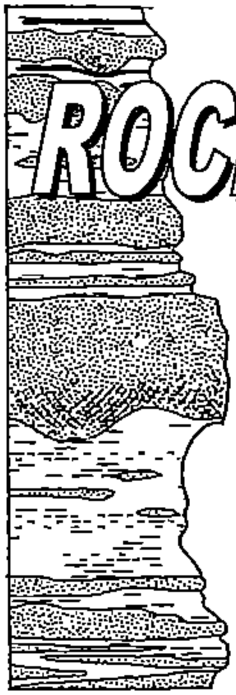
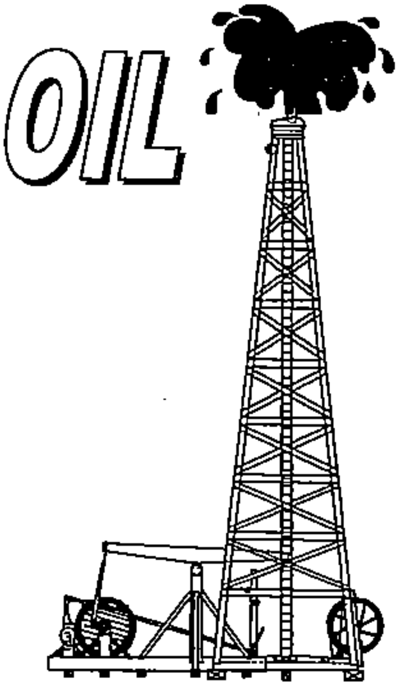




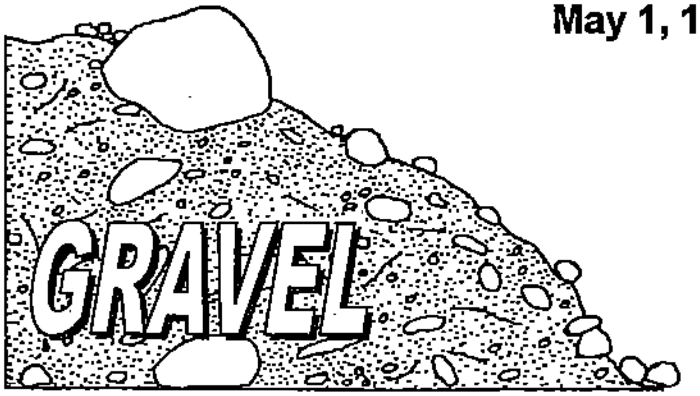
# THE SURFICIAL, BEDROCK, AND ECONOMIC GEOLOGY OF VENANGO COUNTY, PENNSYLVANIA

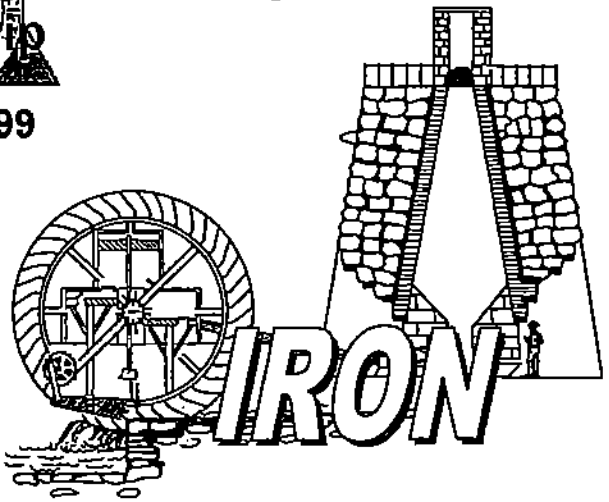
Guidebook for the

Pittsburgh Geological Society

Field Trip

May 1, 1999





Guidebook for the

PITTSBURGH GEOLOGICAL SOCIETY

Field Trip

Saturday, May 1, 1999

# ROCKS, OIL, GRAVEL, IRON:
# THE SURFICIAL, BEDROCK, AND ECONOMIC GEOLOGY OF VENANGO COUNTY, PENNSYLVANIA

Trip leaders:
John A. Harper, Pennsylvania Geological Survey
Albert N. Ward, Jr., Slippery Rock University of Pennsylvania (retired)

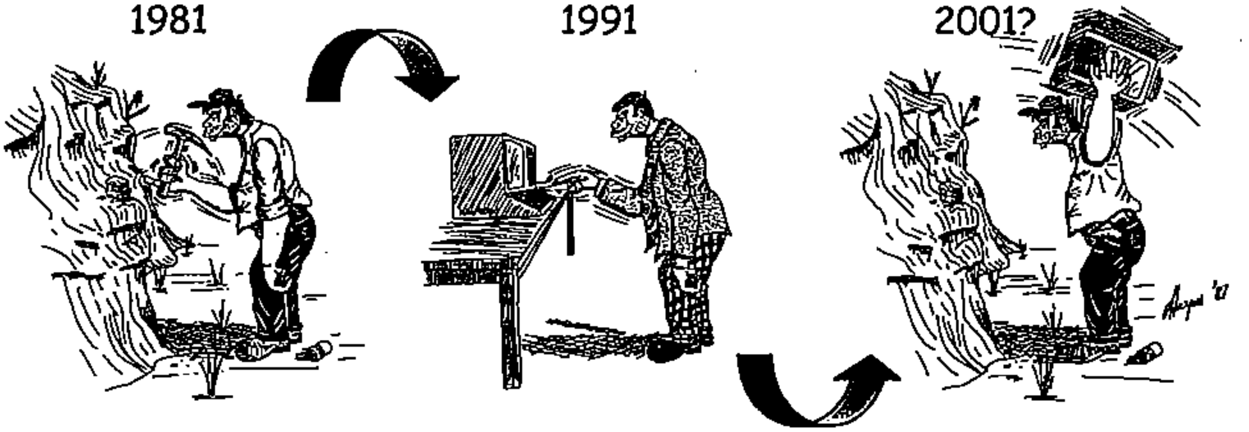
For additional copies of this field trip guidebook, contact:

**Pittsburgh Geological Society**
**PO Box 58172**
**Pittsburgh, PA 15209**

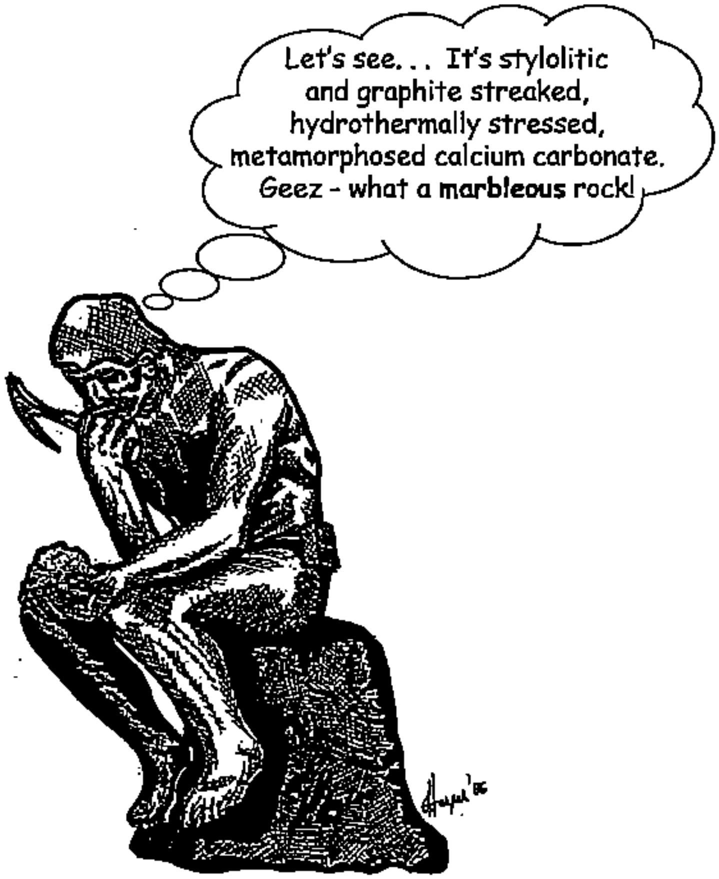
# TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES



EVOLUTION OF A PENNSYLVANIA FIELD GEOLOGIST



Harper's "The Thinker"

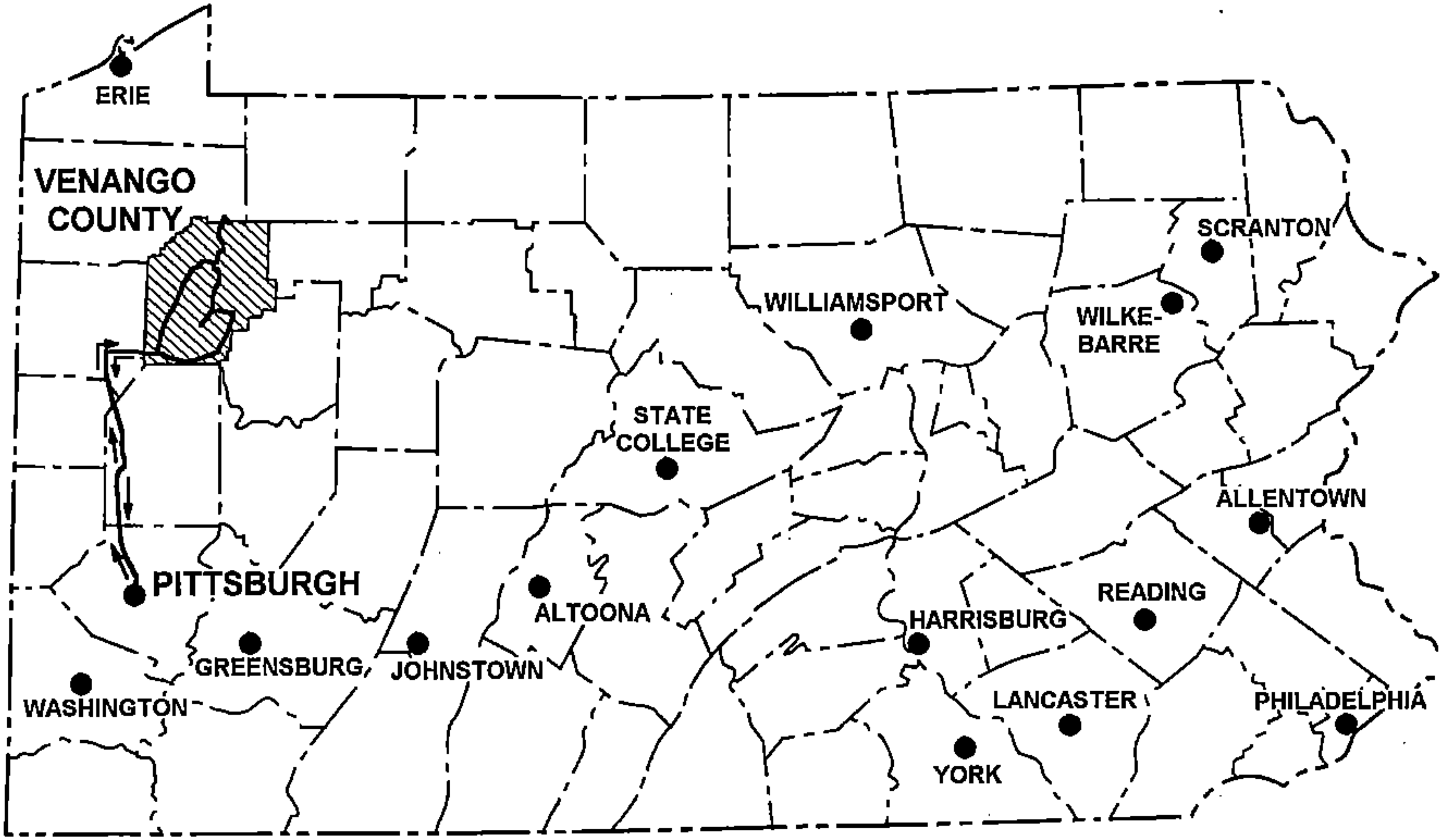


Figure 1. Location of Venango County within Pennsylvania, and generalized location of field trip route (see Figure 15 for details).

# ROCKS, OIL, GRAVEL, IRON:
## THE SURFICIAL, BEDROCK, AND ECONOMIC GEOLOGY OF VENANGO COUNTY, PENNSYLVANIA

John A. Harper, Pennsylvania Geological Survey
and
Albert N. Ward, Jr., Slippery Rock University (retired)

## INTRODUCTION

Northwestern Pennsylvania is a classic area for the study of both Upper Paleozoic and Quaternary geology. It has attracted interest from geologists dating back to the early days of geological studies in the United States. Comprehensive surveys of the geology of the region (together with the remainder of Pennsylvania) were undertaken in the 1870s by the Second Pennsylvania Geological Survey. The early publications resulting from that effort (e.g., Carll, 1875; White, 1881; Lesley, 1885, 1889a, 1889b, 1890) remain a useful source of information more than a century later. On this field trip we will have the opportunity to examine some outcrops of representative Upper Devonian, Mississippian, and Pennsylvanian strata.

Northwestern Pennsylvania, and Venango County in particular, is the region where the petroleum industry was born, and its history is rich with anecdotes as well as solid scientific fact. Many publications of the Second Geological Survey of Pennsylvania were devoted to the origin and occurrence of petroleum (e.g., Carll, 1875, 1880, 1883; Randall, 1875), and these were followed in the Fourth Pennsylvania Geological Survey by such worthy additions as Dickey (1941), Sherrill and Matteson (1941), Dickey and others (1943), and Kelley (1967). We will be examining some aspects of oil history along our field trip route.

In addition, northwestern Pennsylvania has provided a wealth of information on glacial deposits and the history of glaciation. Through such publications as Leverett (1934), Shepps and others (1959), White and others (1969), and Craft (1979) we have become familiar with numerous glacial advances, Pleistocene changes in drainage, and the quality of glacial gravels as an economic resource. Venango County has its fair share of Pleistocene geology, and we will be seeing some of it on this field trip.

Finally, we will spend some time looking over an early American iron furnace, one of those monuments to man's ingenuity during the industrial era of the early 1800s. Venango County has a heritage of iron manufacturing, even though it only lasted for about 30 years, that is almost as rich as that of petroleum.

### Geography And Physiography

Venango County (Figure 1) was formed March 12, 1800 from parts of Allegheny and Lycoming counties. The name "Venango" originated from the Native American name for French Creek. The county is bordered to the north by Crawford and Warren counties, to the east by Forest and Clarion counties, to the south by Butler County, and to the west by Mercer County. It has an area of about 660 sq. mi.

The earliest industry of importance was the iron industry, followed by the oil industry (see Economic Geology). In the past, farming was very important in Venango County. In 1882, for example, 68% of the county was farmland. In 1969, however, only 17% was being farmed.

The county is located within three separate sections of the Appalachian Plateau physiographic province (Figure 2), the Glaciated Pittsburgh Plateau Section, High Plateau Section, and Pittsburgh Low Plateau Section. Topography in the county is rough, with the surface being strongly dissected by the Allegheny River and its tributaries. In many places there is as much as 500 ft. difference in elevation in one-fifth of a mile (Churchill, 1975). Average elevations over much of the county lie between 1,100 and 1,500 ft. above sea level. The uplands are gently sloping over broad areas, and hillsides range from gentle to steep slopes.

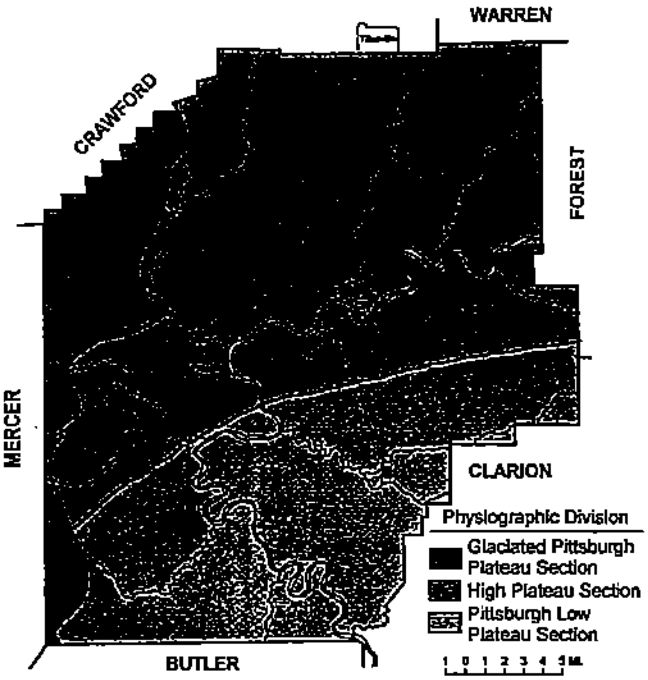


Figure 2. Physiographic divisions of Venango County (modified from Sevon, 1996).

## Surface and Ground Water

Venango County lies within the Ohio River watershed, and is drained mostly by the Allegheny River and its tributaries. The Allegheny River flows west-southwestward into Venango County from Forest County. Near the middle of Venango County, the river changes course to the south and southeast. Sizable tributaries include (from north to south) Pithole Creek, Oil Creek, French Creek, Sandy Creek, East Sandy Creek, and Scrubgrass Creek. Wolf Creek and Slippery Rock Creek, which drain small parts of southwestern Venango County, are tributaries of the Beaver River.

The Allegheny River winds its way through the county for approximately 60 miles. The steep valley walls are wooded and scenic, and they make an attractive background for the summer homes on the terraces. In general, the river is too shallow for motorboats during the summer, but there are some relatively deep pools near Kennerdell and President. Stream pollution from acid mine drainage (AMD) and raw sewage constitute major problems – about 162 mi. of streams have such severe AMD problems that fish can't survive. An additional 128 mi. of streams are contaminated by sewage or oil. Although this water is unsafe to drink, it can still be used for fishing and swimming.

In general, water supplies are considered to be sufficient for the population of the county. Individual water wells 50 to 100 ft. deep supply homes where municipal water is not available. Unfortunately, many wells provide water that is high in iron, making it an unsatisfactory resource.

## SURFICIAL DEPOSITS

The surficial geology of Venango County includes glacial deposits (tills and outwash) and soils (residuum, colluvium, and alluvium)(Figure 3).

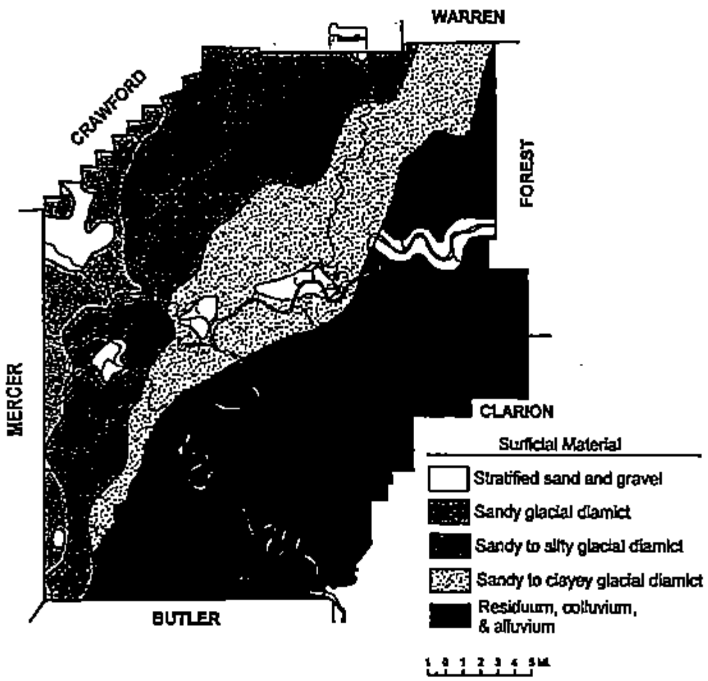


Figure 3. Surficial materials of Venango County (modified from Sevon, 1989).

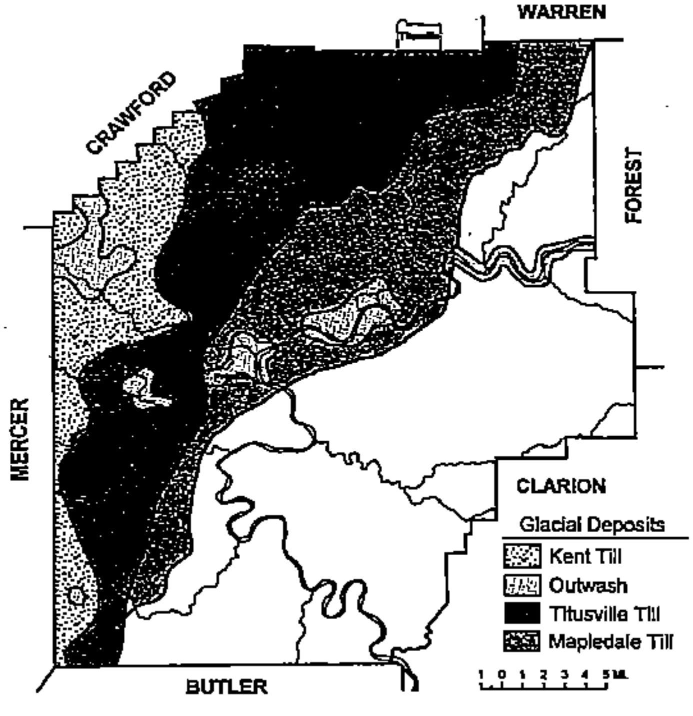


Figure 4. Glacial deposits of Venango County (modified from Sevon and Braun, 1997).

## Tills and Outwash

The western and northern half of Venango County was covered by glacial ice at three, and possibly four, different times during the Pleistocene. The earliest glacier that left a preserved record at the surface had the largest coverage, whereas the latest glacier intruded into only a small part at the western edge of the county. As the glaciers melted, they left behind tills ranging from 2 to 200 ft. thick. These deposits were mixtures of former soils, sandstone, siltstone, limestone, and shale bedrock, and a small percentage of crystalline rocks from the Canadian Shield. Because the youngest till contains small amounts of crystalline and limestone debris, it also contains more plant nutrients than the older till.

Ice that carved the stream valleys was thick. Meltwaters from the glaciers deposited coarse gravel in kames along edges of these valleys. It carried the finer textured material farther from the ice front and deposited it in nearly level terraces, such as those along Sugar Creek and French Creek. The outwash, or glaciofluvial deposits, ranges from a few tens to over 150 ft. thick in some of the buried valleys.

Till and glaciofluvial deposits can be found in many areas of Venango County, generally within the valley of, or west of, the Allegheny River (Figure 4). Occurrences range from scattered pebbles and cobbles in the soil to deposits several tens of ft. thick. They can be found on the highest hills as well as in the valley bottoms of the major streams. Three, and

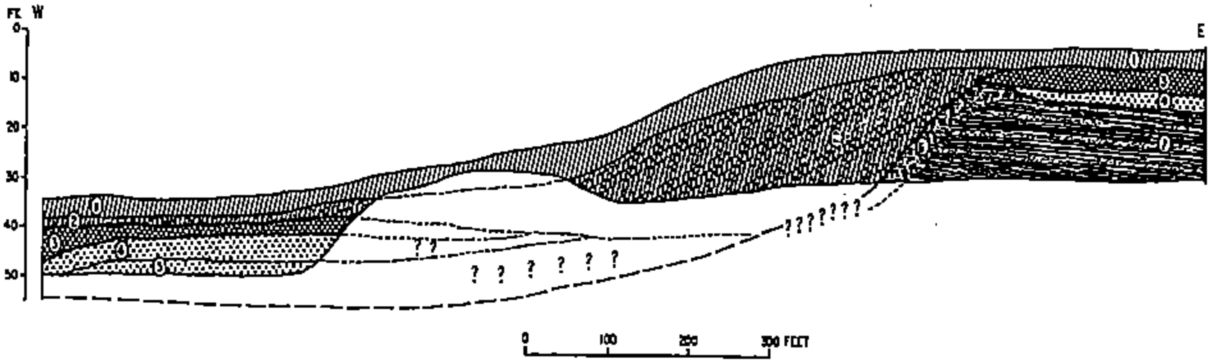


Figure 5. Cross section of the glacial deposits one mile north of Barkeyville, Venango County. 1 -- Kent Till and soil; 2 -- Kent sand and gravel, kames where thick and very extensive to the north and south; 3 -- Titusville Till, olive-brown, noncalcareous, basal part fresh at extreme west end; 4 -- Mapledale Till, yellowish-brown, upper part is extremely weathered and is the base of a paleosol; 5 -- Mapledale Till, gray and noncalcareous; 6 -- Shale and sandstone, much weathered; 7 -- Shale and sandstone. The dashed lines indicate the inferred part of the section, based on spoil from refilled excavations. From White and others, 1969.

possibly four, distinct sets of tills and stratified drift deposits occur within the county. From oldest to youngest, the Slippery Rock (?), Mapledale, Titusville, and Kent (Figure 5).

## Slippery Rock Till

The oldest known glaciation in northwestern Pennsylvania is called the Slippery Rock. The deposits left by this glaciation do not occur at the surface anywhere in Pennsylvania, but they have been encountered in quarries, coal and limestone mines, wells, drill cores, and construction excavations. Although the extent of the Slippery Rock is unknown, White and others (1969) suggested it advanced almost to the position reached by the ice sheet that deposited the Mapledale Till (see below).

Slipper Rock Till, is, in all observed cases, highly weathered. It currently has a clayey character, probably as a result of a granitic content of at least 10%.

## Mapledale Till

White and others (1969) considered the Mapledale to be Illinoian in age, but more recent work has led to a reinterpretation of pre-Illinoian (Nebraskan?) age (Sevon, 1992; Sevon and Braun, 1997). The Mapledale consists of dark gray to bright gray (Munsell soil color designations of 5Y 4/2 to 4/0) pebbly sand, silt, and clay with lots of cobbles and boulders, most of which are sandstone (Ward and others, 1976; White and others, 1969). The till typically weathers to a dark yellowish brown (10YR 4/4). Grain size analysis of 24 samples by White and others, 1969, gave mean values of 44% sand, 36% silt and 20% clay. Crystalline erratics are rare and typically occur as pebble-size fragments. The typical lack of good, unequivocal erratics

*Table 1. Composition and Thickness of the Mapledale Till at Its Type Section Near Franklin*
(Modified from White and others, 1969, p. 15)

| Description | Unit Thickness (feet) | Aggregate Thickness (feet) |
|---|---|---|
| Soil and disturbed material | 3.00 | 3.00 |
| Silty clay loam,mottled | 1.00 | 4.00 |
| Loam, very sandy and deeply weathered till, mottled | 1.00 | 5.00 |
| Till, severely weathered, mottled | 1.00 | 6.00 |
| Till, sandy, yellow-brown, weathered | 1.00 | 7.00 |
| Till, sandy, dark yellow-brown to brown | 3.00 | 10.00 |
| Till, sandy, dark-yellow brown, very stony, not much weathered, noncalcareous | 3.00 | 13.00 |
| Till, sandy, stony, gray-brown, noncalcareous | 1.00 | 14.00 |
| Till, mixed gray and brown, noncalcareous | 2.00 | 16.00 |
| Till, sandy, stony, gray, noncalcareous | 2.00 | 18.00 |

makes the positive identification of Mapledale Till difficult (Ward and others, 1976). The Mapledale Till is 18 ft. thick at its type locality (Table 1).

**Titusville Till**

The type section of the Titusville till occurs about a mile south of Titusville along Route 8 (White and others, 1969) where the sand and gravel can be easily distinguished even from a speeding vehicle (see STOP 4). Fresh Titusville till is olive-gray in color (5Y 4/2), turning olive brown (2.5Y 4/4) with weathering. Compositionally, this debris isn't much different from the Mapledale Till (Table 2), and its most distinguishing characteristics are its color and the presence of manganese staining of pebbles and joints (Ward and others, 1976). The overall mean texture of the Titusville Till is 45.4% sand, 36.9% silt and 17.7% clay.

The Titusville Till varies in thickness from 0 to 110 ft. with an average of about 20 ft. (White, 1971). Where it is exposed, the till appears as a single sheet, although to

*Table 2. Mean Texture and Composition of Mapledale and Titusville Tills*
(Modified from White and others, 1969, P. 44)

| Component | Mapledale Till | Titusville Till |
|---|---|---|
| Sand | 44.0 | 45.4 |
| Silt | 36.0 | 36.9 |
| Clay | 20.0 | 17.7 |
| Quartz | 94.6 | 87.9 |
| Feldspar | 5.4 | 12.1 |
| K-Feldspar | 53.1 | 52.9 |
| Heavy Minerals | 2.1 | 2.9 |
| Calcite | 0.7 | 1.1 |
| Dolomite | 0.6 | 1.3 |
| Total Carbonate | 1.3 | 2.4 |

*Table 3. Composition and Thickness of the Titusville Till*
*at It Type Locality near Titusville, Crawford County*
(Based on White and others, 1969, p. 23-24)

| Description | Unit Thickness (feet) | Aggregate Thickness (feet) |
|---|---|---|
| **Zone I** | | |
| Loam, silty, gray brown; A-1 soil | 0.75 | 0.75 |
| Loam, silty, dark dusky yellow; A-2 soil | 0.58 | 1.33 |
| Loam, silty, clayey, moderate orange and gray mottling, small weathered siltstone and shale pebbles; upper B-1 soil | 0.50 | 1.83 |
| Loam, silty, clayey, pronounced orange and gray mottling, nusifom fracture, small weathered sandstone, siltstone, and shale fragments; middle B-1 soil | 1.58 | 3.42 |
| Loam, silty, clayey, pronounced orange and gray mottling, compact with some prismatic structure, well-weathered crystalline rocks, sandstone, siltstone, and shale fragments | 1.00 | 4.42 |
| **Zone II** | | |
| Till, silty, clayey, thoroughly weathered orange and gray stains in joints, manganese stain coating joint surfaces, weathered crystalline rocks, siltstone, and shales | 1.92 | 6.33 |
| **Zone III** | | |
| Till, as below but not calcareous | 2.25 | 8.58 |
| **Zone IV** | | |
| Till, silty, moderately pebbly, calcareous, moderate yellow brown to olive brown, rough horizontal fracture; till matrix is slightly calcareous, but many small carbonate pebbles react violently to acid. Coal fragments common in places | 7.33 | 15.92 |
| **Zone V** | | |
| Till, as above but light olive gray; many joints are present, along which ground water has oxidized the gray till in zones varying in thickness from 1/16 inch to 1/12 inches | 3.50 | 24.42 |
| Sand and gravel, brown, calcareous, uneven contact with superjacent unit | 7.50 | 31.92 |

the north and west as many as five separate Titusville Till sheets have been described (White and others, 1969). Where more than one Titusville Till is exposed in a cut, the adjacent tills are separated by a layer of sand and gravel which ranges in thickness from a few inches to 20 ft.

(Table 3). The most continuous sand and gravel layer is found beneath the uppermost Titusville Till. White and others (1969) believed that these multiple till sheets separated by sand and gravel layers suggest that the Titusville ice underwent several minor readvances during its general retreat. Numerous Titusville deposits can be found in the vicinity of Titusville and the Drake Well. Many have been quarried in the past. Scattered remnants of widespread tills can be seen in drainage ditches adjacent to the dirt roads throughout the area.

The age of the Titusville Till has created something of a controversy over the years. Shepps and others (1959) called this the "Inner phase" Illinoian ground moraine. White and others (1969) considered it to be Early Wisconsinan in age based on Carbon-14 dates of approximately 40,000 yr. BP. Later authors (e.g. Chapman and Craft, 1976) indicated the dates place the Titusville within Middle Wisconsinan time. The dates were obtained from wood found in a peat deposit underlying what was thought to be Titusville Till in a gravel pit east of Titusville. Palynological and paleobotanical evidence seemed to confirm this age (Berti, 1975), as did fossil beetle data (Cong and others, 1996). Craft (1976), on the other hand, felt the degree of weathering in the sand and gravel associated with the peat was more characteristic of the Mapledale Till. He concluded that, if it was, indeed, the Mapledale at that location, then the Mapledale had to be Middle Wisconsinan in age. This would, by process of elimination, make the Titusville much younger, possibly earliest Late Wisconsinan.

Totten (1987) reinterpreted the peat and weathered sand and gravel as part of a post-Titusville alluvial cycle. As such, Titusville would be Early Wisconsinan in age. However, Eyles and Westgate (1987) indicated that Wisconsinan ice sheets did not extend south of Lakes Ontario and Erie until 30,000 yr. BP. Thus, it appears that the age of the Titusville has come full circle – it is now considered, once again, to be Illinoian in age (Sevon, 1992; Sevon and Braun, 1997).

## Kent Till

The Kent Till covers only the western fifth of Venango County, and will not be seen on this field trip. However, it is likely that much of the debris littering the bed of Oil Creek, and possibly filling the valley, is Wisconsinan outwash. The till is a thin deposit where it exists, ranging from less than five ft. to a little more than 10 ft. thick. In rare unaltered sections, it consists of coarse, gray (5Y 3/2), sandy till containing many pebbles and occasional cobbles and boulders. The till tends to exhibit extreme ranges of weathering (White and others, 1969). Oxidized material is yellow-brown (10YR 4/4) which makes it easy to separate from the underlying olive-brown Titusville Till. Although the texture is variable, White and others (1969) reported a mean texture of 43% sand, 38.5% silt, and 18.5% clay.

The Kent Till has not been dated owing to the lack of preserved organic material. However, owing to its stratigraphic position and correlation with dated tills outside northwestern Pennsylvania, it is considered to be little more than 23,000 yr. old, that is, Late Wisconsinan (Sevon, 1992).

## Glaciofluvial Deposits (Outwash)

One of the glacial problems that occurs in northwestern Pennsylvania involves the nature, origin, and age of the many glaciofluvial deposits in the area. Little recent work has been done with these sand and gravel deposits to determine their age and relationship to the former glaciers that occupied this area, other than the material originally thought to be Titusville Till (see above). There are at least two major groups of glaciofluvial deposits: 1) high terrace gravels, the tops of which lie 100 to over 200 ft. above the floors of the present stream valleys; and 2) relatively low floodplain gravels that are only 5 to 40 ft. above the level of present streams.

White and others (1969) described several outcrops of glaciofluvial deposits considered to be Mapledale kames and kame terraces. Most of these are above the present floodplains and extend to 100 ft. or more above present streams. A well-preserved Mapledale kame deposit occurs within Oil Creek State Park about one mile north of the park office in Petroleum Centre (STOP 7) where, at one time, it had been quarried for construction aggregate.

Glaciofluvial sand and gravel deposits of Wisconsinan age occur in two major settings. Some are seen in the subsurface separating adjacent Titusville Till sheets. Others make up the relatively low terraces that rise 20 to 40 ft. above French Creek and other local streams. It is also possible that some of the higher gravel terraces, such as at Reno along PA 8 between Franklin and Oil City, may be of Wisconsinan age.

## Soils

Figure 6 shows the soil associations in Venango County. A soil association is a landscape that has a distinctive proportional pattern of soils. It normally consists of one or more major soils and at least one minor soil, and it is named for the major soils. The soils in one association may occur in another, but in a different pattern (Churchill, 1975).

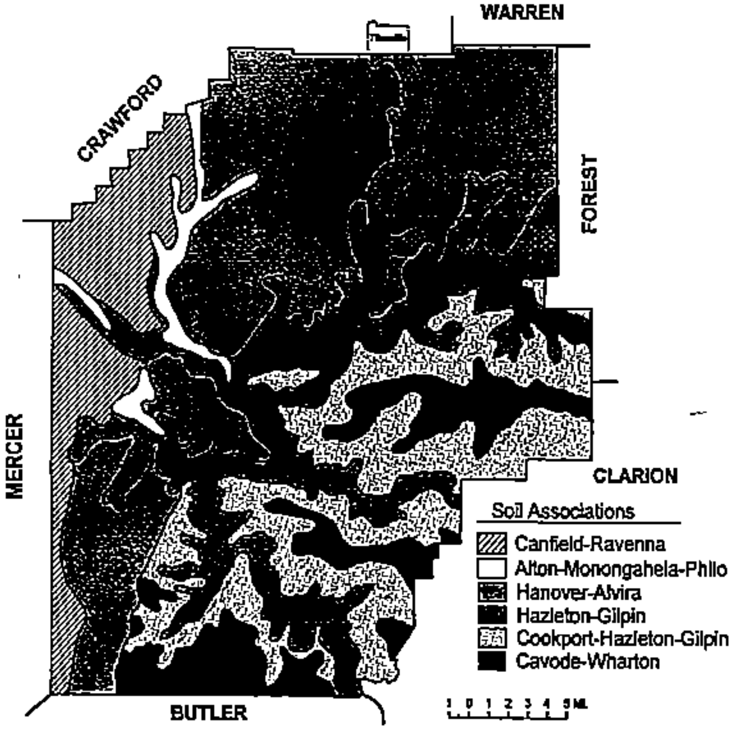


Figure 6. Soil associations in Venango County (modified from Churchill, 1975).

The parent material, the unconsolidated mass from which soils form, influences the initial mineralogical and chemical composition of the soil and the rate and balance of soil-forming processes. In Venango County, soils formed in a variety of parent materials, from Pleistocene glacial till to Devonian, Mississippian, and Pennsylvanian sandstone, siltstone, and shale residuum and colluvium; and from Pleistocene glacial outwash to Recent alluvium. Soils that formed entirely in glacial till, for example, Canfield, Hanover, and Alvira soils, occur in the northwestern part of the county. They are distinguished by a compact subsoil. Examples of soils formed in residuum include Wharton and Hazleton soils. Soils that formed in colluvium occur at the base of slopes. These soils occur in the western part of the county. Soils such as Philo and Atkins formed in alluvium and have little or no soil profile development.

The following descriptions are sythesized from Churchill (1975).

### Canfield-Ravenna Association

Soils of this association are found on gently sloping uplands, many of which have been cleared for pasture or left as woodland. The landscape ranges from smooth slopes to the hummocky topography of a glacial end moraine where the stony and gravelly tills form the parent material. These soils typically are deep and dominantly gravelly, and they exhibit moderately good drainage to somewhat poor drainage. The Canfield soils in particular are moderately well drained and have convex slopes. Ravenna soils, on the other hand, are somewhat poorly drained and occur in depressions. Most of the association has impeded drainage; excess water is a limitation. Restricted permeability and a seasonal high water table limit use of the soils of this association.

### Alton-Monongahela-Philo Association

This soil association occurs on nearly level ground and on gentle slopes in the northwestern part of the county, in wide valleys that formerly contained glacial meltwater. The landscape ranges from elevated terraces to floodplains. These soils include the most productive farmland in Venango County, so most of the land underlain by this association has been cleared and farmed. The soils are deep, well drained to moderately well drained, and underlain by terraces and floodplain alluviums. Alton and Monongahela soils occur on terraces whereas Philo soils occur on floodplains. Alton soils are well drained, and Monongahela and Philo soils are only moderately well drained. A hazard of flooding limits their use on flood plains. Terrace soils have varying limitations for most uses.

### Hanover-Alvira Association

The Hanover-Alvira soils occur on topography ranging from smooth slopes on uplands to a few very steep valley sides. Almost half of the association originally was stony, but in many areas the stones were removed to fence rows and the soils were cultivated. However, many of the areas that once were cultivated have reverted to woodland or are idle. In fact, much of this association is now abandoned farmland. The association includes deep, well-drained to somewhat poorly drained soils underlain by glacial till. Hanover soils are moderately well drained to well drained and have convex slopes. Alvira soils are somewhat poorly drained and occur in depressions. Most of the association has impeded drainage, and restricted permeability. Because of a seasonal high water table, excess water creates limits for use of the soils.

### Hazleton-Gilpin Association

Soils in this association occur on valley sides. Therefore, the landscape is steep to very steep, and the soils are deep or moderately deep, stony, well-drained, and underlain by shale, siltstone, and sandstone. They occur along most of the major streams in the county, especially the Allegheny River. Hazleton soils are deep and well drained. Gilpin soils are well drained and moderately deep. Steepness of the slopes and amount of stoniness limit most uses of these soils, so almost all the association is wooded. The rugged, steep slopes add scenic beauty to the river valleys.

### Cookport-Hazleton-Gilpin Association

The soils in this association occur on uplands. The landscape ranges from gentle slopes and hilltops to moderately steep valley sides and hillsides. Some of this association is stony, and in some areas the stones were removed to piles or fence rows and the soils were cultivated. The steeper soils were cleared for pasture or left as woodland. Many areas that were once cultivated have reverted to woodland or are idle. These are deep to moderately deep, and moderately well drained to well drained soils underlain by sandstone, siltstone, and shale. Cookport soils are deep and moderately well drained. Hazleton soils are deep and well drained. Gilpin soils are moderately deep and well drained. Most of the association has excess water and needs to be drained. Restricted permeability and seasonal high water table limit use of the Cookport and Gilpin soils. Stoniness limits use of most Hazleton soils.

### Cavode-Wharton Association

The Cavode-Wharton Association soils occur on uplands where the landscape is dominated by gentle slopes. Much of the land is agricultural, although idle land is becoming increasingly prominent. Strip mines occur but are of minor importance. The soils are deep, somewhat poorly drained to moderately well drained and underlain by shale and siltstone. Cavode soils are somewhat poorly drained whereas Wharton soils are moderately well drained. Most of the association has impeded drainage, restricted permeability, and a seasonal high water table, so excess water is a limitation for use.

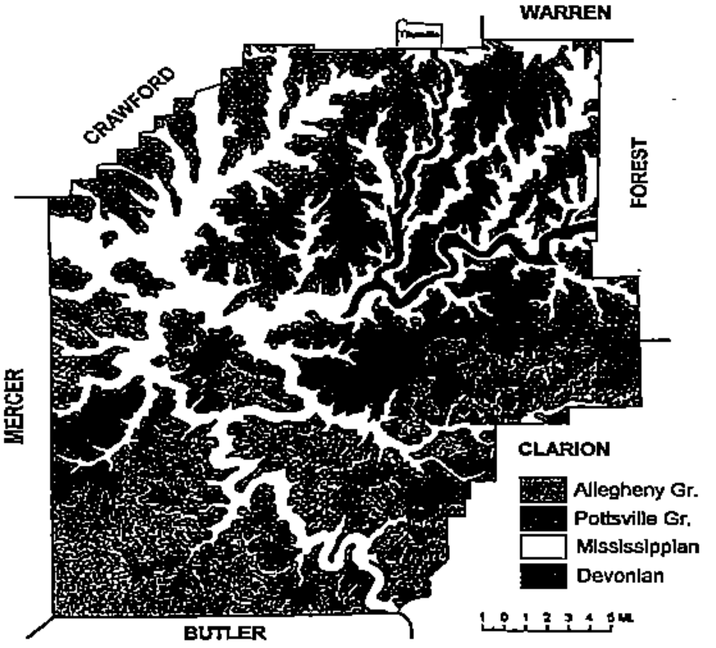


Figure 7. Generalized geologic map of Venango County (modified from Berg and others, 1980).

## BEDROCK STRATIGRAPHY

Bedrock exposures in the county include Upper Devonian through Pennsylvanian strata (Figures 7 and 8). The Upper Paleozoic rocks represent a variety of relatively shallow-water marine through marginal-marine to fluvial-deltaic environments that existed in the western part of the Appalachian foreland basin. These rocks tend to be more nearly horizontally than vertically disposed, yet they show clear structural complications, both at the surface and in the subsurface. Tectonic activity seems to have occurred intermittently during the Paleozoic, and has influenced sedimentary patterns and biofacies patterns in the western Appalachian basin (Harper, 1989, 1992, and 1998b). Seismograph records show that minor adjustment along faults in northwestern Pennsylvania and adjacent areas continues to take place intermittently. The origin of faults and minor folds in the region is conjectural, but it is likely that these structures are related to minor reactivation of basement faults that developed during the initial ifting of Laurentia from the rest of the supercontinent Rodinia during the late Neoproterozoic or early Cambrian (Harper, 1998b). Many Holocene geomorphologic features in the region, such as stream valleys, tend to align along inherited fracture zones, and glacial activity during the Pleistocene has probably enhanced the effects of these relatively minor but interesting structural features.

## Pennsylvanian System

### Allegheny Group

The youngest and highest bedrock formation in Venango County is the Allegheny Group (Figure 8). This group contains most of the commercially available coal of the county (what little there is of it). It is mostly shale and contains some clay and sandstone. In the southern part of the county about 15 ft. of limestone, the Vanport Limestone, occurs on the hill tops. The Allegheny Group in Venango County consists of two partial or complete formations, the upper Kittanning Formation and lower Clarion Formation.

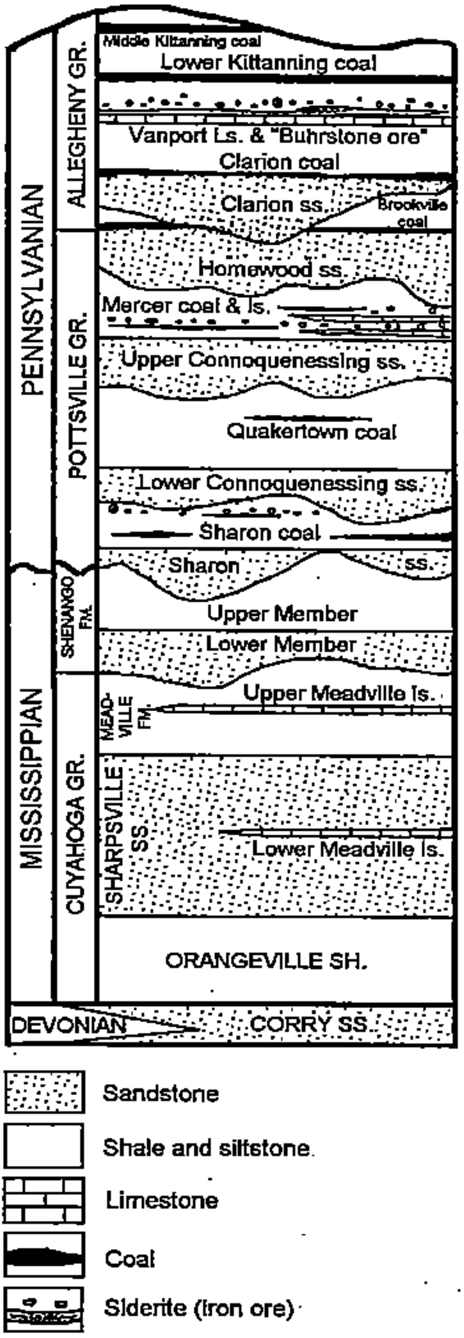


Figure 8. Generalized stratigraphic column for Venango County.

**Kittanning Formation**—Kittanning strata typically are defined by the top of the Upper Kittanning coal and the base of the Lower Kittanning coal. Although the formation probably occurs, in whole or in part, at the highest elevations in southern Venango County, it is unlikely the coals would be economically mineable except in, at best, a few localities. The Upper Kittanning typically is too thin, the Middle Kittanning is best developed toward southern Mercer County, and the Lower Kittanning is best developed toward Clarion County. The sandstones commonly are gray to brown, iron-stained, massive, and coarse grained

**Clarion Formation**—The Clarion Formation is perhaps better known for the Vanport Limestone than for any commercial coals in Venango County. The Vanport can be found in many places. It is a gray, fossiliferous, marine limestone that ranges from 0 to over 25 ft. thick; it most commonly ranges up to 15 ft. It is best developed in the area of Armstrong, Beaver, Butler, Clarion, Lawrence, Mercer, and Venango counties. It is the hardest rock in the county and has created problems where it has been encountered in cuts associated with strip mining and road building. This limestone currently is not being quarried, but has been quarried in Venango County in the past, both for crushed stone and for agricultural lime. This is the limestone that contains the "Buhrstone iron ore" at the top. The old name for the Vanport, the "Ferriferous limestone" refers to its iron content. The ore lies in plates or nodules immediately on top of the limestone, but often the upper layers of limestone are so saturated with iron that it is more proper to refer to the rock as bedded siderite. Much of the ore was mined in the last century for Venango County's iron manufacturing industry (see below).

In addition to the Vanport Limestone, the Clarion Formation typically includes two, often workable coal seams separated by a relatively thick sandstone. The upper coal, the Clarion, lies below the Vanport and the lower coal, the Brookville, lies at the base of the formation. Both are probably of less than workable thickness, and they have been described as pyritous and high-sulfur coals. At least the Clarion was mined for use in powering oil well drilling rigs (Sisler, 1922). The Clarion sandstone can be as thick as 25 ft., but more often is a scattering of sandstone lenses within shales.

### Pottsville Group

Rocks belonging to the Homewood, Mercer, Connoquenessing, and Sharon(?) formations cap most of the hills in the northern part of Venango County (Figure 8). The thickness of the Pottsville Group averages about 250 ft. east of Oil City. It appears to thicken in the Franklin area, where along the exposures on PA 8 the Connoquenessing-Sharon alone exceeds 205 ft.

**Homewood Formation**—This formation includes a thick sandstone (the Homewood sandstone) that commonly is broken up into discrete lenses and layers by numerous brown to gray plastic shales, some thin coals, and siderite nodules. Where the sandstone is well developed, it forms a prominent layer in outcrop. It is coarse grained and iron stained, and often weathers to rough blocks of great hardness.

**Mercer Formation**—Below the Homewood Formation is a sequence of gray to dark gray, plastic shales containing numerous layers of siderite nodules and interbedded thin coals called the Mercer Formation. The coals typically are thin and non-commercial, although there might be local areas where they are well developed and mineable. The siderite nodules of the Mercer Formation, like the "Buhrstone ore" of the Vanport Limestone, provided much of the raw material for Venango County's iron industry during the 1800s.

**Connoquenessing Formation** – Below the Mercer shales and coals is a sequence of sandstones and coal-bearing shales that constitute the Upper, Middle, and Lower members of the Connoquenessing Formation.

The Upper Member of the Connoquenessing is characterized by light-gray, medium-to coarse-grained sandstones that often grade laterally and upward into siltstones, silt-shale, and clay-shale of the Mercer Formation. The finer grained intervals exhibit small-scale trough cross-beds and ripple laminations. The coarser grained thick beds cut into underlying units and exhibit strong tabular and less frequently large-scale trough cross-beds. Ironstone nodules and clay chips are often found in the thicker beds. Numerous small bed forms, such as reactivation surfaces and foreset flow deformation, may be seen in these beds.

Harms and others (1975) suggested that ripples occur only in grain sizes less than about 0.6 mm at low flow velocities. Tabular cross stratification and reactivation surfaces are associated with straight-crested features with well-defined avalanche faces called "sand waves". Sand waves-form at moderate current velocities.

Trough cross-beds result from downflow migrating forms termed "dunes". The crests of such features are sinuous. Dunes form at high flow velocities. We will examine the relationships of these features as seen in the outcrops along PA 8.

Spectacular lateral changes occur in the Pottsville units. The Upper Member of the Connoquenessing interfingers laterally into Mercer shales. This occurs in the east wall of the northbound lane of PA 8. If one stands on the center median at Stop 3 and looks at the west face of the southbound lane, only thick-bedded, dominantly north dipping, cross-bedded sandstone is evident. In the width of a modern superhighway, lateral facies changes result in thinning of the Upper Member of the Connoquenessing Formation by more than 30 ft! The Upper Member attains a minimum thickness of 90 ft. at this site. This may well be an excellent example in the sedimentary record of a laterally migrating point bar and floodplain sequence.

The Middle Member of the Connoquenessing consists of gray to dark-gray clay shales, mud shales, clay, and one or more thin coal beds that are often correlated with the "Quakertown coal". The upper contact of the member is usually sharp and erosional the lower contact is gradational with the sandstone of the Lower Member of the Connoquenessing.

Field trip participants will see several small faults that cut the Middle Member but do not extend through the overlying Upper Member sandstones. Such faults probably are not tectonic in nature but rather are due to slump in muds and clays soon after deposition.

The Lower Member of the Connoquenessing has the same characteristics as the Upper Member. In many places this unit and the underlying "Sharon" interval cannot be separated. This occurs when both the Sharon and Lower Member of the Connoquenessing are sandstone.

**Sharon(?) Formation** – The interval between the Mississippian and the Lower Member of the Connoquenessing Formation is occupied by varicolored, thin-bedded, medium to coarse-grained sandstone 35-70 ft. thick. The thickly bedded units commonly grade upward into fine-grained thinly bedded sandstones, siltstones, and shales. The finer grained sediments often contain carbonized plant fossils. Interbedded with the shaly layers are thin coal beds at some localities.

South of Franklin in roadcuts along PA 8 this interval is occupied by thick-bedded, light gray to pink, coarse-grained, trough and tabular cross-bedded sandstone. The sandstone lies directly on Mississippian shale in the northbound lane. In the southbound lane, the sandstone is thinner bedded with the upper part covered. Coal chips occur in the float in the covered interval. They have not been seen in place. Rocks at these two locations occupy the stratigraphic position of the Sharon Formation. The interval is about 35 ft. thick. Conglomeratic sandstone typical of the Sharon in its type locality has not been seen in the Titusville-Franklin area. It is not known if the Sharon of the type locality is laterally continuous with these beds.

## Mississippian System

Rocks assigned to the Mississippian System will be seen at STOP 2 as well as in many roadcuts and exposures on this field trip. The stratigraphic terminology used for these rocks has a complex history. Caster (1934), Pepper and others (1954), Sass (1960), and Schiner and Kimmel (1972) have dealt at length with the stratigraphic relations in western Pennsylvania. The most recent and detailed work in the area has resulted in extending eastward stratigraphic terms developed in eastern Ohio and the areas between Sharon, Mercer County and Meadville, Crawford County. Accordingly, the Shenango Formation has been redefined to include all rocks between the Pottsville and the Cuyahoga Groups (Schiner and Kimmel, 1972). The Meadville Shale, Sharpsville Sandstone, and Orangeville Shale of the Cuyahoga Group appear to extend as far east as Forest County. Harper (1994) indicated that the Corry Sandstone, Berea Sandstone, Bedford Shale, and Cussewago Sandstone, all previously considered to be Lower Mississippian formtions, are actually Upper Devonian rocks.

### Shenango Formation

The Shenango Formation has been divided into upper and lower members (Figure 8). The Upper Member consists of gray shales, interbedded thin siltstones and very fine-grained sandstones, thin argillaceous limestones, and layers of siderite nodules. Trace fossils and sole markings occur in some of the siltstone beds. The Lower Member consists of from one to four thick cyclic sequences of sandstones, siltstones, and shales. It typically shows up on gamma ray logs as a "dirty sandstone." In fact, in many places it is a sandstone layer several tens of ft. thick that forms a prominent ledge where it crops out. Freedom Falls, just upstream from the Rockland iron furnace (STOP 9), is formed on the Shenango sandstone as are the numerous waterfalls in Oil Creek State Park. However, the upper and lower members are gradational and not sharply separated.

### Cuyahoga Group

The Cuyahoga Group includes about 150 ft. of strata between the Upper Devonian Corry Sandstone and the Shenango Formation (Figure 8). The Cuyahoga has been divided into the Orangeville Shale at the base, the Sharpsville Sandstone in the middle, and the Meadville Shale at the top.

**Meadville Shale** – In the upper portion of the Cuyahoga Group includes interbedded medium-gray and brown sandy shales. Platy sandstones with ripples, burrows, and orbiculoid brachiopods increase upward. This results in a gradational Shenango-Cuyahoga contact in many places. Some beds are conglomeratic. East of Venango County, at Tionesta, quartz pebbles have been concentrated along ripple crests in an 8-inch bed.

**Sharpsville Sandstone** – The Sharpsville interval contains thin greenish-gray platy sandstones often exhibiting low-angle trough cross bedding. Ichnofossils, marine invertebrates and carbonized plant remains occur throughout the unit. Some beds are actually fossiliferous sandy argillaceous limestones. The limestones are light-to medium-dark-gray on a fresh surface, but weather to moderate yellowish brown. Unless broken, these calcareous rocks appear just like sandstone in the interval. They break with a characteristic conchoidal fracture.

**Orangeville Shale** – This formation grades into the overlying and underlying formations. It consists of thin platy beds of greenish-gray siltstone and sandstone, interbedded with gray shales. Sandstones and thin beds of conglomerates are concentrated near the base. Some of the lower sandstone layers are lithically like the Corry Sandstone.

In the Oil City region, Dickey and others (1943) reported that a 1/2- to 1-foot-thick pebbly sandstone occurs about 22 ft. above the base of the Orangeville Shale. This unit thickens until at the Tionesta Dam spillway in Forest County the marker is underlain by 15 ft. of cross-bedded pebbly sandstone lying directly on the Corry.

Lying 1 to 3 ft. above the Corry Sandstone to the west is a peculiar siltstone marker in the Orangeville Shale referred to as the Bartholomew Siltstone Member. The siltstone bears small burrows that give it a characteristic "graphic" appearance. Schiner and Kimmel (1972) indicate that this unit can be traced from Meadville to Oil City.

## Devonian System

Extension of stratigraphic terminology eastward has resulted in major confusion of the limits and names of many Upper Devonian units. West of Venango County, Upper Devonian units include, from youngest to oldest, the Berea Sandstone, Bedford Shale, Cussewago Sandstone, Riceville Formation, and Venango Formation. This division has often been extended eastward into Venango County and beyond. The only exception is the replacement of the Berea with the Corry Sandstone, which is lithologically distinct. The problems caused by this extension are substantial and are addressed below.

### Corry Sandstone

The Corry Sandstone (Figure 8) is a very persistent unit found throughout much of northwestern Pennsylvania. It averages about 30 ft. in thickness and is characteristically a three-part yellowish-gray unit consisting of a lower and upper fine-grained cross-bedded sandstone separated by a thin siltstone-and shale-bearing unit. Only the lower beds are fossiliferous although ichnofossils are common throughout the formation.

Caster (1934, 1941) and Sass (1960) have extensively studied the fauna found in the lower beds of this formation. They agreed that it contains a Kinderhook marine assemblage in the lower sandstone, based principally on the presence of several species of the brachiopod *Syringothyris*. However, most brachiopod experts now claim that *Syringothyris* isn't as good a stratigraphic index fossil as the genus *Cyrtospirifer*, which indicates a Devonian age. *Cyrtospirifer* is plentiful in the Corry, as are several other fossils typically considered Late Devonian in age. As a result, Harper (1994) transferred the Corry and its correlative strata throughout Pennsylvania to the Devonian.

### Tidioute Shale

Caster (1934) proposed the name Tidioute shale member for a 20 ft. thick sequence of olive gray, micaceous shales wedged between the Corry Sandstone and his "Cobham conglomerate" (= upper sandstone member of the Knapp Formation of McKean and Warren counties) along the Allegheny River at Tidioute, Forest County. This unit is notable in that it contains an echinoid fauna in the basal one or two ft. These echinoderm fossils are very rare in the Paleozoic, but the Tidioute apparently provided numerous specimens.

Caster seems to be the only person to use the name Tidioute in formal publication. It is not an accepted term either by the Pennsylvania or US geological surveys. In light of the "Drake Well formation" described below, however, it seems appropriate to resurrect the name.

### "Drake Well Formation"

The bedrock exposed at STOP 5, at Drake Well Memorial Park, can be traced over large areas of northwestern Pennsylvania in the subsurface, but it has never been satisfactorily identified. The names Corry Sandstone and Cussewago Sandstone commonly are used, but as will be shown below, neither name adequately fits the rocks.

White (1881), who named both the Corry and Cussewago sandstones from outcrops in Erie and Crawford counties, respectively, appears to have considered these rocks to be Corry. Caster (1934) didn't mention this locality and it is difficult to determine by inference whether he would have called these rocks Corry, Cussewago, or something else. In his discussion of the Knapp Formation of Warren and McKean counties, he noted that the Corry lies above the Knapp and that the Cussewago correlates to the upper of two conglomerate beds (his Cobham Conglomerate). The Cobham Conglomerate "...is a typical flat-pebble conglomerate, of varying texture. The size of the pebbles tends to grow smaller toward the west and the member loses its massive conglomerate appearance. From Warren west the member is composed of fine, angular pebbles, with only occasional flat pebbles. West of Warren the member is usually, very loosely cemented. The angular pebbled rock ("millet grained" texture) is known as the Cussewago sandstone in Erie and Crawford Counties and eastern Ohio." (Caster, 1934, p. 113). Caster found the Corry Sandstone to be fossiliferous only in the lower foot or foot and a half.

Dickey (1941), Sherrill and Matteson (1941), and Dickey and others (1943) identified the Corry Sandstone and an underlying unit, occurring mostly within the subsurface, which they called the Cussewago Sandstone. They described the Cussewago as 80 to 100 ft. of alternating dark gray shale, dark gray sandy shale, and very fine-grained, light gray to white, thin-bedded, fossiliferous sandstone lying between the Corry and the red shales of the Riceville Formation. These lithologies appear to have far more in common with the Corry Sandstone than with White's (1881) type Cussewago, despite occurring well below the Corry. Dickey (1941) noted that electric logs run in wells in the Titusville area showed this formation to contain three prominent sandstone beds lying 40, 55, and 75 ft. below the base of the Corry. He also noted a faint reddish color in the shales. The sandstones frequently contain abundant crinoid fossils. Sherrill and Matteson (1941) found thin streaks of dark red or brown shale within the Cussewago that were lithologically indistinguishable from the underlying Riceville Formation. Dickey and other (1943, p. 21) stated that the upper third of this Cussewago is exposed along Oil Creek north of Rouseville.

Pepper and others (1954) described the typical Cussewago Sandstone as "...fine to coarse, angular to subangular quartz grains that are normally coated by iron oxides. The sandstone is characteristically poorly cemented; in color it is dull greenish-yellow. In many places small discoidal or ellipsoidal pebbles as much as one-quarter of an inch in diameter occur either scattered through or in small lenses in the lower part of the Cussewago sandstone. The Cussewago sandstone appears to be unfossiliferous except for a few bits of plant tissue." (Pepper and others, 1954, p. 19) They also found the formation disappeared eastward from the type section in central Crawford County. "From outcrop 50 [in North Shenango Township, Crawford County] eastward to outcrop 92 [northern Athens Township, Crawford County] (pl. 4) the Cussewago sandstone rests on the upper part of the Riceville shale, and east of outcrop 92 where the Cussewago sandstone is absent the Corry sandstone lies on the upper beds of the Riceville shale." (p. 17). Pepper and others (1954) disagreed with Caster's (1934) contention that the Cussewago was a sandstone equivalent of the upper conglomerate bed in the Knapp Formation. They indicated that these two formations are separated laterally by a belt of shale and, therefore, have no relationship. Their intensive correlation of outcrops and drill cuttings led them to conclude that the rock typically considered to be Cussewago Sandstone in the Oil Creek Valley was, in fact, the Corry Sandstone. A key marker bed above the Corry called the Bartholomew Siltstone Member of the Orangeville Shale can be easily recognized and traced around Crawford and Venango counties. Pepper and others (1954, p. 42) traced it eastward from near the boundary with Ohio to Corry in Erie County, Pennsylvania, and down Oil Creek valley to Oil City.

The fine work of Pepper and others (1954) more than just redefined the nomenclature of the Corry/Berea-Bedford-Cussewago sequence in northwestern Pennsylvania - it convinced many subsequent workers for years that the exposures along Oil Creek were of the Corry Sandstone. Ward and others (1976), Hoskins and others (1983), Feldman and others (1992), and Harper (1998a) all used the name Corry for the sandstones at the Drake Well Memorial Park, and Sass (1960) used that name for rocks in the Oil Creek valley.

Dissenting from this opinion were Burgchardt and Fox (1989) and Fox (1989) who, with the use of geophysical logs from nearby wells for correlation, returned to calling the outcrop and its subsurface correlatives the Cussewago Sandstone. In fact, they placed the Drake Well Memorial Park outcrop right at the boundary of the Cussewago and Riceville formations, with the Riceville represented by the shales at the bottom of the outcrop.

Dodge (1992, p. 13), defying all tradition, identified this unit in western Warren County as an unnamed marine equivalent of the Knapp Formation. This "unnamed marine mixed clastics" sequence consists of thin, impure, locally calcareous, mostly very fine grained, light-gray sandstone, gray siltstone, and subordinate dark-gray shale. It is about 60 to 100 ft. thick and recognizable on gamma-ray logs and in the field. Dodge interpreted the clastics as offshore or lower shoreface deposits seaward of the Knapp barrier bar/beach system.

Harper (1998c) used subsurface correlation of gamma ray logs to verify that Dodge (1992) was correct. This sequence of rocks attributed to the Cussewago by Dickey (1941) and others, and to the Corry by Pepper and others (1954), is, in fact, a separate, as yet unnamed formation more closely equivalent to the basal Knapp Formation than to either the Corry or Cussewago. Harper (1998c) used the informal name "Drake Well formation" for convenience and suggested that a complete sequence of these rocks exposed at Tidioute and Tionesta would make excellent type localities for a new formal stratigraphic unit.

# ECONOMIC GEOLOGY

Venango County has had a long history of economic mineral resources. Petroleum (oil and natural gas) is the most noticeable of these, but it certainly isn't the only one. The earliest non-fuel mineral resource was limestone, used by farmers for agricultural lime. The discovery of siderite nodules and layers associated with some of those limestones led to Venango County's first industry—iron manufacturing. Sand and gravel, which are abundant in the county, became important as aggregate with the development of the construction industry. Coal probably was mined locally by farmers and iron manufactures, but has not been a major mineral resource in the county.

## Oil and Natural Gas

In 1858, in the employment of a small group of investors from New England, an unassuming former railroad conductor from New Haven, Connecticut named Colonel* Edwin L. Drake moved to Titusville, Pennsylvania, and drilled a well. On August 27, 1859, he struck oil in a sandstone at 69½ ft. below the floodplain of Oil Creek, and the world changed forever.

By 1860 Venango County had a thriving oil business, and by 1880 western Pennsylvania supplied more than half of the total world supply of oil. In fact, it wasn't until the discovery of oil in Texas in 1903 that Pennsylvania lost its place as the world's primary oil producer. Many modern production, refining, and transportation industries originated in this area. Petroleum geology and engineering were invented here, primarily by John F. Carll, a geologist with the Second Geological Survey of Pennsylvania (Lytle, 1957; Owen, 1974; Harper, 1990). Today, Pennsylvania produces less than 1 million barrels of oil annually, and Venango County is known more for its oil history than its oil industry.

The oil and gas industry of Venango County is still in business, although it has slowed considerably since the heyday of the late 1800s. Oil from the Upper Devonian Venango Formation, and oil and natural gas from the Bradford Group, are not nearly as important now as they were up to about 1970. Many of the old oil and gas fields (Figure 9) have long been abandoned, the oil depleted or too difficult to draw from the reservoirs. The abnormally low price for crude oil, plus the high cost of adhering to current environmental laws, has essentially made the oil business a liability for all but the most ardent companies. There are still wells producing oil in Venango County, and the major refineries still cook up some of the best motor oils in the world, but the "black gold" fever of yesterday is little more than a memory. Today, drilling for natural gas in the Lower Silurian Medina Group constitutes the majority of petroleum activity in northwestern Pennsylvania. This is also true for Venango County where Medina activity has been slowly but steadily creeping southeastward from the main fields of Crawford and Mercer counties (Figure 9).

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* Drake, who had never been in the military, was given the spurious title of "Colonel" by his employers to impress the people of Titusville and thereby make his job a little easier in a backward region of Pennsylvania. Although the title lived on long after Drake's death, it took until the centennial celebration of Drake's achievement, to make it valid. At a ceremony that took place at Carter Field in Titusville in 1959, Secretary of Internal Affairs Genevieve Blatt, acting on behalf of Governor David L. Lawrence, posthumously commissioned Drake a Colonel in the Pennsylvania National Guard (Blatt, 1959).

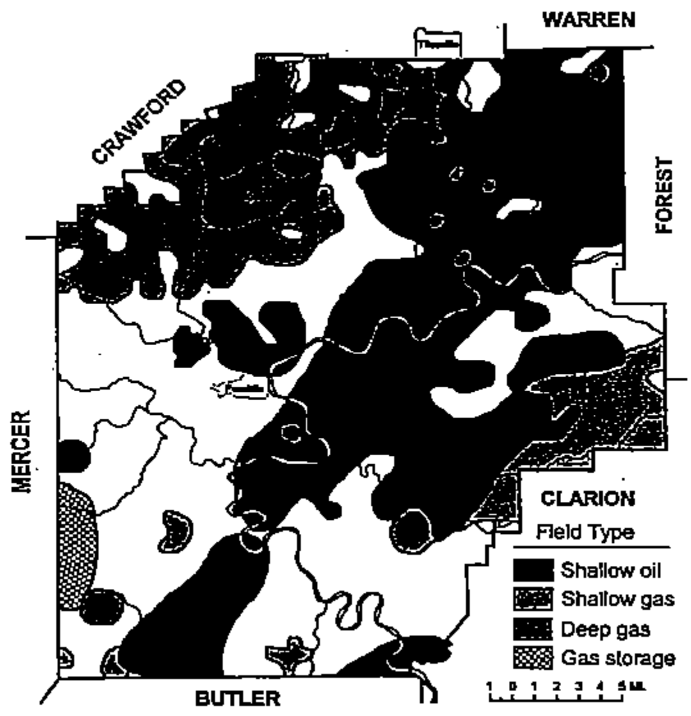

Figure 9. Oil and gas fields map of Venango County (modified from Pennsylvania Geological Survey, 1993).

## Source Rocks and Traps

According to Laughrey (1991), the black, organic-rich mudrocks of the Upper and Middle Devonian and Upper Ordovician are the only reliable source rocks for all known hydrocarbons in Pennsylvania.

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.

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 Venango County as they have benefitted certain operators in Crawford and Venango Counties (Zagorski, 1991).

## Major Reservoir Rocks

The major reservoir rocks of Venango County include the Upper Devonian Venango Formation and Bradford Group, and the Lower Silurian Medina Group (Figures 10 and 12). Subsidiary production has been found in the Mississippian, but it is essentially restricted to a few small fields or pools. To date, nothing has been found in the Middle Devonian Onondaga Limestone, the Lower Devonian Oriskany Sandstone, or Upper Silurian Lockport Dolomite.

**Venango Formation**—In Venango County the Venango Formation 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 (Figure 10). The group as a whole can be traced across the county, and throughout western Pennsylvania, 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 sandstone units develop below the Venango Third. These sandstones act to extend the group downward into the subjacent Chadakoin Formation.

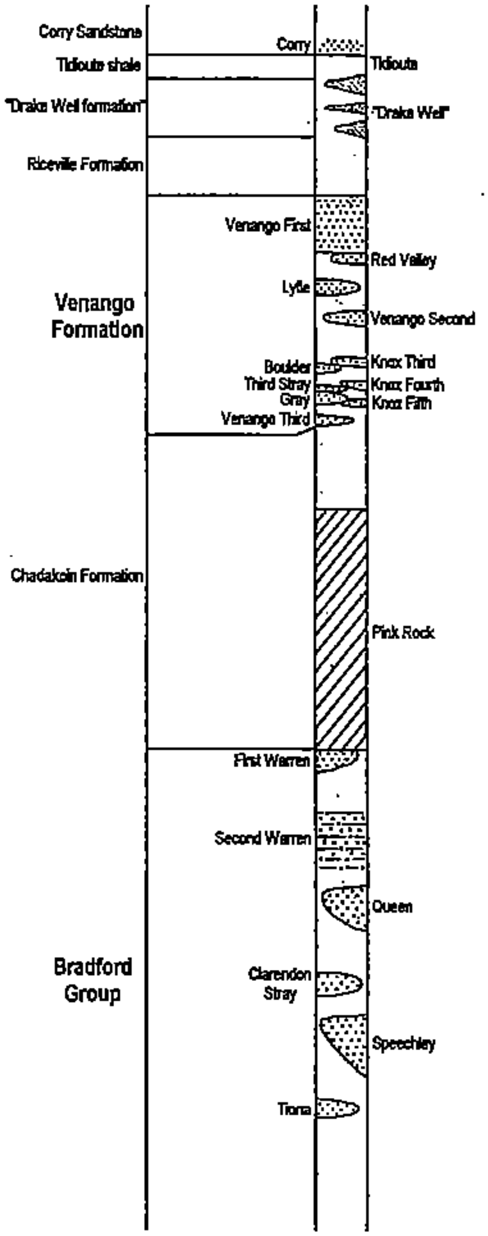

Figure 10. Stratigraphic column of the Venango Formation and Bradford Group showing both the formal names (left) and the drillers names (adjacent to the column). Modified from Dickey and

Typical Venango Formation reservoir rocks consist of relatively thick sequences of interbedded sandstones, siltstones, and shales 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. 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 Formation sandstones have exceedingly variable porosities and permeabilities (Figure 11). 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 Formation drilling in Venango 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.

Venango Formation 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

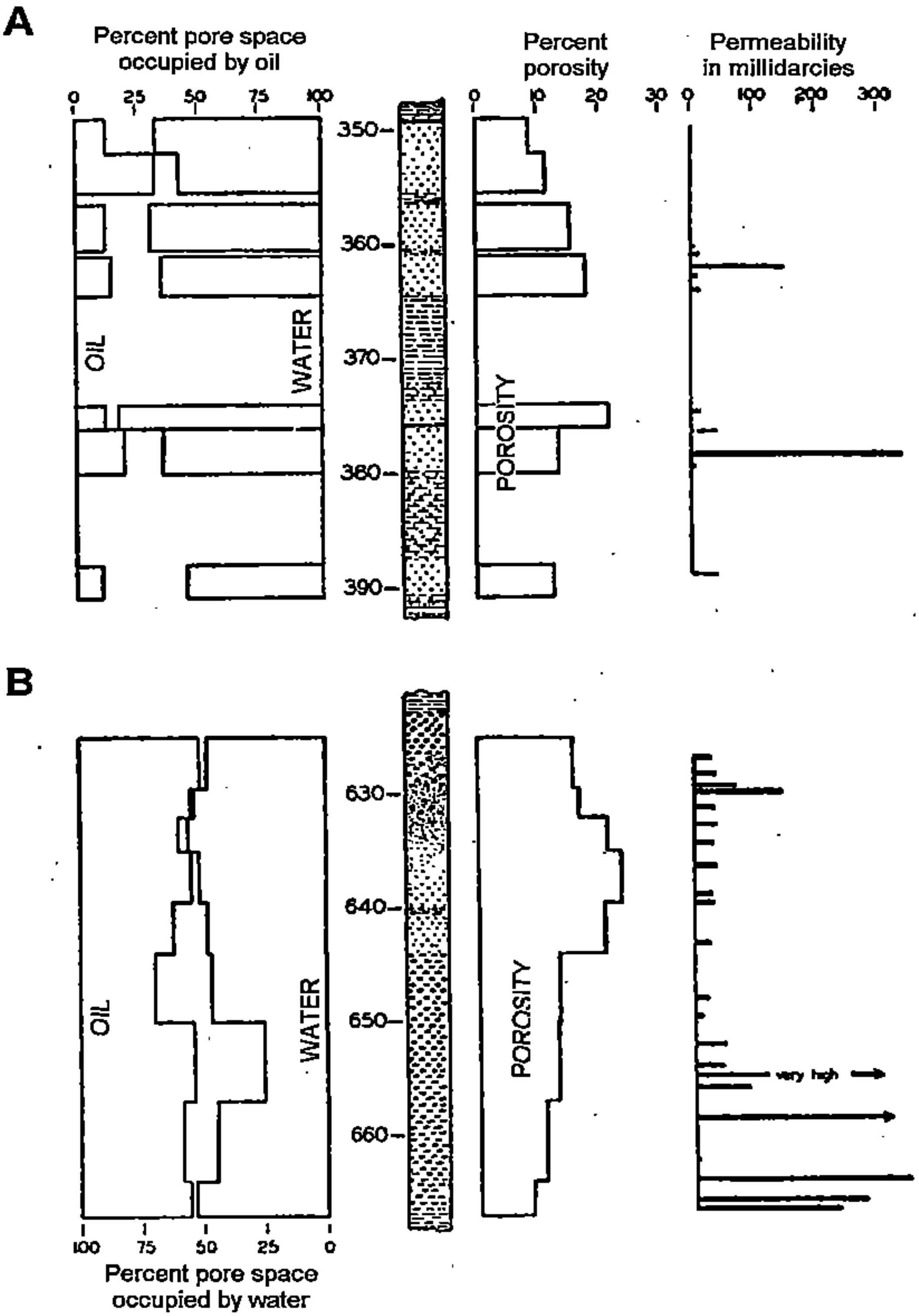

Figure 11. Characteristic core analyses of the Venango First sandstone (A) and Venango Third sandstone (B) in Pioneer oil field, Venango County (modified from Dickey and others, 1943).

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 10. Like the Venango Formation, the Bradford Group 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.

Although the Bradford Group consists of numerous major and minor sandstone strata in the primary producing areas of western Pennsylvania, in Venango County the only oil- and/or gas-producing strata within the group are the Speechley and Tiona sandstones.

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 reservoir sand maps throughout western Pennsylvania (e.g. Ingham and others, 1956). Other depositional systems probably will be delineated as these rocks are studied more fully.

Although Bradford Group reservoirs exhibit variable porosities and permeabilities, they are not nearly so variable as those of the Venango Formation 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.

**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 (Figure 12).

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 In 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 "tight", that is, having very low porosities and permeabilities, throughout most of northwestern-Pennsylvania. Exceptions in-

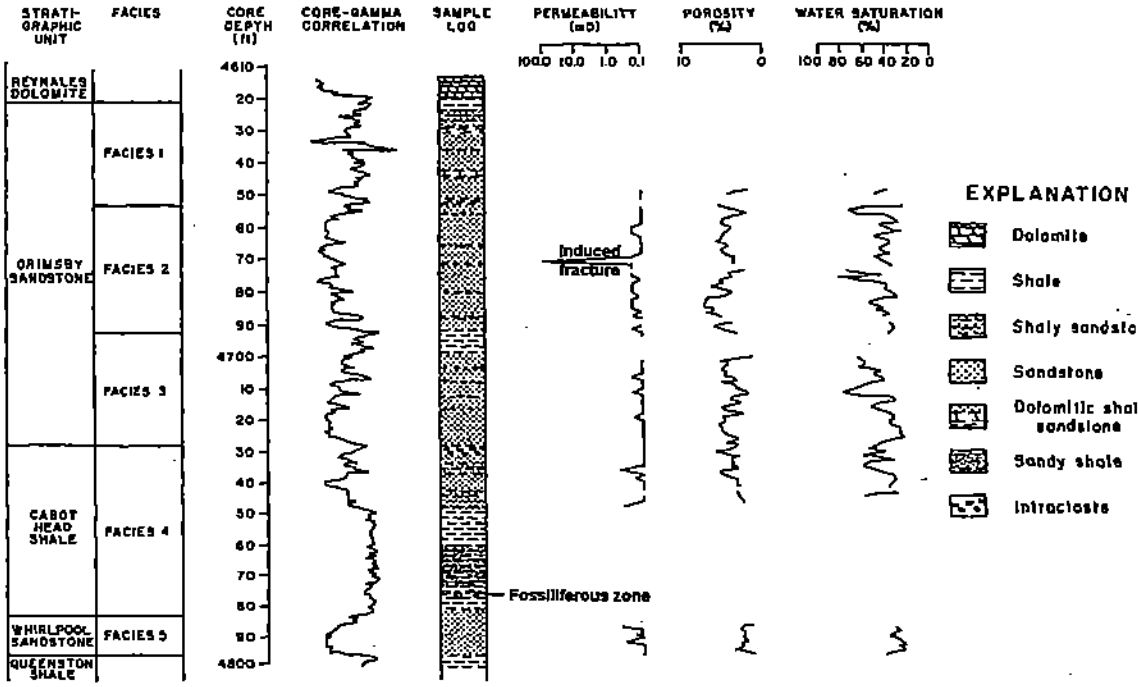

Figure 12. Stratigraphic column of the Medina Group and core analyses of the Craecraft #1 well in Athens Township, Crawford County (modified from Laughrey, 1984).

clude 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.

For many years, Medina gas in producible economic quantities was almost restricted to the western third of Venango County (Figure 9, Deep gas). Since the mid-1980s most of the Medina 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. This might change with renewed incentives such as considerably higher prices for natural gas.

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 well before abandoning them.

## Sand And Gravel

Although sand and gravel are not considered especially exciting mineral resources, they are essential to modem construction, especially paving and building. They are especially important for local uses because their relatively low value precludes long-distance shipping. In fact, construction sand and gravel typically is used within 30 mi. of the source (Craft, 1979). However, despite their low unit cost, the total amount produced in Pennsylvania during any given year exceeds 14.5 million tons and is worth more than $75 million. About 40% of this value is for sand and 60% is for gravel.

Sand and gravel rank third in both quantity produced and in dollar value in Pennsylvania among all non-fuel mineral resources. In 1997 Pennsylvania produced 14.5 million metric tons of sand and gravel, worth $84.4 million. Only crushed stone (93 million metric tons) and dimension stone (54.6 million metric tons) accounted for more volume (US Geological Survey, 1998).

By far the most important use for sand and gravel is in Portland cement concrete. Such concrete typically contains 80 to 85% aggregate by weight. In 1997, Pennsylvania concrete construction projects used 4,970 metric tons of sand and gravel valued at $34.2 million (US Geological Survey, 1998).

The commercial sand and gravel industry uses the term *aggregate* to apply to sand or to sand-size crushed stone, and *coarse aggregate* to gravel or to crushed stone of gravel size. Sands are dominantly quartz, commonly with some admixture of lithics, micas, cherts, and "heavy minerals" such as magnetite, olivine, and garnet. They are known more for their uniformity of composition than are gravels because the dominant constituents of gravel are rock fragments rather than mineral grains; thus, gravels are notably heterogeneous in composition. Gravel varieties may range from "soft" shales and mica schists to "hard" granites and quartzites. Sandstone, limestone, dolomite, chert, and cryptocrystalline volcanic rocks might also be found in gravel deposits. Sand often occurs without gravel (beaches and dunes), but gravel is seldom found without sand; in Venango County, you don't get one without the other.

The properties of aggregates that make them commercially acceptable can be determined by visual inspection, but laboratory tests or petrographic examination should be used for quality control. Sand and gravel must be clean, free of dirt, mica, and organic matter. Silt and clay, in too great a quantity, could render them noncommercial. They must be resistant to abrasion. As such, sand rarely has a problem being commercially acceptable. Weak or crumbly gravel, on the other hand, cannot be tolerated for commercial aggregate. Commercial aggregate must be highly resistance to wetting and drying, and to freezing and thawing, so cracked and porous gravel is unacceptable. Particle shape is also important. Particles of equal dimension are preferred over angular or flat and elongated ones. Certain sand and gravel aggregates must have other properties as well, such as compressibility, elasticity, thermal conductivity, and specific gravity.

One of the more critical factors, especially where gravel is concerned, is chemical inertness when enclosed in cement. As cement hardens, it produces heat and liberates alkalies such as calcium, sodium, and potassium hydroxides. Quartz, feldspar, calcite, and most of the dark silicate minerals are essentially nonreactive, so rocks such as granite, gneiss, sandstone, and limestone are preferred. Materials such as shale, opaline and chalcedonic chert, siliceous limestone, rhyolite, dacite, and andesite, however, react chemically with the alkalies released by the

*Table 4. Comparisons of Texture and Composition of Four Tills from Northwestern Pennsylvania*
(Data from White and others, 1969)

| Unit | % Sand | % Silt | % Clay | % Quartz | % Feldspar | % K Feldspar | % Heavy Minerals | % Calcite | % Dolomite | % Total $CO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Lavery Till | 32.7 | 47.0 | 20.3 | 68.9 | 31.1 | 31.9 | 3.7 | | | |
| Kent Till | 43.0 | 38.5 | 18.5 | 86.9 | 13.1 | 44.7 | 44.7 | 1.4 | 1.8 | 3.2 |
| Titusville Till | 45.4 | 36.9 | 17.7 | 87.9 | 12.1 | 52.9 | 52.9 | 1.1 | 1.3 | 2.4 |
| Mapledale Till | 44.0 | 36.0 | 20.0 | 94.6 | 5.4 | 53.1 | 53.1 | 0.7 | 0.6 | 1.3 |

cement (Bates, 1969) and must be rejected unless the expense of obtaining better materials is exorbitant. Sodium and potassium react with these materials to produce alkalic silica gel. The gel absorbs water during the setting phase of the cement, developing expansive stresses that can exceed the tensile strength of the concrete. This can cause cracking or blisters in the concrete, forcing structures out of alignment and buckling pavement. Even in cases where the cracking and blistering are not serious, they can promote freeze-thaw or wet-dry cycles that will ultimately cause the concrete to deteriorate.

*Table 5. Lithologic Composition, by Weight Percent, of Gravel Deposits in the Franklin Area of Venango County.*

| Composition | Fosters Corners, crush pile | Tionesta Sand and Gravel, Cooperstown, from below water processed through Class A plant | Tionesta Sand and Gravel, Cooperstown, from below clay cover in new part of working pit | Reno pit, sample collected from cemented knob in lower part of pit | Reno pit, sample collected from working face adjacent to cemented knob | Franklin Dredge, 2-B pile | Franklin Dredge, at dock side |
|---|---|---|---|---|---|---|---|
| Gray siltstone | 2.5 | 48.8 | 2.8 | 39.2 | 26.8 | 25.8 | 34.3 |
| Gray calcareous siltstone | -- | -- | 12.3 | 1.5 | -- | 10.7 | — |
| Brown siltstone | 92.0 | 7.1 | 34.7 | 15.5 | — | 26.9 | — |
| Brown calcareous siltstone | — | -- | 9.6 | -- | — | 0.2 | — |
| Crystalline rock | 7.1 | 3.3 | 5.4 | 13.5 | 14.6 | 12 | 15.3 |
| Chert | 4.8 | 1.5 | 7.1 | 13.3 | — | 5.7 | 7.5 |
| Limestone | -- | -- | 6.9 | 1.5 | — | 7.4 | 11 |
| Sandstone | — | 39.1 | 4.7 | 19.6 | 58.6 | 11.5 | 31.9 |

As such, composition, especially of the gravels, is an important determination. Craft (1979) indicated that gravel deposits in northwestern Pennsylvania are generally similar in composition Table 4). Composition of the glacial gravels from the Franklin, Venango County area, as shown in Table 5, indicates that the bulk of any particular deposit is composed of local bedrock material, most of which meets quality tests. Even the small amount of material in the glacial deposits that was transported from hundreds of miles away consists of quality rock that would withstand tests for quality. Any soft bedrock material such as shale that might have been in the glacial deposits has deteriorated and been washed out.

One of the largest users of sand and gravel aggregate in Pennsylvania is the Department of Transportation (PennDOT). Because of its great need for quality materials, PennDOT has established specific quality and grade-size standards for use in the different phases of highway construction. A number of Pennsylvania municipalities and architectural and engineering firms also use PennDOT specifications for construction material. Table 6 shows the quality requirements. The three categories, A, B, and C, refer to PennDOT subdivisions of aggregate. Type A material is the highest quality, required for all concrete and surface courses in asphalt roads. Either type A or type B aggregates are required for bituminous base course and crushed aggregate base course. Type C or better aggregate is required for subbase as well as some other types of base course (Craft, 1979).

*Table 6. PennDOT Specifications—Physical Requirements for Coarse Aggregate*
(Modified from Craft, 1979)

| | Type A | Type B | Type C |
|---|---|---|---|
| Sodium sulfate test--maximum % loss at 5 cycles by weight | 12 | 12 | 20 |
| Loss Angeles Rattler test--% loss by weight at 500 revolutions | 35 | 45 | 55 |
| Maximum weight % of thin and elongated pieces | 10 | 10 | |
| Maximum weight % loss by washing | 1 | 1 | 12 |
| Minimum weight % of crushed fragments, individual and combined sizes | 55 | 50 | 50 |
| Common deleterious substances: | | | |
| Maximum weight % of soft fragments | 2 | 2 | 10 |
| Maximum weight % of shale | 1 | 1 | 10 |
| Maximum weight % of clay lumps | 0.25 | 0.25 | 3 |
| Maximum weight % of coal or coke | 1 | 1 | 5 |

## Iron Manufacturing

When one thinks of nineteenth century industry in Venango County, the first thing that comes to mind is oil. But long before Colonel Drake set foot in the Oil Creek valley, Venango County had a very different mineral resource industry - iron manufacturing.

Iron was mined and smelted in Pennsylvania from the early Colonial days. The industry grew rapidly, Pennsylvania taking and maintaining the lead in iron ore mining and in the production of pig iron until 1880. By 1880 Pennsylvania was importing iron ores from other regions, particularly the great deposits in Michigan and Minnesota. This led to the abandoning of much of the iron ore mining in Pennsylvania with the exception of the magnetite ores of Cornwall, French Creek, and a few other localities which continued to be mined into the second half of the 20th century. At one time there were 32 iron furnaces operating in Venango County, producing 12,000 tons of pig iron per year.

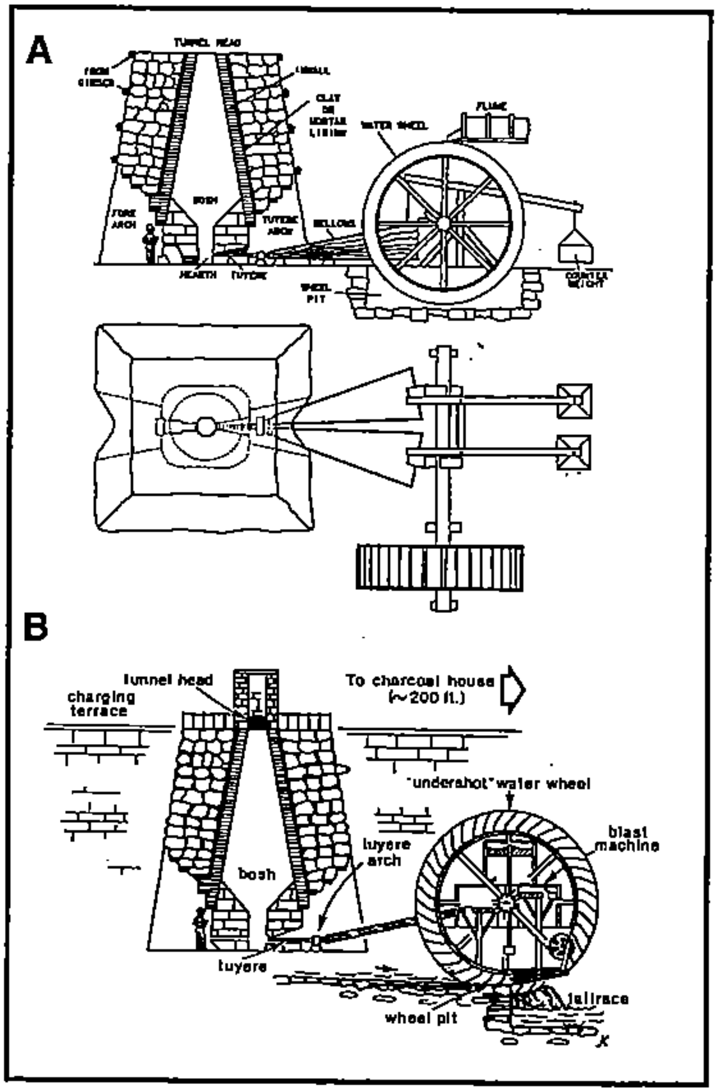

Figure 13. Generalized plans of early American iron furnaces. The earliest furnaces (A) were equipped with bellows to provide the blast (modified from Bining, 1938). In the 1800s, however, iron manufactures developed a different kind of blast machine (B) consisting of pistons and cylinders (from Inners, 1986).

Iron manufacturing in the early 1800s was a relatively simple affair, with a small stone furnace for smelting ores (Figure 13) built where the most important resources could be found in sufficient quantity to assure many years of production. These resources included: 1) iron ore, generally of low quality, especially in western Pennsylvania (see below); 2) limestone beds that could be quarried for flux; 3) wood for charcoal, which was used exclusively as a fuel and for carbon until the iron masters began using anthracite coal (in eastern Pennsylvania) or coke made from bituminous coal (in western Pennsylvania) (Swank, 1878); and 4) running water to generate the power needed to keep the blast machine operating. The old iron furnaces of western Pennsylvania commonly were situated along a small or moderate sized stream having a steady flow of water. Exceptions such as Stapley Furnace (Figure 14, no. 20) in Richland Township, Venango County used steam engines to power the blast machine.

Early iron manufacturers operated their furnaces only six to nine months each year. The remaining time was spent cutting lumber for charcoal and making repairs to the furnace and equipment. They made iron by dumping alternating charges of ore, limestone, and charcoal or coke into the bosh through the tunnel head at the top of the furnace (Figure 13).

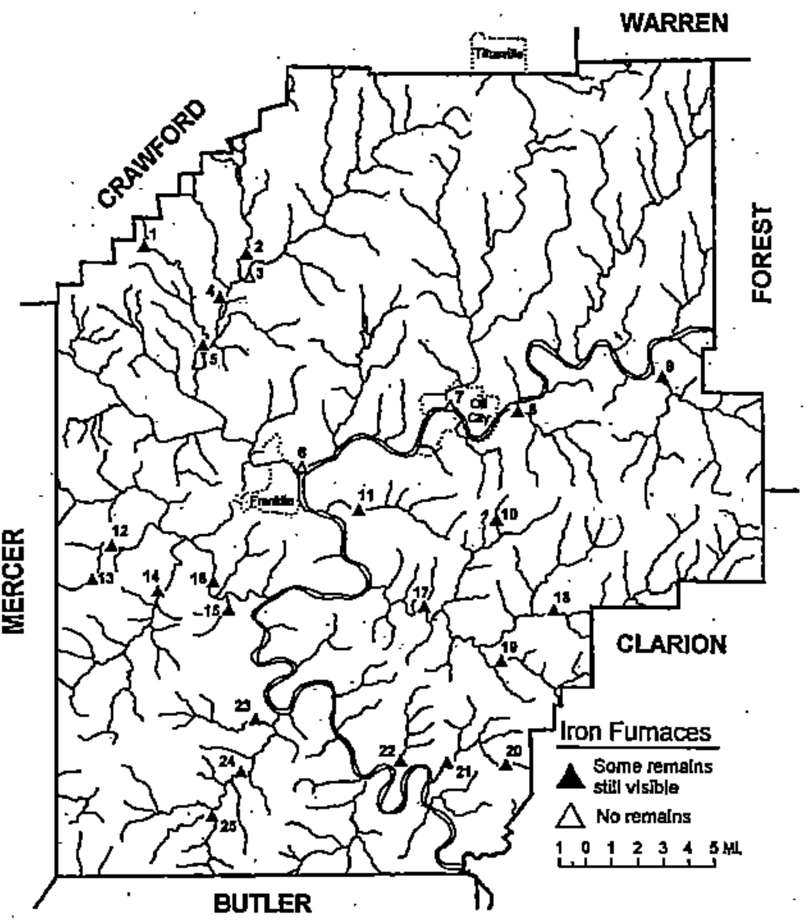

Figure 14. Stream map of Venango County showing the locations of early American iron furnaces. Numbers refer to the list in Table 7.

The blast machine, a waterwheel-powered bellows or air pump, forced air into the furnace through a tuyere, a small opening leading to the hearth. There the air blasted into the bosh, raising the temperature high enough to smelt the iron. At the front of the furnace was a casting shed where the iron master drew off the slag, a scum of cinders, for discarding. The iron ran into sand molds for pig iron ingots that could be forged into nails, wagon wheels, horseshoes, and a variety of other useful domestic products. Two tons of local ore, one or two tons of charcoal or coke, and a few shovelfuls of limestone would produce about one ton of pig iron (Anonymous,1988). When you consider the Venango County furnaces produced between 150 and 800 tons of iron per year you can readily imagine the kind of pick-and-shovel labor that went into mining and lumbering to keep them stocked.

*Table 7. List of the Iron Furnaces Shown in Figure 14.*
(Compiled from Anonymous, 1988 and Lesley, 1859)

| Map # | Furnace Name | Map # | Furnace Name | Map # | Furnace Name |
|---|---|---|---|---|---|
| 1 | Liberty | 11 | Van Buren | 21 | Porterfield |
| 2 | Union | 12 | Reno | 22 | Rockland |
| 3 | Kroemer | 13 | Raymilton | 23 | Bullion |
| 4 | Texas | 14 | Castle Rock | 24 | Anderson |
| 5 | Valley | 15 | Victory | 25 | Jane |
| 6 | McCalmont | 16 | Sandy | | |
| 7 | Oil Creek | 17 | Slab | | |
| 8 | Horse Creek | 18 | Jackson | | |
| 9 | President | 19 | Webster | | |
| 10 | Halls Run* | 20 | Stapley | | |

Four common types of iron ores were used in early Pennsylvania smelting: black iron ore, or magnetite ($Fe_3O_4$), theoretically contains 72.4% iron; red iron ore, or hematite ($Fe_2O_3$), contains 70% iron; brown iron ore, or limonite ($2Fe_2O_3,3H_2O$), is 59.8% iron; and siderite ($FeCO_3$) contains 48.27 % iron.

Magnitite and hematite do not occur in western Pennsylvania. Limonite and siderite, on the other hand, occur widely scattered over western Pennsylvania in Mississippian and Pennsylvanian rocks. They were mined in hundreds of places in western Pennsylvania in the 1800s. In some cases the ore bodies covered extensive areas and contained many tons of ore. These are residual ores that owe their origin to the action of ground water that removed the soluble carbonates and concentrated the iron compounds originally disseminated throughout the strata. The concentration was most pronounced in fractured zones of the limestone where there was free circulation of the ground water. In the case of siderite, the iron only partially replaced the carbonate.

The principle ore used in western Pennsylvania furnaces was siderite, which typically occurs in the form of nodules associated with numerous Mississippian and Pennsylvanian age marine limestones and calcareous shales (Figure 8). Siderite varies in color, but typically is some shade of bluish gray, light gray, or very dark gray and has a weathered rind the color of rust. The ore is dense and commonly breaks with a conchoidal fracture. Although pure siderite contains 48.27% iron, in nature the impurities reduce the iron content to between 25 and 45%.

The primary siderite bed throughout western Pennsylvania is the "Buhrstone ore", a layer associated with the Vanport Limestone of the Allegheny Formation (Figure 8). This layer, which is about 40 percent iron in composition, averages one foot in thickness in the Butler-Clarion-Venango county area, but thicknesses of between two and six feet have been noted. White (1877, p. 101) even reported that the siderite literally replaced the entire Vanport (22 feet of iron ore) at one locality in Lawrence County. The Vanport and, presumably, the Buhrstone, are developed in patches near the tops of the highest elevations in Irwin, Clinton, Scrubgrass, Richland, Rockland, and Cranberry townships in the southern part of the county. There, at least the limestone is similar to that found in Butler, Armstrong, and Lawrence counties where it is best developed.

Another common type of ore used in some of the Venango County furnaces – for example, Van Buren Furnace in Cranberry Township (Figure 14, no. 11) – is bog iron ore. Bog iron ore is formed through precipitation. The iron component is gathered from soils and rocks through the action of acids from decaying organic matter, and is held in solution as a soluble iron bicarbonate ($Fe(HCO_3)_2$). It is precipitated in shallow waters, such as springs and swamps, as a yellow- or orange-colored sediment that consolidates to become ore. Bog ore is spongy, yellow-brown in color, and contaminated with impurities, chiefly clay. Ore bodies vary in thickness and lateral extent, ranging from nodules to sheets of several acres. They range from a few inches to several feet thick, but typically average between one and two feet.

The first iron furnaces built and operated in Venango County were erected in 1824. John Anderson, who had experience in the iron industry in Juniata County, built the Anderson Furnace on Big Scrubgrass Creek near present day Kennerdell in the southern part of the county (Figure 14, no. 24). He also built Oil Creek Furnace, situated at the mouth of Oil Creek, on land bought from Chief Cornplanter, the head of the Seneca Indian Nation. By 1858 Venango County had 25 iron furnaces (Swank, 1878). By that time, however, most of the furnaces had been abandoned for a variety of reasons, any one of which could have single-handedly subverted the industry. The primary reasons included overlumbering which exhausted the source for charcoal, depletion of iron ore, increased mining and hauling costs, increased tariffs (always a business killer), and increased competition from large manufacturing towns like Pittsburgh and Sharon. These latter towns found it was far more profitable to use coke and high quality iron ore from the Lake Superior region.

Venango County had a rich trade in iron manufacturing while it lasted. Many of the wealthier people in the region invested in the industry and got back a tidy dividend for their investment. Iron provided a considerable amount of money to the local economy during times when few other industries could. In a sense, iron manufacturing helped the county residents weather the economic problems of the early to mid-1800s until oil came along to take on the mantle of "primary industry". Today, iron manufacturing in Venango County is just a memory. Fortunately, many picturesque remains of old furnaces, such as Rockland Furnace, help us remember. Some of them are in out-of-the-way places that require long arduous hikes in the woods and creek beds in order to find the remains.

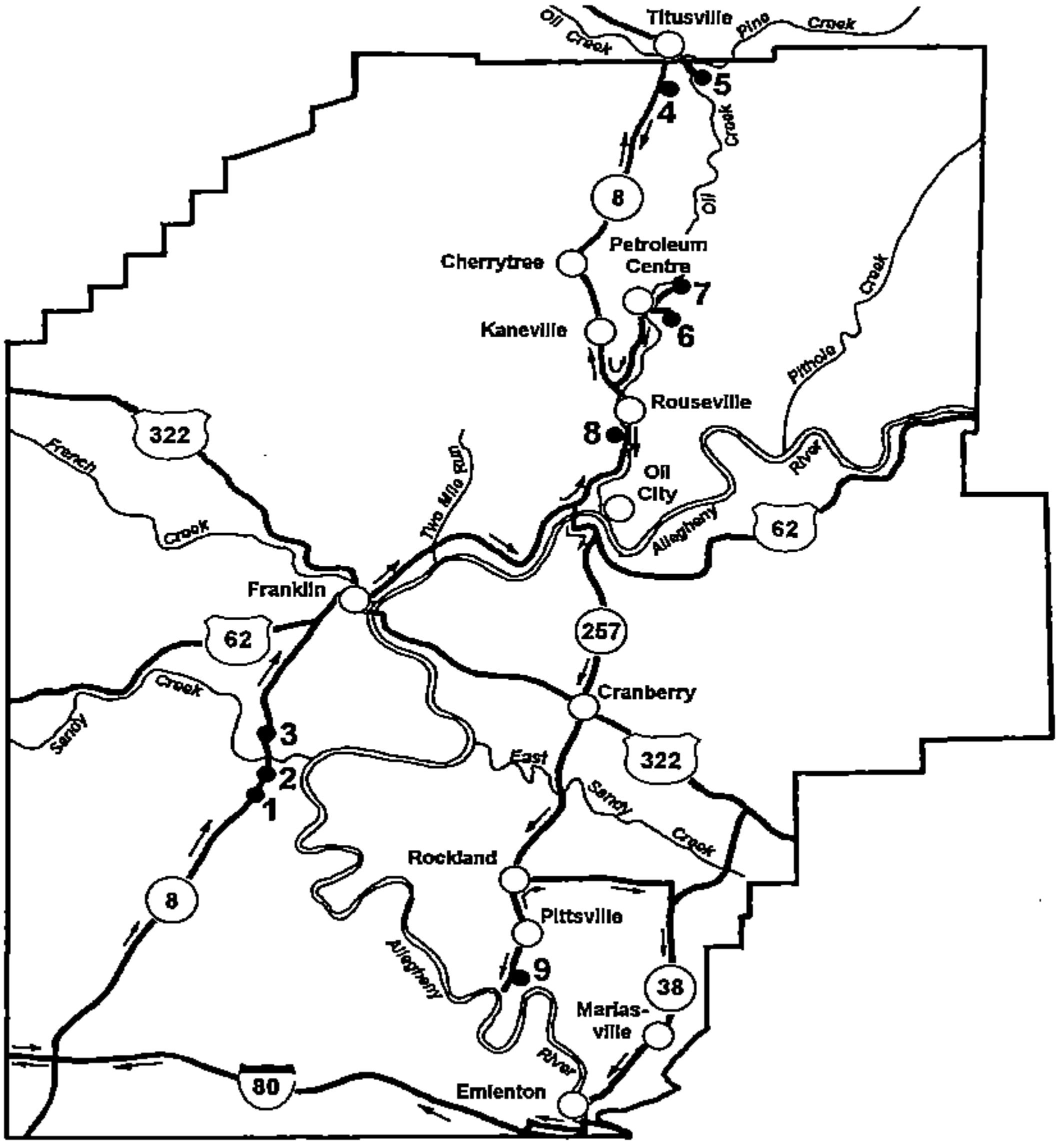

Figure 15. Map of Venango County showing field trip route and stops.

## ROAD LOG

| Mileage | | |
|---|---|---|
| **Int.** | **Cum.** | **Description** |
| 0.00 | 0.00 | Begin fieldtrip. Leave Parkway Center parking lot. |
| 0.10 | 0.10 | Turn left onto Parkway Center Drive and cross the Parkway West (I-279/US 22 & 30). |
| 0.45 | 0.55 | Merge with traffic on I-279, the Parkway West, headed N. |
| 0.80 | 1.35 | Exit 7 to US 19 and PA 51. Continue N on I-279. |
| 0.25 | 1.60 | Enter Fort Pitt Tunnel in left hand lane. |
| 0.70 | 2.30 | Exit Fort Pitt Tunnel and cross Monongahela River on Fort Pitt Bridge in left hand lane. Take exit to Fort Duquesne Bridge. |
| 0.45 | 2.75 | Cross Point State Park and bear left onto entrance ramp to Fort Duquesne Bridge. Cross Allegheny River on Fort Duquesne Bridge and get into the right hand lane. Follow I-279 N. |
| 0.75 | 3.50 | Exit 13 to PA 28. Continue N on I-279. |
| 1.85 | 5.35 | Exit 16 to Hazlett Street. Continue N on I-279. Roadcuts on both sides of the highway are good illustrations of the state highway department's approach to reducing erosion of roadcuts by cutting numerous small terraces into sloping surfaces. We will see more of this technique at along I-279. The bedrock in these ranges from upper Glenshaw Formation to lower Casselman Formation, that is from the Upper Saltsburg sandstone at Suffolk Street across the highway from St. Boniface Church to the Birmingham shales and siltstones at the Bellevue exit and the Morgantown sandstone at the top of the vertical cuts from Camp Horne Road northward. This entire section is prone to instability. |
| 1.15 | 6.50 | Exit 18 to McKnight Road and Evergreen Road. Continue N on I-279. |
| 1.20 | 7.70 | Exit 19 to US 19 (Perrysville Avenue). Continue N on I-279. |
| 1.80 | 9.50 | Exit 20 to Bellevue and West View. Continue N on I-279. |
| 1.10 | 10.60 | Exit 21 to Camp Horne Road. Continue N on I-279. The commercial complex on the left containing a Giant Eagle grocery store and Home Depot hardware store is built on fill that sits on the Pittsburgh red beds. Notice the numerous small examples of landsliding that occurs in the vicinity. |
| 3.80 | 14.40 | The roadcut on the left extends approximately 0.3 mi. to the south, exposing a thick sequence of sandstone. A cursory look at this outcrop as you drive by appears to reveal a single sandstone unit. However, if you pull to the side of the road and spend some time studying the roadcut, you will see some distinct differences within the sandstone. The lower portion of the outcrop consists of thick-bedded, massive, gray sandstone, highly fractured in a nearly circular pattern, with mineralization stains along the fractures. The upper part of the outcrop consists of massive yellowish sandstone, very different from the lower part. Right around the bend from where the outcrop begins, a thin coal seam with underlying dark-colored shale splits the seemingly single sandstone unit into two discrete units. In stratigraphic terms,what you see is the |

Wellersburg coal and shale interval separating the underlying Birmingham sandstone from the overlying Morgantown sandstone.The coal and shale dis appear abruptly to the north beneath the Morgantown channel cut and fill.

| | | |
|---|---|---|
| 0.70 | 15.10 | Roadcuts on the left over the next 0.45 mi. expose thick sequences of lower and middle Casselman Formation sandstones that probably consist of combined Morgantown and Birmingham units. |
| 1.00 | 16.10 | Merge with traffic on I-79 N. Roadcut on right side of highway exposes a small, gentle anticline and syncline in the Clarksburg limestone and overlying Connellsville sandstone. The Clarksburg limestone here contains numerous nonmarine fossils, mostly ostracodes and worm tubes (*Spirorbis*). The folds seen here are not tectonic in origin. They represent draping caused by differential compaction of mudrocks and sandstone. |
| 1.40 | 17.50 | Exit 22 to PA 910 and Wexford. Continue N on I-279. |
| 0.70 | 18.20 | Roadcut on right and left exposes an excellent example of multiple (at least four) channel cut-and-fill sequences. |
| 2.80 | 21.00 | Exit 25 to US 19 and I-76 (the Pennsylvania Turnpike) at Cranberry. Continue N on I-279. |
| 1.00 | 22.00 | Entering Butler County. |
| 5.90 | 27.90 | Exit 26 to PA 228 in Evans City. Continue N on I-79. |
| 3.50 | 31.40 | Exit 27 to PA 68 in Zelienople. Continue N on I-79. |
| 9.10 | 40.50 | Exit 28 to Portersville and Prospect via PA 488. Continue N on I-79. |
| 3.10 | 43.60 | Exit 29 to US 422. Continue N on I-79. This is where you'd get off I-79 to go to either Moraine or McConnells Mills State Park. |
| 4.40 | 48.00 | Crossing the axis of the West Liberty esker. This esker is three miles long and probably represents the best remaining example of this type of glacial deposition in western Pennsylvania. Eskers are sinuous, ridge-like sand and gravel deposits formed during the melting of a glacier. The sinuous form marks the trace of a meltwater stream confined in the mass of the ice during the stagnation phase of glacial episodes. Although many people believe eskers form as a result of meltwater flow through an ice tunnel at the base of the glacier, the West Liberty esker most likely represents a meltwater channel deposit or crevasse filling on the surface of the ice. Crevasse eskers and tunnel eskers look very much alike. However, where tunnel eskers generally have smooth sinuous curves, much like typical stream channels, crevasse eskers tend to have long, straight, essentially parallel or subparallel segments separated by sharp, angular bends. Even the compositions of the two types of eskers offers a clue to the oigin of the West Liberty esker. A till blanket often covers the top of a tunnel esker with the resulting sand and gravel defining a pseudo-anticlinal aspect. Crevasse eskers have no such till blankets. They might have till flows incorporated within them as a result of supraglacial material flowing into the crevasse at the surface. Also, crevasse eskers commonly exhibit ice-contact faulting that developed as the glacier melted and let the sides of the deposit down. The West Liberty esker has all the earmarks of |

a crevasse esker: the shape consists of long straight segments separated by sharp bends (Figure 16); the entire deposit consists of glaciofluvial sand and gravel with no till blankets in evidence; and numerous ice-contact faults occur along the edges of the ridge.

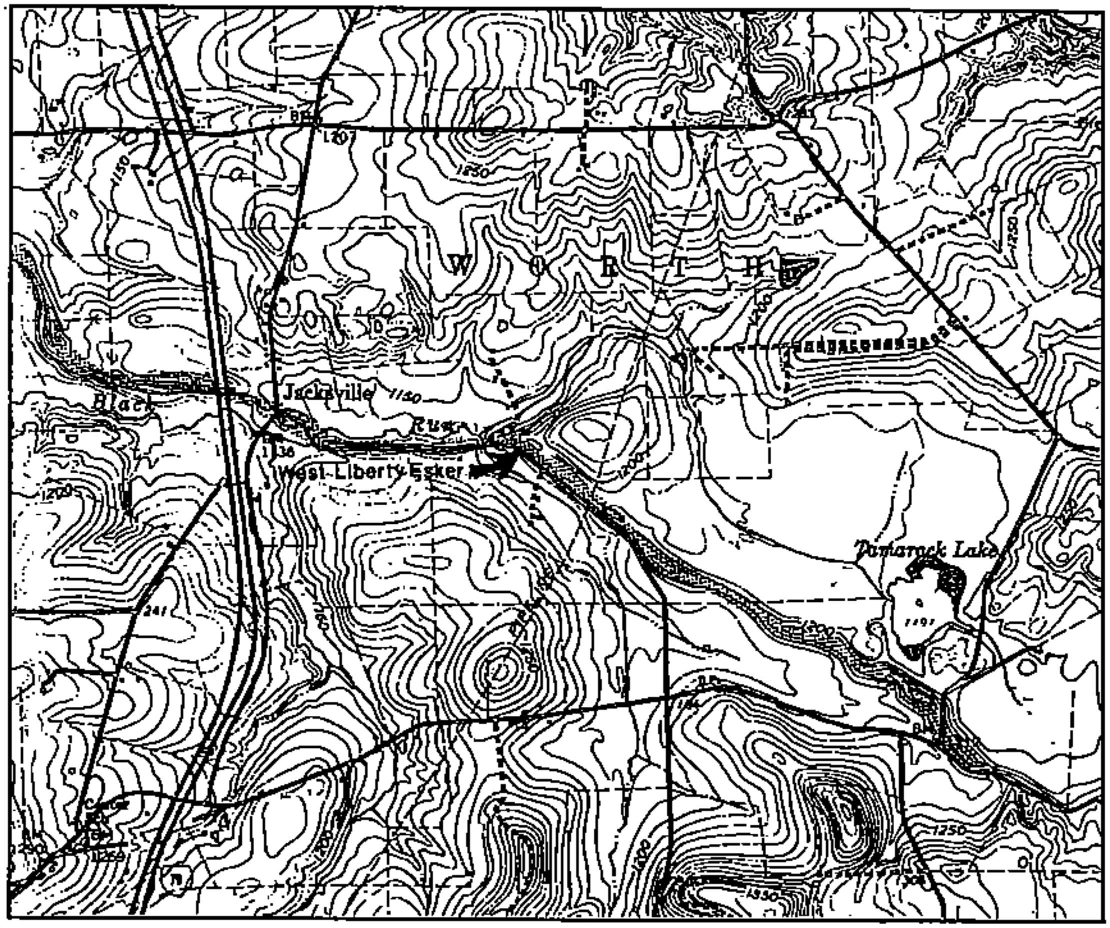

Figure 16. Location of the West Liberty esker on the Slippery Rock 7.5-minute topographic quadrangle (from Geyer and Bolles, 1979).

| | | |
|---|---|---|
| 1.50 | 49.50 | Exit 30 to PA 108 in Slippery Rock. Continue N on I-279. |
| 7.50 | 57.00 | Exit 31 to Grove City via PA 208. Continue N on I-79. |
| 3.85 | 60.85 | Bear right onto exit ramp to I-80 E. |
| 0.65 | 61.50 | Merge with traffic on I-80 E. |
| 4.30 | 65.80 | Exit 3A to PA 173 and Grove City. Continue E on I-80. |
| 4.95 | 70.75 | Bear right onto ramp at Exit 3 to Franklin and Butler at PA 8. |
| 0.30 | 71.05 | At the top of the ramp, turn left and head N on PA 8 toward Franklin and Oil City. |
| 5.15 | 76.20 | Exit to Pearl and Bullion via PA 308. Continue N on PA 8. |
| 1.20 | 77.40 | Outcrop of sandstone on both sides of highway. |
| 1.60 | 79.00 | Descending into the valley of Sandy Creek. |

0.70 79.70 **STOP 1: Outcrop of the Mercer Formation.**
Leader – Albert N. Ward, Jr.

This stop, as well as the next two, is situated along PA 8. Stay off the highway. It is extremely busy and dangerous.

This outcrop contains a wide variety of features. One of the first things of note is the extreme vertical and lateral variability of lithic units. Near the top of the outcrop on the east side of the roadcut is a sandstone unit with trough to planar cross beds dipping southward. The unit overlies a yellowish bleached zone which is probably a paleosol. The paleosol clearly outlines a small hill and valley beneath the overlying sandstone. Beneath the paleosol is a sequence of black carbonaceous shale containing at least one thin pyritic coal, sideritic nodules, and laterally discontinuous sandstone beds.

Exposures on the west side of the roadcut within the same lower interval reveal siderite nodule conglomerates in the base of small sandstone lenses.

A wide variety of sedimentary structures is associated with sandstones throughout the section. Look for flat-topped ripples, ripple cross-laminations, flaser bedding, and symmetrical and asymmetrical ripples. Bioturbation is common and is often well preserved in siderite nodules.

As one traces the Mercer Formation westward into Mercer County, the formation frequently contains thin marine shales and limestones. Over the years my students have found very questionable fragments of brachiopods in the shales. This year one of my students found a brachiopod preserved in a siderite nodule. Unfortunately, the nodule was not in place.

What environments are represented here?

I will attempt to put all of this together as we examine the outcrop. In that this is opening day of turkey season, I hope no one shoots me down with live ammunition.

Return to the vehicles and continue on to STOP 2.

0.85 80.55 Outcrop of the Connoquenessing sandstone to the right. Somewhere in the covered interval below the outcrop is the Mississippian/Pennsylvanian regional unconformity.

0.60 81.15 **STOP 2: Outcrop of the Upper Shenango Formation.**
Leader – Albert N. Ward, Jr.

This stop is situated along PA 8. Stay off the highway. It is extremely busy and dangerous.

At this site the Shenango Formation is 248 ft. thick and nearly completely exposed. The Lower Member of the Shenango Formation is very well exposed at Tionesta, Forest County, along PA 36 above the entrance to Tionesta Dam. At that location the Shenango is 165 ft. thick.

The Shenango Formation has been divided into upper and lower members (Figure 8). The Upper Member contains more mudstones and shales than the Lower Member. The Lower Member contains from one to four thick cyclic sequences of sandstones and shales. The two units are gradational and not sharply separated. The cycles persist into the Upper Member.

A typical cycle may begin with thin interbeds of mudstone, siltstone, and sandstone.

The lower beds may contain abundant productid brachiopods, sometimes constituting a near coquina. Sandy layers grade upward into siltstones and mudstones, bearing current ripple and ripple drift laminations; finely comminuted carbonized plant fragments are common in the silty layers. These beds grade upward into highly burrowed mudstones that have a mottled appearance. Many beds contain ichnofossils, brush, bounce and prod marks and striations. In turn, these beds may be overlain by fine-grained sandstones that contain shale pebbles, ironstone nodules, bone chips, and brachiopod fragments in the basal beds. These sandstone units typically exhibit trough cross stratification.

Dickey and others (1943) recognized three sandstone intervals constituting the lower Shenango. They referred to them as the "A", "B", and "C" (Carl) sandstones. Gamma ray logs, as well as measured sections, show the "B" interval to be at least two cycles of shale and sandstones. This is the situation at the Sandy Creek Section.

Pepper and others (1954) and Schiner and Kimmel (1972) have noted that the regional distribution of the Shenango, Corry and associated rock units is highly suggestive of deltaic sedimentation. The sandstone units appear to be portions of distributary channels, subaqueous levees, and distributary mouth bars. The siltstones, shales and mudstones may represent interdistributary bay, marsh, and minor prodelta or shelf deposits. Coleman and others (1964) indicate that ironstone nodules, plant fragments, and shell fragments occur together only in marsh environments associated with the Mississippi River delta distributary system.

Scour-and-fill structures with clay-chip inclusions are associated with distributary channel and subaqueous levee environments. This is much the same sequence as seen in outcrop at STOP 2. At this site prograding distributary channel and subaqueous levee sands have built out over marsh and interdistributary bay deposits.

Exposures of the Upper Shenango in the southbound lane of Route 8 (along Morrison Run) contain thin sandstone beds containing crinoids and bryozoans. This may well represent a more open bay than the units exposed at STOP 2. The crinoidal units are overlain by reddish shales and mudstones containing siderite nodules and plant fragments. A few inches below the Pottsville, a few sandstone beds contain exceptionally well-preserved plant remains.

Return to the vehicles and continue on to STOP 3.

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| 0.50 | 81.65 | Crossing Sandy Creek. The highway follows the valley of Morrison Run to the north and the valley of Victory Run to the south of Sandy Creek. Up the valley of Victory Run stand the remains of the old Victory iron furnace, built in 1843 by Andrew Bonner. Quantities of slag supposedly remain (Anonymous, 1988). |
| 0.30 | 81.95 | Lower Shenango distributary sandstones are exposed in the outcrop to the right. |
| 0.10 | 82.05 | Crossing Morrison Run. |
| 0.80 | 82.85 | Unconformable contact between the Pennsylvanian Connoquenessing Formation and the Mississippian Shenango Formation. The Sharon Formation is not present here. |
| 0.45 | 83.30 | **STOP 3: Outcrop of the upper Pottsville Group.**<br>Leader – Albert N. Ward, Jr. |

This stop is situated along PA 8. Stay off the highway. It is extremely busy and dangerous.

At this location one can trace a lateral sequence of facies changes within the Quakertown Member (Middle) of the Connoquenessing Formation (Figure 8). From south to north, facies grade laterally from coal swamp to natural levee to fluvial bars representing a river system that progressively shifted its channel to the north. The *en echelon* "bars" form lenticular deposits that interfinger with Mercer shales (in the east side of the road cut). On the west side of the road cut the lenticular units are truncated by tabular sandstone units of a totally different structural style. Could this be Homewood? Whatever the case, the exposures on opposite sides of the highway clearly illustrate how fast field relationships can change in these fluvial sequences.

Other features in this outcrop include crevasse splay sandstones riding across the swamp deposits, and a small fault (probably a slump block) cutting through the shales and coal of the Quakertown.

Return to the vehicles and continue on to STOP 4.

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| 2.20 | 85.50 | Traffic light at Pone Lane. Franklin Area Middle School and High School are to the right. |
| 0.15 | 85.65 | Entering historic Franklin. Venango Regional Airport to the left (W) The ridge we are traversing is capped by Mapledale (pre-Illinoian) glacial tills. Franklin is the Venango County seat. It started as a series of posts and forts during the late 18th century and quickly became a strategic point during the French and Indian War and the Revolutionary War. Under the French, Fort Machault stood from 1756 to 1759 when the British drove them from western Pennsylvania. The British outpost was called Fort Venango. It was burned by the Indians during Pontiac's War, and the land reverted to the Indians for more than 10 years. In 1787 Fort Franklin was built on the south bank of French Creek. Today, historical markers are all that is left of these three forts. Franklin finally became a full-fledged community in 1795, five years before the county became a political entity. With the discovery of oil, Franklin prospered. It was chartered as a city in 1868 and became home to many of the world's wealthiest oil barons of the mid- to late-1800s. |
| 0.65 | 86.30 | Intersection with US 62. Continue N on PA 8 and US 62. |
| 1.00 | 87.30 | Notice the rich variety of architecture as we travel through town. Franklin was the home of some of the world's wealthiest oilmen during the last century. Many of the private houses have been converted to apartments, inns, funeral homes, etc. |
| 0.25 | 87.55 | Turn right (E) and continue on PA 8/US62 through the heart of Franklin. Many of the buildings exhibit a Victorian architectural style. |
| 0.25 | 87.80 | Intersection with US 322 and PA 417. Continue straight (E) on PA 8, US 62, and US 322. Notice the business district. The character is late 1800s, complete with old style street lamps. Many people consider Franklin to be a good example of Americana from the turn of the 20th century. |
| 0.20 | 88.00 | The Venango County Courthouse on the left was built in 1868-69 as a result of the influx of oilmen, speculators, attorneys, etc. who came to this area |

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| | | during the early years of the oil boom. The old courthouse simply wasn't big enough to handle the traffic. Sloan and Hutton, a Philadelphia architectural firm, drew up the plans. In 1932 an addition was added to the rear of the courthouse to help alleviate crowding. In the park you can see the Dr. A. G. Egbert Memorial Fountain. Dr. Egbert was one of the oil pioneers at Petroleum Centre (now Oil Creek State Park). |
| 0.25 | 88.25 | Turn left and continue N on PA 8/US 62. |
| 0.15 | 88.40 | Crossing French Creek. The rounded mountain ahead and to the left is Point Hill, a remnant of the pre-glacial landscape. The "Middle Allegheny" River flowed around the N side of this remnant, then flowed NW into the Erie basin approximately along the trend of present day French Creek. To the north, the Franklin suburb of Rocky Grove occupies a terrace that once was the bottom of the "Middle Allegheny" River. |
| 1.90 | 90.30 | Crossing Two Mile Run. |
| 0.60 | 90.90 | Tionesta Sand and Gravel Co. quarry across the Allegheny River to the S. This quarry is developed on Wisconsinan glaciofluvial deposits. The land is part of the old River Ridge Farm that was built in 1913 by Joseph Crocker Sibley. Sibley was president of Signal Oil Works and later a state legislator. |
| 1.20 | 92.10 | The buildings on the left mask the old entrance to the now defunct Reno Gravel Pit. The quarried material here was Wisconsinan glaciofluvial deposits at an elevation about 120 feet above the Allegheny River. |
| 0.60 | 92.70 | Wolf's Head motor oil packaging plant to the right. Originally the Empire Oil Works, the company merged with Wolverine Lubricants Company in 1929 and later changed the name to Wolf's Head Oil Refining Company. Wolf's Head became a subsidiary of Pennzoil in the 1960s. This plant used to refine oil, but that is now done at Pennzoil's refinery in Rouseville. |
| 1.00 | 93.70 | Oil City's wastewater treatment plant across the Allegheny River (S) marks the Oil City terminus of the Samuel Justus Trail, one of Venango County's well developed rail trails. |
| 1.30 | 95.00 | Crossing Charley Run. |
| 0.30 | 95.30 | Entering historic Oil City, incorporated in 1862. The land now occupied by downtown Oil City had been granted to Cornplanter, chief of the Seneca Indian Nation, in 1796 for services rendered during the Revolutionary War. He sold the land in 1818 to William connelly and William Kinnear. A few years later, the Oil City iron furnace was built at the site of the present day Holiday Inn, and this became the focus of a small community that grew at the mouth of Oil Creek. Even though river traffic kept the town from becoming defunct after the demise of Venango County's iron industry, it was not until the discovery of oil that the town of Oil City as we know it came into existence. It took a series of floods and fires wiping out all the old shanties and derelict buildings before the townspeople got serious about building a permanent city. |
| 0.50 | 95.80 | Intersection with US 62 and PA 428. Continue N on PA 8. |
| 0.30 | 96.10 | Intersection with Business Route 8 at traffic light. Continue straight on PA 8. The Corry Sandstone crops out on the left at or just above highway level from here to the north end of the city. It is a major marker horizon in this area. It dips about 25 ft./mi. to the SW. |

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| 0.70 | 96.80 | Intersection with Business PA 8 at the stop sign. Continue N on PA 8. |
| 0.70 | 97.50 | One of two Pennzoil refineries in his area (the other is to the north in Rouseville) straddles PA 8. The original refinery belonged to Penn Refining Company which built a 250 barrel/day plant in 1886. |
| 0.85 | 98.35 | Notice the historical marker on the left (W). This commemorates the McClintock well, the world's oldest producing oil well. We will stop and take a look at it in more detail on the return trip see STOP 7). |
| 0.15 | 98.50 | Crossing Oil Creek |
| 0.05 | 98.55 | Entering Rouseville, founded in 1798. Rouseville was named for Henry R. Rouse, a teacher, lumberman, merchant, and honorable member of the state House of Representative from Warren County. Rouse and some partners had a lease on the John Buchanan farm near the lower end of Oil Creek and, in 1860, had drilled a well 160 feet deep. It wasn't a particularly successful well, so they sublet the location to another group who drilled the well deeper in 1861. During drilling the well bore encountered not only a large flow of oil, but a huge pocket of natural gas as well. Under this natural gas drive, the well began flowing at the enormous rate of about 3,000 barrels per day. Unfortunately, it didn't take long for the gas to ignite, setting off an explosion and a tremendous fire. Henry Rouse was one of the spectators who was standing nearby when the well caught fire. In an instant, an acre of ground with two oil wells, their stock tanks, a barn, and a large number of barrels filled with oil were ablaze. The spectators who had stood nearby to look at the gusher were, unfortunately, also part of the conflagration. The gushing oil had soaked their clothing and their skin, and it ignited in a flash. Henry Rouse had been standing not more than 20 feet from the well. He managed to escape the flames, but was so badly burned there was no way he would survive. He was taken to a nearby shanty where he gasped through five hours of excruciating agony before death finally gave him relief. His body from the top of his head down the back and legs to the knees had been burned to a crisp. Despite his injuries, however, he managed to spend his last hours dictating his will before he finally succumbed. He bequeathd most of his considerable fortune to the Commissioners of Warren County, where he lived, to support the poor and improve the roads. The "Rouse fire", as it came to be known, was the earliest, and one of the greatest, of the oil-well fires in the oil region. It lasted three days before it finally was smothered with earth and manure. All in all, 19 men died and 17 were injured, of which eight had been either maimed or badly disfigured. |
| 0.40 | 98.95 | Pennzoil's Rouseville refinery on the left refines Penn Grade crude oil under several different names. |
| 0.25 | 99.20 | Intersection with PA 227 in beautiful downtown Rouseville. Continue N on PA 8. |
| 0.65 | 99.85 | Crossing the Oil City and Titusville Railroad tracks. |
| 0.25 | 100.10 | Entrance to the Oil City and Titusville Railroad down the road to the right (E). |
| 0.05 | 100.15 | Crossing Cherry Run. |

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| 0.05 | 100.20 | Main entrance to Oil Creek State Park on the right (E). We will visit this area on our return trip. |
| 0.15 | 100.35 | Crossing Cherrytree Run. |
| 1.20 | 101.55 | Entering Kaneville. |
| 2.15 | 103.70 | Entering Cherrytree. |
| 0.35 | 104.05 | Intersection with PA 417 to Dempseytown and Franklin. Continue N on PA 8. |
| 1.35 | 105.40 | Road to the right is a back way into Oil Creek State Park. |
| 1.40 | 106.80 | Cross Creek Resort on the left. |
| 0.70 | 107.50 | Medina (Lower Silurian) gas well in the field on the right (E). The large tank is for holding produced brines. The tall missile-shaped tank is called a separator, used to separate the gas from the liquids in the well. |
| 2.05 | 109.55 | **STOP 4: Type locality of the Titusville Till.**<br>Leader – John A. Harper |

The grassy slope here is the type section of Titusville Till. Much of it has been covered up and planted, but there are a few odd and sundry places where we can look at the deposit. This will be a quick stop (approximately 15 minutes).

Droste and Tharin (1958) first measured and described this type section in order to examine the sequence of alteration of clay minerals in the till. White and others (1969, p. 23) later republished the section, describing it as "a fresh cut in an excavation for relocation of Pennsylvania Highway 8, 1.6 miles south of the post office in Titusville and 1.2 miles southwest of the Drake Oil Well". Table 3 illustrates the section. Droste and Tharin (1958) and Shepps and others (1959) referred to this till as "inner Illinoian". As explained on in the section on the Titusville Till, based on carbon-14 dates of wood that had nothing to do with the Titusville Till, it was erroneously considered to be Middle Wisconsinan, and later yet, earliest Late Wisconsinan in age. However, evidence that Wisconsinan ice sheets did not push south of the Great Lakes until about 30,000 yr. BP strongly suggests the Titusville is, as originally thought, Illinoian.

At this stop we should be able to observe the olive brown to olive-gray color of the Titusville Till. The color makes it reasonably easy to distinguish from the more reddish brown, highly weathered Mapledale Till. Other differences between the Titusville and Mapledale Tills include the texture and mineral composition summarized in Table 2. The Titusville Till at this locality is underlain by gravel deposits, and the till itself is made up of several "till sheets" separated by layers of silt or sand and gravel. These intervening layers are typical of the Titusville Till. The interpretation made by White and others (1969) is that each silt, sand or gravel layer separates deposits from a different Titusville advance. Unfortunately, we will not be able to see any of this.

Also of interest is the black manganese staining commonly found in the till matrix and coating some pebbles in the Titusville Till. This phenomenon is not observed in Mapledale deposits.

Return to the vehicles and continue on to STOP 5.

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| 0.30 | 109.85 | Old gravel quarry on the right, now used as a dump and rusting vehicle storage area. The gravels quarried here are probably part of a kame terrace. |

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| 0.65 | 110.50 | Entering Crawford County and historic Titusville. Titusville is perhaps best known for its oil heritage. However, it is also the hometown of one John Heisman of Heisman Trophy fame. Heisman began his long and illustrious career in football right here at Titusville High School in 1887. |
| 0.15 | 110.65 | The historical marker on the right commemorates the Roberts Torpedo. Lieutenant Colonel E. A. L. Roberts had served with the 28th New Jersey Volunteers during the Civil War. There he conceived of the idea of opening up crevices in oil-bearing rock by exploding an elongated shell, or torpedo, inside the well bore. Col. Roberts resigned his commission in 1864, went home to New York City, and, in November of that year, filed an application for, and received a patent to use his torpedo as a means of increasing the production of oil wells. About 3/4 of all the oil wells drilled in those days were dry holes or under-productive, typically because of low porosity and/or permeability in the reservoir rock. The torpedo, consisting of a cylindrical tube four feet long and approximately the width of the oil well bore hole, was filled with gunpowder and lowered by a wire into the well to any desired point. It was exploded by percussion, induced by an iron weight (called a "follower"), that is sent down the wire after the torpedo is lowered. The explosion opened fractures into the reservoir rock, thus increasing both the porosity and permeability. When he took his device to Titusville, Roberts met a great deal of resistance from local oilmen until he proved his invention worked. In January, 1865, Colonel Roberts made the first public experiment with the use of an 8 lb. torpedo in the "Ladies' Well" on Watson Flats below Titusville. The well had stopped flowing because paraffin was clogging the well bore. Roberts lowered the torpedo to a depth of 463 ftt., and exploded it. The well flowed paraffin, oil, and water for 10 or 15 minutes, proving to the onlookers that the tool was successful in greatly increasing the production of the well. This, of course, created intense interest in the torpedo throughout the oil regions. It didn't take long for the copycats to get involved. Many infringements were made upon Roberts' patent and he became involved in a long series of lawsuits. Many of those sued contended that they had invented the idea of using the torpedo in an oil well. In August, 1866, the US Patent Office resolved the dispute by giving Roberts sole claim to the invention because he was the only one who could show undisputed evidence that he had carried out the method in practice and, as a result, had obtained practical results. |
| 0.25 | 110.90 | Turn right at the stoplight onto Bloss Street. |
| 0.90 | 111.80 | Entering Venango County. |
| 0.20 | 112.00 | Cross Oil Creek. |
| 0.05 | 112.05 | Turn right and enter DrakeWell Memorial Park. |
| 0.15 | 112.20 | Park vehicles in the parking lot and walk up the foot path toward the Drake Well railroad station. |

## STOP 5: Outcrop of the "Drake Well formation".

Leader – John A. Harper

The bedrock exposed across the Oil City and Titusville Railroad tracks from the Drake Well train station at Drake Well Memorial Park can be traced over large areas in the subsurface, but it has never been satisfactorily identified. The names Corry Sandstone and Cussewago Sandstone commonly are used, but as will be shown below, neither name adequately fits the rocks.

For the purposes of this guidebook, I am calling this the "Drake Well formation," and defining it as the sequence of Upper Devonian sandstones and shales occupying the stratigraphic position between the Tidioute Shale and the Riceville Formation (Figure 17).

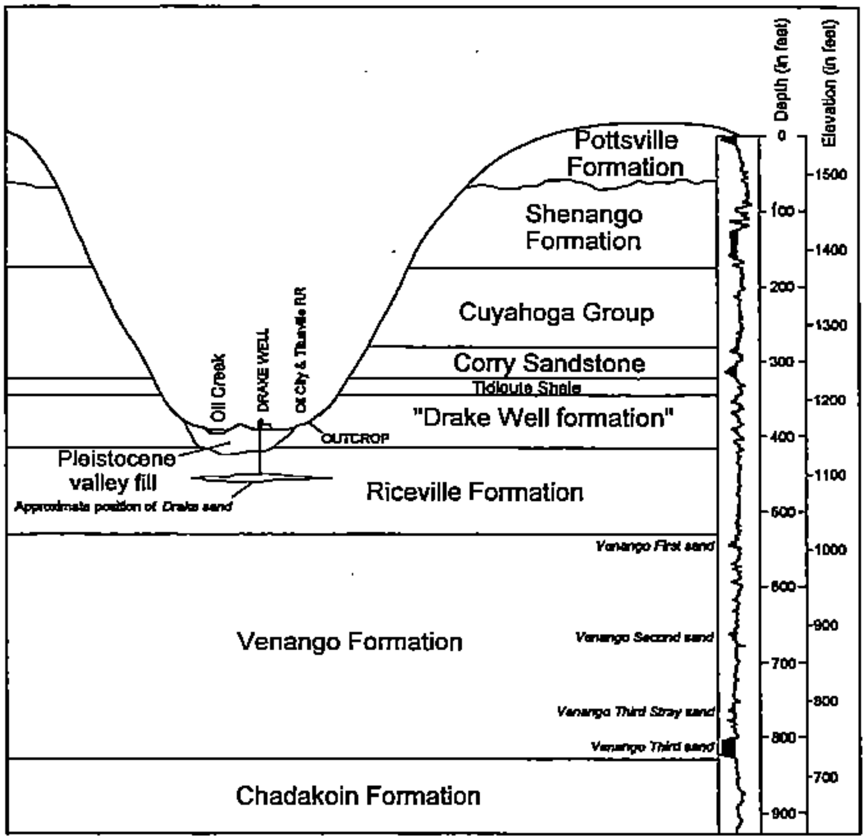

Figure 17. Portion of the gamma ray log of the #2 Kinley well on the hill just east of the Drake Well showing correlation of the outcrop at Drake Well Memorial Park with the "Drake Well formation" (from Harper, 1998d).

The exact geographic expanse of the "Drake Well formation" is uncertain at this time, although it should be easy to determine from geophysical logs and outcrops. Based on cross sections A-A' and B-B' (Figure 18), it is limited to the eastern third of Crawford County, the northern half of Venango County, and the western half of Warren County. I am uncertain of its northern limit. I am using the name Tidioute Shale for the shale section between the Corry Sandstone and "Drake Well formation" because the definition of the Bedford and Hayfield shales doesn't fit the stratigraphy. The Tidioute was named by Caster (1934, p. 117) for several excellent exposures of fossiliferous shale between the overlying Corry Sandstone and the underlying "Cobham or Cussewango [sic] sandstone" in the vicinity of Tidioute, Warren County. The combined Tidioute Shale and "Drake Well formation" grade laterally into the Knapp Formation in eastern Warren County and into the upper part of the Riceville Formation in Crawford County. Based on Figure 18, one could argue that the combined Tidioute Shale and "Drake Well formation" grade southward into the "Oswayo Formation" and Hundred-Foot sand of the Venango Group. At this writing, however, it seems expedient to limit them to the area north of the development of the Cussewago Sandstone/Murrysville sand.

In outcrop along the Oil City and Titusville Railroad tracks at the Drake Well station (the

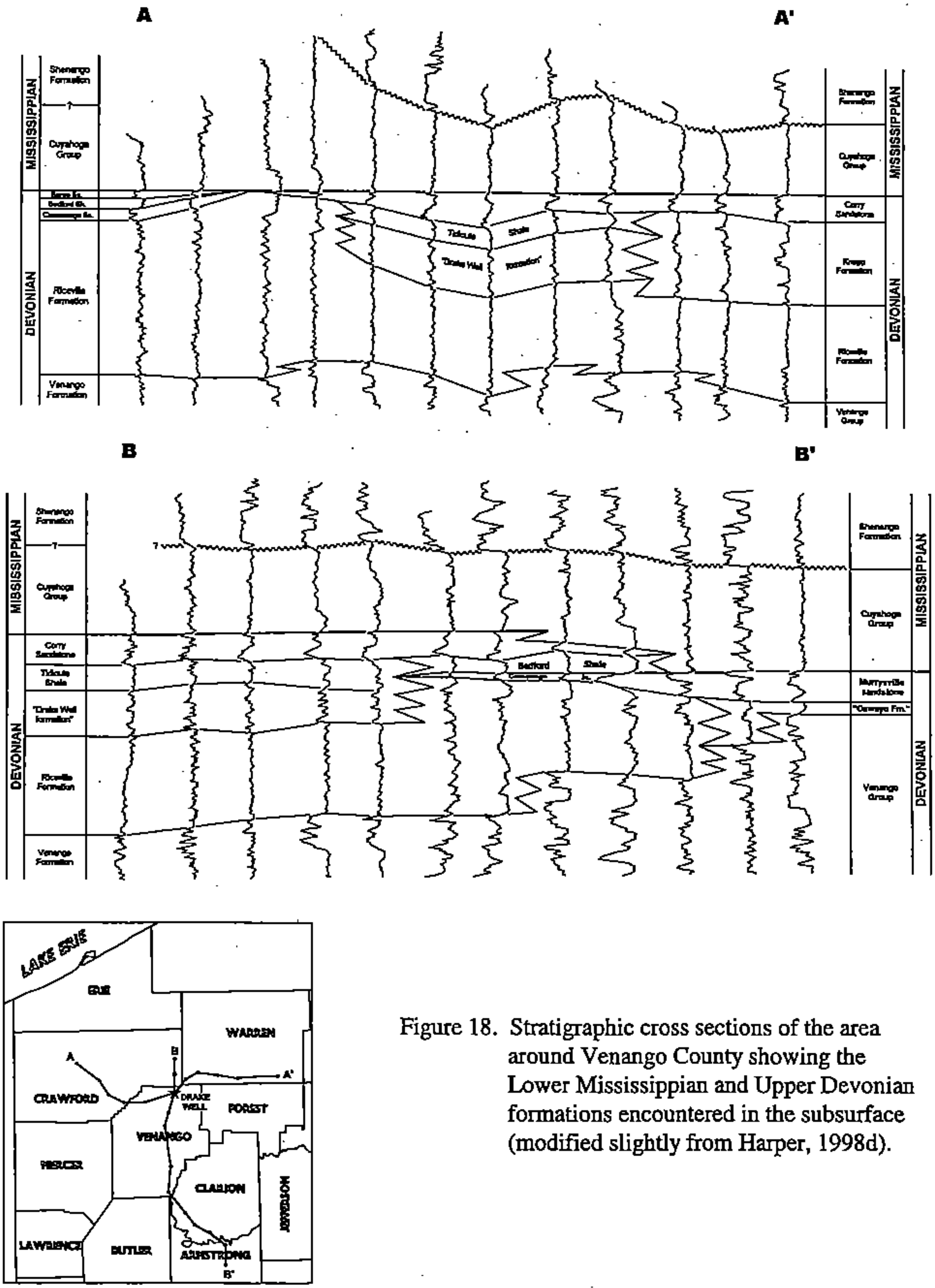

Figure 18. Stratigraphic cross sections of the area around Venango County showing the Lower Mississippian and Upper Devonian formations encountered in the subsurface (modified slightly from Harper, 1998d).

"type locality") (Figures 17 and 19), the "Drake Well formation" consists of about 14 ft. of sandstone with a few thin interbedded dark gray shales and fissile siltstones, underlain by about 10 ft. of darker colored mudrocks. The entire formation is actually about 60 ft. thick in the vicinity of the Drake Well (Figure 17).

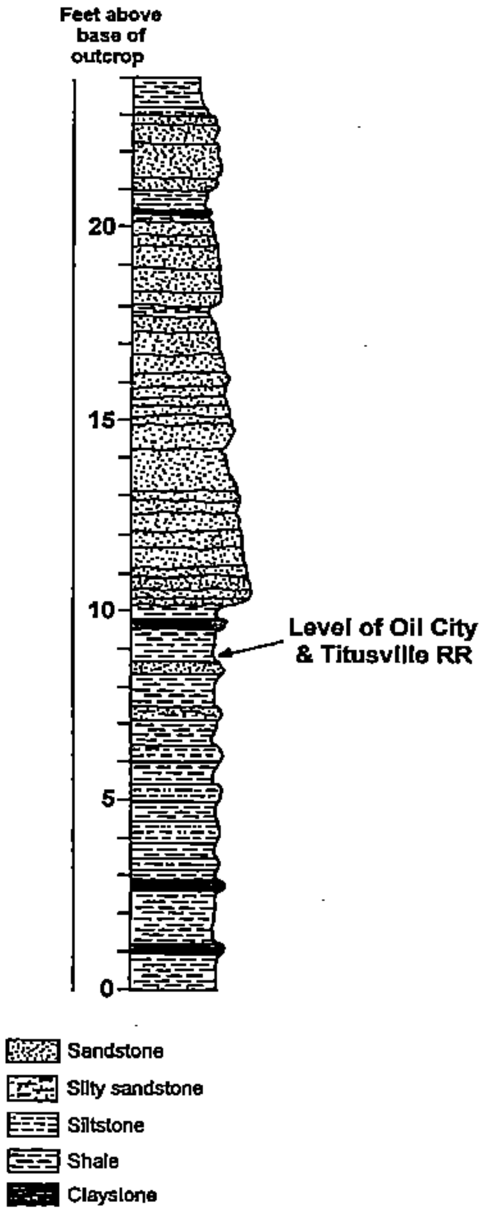

Figure 19. Lithology of the "Drake Well formation" exposed at Drake Well Memorial Park. From Harper, 1989d as modified from Burgchardt and Fox (1989), and based on work by Assad Panah and students, University of Pittsburgh at Bradford.

The upper sandy unit consists of light gray to white, fine- to very fine-grained, thin bedded to flaggy sandstone. Upon weathering, some of the sandstones turn a soft yellowish gray or olive gray, probably as a result of oxidation of iron in the matrix. The sandstones contain a variety of mineral, sedimentological, and biological constituents. Calcite cement, mica, and hematite stains, especially coating the fossil molds, are abundant. Less common are marcasite nodules. Some of the sandstone beds exhibit tabular to trough cross-bedding, and common sedimentary structures include hummocky cross stratification, symmetrical and asymmetric ripples, small-current ripples, Runzelmarken (wrinkle marks), groove, bounce, prod, and brush casts and striations, and other sole markings. Body fossils of the normally rare siliceous sponge *Titusvillia drakei* Caster occur here, along with more common brachiopods (*Lingula*, and external molds of *Rugosochonetes*, *Shumardella*, and *Cyrtospirifer*), gastropods (*Bellerophon* and *Euomphalus*), bivalves (*Parallelodon* and *Leiopteria*), and scattered crinoid columnals (Figure 20). Trace fossils observed at the site include *Bifungites*, *Palaeodictyon*, *Monocraterion*, *Palaeophycus*, *Pelecypodichnus*, *Phoebichnus*, *Planolites*, and numerous, tiny, undetermined forms. Only a few isolated pieces of plant fossil debris were found.

The shale section below the sandstones consists of dark reddish-brown, greenish-gray, and dark gray shales interbedded with similarly colored, fissile and micaceous siltstones and a few layers of claystone. Some of the siltstones contain body fossils, especially near the top of the shale/siltstone sequence, but as a whole the section contains mainly trace fossils. In appearance, it isn't much different from the Riceville Formation in this area. The Riceville tends to be more reddish, especially in the lower part (Dickey, 1941).

The sequence is easily recognized in the subsurface. As Dickey (1941, p. 6) pointed out, "It is not possible to correlate the individual sandstone beds from drill cuttings throughout the Titusville quadrangle. However, electric logs of several wells show that there are three prominent sandstone beds which are widespread in the southern part of the quadrangle." Actually, four sandstones appear in the "type" log (Figure 17), but the number varies from location to location. This suggests the sandstones are lenticular, and perhaps imbricate, rather than tabular.

Dodge (1992) thought the "Drake Well formation" would represent the offshore or lower shoreface deposits seaward of the Knapp barrier bar/beach system. Although the hummocky cross stratification, a result of storm activity, could occur in water below normal wave base, the wave ripples and small-current ripples probably represent the littoral environment. Likewise, the abundance of marine fossils in many beds suggests a beach or littoral environment. In contrast, the brachiopod *Lingula* generally indicates shallow water, often more brackish conditions, which might suggest an estuary or restricted lagoon. The majority of the iron-stained shells of the brachiopod *Rugosochonetes* lying in various orientations and mixed with crinoid columnals indicates a mixed assemblage of current or wave scattered shells. Beds of fragmented *Lingula* shells, typically intermixed with true marine fossils, such as crinoid columnals, probably indicate storm debris or a high-energy swash zone. The general rarity of plant fossils and debris suggest the formation was deposited relatively far from a source of continental influx. Runzelmarken are known to occur where the bottom is intermittently emergent. Delicate tool marks such as brush and prod casts, however, suggest preservation in water deep enough not to be disturbed by waves. Orientations of these tool marks at several angles to each other indicate the currents changed regularly. These various sedimentary features suggest the "Drake Well formation" was deposited in a variety of marine and transitional environments from possible beach (supratidal) to below wave base (subtidal). A more thorough study of the formation, here and at outcrops along the Allegheny River in Forest and Warren Counties, should provide more information.

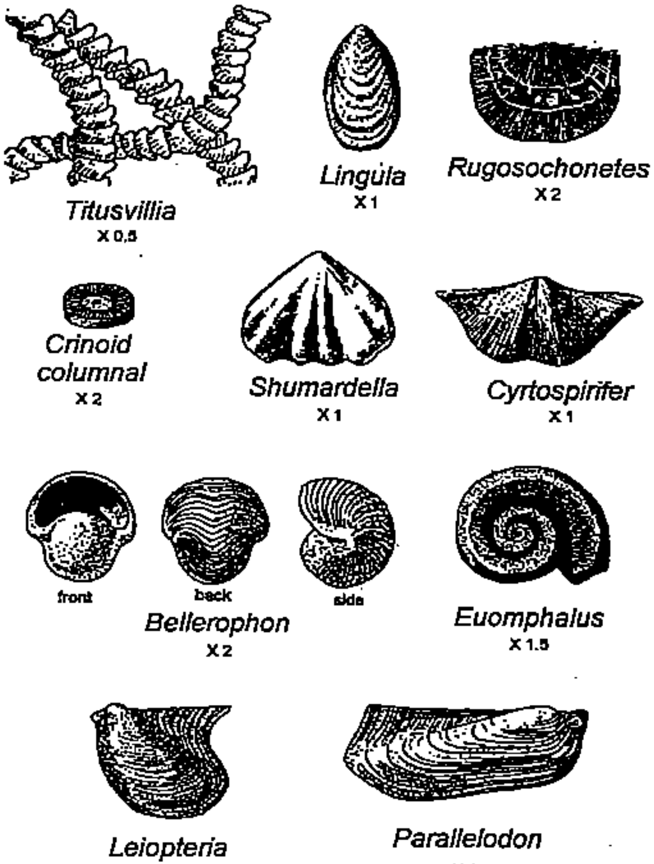

Figure 20. Illustrations of the more common fossils that have been found at the Drake Well locality (modified from Hoskins and others, 1983). Sketches are not to scale.

Return to the vehicles and continue on to STOP 6.

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| 1.30 | 113.50 | Return to PA 8 and turn left (S) toward Oil City. |
| 10.65 | 124.15 | Turn left (E) into Oil Creek State Park. |
| 0.60 | 124.75 | Blood Farm on right (S). |
| 0.20 | 124.95 | Oil Creek Dam, part of the US Army Corps of Engineers Oil Creek Ice Control Project. |
| 0.50 | 125.45 | The bridge over Oil Creek to the right (S) carries the Oil City and Titusville Railroad. |
| 0.40 | 125.85 | Columbia Farm on the right. |
| 0.75 | 126.60 | Scenic view on right of the Oil Creek State Park office at Petroleum Centre. |
| 0.35 | 126.95 | Entering Petroleum Centre. Notice the beaver dam and lodge in the valley to the left. The valley is a cut-off meander of ancient, pre-glacial Oil Creek called Wildcat Hollow. The prominent hill directly in front is a hogback, a half-moon shaped remnant left behind when Oil Creek cut its current channel. |
| 0.10 | 127.05 | Cross the Oil Creek and Titusville Railroad tracks. |
| 0.05 | 127.10 | Petroleum Centre railroad station ahead of us and to the left (W). |
| 0.10 | 127.20 | Crossing Oil Creek on one-lane bridge. |
| 0.10 | 127.30 | Turn right into the parking lot opposite the Oil Creek State Park office and drive to the rear of the lot, adjacent to the large pavilion. Park the vehicles. From here we will walk across the field and up the road about 100 yards. |

### STOP 6: The Great Petroleum Shaft.

Leader – John A. Harper

In 1865, a group of oilmen formed The Petroleum Shaft and Mining Company to dig to the main producing reservoir on Oil Creek, the Venango Third sandstone. The Great Petroleum Shaft, 12 by 17 ft, was planned to go straight down into the earth 500 feet "for investigating purposes". The backers of the project wanted to see with their own eyes the nature of the strata underneath that was pouring out oil and gas with such profusion almost every time a well was drilled. They hoped "to prove that oil exists in regular veins; the extent and direction of same". The site chosen was 20 rods from the Jersey well, a 300 barrel well that "came in" in 1864, and the same distance from the Maple Shade well, a 900 barrel producer in 1861. It was 40 rods from the Coquette well, which flowed 800 barrels a day.

The shaft was sunk 30 feet in the first two weeks of work in July, 1865 by the 14 hands employed, mostly Welsh coal miners from the anthracite regions of eastern Pennsylvania. The director of the work had also had mining experience in Schuylkill County. He counted on using a windlass to remove debris for the first 100 feet unless water interferred. After that depth was reached, machinery for hoisting, pumping and ventilating would be installed, the pump engine of 90 HP. and the hoisting and ventilating engines of 50 HP each. They estimated it would take 12 months to complete the shaft.

The work went on night and day. They constructed a surface installation for the hoisting machinery and other equipment from local Pottsville sandstone. In September, 1865, the shaft was 73 feet deep, according to D. W. Davies, engineer and superintendent. Work was suspended pending the arrival of the machinery mentioned above. The cost of transporting the machinery from Schuylkill County was figured at $1,500.

What happened next is not clear to historians of today. However, the experiment was never completed. The shaft was eventually filled in to a level of about 20 ft, and the masonry and shaft can still be seen today in the woods a few dozen ft south of the Petroleum Center-Plumer road. These remains stand as mute witness to what one wag called "the absurd undertaking."

Return to the vehicles and continue on to STOP 7.

| | | |
|---|---|---|
| 0.35 | 127.65 | Exit the parking lot and turn left (W) onto the main park road. |
| 0.10 | 127.75 | Turn right on Petroleum Centre Road just before the bridge. Be aware that this road carries a heavy load of walkers and bikers. Maintain the 15 mph speed limit. |
| 0.45 | 128.20 | Oil Creek bike trail enters from the left. Just beyond this bike trail entrance is a large pond. There is a beaver lodge on the opposite shore and lots of evidence of beaver activity on the near shore. |
| 0.50 | 128.70 | Park in the clear area on the left side of the road. We will walk down the adjacent rutted dirt road. Beware of rough terrain and water-filled potholes. |

### STOP 7: Abandoned quarry in a kame deposit.

Leader – John A. Harper

During the Ice Age, when continental ice sheets covered parts of North America, the glaciers moved southward across northwestern Pennsylvania, including Oil Creek State Park, to as far as the Allegheny River. The moving ice scraped up rock from the wherever it touched, grinding it down to sand and gravel. This debris was left scattered over broad areas of the park. Both till and glaciofluvial debris occur in the park. Till, the material left behind as the ice melts, has no distinct layering. Glaciofluvial debris, or outwash, is glacial material deposited in layers or beds, usually by quick-flowing glacial meltwaters. As such, it has stratification and structure, much like any other water-deposited sedimentary facies.

At STOP 7, there are two or three pits that were once quarried for sand and gravel for construction material. These pits contain about 50 feet of sand and gravel held together by carbonate cement, giving the rock the look and feel of poorly made concrete that was just dumped in layers on the ground. The sand and gravel form a *kame terrace,* a mound of stratified sand and gravel left by meltwater streams flowing between the glacier and the valley wall of Oil Creek gorge. This glaciofluvial deposit exhibits cross bedding due to the formation and movement of underwater dunes. There are several things to examine and think about here.

1. Can you determine the age of this kame deposit? Hint: examine the gravel to see what degree of weathering has taken place. Also, if you happen to have a Munsell color chart handy, check it against the color of the weathered gravels. Then compare it to the descriptions of the tills in the front of this guidebook. Of course, since this is glaciofluvial debris, rather than till, the descriptions might not match.
1. Take a few moments to examine the gravel. See if you can get a feel for its basic composition. What percentage of the kame is sandstone, siltstone, or limestone that might be locally derived? Do you see any granitic or gneissic components?

Return to the vehicles and continue on to STOP 8.

|  |  |  |
|---|---|---|
| 1.00 | 129.70 | Turn right onto the bridge and retrace route to PA 8. |
| 3.15 | 132.85 | Turn left (S) onto PA 8 and head toward Oil City. |
| 0.40 | 133.25 | John W. Steele, popularly known as "Coal Oil Johnny," lived just across Oil Creek from here. Steele's claim to fame came from the stories of his prodigal years when he was an inexperienced youth. He came into his fortune fairly early in life and fell victim to the gamblers and other ne'er-do-wells that infested the Oil Regions at the time. Many of the stories told about him were magnified and distorted, and the vast majority are completely devoid of fact. Steele was born in Venango County around 1841. Between the ages of seven and eight years old he was adopted and became the legal heir of Culbertson McClintock, a well-to-do farmer living on Oil Creek near Rouseville. He obtained a common school education and grew up on the McClintock farm. Culbertson McClintock died several years prior to discovery of oil on his farm. The first well on the farm was in March, 1860. Other wells followed at different periods, all of them profitable. At that time, Steele worked as a teamster, hauling oil and materials for the oil wells. The Widow McClintock died in 1863 and Steele inherited most of the estate. The seemingly endless fortune that flowed from the wells on the farm captured the imagination of the impressionable young man, and he was not the only one. He found plenty of others willingto help him spend his inheritance. He fell in with scoundrels and rogues who were quick to take advantage of his naiveté. One of these, Seth Slocum, had particular influence over Steele until his money was gone. His so-called friends robbed him blind in a mere twelve months. When his money, which many wrongly thought amounted to millions of dollars (it was probably closer to $500 thousand), was all gone, he returned to the Oil Creek valley and worked as a baggage agent of the Oil Creek Railroad at Rouseville. There he tried desperately to redeem his reputation. He succeeded admirably, but the wild stories of his earlier years continued to haunt him, thanks to newspaper reports who had nothing better to do than make up wild stories about him. He finally had to abandon the life he knew in the valley and move to Iowa and, eventually, Nebraska. "Coal Oil Johnny's" house still stands today, a ramshackle building on Weitz Road. On a good day (when there are no leaves on the trees), you can see it from here. |
| 0.60 | 133.85 | Intersection with PA 227 in beautiful downtown Rouseville. Continue S on PA 8. |
| 0.60 | 134.45 | Cross Oil Creek |
| 0.15 | 134.60 | Turn right into the parking lot of the abandoned building, and follow Waitze Road over the railroad tracks. |
| 0.05 | 134.65 | Turn right immediately after crossing the tracks. Park the vehicles. |

## STOP 8: The McClintock #1 oil well.

Leader – John A. Harper

The McClintock #1well was drilled in August, 1861 on the farm of Hamilton McClintock and is still producing oil today from the Venango Second and Venango Third sand reservoirs

(Figure 10) in the Oil City-Rouseville oil field. This makes it the oldest producing well in the United States, if not the world. In all, about 60 wells were drilled on this property.

The Venango Third sand typically is pebbly, with the pebbles more abundant in the upper part of the reservoir. The permeability is extremely variable, ranging from several darcies in the pebble beds in the northern part of the pool to an average of less than one millidarcy in the finer grained sandstone. The permeability, porosity, and oil content, as a rule, decrease as the thickness decreases.

The Venango Third sand in this field is characterized by multiple bars or "streaks", as it is in the Titusville area. Productive belts ranging from 500 to 2, 000 ft in width, trend north or northeast, separated by relatively barren belts of approximately the same width. Third sand oil is dark green, and has an API gravity of 42° to 47° (as determined by the Hempel method). Since 1930 parts of the pool have been repressured with air.

The Second Venango sand is also productive in this field. It covers a larger area than the Third sand. Most drilling before 1880 was in the hope of finding large Third sand wells, and the Second sand was not generally developed until the late 1880s. The Second sand is 20 to 35 ft thick, and is generally medium- to coarse-grained with a conglomeratic bed either at the top of the sand body or in the middle. It has porosities between 15 and 20 percent, permeabilities ranging up to 600 millidarcies, and oil saturations between 15 and 30%. Initial productions typically ranged between 5 and 50 barrels per day, but some of the early wells had much higher initial productions. Much of the reservoir has been operated under air drives.

The Colonel, Inc., a non-profit group interested in oil history, acquired the McClintock well from Quaker State in August, 1998. The Colonel, Inc. will act as an interim holding company until the state legislature enacts legislation deeding ownership to the Commonwealth of Pennsylvania. At that time, the Historical and Museum Commission will take over management of the well.

In the meantime, the well was in great need of repair. It had been off line for a while so that, when The Colonel, Inc. acquired the well, they set to work repairing it for posterity. Volunteer members and companies lent their expertise and resources to the project. They extracted the sucker rods, replaced sections of the tubing and the sanding valve, and repaired the traveling valve. There were also repairs to the 15 HP Reir gas engine that powers the eccentric. Goss Gas, a Reno company, donated a large propane tank for use in powering the engine.

On November 19, 1998, after the repairs had been made, the engine was started and the pump commenced to pumping. It took a few days, and the brine tank filled in 18 hours, but the well began producing oil again. On November 23, the brine was hauled to the Franklin Brine Disposal facility where the company disposed of it for free.

Return to the vehicles and continue on to STOP 9.

| | | |
|---|---|---|
| 0.20 | 134.85 | Return to PA 8 and turn right (S) toward Oil City. |
| 2.60 | 137.45 | Turn left (S) onto US 62 at the traffic light. |
| 0.05 | 137.50 | Crossing the Allegheny River. |
| 0.25 | 137.75 | Turn left and continue E on US 62 (W. First Street). |
| 0.95 | 138.70 | Bear right (S) onto PA 257. |
| 1.95 | 140.65 | Entering Seneca. Continue straight on PA 257. |
| 0.65 | 141.30 | Intersection with SR2006 at traffic light. Continue straight on PA 257. |

| | | |
|---|---|---|
| 2.25 | 143.55 | Entering Cranberry. Continue straight on PA 257. |
| 0.35 | 143.90 | Intersection with US 322 at traffic light. PA 257 ends here. Continue straight ahead on SR2013. |
| 2.60 | 146.50 | Crossing East Sandy Creek. |
| 2.85 | 149.35 | Entering Rockland. Continue straight ahead. |
| 0.20 | 149.55 | Intersection at stop sign with SR3008 (to Nickleville and Kennerdell) to the left (W) and SR2002 to the right (E). Continue straight. |
| 1.40 | 150.95 | Entering Pittsville. Continue straight ahead. |
| 0.30 | 151.25 | Turn right onto dirt road, across small bridge. |
| 1.00 | 152.25 | Dogleg in road. |
| 0.40 | 152.65 | Pull vehicles to the side of the road. We will walk down the trail to Shull Run. |

## STOP 9: Rockland Iron Furnace and Freedom Falls.

Leader – John A. Harper

Built in 1832 by Andrew McCaslin, Rockland Furnace was a profitable venture on Shull Run for at least 22 years. McCaslin himself became insolvent at one point and had to sell his smelting business (he later became the Venango County sheriff). Rockland Furnace passed through several hands before being abandoned, supposedly in 1854 (Anonymous, 1988). According to Lesley (1859) the furnace was still operating in 1856, owned and managed by E.W. and H.M. Davis of Rockland. Without a thorough search of historical records, it probably won't be established which story is correct.

The furnace had a bosh (Figure 13) eight feet across and produced about 800 tons of iron per year using the Buhrstone ore. The stack is still well preserved after 167 years, but is showing signs of deterioration (notice the separation of blocks on the sides of the stack, probably resulting from soil creep associated with erosion of the Shull Run creek bed and banks). The flat ground just above the stack is the area where carts loaded with raw materials delivered ore, charcoal, and limestone for smelting. Undoubtedly, the materials were transported from here to the stack via a catwalk or bridge. On the upstream side of the furnace you can see several places where dressed stone defines the wheel pit, millrace, and foundation for the blast machinery. Water presumably was shunted to the wheel via a wooden flume from the top of nearby Freedom Falls.

As a bonus, Freedom Falls is a spectacular site in this part of Pennsylvania. With luck, it will have rained within a few days of the field trip so that the rush of runoff will add to the majesty of the spectacle. Freedom Falls occurs here as a result of a resistant sandstone in the Shenango Formation.

Perhaps, if we're lucky, we'll find some Burhstone ore or some slag lying around at this site before we leave.

Return to the vehicles and continue back to Pittsburgh.

| | | |
|---|---|---|
| 0.40 | 153.05 | Continue down the road to Rockland Station and turn the vehicles around. Return to Pittsville. |
| 1.90 | 154.95 | Turn left in Pittsville and drive N to Rockland. |
| 1.30 | 156.25 | Turn right (E) at stop sign onto SR 2002 in Rockland. |

| | | |
|---|---|---|
| 3.75 | 160.00 | Ella Gardner Corners. Continue straight (E) on dirt road. |
| 0.85 | 160.85 | Crossing Bear Run. |
| 0.45 | 161.30 | Turn right (S) at the T intersection. |
| 0.25 | 161.55 | Bear right (E) onto PA 38. |
| 4.90 | 166.45 | Entering Mariasville. Continue straight on PA 38. |
| 0.30 | 166.75 | Intersection with PA 208. Continue straight on PA 38. |
| 1.55 | 168.30 | Turn left onto access ramp to I-80 W |
| 0.30 | 168.60 | Merge with traffic on I-80 W. |
| 1.25 | 169.85 | Crossing the Allegheny River on the Allegheny River Bridge. At the time of its construction, it was the highest bridge east of the Mississippi at 270 ft. (the New River Bridge in West Virginia has since stolen this distinction). The bridge is a three-span continuous truss, with a substructure containing 13,100 cubic yards of concrete and nearly 2,000,000 lb. Of reinforcing steel. The footers of the two river piers sit on bedrock 26 feet below river bottom. Notice Emlenton on the edge of the river to the right (N), home of the historic Emlenton Refinery. Established in 1891 as Emlenton Producers' Oil Company, Limited, it later (1898) became Emlenton Refining Company. By 1914, because of the rapid development of the technical aspects of automobile engines, there arose a huge market for motor oils meeting new and critical demands. The Franklin, a popular automobile made in Syracuse, NY, had special needs. The car had a high-temperature air-cooled engine that was especially hard on the motor oils available at the time. As a direct result, the Emlenton Refinery created improved oil that became marketed as Quaker State Motor Oil, and a legacy began . . . |
| 2.30 | 172.15 | Exit 5 to Emlenton. Continue W on I-80. |
| 7.30 | 179.45 | Exit 4 to Clintonville via PA 308. Continue W on I-80. |
| 5.80 | 185.25 | Exit 3 to Butler and Franklin via PA 8. Continue W on I-80. |
| 5.20 | 190.45 | Exit 3A to Grove City and PA 173. Continue W on I-80. |
| 5.00 | 195.45 | Bear right onto the exit ramp to I-79 S toward Pittsburgh. |
| 0.40 | 195.85 | Merge with traffic on I-79 S and continue toward Pittsburgh. |
| 58.20 | 254.05 | Crossing the Allegheny River on the Fort Duquesne Bridge. |
| 0.40 | 254.45 | Crossing the Monongahela River on the Fort Pitt Bridge |
| 2.00 | 256.45 | Bear right onto the ramp at Exit 5 to Parkway Center Drive. |
| 0.40 | 256.85 | Turn right into Parkway Center Mall parking lot. **End of field trip.** |

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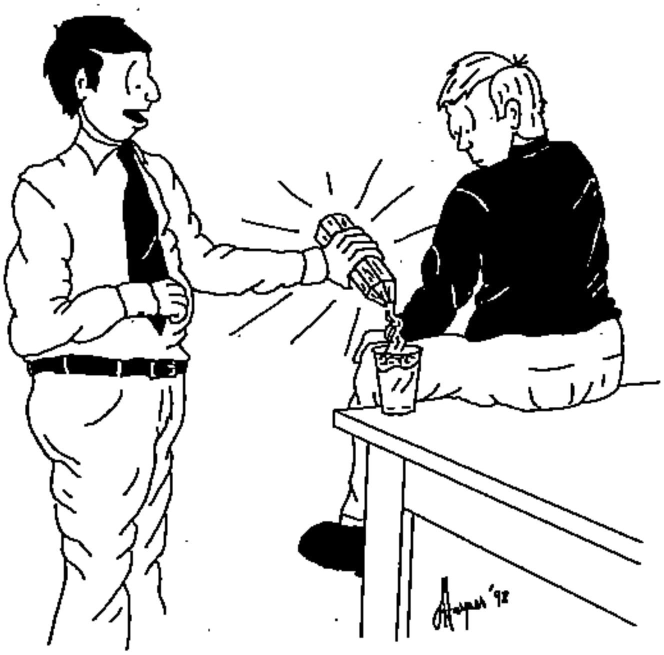
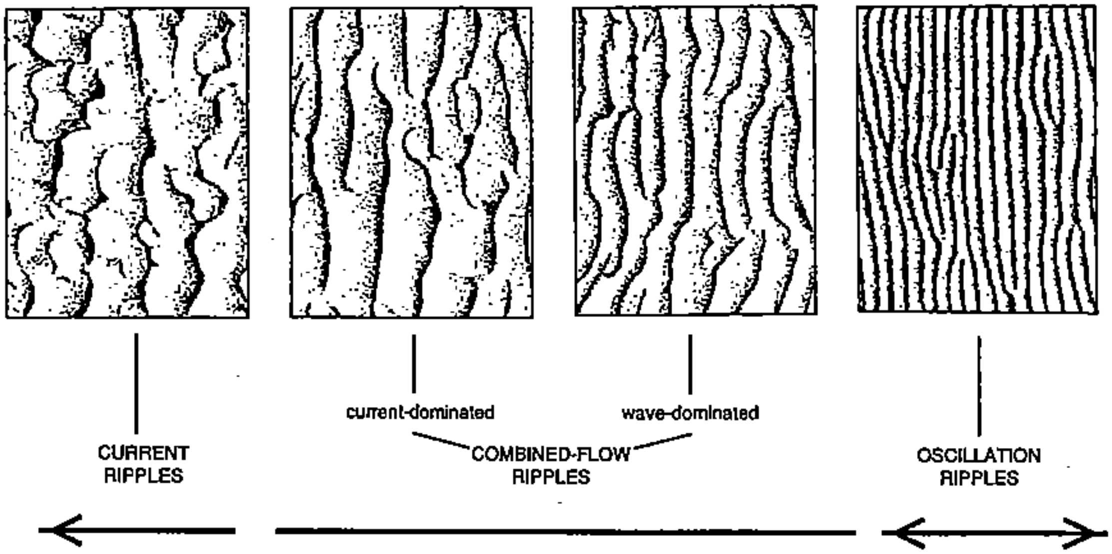


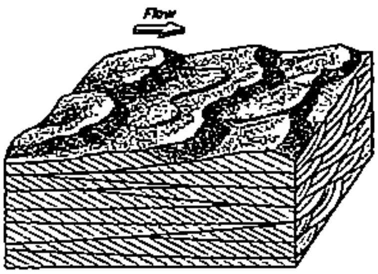
My new milkman is an unemployed geologist,
so now I get my milk delivered in quartz!

# APPENDIX

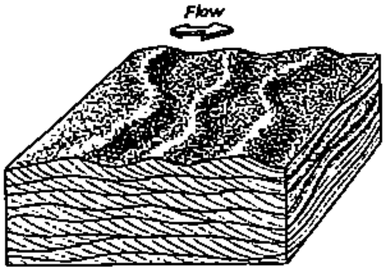
Illustrations of Some Common Sedimentary Structures and Trace Fossils



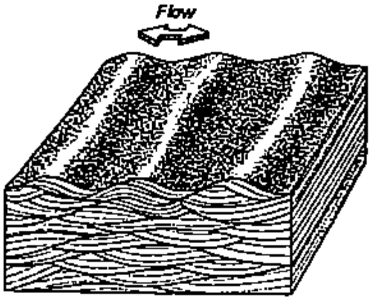
Relationship of ripple marks to current flow



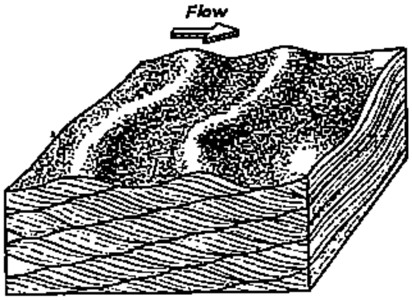
Current ripples



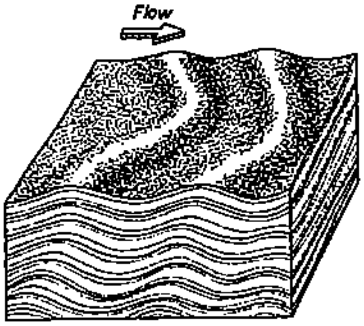
Combined flow ripples



Asymmetrical wave ripples

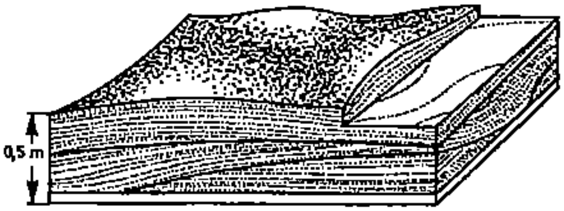


Climbing ripples

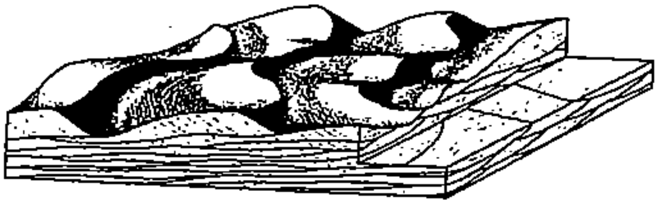


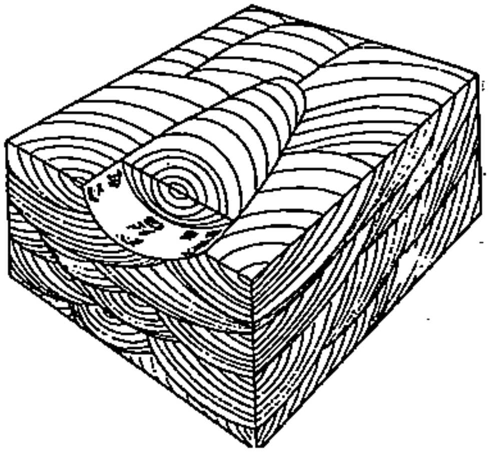
Symmetrical wave ripples

Planar bedding (laminations)

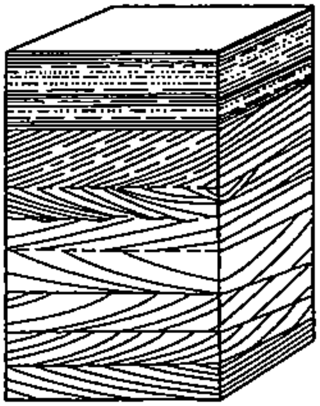


Hummocky cross stratification

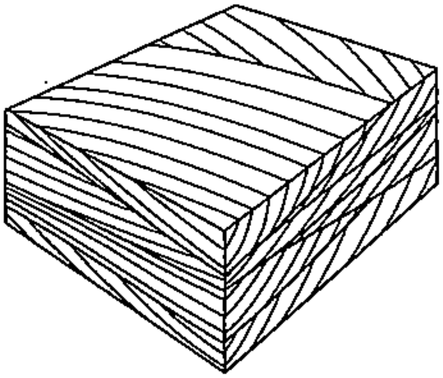




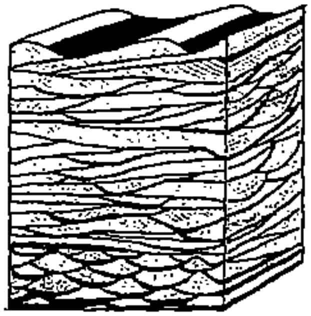
Large-scale trough cross stratification



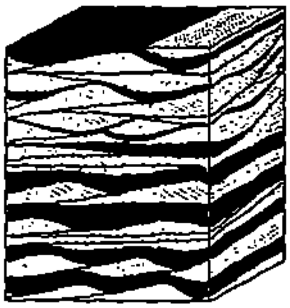
Herringbone cross bedding



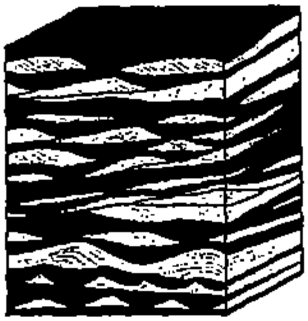
Planar cross bedding



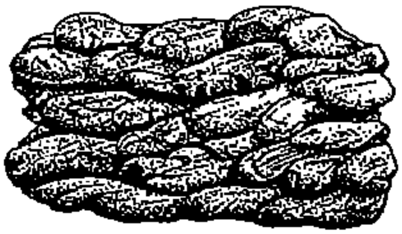
Flaser bedding



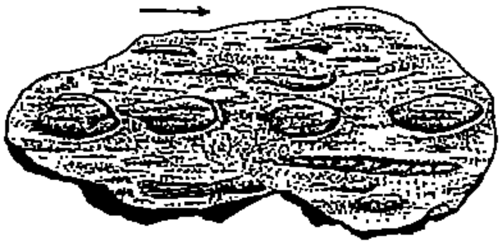
Wavy bedding



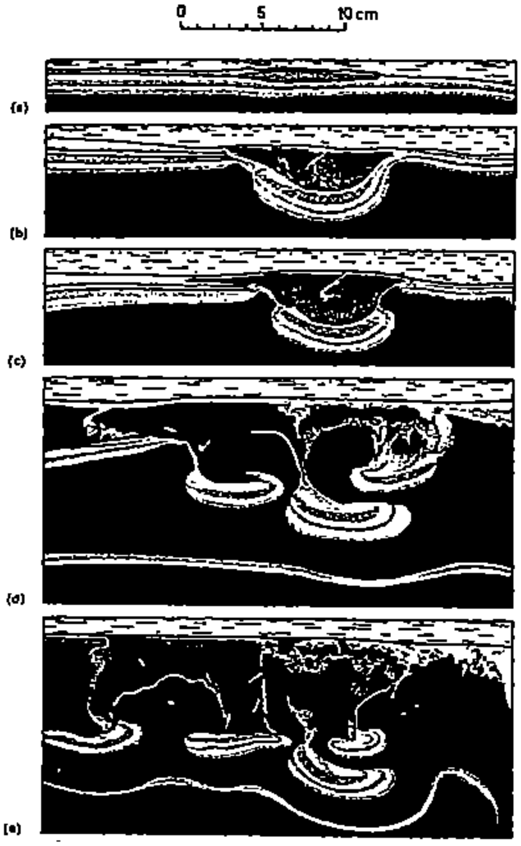
Lenticular bedding



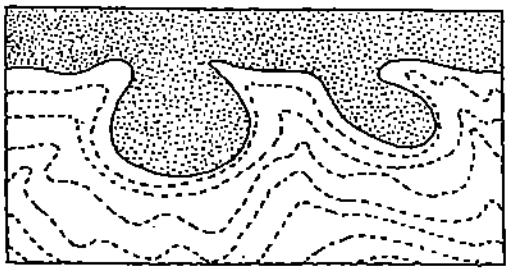
Sole marks



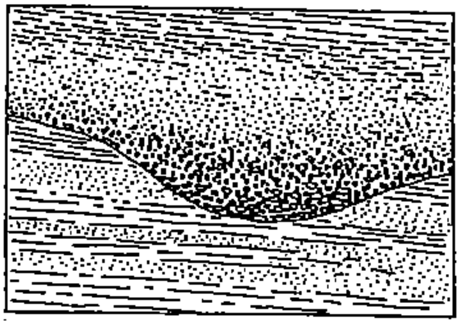
Tool marks



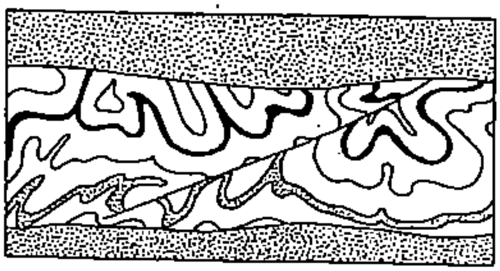
Formation of ball and pillow structures



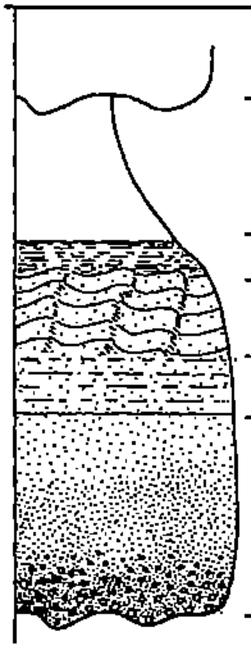
Load casts



Scour and fill

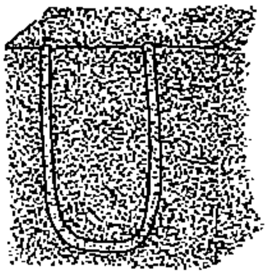


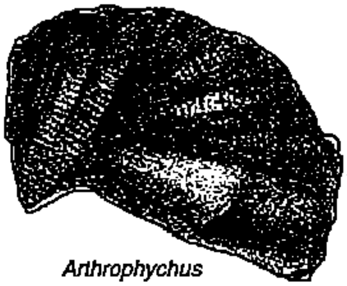
Slumps and disturbed bedding



| Grain Size | | Bouma Divisions | |
|---|---|---|---|
| Mud | **E** | Pelite | Pelagic sedimentation or fine grained, low density turbidity current deposition |
| Silt | **D** | Upper parallel laminae | ? ? ? |
| Sand | **C** | Ripples, wavy or convoluted laminae | Lower part of Lower Flow Regime |
| Sand | **B** | Plane parallel laminae | Upper Flow Regime Plane Bed |
| Sand with granules at base | **A** | Massive, graded | ? Upper Flow Regime Rapid deposition and Quick bed (?) |

Bouma sequence


*Arenicolites*


*Arthrophychus*

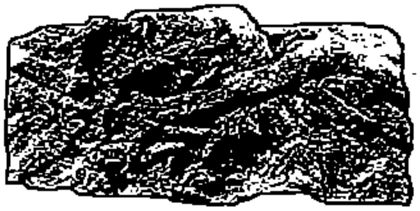

*Bifungites*


*Chondrites*

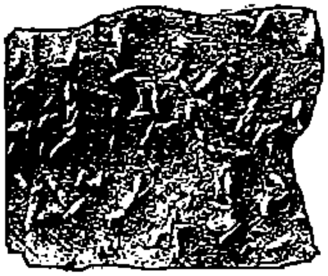

*Conostichus*


*Diplocraterion*


*Monocraterion*


*Palaeophychus*

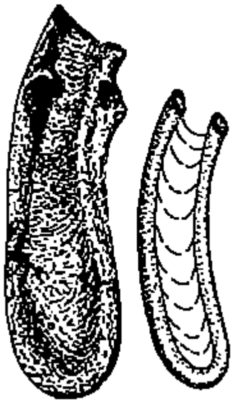

*Paleodictyon*


*Pelecypodichnus*


*Phoebichnus*


*Planolites*


*Zoophycos*


*Rhizocorallium*