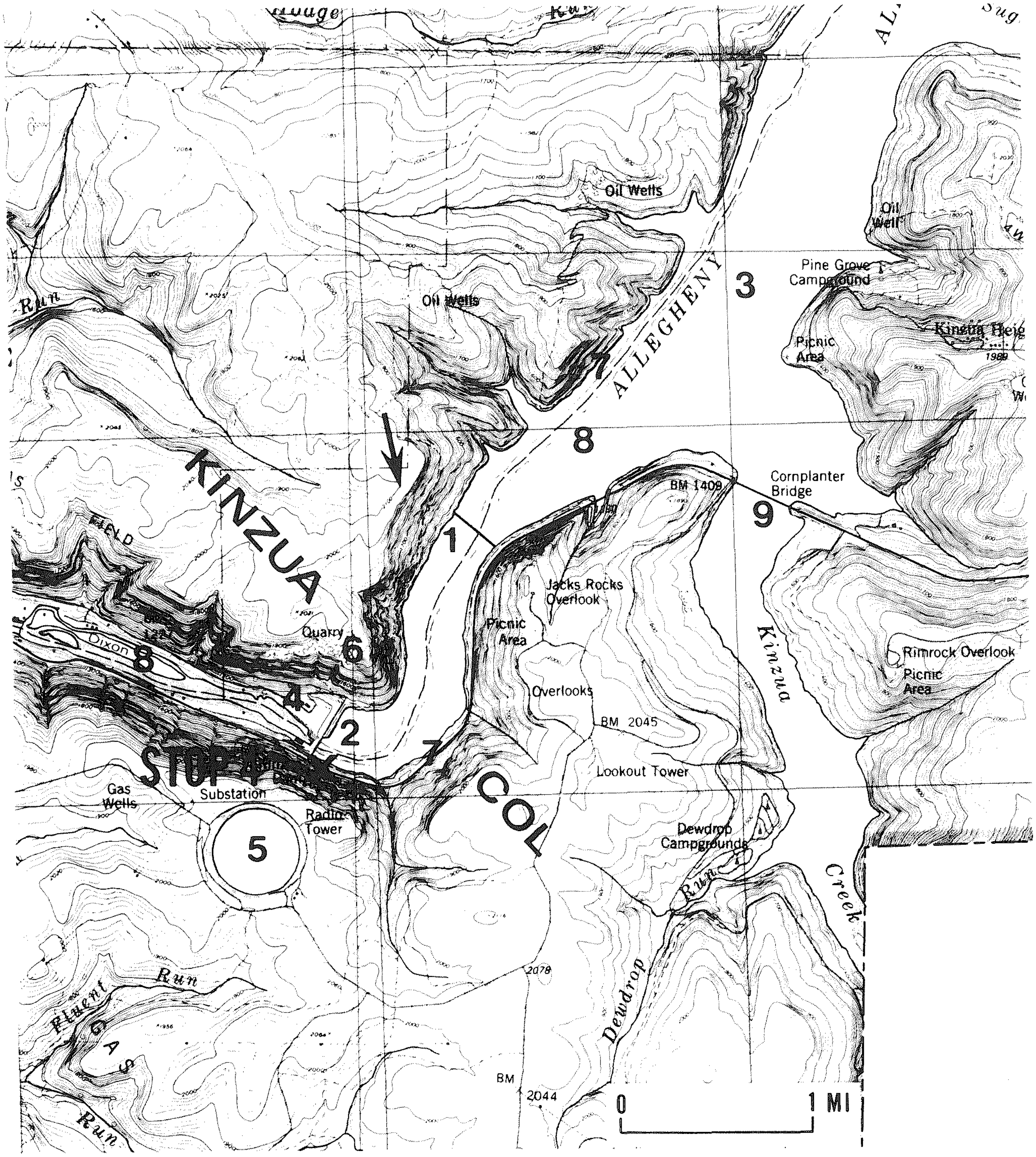


Figure 37. Location map for Stop 4, showing the site of the Kinzua Col. Key: 1 = 1936 damsite; 2 = Kinzua Dam (Figure 39A, cross-section); 3 = Allegheny Reservoir; 4 = Seneca Hydroelectric Station; 5 = power reservoir for Seneca Station; 6 = dam-riprap quarry; 7 = earth-fill borrow areas (approximate locations); 8 = island-sources of fine sand for upstream cut-off; and 9 = Cornplanter Bridge (Figure 39B, cross-section).

HISTORY

The impetus for construction of a dam at Kinzua was the devastation wrought throughout the Northeast by the great spring floods of 1936. Soon after the floodwaters had subsided in streams from Virginia to Massachusetts, the U. S. Congress passed the Flood Control Act of 1936 and authorized construction of a dam on the upper Allegheny River. The U. S. Army Corps of Engineers went immediately to work on site investigations for a 150-foot-high concrete-gravity dam above Warren. Because of the bottleneck-like constriction of the river valley at Big Bend, the Corps concentrated its efforts along a two-or-three-mile reach in that vicinity. A preliminary site at the narrowest point in the valley, about 2000 feet upstream of the present dam (Figure 37), was rejected when it was determined that the bedrock floor of the valley lay about 75 feet below the streambed. (An increase in the height of the dam from 150 to 225 feet would more than double the required quantity of concrete and double the cost of the proposed dam. The high anticipated construction costs—when considered in the light of probable problems related to land condemnation and to the flooding of Indian lands—led to postponement of the project (except for brief field studies in 1938) (Philbrick, 1976).

Field work was resumed in 1955 (following years of controversy over the Indian-lands issue), with subsurface investigations concentrated at the present site. Discovery of a shallow 450-foot-wide bedrock shelf (largely covered by Wisconsinan/Holocene landslide deposits) on the south side of the valley prompted a change in design to a combination concrete gravity-earth fill dam. An estimate of the cost of a combination dam at the present site compared with the cost of a straight concrete dam at the 1936 side (too narrow for a combination dam) showed savings of about $4 million (Philbrick, 1976).

The efforts of the Seneca Nation to save the small, but religiously significant, Cornplanter Tract in Pennsylvania and 9,000 acres of rich bottomland on the Allegheny Reservation in New York State, both of which would be flooded by the Kinzua project (Figure 38), continued into the late 1950's (Wilson, 1966; Wallace, 1972; Graymount, 1988). On August 30, 1957, the Senecas petitioned for an injunction against the Secretary of the Army and the Chief of Engineers to stop construction of the dam. But on November 25, 1958, the U. S. Court of Appeals for the District of Columbia Circuit rejected the petition, ruling that Congress had the right to authorize taking of the land—despite the Pickering Treaty of 1794, which guaranteed the lands to the Indians "until they chose to sell the same to the people of the United States." This ruling was let stand by the U. S. Supreme Court on June 15, 1959 (Warren Times-Mirror, 11-25-58; Wilson, 1966).

After further delays occasioned mainly by President Dwight Eisenhower's vetoing of two Public Works Appropriation Bills containing funds for Kinzua, groundbreaking at the dam site finally took place on October 22, 1960 (Wilson, 1966; Warren Times-Mirror, 10-24-60). Building of the dam and necessary

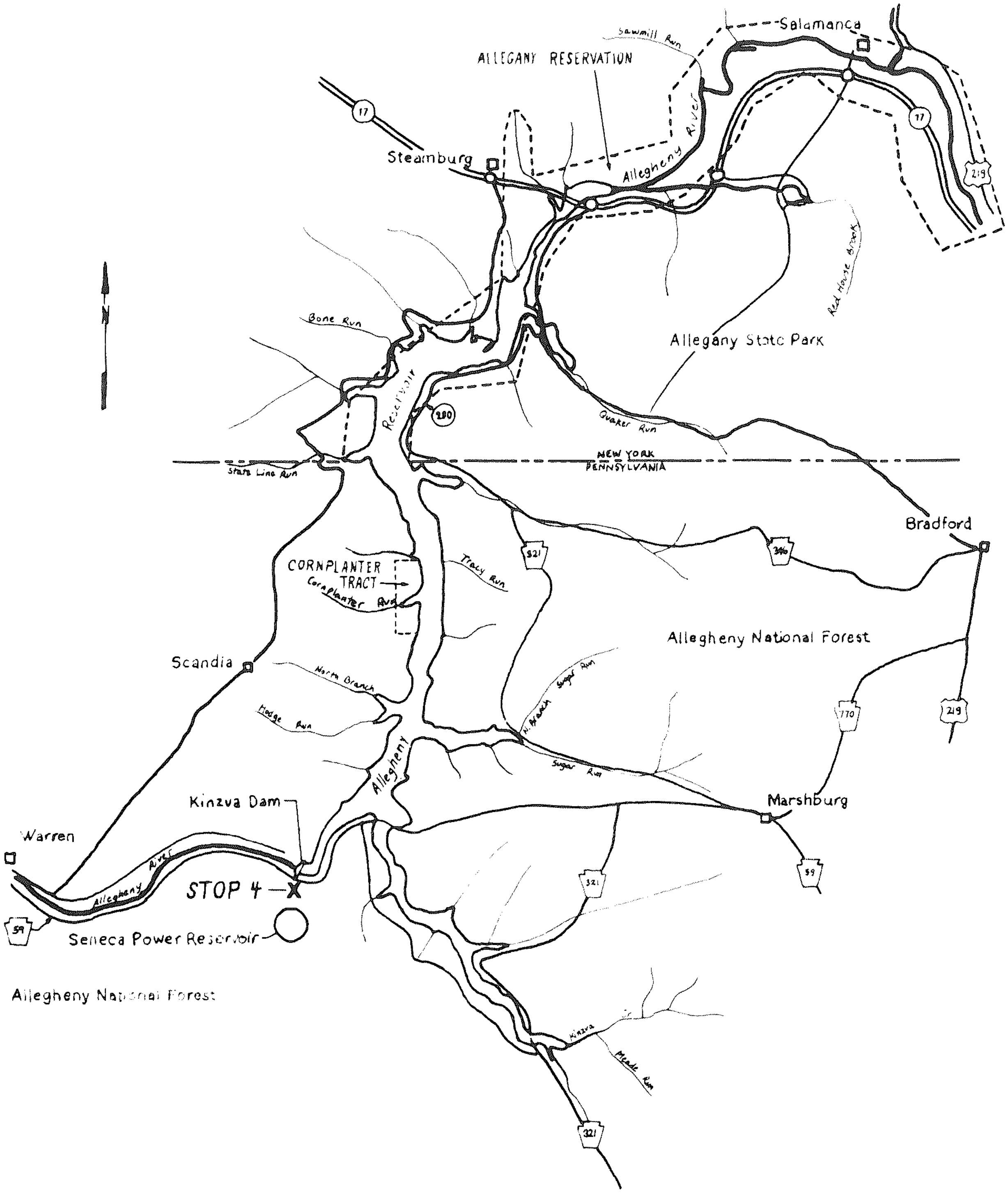


Figure 38. Map of the reservoir behind Kinzua Dam (from U. S. Army Corps of Engineers, Pittsburgh District), showing flooding of Indian lands. The Cornplanter Tract was a 750-acre parcel of land given to the Seneca Chief Cornplanter (c. 1750-1836) by the Pennsylvania Assembly in 1791 to show its appreciation for his efforts to maintain peaceful relations between the various Indian nations and the fledgling United States. It was here that Handsome Lake (1735-1815), the Seneca prophet and Cornplanter's half-brother, lived and had the revelations that led to the founding of a nativist religion practiced by many Indians today (Deardorff, 1972; Wallace, 1972).

auxiliary construction progressed quickly over the next five years. Structural relocations for the reservoir involved 83 miles of highways (including a 4.5-mile section of PA Route 59 past the south abutment of the dam) and 37 miles of railroads (Philbrick, 1976). The dam-and-reservoir project was completed in 1965. The next year, Pennsylvania Electric Co. (Penelec) began construction of the Seneca Pumped-Storage Hydroelectric Station. First commercial operation of the station was on December 21, 1970.

GEOLOGY

The Kinzua Dam-Allegheny Reservoir project is a classic example of the effective use of geomorphology and geology in the siting and construction of a major engineering structure. While the bedrock geology of the project area is relatively simple, a complex geomorphic and glacial history has resulted in the development of an intricate sequence of surficial deposits both at the dam site and in the reservoir area upstream (Figure 03). The early regional studies of Carll (1880, 1883) and Butts (1910) (see Sevon, this guidebook) provided the basic geologic framework that, decades later, greatly assisted Shailer Philbrick and other Corps geologists in siting the dam and solving a variety of construction problems.

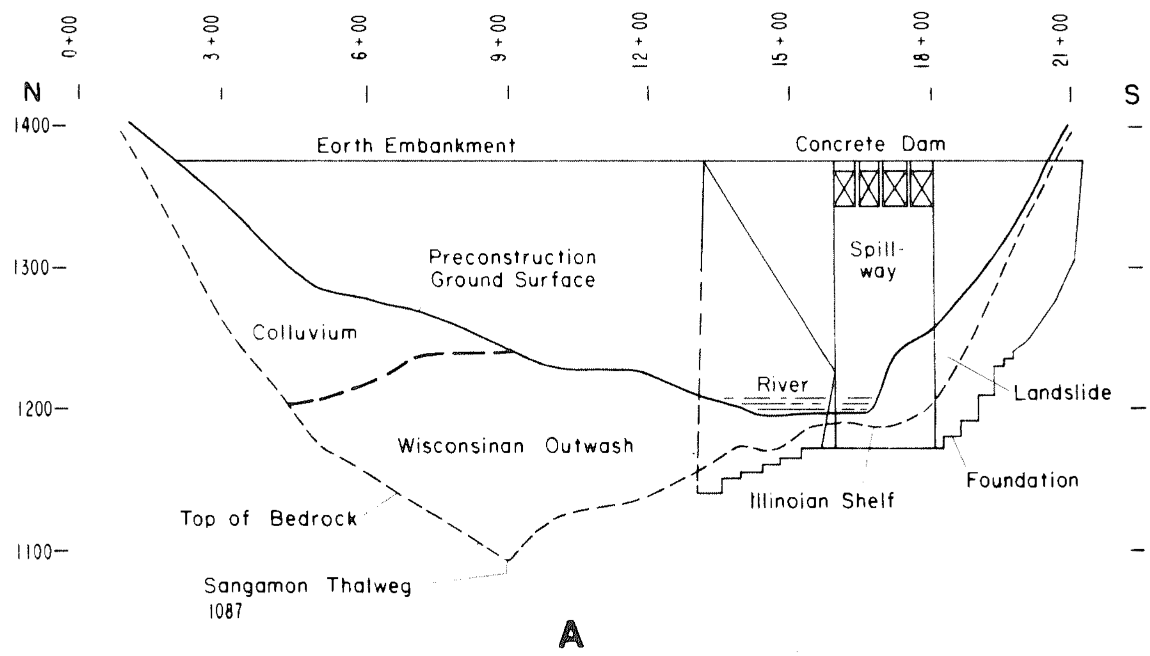
Bedrock Geology

The site of Kinzua Dam is underlain by Upper Devonian shales, siltstones, and sandstones currently assigned to the Venango and Chadakoin Formations (see Dodge, this guidebook). On the south abutment, the contact of the two formations occurs at an elevation of about 1250 feet (below road level) (Figure 39A). About 50 feet of well jointed, interbedded gray shale and sandstone in the lower part of the Venango is exposed in the long road cut adjacent to PA Route 59 (Plate 3A). The only problem occasioned by bedrock conditions during construction involved slight lowering of the foundation elevation of one concrete monolith due to stress-release opening of some subvertical joints on the hillside and subhorizontal bedding partings in the valley bottom (Philbrick, 1976).

Surficial Geology and Geomorphology

Surficial deposits at the dam site prior to construction consisted of Wisconsinan/Holocene landslide deposits on the south abutment (and extending out onto the bedrock shelf noted above), Wisconsinan glacial outwash filling a 100-foot-deep bedrock "gorge" in the north-central part of the valley, and thick Wisconsinan/ Holocene colluvium on the north abutment (Figure 39A). The landslide deposits were removed during construction of the concrete section of the dam, while the outwash and colluvial deposits formed the foundation of the earth embankment.

The Kinzua-Dam site is located on the south side of an ancient interstream divide, the Kinzua col of Muller (1963),



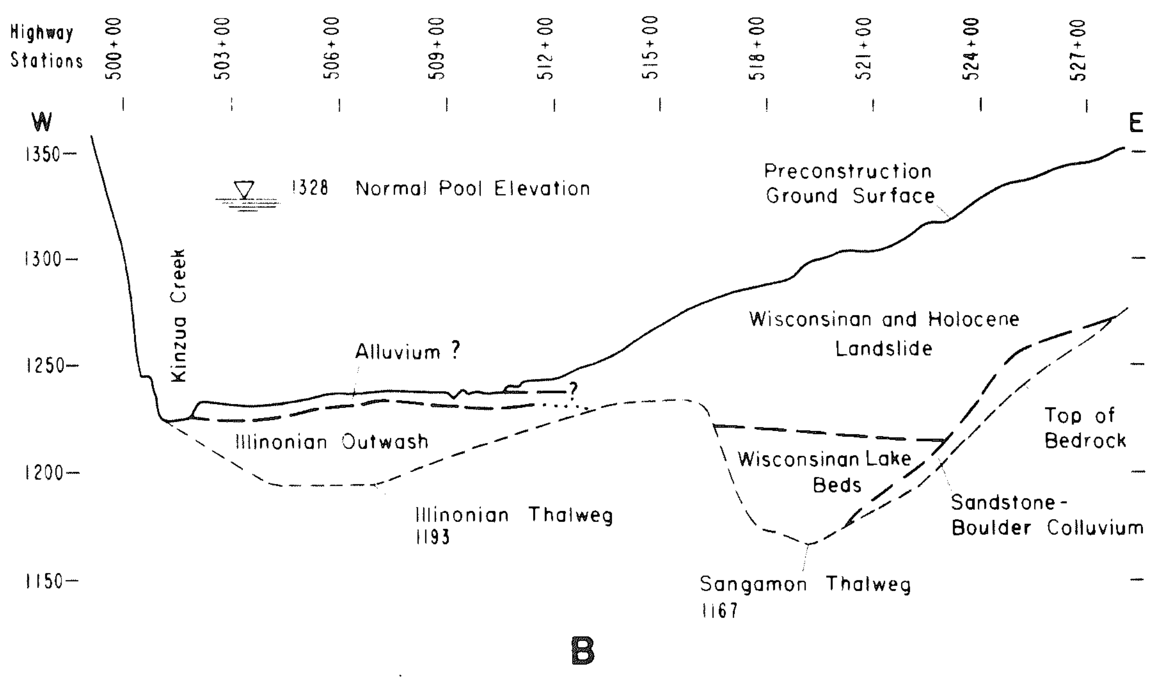
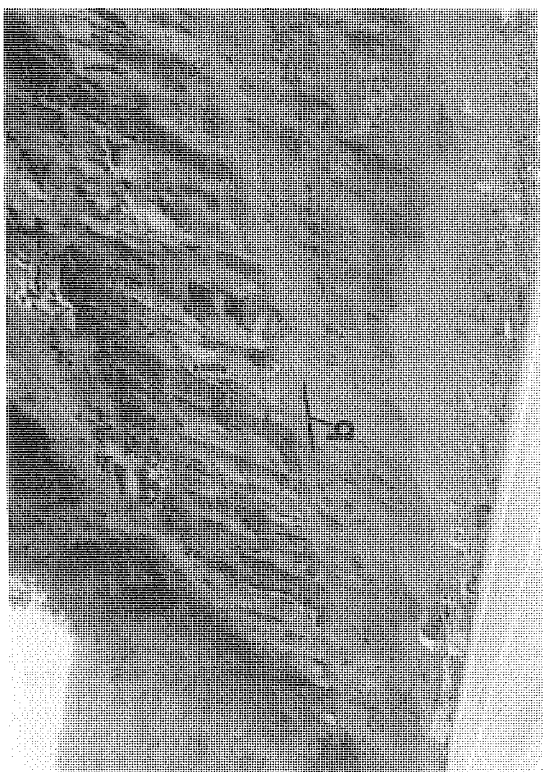
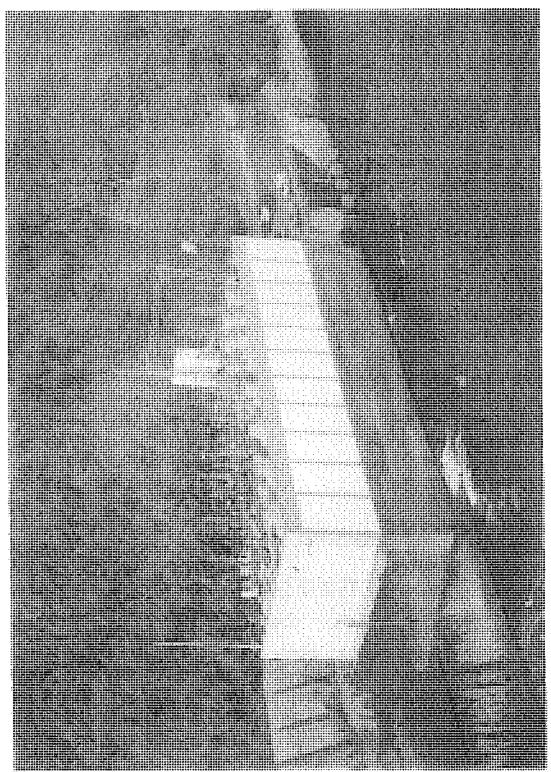


Figure 39. Geologic cross sections at Kinzua Dam (A, view upstream) and Cornplanter Bridge (B, view downstream), showing the complex geomorphic setting of the Big Bend-Kinzua area. Note particularly the landslide deposits on the right of both cross sections.

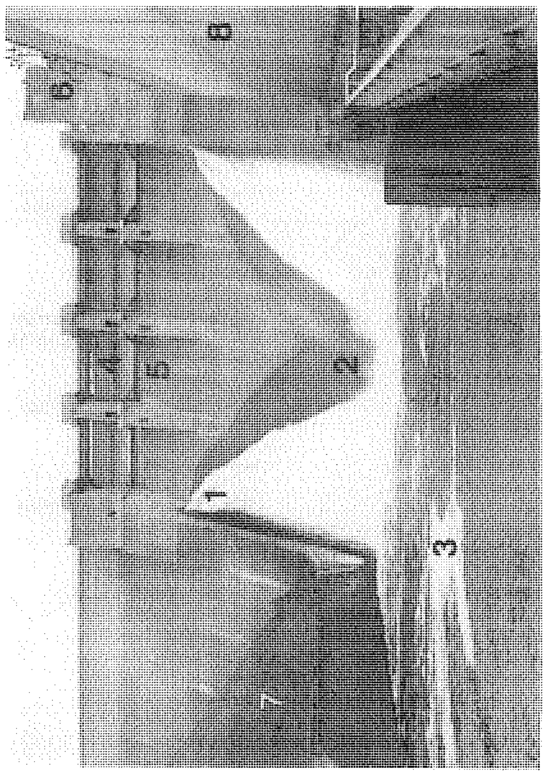


A

B



C



D

between a north-flowing tributary of the ancestral Kinzua Creek on the northeast and a west-flowing tributary of the ancestral Conewango Creek on the west. Both these ancestral stream systems drained northward into the St. Lawrence prior to the onset of Pleistocene glaciation. Originally recognized by Carll (1880), the col was located at Big Bend, 1000 feet upstream of Kinzua Dam. Modern topographic maps clearly illustrate the lines of evidence recognized by Carll (Figure 37):

1. The local constriction of the Allegheny valley at Big Bend;
2. The barbed Allegheny River-tributary stream intersections north of the site of the col (particularly that of the Allegheny with modern Kinzua Creek);
3. The normal stream intersections along the reach of the Allegheny west of the col, indicative of westerly flow "in harmony with the present drainage."

The prominent northwest-southeast ridge that marks the site of the Kinzua col is capped by resistant conglomeratic sandstones of the Pottsville Formation (Butts, 1910; Berg and Dodge, 1981). The presence of numerous shallow cols at elevations of 2000 to 2020 feet along this ridge suggests that the Kinzua Col may originally have stood at a similar elevation (Philbrick, 1976). Prior to erosion of the ancient col, the stream configuration must have resembled the current situation at the arrow on Figure 1, where a branch of Hemlock Creek has eroded headward to within a half mile of the Allegheny.

Reduction of the Kinzua col probably took place mainly in early to middle Pleistocene (pre-late Illinoian?) time (see Muller, 1963) and may have spanned several glacial epochs. Impounding of the ancestral Upper Allegheny by an early advance of the continental ice sheet from the north created a huge proglacial lake (Lake Carll of Philbrick, 1976) that filled the ancestral Kinzua and Upper Allegheny drainages to an elevation of about 2000 feet. In time, waters of this temporary lake overflowed southward across the lowest available divide, which

Plate 3. A. Discontinuities in interbedded sandstones and shales of the Venango Formation along PA Route 59 near the south abutment of Kinzua Dam. Bedding (b) is approximately horizontal. Tectonic joints (j: attitude N61W, 77NE) are oriented subparallel to the valley walls and "geotechnically" act the same as stress-release joints.

B. View (west) of the Kinzua Dam and lower end of the Allegheny Reservoir from an overlook on the southeast side of the Kinzua Col. Note the "combination" nature of the dam, concrete on the left and earth-fill on the right.

C. Concrete part of Kinzua Dam, viewed from downstream. Key: 1 = upper sluices; 2 = lower sluices; 3 = stilling basin; 4 = crest gates; 5 = spillway; 6 = pylon office; 7 = edge of earth-fill part of dam; and 8 = Seneca Hydroelectric Station.

D. Seneca Hydroelectric Station, as seen from the crest of Kinzua Dam. The water to the right is in the stilling basin.

happened to be the Kinzua Col, and initiated the downcutting of an 800-foot-deep gorge (Muller, 1963; Philbrick, 1976).

Erosion and subsequent stream capture at the Kinzua Col probably did not take place entirely in one episode of glacial impoundment. Most likely, the col was initially breached during a pre-Illinoian glaciation and then farther lowered by headward erosion of the two ancestral tributary streams in the ensuing interglacial period. Final cutting of the Big-Bend gorge and actual reversal of drainage would then have resulted from the catastrophic discharge of a second glacial lake over the col, probably in the early Illinoian (in keeping with Philbrick's terminology, these lakes could be called Lake Carll I and Lake Carll II).

By late Illinoian time, the modern south-and-west-flowing Allegheny River had eroded its bedrock floor down to an elevation of about 1180 feet at the dam site, and Kinzua Creek had cut its valley down to 1193 feet at the site of Cornplanter Bridge. Maximum entrenchment took place during the Sangamon Interglacial, at which time the Allegheny eroded down to 1087 feet and the Kinzua to 1193 feet. With the onset of late Wisconsinan glaciation, the Sangamon "gorge" at the dam site was filled by more than 100 feet of outwash gravel. These gravels blocked the drainage of Kinzua Creek, resulting in deposition of about 50 feet of lake beds in the Sangamon creek-channel (Figure 39; Philbrick, 1976).

After melting of the late Wisconsinan glacier, the Allegheny River and Kinzua Creek began incising the various deposits that filled their respective valleys. The pre-dam courses of both streams was significantly affected by Wisconsinan and Holocene colluviation and landsliding on the steep bordering slopes. At the dam site, the Allegheny River was pushed partly off the Illinoian shelf by landslide deposits; at the site of Cornplanter Bridge, Kinzua Creek hugged the western bluffs largely because of an immense fill of landslide and colluvial material on the east side of its broad valley (Figure 39).

Construction Materials for the Dam

With one major exception, local sources supplied all of the important construction materials for Kinzua Dam (see Figure 37). Borrow for the impervious section of the earth embankment, as well as much of the material for the random section, was obtained downslope of relocated PA Route 59 on the outside of Big Bend; a colluvial slope about 2 miles upstream on the west side of the river supplied the remainder of the random fill. Fine alluvial sands from Dixon Island downstream of the dam and from other upstream islands now submerged by the reservoir provided impervious material to fill an upstream cutoff trench; this trench—which extended to bedrock between the edge of the upstream blanket and the north bank of the river channel—was designed to prevent water from the pervious river channel from passing beneath the upstream blanket and through the embankment foundation (Philbrick, 1976). Sandstone rockfill and riprap was quarried from the Pottsville Formation on top of the bluff directly north of the dam site.

Despite the fact that a ready supply of acceptable concrete aggregate could have been obtained from Wisconsinan outwash gravel on site (see Figure 39A), the contractor negotiated a deal with the Penn Central Railroad to haul—at very low freight rates—coarse aggregate from a limestone quarry at Pleasant Gap in Centre County, Pennsylvania, 165 miles away. Thus, no local gravel was used in the 500,000 yd^3 of concrete for the gravity dam and upstream cutoff wall of the earth embankment (Philbrick, 1976).

INFRASTRUCTURE

Kinzua Dam

Kinzua Dam is a combination concrete gravity-earth fill dam with a gated overflow spillway in the concrete section (Plate 3B). The design of the dam is controlled by the transverse profile of the valley, the concrete section being founded on the bedrock shelf on the south side and the earth section lying over the deep thalweg on the north side (see Figure 39A). Total length of the dam is approximately 1900 feet, and its maximum height above the bed of the Allegheny River is nearly 180 feet (Table 5).

Table 5. Project data: Kinzua Dam and Allegheny Reservoir (U. S. Army Corps of Engineers, Pittsburgh District; T. Emerson, unpublished manuscript; Philbrick, 1976.)

Kinzua Dam	
Maximum height above stream bed (ft)	179
Overall length (ft)	1,877
Concrete section	778.5
Earth embankment	1,098.5
Maximum base widths (ft)	
Concrete section	195
Earth embankment	1,050
Volume of concrete (yd^3)	500,000
Volume of earth-fill	3,000,000
Cost (1958-1966 dollars)	$22,600,000
Allegheny Reservoir	
Length at summer pool (mi)	21
Area (acres)	
Summer pool	12,080
Maximum pool	21,180
Elevation (ft. AT)	
Streambed at dam	1,198
Summer pool	1,328
Maximum pool	1,365

Significant flow-control structures in the concrete section of the dam are as follows (Plate 3C):

Upper Sluice Gates (1). Located just below the spillway (see below), the two 5.75-foot x 10.0-foot upper sluices are used primarily in the warmer, low-flow months of May to October to skim the upper layer of warm water off the surface of the reservoir and discharge it to the river below.

Lower Sluice Gates (2). These six gates (also 5.75 feet x 10.0 feet) are located at the base of the dam. They are used mostly in the winter months when high discharges are required to handle rapid runoff.

Stilling Basin (3). The concrete-lined channel below the dam serves as an energy dissipater and protects the dam and river banks from erosion. Discharged water from both the dam and the Seneca Power Station moves toward the end of the basin where submerged baffles reduce its speed before it comes in contact with the end sill.

Crest Gates (4). Positioned atop the spillway, these four 24-foot x 48-foot gates serve as an overflow control and add an additional 20 feet of flood storage to the reservoir.

Spillway (5). The concrete lip below the crest gates is the "overflow-valve" to insure that the earthen part of the dam is not overtopped in extreme flood events.

Pylon Office (6). The operations center of the dam is situated in the low tower directly south of the spillway. It is connected by satellite communication with the Corps' District Office in Pittsburgh (as well as with other meteorologic and hydrologic recording stations), and houses a variety of hydrologic gauges, gate-operating mechanisms, and computer equipment.

Allegheny Reservoir

Behind Kinzua Dam, the Allegheny Reservoir extends more than 20 miles north up the Allegheny Valley and more than 8 miles south down the Kinzua Creek valley at the normal (summer) pool elevation of 1,328 feet (see Figure 38; Table 5). Total length of the summer-pool shoreline is about 91 miles. Maximum water depth of this recreational pool is 130 feet. The total watershed area behind the dam is 2,100 square miles, or twice the size of the state of Rhode Island.

Operation of the Reservoir

During "normal" years, the reservoir is lowered from the summer-pool elevation in the autumn, winter, and early spring to provide added storage. Three factors make this necessary:

- Lower evapotranspiration in the colder months, due to lower sun angle and virtual shut-down of plant activity.
- More widespread rainfall patterns, especially between October and April, resulting in greater runoff over the drainage basin. (The seasonal demise of ground-covering vegetation also contributes to greater runoff.)
- The development of a winter snowpack, which may account

for 4 to 6 inches of water temporarily stored over the entire basin.

The highest level yet attained by the reservoir occurred in June, 1972, and resulted from the late-stage incursion of Tropical Storm Agnes into the Allegheny watershed. Particularly heavy rains fell about 40 miles east of Kinzua Dam in McKean and Potter Counties and adjacent New York State, where more than 10 inches of precipitation were recorded (mostly on June 22-23) (Sevon, 1972; Bailey and others, 1975). On June 27, the reservoir level peaked at 1,362.17 feet, less than three feet below maximum storage capacity. Prior to the onset of the upstream flood, 585,000 acre-feet of storage was available in the reservoir; 526,000 acre-feet of this storage space was eventually used in holding back the floodwaters. Peak inflow during the event was 88,000 cfs, and peak outflow was 25,000 cfs (Bailey and others, 1975, Table A7). It is estimated that retention of these flood waters in Allegheny Reservoir prevented downstream damages of about $166 million (Philbrick, 1976).

Seneca Power Station

The Seneca Pumped-Storage Hydroelectric Generating Station gives an added economic benefit to the Kinzua Dam, one that was not envisioned when the dam-and-reservoir project was first conceived in the 1930's. Seneca is jointly owned by The Cleveland Electric Illuminating Co. and Pennsylvania Electric Co. (Penelec) and operated by Penelec. The Seneca powerhouse is located adjacent to the stilling basin about 200 feet downstream of the crest of Kinzua Dam (Plate 3D). Allegheny Reservoir serves as the lower (storage) reservoir, and the 100-acre upper (power) reservoir is situated on top of the ridge above PA Route 59 (see Figures 37 and 38).

Aside from the two reservoirs noted above, the major elements of the power station are:

1) A water-intake structure near the south bank of Allegheny Reservoir on the upriver side of the dam.
2) Two 15-foot-diameter steel pipes from the intake structure, through the dam, to the powerhouse.
3) The powerhouse, housing two reversible pump-turbines and one non-reversible turbine.
4) A 22-foot-diameter, steel-and-concrete lined penstock-tunnel extending 1/4-mile into the mountain and more 700 feet up to the upper reservoir.

Operation

During periods of low power demand—such as nights, Sundays, and holidays—Seneca buys inexpensive electricity from conventional power plants to drive the two reversible units, operating as motors and pumps, that lift water from the lower reservoir (via the intake structure, steel pipes, and penstock-tunnel) to fill the upper reservoir. At times of peak-demand during daylight hours, water is released from the upper reservoir to fall through the penstock-tunnel and reversible units (and at certain times, the non-reversible unit) to produce electric power. (The non-reversible unit operates only during periods of water discharge.) Maximum generating capacity of the Seneca Station is 380,000 kw/hr, or enough to serve nearly 400,000 homes.

The operation of the power cycle at Seneca is complicated by the necessity of coordinating water discharge with the Corps' river flow requirements. During power generation, one of the reversible turbines returns all of its discharged water only to the reservoir behind the dam. The other reversible unit discharges either behind the dam or downriver, in keeping with flow requirements. The non-reversible unit discharges only downriver. Thus, when Allegheny Reservoir storage must be conserved, the Station can return all operating water, except the minimum specified release, to storage. When a large downriver discharge from the dam is desired, the station can discharge a correspondingly large amount of water downstream.

This article is in part based on undated pamphlets and maps prepared and/or published by the U. S. Army Corps of Engineers, Pittsburgh District, and the Pennsylvania Electric Company. Particularly useful were the Corps' "Kinzua Dam —a tour from the top," "Instructor/group-leader guide to Kinzua Dam," and "Kinzua Dam and Allegheny Reservoir" *[map], and Penelec's* "Seneca pumped-storage hydroelectric generating station." *Mona Becker of Millersville University helped to research the Indian-lands controversy.*

Leave Stop 4. **CROSS KINZUA DAM.**

ALTERNATE ROUTE TO STOP 5. Normally it is not permissible to cross the dam in motor vehicles. Therefore, the following alternate route is provided.

	Leave Stop 4. **CONTINUE STRAIGHT AHEAD** following PA Route 59 West.
6.7	**STOP LIGHT. TURN RIGHT** onto US Route 6 West.
0.2	**STOP LIGHT. TURN RIGHT** onto Business US Route 6 West. Cross the Allegheny River.
0.2	**TURN RIGHT** onto paved road at Allegheny River Hotel immediately after crossing bridge.
6.0	Cross creek issuing from gully of Stop 5.
0.1	Parking area on right is mileage 38.1 on regular road log.
0.2	Parking area on right for Stop 5 is mileage 37.9 on regular road log.

REGULAR ROAD LOG.

0.4	37.1	**TURN LEFT** at north end of dam. Note boulders and blocks on colluvial slope ahead on right.
0.4	37.5	Drive through Allegheny National Fish Hatchery.
0.4	37.9	Parking area on left just before large block of cross-bedded Knapp on left side of road and partly "chewed" block on right.

STOP 5. DIXON GULLY: BEDROCK AND SURFICIAL GEOLOGY

Discussants: Bedrock: Michael Moore and Clifford H. Dodge
Surficial: W. D. Sevon

INTRODUCTION

In the vicinity of Dixon gully, bedrock exposures and float comprise elements of the Venango, Oswayo, Knapp, and Pottsville Formations. As was seen during the climb, blocks of sandstone and conglomerate of the Pottsville and Knapp dominate the float.

The rocks and rugged beauty of Dixon gully have long captivated geologists. The geology of the gully was initially described by John F. Carll (1883, p. 301) of the Second Geological Survey of Pennsylvania (1874-1889). It was later reexamined by Charles Butts, U.S. Geological Survey, in 1907 during his field investigations for the Geologic Atlas of the Warren 15-Minute Quadrangle (Butts, 1910).

The main bedrock feature at Dixon is a spectacular exposure of the Knapp Formation (Site 1, Figure 40), one of the most accessible of many similar outcrops along the Allegheny River valley between Warren and Big Bend (Kinzua Dam). The cliff-forming Knapp is about 30 feet thick here. The top of this exposure is approximately 35 feet below the top of the Knapp Formation and 65 feet below the base of the Pottsville Formation. Total thickness of the Knapp is about 115 feet in the vicinity of Dixon Gully.

Rocks of the Pottsville Formation are described in the surficial geology part of this stop and at Stops 3 and 8 and are not discussed further here. Limited exposures of the Oswayo and Venango Formations will be described briefly and can be observed during the walk down the trail to the buses (Site 3, Figure 40).

GEOLOGY OF THE KNAPP FORMATION

Description

The general description of the Knapp Formation in Warren County is given on pages 12-13 of this guidebook. The Knapp was studied at two sites near Dixon Gully. Site 1 (Figure 40) will be examined during the Field Conference. Site 2 (Figure 40) is located about 0.3 mile to the southeast but will not be visited by conference attendees, instead, they can examine float blocks from that exposure which have been conveniently placed near the buses. The exposures at Site 2 appear to be stratigraphically equivalent to the section at Site 1. The rocks at Sites 1 and 2 are subdivided into four lithofacies on the basis of sedimentary structures and lithologic associations.

Lithofacies I

This unit consists of planar-crossbedded, very light gray pebbly sandstone and extraformational conglomerate (Plate 4A). The pebbles are mostly milky-white quartz, well rounded, discoidal, and occasionally imbricated. Pebble sizes range from

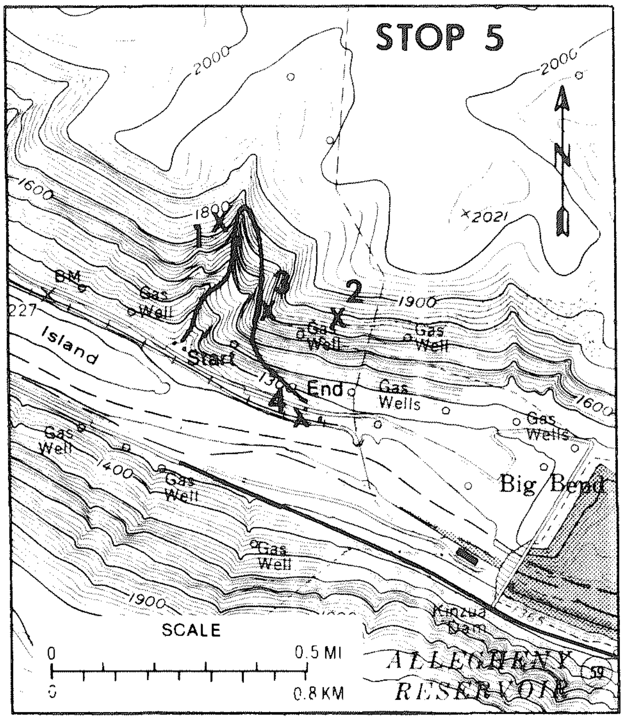


Figure 40. Map of Stop 5 showing suggested route of travel and points of discussion for the bedrock geology. Map from the Clarendon 7.5-minute quadrangle.

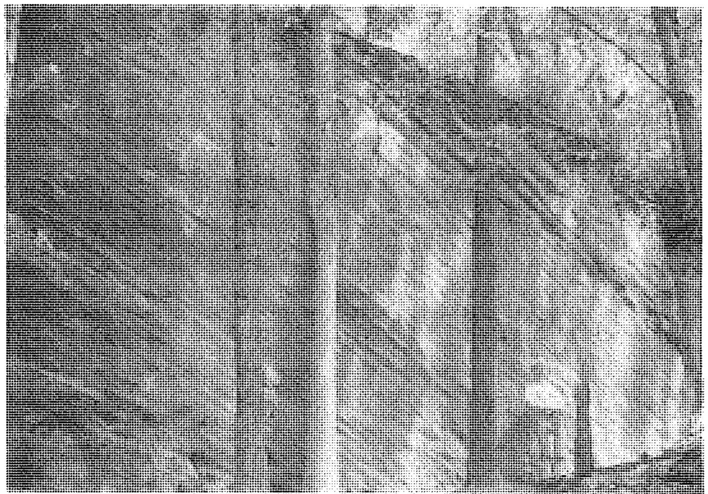
granules to medium with a few scattered large pebbles. The conglomerates are generally matrix supported. The sandstone beds and matrix are commonly medium to very coarse grained. Fossils have not been observed. Normally graded bedding is common.

The outcrop is composed of a single planar-tabular crossbed set up to 17 feet thick (Plate 4A). Individual beds in the set are about 0.4-4 inches thick and contain scattered to abundant (graded) quartz pebbles. A few of the foreset beds are internally planar-crossbedded or ripple-bedded. Some of the smaller scale foresets dip in the opposite direction relative to the larger foresets. Crossbed attitudes of the large foresets are summarized in Figure 41 and yield consistent dips from east to east-northeast.

Lithofacies II

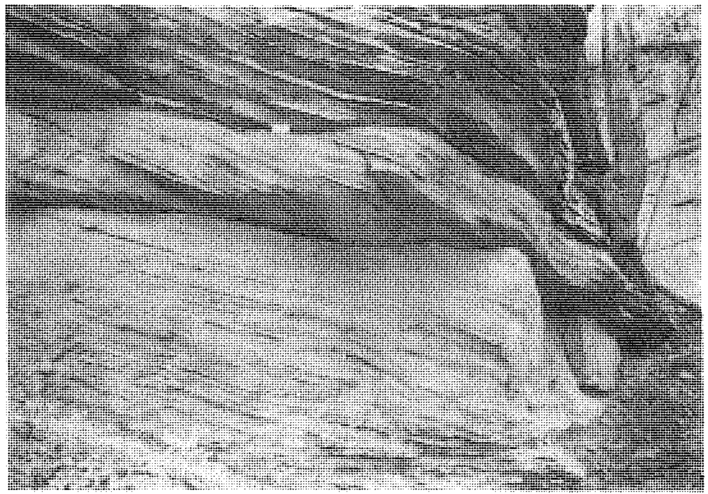
The lowest unit exposed at Site 1, Lithofacies II consists of crossbedded, very light gray sandstone, pebbly sandstone, and extraformational, flat-pebble conglomerate (Plate 4B and 4C).

Plate 4. A. Lithofacies I: 17-foot, angular, crossbed set. Outcrop is located approximately 0.3 mile southeast of Dixon Gully. B. Lithofacies II: tabular crossbeds bounded by planar surfaces. C. Lithofacies II: wedge-shaped, crossbed sets with reactivation (R) surface. D. Lithofacies III: ripple-bedded sandstone. E. Lithofacies IV: example of more massive, mildly trough-crossbedded subunit of the Knapp Formation. F. Example of graded bedding in Lithofacies II.

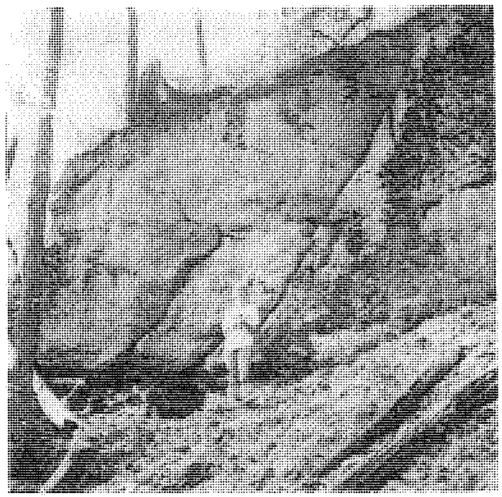


A

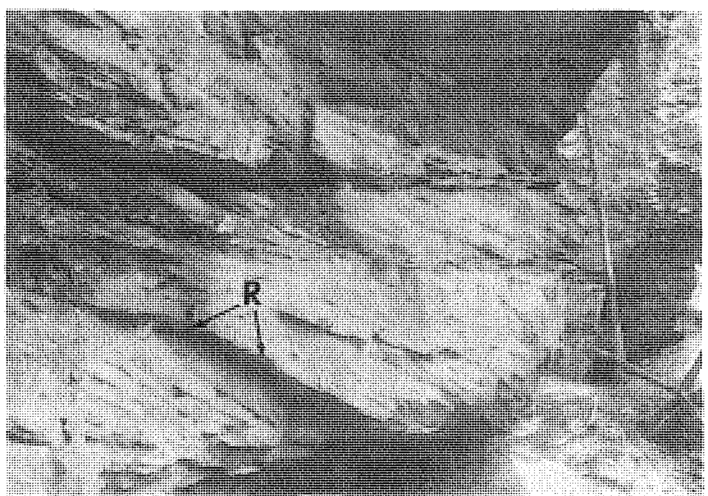
D



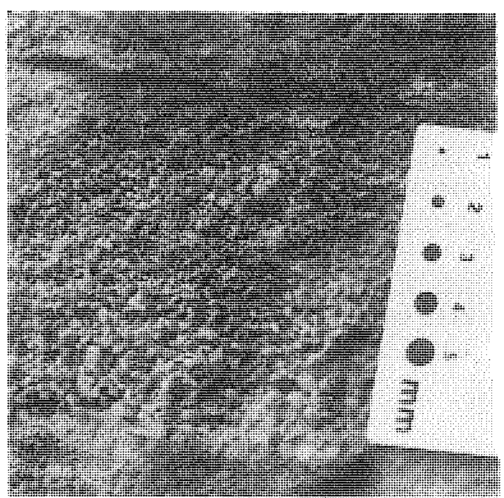
B



E



C



F

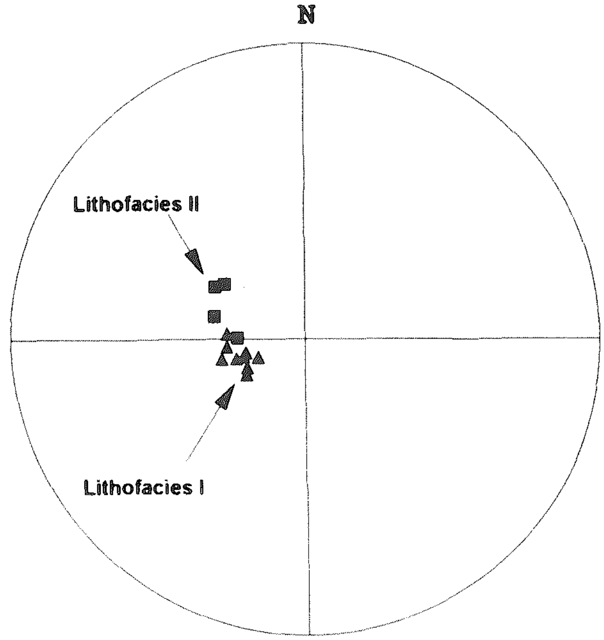


Figure 41. Plot of poles for crossbed attitudes measured in the Knapp Formation at Stop 5.

Both clast and matrix supported conglomerates are present. The sandstones, pebbles, and matrix are similar in composition and grain size to those in Lithofacies I. Many of the beds are normally graded. A few scattered brachiopod shells and plant fragments can be found in the finer grained beds. Crinoid stem plates were found in sandstone float, probably from this unit. Similarly, a single *Paleophycus* burrow was found in pebbly sandstone float that probably came from this Lithofacies.

Lithofacies II comprises one crossbed coset, which typically contains 7 crossbed sets. Despite internal lateral changes, the coset thickness varies only from about 11 to 13 feet. Crossbed sets are commonly tabular to wedge shaped, but more complex geometries are also present. Crossbed sets range from 1 to 3.6 feet thick. Foresets have angular to tangential and locally concave contacts with the lower bounding surfaces of the sets. Individual cross-strata vary in thickness from 1-5 inches but occasionally reach 8 inches. Normally graded beds are common, with pebbles comprising the bottom 1-3 inches of the bed (Plate 4F). The maximum average size of the pebbles is greatest in the lower sets. Pebbles are more scattered and the degree of grading declines near the top of the lithofacies. Reactivation surfaces occur locally.

Crossbed style in Lithofacies II most closely resembles omikron-cross-stratification of Allen (1963). Paleocurrent directions indicated by crossbed attitudes are to the east and east-southeast (Figure 41).

Lithofacies III

Lithofacies III is present toward the east end of the Site

1. The unit is discontinuous and laterally equivalent to much of Lithofacies I. The lithofacies ranges in thickness from 0-8 feet. It is characterized by ripple-bedded, light-gray sandstone and pebbly sandstone (Plate 4D). Several beds are locally conglomeratic. The sandstone is fine to coarse grained and, where conglomeratic, contains scattered quartz granules to small discoidal pebbles. Sinuous, asymmetrical ripple bedding is common. Trough crossbedding occurs locally. Rare brachiopod shell fragments and a few horizontal burrows were observed. The few paleocurrent measurements made indicate a direction almost due east.

Lithofacies IV

This unit caps the Knapp exposure at Dixon gully and overlies Lithofacies I and III. It consists of very light gray sandstone, pebbly sandstone, and extraformational conglomerate. The unit thickens northward from about 12 to 19 feet. Overall the sequence fines upward. The lithofacies is divided into three subunits.

The lowest subunit comprises up to 4 feet of massive, very light gray quartz-pebble conglomerate. The pebbles are generally milky-white, well rounded, discoidal, and small to medium and locally large. The matrix is medium to very coarse grained sand. Concretionary banding is common. The base of the unit is sharp but scoured, displaying up to 4 inches of local relief.

The middle subunit consists of about 3 feet of trough-crossbedded, quartz-pebble conglomerate and conglomeratic sandstone. Clasts are mostly granules to small discoidal pebbles. The lower contact is sharp to slightly wavy. A few brachiopod shell fragments are present locally. Westward, this interval takes on more of the characteristics of the overlying subunit.

The upper subunit of Lithofacies IV is 5-12 feet thick and is composed of trough-crossbedded, medium to very coarse grained sandstone that is locally pebbly (mostly quartz granules). The trough crossbeds are larger and more pronounced than in the underlying subunit. A few scattered brachiopod shells were observed. Several paleocurrent measurements were taken in the middle and upper subunits and are to the north-northeast.

Interpretation

The Knapp Formation is interpreted as offshore bar/beach deposits by Dodge (this guidebook), but the height of the crossbed set in Lithofacies I and the prevalence of normally graded bedding in much of the section at Dixon Gully suggest that a much more detailed analysis needs to be done. Laughrey and Harper (1992, personal communication), after viewing photographs of the Knapp at Dixon Gully, present a strong argument for a fluvial origin. While the fluvial model seems to explain some of the more difficult aspects of the interpretation, such as the scale of the cross strata in Lithofacies I, the discoidal pebbles are more characteristic of beach and nearshore marine environments (Dobkins, 1970). Although less troublesome, the presence of marine fossils in Lithofacies II and III seems to contradict a fluvial model. In the end, both the fluvial and marine interpretations are hampered by a lack of information on the finer grained sediments known to occur in the Knapp. Subsurface data indicates that the coarse grained rocks in the Knapp are usually lenticular, but their geometry is poorly known. Furthermore, little is known about the areal distribution and characteristics of the finer grained lithologies. The limited exposures of the Knapp that were examined for this Field Conference are tantalizing and permit only preliminary understanding of their environments of deposition.

Despite the discrepencies, the evidence does favor a fluvial interpretation. Unfortunately for the Field Conference, Lithofacies I provides the strongest evidence supporting a coastal fluvial origin for the sediments at Dixon Gully. The height of the crossbed set, a foreset dip in excess of 15^{o}, and the fact that it appears to be a solitary set all support its interpretation as an oblique or transverse bar. Lithofacies II through IV can then be interpreted as subordinate barforms or dunes that form in varying combinations of current strength, sediment load, and water depth. The flat, quartz pebbles and fragments of marine fossils could result from the reworking of unconsolidated nearshore marine sediments by the fluvial system. This is consistent with the recognized progradation or regression associated with the Knapp.

GEOLOGY OF THE OSWAYO AND VENANGO FORMATIONS

An overview of the geology of the two formations in Warren County is presented by Dodge (this guidebook). Discontinuous exposures of the lowermost Oswayo Formation and Upper Venango Formation (Site 3, Figure 40) occur from about 200-300 feet vertically below the Knapp outcrop (Site 1) along the east side of the trail leading downhill back to buses.

The Oswayo exposures, totaling about 40 feet, are typically slabby to flaggy, very thin to thin bedded, locally micaceous, very fine grained, light olive gay sandstone. Shale chips and carbonized plant material are present locally. Asymmetrical ripple bedding is common. A few thin interbeds of siltstone and sandy siltshale are present and often ripple bedded.

Exposures of the Venango Formation occur farther to the south and total about 30 feet of section. The outcrops comprise mostly sandstone with some silty sandstone and minor amounts of sandy siltshale, siltshale, and clayshale. Ripple bedding occurs in places. A few scattered shale chips and carbonized plant debris are present locally. Horizontal burrows are few to common.

GEOMORPHOLOGY

A walk up Dixon Gully and back down the old road is a very interesting tour despite the moderately strenuous parts of the uphill climb. Access to the base of the gully is from a small clearing north of the main road and west of the gully stream. A small track leads from the road to the clearing and automobiles can be driven into the clearing and parked there.

At the northeast edge of the clearing, **cross the creek** and **proceed uphill** on the east side of the creek. Note as you cross the creek the upstream, abrupt end of blocky rubble. Downstream from this point the stream has incised about 5-6 feet into a bouldery colluvium which probably extends downslope to the river. Note the size and quantity of rubble in the valley bottom and the relative lack of finer-grained matrix. Consider whether the blocks tumbled downhill or whether they moved by gelifluction with finer-grained matrix which subsequently has been eroded. Note the types of rock comprising the blocks: crossbedded sandstones and conglomerates.

You will encounter a block of conglomerate measured at about 40x27x10 feet lying athwart the east side of the gully. Walk around the west side of the block and onto its top. Note the long, upslope, colluvial mass which is graded to the top of the block. The mass is eroded on both sides. The large block acted as braking block causing jamming of debris behind it.

Continue on upslope moving diagonally left to the creek. The slope will steepen and you should follow the creek. When you reach a section which is very steep, pause, rest, and observe.

Fine-grained matrix exposed by erosion along the creek at this point gives a better visual impression that the blocks are really floating on fine-grained debris which could be mobilized by gelifluction.

Do not follow the creek too closely on this steep section. Walk on the grassy slope to the right. At the top of this steep section is a flat area at the base of short slopes leading to a source ledge, that of the Knapp. Note the general absence of large blocks immediately below the ledge. The slope material resembles talus and may be a late- or post-glacial accumulation. Note the semi-circular form of the gully head. It is similar in form to a cirque basin. Contemplate the possibilites of a small valley glacier or a rock glacier for the valley fill below.

The ledge is well exposed to the left. At one place there is a large block of Olean resting on the edge of the Knapp ledge with two blocks perched on top of it. It is waiting to move on.

After examining the ledge, walk to the right (east) end of the ledge and find the road just above the ledge. This is the route back to the main road. Follow the road downhill. Note the ledge of Olean conglomerate above the road. Because of the wide bedding and joint spacings in that rock, it has contibuted the larger blocks to the valley fill and is the source of the large braking block in the lower part of the gully.

As you walk down the road, note the profile of the first large gully on the left: it appears to be stepped with relatively flat-surfaced lobes behind steep fronts. These could be solifluction lobes or they could be debris piles behind braking blocks.

Some distance farther down the road, the road is crossed by an erosion channel cut since the road was constructed. The head of the scar is at a hairpin turn on the haul road which was used to take material from a hilltop quarry to the dam. Apparently excess water which flows down the road and over the bank has cut this channel. The channel margins below the road have some debris accumulations similar to levees and in places the channel could be interpreted as a debris-avalanche track.

Near the lower part of the slope, the road makes a large curve to the left and then crosses an open area several 10's of feet wide. This is a debris-avalanche track which shows most of the features typical of such tracks. The upper end is in view and bedrock may be at the surface there. The upper end is below the haul road and is separated from it by a few 10's of feet of forest. The track has been excavated by the debris avalanche to a depth of about 3-5 feet and is covered with some debris over its entire length. There is a mound of debris on the east side of the track just above the road level which may represent a levee, but for the most part levees are absent adjacent to this track. There is one tree on the east side of the track upslope from the road that is bent in such a manner as to suggest that it was knocked down by the avalanche and has since grown back to a vertical position.

The end of the debris avalanche is below the road and is best accessed by looping through the forest just east of the track. The end is mounded, has a steep front, and has number of tree trunks protruding from the debris. There are also some young trees growing from this mounded debris which may have grown from buried trees. The debris avalanche occured between 9/16/1968 and 5/23/1971 (dates of aerial photography). Despite the separation of the avalanche track from the haul road, the proximity of the haul road makes it suspect as the source of excess water to trigger the landslide. Note that no trees have grown in this track since it formed over 20 years ago.

From the end of the debris avalanche go straight down the slope to the main road which is in sight.

Leave Stop 5. **CONTINUE STRAIGHT AHEAD** (alternate route users need to turn around).

0.2 38.1 Parking area on left.

0.1 38.2 Cross creek issuing from gully of Stop 5. Note colluviated blocks on slopes ahead on right.

1.7 39.9 Note lack of of colluviated blocks on slopes on right. Source ledge is no longer at top of slope.

2.8 42.7 Oil pumpers and storage tanks on right. In early days of oil exploration, most wells were drilled in the valleys. Logs from the many wells enabled Carll (1880) to do an accurate reconstruction of the pre-glacial drainage of the area.

0.3 43.0 More storage tanks on right.

1.1 44.1 View to right of site of former sand and gravel quarry sited in older (Illinoian ?) material.

0.1 44.2 **STOP SIGN. TURN LEFT** onto Business US Route 6 East. Allegheny River Hotel (est. 1885) is a good eatery. Cross Allegheny River.

0.2 44.4 **STOP LIGHT. TURN RIGHT** onto US Route 6 West. Good view of refinery on right.

1.2 45.6 Old wells with central power on right.

0.6 46.2 **STOP LIGHT. CONTINUE STRAIGHT AHEAD.**

0.8 47.0 **EXIT RIGHT** to Ludlow Street and US Routes 62 and 6 East Business.

0.3 47.3 **BEAR RIGHT** at end of ramp. Get in left lane.

0.1 47.4 **TURN LEFT** into the Holiday Inn parking lot.

END OF DAY I. SEE YOU AT THE BANQUET.

ROAD LOG AND STOP DESCRIPTIONS - DAY 2

Mileage Inc	Cum	
0.0	0.0	Leave parking lot of the Holiday Inn. **TURN RIGHT** onto Ludlow Street.
0.1	0.1	**TURN RIGHT** onto US Route 6 West.
0.1	0.2	Join US Route 6 West.
2.4	2.6	**STOP LIGHT. CONTINUE STRAIGHT AHEAD.**
2.0	4.6	**EXIT RIGHT** onto US Route 62 South - Tionesta. Road to right immediately after crossing over US Route 6 leads to the Forestry Sciences Laboratory, USDA Forest Service, Northeastern Forest Experiment Station and Buckaloons Recreation Area.
0.6	5.2	Cross Allegheny River. Ahead on left is the Blair Distribution Center. Route ahead will travel on the left bank of the Allegheny River as it flows through its narrow valley.
1.0	6.2	Road on left leads to the Grunderville landfill which is developed in Illinoian outwash sands and gravels.
3.4	9.6	Thompson Island historical marker on right. "An advance party of Brodhead's expedition of 1779 into the Seneca Country had a skirmish here with 30 or 40 Indians, the only fighting which took place in that campaign and the only Revolutionary battle in northwestern Pennsylvania." This is the presumed site of a preglacial col between the Upper Allegheny and Middle Allegheny drainage of Leverett (1902) (Figure 23, p. 77)
0.7	10.3	Large colluvial block on left. Lots of colluvial material on slope along road.
6.1	16.4	Indian Paint Hill historical marker on right. "Across the river from here deposits of red ochre and adjacent petroleum springs provided the Indians with raw materials for face and body paint."
4.4	20.8	Bridge to Tidioute on right. **CONTINUE STRAIGHT AHEAD.**
0.4	21.2	The Grandin Well historical marker on right. "At oil spring across river at this point J. L. Grandin began second well drilled specifically for oil, Aug., 1859, after Drake's success. It was dry, showing risks involved in oil drilling."
0.9	22.1	**STOP 6. TIONESTA SAND AND GRAVEL, INC.** Discussants: W. D. Sevon and Samuel W. Berkheiser

The excellent exposures at the Tionesta Sand and Gravel, Inc. operation at Tidioute afford a detailed look at an important economic resource as well as part of the older glacial history of Warren County. Permission to visit this operation must be obtained from the main office in Tionesta.

This sand and gravel deposit, here called the Myers Run site, is a terrace remnant of former valley fill which originated somewhere to the north and continued for an unkown distance down the Allegheny River. Three other terrace remnants occur up

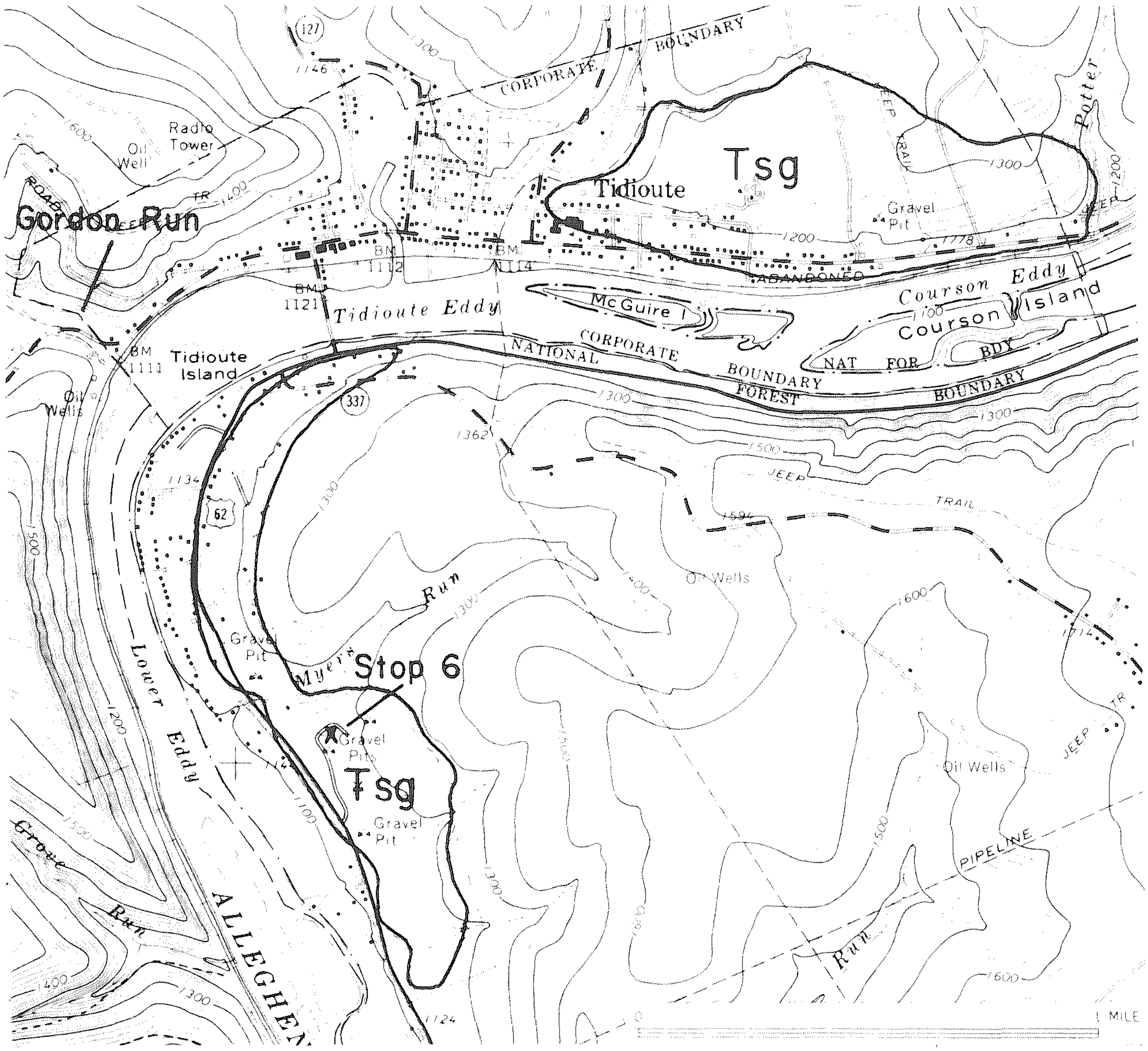


Figure 42. Map of terrace sand and gravel deposits at Tidioute. Tsg = Terrace sand and gravel. Topographic map from the Tidioute 7.5-minute quadrangle.

river: a large deposit underlying Tidioute (Figure 42); a large deposit just east of Irvine opposite the junction of Brokenstraw Creek and the Allegheny River, the Grunderville site; and a smaller deposit at Warren underlying the Oakland Cemetery just south of the junction of Conewango Creek and the Allegheny River. All of these deposits have been eroded and colluviated since deposition which makes it difficult to determine either the upper limit of deposition or the level to which the valley fill may have been graded prior to erosion of the bulk of the fill. However, upper flat-surface elevations of 1320 feet at Oakland Cemetery, 1300 feet at Grunderville, and 1260 feet at Tidioute approximate the present gradient of the Allegheny River and may represent a former surface, probably cut after initial valley fill. Aerial photographs of the Myers Run deposit taken in 1950 and 1958 prior to extensive quarrying show an irregular upper surface which suggests that it was more eroded than the other deposits. Thus, the elevation of 1180 feet for a small flat surface (Figure 42) may represent a lower, cut terrace level. The presence of gravels at about 1300 feet elevation indicate deposition to that level prior to erosion.

The only other known possible correlative terrace deposit downstream from Tidioute is at Oil City, but the information on that deposit given by Leverett (1934, p. 96-97) is inconclusive regarding the reality of a correlation. Some remnant terrace gravels could exist beneath colluvial deposits, but there are almost no probable locations based on topography between Tidioute and Oil City.

These several terrace deposits are considered here to be Illinoian in age, the assignment given them by Leverett (1934). This assignment seems correct because: (1) the terraces are higher than Late Wisconsinan outwash which essentially comprises the modern floodplain and low terraces adjacent to the floodplain, (2) the terrace sands and gravels are more deeply oxidized and leached than Late Wisconsinan sands and gravels, and (3) the terrace sands and gravels are not sufficiently weathered to be pre-Illinoian in age.

The sand and gravel deposits at Stop 6 are an excellent example of glacial outwash. Both crossbedding and horizontal bedding occur. Imbrication of flat pebbles is common. The deposit has moderate quantities of silt and clay, a large quantity of sand and gravel, and no large boulders. The lithologic composition and texture of the Myers Run deposit is variable. Although the amount of sampling is inadequate to tightly quantify variations, some general trends occur (Table 6).

Table 6. Composition data from selected samples collected at Stop 6 and Stop 9.

Attribute	Stop 6 Samples: Upper	Middle	Lower Leached	Lowermost Unleached	Stop 9 Sample
Washing loss	45*	14	12	33	31
Sandstone and siltstone	84	82	77	65	93
Bull quartz	7	3	3	1	<1
Chert	4	9	12	22	6
Shale	<1	5	6	-	<1
Igneous and metamorphic	-	1	<1	2	<1

* Percent

The upper portions of the pit appear to contain mostly crudely stratified, locally derived, weathered and punky flat-pebble and slabby-bedrock material (sandstone and siltstone). The middle portion of the pit appears to contain less weathered and less punky material than the top, as well as, more identifiable, weathered, rounded, igneous and metamorphic rocks. The lowest portion of the pit contains what appears to be a cleaner (less clay), less weathered, outwash gravel that is well stratified and locally cross-stratified. The gravel portion of this lower unit is estimated to contain between 5 to 10 percent foreign rocks (non-indigenous igneous, metamorphic, and sedimentary rocks).

Preliminary analyses of the minus 1/2 inch and plus 3/8 inch fraction of three, 6-foot-long, channel samples from the pit (upper, middle, and lower) confirm a few trends. Sandstone and siltstone abundance increases from 65 percent in the lower part of the deposit to 82 percent near its top, as do rounded, milky-quartz pebbles (1 to 3 percent), and shale fragments (0 to 5 percent). The amount of approximately minus-200-mesh fraction appears highly variable ranging from a low of 12 percent in the oxidized and leached upper part of the deposit to a high of 33 percent in the lowermost active pit. The reason for this is not certain, but it may be due to leaching of carbonate fines because the minus 2 mm fraction of the unoxidized and unleached sample from the lower pit had a 15 percent weight loss after dissolution in HCl. Chert content increases with depth (9 to 22 percent) as do igneous and metamorphic rock content (1 to 2 percent). Thus the overall trend appears to be that of concentration of foreign materials in the lower, earliest deposited part of the deposit with upward dilution by locally derived materials. Unknown is what percentage of claystone and siltstone pebbles and cobbles have or did have carbonate cement or how much limestone was originally present in the deposit.

As can be seen in the lowest bench at the north and northeast end of the active pit, these normally unconsolidated glacial sediments locally become true conglomerates. Carbonate cement is the binding substance and appears to be related to groundwater flow or ponding. Notice the aquaclude directly beneath the 6-inch-thick layer of cemented material on the northeast face. In a deposit with as much as 22 percent chert surviving, up to 15 percent (by weight) of calcareous, minus-2-mm fraction, and unkown quantities of other carbonate bearing rocks, a large amount of carbonate must have entered and exited solution during the post-depositional history of this deposit. The total depth of leaching in this deposit is unknown, but it certainly exceeds 100 feet.

Economic Geology

There is an old adage that states "...to assume...makes an ass out of u and me." It would be easy to assume that the products from this sand and gravel occurrence would fill a high-quality, construction-aggregate, market-niche. After all, the deposit is mostly composed of glacial outwash material occurring less than two miles beyond the front of the mapped Illinoian ice advance (Figure 26) and both the coarse and fine aggregate produced from this site are PennDOT approved (PennDOT, 1991). However, like many things in life, the working of this deposit is ahead of its time. For the most part, Warren County and surrounding Commonwealth counties have populations of less than 100,000 individuals per county, which is a mere token when compared to the varmint population. People consume aggregates, varmints do not.

Tionesta Sand & Gravel, Inc. produces more than 100,000 tons per year of construction aggregate at this site. The majority of the material is dedicated to the production of antiskid (fine aggregate for use on ice- or snow-covered pavements), subbase, and drainage material (J. Sherman, personal communication, 1992). These products play a vital role in society (increased traction and safety of vehicles in the winter, subbase material for new construction and rural road construction and maintenance, and the material to drain water away from pipes such as sewer, water, gas, and oil). However, in the pecking order of construction aggregate prestige, these uses are on the low end of the spectrum. Most of these products sell for less than $5 per ton.

More glamourous (?), newly developed markets that Tionesta Sand & Gravel is developing include "flow zone" stone for landfills (J. Sherman, personal communication, 1992). This is a non-crushed (rounded to subrounded), fine aggregate product used to provide avenues for leachate travel and collection in modern landfills. This type of material needs to be low in total carbonate content.

Most of the higher end-use construction material is consumed in concrete aggregate and to a lesser extent in bituminous surfaces. Most of these minor products sell for more than $5 per ton (J. Sherman, personal communication, 1992).

Mining is accomplished with rubber-tired, front-end loaders hauling face material to the primary crusher and screens. In-pit selective blending, based on years of experience, is required to formulate the desired product (J. Sherman, personal communication, 1992).

Adaptation and innovation have enabled Tionesta Sand & Gravel to make the most of the products that they are able to market. Indeed a similar operation in the southeastern portion of the Commonwealth would be primarily producing bituminous and concrete aggregate. Until the varmints start to consume aggregate or the people population increases, it just goes to show, "...you can not always judge a book by it's cover."

		Leave Stop 6. **TURN RIGHT** onto US Route 62 North.
1.3	23.4	**TURN LEFT** onto PA Route 127 South. Cross the Allegheny River and enter Tidioute.
0.3	23.7	**STOP SIGN. TURN RIGHT** onto Main Street in Tidioute.

The following information is taken from Burgchardt and Fox (1989) and is inserted for its historical significance.

The village of Tidioute was a well known and permanent Indian settlement before the coming of the white man. The name in the Seneca language means "Point of Land." The area was first settled by white men in 1806 and, until 1860, lumbering was the main industry, utilizing the vast expanses of virgin white pine and hemlock of the area. The Allegheny River was the main artery of transportation to all points south. By 1860 there were 400 people living in Tidioute and lumbering was at its peak. In July 1860, the discovery well for the Tidioute area was drilled just below Gordon Run (Figure 42) on the river bank probably near the present day water treatment facility. The discovery well produced only 10 barrels a day, but by the end of the month 60 wells were being drilled at the mouth of Gordon Run.

Tidioute takes credit for several "firsts": (1) the Grandin well (discussed below), (2) the first well casing was used in a well on Tidioute Island in 1861, and (3) the first river crossing of an oil pipeline occurred here.

The Grandin Well Monument can be reached by going left at the west end of the bridge. Park across from the water treatment plant and follow a pathway along Gordon Run to the monument. As you pass over a wooden foot bridge notice the oily water standing in depressions on the right. This is the site of the oil springs which were known long before drilling of the Drake Well. The oil in the spring is believed to be from the Venango Third sand about 140 feet below the spring and is probably migrating up a fracture to valley-fill sand and gravel, or to the Red Valley sand which forms the stream bed of Gordon Run, and which crops out on the hillside above the spring.

Along the path, there is an abandoned building which is the remains of a National Transit Company pump station. At one time there were 13 pipelines coming down Gordon Run which delivered oil into a half dozen large stock tanks. Two are still present several hundred yards up the hollow. The oil was transported by gravity to the tank farm and was then pumped from the tanks through a 3-inch line to Titusville. The installation was shut down around 1963 due to decreasing oil volumes caused by depletion of existing fields. Ironically, abandonment occurred on the eve of the rejuvenation of Appalachian oil production due to the introduction and application of hydrofracturing.

Next to the abandoned pump station is the Grandin Well Monument, commemorating the world's first dry hole. Two days after the Drake Well was successfully completed outside of Titusville, J. L. Grandin of Tidioute heard the story and immediately purchased 30 acres of the farm on which the oil spring was located. He drilled a well at the location of the spring to the depth of 134 feet which at that time was deemed ample for striking oil and was twice the depth of the Drake Well. Grandin ordered tubing for the well and a pump for bringing up the oil. The Pittsburgh company furnishing the pump told him the bore was too small, and that it would have to be at least 4 inches in diameter to handle the pump. After reaming the well to total depth, Grandin decided to run the bit down one more time. He did so, but the bit stuck and he could not get it loose. The driller invented the world's first torpedo by plugging one end of a section of pipe, loading it with blasting powder, and setting if off in the hole. The charge was unsuccessful in freeing the tools, or bringing in oil.

Grandin abandoned the well as a failure, but it became a historic landmark because it was: (1) the first well spudded after Drake's discovery well, (2) the first well in Warren

County, (3) the first fishing job, (4) the first well in which an explosive charge was used, and (5) the world's first dry hole.

A short walk of several hundred feet farther up the path leads to the last tanks which originally served the old pump station. The first refinery in Warren County is believed to have been located near the mouth of Gordon Run.

0.2	23.9	Road intersection. **CONTINUE STRAIGHT AHEAD** on State Route 3007. Route travels here on sand and gravel terrace similar to that at Stop 6.
3.7	27.6	**STOP 7. SEDIMENTOLOGY AND PETROLEUM GEOLOGY OF THE RED VALLEY SAND (VENANGO UPPER SECOND)** Discussants: Assad A. Panah and Edgar M. Hopkins

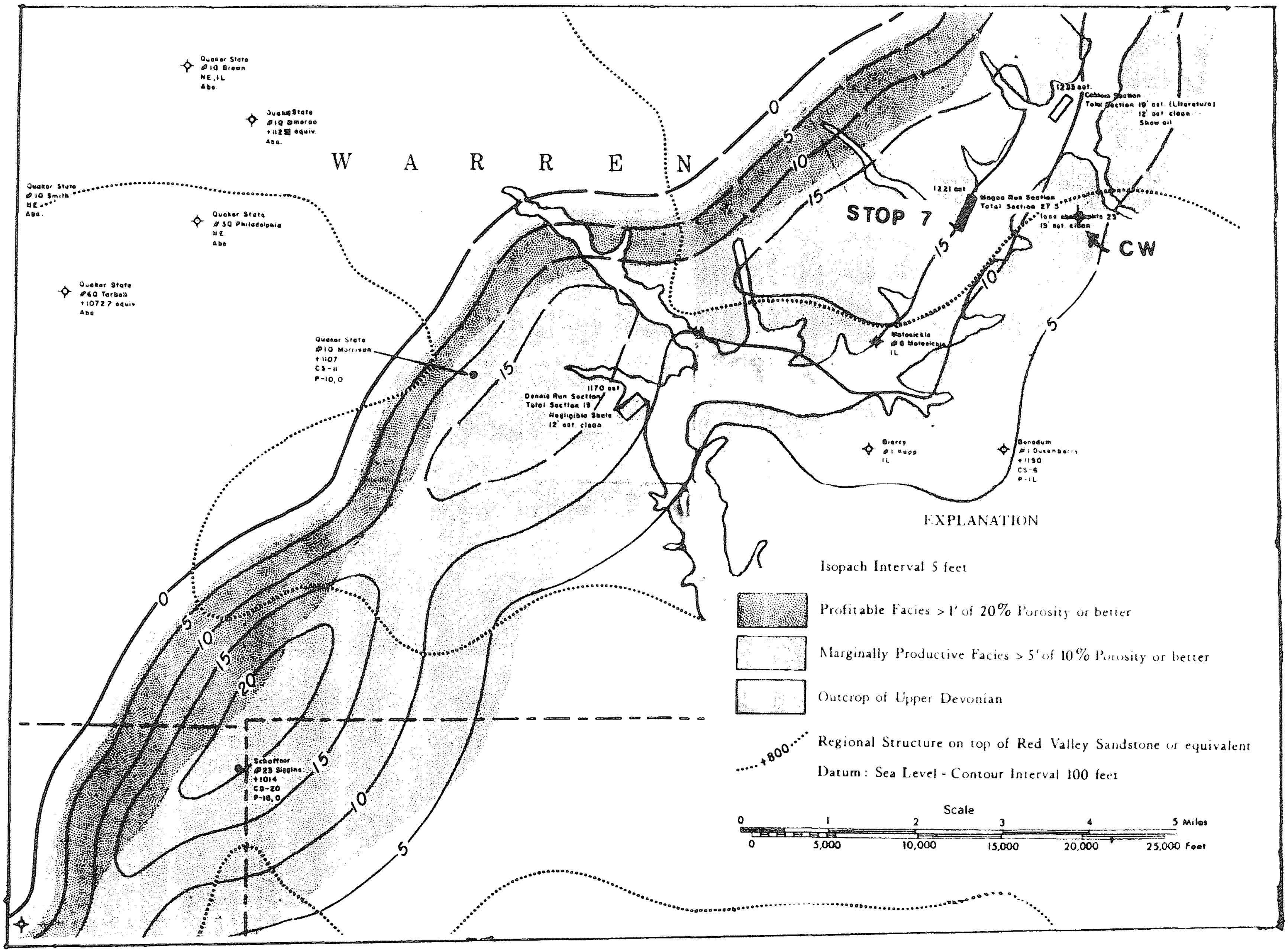
INTRODUCTION

One of the finest Warren County exposures of a Venango reservoir unit is a 1600-foot-long roadcut along the northwest bank of the Allegheny River between Magee and Cobham Station, approximately 2.5 miles northeast of Tidioute, Pennsylvania (Figure 43). The laterally continuous and readily accessible Red Valley "Sand" exposure along the northwest side of the road provides a unique opportunity to study the environments of deposition and reservoir properties of a major Upper Devonian oil sand along the actual reservoir sandbody (Figure 43). The rock units seen here can be recognized in surrounding well logs and in photographs of a core from the surrounding subsurface.

The Red Valley Sand is also known locally as the Venango Upper Second Sand and the Lytle Sand. This outcrop was first noted by Carll (1880) and later by Cahn (1940) in his thesis on the origin of the Venango "Second Sands." Kelley (1967) noted this outcrop on his "clean sand" isopach map (his Plate II), but does not discuss or describe it . Nevertheless, his study on the Red Valley Sand is one of the most thorough studies on the petroleum geology of a single reservoir unit in the northern part of the state's oil field belt. It also is comprehensive in interpretation of the Venango sand reservoirs. Generally, the hypothesis is advanced that most, if not all, of the Venango reservoirs are regressive-climax coastal deposits, with the transgressive phases represented by thin conglomeratic "caprocks" found above the reservoir sands. Also, the association of thin redbeds with the reservoir build-ups and their landward thickening west of the build-ups is documented and is key to the interpretation that the oil pools in each of the Venango sands formed at the distal "turn around point" of the shoreline in a progradational clastic wedge (Kelley, 1967).

OUTCROP STRATIGRAPHY

During this past spring and summer we have made more than six visits to this outcrop. The exposed rocks are divided into eight informal units alternating between shale and sandstone, with sandstone predominating. Figure 44 is a vertical section displaying these units; also shown is the correlation with a


W A R R E N
STOP 7
CW
Quaker State
#10 Brown
NE, IL
Abs.
#10
Abs.
Quaker State
#10 Smith
Abs.
Quaker State
#30 Philadelphia
Abs
Quaker State
#60 Tarbell
+1072.7 equiv
Abs
Quaker State
#10 Morrison
+1107
CS-11
P-10,0
1170 est
Dennis Run Section
Total Section 19
Negligible Shale
12' est. clean
1221 est
Magee Run Section
Total Section 27.5
15' est. clean
Total Section 19' est. (Literature)
12' est clean
Show oil
#6 Motosickle
IL
#1 Kapp
IL
Benedum
+1150
CS-6
P-IL
Schaffner
#23 Siggins
+1014
CS-20
P-16,0
0
5
10
15
20
EXPLANATION
Isopach Interval 5 feet
Profitable Facies > 1' of 20% Porosity or better
Marginally Productive Facies > 5' of 10% Porosity or better
Outcrop of Upper Devonian
+800
Regional Structure on top of Red Valley Sandstone or equivalent
Datum: Sea Level - Contour Interval 100 feet
Scale
0
1
2
3
4
5 Miles
0
5,000
10,000
15,000
20,000
25,000 Feet

gamma-ray log from a well approximately 1.5 miles to the east. These sections and other logs from the Red Valley Sand fairway through eastern Elk County indicate that the Red Valley generally consists of two sandstone units separated by a thin shale; at the center of the sandstone "thick" the shale pinches out (Kelly, 1967). At Stop 7, the lower sandstone reaches a local maximum thickness of 15.5 feet and the upper sandstone reaches 9 feet. The intervening shale is 2 to 3 feet thick. These are designated as Units 4, 5, and 6 in ascending order (Figure 44).

Less than 10 feet of strata are exposed beneath the Red Valley at Stop 7. Alternating sandstone and shale beds here are designated as Units 1, 2, and 3 in ascending order. Slightly more than 10 feet is exposed above the Red Valley; a 5-foot-thick shale bed is overlain by a 6-foot-thick, "ratty" (broken) sandstone bed. These are designated as Units 7 and 8 respectively. An outcrop 3.4 miles to the northeast provides some information about the strata overlying the Red Valley but not exposed at Stop 7. This outcrop displays about 15 to 20 feet of a "gutter-cast facies" consisting of abundant sandstone gutter casts in a dark gray shale, covered by a 3- to 5-foot-thick sand (Plate 5).

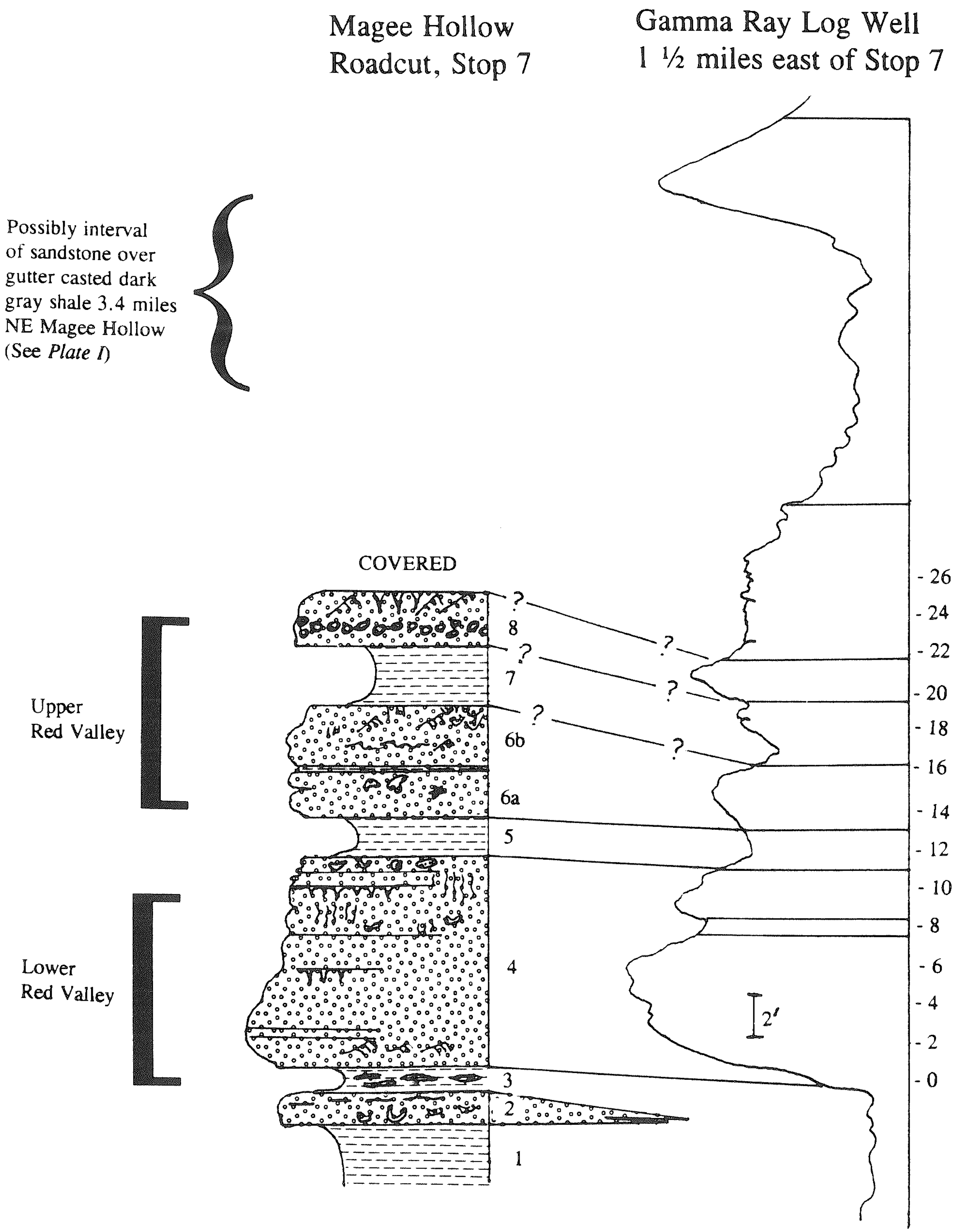
Exposures Below the Red Valley

Below the Red Valley sand, in ascending order, are Units 1, 2, and 3 (Figure 44). Unit 1 consists of 6 feet of light gray fissile to cobbly (where bioturbated) clay shale. Thin, light brown, micaceous, siltstone lenses and blebs less than 0.5 inch in thickness are scattered through this shale. Only a single partial brachiopod (or pelecypod) fossil, which disintegrated before identification could be made, was found in a diligent search of this unit.

Unit 2 is a 1.5-foot thick, light olive-gray sandstone that is fine to medium grained, thin to medium bedded, possibly laminated and parted by shale towards the top. It changes thickness along the outcrop and splits into a one-foot-thick lower layer and a 4-6-inch-thick upper layer separated by a thin clay shale. It is slightly petroliferous in spots. The top of the unit has both interference and flat-topped ripples. One-half inch trace fossils, irregular "bumps," occur on the base of this sandstone. At another locality, 2.5-inch *Rhizocorallium* (?) (reclining, U-shaped burrow-fills) protrude from the underside of this bed. Clay clasts 0.5 to 2 inches long, varying from flakes to flat pebbles, are found along some bedding planes. Brachiopod molds occur at one locality.

Unit 3 varies from 1 to 3 feet in thickness. It is a gray-brown, clay shale containing medium grained, ripple-form and flatter, sandstone lenses 0.25 to 1.5 inches thick. Thicker lenses are near the bottom and top of the bed. The top of one sand lens contains current ripples indicating south-southwest

Figure 43. Location map for Stop 7, the Magee Run section. Red Valley sand clean sand map after Kelley, 1967. CW = well location, see log, Figure 44.


Magee Hollow
Roadcut, Stop 7
Gamma Ray Log Well
1 ½ miles east of Stop 7
Possibly interval
of sandstone over
gutter casted dark
gray shale 3.4 miles
NE Magee Hollow
(See *Plate I*)
COVERED
Upper
Red Valley
Lower
Red Valley
8
7
6b
6a
5
4
3
2
1
?
2'
26
24
22
20
18
16
14
12
10
8
6
4
2
0

transport. Runzel marks (foam lines?) occur on the top of one sand lens. Some sandstone lenses contain tiny vertical burrows.

Lower Red Valley Sand Description

Unit 4, the "lower Red Valley Sand," is a 12- to 15.5-foot-thick, pale yellowish gray, fine- to medium-grained, silica-cemented sandstone. It is generally thick bedded, except at the top where it is thin bedded, greenish in color, with some red claystone intraclasts (Figure 44).

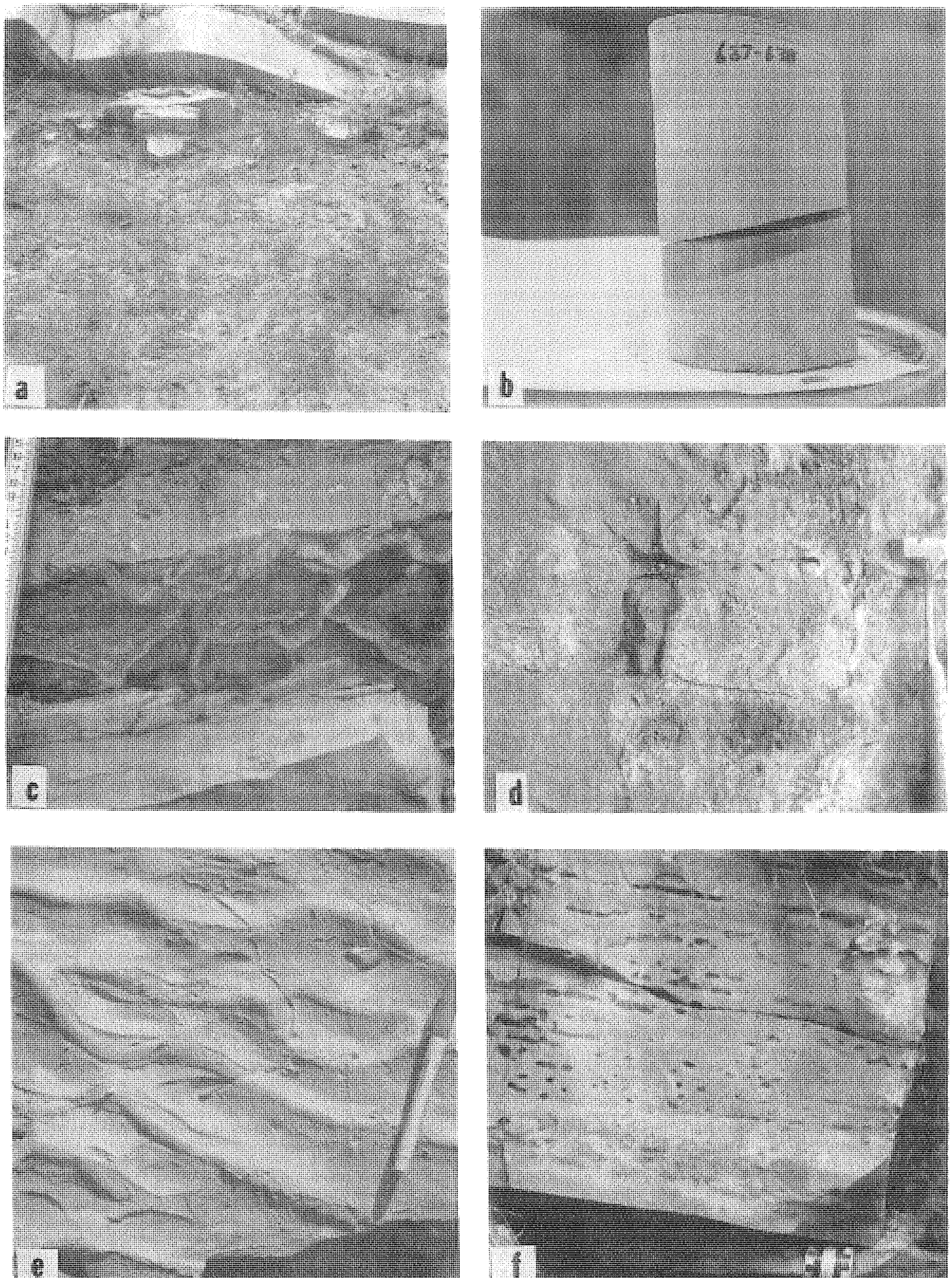
Except at shale partings, bedding is generally indistinct in Unit 4. Parallel lamination and ripple crossbedding predominate over large-scale crossbedding. The upper and central parts of this unit contain large-scale, low-angle (accretionary), laminated layers, some topped by small-scale crossbedding. Ripple marks, common beneath numerous shale partings, are best developed near the top of the unit. Also near the top of Unit 4, well-developed mudcrack fillings totally penetrate a claystone bed several inches thick (Plate 5). Some smaller mudcracks also occur in the middle and near the base of this unit. Claystone intraclasts are common at the bases of sandstone beds throughout the unit. Towards the bottom it is micaceous, with numerous shale partings and occasional 0.5- to several-inch pieces of fossil wood (Figure 44).

Bedding-plane trace fossils include *Cruziana* (?) (double grooved furrows) and *Glockeria* (?) (radial spokes). *Skolithos* (?) (very small, vertical, slightly irregular, shale-filled burrows) penetrate the top few inches of sandstone beds which range from several inches thick near the top to several feet thick lower in the unit. The thin-bedded, greenish sand at the top of this unit contains small (white) horizontal burrows. Several relatively continuous 8-inch- to 1-foot-thick zones within the middle and upper part of the unit have abundant secondary iron cementation and are weakly concretionary. Most paleocurrent measurements in this sand indicate south-southeast flow. Bipolar crossbedding was noted at one locality.

Upper Red Valley Sand Description

Unit 5 separates the lower and the upper Red Valley Sand. It is a 2- to 3-foot-thick, deep red, silty shale, containing "floating" coarse sand grains (Figure 44). It becomes increasingly sandy towards the top, changing to bioturbated (?), green-colored, muddy sandstone with purple, claystone pebbles in the top 6 inches. The shale is unfossiliferous and quite featureless, possibly homogenized by burrowing. It does display small shiny surfaces marked by dendrite-like specks. Could these

Figure 44. Vertical measured section showing lower and upper Red Valley sandstone and correlation with a well 1.5 miles to the east. Symbols are from Compton (1962), or see text (ripples, mudcracks, tubular horizontal burrows and string-like vertical burrows, pisolites at top of Unit 4, conglomerate, and echinoderms are shown).


a
b
c
d
e
f

be a type of root structure?

The upper Red Valley is designated as Unit 6. It is about 8 feet thick (Figure 44). The lower 3 feet are distinctive: two green-brown mottled, medium- to coarse-grained, poorly sorted, dirty, sandstone beds containing layers of flat quartz pebbles are separated by a thin shale bed. At the top of the upper, 20-inch thick, green, sand bed are claystone clasts, small concretionary spherules (pisolites?), and quartz pebbles. A "mini" ball-and-pillow structure was noted in the middle of the bed. A 0.75-inch-diameter, horizontal, tubular, burrow fill forms a horseshoe shape 5 inches across within this bed (Plate 5). At the top, more typical burrowing has introduced clay from a 6-inch shale overlying this bed. The thin overlying shale is gray brown and has medium-grained, sandstone lenses less than 0.5 inch thick. An unusual sand-filled burrow beneath one of these sandstone lenses is barrel-shaped and decorated with vertical "claw" marks (Plate 5).

The upper 5 feet of Unit 6 is light gray to yellowish-gray, fine-grained sandstone. Some layers with claystone clasts occur. It is thickly bedded, especially in a lower 2.5-foot bed, which has a very blocky weathered appearance. The top of this bed has thin, ripple-marked, sandstone layers. Occasionally a shale up to a foot thick separates this sandstone bed from the overlying 2-foot-thick sandstone. The base of this next sandstone displays double-furrowed trails which connect to "splayed out," bulbous, burrow fills (Plate 5). Its top has linguoid ripples with rounded crests, and tiny vertical burrows. Above this is less than 6 inches of thin sandstone beds with shale partings. A climb above the road cut located a tiny stream channel exposing this sandstone bed. In the middle this sandstone has large scale (planar?) crossbedding to the south-southeast and is horizontally layered above and below this.

Exposures Above the Red Valley

Above the upper Red Valley Sand is 5 feet of poorly exposed

Plate 5. Sedimentary features of the Red Valley Sandstone. a. "Gutter-cast facies" thought to overlie red valley sandstone 4.3 miles north of Stop 7. Note multistoried large gutter cast under sheet sandstone. Smaller gutters seen in horizons throughout shale. These are thought to be proximal shales, with most sand bypassing this area. Overlying sandstone has ripples, fossil wood, burrows. b. Red Valley Sand "pay" from a well many miles south. Note two cycles of sand deposition, separated by clay shale. Upper sand coarsens up and is laminated. Probable tidal cycles. c. Large mudcrack fillings near top of Unit 4; note red shale (at 750-foot marker). d. Unusual "packed" horizontal burrow fills, possibly allochthonous, resting in swale of underlying sand bed (at 850-foot marker). e. Round-topped ripples, Unit 4. f. Unit 4, blocky weathering with low angle to horizontal lamination. Note claystone pebble solution vugs, associated with ankerite cement.

gray shale containing some sandstone beds (Unit 7) (Figure 44). In ascending order are a 2.5-foot-thick shale, a 1.5-foot-thick sandstone with thin, horizontal bedding, and a thin shale obscured by cover. Above this is another sandy bed (Unit 8), which is poorly exposed, but may be up to 6 feet thick. The bed seems to thicken towards the north. It consists of a basal 1- to to 2-foot-thick sandstone overlain by a 3-foot-thick, more shaly section topped by another sandstone. Some small scale cross-bedding and crinoid ossicles occur. A 1-foot-thick bed is rippled and cut by *Monocraterion* (?) (vertical burrows with a golf tee shape). The top of the basal bed in this unit is a "carpet-like," discoidal, quartz-pebble conglomerate. This may be significant because Kelley notes thin, transgressive lag conglomerates over what he infers to be predominantly regressive Venango reservoir units.

PALEOENVIRONMENTAL INTERPRETATION

The previous work of Kelley (1967) establishes a north-easterly linear trend for the thickest "clean" Red Valley Sand (Figure 43), and a northwesterly (offshore) facies change to dark gray shales and southeasterly (onshore) change to redbeds. A nearshore bar/beach origin is attributed to this reservoir sand by Kelley (1967).

The Red Valley appears in outcrop to be bracketed by marine strata, as marine fossils occasionally occur below and above it (Figure 44). Both units comprising the Red Valley (Units 4 and 6) also contain rare brachiopods. The large variety of trace fossils and interference ripples also suggest marine influence. Therefore, exposure features such as the mudcracks and flat-topped ripples in Unit 4 prove an intertidal deposit rather than a supratidal one. The accretionary bedding, shale partings, and burrowed tops of sand beds in this lower sand suggest a low-tidal flat or tidal creek/channel deposit. The general lack of shell pavements and shallowness of channeling indicated by limited thickness of accretionary sedimentation units argues for the former interpretation.

A backbarrier intertidal environment for the lower Red Valley Sand is consistent with Kelley's (1967) interpretation, because the "clean" sandstone body occurs immediately to the west.

The red shale separating the two sandstone units of the Red Valley, along with the contiguous green sandstones, are taken to represent a non-marine setting. The red shale may be a marsh or a supratidal flat. The associated conglomeratic green sandstone may include paleosol derivatives, and probably represents sluggish stream deposits meandering across supratidal(?) marshes. There is no marine aspect to these beds to suggest a marine erosion surface, although the bed at the top of the red shale is thought to underlie a possible hiatal surface.

Considering the marine strata above and below the Red Valley and the probable nonmarine strata within it, the interpretation of Kelley (1967) is probably correct with respect to the regressive nature of the lower units and transgressive nature of the strata above the Red Valley sandstone unit. It is not clear how much of the sandstone Kelley viewed as being transgressive, but he refers to sandstone above varicolored beds and may have intended to lump the variable thickness, upper sand (Unit 6 of the outcrop) with the overlying conglomeratic beds. At any rate, it appears that the upper part of the Red Valley Sand (Unit 6) is part of the transgressive phase of deposition. With its (rare) brachiopods, interference ripples, and south-southeast directed crossbedding, it represents a subtidal upper shore-face to foreshore depositional environment, perhaps also including overwash deposits. Most of the above-sea-level portion of the ancient barrier has presumably been eliminated by ravinement during transgression. Paleocurrent measurements from ripples indicate largely onshore (southeast) and shore-parallel (southwest) flow. Continued transgression probably introduced the overlying shale (Unit 7) of the lower shore face onto the foreshore and upper shoreface deposit (Unit 6). Unit 8 may be a deeper water inner-shelf deposit which represents a deeper scouring zone, perhaps related to storm waves.

The inferred overlying section exposed several miles to the northeast is representative of more open marine conditions. The abundance of gutter casts in these marine shales probably indicates a nearshore environment where storm relaxation currents flowing directly or obliquely offshore erode mud and bypass sand to deeper, lower energy areas (Myrow, 1992). Such a gutter-cast facies is probably unrecognized in drill holes considering the small volume of sand, but differentiating it from pure shale sections may be important for determining proximality trends and shelf versus shoreline nature of some of the sandstones encountered in the Venango Group.

No presumably deeper, shelf-coquinitic tempestites are reported nor have been seen by us in Warren County Venango Group outcrops. However, Baird and Lash (1991) report such a "Chemung/Chadakoin" magnafacies through much of the Venango some 30 miles to the west and northeast, in Erie County, Pennsylvania and Chautauqua County, New York, respectively. Such a facies completes the onshore-offshore transition of sandy deposits for the Venango, like that displayed by each of the lower progradational wedges of the Catskill tectonic delta complex.

There appear to be subtle differences between the lithology of the Venango Group wedge and the older Bradford and Elk Group wedges (see Hopkins, this guidebook). Did the basin subsidence rate decline with time through the Late Devonian or had the strata merely extended across a fixed-basin hinge line onto a more stable crustal forebulge, as the Catskill coarse clastic sediments filled more and more of the Acadian side of the Appalachian Basin? Can the subtle paleoenvironmental changes alluded to, if real for the Upper Devonian, be extended into the Mississippian/Pennsylvanian strata of the Appalachian Basin?

RED VALLEY SAND PETROGRAPHY

Thin Section Descriptions

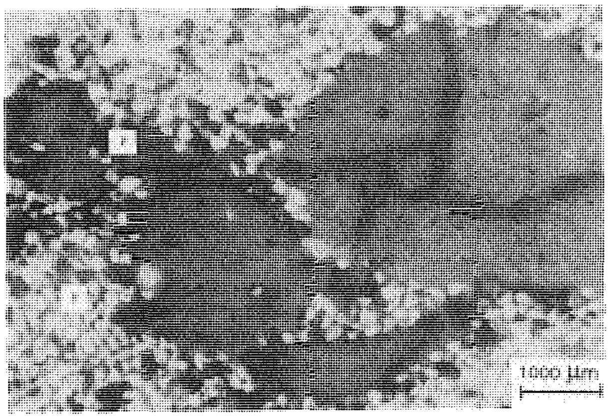
A total of 19 thin sections from four sandstone units of the Venango Group collected from Tidioute, Pennsylvania, have been described using Folk's (1980) sandstone classification scheme. The results are preliminary because no point counts were made. Venango sand petrography has been reported from other areas by Harper and Laughrey (1989).

Do the mineralogical characteristics of these sandstones lead us to the tectonic and lithologic conditions of the source area? The Red Valley sandstones examined are transitional to mineralogically mature rocks, mostly sublitharenites to subarkoses, which probably signifies a combination of relatively mineralogically immature source rocks, and a long transport history and high energy environments of deposition.

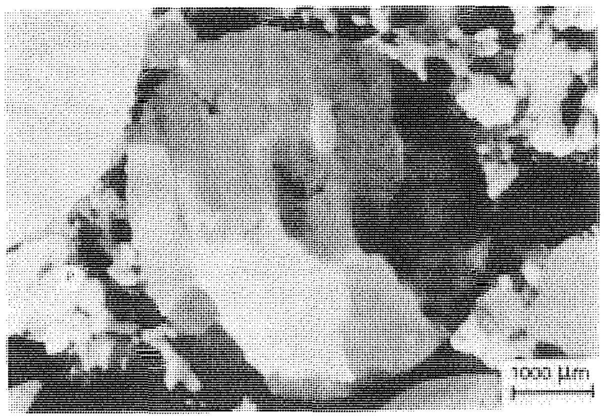
The presence of metamorphic rock fragments, vein quartz, polycrystalline metaquartz, and schistose and stretched-metamorphic quartz indicates that these detrital grains originated from a metasedimentary source (Plate 6).

The Acadian Mountains were experiencing thrusting and (Taconic) metasedimentary rocks were being exposed. The absence of labile metasedimentary rock fragments from framework grains attests to the fact that the source area was distant and separ-

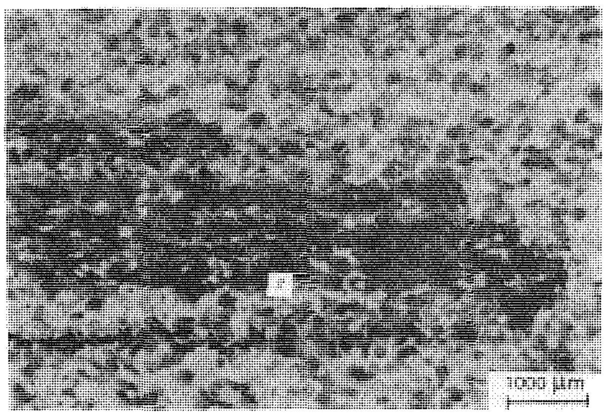
Plate 6. Thin-section photomicrographs showing lithologic characteristics of the Red Valley "Sand" (Stop 7). a. Rip-up mud clasts formed during a dessication stage enclosed in fine-grained, micaceous, porous, feldspar-bearing, siliceous sublitharenite. Note the presence of fracture porosity developed along non-systematic micro-joints in mud clasts. F = Feldspar; P = Pore spaces, both intergranular and fracture porosity (dark). Plane-polarized light (Unit 2). b. Fine- to coarse-grained, bimodal, porous (P), conglomeratic sandstone. Note well-rounded pebbles of composite metamorphic quartz with undulose extinction. Cross-polarized light. From above the Red Valley 2 miles north of Stop 7. c. Very coarse grained siltstone to very fine grained, limonite-rich sandstone with lamination and porosity. Lamination was disrupted on the right by burrowing. P = pore space; F = feldspar. Plane-polarized light (Unit 4). d. The same sample as in b, showing a composite stretched metamorphic quartz pebble (STM) with crenulated (C) and granulated (G) boundaries. Note the strained quartz pebble (SD) on the left. Cross-polarized light with gypsum plate. e. Sandy, siliceous, quartz conglomerate showing a vein-quartz grain which contains abundant inclusions of vermicular chlorite (VC). Note quartz overgrowths (QO) in the upper right corner. (Unit 8). f. The same sample as in e. Epoxy (in shades of gray) impregnated sand grains to illustrate typical pore shapes (P) and dominating intergranular porosity. Plane-polarized light (Unit 8).



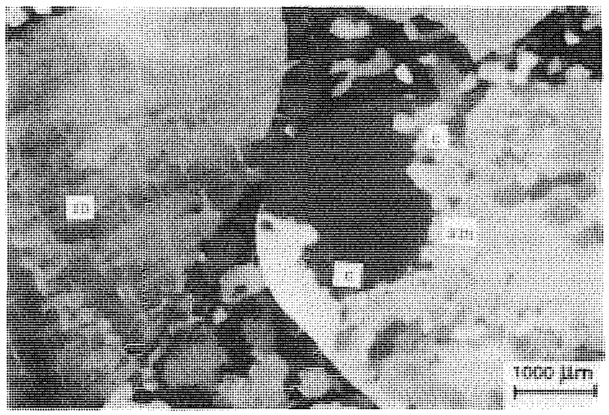
a



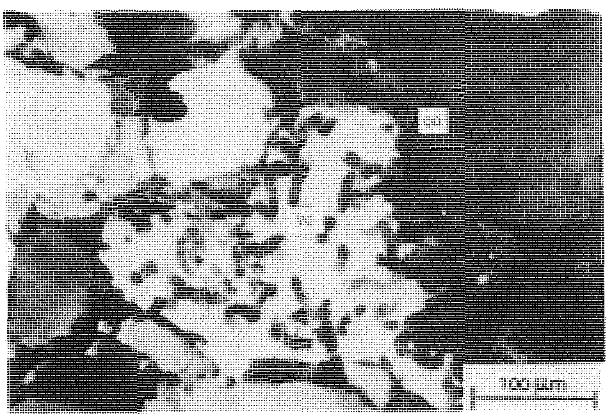
b



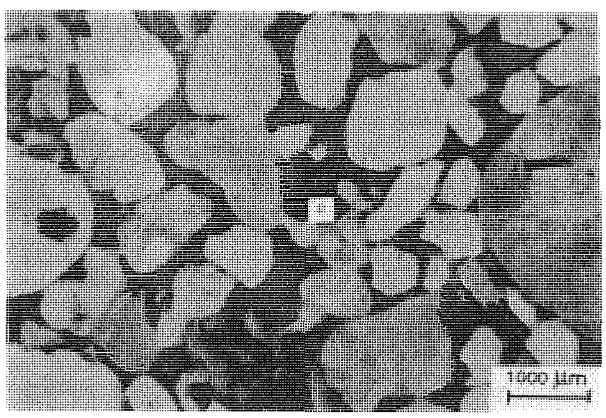
c



d



e



f

ated from Warren County by an area of low relief characterized by a slow rate of sediment influx. This is also indicated by the predominance of well-rounded, highly stable heavy minerals, such as zircon and tourmaline. A few opaque heavies occur.

The presence of some abraded feldspars, along with the metamorphic materials and vein quartz, indicates a source with complex igneous-metamorphic composition. A few well rounded chert grains, indicating some sedimentary rocks in the source area, occur in some thin sections (Plate 6).

Vein quartz is common in all sandstone units. Some grains are badly sheared and they often show comb structures. The sandstone in Unit 8 is especially characterized by coarse-grained vein quartz containing abundant vacuoles and some vermicular chlorite (Plate 6). The conglomeratic bed in Unit 8 indicates introduction of surfeit energy in the environment creating a textural inversion to a bimodal sediment made up of the products of two energy levels. Considering that quartzose metamorphic rock fragments are hydraulically equivalent (RE: specific gravity and shape) to quartz, they travel together. However, the majority of the metamorphic rock fragments are characteristically associated with the finer-grained-sand matrix. This is because the metamorphic rock fragments wear down faster than counterpart quartz grains. A large fraction of the original coarse metamorphic material has probably been eliminated by abrasion, and what remains is highly weathered schist fragments and micaceous clay filling the interstices of dirty sands or comprising the bulk of the mudstones and shales.

The Red Valley sandstone is predominantly cemented with quartz overgrowths. Porous, reservoir quality sands appear to have escaped such cementation (Plate 6). Carbonate cement is generally minor. Ankerite is the most abundant carbonate, as noted by Kelley (1967). It is typically patchy, being associated with replacement of fossils and intraclasts. Some calcite cement which probably predates the ankerite is also noted (Plate 6).

To determine tectonic and depositional effects on Venango petrography, a comprehensive sampling laterally and vertically throughout the section is necessary in order to differentiate paleoenvironmental variations, such as noted by Harper and Laughrey (1989), from tectophase changes. Such a study might be fruitful, as Manspeizer (1963) notes an upward increase in feldspar content through the Bradford Group of Allegany County, New York. It would be interesting to know whether this trend continues into and through the Venango Group, or whether each of the wedges might reflect an uplift/unroofing sequence.

JOINTS

Stop 7 is located in the western part of the Allegheny Plateau region. The structure here is very subdued. The site is well west of a region of still subdued, regularly spaced folds, striking east-northeast (ENE) with limb dips of 1^{o} to 2^{o} (Gwinn, 1964), and beyond the limits of anticlines shown on the state geological map (Berg and others, 1980). Nevertheless, a slight anticlinal nosing is shown by Kelly (1967) to parallel the Red

Valley sand body which, coincidentally (?), has the same general trend as the ENE regional strike of the anticlines to the east (Figure 43). It is uncertain whether this structural axis is supratenuous, a residual (drape) effect of the sand thick, or is a tectonic axis (an uncertainty prevalent within the oil field belt) (Kelley, 1967; see also Hopkins, this guidebook).

Despite the subtlety of folding, jointing is prevalent in Venango sandstone outcrops in Warren County. The joints at Stop 7 are well formed through the sandstone units, but effectively do not cross the interface between the sandstones and the alternating shales.

A total of 47 tectonic joints were measured along the roadcut. They are grouped into two distinct sets. Both sets are subvertical to vertical. The principle joints (Set I) considered as strike joints, trend N50^{o}-80^{o}E (Figure 45), which is more or less parallel to the strike lines of the regional and local fold axes. The second set is identified as cross-fold jointing. The cross-fold joints (Set II) trend N20^{o}-40^{o}W and are approximately orthogonal to the regional strike lines (Figure 45). The greatest horizontal principal stress axis is postulated to be southeast-northwest, parallel to the cross-fold joints.

In addition to the tectonic joint sets, some release joints have also been identified at the outcrop. These release joints probably formed in response to the removal of stress during the final stage of deformation. Their orientation is normal to the direction of compressional stress in the region.

The orientation of tectonic joints is stress controlled, whereas the orientation of release joints is believed to be fabric controlled (Engelder, 1985). Examination of the strike and cross-fold joints in this areally limited outcrop indicates that these joints probably formed at the same time. They are nearly evenly spaced and regularly oriented fractures, suggesting that they have been propagated by stresses which were uniform in both strength and direction. The joint surfaces are characterized with arrest features with no distinct plumose patterns.

A plot of a beta intersection diagram between two tectonic joint sets presents a total intersection points number of 1078, and a pole to best-fit great circle orienting 318.3^{o} 2.2^{o} (Figure 45).

The eigenvalues and eigenvectors were calculated for the measured data from the field, and the best-fit vector was plotted on a stereonet (Figure 45). The plot shows a pole to the best-fit circle oriented at 82.3^{o} 84.9^{o}. Three other statistical values associated with eigenvalues are: r1, which is the ratio of LN (E1/E2); r2, which is the ratio of LN (E2/E3); and k, which is the ratio of r1/r2 (McEachran, 1990) (Figure 45). These three values further demonstrate the distribution of points using the distribution diagram of Woodcock (1977) and Davis (1983). Scrutiny of the statistical results demonstrates that the first and the second eigenvalues (E1 = 0.560, E2 = 0.431) are roughly equal, and they are much greater than the third eigenvalue (E3 = 0.009). This indicates a girdle distribution in the stereographic projection. The large value of r2 (3.89) and the small value of r1 (0.26) also suggests a girdle distribution

(Figure 45).

Three stages of tectonic cycles have probably affected the Venango Group in Western Pennsylvania. First, the clastic sediments of the Venango Group (Late Devonian) were deposited in a coastal to shallow marine environment. Second, the sediments were affected by burial load and diagenesis and then affected by a tectonic deformation during the Alleghanian Orogeny of the Carboniferous and Permian. Third, the sediments were uplifted and relieved of overburden during the Mesozoic to present.

Significance of Jointing to Reservoir Behavior

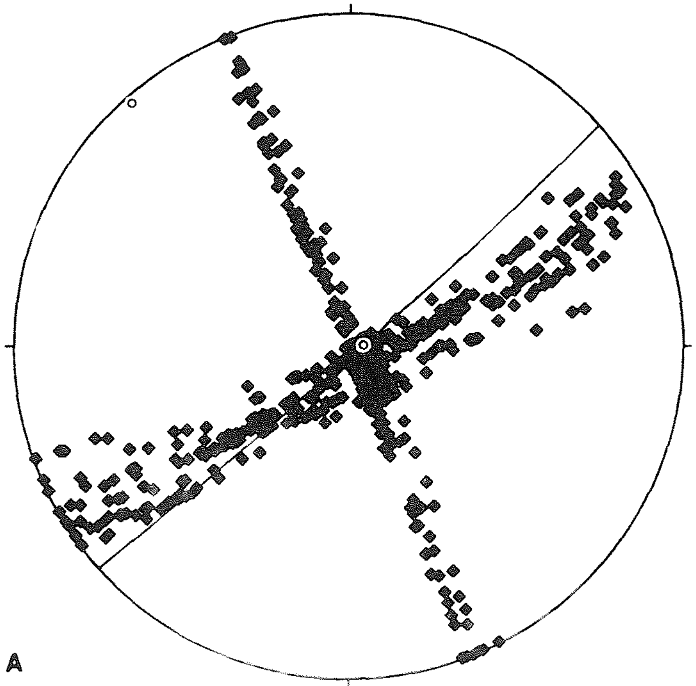
Kelley (1967) suggests that most joints/fractures in the Red Valley reservoir are calcite filled, and hence not effective in modifying reservoir or reservoir treatment behavior. The outcrop joints are clearly open, and there is no evidence of late solution of calcite on any of these joints. Might these joints not be a factor in treatment procedure of the Red Valley and other Venango Reservoirs?

WALKING LOG OF RED VALLEY SANDSTONE OUTCROP

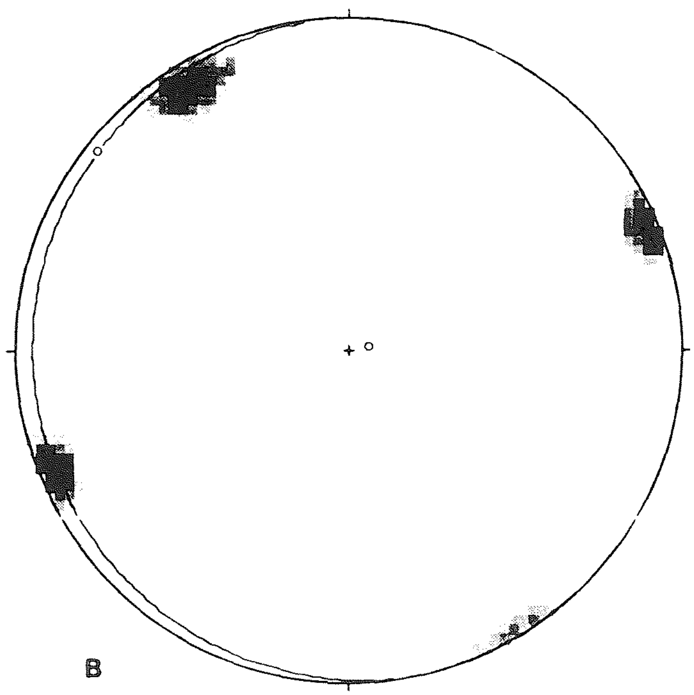
The outcrop at Stop 7 will be walked from north to south. Please watch for traffic, as the road is narrow. The route along the outcrop is marked along the guiderail in 50-foot increments. Please note the blaze tape markers for this. We have one hour for this stop, so pace yourself. Hopefully we will have some time left at the south end to discuss this outcrop.

Distance in feet	**Observable Features**
0	The walk begins by descending a short hill at the first exposure. The thick-bedded, pale yellowish gray, fine-grained sandstone on your right is Unit 4. This is the Lower Red Valley sandstone.
100	**Unit 4**. The base appears at road level. Between here and the 150-foot marker cropping out in descending order are: **Unit 3**. A 2-foot-thick, brownish gray, clay shale with sand ripples and lenses which display trace fossils and burrows and non-flat shale clasts. **Unit 2**. A 1.5-foot-thick sandstone with shale rip-up clasts. **Unit 1**. A light gray, fissile to "cobbly" shale, the bottom of which is not exposed. A lone brachiopod or pelecypod was found in this unit.

Figure 45. A. Beta-intersection points of measured tectonic joint sets I and II in Venango outcrop, north of Tidioute, Pennsylvania. The total number of intersection points is 1078. B. Stereogram of all measured joints in the roadcut. The vertical to subvertical strike joints are oriented east-northeast (N50°-80°E), and the cross-fold joints trend north-northwest (N20°-40°W).



A



B

Data	Schmidt Equal Area Projection	Statistics
◆ BETAVEN.JOINTS N = 1078		○ Pole to Bestfit Great Circle 318.3 2.2 E1 = 0.801 E2 = 0.121 E3 = 0.078 r1 = 1.89 r2 = 0.44 K = 4.25 s. var. = 0.136 Rbar = 0.864

Data	Schmidt Equal Area Projection	Statistics
VENANGO JOINTS 2.1-9.8% 9.8-17.4% 17.4-25.1% 25.1-32.8% 32.8-40.4% N = 47		○ Pole to Bestfit Great Circle 82.3 84.9 E1 = 0.560 E2 = 0.431 E3 = 0.009 r1 = 0.26 r2 = 3.89 K = 0.07 s. var. = 0.315 Rbar = 0.685

150 **Unit 4.** Note shale partings and slight angular discordance of bedding in lower part.
Unit 3. Brachiopod molds.

200 **Unit 4.** More discordant, low angle bedding at base.
Unit 2. Large overturned block in ditch; incipient mudcrack fillings (?), high mica content.

250 **Unit 4.** Gutter casts, some shale layers in Unit 4.
Unit 3. Ovoid horizontal burrow horizons, oriented traces on the base of sandstone lenses, also, "micro-gutter casts," tops of sands are rippled, S30^{O}E paleocurrents. (Across road in massive sandstone floatblock 3 feet behind guardrail are some unusual trace fossils.)

350 **Unit 4.** You can examine details by climbing behind the small, straight, stripe-barked tree. There are about four subunits here; the uppermost is thin bedded throughout, the lower ones may be thin bedded near the tops; note vertical burrows near base of Unit 4.
Unit 3 may nearly pinch out here; only a few inches separate a sand bed inferred to be Unit 2 from Unit 4. Unit 4 may have cut down into Unit 3 here. Farther to the south, the thickness of this shale is restored.
Unit 2. If the above interpretation is correct, the sandstone only a few inches under Unit 4 is Unit 2. Nearby, this was sampled and slabbed. It is fine to very coarse grained, with several sets of ripple crossbedding. Ripples are bounded by erosional (reactivation) surfaces.

400 **Unit 2.** Note three types of trace fossils on sole, including U-shaped.

450 **Unit 4.** Note telodiagenetic vugs. Claystone clasts weathered out.
Unit 1. Note thin, micaceous siltstone lenses.

500 **Unit 2.** Thickens from **450** feet, splits into two subunits: upper subunit has flat-topped, interference (?) ripples.

550 **Unit 3.** Hummocky crossbedding (?).

650 **Unit 4.** Two feet up (third subunit) has good polygonal mudcracks, 8-foot-thick slump block is from bottom of Unit 4; top has high relief, round-crested ripples.
Unit 2. Well-developed, flat-topped ripples, with traces along crests, fossil wood and/or mineralization.

750 **Unit 4.** Excellent large mudcrack fillings on base of overhanging bed near top of unit. Also note trace fossils *Granularia* (?).

780-800 **Unit 3.** Streaky and lenticular lamination. Thicker sand lenses in lower part have paper-thin (mudcurl?) intraclasts.
Unit 2. Shale partings in middle, shale clasts near base of 2-inch-thick sand beds, base "pock-marked," very weakly developed mudcracks (?). At **800 feet**, runzel marks (at top) and burrows with medial grooves.

850 **Unit 4.** Above thinly-bedded middle section is a somewhat massive bed; one foot above its base is a cross-laminated, iron-rich zone; above this is 6 inches of nested, horizontal burrow tubes oriented out of the outcrop (S35^{O}E sense). These occur in a swale in the underlying bed--could they be transported rather than in place? Much faint cross lamination; interference ripples--S20°E sense and S85°E current.

Unit 2 (or split from base of Unit 4); top of 4-6-inch-thick sandstone, interference ripples--S65°E sense and S25°W current.

900-950 **Unit 4**. Local trough-like crossbedding in middle, faint lamination and cross lamination elsewhere; "squared off" horizontal burrows at base, N50E trend.

1000 **Unit 4**. Flat laminations; quartz granules along basal horizons of beds; low angle cross bedding in upper part; one brachiopod found in middle of unit. Reddish thin-bedded layers near top show gradation into the red shale (Unit 5) above.

1100 **Unit 4** (caprock). Sandstone; 1.5 thick, green, brown stained, bioturbated, clayey, with tiny shale-filled vertical burrows, tiny horizontal burrows, slight channeling into underlying bed, which also shows low angle cross-bedding. Bidirectional crossbedding noted.

Beginning of hill along road prior to July, 1992

NOTE: The road is to be lowered 5 feet from the hilltop at marker **1450**, and widened to correct undermining, so that from here on the walking log will not jibe at the south end of the outcrop. Before cutting, none of sub-Unit 4 was exposed at the high point along the road. One of us (Panah) conjectures that the road washed out at this locality because it was built across the outcrop of the red shale (Unit 5).

1200 **Unit 6** (upper Red Valley Sandstone). Locally, Unit 6 includes a shale subunit towards the base, and several feet of sandstone below the shale quite different than that above the shale. Shale is 1.5 feet thick, brownish gray, clayey, with thin sand lenses. It has large horizontal sand-filled burrows, with vertical ellipsoidal cross sections.

Basal subunit is a 20-inch-thick, bioturbated, green sandstone. It contains quartz pebbles up to 0.75 inch diameter, brown, spherical clasts (pisolitic?), and more typical clay clasts. The middle of the sandstone has "micro-gutters" or "micro-ball and pillows." Unit 4 disappears below road level.

1250 **Unit 6**. Top has festoon crossbeds which point S30E.

1300 **Unit 8**. Base; thickens to north, 2 feet thick here; vertical burrows 6 inches below top of exposure.

1400 Site of old washout before road lowering.

Unit 8. Basal 1-foot-thick bed exposed; top has round-crested ripple marks (N30°E orthogonal to crests), and is vertically burrowed with golf-tee-shaped *Monocraterion* burrows. Small scale crossbedding. "Carpet" conglomerate near top.

Unit 7. Shale 5 feet thick.

1550 **Unit 6**. (best exposure--**NOTE**: Lower 3-foot-thick, green sand, 6-inch-thick shale, and upper 5-foot-thick light gray sand.) Top has tiny vertical burrows, large burrows which splay to bulbous terminations, and linguoidal ripples; the middle is also rippled and flaser bedded at several horizons. The lower sand is as described at 1200-foot marker.

Unit 5 Dark red shale, 2 feet thick, bioturbated (homogenized), with floating coarse sand grains. Possible plant detritus (algal ?) occurs as dark specks along shiny surfaces.

		Leave Stop 7. **CONTINUE STRAIGHT AHEAD.**
1.5	29.1	Intersection at Cobham Station. **TURN LEFT** following State Route 3007.
3.5	32.6	Pumpers and storage tanks. Oil is produced from the Venango First sand (McGlade, 1964).
1.9	34.5	**BEAR LEFT** at intersection.
0.9	35.4	Good view ahead of Allegheny Plateau uplands.
3.1	38.5	Cross Brokenstraw Creek.
0.1	38.6	**STOP SIGN. CONTINUE STRAIGHT AHEAD** at intersection with PA Route 27 in Pittsfield.
0.4	39.0	**STOP SIGN. CONTINUE STRAIGHT AHEAD** joining US Route 6 West. Route will travel up the valley of Little Brokenstraw Creek which has Late Wisconsinan outwash at the surface.
1.5	40.5	Good exposure of colluvium on right.
0.7	41.2	**TURN RIGHT** onto State Route 4009. Travel up valley of Page Run. There is outwash in the valley and colluvium on the slopes in the lower part of the valley which was glaciated in the pre-Wisconsinan. Try to pick the Late Wisconsinan border.
2.7	43.9	Now in area glaciated during the Late Wisconsinan.
0.8	44.9	**TURN RIGHT** onto Sheldon Road, State Route 4006. Note constructional topography on the left.
0.6	45.5	**TURN RIGHT** at T-intersection onto Stillson Hill Road.
1.3	46.8	**STOP 8. NUTTLES ROCKS--A PLACE TO MEDITATE, SPECULATE, AND DELIBERATE**
		Discussant: Thomas M. Berg

THE OUTCROP

This impressive and fascinating outcrop (Plate 7A) of basal Pennsylvanian conglomerate and sandstone is located on the property of Mr. Samuel H. Anderson. The land was first owned by the Nuttle family who settled in this part of Warren County in the 1850's. The Nuttles originally came from England and remained in the area until the 1920's.

The large, thick slab of sandstone set up at the north side of Nuttles Rocks was brought in many years ago by Mr. Anderson's father who enjoyed picnicking at the outcrop and saw the need for a permanent table. The sandstone slab had long served as a mounting block for the engine that ran the feed mill at Sugar Grove.

The outcrop is located approximately two miles southeast of the Wisconsinan ice border and about three miles northwest of the pre-Wisconsinan ice margin. Most probably, the rock exposure was overridden by one or more pre-Wisconsinan glaciers, and was subjected to intense Wisconsinan periglacial conditions. The massive conglomerate is broken by widely-spaced joints oriented N58°E, N68°E, N43°W, and N-S.

There are similar outcrops of this massive rock unit throughout Warren and surrounding counties, mostly at higher elevations. The unit was mapped with great facility across northern Pennsylvania for the 1980 state geologic map because it is so easily recognized on aerial photographs and 7.5-minute topographic maps.

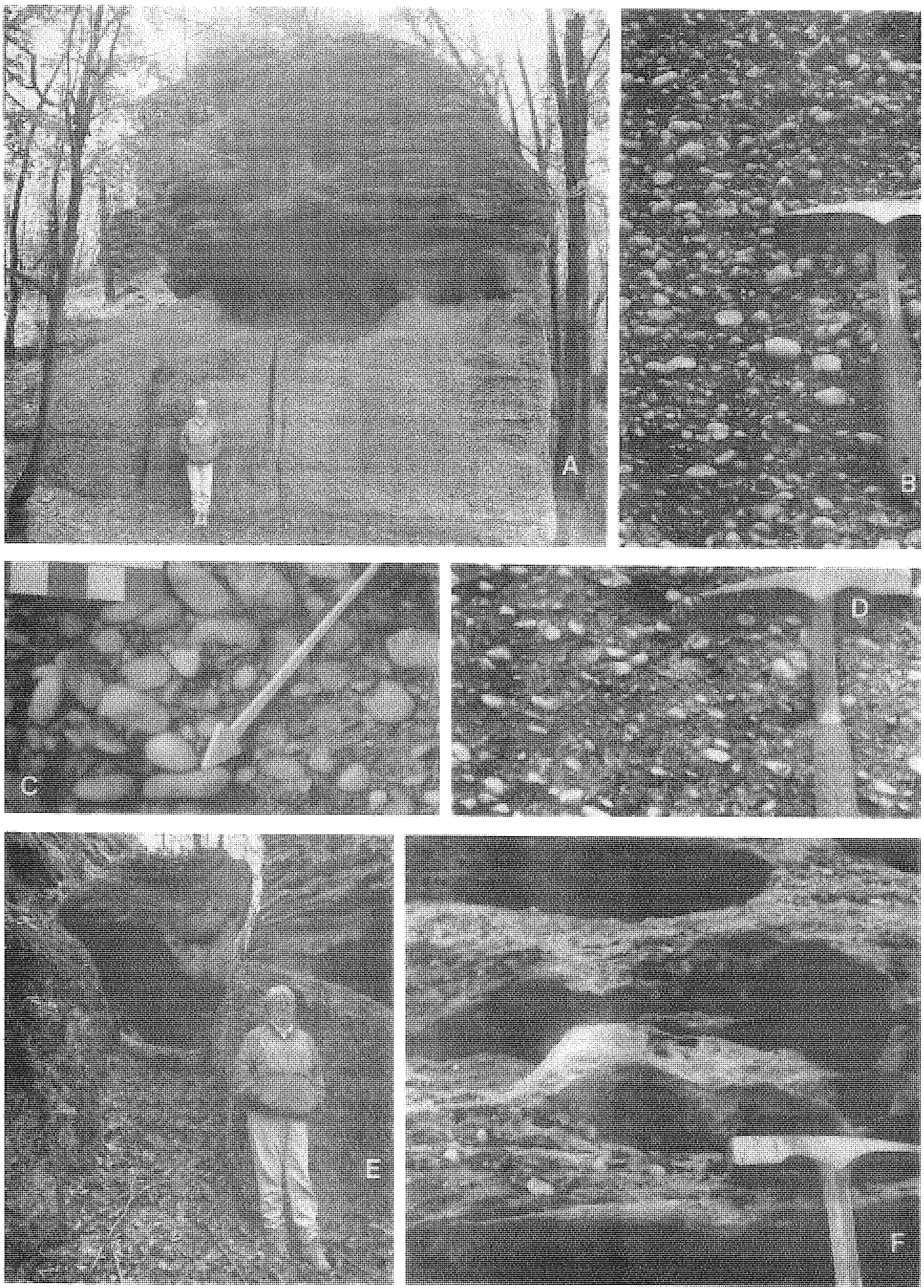
STRATIGRAPHY

Nuttles Rocks is mapped as the Olean Conglomerate, a name originally applied by J. P. Lesley (1875, p. 89, 96) for the massive conglomerates exposed near Olean, New York. The Olean Conglomerate is the basal unit of the Pottsville Group in much of Warren County and disconformably overlies Mississippian marine siltstone and shale of the Cuyahoga Group. At the location of Nuttles Rocks, it is unlikely that any of the sandstone and shale of the Shenango Formation remain, having been removed by pre-Pottsville erosion. Farther south in Warren County, the Shenango is present beneath the Pottsville. Pre-Pottsville erosion removed progressively older strata from south to north; at locations near Olean, New York, the basal Pennsylvanian conglomerates rest on Devonian rocks. In northeastern and eastern parts of the county, the Olean rests directly upon flat-pebble conglomerates of the Mississippian, marine Knapp Formation. In the Warren County region, erosion probably persisted from mid-Meramecian, through Chesterian, and into Morrowan time (Edmunds and others, 1979).

The Olean is equivalent to unnamed basal conglomerates within the Pottsville Group of south-central Pennsylvania. It is also equivalent to the Schuylkill and/or Tumbling Run Members of the Pottsville Formation of the anthracite fields (Berg and others, 1986). The Olean Conglomerate is commonly considered the lateral equivalent of the Sharon Conglomerate of westernmost Pennsylvania and northeastern Ohio. The Sharon was named by Lesley (1879, p. 333) for exposures near Sharon, Pennsylvania. Ashburner (1880, p. 61) concluded that the Olean and Sharon are correlative. Meckel (1967) treated them as the same unit in his analysis of Pottsville conglomerates of the central Appalachians.

SEDIMENTOLOGY

The vertical sequence exposed at Nuttles Rocks is shown in Figure 46 and Plate 7A. Unit 1 includes 11 feet of light gray to very light brownish-gray, quartz conglomerate arranged in planar sets varying from 6 to 30 inches thick. The quartz pebbles (Plate 7B) in Unit 1 average 1.5 to 2.0 cm in diameter; the largest are about 7.0 cm in diameter. Unit 2 is approximately 5 feet thick and is light gray to very light brownish-gray quartz conglomerate arranged in broad sets of trough cross strata about 1.0 to 1.5 feet thick. The texture of Unit 2 is similar to


A
B
C
D
E
F

Unit 1, but Unit 2 is somewhat friable and has weathered to recesses, holes, and small arches in the outcrop. Unit 3 includes 9 to 10 feet of medium gray to light gray sandstone and conglomeratic sandstone. The sandstone is medium to very coarse grained and grades to granule conglomerate with thin, discontinuous bands of quartz-pebble conglomerate. Unit 3 displays well-developed sets of trough cross strata.

Quartz pebbles in the Olean Conglomerate at Nuttles Rocks are dominantly white, but some are as dark as medium dark gray. Some quartz pebbles are grayish pink and yellowish gray. Rarely, small clear quartz pebbles occur.

Besides the prevailing quartz, other pebbles commonly include medium gray to very light gray metaquartzite; less common are medium gray chert, grayish black, quartzose schist, and dark gray, fine-grained, quartz diorite. Conference attendees can probably add to the list. In the Sharon Conglomerate of Ohio, reworked Devonian fossils have been found (Fuller, 1955), but to the best of my knowledge, none have been found in the Olean of Pennsylvania.

The quartz pebbles are dominantly rounded to subrounded and have moderate to low sphericity. A significant number of pebbles occur that are rounded and flat (Plate 7C) or disk-shaped. The flat quartz pebbles are significant in the interpretation of the origin of the Olean.

ORIGIN

Meckel's (1967) analysis of crossbedding orientations and pebble size distributions demonstrates that the Olean Conglomerate derived from a northern source. The vertical sequence at Nuttles Rocks best fits the braided Donjek River (Yukon) model elaborated by Miall (1978, p. 602). Unit 1 (Figure 46) matches Miall's lithofacies "Gm" which is massive or crudely bedded gravel displaying horizontal bedding and imbrication, and interpreted as longitudinal bars in a braided river. With a little searching through the exposures of Unit 1, some evidence of imbrication may be found (Plate 7D). Unit 2 at Nuttles Rocks fits Miall's lithofacies "Gt" which is trough crossbedded gravel interpreted as minor channel fills of a braid system. Unit 3

Plate 7. A. Outcrop of Olean Conglomerate at Nuttles Rocks in Warren County. Vertical sedimentary sequence fits well with the interpretation of a fining-upward cycle in a braided river system. B. Quartz-pebble conglomerate of Unit 1 of the vertical sequence at Nuttles Rocks. C. Quartz pebbles within Unit 1. Arrow points to flattened quartz which is probably reworked from the underlying Knapp Formation. Scale divided in cm. D. Quartz pebbles in Unit 1 that appear to be arranged in imbricate fashion. E. Joint surfaces separated by nearly 3 feet of lateral displacement due to severe periglacial conditions. Note large boulder of Unit 3 sandstone which has dropped into void. Betty Berg provides scale. F. Exudation hollows in Unit 3 sandstone attesting to intense periglacial conditions.

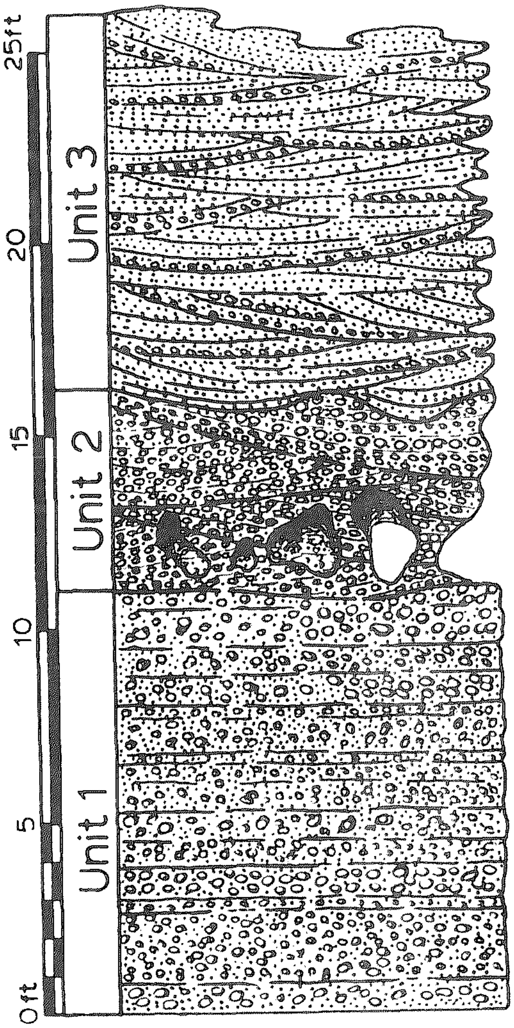


Figure 46. Generalized columnar section showing vertical sequence exposed at Nuttles Rocks. See text for description of units.

fits his "St" lithofacies which is medium- to very coarse grained and pebbly sand grouped in trough crossbeds, and interpreted to represent lower flow regime dunes. The Nuttles vertical sequence represents diminishing flow regimes from bottom to top and matches the fining-upward cyclic sequences seen in the braided Donjek River. The Olean Conglomerate is the signature of a rapid influx of coarse sand and gravel coming from a northern source at approximately the same time as coarse fluvial input to the rest of the Appalachian Basin during late Morrowan and Atokan time. This rather momentous event occurring after a long period of erosion speaks of major tectonic adjustments--renewed downwarping of the Appalachian Basin and probable upwarping of the source areas surrounding the basin.

Quartz conglomerates and quartz arenites of the Olean are most probably multicyclic in origin. I would suggest that the Olean is the result of two and/or three cycles of transportation and sedimentation. The first cycle likely occurred during formation of the protoliths of the Middle Proterozoic Grenville orogen to the north. A second cycle may be represented by quartz conglomerates and quartzose litharenites shed into the Appalachian Basin from northern cratonic or eastern Appalachian highland sources during the Mississippian. The underlying Knapp Formation in Warren and McKean Counties contains abundant flat quartz pebbles, the size of which do not seem to derive from an eastern source because no major quartz conglomerate zones occur in laterally-equivalent Mississippian rocks to the east (Huntley Mountain Formation). The flat-pebble conglomerates of the Knapp may well represent deposition as offshore bars receiving quartz clasts from the craton to the north. Many of the pebbles within the Olean at Nuttles Rocks and elsewhere in Warren County are flat quartz pebbles which surely have been reworked from the underlying Knapp Formation. Thus, the Olean must be in part a third-cycle quartz conglomerate, owing to the reworked Knapp pebbles. The Olean must also be in part a second-cycle quartz conglomerate, containing pebbles transported directly from the Grenville orogen to the north.

GEOMORPHOLOGY

Nuttles Rocks survived the advance of two pre-Wisconsinan glaciers, but little evidence of that is visible in the immediate vicinity of the outcrop. There is however, overwhelming evidence of Wisconsinan periglacial activity. As stated above, the Wisconsinan border is very close to Nuttles Rocks, and the splitting and lateral separation (Plate 7E) of large blocks here testify to intense periglacial climatic conditions. In addition, the hollowed-out weathering surfaces in Unit 3 (Plate 7F) and undercut hollows and arches in Unit 2 (Plate 7A) speak of severe frost exudation typical of periglacial climatic conditions.

		Leave Stop 8. **RETURN THE WAY CAME.**
1.5	48.3	**TURN RIGHT** onto Saunders Road. Route is within area glaciated during the Late Wisconsinan.
0.9	49.2	**STOP SIGN. BEAR RIGHT** onto Hazletine Hollow Road. Route is now beyond limits of Late Wisconsinan glaciation.
1.3	50.5	Pumpers and storage tanks. Oil production is from the Glade sand throughout this area at a depth of about 800 feet in the valley. The pay zone is about 30 feet thick (McGlade, 1964).
0.5	51.0	**STOP SIGN. TURN LEFT** onto PA Route 27 North. Route travels up valley of Mathews Run.
0.9	51.9	Pumpers and storage tanks. Same source as at mileage 50.5.
0.3	52.2	Now in valley of Patchen Run which was cut as a narrow gorge during one or more glaciations.
0.8	53.0	Note constructional topography on right and ahead on left.
1.2	54.2	**STOP 9. ZURKAN GRAVEL PIT AT CHANDLERS VALLEY** Discussants: W. D. Sevon and Samuel W. Berkheiser

The Zurkan gravel pit occurs in a Late Wisconsinan recessional moraine (Figure 47) located about four miles behind the position of maximum ice advance southeast of Chandlers Valley. The moraine can be properly called a kame moraine because it appears to be primarily sand and gravel. The moraine has well-developed constructional topography which shows on the topographic map (Figure 47) and will be traversed in part on the route immediately after leaaving Stop 9. The outwash plain of Jackson Run to the southeast is graded to this moraine.

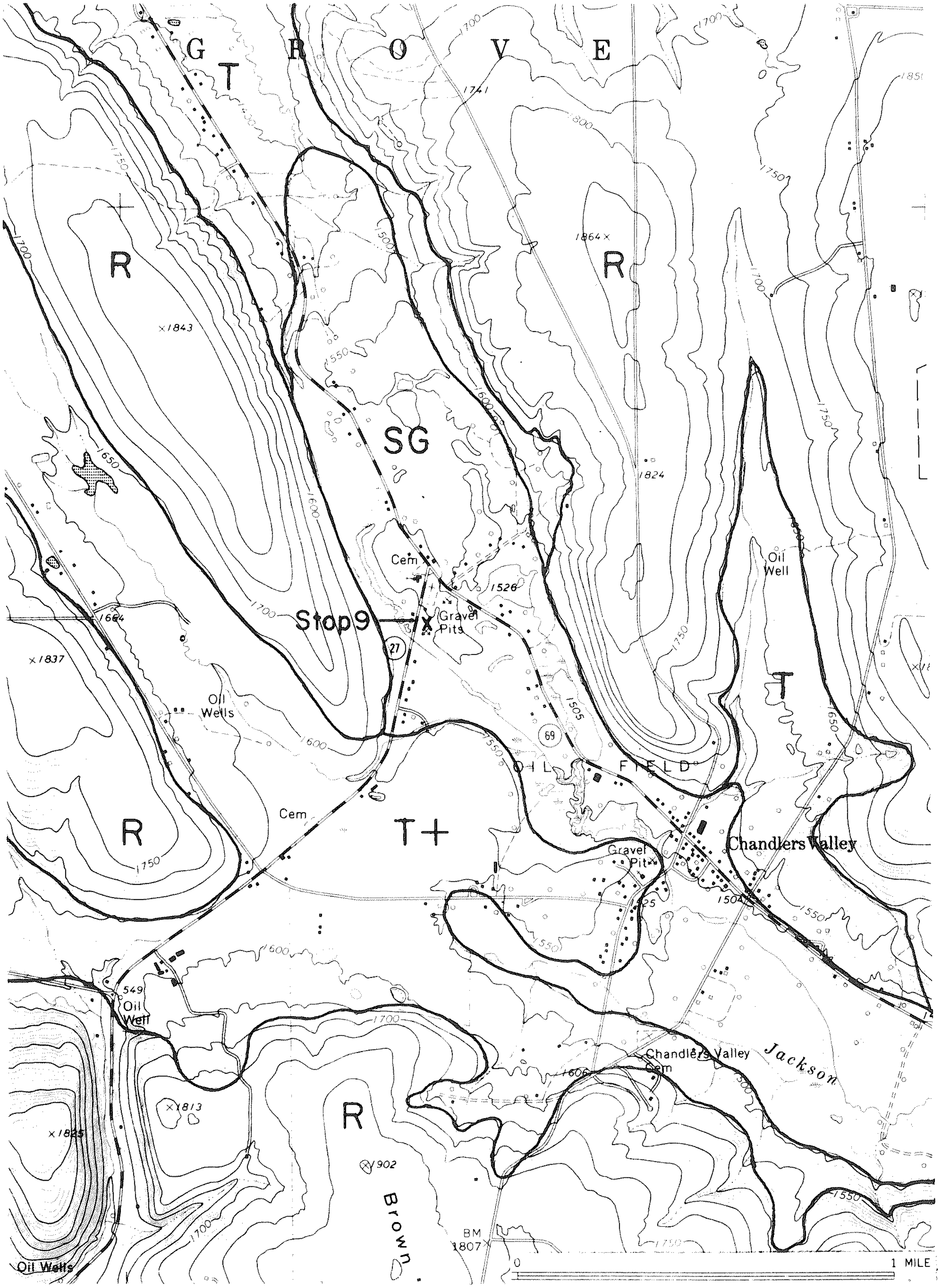
The valley topography to the northwest of Stop 9 suggests that the valley has been filled with 300 feet or more of debris, but this is not true. The valley containing this moraine was the drainage divide between Jackson Run to the southeast and Still-water Creek to the northwest prior to the last glaciation. The valley was widened by glaciation and deepened primarily on the northwest side of the drainage divide. Subsequent glacial deposition occurred primarily on the southeast side of the divide. Limited water-well data in the area of Chandlers Valley indicates that there is less than 50 feet of fill in the valley.

The sand and gravel present at Stop 9 has some similarities and contrasts to that at Stop 6. Although the bedding is poorly defined here,the deposit appears to be essentially horizontally stratified and can be called outwash. Other exposures within this moraine show randomly oriented, steeply-dipping crossbedding typical of ice-contact deposits. This deposit does not appear as texturally clean as some of the material at Stop 6 but the washing loss data (Table 6, p. 147) indicates that it is very similar. The deposit does give the impression that it has not been transported very far or sorted very well. Whether this deposit reflects deposition of only partly sorted material or whether there is an additional complication, such as deposition followed by ice override is a matter for speculation.

The materials present in this pit are comparable to those present at Stop 6 (Table 6). Local material dominates, but there are foreign clasts as well as an abundance of materials larger than those at Stop 6. This is to be expected considering the proximity of the source ice at the time of deposition. However, note the general lack of big boulders. They apparently were not present in the ice sheet in this area.

Of considerable interest here is the carbonate cementation. The material has been oxidized to the depth of the quarry floor and at least partly leached. However, carbonate cementation is occurring within a few feet of the surface in contrast to the carbonate cementation at Stop 6 which was occurring only at depth. Mr. Zurkan says that widespread, 1-foot-thick, cemented zone occurs just below the working floor of the pit. Is this lower level of cementation related to the groundwater table? What does the depth difference in cementation at the two stops indicate? Does the cementation occur at near-surface levels during the early history of gravel-body leaching, only to be

Figure 47. Map of the Chandlers Valley area. R = rock and thin (<2 m) glacial drift, T = till, SG = sand and gravel, T+ = till + sand and gravel. Topographic map from the Sugar Grove 7.5-minute quadrangle.


G R O V E
T
R
R
SG
Cem
1526
Stop9
Gravel Pits
27
69
Oil Wells
Oil Well
T
OIL FIELD
Cem
T+
R
Gravel Pit
Chandlers Valley
1504
1664
x1837
x1843
1864
1824
549
Oil Well
Chandlers Valley Cem
Jackson
x1813
x1825
R
902
Brown
BM 1807
Oil Wells
0
1 MILE

redissolved subsequently and reprecipitated at lower levels as the time interval increases? Or is it primarily a function of the position of the groundwater table which is still close to the surface here but changed considerably through time at Stop 6. A topic for discussion.

This sand and gravel operation contrasts with that at Stop 6. Here material is loaded on demand directly onto trucks by front-end loader and sold as bankrun. Limited screening is done, mainly to eliminate the larger cobbles and small boulders which occur here. The floor of the present operation is at the lower limit of simple surface mining because of the cemented layer.

Mr. Zurkan estimates that he mines 10-15,000 tons/year. The uses of the material are known mainly to the buyers although some is used on local secondary roads. This operation is probably very typical of the many small operations found throughout the glaciated areas of northeastern and northwestern Pennsylvania.

		Leave Stop 9. **CONTINUE STRAIGHT AHEAD** on PA Route 27 North.
0.1	54.3	**STOP SIGN. TURN RIGHT** onto PA Route 69 South.
0.2	54.5	Nice example of a kettle lake on the left. Note constructional topography ahead.
2.7	57.2	Constructional topography in this area is close to the maximum extent of Late Wisconsinan ice.
0.6	57.8	Jackson Valley Country Club on right is at the approximate maximum extent of Late Wisconsinan ice. Valley of Jackson Run from here on has Late Wisconsinan outwash at the surface and colluvium on the slopes.
6.7	64.5	**STOP LIGHT. TURN LEFT** onto US Route 62 North. Warren State Hospital ahead on right. Note signs "Do not pick up hitch hikers." Travelling in the valley of Conewago Creek which has Late Wisconsinan outwash at the surface.
1.1	65.6	Site of Stop 10 on left.
0.3	65.9	**STOP LIGHT. BEAR RIGHT** onto Hatch Run Road.
0.1	66.0	**TURN LEFT** into the Warren Mall. **DRIVE STRAIGHT AHEAD.**
0.2	66.2	**STOP SIGN. TURN LEFT.**
0.1	66.3	**STOP SIGN. TURN LEFT** onto US Route 62 South at entrance to Warren Mall.
0.5	66.8	**STOP 10: STRATA OF THE CHADAKOIN FORMATION, NORTH WARREN HIGHWAY 62 ROADCUT, WARREN COUNTY; "CHEMUNG EQUALS TEMPESTITES"** Discussants: Edgar M. Hopkins and Assad A. Panah

INTRODUCTION

The Chadakoin Formation is important to an understanding of the Famenian-aged "Catskill" wedge of western Pennsylvania for two reasons: (1) the formation typifies the marine "Chemung" magnafacies seen throughout the "Catskill" wedge, and (2) it represents a large-scale transgression of the late Catskill Sea, while internally continuing to record smaller-scale, sea-level fluctuations which link it to the underlying and overlying coastal wedges.

The Chadakoin Formation was named by Tesmer (1963) after Chadwick's (1923) "Chadakoin beds" seen along the Chadakoin River east of Jamestown, New York. The Chadakoin includes parts of at least two "magnafacies" of the "Catskill" wedge, best described as inner "Portage" to "Chemung" as detailed below. It is characterized by thinly interbedded (heterolithic) clean sandstones, siltstones, mudstones, and shales. Coquinites are common. Some slightly thicker sandstones, often load-casted, are also seen. Several still thicker sandstone horizons separated by uniform shale intervals are included in the lower part of the formation, as it is defined to the northeast. The latter strata are of a different facies than the typical Chadakoin and are not everywhere included in it. The Chadakoin is generally poorly exposed due to the high shale and mudstone content and thin-bedded nature of its sandstone units.

The Chadakoin crops out along an extensive ENE-trending belt across the low plateau region of the Great Lake counties of far-western Pennsylvania and western New York. Other outcrops extend south along several river valleys incising the higher Allegheny Plateau. It is exposed along that part of the Allegheny River valley trending west across the eastern two-thirds of Warren County. It is partially covered by water along the Allegheny Reservoir, but crops out again farther east, along a north-flowing segment of the Allegheny River in eastern McKean County. Several tributary valleys of the Allegheny also expose the Chadakoin, including Conewango Creek, which drains southward to the Allegheny River at Warren, and Tuna Creek, which drains north across north-central McKean County.

In addition to the Allegheny and its tributaries, the Genesee River of Allegany County, New York, 80 miles east of Warren County, also cuts Chadakoin equivalent strata, assigned by Manspeizer (1963a,b) to the Rawson Formation. The Genesee Valley exposures, among the most source-proximal, may hold clues to the genetic relationships of the Chadakoin and enclosing strata.

South of central Warren County, Chadakoin rocks do not resurface along strike; however, these rocks are apparently continuous in the subsurface. This continuity, as well as it being everywhere bounded by the more sandy, nearer-shore Venango and Bradford Groups, supports the idea that the Chadakoin spans a large order, perhaps eustatic, transgressive/regressive sea level cycle (Dennison, 1985a,b; Harper and Laughrey, 1987).

Stop 10 is located at a highway cut into a cutbank of Conewango Creek, near the southwest terminus of the high plateau outcrops (Figure 48).

The 80-foot bank exposes the lower part of the formation, although the exact stratigraphic position of this outcrop is not known. This stop is only 15 miles south of the type area for the "Chadakoin beds," now regarded as the type area of the lower, Dexterville Member (Tesmer, 1963). Tesmer (1963; 1975) mapped the Chadakoin in Chautauqua and Cattaraugus Counties, taking particular note of the paleontology and reviewing and synthe-

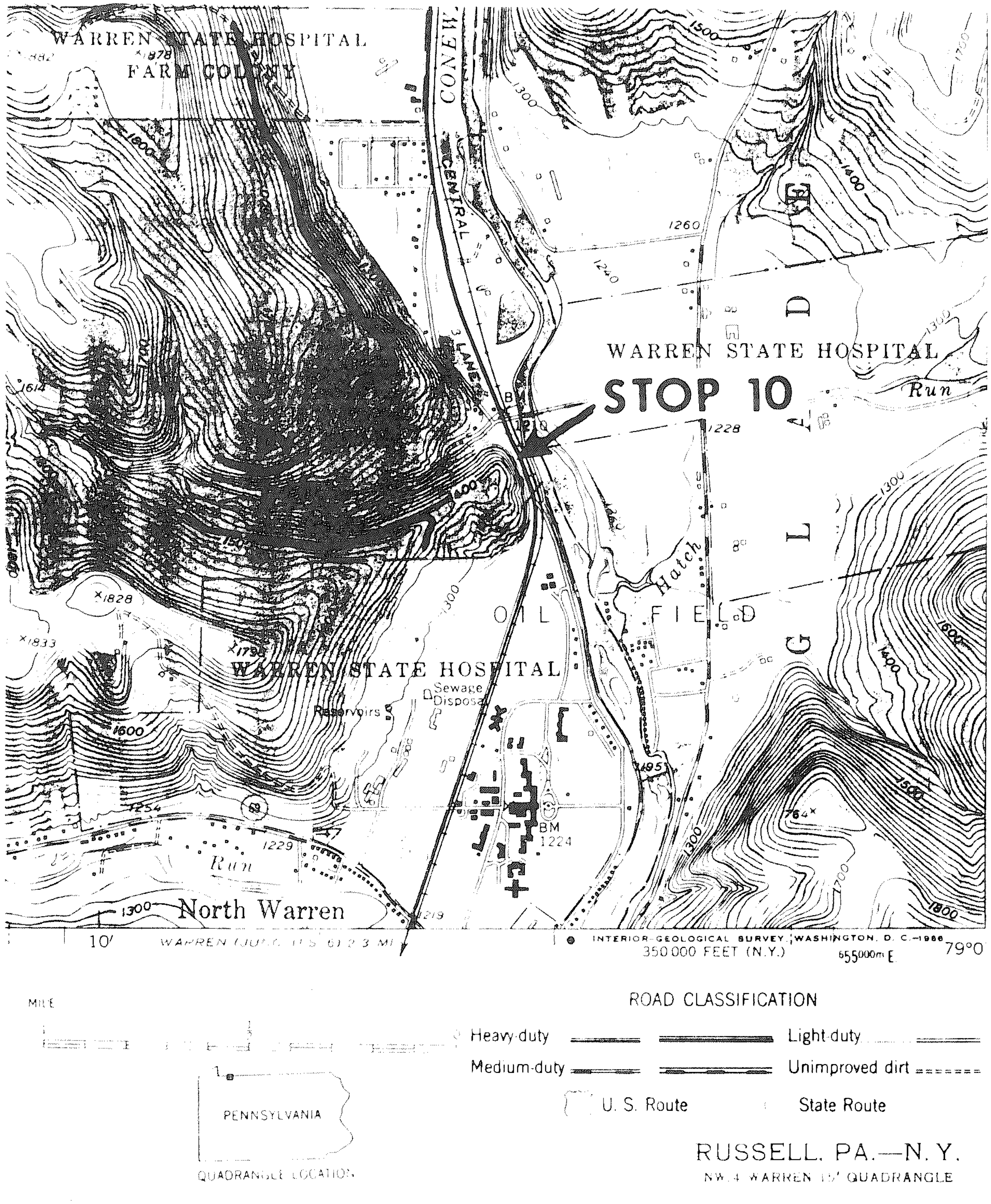


Figure 48. Location map for Stop 10.

sizing previous studies of the Chadakoin in western New York.

STRATIGRAPHY

Thickness

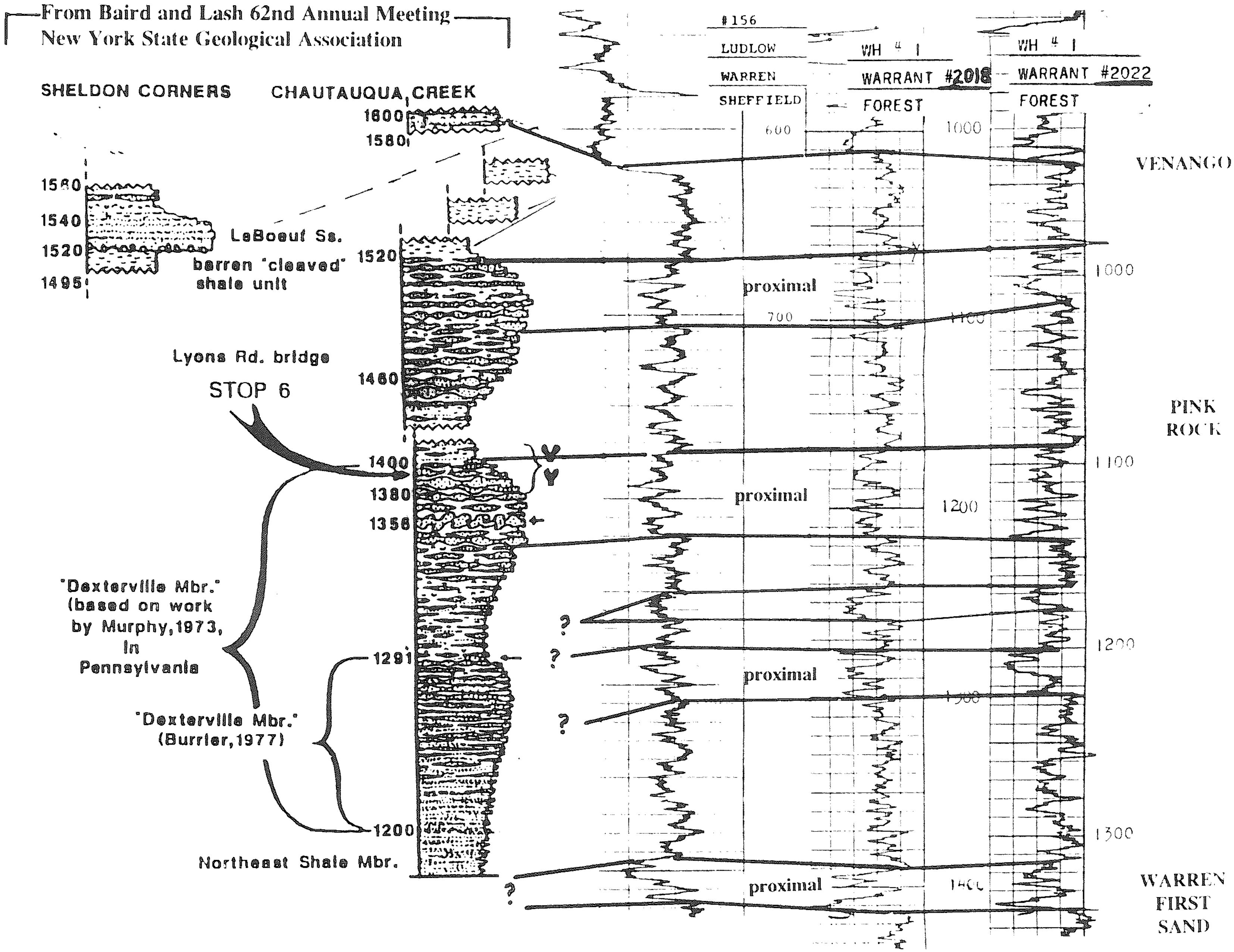
According to Tesmer (1963, 1975), the Chadakoin thins toward the northwest, from 750 feet thick in southeastern Cattaraugus and western Allegany Counties to as little as 250 feet thick in northwestern Chautauqua County. Part of this apparent thinning may be due to picking the base at a higher stratigraphic level to the west, as discussed below (Lower Contact). Also related, offshore facies changes to more shaly rocks (of the "Portage" magnafacies) account for some of the thinning (Baird and Lash, 1991). Yet another mechanism proposed for thinning is erosion at the top of the unit (Manspeizer, 1963a,b).

Upper Contact

The upper boundary is generally not disputed; the Chadakoin is almost everywhere overlain either by flat pebble conglomerates and conglomeratic sandstones or equally distinctive "redbed" shales, all belonging to the Venango Group (Cattaraugus Formation). The apparent great lateral offset in vertically contiguous facies drew the attention of early workers, some of whom noted a faunal break suggestive of a large scale disconformity at this contact (Chadwick, 1934; Manspeizer, 1963a,b).

Lower Contact

The base of the Chadakoin is not clearly defined. It is variably picked across western New York. In western Chautauqua County, Baird and Lash (1991) place it at the contact with underlying gray to dark gray shales assigned to the Northeast Shale; in eastern Chautauqua County, Tesmer (1963) placed it at the base of a siltstone "package" and infers that the siltstone may correlate with the base of the Cuba Sandstone further east in western Allegany County, although the Cuba has not been positively identified west of Allegany County (Manspeizer, 1963a). Caster (1934) also employed a siltstone "package" as a basal unit of the Chadakoin. Interestingly, this is the only basal sandstone employed which exhibits the "pink to purple-red" color so typical of (higher) parts of the unit in the subsurface (and seen at this stop). Caster named his basal unit the Lillibridge Sandstone, after a locality in eastern Cattaraugus county. The Lillibridge is clearly well above the Cuba and is not recognized to the west according to Tesmer (1963). Arguably, either this horizon, possibly also equivalent to the Hinsdale Sandstone, or the Cuba Sandstone could correlate with the siltstone package used by Tesmer as the base of the Chadakoin (Figure 49).


From Baird and Lash 62nd Annual Meeting
New York State Geological Association
SHELDON CORNERS
CHAUTAUQUA CREEK
1600
1580
1560
1540
1520
1495
LeBoeuf Ss.
barren "cleaved" shale unit
1520
1460
Lyons Rd. bridge
STOP 6
1400
1380
1356
"Dexterville Mbr." (based on work by Murphy, 1973, in Pennsylvania
1291
"Dexterville Mbr." (Burrier, 1977)
1200
Northeast Shale Mbr.
#156
LUDLOW
WARREN
SHEFFIELD
WH 4 1
WARRANT #2018
FOREST
WH 4 1
WARRANT #2022
FOREST
600
700
1000
1200
1000
1100
1200
1300
VENANGO
PINK ROCK
WARREN FIRST SAND
proximal
proximal
proximal
proximal
?
?
?
?

Subsurface Stratigraphy

This interval has received less attention in subsurface studies than the prolific oil and gas bearing sandy wedges encompassing it. Tesmer's (1975) inclusion of the Cuba sandstone as a basal member of the Chadakoin (at least to the east) is similar to the usage in the Conneaut Group in Pennsylvania, which also includes the Cuba-subsurface-equivalent Glade Sand and overlying sandstone and shale units with the higher siltstone/mudstone "Chemung" type rocks (Lytle, 1965). Generally, however, treatment of these rocks in the subsurface follows a slightly different scheme; the "Bradford Group" (B-sand Zone) includes strata up through the Warren First Sand, the higher "Chemung" type rocks and overlying gray shales are termed the C-shale Zone, and above this are redbeds or sandstones forming the "Venango Group" (D-sand Zone) (Piotrowski and Harper, 1979). The more inclusive Conneaut Group is 850 feet thick in the Warren quadrangle of northeastern Warren County as opposed to 450 feet for the C-Shale ("Pink Rock" and 100 feet of overlying gray shale). These workers show the C-Shale Zone to thin to the east by descent of the base of the Venango Group (see also Harper and Laughrey, 1987).

Across McKean, Warren, and Venango Counties, Pennsylvania, the lower 350 feet of the C-shale is called the "Pink Rock" due to a diagnostic purplish-gray color seen in well cuttings (although some gray-green sections are intermixed). Much note has been taken of the "Pink Rock's" very consistent thickness and widespread occurrence as a siltstone dominated unit with a very characteristic "ratty" or "broken" gamma-ray log signature. The strata below the Warren First Sand are more typical gray to gray-green shales containing several regional sandstone units, a lithofacies similar to underlying strata having more nearshore affinities than the "Pink Rock."

The very fine-grained, greenish gray Warren First Sand consistantly marks the base of the "Pink Rock." The relationship between this sandstone and the siltstone package employed as the base of the outcropping Chadakoin beyond the limits of the Cuba Sandstone is not known. However, because the Warren First Sand is approximately 180 feet higher than the Cuba-equivalent Glade Sand in the Warren quadrangle (Lytle, 1965), and the Hinsdale Sandstone is approximately 230 feet above the Cuba Sandstone in eastern Cattaraugus County, New York (Manspeizer, 1963a), it is conceivable that in some outcrop areas the Chadakoin is being defined as equivalent to the Pink Rock plus the overlying shales below the (Cattaraugus) sandstones and redbeds, ie., equivalent to the C-shale Zone. There is a need to establish continuity

Figure 49. Regional paleodip cross section of the Chadakoin Formation (western). To the east the Chadakoin is defined to include 200 feet more below the Warren first sand. Note apparent continuity of cyclic units across three counties (Chautauqua, New York, Warren and Forest Counties, Pennsylvania). Black Y shows *Foerstia* zone, a possible isochron. Outcrop data from Baird and Lash, 1991.

between the surface and subsurface units in order to better understand the stratigraphy of these rocks, as for example establishing paleostrike via thickness of a synchronous package.

Internal Cyclicity

Several fossiliferous zones are reported from the "Pink Rock" of the subsurface (Lytle, 1965). By comparison with surface outcrops it is clear that these zones are coquinite-rich "tempestites" (storm deposits). In the Warren quadrangle, these zones are said to be near the base, near the top, and near the middle of the "Pink Rock." Occasionally a fourth fossiliferous zone occurs between the middle and basal ones (Lytle, 1965). One of us (Hopkins) tentatively correlates these "fossiliferous" zones with the coarser-grained parts of the coarsening-up cycles recognized by Baird and Lash in 1991 (Figure 49).

Facies

The Chadakoin is lithologically complex, containing units dominated variously by (1) thin, irregular- and hummocky-bedded, coquinitic, coarse-grained siltstones to very fine grained sandstones with shale, (2) evenly-bedded (clean) siltstones, (3) shales, and (4) sandstones. The coquinitic units are "tempestites," deposited largely below storm-weather wave base. The other units are of debatable origin.

The Chadakoin generally has the coquinite-dominant aspect which according to Manspeizer (1963a) typified "Chemung" to early workers. This time-transgressive "magnafacies" has also recently been reported near the top of the wedge, in the distal portion of the overlying Venango Formation of Erie County, Pennsylvania (Baird and Lash, 1991). It is also found to the east in the older "Machias beds" of Allegany County, New York along the bottom and toward the west side of the Bradford Group wedge (Manspeizer, 1963a,b). Finally, the Chemung facies is seen in the still older Chemung (formational) unit well to the east in Chemung County, New York, where it may form the westerly and lower part of the Elk Group wedge. The Venango Group, Bradford Group, and Elk Group also contain abundant nearshore and shoreline sand bodies ("Cattaraugus magnafacies" of Rickard, 1975) not in evidence in the Chadakoin Formation (Figure 49).

Non-coquinitic strata attributed to the Chadakoin may span facies incorporating the entire shelf paleoenvironmental spectrum. In one Chadakoin outcrop in eastern McKean County (Eldred Bridge), a 50-foot-composite section includes a dark gray shale overlain successively by a channel sand with extensive ball and pillowing, a thinly interbedded sandstone and shale interval, a shale unit, and a thin, fossiliferous sandstone cap indicating regressive intertidal environments followed by a marine transgression.

Another outcrop in eastern Cattaraugus County (Olean Industrial Park) has a deeper water origin with dark shales and very thin, vertically-sparse tempestites or turbidites.

Across the Youngsville quadrangle, located west of the

Warren quadrangle, the "Pink Rock" reportedly changes westward from its typical siltstone lithology to a ("Northeast") shale lithology (McGlade, 1964). This is the only reported facies change in the subsurface part of the unit of which we are aware. It corresponds to westward changes noted by Baird and Lash (1991) on outcrop, a good deal farther west.

Stratigraphic Analysis

The cyclic stratigraphy and internal facies heterogeneity of the Chadakoin noted by Baird and Lash (1991) suggest a more complex history than that of a simple transgressive/regressive wedge.

Tesmer (1963) regards the separation of the Chadakoin into two members, a lower Dexterville Siltstone and an upper Ellicott Shale, as being valid in Chautauqua County, New York (located north of Warren County, Pennsylvania), but not viable farther east in Cattaraugus County, New York. There is some question, however, about the criteria used to differentiate these two members, as Tesmer admits a great lithologic similarity between the two and concentrates instead on the restriction of the brachiopod *Pugnoides duplicatus* to the lower member. Whether there is a definite lithologic distinction to justify these two members in Chautauqua County (or to the south into Pennsylvania) remains in doubt. In western Chautauqua County, Baird and Lash (1991) suggest that the siltstone-rich section used to differentiate the Dexterville Member as defined by Tesmer (1963) may be only one of at least three siltstone-rich, cyclic intervals, and as defined by Burrier (1977), the lower two of these three coarsening-up sequences. Each sequence starts with shale and culminates with siltstone and/or coquinitic sandstones. A brief review of logs from Pennsylvania, suggests that from three to four correlative cycles may exist here (Figure 49).

Baird and Lash (1991) also note a possible algal fossil (*Protosalvis*) isochron within the upper Chadakoin. Tracing of such time-stratigraphic markers to the east, into the field trip area would be of major import, as no useful time-stratigraphic markers are known to exist between the isochronous black shales at the base of the Bradford Group and the less certainly isochronous lowest conglomerates of the Venango Group.

The stratigraphic relations of the Chadakoin Formation along its outcrop belt in northwestern and north-central Pennsylvania and western New York have not been resolved. Good exposures are scattered, and unless underlying or overlying units are exposed, the vertical position of outcrops within the Chadakoin is difficult to determine, because the lithologies are both repetitive and somewhat monotonous.

OUTCROP DESCRIPTION

Stop 10 appears to be representative of the Dexterville Member of the Chadakoin Formation as defined in quarries east of Jamestown, New York by Chadwick (1934) and Tesmer (1963). It is also assumed to be typical of the subsurface "Pink Rock."

The outcrop is generally inaccessible. The stratigraphic position of individual floatblocks lining the roadway is hard to identify due to repetitious interbedding, but a good random sampling of the outcrop is possible. A climb up the slumped slope near the north end of the outcrop allowed recognition and direct sampling of nine of the more prominent sandstone/siltstone beds. The bottom, middle, and top of each bed were sampled, where possible. A measured section was constructed by plane tabling and binocular sighting (Figure 50).

A monotonously interbedded, heterolithic sequence of tan to gray to purplish gray to reddish brown sandstones/siltstones, mudstones, and shales crop out here. Although individual sandstone/siltstone beds pinch and swell, most sandstone horizons carry the length of the outcrop. The thinnest sandstone beds are distributed every few inches through the section, but thicker units occur every 10 feet or so (Figure 50; Plate 8).

Sandstones/Siltstones

Many of the sandstones are fossiliferous, containing basal and, less often, internal or even capping, coquinitic lenses. A few "sandwich" beds were noted, coquinitic at the top and base, but unfossiliferous between.

A few of the thicker sandstones may show load-casted bases, although this is not common. The bases of the majority of the sandstones are either planar or irregularly channeled, and the tops may be either flat or hummocky (Plate 8). Gutter casts attached to the bases of the sandstones are present but uncommon. Isolated gutter casts are even more uncommon.

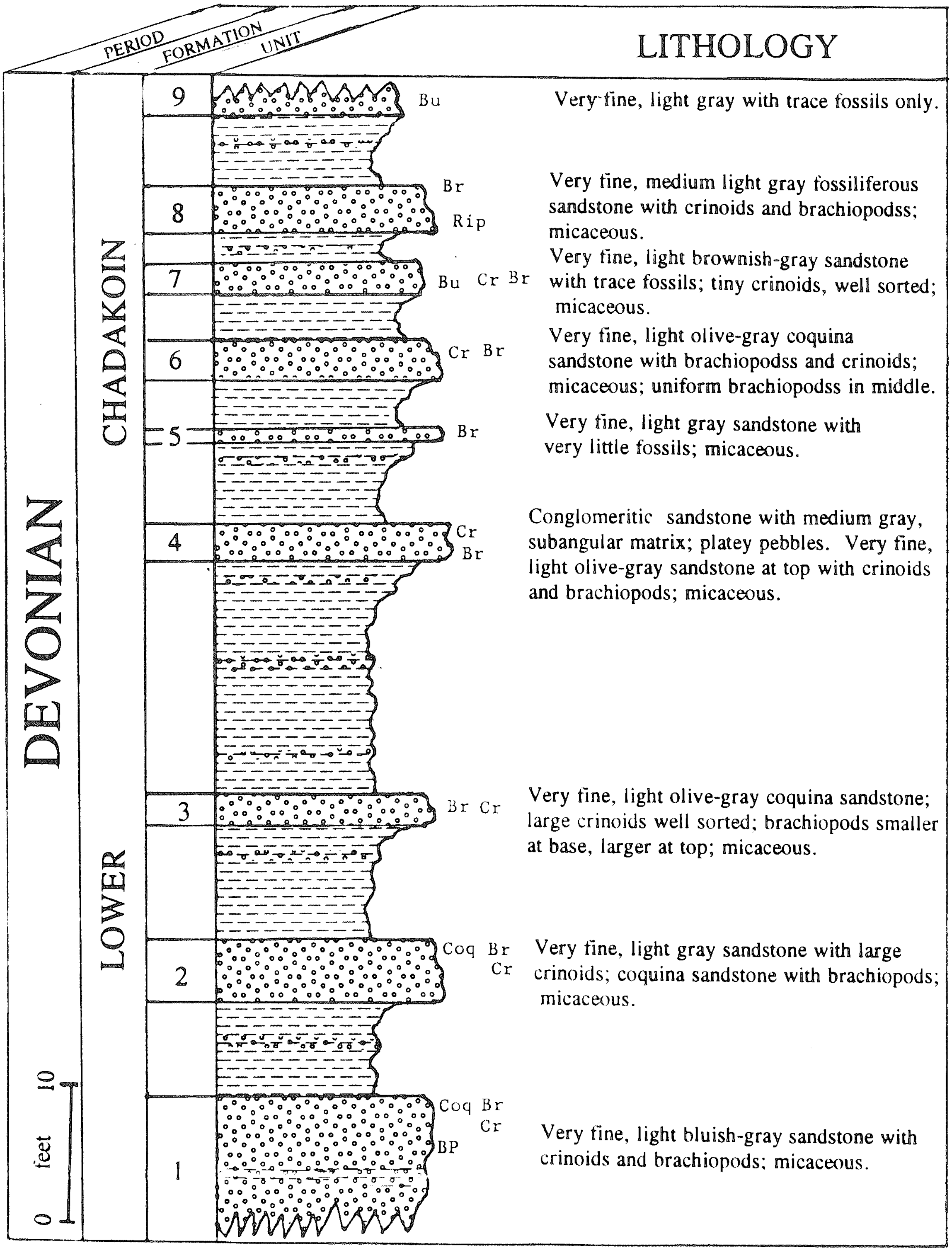
The bottoms of some sandstones are flute casted or micro-groove casted. Bounce and prod marks are more abundant. Bipolar prod marks are suggested as typical of tempestites by Aigner (1985), but not definitely established by us here.

There is an internal bedding sequence within many of the thicker sandstones, with flat lamination tending to be overlain by swaley or hummocky stratification (Plate 8). The grain size appears to fine upward through each sandstone bed, but this could not be verified in thin sections of bottom, middle, and top samples. None of the observed sandstones had amalgamated bedding (built up of stacked bedding sequences or containing internal erosion surfaces).

Burrows are predominantly horizontal, although some vertical burrows are noted. Ripple marks are fairly common at the top of the sandstone/siltstone units, including some interference forms. One type that is very common in siltstones consists of very tiny ripple sets with parallel but slightly undulatory ripple crests (millimeter ripples of Jeanette and Pryor, 1987).

Trace fossils are common at the bottoms and tops of

Figure 50. Diagrammatic vertical section of outcrop. Only major sand beds are shown (named and sampled as units 1 through 9). Symbols: Bu= burrows, Br= brachiopods, Rip= ripple-marks, Cr= crinoid ossicles, BP= pseudo (?) ball and pillow (now thought to be a photo artifact).


PERIOD
FORMATION
UNIT
LITHOLOGY
DEVONIAN
LOWER
CHADAKOIN
9
Bu
Very-fine, light gray with trace fossils only.
8
Br
Rip
Very fine, medium light gray fossiliferous sandstone with crinoids and brachiopodss; micaceous.
7
Bu Cr Br
Very fine, light brownish-gray sandstone with trace fossils; tiny crinoids, well sorted; micaceous.
6
Cr Br
Very fine, light olive-gray coquina sandstone with brachiopodss and crinoids; micaceous; uniform brachiopodss in middle.
5
Br
Very fine, light gray sandstone with very little fossils; micaceous.
4
Cr
Br
Conglomeritic sandstone with medium gray, subangular matrix; platey pebbles. Very fine, light olive-gray sandstone at top with crinoids and brachiopods; micaceous.
3
Br Cr
Very fine, light olive-gray coquina sandstone; large crinoids well sorted; brachiopods smaller at base, larger at top; micaceous.
2
Coq Br
Cr
Very fine, light gray sandstone with large crinoids; coquina sandstone with brachiopods; micaceous.
1
Coq Br
Cr
BP
Very fine, light bluish-gray sandstone with crinoids and brachiopods; micaceous.
0 feet 10

sandstone/siltstone beds. *Rhizocorallium* is seen most often in brown siltstones. Another less common trace is a horizontal trail branching into several bulbous terminations. Other simple horizontal trails are common. A thorough survey of trace fossils relative to stratigraphic positon would be difficult at this outcrop, but perhaps helpful in defining any paleodepth trends.

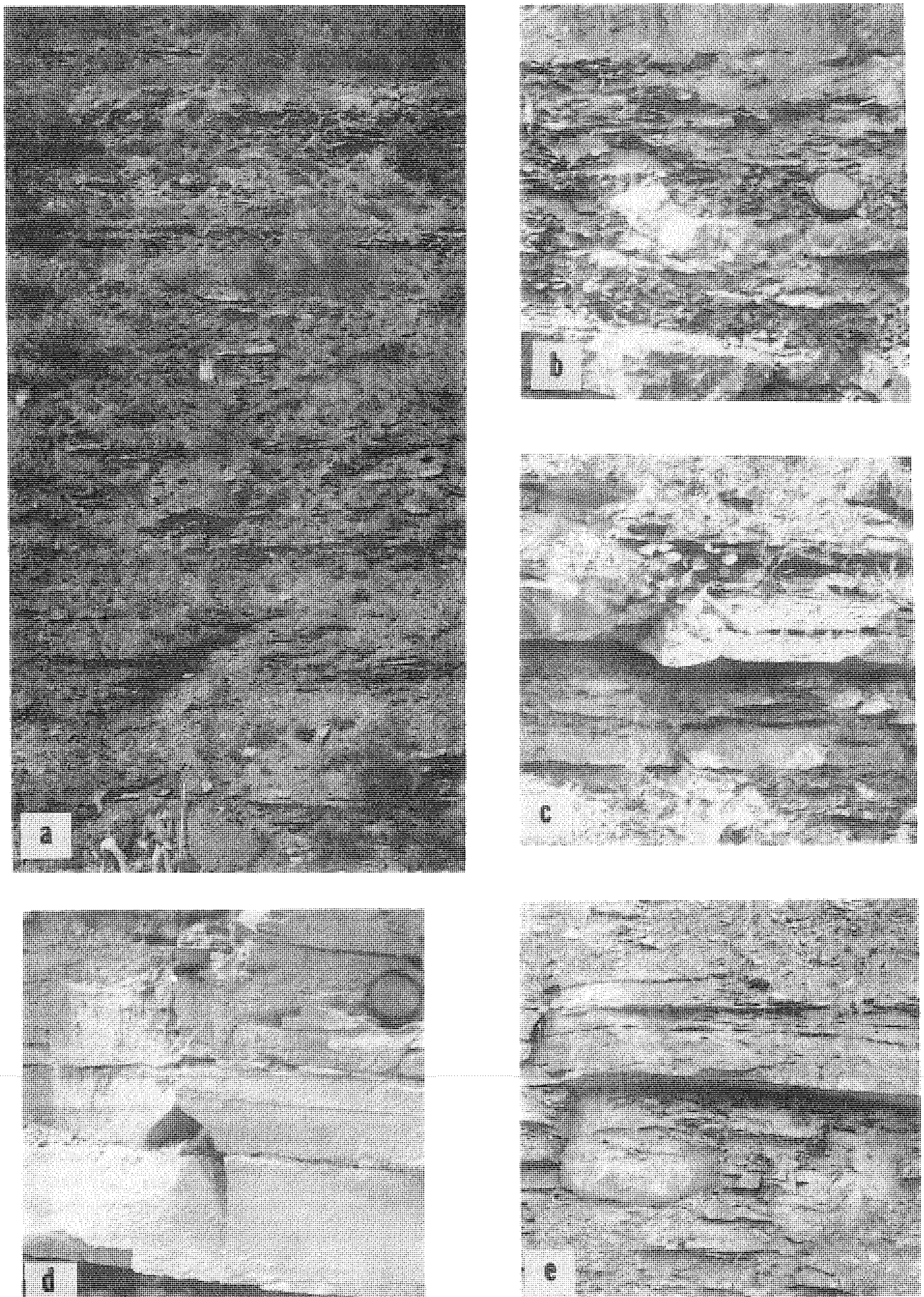
Coquinite Lenses

The coquinitic lenses and layers are brachiopod rich, especially with *Cyrtospirifer*. These large brachiopods are especially common at the very bottom of the bed, typically with single valves oriented concave-up. Crinoid ossicle layers are also common. The size varies between beds, from 1/8 inch to 1/3 inch in diameter, but within a single bed the ossicles are usually very well sorted. There are several distinct crinoidal layers within some beds. Larger shells may be mixed in with crinoid ossicles. One bed was noted that had a clayey layer at the top which was packed with crinoid ossicles, but crinoidal layers are generally found within a very fine, clean sand matrix.

Other brachiopods include the Rhynchonellids, *Camaroteochnia*, *Pugnoides*, and several productids. Other fossils are pelecypods, including *Leptodesma* and *Grammysia*, and a few gastropods. Other fossils reported to the west by Baird and Lash (1991) include glass sponges, horseshoe crabs, and several types of echinoderms. Also see Tesmer (1963, 1975) for descriptions of Chadakoin faunas at various New York outcrops. Bastedo (1980) studied the Pelecypods of the New York Chadakoin strata. Generally very small pieces of fossilized wood and collophane are also fairly common constituents of the sandstones (Plate 8).

Editor's note. During a visit to this outcrop in November, 1991, I collected a float slab with brachiopods on one side and crinoid ossicles on the other. The crinoid ossicles were slightly deformed, presumably by tectonic stress. Many other surfaces of float with crinoid ossicles have been examined subsequently, but none with deformed ossicles have been found. Crystal lattice orientation is a factor in calcite deformation

Plate 8. Outcrop photos of Chadakoin bedding. a. Stop 10 section. Highest resistant bed visible is Unit 8, Unit 1 is at base of outcrop. b. Turned-up, truncated sand layer indicating soft-sediment deformation after deposition and truncation of soft-sediment fold by a following storm event. c. Unit 1. Note axe for scale. Bottom of middle sand bed is at two levels, with a lens of coquinite "filling" the lower eroded part of the sea floor only. Two phases of deposition during the same storm is suggested. d. Close-up view of Unit 3 with parallel lamination to slightly swaley bedding (?) at base followed by slightly cross laminated bedding near top. Note appearance of fining up through bed. e. Unit 1 showing area of planar base and change from lower massive coquinite to upper thin bedded siltstone/sandstone. Questionable ball and pillow structure.

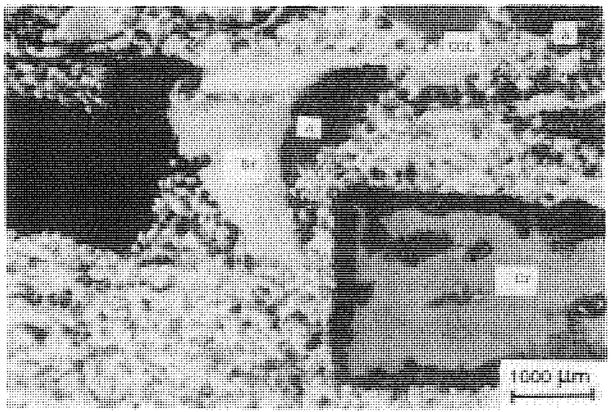

a
b
c
d
e

and apparently most of the calcite in this outcrop in not favorably oriented for deformation.

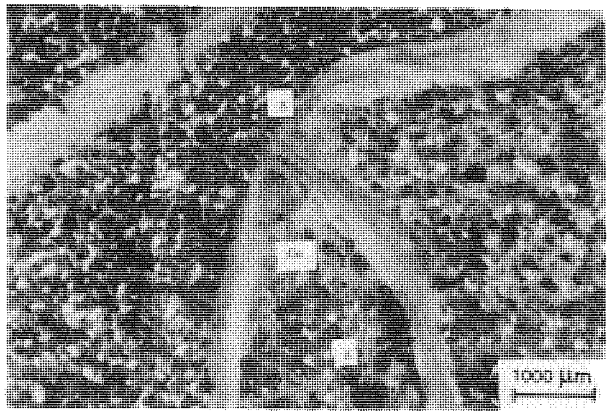
Petrography

Thin sections made from sandstone/siltstone-bed samples (Plate 9) show that the sandstones are mostly very fine grained and well sorted. Some contain large isolated clay clasts. Sandstone Unit 4 contains discoidal quartz pebbles. Calcite cement is most common. It is especially associated with bivalve shells, sometimes forming a geopetal filling in the hollow of a brachiopod rostrum. Secondary ankerite cement is seen around crinoid ossicles and clay clasts (Plate 9).

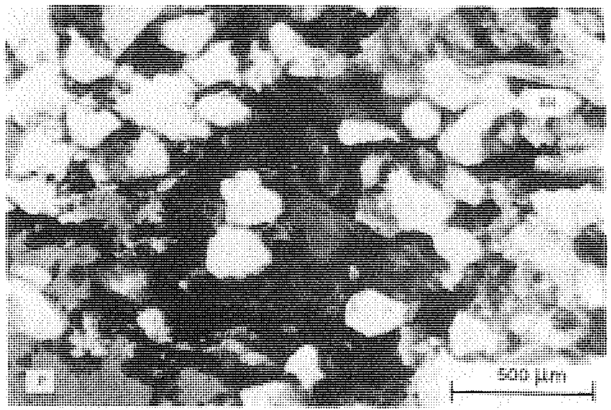
Plate 9. Thin-section photomicrographs showing lithologic characteristics of the Chadakoin Formation at Stop 10. a. Highly calcareous, fossiliferous (bioclasts are rudite size) bimodal fine-grained sandstone, showing the secondary iron-dolomite (ankerite = A) rhombs (n shades of grey) coating the crinoid ossicles (Cr) and the brachiopod fragments (Br). It also replaces calcite cement. The iron-dolomite rhombs are embedded in dark brown very fine to cryptocrystalline ankeritic siderite cement. Iron-rich dolomite the common cement in most samples. Note the collophane (COL) on the upper right of the picture. Plane-polarized light. Unit 3. b. Highly calcareous fossiliferous (bioclasts are rudite size) bimodal, fine-grained sandstone. The brachiopod fragments are replaced at the edges by dark dolomite and iron-dolomite (ankerite = A) respectively. Note calcite filling inside shell (Geopetal = Ge). Cross-polarized light. Unit 2. c. Micaceous, siliceous fine sandstone showing abundant intergranular porosity (P) filled with epoxy (shades of grey). Note bent mica on top right corner (BM), and the yellow to light brown limonitic matrix (shades of grey). Plane-polarized light. Unit 4. d. Very fine grained, fossiliferous (bioclasts are rudite size), bimodal sandstone with collophane debris (COL), feldspar grains (F), and intergranular porosity (P). Plane-polarized light. Unit 7. e. Very fine grained calcareous sandstone. Note that light carbonate rhombs of dolomite and iron-dolomite (ankerite = A) are embedded in darker, finely crystalline to cryptocrystalline, ankeritic/sideritic clast. This texture indicates that both the dolomite and iron-dolomite rhombs are secondary in origin. Also, note corrosion of quartz grains by carbonate cement. Cross-polarized light. Unit 7. f. Highly calcareous, highly fossiliferous (bioclasts are rudite size), bimodal sandstone showing the corrosion of quartz grains by calcite cement; and light dolomite and dark iron-dolomite (ankerite = A) rhombs replacing the bioclasts of brachiopods and the crinoid ossicles respectively. Cross-polarized light. Unit 6.



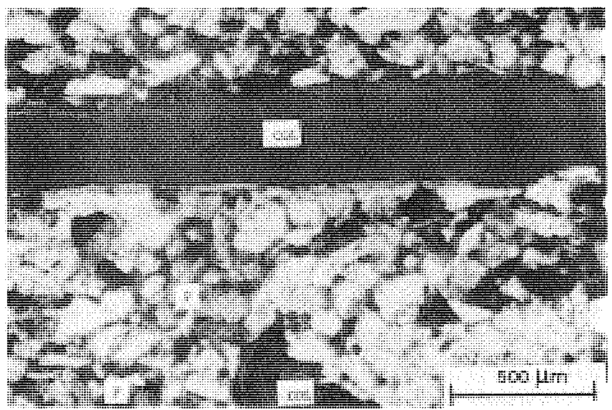
a



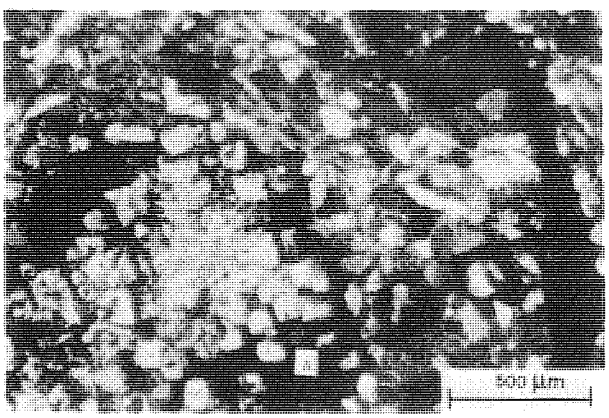
b



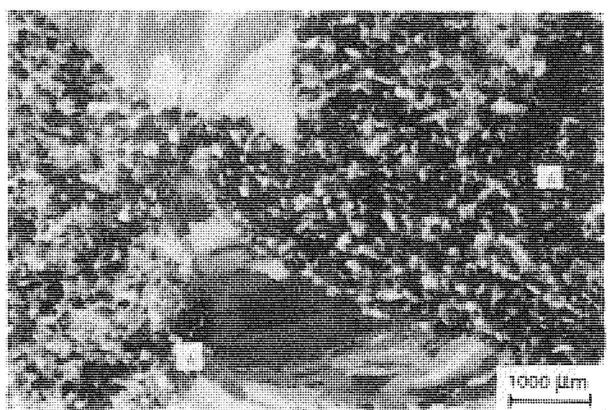
c



d



e



f

Depositional Environments

It is obvious that the strata here are representative of a marine shelf frequently (geologically) impinged upon by violent storms and possibly also affected by tidal and other marine currents. The shales and mudstones represent the quieter times, and indicate that the bottom was deeper than fair-weather wave base. The coquinitic sandstones record storms of various sizes. Large waves felt bottom here, and offshore flowing storm-relaxation currents interacted with the incoming wave-oscillation currents. Huge mass-mortalities were associated with the storms as infaunal organisms were exhumed and, along with epifaunal organisms, transported variable distances before being dumped onto the sea floor and buried by sand entrained by the storms. Some tempestitic sandstones record the declining strength of post-storm offshore-directed currents in their bedding sequences. Others record simple sea floor stirring by large waves. At the top of these beds post-storm modification can be studied, including rippling and settlement by organisms.

Another point of interest is the amount of erosion of the underlying strata before sand/coquina deposition. Dissection level of various depth types of mud burrows are discussed by Aigner (1985). An absence of burrowing of shales may indicate significant erosion before sand deposition.

Proximality Trends

The Chemung magnafacies can be reappraised because of a growing understanding of processes on marine shelves achieved by remote sensing and sampling of modern shelves and application to a large array of ancient strata. Several relationships occur in tempestite sequences which attest to the distance from shore and depth of water when the deposits formed. Progressive changes through a section may record changes in depth and distance from shore with time (assuming a constancy of range in storm size), referred to as proximality trends. Stratigraphic study then allows reconstruction of the geologic history, including sea level changes relating to regression and transgression of the ancient sea (Figure 51).

A general outline of proximality indicators is given by Aigner (1985), who states "...qualitatively and quantitatively, such tempestites show systematic changes in their sedimentological and paleoecological characteristics from nearshore to offshore. These proximality trends reflect the decreasing effect of storms away from the coastal sand source and with increasing depth." Storm-bed features include encasement by lower energy strata, coquinite pavements and beds, declining current internal bedding cycles, hummocky and swaley bedding, erosional bases, and current or biologic modification of tops (Aigner, 1985).

Near-source indicators include thicker deposits, with fewer interstorm beds. Amalgamation by erosion of the top of a storm bed followed by deposition during the following storm is common.

In the mid shelf, erosion of the upper layer of fair-weather, bioturbated mud by erosion before sand deposition keeps

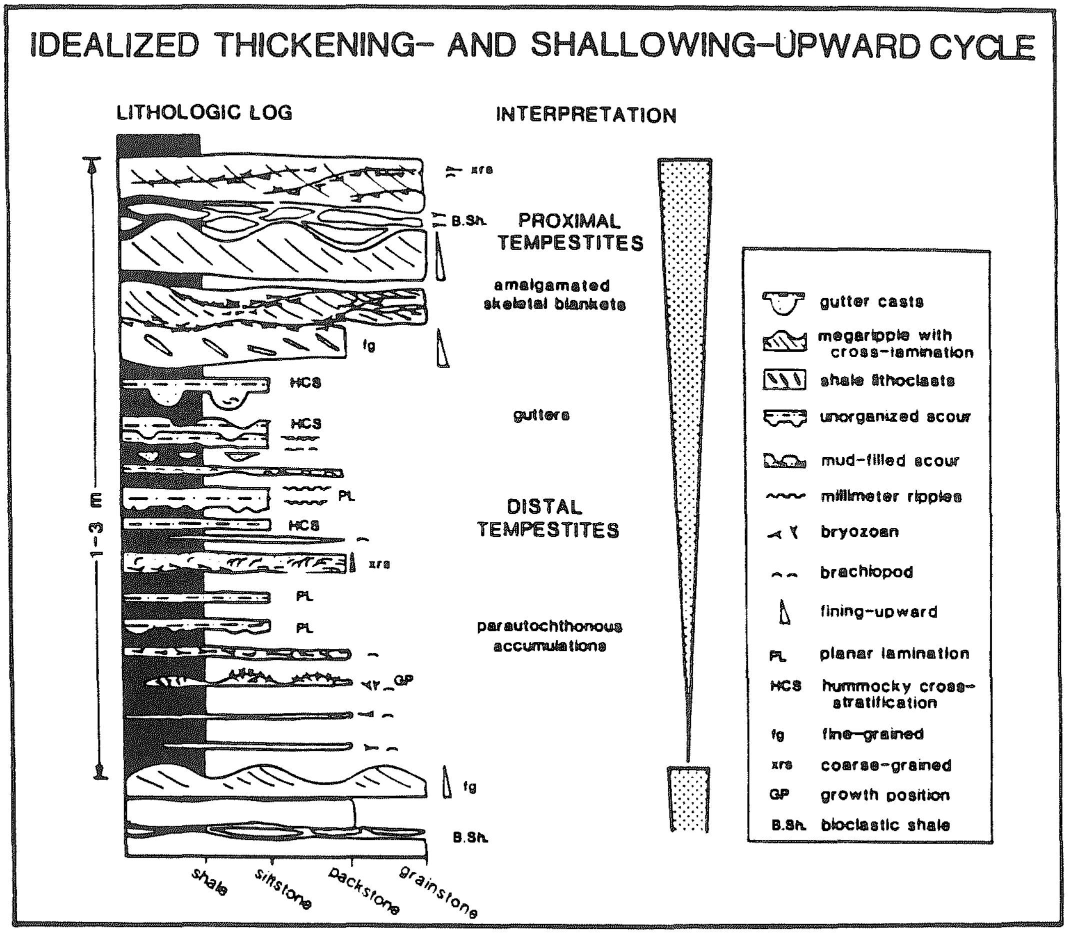


Figure 51. Idealized proximality cycle (from Jeanette and Pryor, 1987). Note millimeter ripples, which are common in red-brown siltstones at Stop 10.

bioturbated shales out the geological record of this area (Goldring and Langenstrassen, 1979). Sandstones are of an intermediate thickness, but may accumulate to the greatest overall thickness here, because much of the nearshore sand may be re-eroded and bypassed to these sites and only a little material goes farther offshore.

Offshore indicators include thin beds of silt, with a greater suspension-load contribution, overlain by non-bioturbated muds. Such rythmite deposits are transitional to turbidites (Goldring and Langenstrassen, 1979).

Many problems remain in modeling the stratigraphic record of ancient shelves. The concentration of sand into positive topographic features on mid and outer shelves, with resultant feedback to increased sand deposition needs to be put into a general model. The relative importance of shelf sandstone bodies on the Catskill Sea is not documented. The model for a delta platform with a delta front sand facies might be re-examined in light of mid to outer shelf sand ridge belts seen on other modern and ancient shelves.

Most models developed for storm-bed proximality have been for shelves off sandy shorelines. Myrow (1992) develops a model for muddy shorelines which differs somewhat from these. The apparent significance of a gutter-cast facies (shale with frequent sandstone ribbons filling small channels) is that high energy erosion of nearshore muddy bottoms is associated with bypassing of most storm sandload to greater depths. A similar nearshore (?) gutter-cast facies has been noted in the Lower Chadakoin of eastern McKean County, Pennsylvania, and eastern Cattaraugus County, New York, and in parts of the higher Venango Group by us. A detailed summation of such facies in the Famenian of this region might help to better establish the Bradford and Venango shoreline positions and the easterly limits of Chadakoin transgression.

Outcrop Interpretation

This outcrop is thought to exhibit the typical "Chemung" magnafacies as envisioned by Chadwick (1934). Stop 10 is tentatively attributed to either the "outer delta-platform" or "delta front" facies of the previous models developed for this magnafacies (Sutton and others, 1970; Thayer, 1974; Burrier, 1977; Sutton and McGhee, 1985).

Following models for the Frasnian-aged part of the "Chemung magnafacies" in west central New York, Burrier (1977) attributes the Chadakoin of Chautauqua County, New York to deposition across a submergent "delta platform". According to Burrier, the environment of deposition of the Dexterville Member varied across Chautauqua County from a prodelta in the west to a delta front in the east, whereas the overlying lower Ellicott formed on a delta platform, which is divisible into three areas: offshore, mid-platform, and nearshore. The very rudimentary work at this outcrop suggests that it equates with the offshore portion or mid-platform according to its fossil content and distal location according to its sedimentary structures, as outlined by Burrier (1977) and Jeanette and Pryor (1987) respectively.

There is a wealth of fossil information to be gained in "Chemung" strata, but the paleoecologic issues are very complex (Thayer, 1974), and we are not paleontologists. If future work is undertaken by us in the Chadakoin rocks, we would hope to involve our paleontologist colleague, Touran Panah.

Although there is undoubtedly much validity in an onshore to offshore facies model for the "Chemung", the universality of a (submarine) constructional delta platform along the margin of the Catskill Sea is questioned by one of us (Hopkins, this guidebook). A simpler shelf model allows other interpretations for the mechanisms controlling the physiographic elements of the Catskill Sea. In modern environments, storm relaxation currents are most typical on continental shelves in <u>front</u> of delta platforms (such as hypothesized for the Carolina Outer Banks by Hopkins (1971), or fronting other types of coastal deposystems.

		Leave Stop 10. **CONTINUE STRAIGHT AHEAD** on US Route 62 South.
2.0	68.8	**STOP LIGHT. CONTINUE STRAIGHT AHEAD.**
1.2	70.0	**STOP LIGHT. TURN RIGHT** following US Route 62 South

and 4th Street. Warren County historical marker on right. "Formed March 12, 1800 from Allegheny and Lycoming counties. Named for Gen. Joseph Warren, killed at Bunker Hill. Warren, the county seat, was laid out in 1795. Long known for its oil and timber operations, and site of the Cornplanter Indian Grant."

0.5 70.5 **TURN LEFT** onto Laurel Street following US Route 62.

0.1 70.6 **TURN RIGHT** onto Pennsylvania Avenue following US Route 62.

0.9 71.5 **TURN LEFT** following US Route 62 South.

0.3 71.8 **TURN RIGHT** into parking lot of Holiday Inn.

END OF DAY 2 AND THE FIELD CONFERENCE!

HAVE A SAFE TRIP HOME!!

REFERENCES CITED

Adewumi, M. A. and Watson, R. W., 1992, The development of cost effective, economically advantaged and economically advantaged and environmentally sensitive drilling technology: Drilling-Hydraulics Research Center, College of Earth and Mineral Sciences, The Pennsylvania State University.

Afifi, A. A. and Bricker, O. P., 1983, Weathering reactions, water chemistry and denudation rates in drainage basins of different bedrock types: I - sandstone and shale, in Webb, B. W., ed., Dissolved loads of rivers and surface water quantity/quality relationships: Proceedings of the Hamburg Symposium, International Association of Hydrological Sciences Publication 141, p. 193-203.

Aigner, T., 1985, Storm depositional systems: dynamic stratigraphy in modern and ancient shallow-marine sequences, in Friedman, G. M., Neugebauer, H. J., and Seilacher, A., Lecture notes in earth sciences: Berlin, Springer Verlag, 174 p.

Allen, J. R. L., 1984, Sedimentary structures--their character and physical basis: Developments in Sedimentology 30: Amsterdam, Elsevier, v. 2, 663 p.

Alling, H. L. and Briggs, L. I., 1961, Stratigraphy of Upper Silurian Cayugan evaporites: American Association of Petroleum Geologists Bulletin, v. 45, p. 515-547.

AONGRC, 1991, Measuring and predicting reservoir heterogeneity in complex deposystems, Annual Report to U.S. Department of Energy for Fiscal Year 1991, Contract no. DE-AC22-90BC14657, Morgantown, WV.

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

Auchmoody, L. R., Ciolkosz, E., Cronce, R., and Johnson, N., 1983, Northeastern forest soils conference, 1983: Northeastern Forest Experiment Station, Warren, PA, Guidebook, 83 p.

Ayrton, W. G., 1963, Isopach and lithofacies map of the Upper Devonian of northeastern United States, in Shepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geological Survey, 4th ser. Bulletin G39, p. 3-6.

Bailey, J. F., Patterson, J. L., and Paulhus, J. L. H., 1975, Hurricane Agnes rainfall and floods, June-July 1972: U. S. Geological Survey Professional Paper 924, 403 p.

Baird, G. C. and Lash, G. G., 1991, Devonian strata and paleoenvironments: Chautauqua County region, New York State: New York State Geological Association, 63rd Annual Meeting, Field Trip Guidebook.

Barrell, J., 1913, The Upper Devonian delta of the Appalachian Geosyncline: American Journal of Science, 4th ser., v. 36, p. 430-472.

Beardsley, R. W. and Cable, M. S., 1983, Overview of the Appalachian Basin: Northeastern Geology, v. 5, p. 137-145.

Beecher, C. E., 1884, Ceratiocaridae from the Upper Devonian measures in Warren County: Pennsylvania Geological Survey, 2nd ser., Report P3, p. 1-22.

Berg, T. M. and Dodge, C. M., 1981, Atlas of preliminary geologic quadrangle maps of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 61, 636 p.

Berg, T. M., Edmunds, W. E., Geyer, A. R., and others, compilers, 1980, 2nd ed., Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 1, scale 1:250,000, 3 sheets.

Berg, T. M., McInerney, M. K., Way, J. H., and MacLachlan, D. M., 1986, Stratigraphic correlation chart of Pennsylvania, 2nd printing, revised: Pennsylvania Geological Survey, 4th ser., General Geology Report 75, 1 sheet.

Bernabo, J. C. and Webb, T., III, 1977, Changing patterns in the Holocene pollen record of northeastern North America: a mapped summary: Quaternary Research, v. 8, p. 64-96.

Boswell, R. M., 1988, Eustacy, Acadian Orogeny and Famenian shorelines of the Central Appalachian Basin: 19th Annual Appalachian Petroleum Geologists Symposium, West Virginia Geological and Economic Survey Circular C-42, p. 8-11.

Boswell, R. M. and Donaldson, A. C., 1988, Depositional architecture of the Upper Devonian Catskill delta complex: Central Appalachian Basin, U.S.A., in McMillan, N. J., Embry, A. F., Glass, D. J., eds., Devonian of the World, Proceedings of the 2nd International Symposium on the Devonian System, v. 2: Canadian Society of Petroleum Geologists Memoir 14, p. 65-84.

Boswell, R. M. and Jewell, G. A., 1988, Atlas of Upper Devonian/Lower Mississippian sandstones in the subsurface of West Virginia: West Virginia Geological and Economic Survey Circular C-43, 143 p.

Bowen, Z. P., Rhoads, D. C., and McAlester, A. L., 1974, Marine benthic communities in the Upper Devonian of

New York: Lethia, v. 7, p. 93-120.

Braun, D. D., 1988, Glacial geology of the Anthracite and north branch Susquehanna lowland regions, in Inners, J. D., ed., Bedrock and glacial geology of the north branch Susquehanna Lowland and the eastern middle Anthracite field northestern Pennsylvania: 53rd Annual Field Confernce of Pennsylvania Geologists, Hazleton, PA, Guidebook, 228 p.

Budel, J., 1982, Climatic geomorphology: Princeton, NJ, Princeton University Press, 443 p.

Burgchardt, C. and Fox, J. S., 1989, Oil region of Titusville, Pleasantvile, Tidioute, and Tionesta in Pees, S. T. and Greenwalt, J. C. chairmen, History of the petroleum industry symposium: American Association of Petroleum Geologists, Field Trip #1, Guidebook, p. 25-27.

Burgchardt, C. R., 1992, Stratigraphic correlation: Penn State— IPSCO well #1, Sheffield Township, Warren County, Pennsylvania.

Burrier, D. 1977, The paleoecology of the Chadakoin Formation of Chatauqua County, New York: unpublished MS thesis, State University of New York at Fredonia, 129 p.

Busch, D. A., 1943, Paleontology, in Dickey, P. A., Sherrill, R. E., and Matteson, L. S., Oil and gas geology of the Oil City [15-minute] quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 25, appendix C, p. 149-154.

Butts, C., 1903, Fossil faunas of the Olean Quadrangle: New York State Museum Bulletin 69, p. 990-995.

Butts, C., 1910, Warren folio, Pennsylvania-New York: U. S. Geological Survey Geologic Atlas, Folio 172, 11 p.

Cahn, J. H., 1940, The origin of the Venango second sand formation: unpublished MSc thesis, University of Pittsburgh, Pittsburgh, PA, 37 p.

Carll, J. F., 1880, Geology of the oil regions of Warren, Venango, Clarion and Butler Counties, including surveys of the Garland and Panama conglomerates in Warren and Crawford, and in Chautauqua Co., N.Y., descriptions of oil well rig and tools, and a discussion of the preglacial and postglacial drainage of the Lake Erie country: Pennsylvania Geological Survey, 2nd ser., v. I-3, 482 p.

Carll, J. F., 1883, Geological report on Warren County and the neighboring oil regions, with additional oil well records: Pennsylvania Geological Survey, 2nd ser., v. I4, 439 p.

Carll, J. F., 1886, Preliminary report on oil and gas, in Lesley, J. P., Annual report of the Geological Survey of Pennsylvania for 1885: Pennsylvania Geological Survey, 2nd ser., Annual Report for 1885, p. 1-81.

Carll, J. F., 1890, Seventh report on the oil and gas fields of western Pennsylvania for 1887, 1888: Pennsylvania Geological Survey, 2nd ser., Report I-5, 356 p.

Carswell, L. D., and Bennett, G. D., 1963, Geology and hydrology of the Neshannock [15-minute] quadrangle, Mercer and Lawrence Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Water Resource Report 15, 90 p.

Carter, B. J. and Ciolkosz, E. J., 1980, Soil temperature regimes of the central Appalachians: Soil Science Society of America Journal, v. 44, p. 1052-1058.

Carter, J. L., and Kammer, T. W., 1990, Late Devonian and Early Carboniferous brachiopods (Brachiopoda, Articulata) from the Price Formation of West Virginia and adjacent areas of Pennsylvania and Maryland: Annals of Carnegie Museum, v. 59, no. 2, p. 77-103.

Caspero, N. A., Wertman, W. T., and Eckard, W. E., 1963, Underground combustion oil-recovery experiment in the Venango First sand, Warren County, Pa.: U.S. Bureau of Mines, Report of Investigations 6320, 39 p.

Caster, K. E., 1934, The stratigraphy and paleontology of northwestern Pennsylvania, Part 1: Stratigraphy: Bulletins of American Paleontology, v. 21, no. 71, 185 p.

Cate, A. S., 1962, Subsurface structure of the plateau region of north-central and western Pennsylvania on top of the Oriskany Formation: Pennsylvania Geological Survey, 4th ser., Map 9.

Cathcart, S. H., Sherrill, R. E., and Matteson, L. S., 1938, Geology of the oil and gas fields of the Tidioute quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Progress Report 118, 14 p.

Chadwick, G. H., 1923, Chemung stratigraphy in western New York (abs.): Geological Society of America Bulletin, v. 34, p. 68-69.

Chadwick, G. H., 1924, The stratigraphy of the Chemung Group in western New York: New York State Museum Bulletin, v. 251, p. 149-157.

Chadwick, G. H., 1934, Chemung is Portage: Geological Society of America Bulletin, v. 46, p. 343-354.

Ciolkosz, E. J., Waltman, W. J., Simpson, T. W., and Dobos, R. R., 1989, Distribution and genesis of soils of

the northeastern United States: Geomorphology, v. 2, p. 285-302.
Cerutti, J. R., 1985, Soil sruvey of Warren and Forest Counties, Pennsylvania: U. S. Department of Agriculture, Soil Conservation Service, 148 p.
Chamberlin, T. C. and Leverett, F., 1894, Further studies of the drainage features of the upper Ohio basin: American Journal of Science, 3rd ser., v. 47, p. 247-283.
Compton, R. R., 1962, Manual of field geology: New York, John Wiley and Sons, Inc., 378 p.
Craft, J. L., 1979, Quality of gravel resources in northwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Information Circular 86, 54 p.
Cronce, R. C. and Ciolkosz, E. J., 1983, Soils of the Allegheny National Forest, in Auchmoody, L. R., Ciolkosz, E. J., Cronce, R. C., and Johnson, N., Northeastern forest soils conference 1983: Allegheny National Forest, Warren, PA, 24-26 July, Guidebook, p. 8-19.
Cunningham, R. L. and Ciolkosz, E. J., eds., 1984, Soils of the northeastern United States: University Park, The Pennsylvania State University, College of Agriculture, Agricultural Experiment Station, Bulletin 848, 47 p.
Curtin, T., 1992, Penn State and IPSCO collaborate on drilling research center in the valley: The Valley Voice and Echo (Sheffield, Pa.), March 13, 1992.
Daniels, P., Jr., 1986, Cambrian-Ordovician sedimentary-tectonic evolution of Michigan Basin (abs.): American Association of Petroleum Geologists Bulletin, v. 70, p. 1064.
Davis, D. C., 1968, Statistics and data analysis in geology, 2nd ed.: New York, John Wiley and Sons, 646 p.
Deardorff, M. H., 1972, Chief Cornplanter: Pennsylvania Historical and Museum Commission, Historic Pennsylvania Leaflet No. 32, 4 p.
Demarest, D. F., 1946, Map of the Berea and Murrysville sands of northeastern Ohio, western Pennsylvania, and northernmost West Virginia: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 49, scale 1:190,080, 1 sheet.
Dennison, J. M., 1985a, Sedimentary tectonics of the Appalachian Basin: Houston Geological Society Short Course Notes.
Dennison, J. M., 1985b, Catskill Delta shallow marine strata, in Woodrow, D. L. and Sevon, W. D., eds., The Catskill delta: Geological Society of America Special Paper 201, p. 91-106.
Dickey, P. A., 1941, Oil geology of the Titusville quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 22, 87 p.
Dickey, P. A., Sherrill, R. E., and Matteson, L. S., 1943, Oil and gas geology of the Oil City quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 25, 201 p.
Donaldson, A. C. and Boswell, R., 1986, Synsedimentary tectonics indicated by facies of Devonian-Mississippian rocks of central Appalachians, in Appalachian Basin Architecture: 17th Annual Appalachian Geologists Symposium, West Virginia Geologic and Economic Survey, Circular C-38.
Eames, L. E., 1974, Palynology of the Berea Sandstone and Cuyahoga Group of northeastern Ohio: unpublished PhD thesis, Michigan State University, East Lansing, 294 p.
Edmunds, W. E., Berg, T. M., Sevon, W. D., and others, 1979, The Mississippian and Pennsylvanian (Carboniferous) systems in the United States--Pennsylvania and New York: U.S. Geological Survey Professional Paper 1110-B, p. B1-B33.
Emerson, T., 1992, Kinzua Dam: unpublished manuscript, 3 p.
Engelder, T., 1982, Is there a genetic relationship between selected regional joints and contemporary stress within the lithosphere of North America?: Tectonics, v. 1, p. 161-177.
Engelder, T., 1985, Loading paths to joint propagation during a tectonic cycle: an example from the Appalachian Plateau, U.S.A.: Journal of Structural Geology, v. 7, p. 459-476.
Ensign, J., 1991, Geologic observations of the Whirlpool Sandstone in western Warren County, Pennsylvania (abs.): American Association of Petroleum Geologists Bulletin, v. 75, p. 1382.
Faill, R. T., 1985, The acadian orogeny and the Catskill delta, in Woodrow, D. L. and Sevon, W. D., eds., The Catskill delta: Geological Society of America Special Paper 201, p. 15-37.
Famy, S. M., 1979, Relationship between the cross-strike lineaments and the distribution of oil and gas fields in northwest Pennsylvania: unpublished MSc thesis, Pennsylvania State University, 137 p.
Ferguson, H. F., 1967, Valley stress release in the Allegheny Plateau: Engineering Geology, v. 4, p. 63-71.
Fettke, C. R., 1938, Bradford oil field, Pennsylvania and New York: Pennsylvania Geological Survey, 4th ser., Report M-21.

Fettke, C. R., 1950, Water flooding in Pennsylvania, in Secondary Recovery in the United States, 2nd ed.: American Petroleum Institute, p. 413-443.

Fisher, S.P., Fanaff, A.S., and Picking, L. W., 1968, Landslides of southeastern Ohio: Ohio Journal of Science, v. 68, p. 67-80.

Folk, R. L., 1980, Petrology of sedimentary rocks: Austin, TX, Hemphill Publishing Co., 185 p.

Frey, R. W. and Pemberton, S. G., 1984, Trace fossil facies models, in Walker, R. G., ed., 2nd ed., Facies models: Geoscience Canada Reprint Series 1, p. 189-207.

Fuller, J. O., 1955, Source of Sharon Conglomerate of northeastern Ohio: Geological Society of America Bulletin, v. 66, p. 159-176.

Fürish, F. T., 1974, Ichnogenus Rhizocorallium: Paläontologische Zeitschrift, v. 48, p. 16-28.

Geiser, P. and Engelder, T., 1983, The distribution of layer parallel shortening fabrics in the Appalachian foreland of New York and Pennsylvania: evidence for two non-coaxial phases of the Alleghanian orogeny, in Hatcher, R. D., Jr., Williams, H., and Zietz, I., eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 161-175.

Gilman, R. A. and Metzger, W. J., 1967, Cone-in-cone concretions from western New York: Journal of Sedimentary Petrology, v. 37, p. 87-95.

Glenn, L. C., 1903, Devonic and Carbonic formations of southwestern New York: New York State Museum Bulletin, v. 69, p. 967-989.

Goldring, R. and Langenstrassen, F., 1979, Open shelf and nearshore clastic facies in the Devonian: Special Papers in Paleontology, no. 23, p. 81-97.

Gray, C., Conlin, R. R., Hoskins, D. M., and others, compilers, 1960, 1st ed., Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 1, scale 1:250,000, 2 sheets.

Graymont, B., 1988, The Iroquois: New York, Chelsea House Publishers, 128 p.

Greiner, Hugo, 1957, "Spirifer disjunctus": its evolution and paleoecology in the Catskill Delta: Peabody Museum of Natural History Bulletin, v. 11, 70 p.

Gresley, W. S., 1894, Cone-in-cone: how it occurs in the 'Devonian' series in Pennsylvania, U.S.A., with further details of its structure, varieties, etc.: Quarterly Journal of the Geological Society (London), v. L, p. 731-739.

Gwinn, V. E., 1964, Thin-skinned tectonics in the plateau and northwestern valley and ridge provinces of the central Appalachians: Geological Society of America Bulletin, v. 75, p. 863-900.

Hall, J., 1839, Third annual report of the survey of the third geological district: New York Geological Survey, Annual Reports, p. 287-347.

Hall, James, 1884, Note on Eurypteridae of the Devonian and Carboniferous formations of Pennsylvania: Pennsylvania Geological Survey, 2nd ser., Report P3, p. 23-39.

Hallam, A. and Swett, K., 1965, Trace fossils from the Lower Cambrian Pipe Rock of the north-west Highlands: Scottish Journal of Geology, v. 2, p. 101-106.

Halsey, S. D., 1979, Nexus: New model of Barrier Island development, in Leatherman, S. P., ed., Barrier Islands: New York, Academic Press, p. 185-210.

Harms, J. C., Southard, J. B., and Walker, R. G., 1982, Chapter 3. Deposition and stratification, in Structures and sequences in clastic rocks: Society of Economic Paleontologists and Mineralogists Short Course, no. 9, p. 3-1--3-51.

Harper, J. A., 1989, Effects of recurrent tectonic patterns on the occurrence and development of oil and gas resources in western Pennsylvania: Northeastern Geology, v. 11, p. 225-245.

Harper, J. A., 1992, Possible basement influence on glaciation in NW Pennsylvania and adjacent areas (abs.): Geological Society of America Abstracts with Programs, v. 24, no. 3, p. 27.

Harper, J. A. and Abel, K. D., 1980a, Structure contours on the base of the Perrysburg Formation and Huron Shale (Dunkirk facies), northwestern Pennsylvania: Morgantown Energy Technology Center, Eastern Gas Shales Project Series No. 26, Map.

Harper, J. A. and Abel, K. D., 1980b, Structure contours on base of Java Formation, northwestern Pennsylvania: Morgantown Energy Technology Center, Eastern Gas Shales Project Series No. 29, Map.

Harper, J. A. and Laughrey, C. D., 1987, Geology of the oil and gas fields of southwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 87, 166 p.

Harper, J. A. and Laughrey, C. D., 1989, in Harper, J. A., ed., Geology in the Laurel Highlands of southwestern Pennsylvania: 54th Annual Field Conference of Pennsylvania Geologists, Johnstown, PA, Guidebook, p. 35-62.

Harper, J. A. and Piotrowski, R. G., 1979, Structure contour map on top of the Middle Devonian Onondaga Group in western and northern Pennsylvania: Morgantown Energy Technology Center, Eastern Gas Shales Project Series No. 12, Map.

Hays, M. O., 1979, Barrier Island morphology as a function of tidal and wave regime, in Leatherman, S. P., ed., Barrier Islands: New York, Academic Press, p. 1-27.

Holland, F. D., Jr., 1958, The Brachiopoda of the Oswayo and Knapp Formations of the Penn-York embayment: unpublished PhD thesis, University of Cincinnati, Cincinnati, OH, 525 p.

Hopkins, E. M., 1971, Origin of capes and shoals along the southeastern coast of the United States: discussion: Geological Society of America Bulletin, v. 82, p. 3537-3540.

Hopkins, E. M., 1987, Paleogeography of the Upper Devonian oil sands of Pennsylvania (abs.): Geological Society of America Abstracts with Programs, v. 19, no. 1, p. 20.

Hopkins, E. M., 1988, Sedimentology and paleogeography of Upper Devonian sandstones in north-central Pennsylvania and western New York (abs.): American Association of Petroleum Geologists Bulletin, v. 72, p. 965.

Hopkins, E. M., In Preparation, Outcropping marine and coastal lithofacies of the Upper Devonian of northcentral Pennsylvania:

Hoskins, D. M., 1976, Geology and mineral resources of the Millersburg 15-minute quadrangle, Dauphin, Juniata, Northumberland, Perry, and Snyder Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Atlas 146, 38 p.

Ingham, A. I., Lytle, W. S., and Matteson, L. S., 1956, Oil and gas geology of the Sheffield quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 38, 72 p.

Iranpanah, A. and Hopkins, E. M., 1987, Tectonic analysis of lineaments delineated on Landsat imagery of the Allegheny Plateau in north-central Pennsylvania and western New York (abs.): Geological Society of America Abstracts with Programs, v. 19, no. 1, p. 21.

Jeanette, D. and Pryor, W., 1987, Local Cincinnati geology--idealized thickening- and shallowing-upward cycle: Figure in 1986-87 Sedimentology Newsletter, Fisk Laboratory of Sedimentology, University of Cincinnati.

Johnson, S. S., 1984, Depositional environment and reservoir characteristics of the Upper Devonian Kane Sand in central western Pennsylvania (abs.): American Association of Petroleum Geologists Bulletin, v. 68, p. 1921.

Kamakaris, D. G. and Van Tyne, A. M., 1980a, Isopach map of black shales in the Perrysburg Formation: Morgantown Energy Technology Center, Eastern Gas Shales Project Series No. 105.

Kamakaris, D. G. and Van Tyne, A. M., 1980b, Isopach map of black shales in the Java Formation: Morgantown Energy Technology Center, Eastern Gas Shales Project Series No. 106.

Kelley, D. R., 1967, Geology of the Red Valley sandstone in Forest and Venango Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 57, 49 p.

Kelley , D. R. and Wagner, W. R., 1970, Surface to Middle Devonian (Onondaga) stratigraphy: Pennsylvania Geological Survey, 4th ser., Open File Report.

Kelley, D. R. and Wagner, W. R., 1972, Surface to Middle Devonian (Onondaga) stratigraphy--gamma ray log cross sections, part 1: Pennsylvania Geological Survey, 4th ser., open-file report, 5 p.

Kimmel, G. E. and Schiner, G. R. 1970, The Shenango Formation (Mississippian) in northwestern Pennsylvania: U.S. Geological Survey Bulletin 1294-C, 13 p.

Kreidler, W. L., 1957, Stratigraphy of southwestern New York, Trips A-1, A-2, E: 29th Annual Meeting of the New York State Geological Association, Wellsville, NY, Field Trip Guidebook.

Lattman, L. H., 1954, The one-sided development of tributaries in tilted sedimentary rocks in eastern Allegheny Plateau of West Virginia: Papers of the Michigan Academy of Science, Arts and Letters, v. 39, p. 361-365.

Laughrey, C. D., 1984, Petrology and reservoir characteristics of the Lower Silurian Medina Group sandstones, Athens and Geneva fields, Crawford County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 85, 126 p.

Laughrey, C. D., 1991, Utility of petroleum geochemistry in the search for new gas reserves in Pennsylvania (abs.), in Exploration strategies in the Appalachian basin: 22nd Annual Appalachian Petroleum Geology Symposium, Program and Abstracts, I. C. White Memorial Fund Publication 3, p. 49-50.

Laughrey, C. D. and Harper, J. A., 1986, Comparisons of Upper Devonian and Lower Silurian tight formations in Pennsylvania - geological and engineering characteristics, in Spencer, C. R., and Mast, B. E., eds., Geology of tight reservoirs: American Association of Petroleum Geologists, Studies in Geology 26, p. 9-43.

Laughrey, C. D. and Harper, J. A., 1989, Stop A, Youghiogheny Gorge through Laurel Hill: Late Devonian stratigraphy and sedimentology of the Venango Group, lower sandy zone, in Harper, J. A., ed., Geology in the Laurel Highlands, southwestern Pennsylvania: 54th Annual Field Conference of Pennsylvania Geologists, Johnstown, PA, Guidebook, p. 161-167.

Lavin, P. M., Chaffin, D. L., and Davis, W. F., 1982, Major lineaments and the Lake Erie-Maryland crustal block: Tectonics, v. 1, p. 431-440.

Lesley, J. P., 1875, Note on the comparative geology of northeastern Ohio and northwestern Pennsylvania, and western New York, in Carll, J. F., Report of progress in the Venango County District, Pennsylvania Geological Survey, 2nd ser., Report I, p. 57-108.

Lesley, J. P., 1876, The Boyd's Hill gas well at Pittsburg, in Platt, F., Special report on the coke manufacture of the Youghiogheny River valley in Fayette and Westmoreland Counties: Pennsylvania Geological Survey, 2nd ser., Report L, appendix E, p. 217-237.

Lesley, J. P., 1879, Index to the beds, vertically arranged, in White, I. C., The geology of Lawrence County, Pennsylvania Geological Survey, 2nd ser., Report QQ, p. 319-333.

Leverett, F., 1902, Glacial formations and drainage features of the Erie and Ohio Basins: U. S. Geological Survey Monograph XLI, 802 p.

Leverett, F., 1934, Glacial deposits outside the Wisconsin terminal moraine in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin G 7, 123 p.

Lytle, W. S., 1955, Summary secondary recovery operations in Pennsylvania to January 1, 1954, including petroleum reserves and production by counties: Pennsylvania Geological Survey, 4th ser., Progress Report 148, 23 p.

Lytle, W. S., 1959, History, present status and future possibilities of secondary recovery operations in Pennsylvania: Interstate Oil Compact Commission Committee Bulletin, v. 1, no. 2, p. 28-42.,

Lytle, W. S., 1965, Oil and gas geology of the Warren quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 52, 84 p.

Lytle, W. S., 1966, Steam injection operations in Pennsylvania: Producers Monthly, v. 30, no. 12, p. 2-5.

Lytle, W. S. and Goth, J. H., 1970, Oil and gas geology of the Kinzua quadrangle, Warren and McKean Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 62, 99 p.

Manspeizer, W., 1963a, A study of the stratigraphy, paleontology, petrology, and geologic history of the Canadaway and Conneaut Groups in Allegany County, New York: unpublished PhD thesis, Rutgers University, New Brunswick, NJ.

Manspeizer, W., 1963b, A restudy of the Chautauquan series of Allegany County, New York, in Shepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geological Survey, 4th ser., General Geology Report G 39, p. 259-277.

McEachran, D. B., 1986-1990, Stereographic projection programs for the Macintosh: Denver, CO, RockWare Inc., 45 p.

McGhee, G. R., Jr. and Dennison, J. M., 1980, Late Devonian chronostratigraphic correlations between the Central Appalachian Allegheny front and central and western New York: Southeastern Geology, v. 21, p. 279-286.

McGhee, G. R., Jr. and Sutton, R. G., 1981, Late Devonion marine ecology and zoogeography of the central Appalachians and New York: Lethaia, v. 14, p. 27-43.

McGlade, W. G., 1964, Oil and gas geology of the Youngsville quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 53, 56 p.

Meckel, L. D., 1967, Origin of Pottsville conglomerates (Pennsylvania) in the central Appalachians: Geological Society of America Bulletin, v. 78, p. 223-258.

Miall, A. D., 1978, Lithofacies types and vertical profile models in braided river deposits: a summary, in Miall, A. D., Fluvial sedimentology: Canadian Society of Petroleum Geologists, Memoir 5, p. 597-604.

Muller, E. H., 1963, Geology of Chautauqua County, New York, Part II. Pleistocene geology: New York State Museum and Science Service Bulletin 392, 60 p.

Muller, O. H., Lavin, P. M., and Diment, D. H., 1980, A major northwest trending Precambrian strike-slip

fault in Pennsylvania (abs.): American Geophysical Union Transactions, v. 61, p. 360.
Myrow, P. M., 1992, Bypass-zone tempestite facies model and proximality trends for an ancient muddy shoreline and shelf: Journal of Sedimentary Petrology, v. 62, p. 99-115.
Newberry, J. S., 1871, Report on the progress of the Geological Survey of Ohio in 1869: Ohio Geological Survey, 2nd ser., Report of Progress 1869, p. 1-53.
Newman, F. B. and Gower, T. R., 1987, Geological hazards along Dorcon Road and L.R. 1099: Highway Construction in Unstable Topography--Proceedings of the 38th Annual Highway Geology Symposium, Pittsburgh, PA, p. 50-56.
Oliver, W. A., Jr., de Witt, W., Jr., Dennison, M. M., Hoskins, D. M., and Huddle, J. W., 1971, Isopach and lithofacies maps of the Devonian in the Appalachian Basin: Pennsylvania Geological Survey, 4th ser., Progress Report 182.
Pemberton, S. G. and Frey, R. W., 1982, Trace fossil nomenclature and the Planolites-Palaeophycus dilemma: Journal of Paleontology, v. 56, p. 843-881.
Pemberton, S. G., 1984, Quantitative methods in ichnology: spatial distribution among populations: Lethaia, v. 17, p. 33-49.
Pemberton, S. G. and Risk, M. J., 1982, Middle Silurian trace fossils in the Hamilton, Ontario region: their identification, abundance, and significance: Northeastern Geology, v. 2, p. 98-104.
Penland, S., Boyd, R., and Suter, J. R., 1988, Transgressive depositional systems of the Mississippi delta plain: A model for barrier shoreline and shelf sand development: Journal of Sedimentary Petrology, v. 58, p. 932-949.
PennDOT, 1991, Bulletin #14 - aggregate producers: Publication #34.
Pepper, J. F., Witt, W. D., Jr., and Demarest, D. F., 1954, Geology of the Bedford Shale and Berea Sandstone in the Appalachian Basin: U.S. Geological Survey Professional Paper 259, 109 p.
Philbrick, S. S., 1976, Kinzua Dam and the glacial foreland, in Coates, D. R., ed., Geomorphology and engineering: Stroudsburg, PA, Dowden, Hutchinson and Ross, Inc., p. 175-197.
Piotrowski, R. G., 1981, Geology and natural gas production of the lower Silurian Medina Group and equivalent rock units in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 82, 11 plates.
Piotrowski, R. G. and Harper, J. A., 1979, Black shale and sandstone facies of the Devonian "Catskill" clastic wedge in the subsurface of western Pennsylvania: U.S. Department of Energy, Eastern Gas Shales Project, EGSP Series 13, 40 p.
Poag, C. W. and Sevon, W. D., 1989, A record of Appalachian denudation in postrift Mesozoic and Cenozoic sedimentary deposits of the U. S. Middle Atlantic continental margin: Geomorphology, v. 2, p. 119-157.
Pomeroy, J. S., 1981, Landslides and related features Pennsylvania--Warren $1^{o}x2^{o}$ Sheet: U.S. Geological Survey Open-File Report 81-238, 112 plates, scale 1:24,000.
Pomeroy, J. S., 1982, Landslides in the greater Pittsburgh region, Pennsylvania: U.S. Geological Survey Professional Paper 1229, 48 p.
Pomeroy, J. S., 1983, Relict debris flows in northwestern Pennsylvania: Northeastern Geology, v. 5, p. 1-7.
Pomeroy, J. S., 1986, Slope movements in the Warren-Allegheny Reservoir Area, northwestern Pennsylvania: U.S. Geological Survey Bulletin 1650, 15 p.
Poth, C. W., 1963, Geology and hydrology of the Mercer [15-minute] quadrangle, Mercer, Lawrence, and Butler Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Water Resource Report 16, 149 p.
Prouty, C. E., 1986, Tectonic development of Michigan Basin (abs.): American Association of Petroleum Geologists, v. 70, p. 1069.
Rahmanian, V. D., 1979, Stratigraphy and sedimentology of the Upper Devonian Catskill and uppermost Trimmers Rock Formation in central Pennsylvania: unpublished PhD Thesis, Pennsylvania State University, University Park, 340 p.
Rickard, L. F., 1973, Stratigraphy and structure of the subsurface Cambrian and Ordovician carbonates of New York: New York State Museum of Science, Map and Chart Series, No. 18, 26 p.
Rickard, L. F., 1975, Correlation of the Silurian and Devonian rocks of New York State: New York State Museum of Science, Map and Chart Series, No. 24, 16 p.
Ridge, J. C., Braun, D. D., and Evenson, E. B., 1990, Does Altonian drift exist in Pennsylvania and New Jersey?: Quaternary Research, v. 33, p. 253-258.
Rogers, H. D., 1858, The geology of Pennsylvania--A government survey: Pennsylvania Geological Survey, 1st

ser., v. 1, 586 p.; v. 2, 1045 p.

Rough. R. L. and Eckard, W. E., 1963, Results of hydraulic fracturing in shallow oil sands, Warren County, Pa.: Producers Monthly, v. 27, no 8, p. 9-15.

Rough, R. L. and Eckard, W. E., 1964, Hydraulic fracture treatments in Glade and Clarendon oil reservoirs, Warren County, Pa.: U.S. Bureau of Mines Report of Investigations 6471, 22 p.

Sass, D. B., 1960, Some aspects of the paleontology, stratigraphy, and sedimentation of the Corry Sandstone of northwestern Pennsylvania: Bulletins of American Paleontology, v. 41, no. 192, p. 251-381.

Schiner, G. R., and Kimmel, G. E., 1972, Mississippian stratigraphy of northwestern Pennsylvania: U.S. Geological Survey Bulletin 1331-A, 27 p.

Schiner, G. R., 1976, Geology and ground-water resources of northern Mercer County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Water Resource Report 33, 136 p.

Seilacher, A., 1967, Bathymetry of trace fossils: Marine Geology, v. 5, p. 413-428.

Sevon, W. D., 1981, Middle and Upper Devonian clastic wedge in northeastern Pennsylvania, in Enos, P., ed., Guidebook for field trips in south-central New York: The New York State Geological Association, 53rd Annual Meeting, Binghamton, NY, p. 31-63.

Sevon, W. D., 1985, Nonmarine facies of the Middle and Late Devonion Catskill alluvial plain, in Woodrow, D. L. and Sevon, W. D., eds., The Catskill delta: Geological Society of America Special Paper 201, p. 79-90.

Sevon, W. D., 1989, The rivers and valleys of Pennsylvania then and now: 20th Annual Geomorphology Symposium and the Harrisburg Area Geological Society Field Trip, Carlisle, PA, Guidebook, 59 p.

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

Shepps, V. C., White, G. W., Droste, J. B., and Sitler, R. F., 1959, Glacial geology of northwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin G 32, Map 1: 125,000 scale, 59 p.

Slingerland, R. and Loule, J.-P, 1988, Wind/wave and tidal processes along the Upper Devonian Catskill shoreline in Pennsylvania, U. S. A., in McMillan, N. J., Embry, A. F., and Glass, D. J., Devonian of the World, Proceedings of the 2nd International Symposium on the Devonian System, v. 2, Sedimentation: Canadian Society of Petroleum Geologists Memoir 14, p. 125-138.

Smith, A. T. and Rose, A. W., 1985, Relation of red-bed copper-uranium occurrences to the regional sedimentology of the Catskill Formation in Pennsylvania, in Woodrow, D. L. and Sevon, W. D., eds., The Catskill delta: Geological Society of America Special Paper 201, p. 183-197.

Snyder, K. E. and Bryant, R. B., 1992, Late Pleistocene surficial stratigraphy and landscape development in the Salamanca Re-entrant, southwestern New York: Geological Society of America Bulletin, v. 104, p. 242-251.

Sutton, R. G. and McGhee, G. R., Jr., 1985, The evolution of Frasnian marine "community-types" of south-central New York, in Woodrow, D. L. and Sevon, W. D., eds., The Catskill delta: Geological Society of America Special Paper 201, p. 211-224.

Sutton, R. G., Bowen, Z. P., and McAlester, A. L., 1970, Marine shelf environments of the Upper Devonian Sonyea Group of New York: Geological Society of America Bulletin, v. 81, p. 2975-2992.

Tesmer, I. H., 1963, Geology of Chautauqua County, part 1--Stratigraphy and Paleontology (Upper Devonian): New York State Museum Bulletin 391, 65 p.

Tesmer, I. H., 1975, Geology of Cattaraugus County, New York: Buffalo Society of Natural Sciences Bulletin, v. 27, 105 p.

Thayer, C. W., 1974, Marine paleoecology in the Upper Devonian of New York: Lethaia, v.

Thompson, A. M. and Sevon, W. D., 1982, Excursion 19B: Comparative sedimentology of Paleozoic clastic wedges in the central Appalachians, U.S.A.: Field excursion guide book, 11th International Congress on Sedimentology (Hamilton, Ontario, Canada), International Association of Sedimentologists, 136 p.

Walker, R. G., 1971, Non-deltaic depositional environments in the Catskill clastic wedge (Upper Devonian) of central Pennsylvania: Geological Society of America Bulletin, v. 82, p. 1305-1326.

Walker, R. G., 1972, Upper Devonian marine-nonmarine transition, southern Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report 62, 25 p.

Walker, R. G., ed., 1984, Facies models, 2nd ed.: Geoscience Canada Reprint Series. 1, 317 p.

Walker, R. G. and Harms, J. C., 1971, The "Catskill Delta" - a prograding muddy shoreline in central

Pennsylvania: Journal of Geology, v. 79, p. 381-399.
Wallace, A. F. C., 1972, The death and rebirth of the Seneca: New York, Vintage Books, 384 p.
Waltman, W. J., Cunningham, R. L., and Ciokosz, E. J., 1990, Stratigraphy and parent material relationships of red substratum soils on the Allegheny Plateau: Soil Science Society of America Journal, v. 54, p. 1049-1057.
Ward, A. N., Jr., Chapman, W. F., Lukert, M. T., and Craft, J. L., 1976, Bedrock and glacial geology of northwestern Pennsylvania in Crawford, Forest, and Venango Counties: Guidebook, 41st Annual Field Conference of Pennsylvania Geologists, Titusville, PA, Guidebook, 64 p.
Ward, A. N., Jr., Lukert, M. T., and Chapman, W. F., 1979, Geology and mineral resources of the Oil City [7.5-minute] quadrangle, Venango County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Atlas 33a, maps.
Warren Times-Mirror (April to November 1958; October 1960), Warren, Pa.
Washburn, A. L., 1980, Geocryology: New York, John Wiley and Sons, 406 p.
Watts, W. A., 1983, Vegetational history of the eastern United States 25,000 to 10,000 years ago, in Porter, S. D., ed., The late Pleistocene, Volume 1, Wright, H. E., Jr., ed., Late-Quaternary environments of the United States: Minneapolis, University of Minnesota Press, p. 294-310.
Weimer, R. J., Howard, J. D., and Lindsay, D. R., 1982, Tidal flats and associated tidal channels, in Scholle, P.A., and Spearing, Darwin, eds., Sandstone depositional environments: American Association of Petroleum Geologists Memoir 31, p. 191-245.
White, G. W., Totten, S. M., and Gross, D. L., 1969, Pleistocene stratigraphy of northwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report G 55, 88 p.
White, I. C., 1879, The geology of Lawrence County: Pennsylvania Geological Survey, 2nd ser., Report Q2, 336 p.
White, I. C., 1880, The geology of Mercer County: Pennsylvania Geological Survey, 2nd ser., Report Q3, 233 p.
White, I. C., 1881, The geology of Erie and Crawford Counties: Pennsylvania Geological Survey, 2nd ser., Report Q4, 355 p.
White, I. C., 1891, Stratigraphy of the bituminous coal field of Pennsylvania, Ohio, and West Virginia: U. S. Geological Survey Bulletin 65, 212 p.
Willard, B. and others, 1939, The Devonian of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin G-19, 481 p.
Williams, E. G. and Bragonier, W. A., 1974, Controls of early Pennsylvanian sedimentation in western Pennsylvania, in Briggs, G., ed., Carboniferous of the southeastern United States: Geological Society of America Special Paper 148, p. 35-152.
Williams, E. H., Jr., 1917, Pennsylvania glaciation first phase: York, PA, The Maple Press, 101 p.
Wilson, E., 1966, Apologies to the Iroquois: Vintage Books, 310 p.
Woodcock, N. H., 1977, Specification of fabric shapes using the eigenvalue method: Geological Society of America Bulletin, v. 88, p. 1231-1236.
Woodrow, D. L., 1968, Stratigraphy, structure, and sedimentary patterns in the Upper Devonian of Bradford County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report G54, 78 p.
Woodrow, D. L., 1985, Paleogeography, paleoclimate, and sedimentary processes of the Late Devonian Catskill delta, in Woodrow, D. L. and Sevon, W. D., eds., The Catskill delta: Geological Society of America Special Paper 201, p. 51-63.
Woodrow, D. L., Fletcher, F. W., and Ahrnsbrak, W. F., 1973, Paleogeography and paleoclimate at the deposition sites of the Devonian Catskill and the Old Red Facies: Geological Society of America Bulletin, v. 84, p. 3051-3064.
Woodrow, D. L. and Isley, A. M., 1983, Facies, topography, and sedimentary processes in the Catskill Sea (Devonian), New York and Pennsylvania: Geological Society of America Bulletin, v. 94, p.459-470.
Woodrow, D. L. and Sevon, W. D., eds., 1985, The Catskill Delta: Geological Society of America Special Paper 201, 246 p.
Wright, G. F., 1914, Evidence of a glacial dam in the Allegheny River between Warren, Pennsylvania and Tionesta: Geological Society of America Bulletin, v. 25, p. 215-218.
Wright, H. E., Jr., 1981, Vegetation east of the Rocky Mountains 18,000 years ago: Quaternary Research, v. 15, p. 113-125.
Zagorski, W. A., 1991, Trapping models for the Lower Silurian Medina Sandstone Group - A comparison of

trapping styles and exploration methodology for both "deep" and "shallow" Medina plays in the Appalachian basin (abs.): American Association of Petroleum Geologists Bulletin, v. 75, p. 1329.