GEOLOGY

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Since the time of the First Pennsylvania Geologic Survey, 1836 to 1858, geologic investigations concerned with surface geology, stratigraphy, structure, sedimentation, glaciation, hydrology, coal resources and mine drainage have been carried out in Western Pennsylvania and the Slippery Rock Creek Watershed. Results of these investigations are detailed in the excellent geologic reports on the area. The geologic publications which were utilized in this study are listed under References at the end of this report. They are referred to in the text whenever appropriate.

The results of this investigation in the Slippery Rock Creek Watershed are based on a study of published reports, supplemented by knowledge obtained from discussions with geologists and engineers concerned with the geology of the area and the mine drainage pollution problem. Additional information was obtained from topographic maps, aerial photographs, mine maps and records, logs of drill holes, and mechanical logs which were available.

Geologic Factors Affecting Mine Drainage

Hydrogeologic and other geologic conditions determine the nature and quantity of the mine drainage emanating from coal-mined lands within the Slippery Rock Creek Watershed. Some of these factors are:

1. Thickness and composition of the coal seams and associated strata related to the source of these sediments and their depositional environment.

2. Surface topography modified by erosional processes.

3. Structure, folding, strike and dip of strata, fracturing, and joints. Minor faults may also be present.

4. Roof thickness and character.

5. Location and extent of mined area in relation to topographic and geologic setting.

Mining of coal exposes the sulphur-bearing minerals, pyrite and marcasite, to air and water. These disulphides are then oxidized, chemically and biochemically, to produce sulphuric acid, ferrous and ferric sulphate, and other acid salts such as the sulphates of iron, aluminum, and manganese. The mine drainage may also contain the neutral sulphates of calcium and magnesium when calcareous rocks are present.

Erosion of mined areas results in suspended sediments and mineral matter which is deposited in stream channels with harmful effects on aquatic life

An excellent summary of the constituents, source, formation, and occurrence of mine drainage is contained in reports by the Appalachian Regional Commission (Acid Mine Drainage in Appalachia, 1969; The Incidence and Formation of Mine Drainage Pollution in Appalachia, Appendix C, 1969).

The current investigation, past history and studies made by Williams (1957, 1960); Williams and Keith (1963); Williams, Ferm, Guber, and Bergenback (1964); Mansfield and Spackman (1965); Emrich and Thompson (1968); Carrucio and Parizek (1968) show that certain coal seams in the Watershed and elsewhere in Pennsylvania have a high percentage of discharges that are acid, while others are predominantly alkaline. Discharges from important coal beds and associated strata of the Allegheny Group in the Watershed have in general the following quality:

1.	Upper Freeport	-	predominantly alkaline
2.	Lower Freeport	-	predominantly acid
3.	Upper Kittanning	-	predominantly acid
4.	Middle Kittanning	-	predominantly acid
5.	Lower Kittanning	-	predominantly acid
6.	Clarion - Brookville	-	predominantly acid

Generally, studies have shown that mines in coal seams in the lower portion of the Allegheny Group produce more acid drainage than mines in coal seams in the upper portion of the group.

Variations in the acidity generated - regionally, locally, horizontally and vertically - have been attributed to the environments in which these rocks of Pennsylvanian age were deposited, marine, brackish or fresh-water. Acid forming minerals, pyrite and marcasite, are generally found to be more abundant in marine and brackish water sediments laid down under reducing conditions. Marine sediments overlying coal seams are higher in sulphur content than rocks of continental origin. Rocks of continental origin have been oxidized.

Since the reducing environment favors the formation and deposition of iron disulphide, the sulphur content should increase as the rocks gradate from a fresh-water - upper portion of Allegheny Group - to a marine environment of deposition - lower portion of Allegheny Group in Western Pennsylvania. Rocks in the Slippery Rock Creek Watershed belonging to the Allegheny Group appear to be mainly of marine origin.

A recent study by Caruccio (1970) has demonstrated that the production of acidity is related to primary fine grained framboidal pyrite formed contemporaneously with the coal. This type of pyrite is found in marine strata (Brookville and Clarion) and readily decomposes. A secondary coarser grained pyrite associated with freshwater deposits with about the same sulphur content (Upper Freeport strata) is stable and does not produce significant amounts of acid mine drainage.

Additional studies are needed to increase the knowledge of depositional environments to understand the character of sulphur-bearing minerals and to map their stratigraphic distribution. This knowledge, along with hydrogeologic information, distribution and geometry of aquifers and nonaquifers, lateral and vertical permeability, the water table and ground water movement, storage capacity, character and distribution of recharge and hydraulic boundaries - to be obtained from surface and subsurface investigations, is essential to the adequate prevention and abatement of mine drainage - through neutralization, diversion and dilution, dewatering, mine sealing and surface reclamation.

Regional Stratigraphy

The Slippery Rock Creek Watershed is underlain by sedimentary rocks which reach a maximum thickness of about 12,000 feet. This sedimentary succession ranges in age from Cambrian through Pennsylvanian (Figs. 5,6). The sedimentary rock layers accumulated during Paleozoic time on a stable shelf or shallow platform near the northwest margin of the Appalachian basin - a downwarped segment of the earth's crust (Fig. 7).

Subsidence of this marine basin generally kept pace with the deposition of the sediments. Deposition was interrupted repeatedly by uplifts. Parts of the basin were raised above sea level and subjected to erosion. There are numerous gaps in the rock sequence due to

erosion or nondeposition. The rocks consist of sandstones, siltstones, shales, limestones, clays and coals. Vertical and lateral changes occur in the rocks which reflect the differences in the environments or special conditions under which these deposits were formed.

Surface rocks in the Watershed are of Pennsylvanian age. They have been divided, in ascending order, into the Pottsville, Allegheny and Conemaugh Groups. The exposed thickness of these coal-bearing strata is about 550 feet (Figs. 8, 11).

Erosional processes have modified and leveled the surface rocks to develop the present landscape. Two major advances of continental ice sheets - Illinoian and Wisconsin - during Pleistocene time covered a large part of the land surface of the Watershed for thousands of years (Fig. 8). In the western two-thirds of the Watershed uneven thicknesses of rock debris or drift, consisting of generally unsorted till and stratified material, remained as the ice sheets melted and retreated. These deposits obscure the older bedrock in much of the glaciated area.

Ridges of glacial till - sandy loam, boulders, sand and gravel of end and ground moraines - piled up at the ice edges. Associated waterlaid sediments, bedded silt, clay, sand and gravel of kame terraces, eskers, outwash (valley train) and lake deposits, were deposited after being fed to the meltwater from the stagnant ice. These deposits were formed both in front of and behind the terminal moraine. Lake deposits were built up to 80 feet in thickness ahead, of the ice sheet and the end (terminal) moraine by the impoundment of melt waters which created Lake Arthur. This lake later split into Lake Edmund and Lake Watts (Fig. 9). Moraine State Park is located on the site of former Lake Watts.

Several excellent reports dealing with the glacial geology of the Slippery Rock Creek Watershed have been published (Leverett 1902, 1934; Preston 1950; Shepps, White, Droste and Sitler 1959).

Unconsolidated stream deposits of Recent age (alluvium) are present in the valleys of many streams in the Watershed.

This report is principally concerned with the stratigraphy of the coal-bearing rocks of Pennsylvanian age which underlie the Watershed. These coal beds, along with the overlying and underlying rock units, contain acid forming material (pyrite and marcasite) which is the source of the mine drainage problem in the Watershed. Of primary importance are their individual characteristics, and their relations to one another to determine their role in the production of the mine drainage which pollutes the streams in the Watershed.

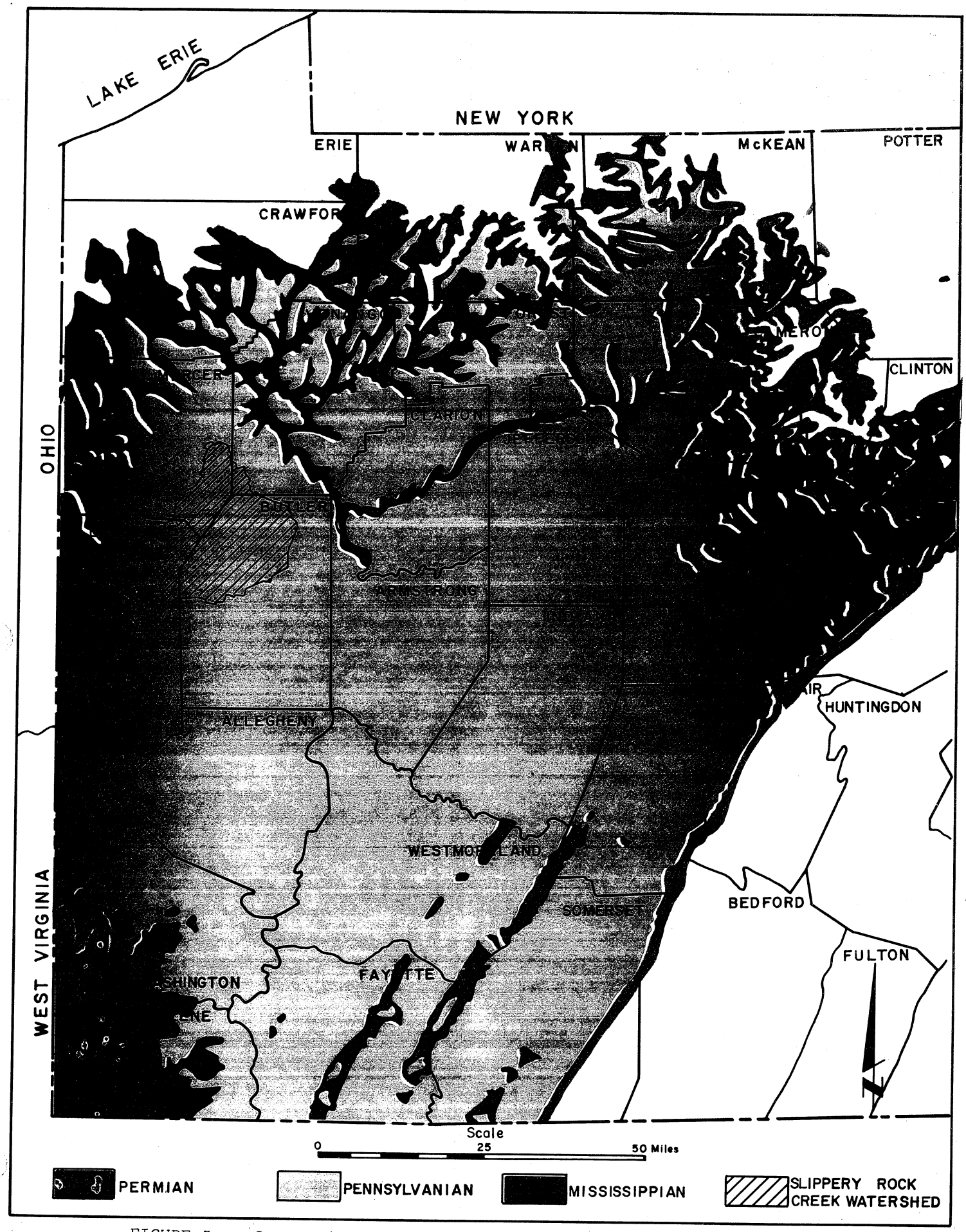

FIGURE 5. - Generalized Geologic Map of Western Pennsylvania - From Pennsylvania Topographic and Geologic Survey Map.

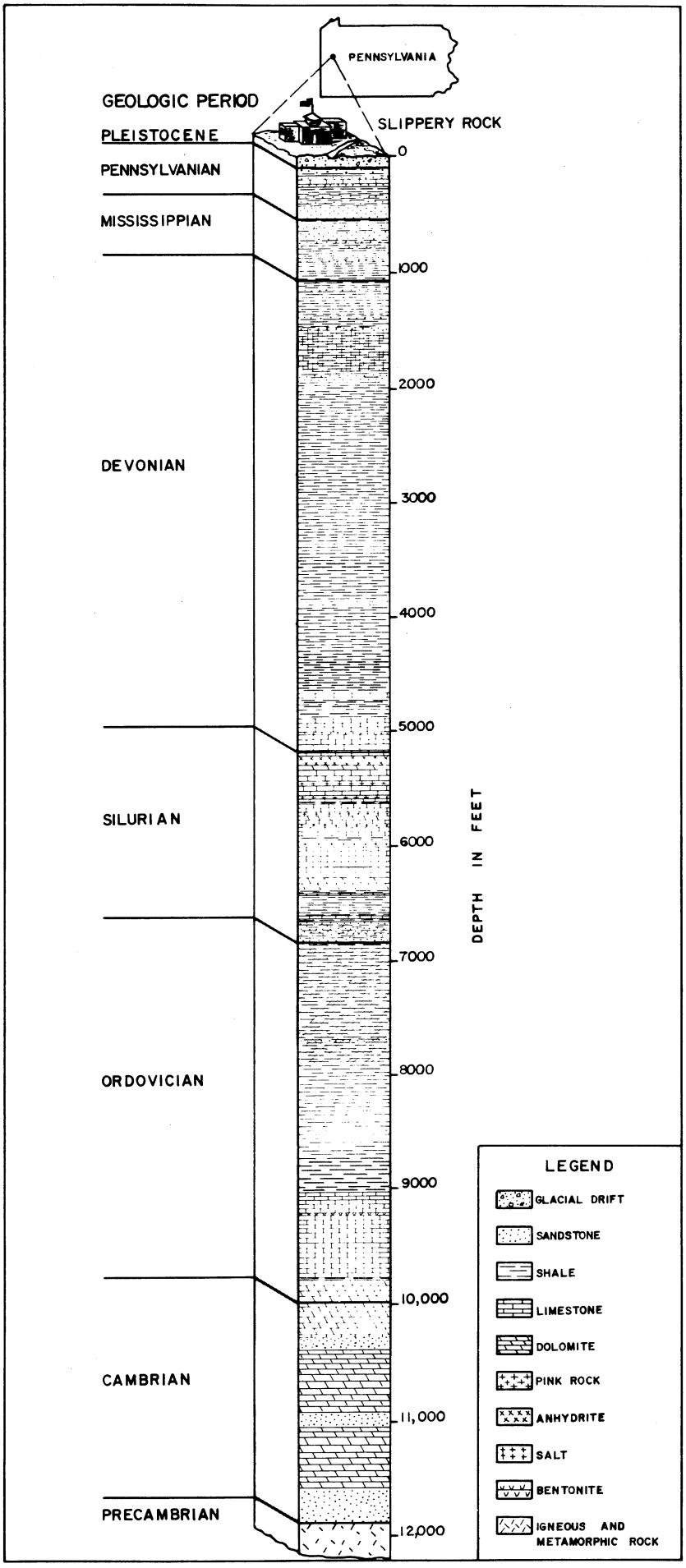

FIGURE 6. - Subsurface stratigraphic column at Slippery Rock Pennsylvania - Modified Columnar Section of J.G. Hockenberry Well No. 1, from Pennsylvania Geologic Survey Bulletin M39, Fettke 1953; from Wagner and Lytle 1968.

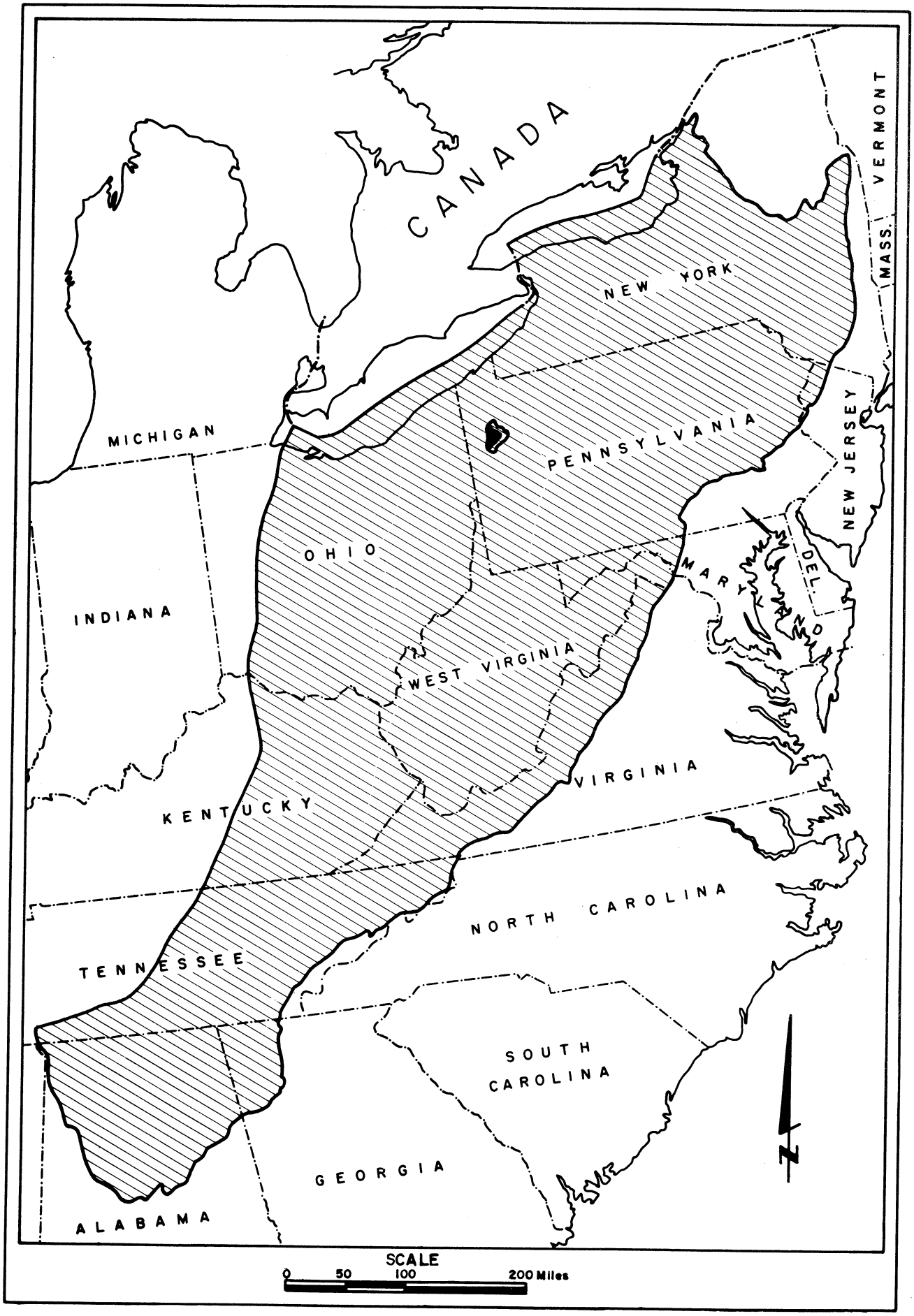

FIGURE 7. - Map of Appalachian basin showing location of study area - From Colton 1961.

Pennsylvanian Rocks - Located at the northern end of the Appalachian bituminous coal basin (Fig. 10), the Watershed contains eleven beds of high volatile A coal, ranging in thickness from less than 14 inches to more than 42 inches - generally less than 36 inches. High in ash and sulphur, the coals are in general more variable and thinner than those in adjoining areas.

These coal beds of varied thickness and extent are present in much of the Watershed. They occur at irregular stratigraphic intervals throughout the sequence of Pennsylvanian rocks which underlie the Watershed. Locally the coals gradate into shale and are cut by channel sandstones. Light to dark gray underclay occurs beneath most coal beds (Patterson and Van Lieu 1964, 1969).

Figure 11 shows the stratigraphy of the coal-bearing Pennsylvanian rocks which are divided into three major units. From oldest to youngest, they are the Pottsville, Allegheny and Conemaugh Groups. Deposited in a near-shore marine or continental environment, these rocks consist of interbedded sandstone, siltstone, shale, limestone, coal and clay, listed in approximate order of decreasing abundance (Patterson and Van Lieu, 1969).

Detailed information on the stratigraphy, occurrence and distribution of coal in Western Pennsylvania has been published in reports by Sisler (1925, 1926), Reese and Sisler (1928), Ashley (1928), Patterson (1963), Carswell and Bennett (1963), Poth (1963), Van Lieu and Patterson (1964), Edmunds (1969). Reference should be made to these published reports for a comprehensive discussion of the coal geology of the Watershed. A generalized description of the stratigraphy of the coal-bearing units is presented in this report.

Pottsville Group

Only the upper part of the group, which rests unconformably on Mississippian rocks, is present in Western Pennsylvania. It underlies the entire area of the Watershed. A section about 180 feet thick is exposed in the gorge of Slippery Rock Creek in Lawrence County (Richardson, 1936). A thickness of 224 feet was logged in the Jessie G. Hockenberry No. 1 Well, Mercer Township, Butler County (Fettke, 1961).

The Pottsville Group is predominantly massive, coarse grained, lenticular sandstones, in places conglomeratic. Some shale interbeds

are present in parts of the rock sequence, along with thin beds of coal, clay and limestone. In descending order the Pottsville Group includes three formations - Homewood, Mercer and Connoquenessing. These formations change character from place to place. Locally they may be very shaly, making the correlation of individual sandstones difficult. Coal may occur in each of the formations (Poth, 1963).

Homewood Formation - (50 feet average thickness). This formation is composed of white to light gray, medium to coarse grained, thick to thin bedded, conglomeratic, ironstained, cross-bedded, lenticular sandstone. A coal bed with an average thickness of 6 inches occurs at the base of the Homewood Sandstone. This coal, which occupies a stratigraphic position between the Homewood Sandstone and the Upper Mercer Limestone, is spotty in distribution (Van Lieu and Patterson, 1964).

Mercer Formation - (55 feet average thickness). This formation consists of brown, dark gray to black, silty, carbonaceous, fissile shale; interbedded sandstones, coals, dark gray silty fossiliferous limestones and siderite (ironstone) concretions. The formation contains three coal beds - the Lower, Middle and Upper Mercer. These coals are associated with two thin beds of limestone near the center of the formation (Patterson and Van Lieu, 1969). The upper coal occurs about 60 to 80 feet below the top of the Vanport Limestone and 40 feet above the middle coal bed. The lower coal lies about 25 feet below the middle coal bed. Thickness of the coals is commonly 12 to 24 inches. Only the middle and lower coal beds - called the Upper and Lower Mercer coals - appear to occur in the Watershed. Where observed, the coals are thin with an average thickness of 5 to 11 inches. They are generally noneconomic (Poth, 1963; Patterson and Van Lieu, 1964, 1969).

Connoquenessing Formation - (115 feet average thickness). This formation comprises the lower part of the Pottsville Group and rests unconformably on Mississippian rocks. The Connoquenessing Formation has been divided into three members described below in descending order.

1. Upper Connoquenessing Member (40 feet) consists of white, tan to light gray, fine to coarse grained, hard, cross-bedded, massive sandstone.

2. Quakertown Member (40 feet) is predominantly dark brown, gray to black, sandy shale with siderite concretions at

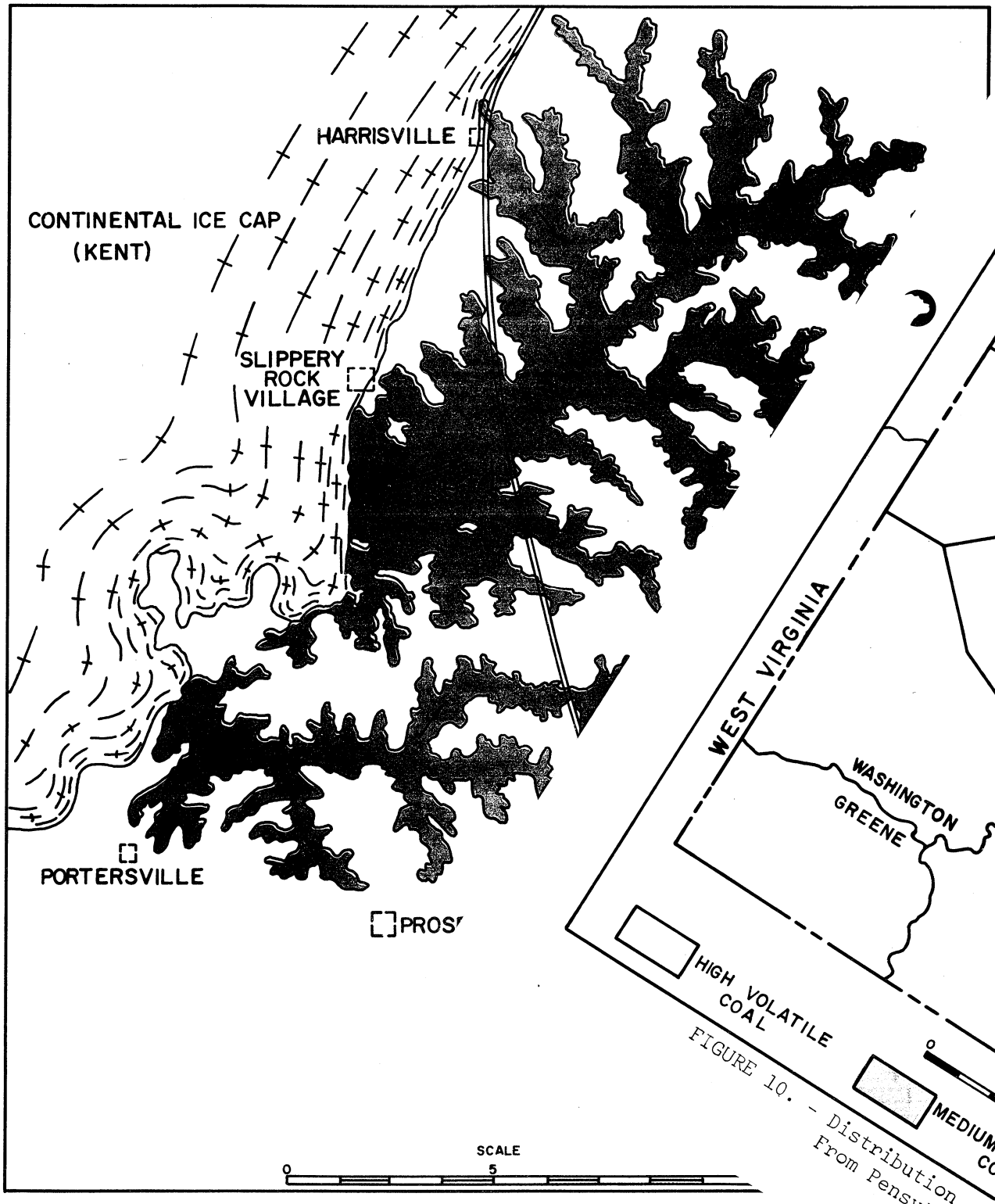

Figure 9. Distribution of glacial Lake Watts and Lake Edmund in front of the Kent ice sheet (after Preston, 1950).

FIGURE 10. - Distribution of Bituminous
From Pensylvania Topographic

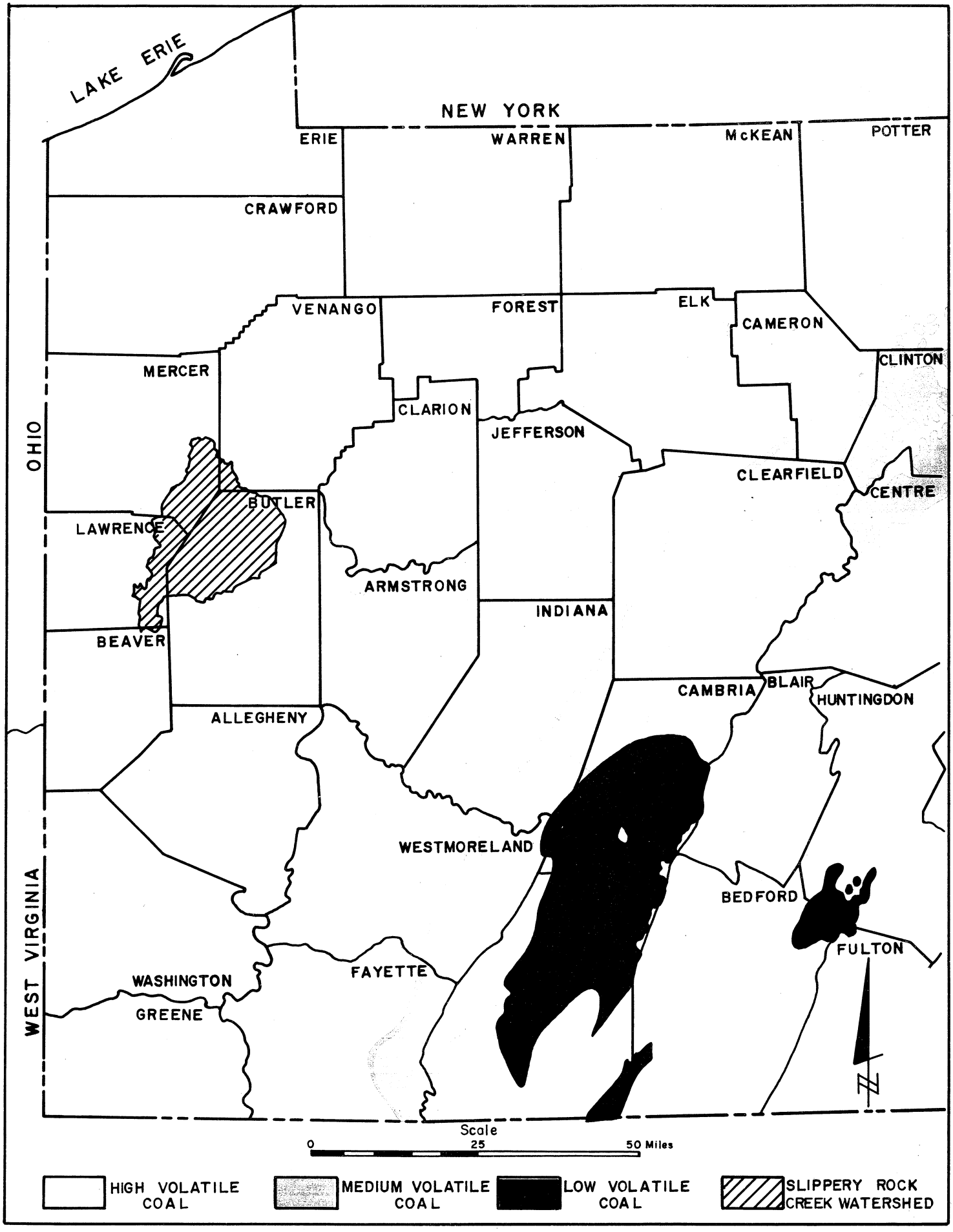

FIGURE 10. - Distribution of Bituminous Coals in Western Pennsylvania - From Pensylvania Topographic and Geologic Survey Map.

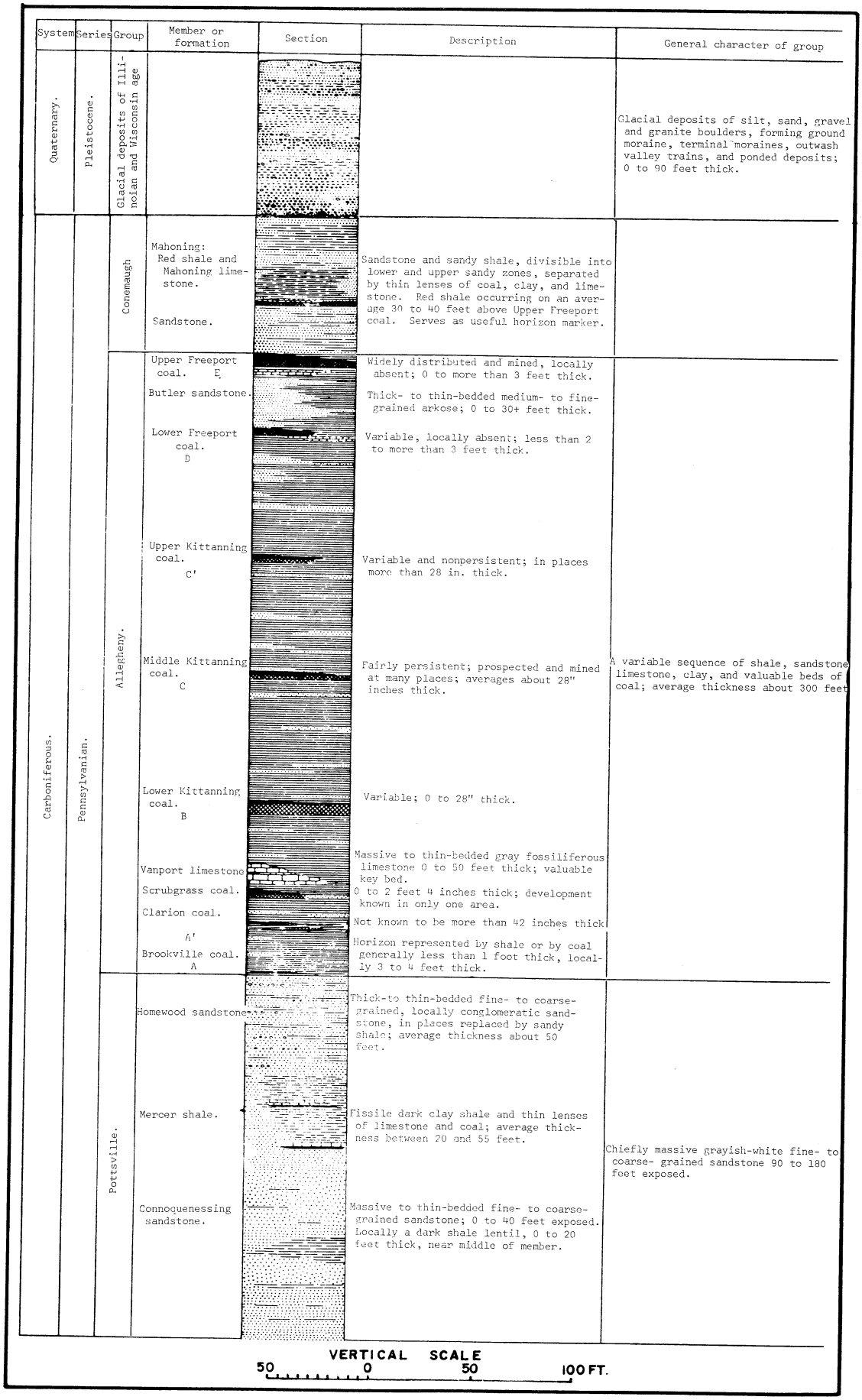

FIGURE 11. - Generalized stratigraphic column for the Pennsylvanian rocks of Slippery Rock Creek Watershed - Modified from Richardson, U.S.G.S. Bulletin 873, 1936.

the top, irregular thin beds of crossbedded sandstone, clay and thin coal beds. The coal beds are generally less than 2 feet in thickness and occur 75 to 100 feet below the Upper Mercer coal. These coal beds are noneconomic since they are either very thin or absent in the Watershed.

3. Lower Connoquenessing Member (35 feet) is composed of white, tan to light gray, fine to medium grained, hard, thin to thick bedded sandstone. The Lower Connoquenessing Member is similar to the Upper Connoquenessing Member in character and thickness.

Allegheny Group

The Allegheny Group commonly includes those rocks between the base of the Brookville underclay and the top of the Upper Freeport coal. Recent studies by Edmunds (1968, 1969) have resulted in newly defined stratigraphic units for the Allegheny Group in Central Pennsylvania. This work has not been extended to Western Pennsylvania.

Rocks of the Allegheny Group reach a maximum thickness of about 300 feet and outcrop over the major portion of the Watershed (Fig. 8). The group conformably overlies the Pottsville sequence and consists of shale and sandstone interbedded with coal, clay and limestone. The strata are variable and the generalized section shown on Figure 11 does not apply to one area or locality.

The Allegheny Group, from youngest to oldest, has been divided into four formations. These formations contain the most valuable coal beds in the Watershed.

Freeport Formation - (100 feet average thickness). This formation includes the strata in the interval from the top of the Upper Kittanning coal to the top of the Upper Freeport coal (Poth, 1963).

The Freeport Formation is divided into two members in descending order:

1. Upper Member (40 feet). This member consists primarily of reddish-brown and tan, fine to medium-grained sandstone, with some dark gray fissile shale interbeds. The Upper Freeport

coal, 14 to 42 inches thick, occurs at the top of the member. The coal is underlain by gray underclay. Several feet below lies the bluish-gray, freshwater Upper Freeport Limestone. This limestone overlies the Butler Sandstone. The sandstone is about 30 feet thick.

2. Lower Member (60 feet). This member is predominantly sandy shale and sandstone. The Lower Freeport coal, 14 to 28 inches thick, is present at the top of the unit. Beneath the Lower Freeport coal is a tan to blue-gray underclay followed by the light to medium blue-gray, freshwater Lower Freeport Limestone.

The two coal beds are spaced about 60 feet apart. Strip mining of the Lower Freeport coal has been extensive in the Hilliards quadrangle (Patterson and Van Lieu, 1969).

Kittanning Formation - (150 feet average thickness). The Kittanning Formation underlies the Freeport Formation. The formation includes those rocks between the top of the Vanport Limestone and the top of the Upper Kittanning coal. For practical use, this report follows the definition of Carswell and Bennett (1963) and Poth (1963), until further stratigraphic studies are completed in Western Pennsylvania. The stratigraphic nomenclature of Ashley (1926) and Edmunds (1968, 1969) places the base of the Kittanning sequence at the base of the Lower Kittanning underclay in Central Pennsylvania. Edmunds (1968) raised each of the Kittanning coals and associated beds to formation rank.

The Kittanning Formation consists principally of shales and siltstones, with associated coals and underclays. The sequence has been divided into three members, in descending order:

1. Upper Member (50 feet) is made up of the Upper Kittanning coal, tan and blue-gray to black sandy shale, and tan to brown, clayey silty sandstone. This member extends from the top of the Middle Kittanning coal to the top of the Upper Kittanning coal. The Upper Kittanning coal, 14 to 28 inches thick, occurs at the top of the member and is underlain by gray underclay.

   In many localities the Upper Kittanning is a cannel coal, east of Murrinsville, northeast of Boyers and southwest of North Washington. Since it is thin and discontinuous, the coal is not generally mineable. It is known locally as "Pot Vein"

where unusually thick lenses or pods occur about 22 miles southeast of North Washington (Patterson and Van Lieu 1969).

2. Middle Member (70 feet) consists of the Middle Kittanning coal, clayey and sandy shale, along with thin local sandstones and siltstones. The member occupies the interval from the top of the Middle Kittanning coal.

   The Middle Kittanning coal, present at the top of the section, is one of the thickest - about 28 inches and most widely distributed coals in the Watershed. Several partings occur where the bed is thick. A bed of clay up to 3 feet thick underlies the coal.

   Extensive strip mining of the Middle Kittanning coal has taken place in recent years. In the past, underground mining of the coal was carried out in the Watershed. Abandoned underground mines are located in the vicinity of Claytonia, Hallston, and Coaltown.

3. Lower Member (30 feet) is composed of the Lower Kittanning coal, underclay, blue gray, clayey shale and thick coarse-grained channel sandstones. The channel sandstones cut the underlying Vanport Limestone in places. The member occupies the interval from the top of the Vanport Limestone to the top of the Lower Kittanning coal. Over the eastern two-thirds of the Watershed the coal is very thin or absent. In the western and northwestern portions of the Watershed the coal outcrops and is 14 to 28 inches thick. Poth (1963) determined that the thickest deposits of Lower Kittanning coal occupy an area extending southwestward from Slippery Rock Borough, Butler County to Ridge School, Lawrence County.

Vanport Limestone - (15 feet average thickness). This formation consists of light-gray, dense, fossiliferous massive limestone. The Buhrstone limonitic iron ore, about 1 to 4 feet thick, occurs at the top of the formation in some areas, for example, at Harlansburg in Lawrence County.

In the Watershed the Vanport Limestone has an average thickness of 15 feet. It reaches a thickness of 50 feet south of Plain Grove, Lawrence County (Poth, 1963). The limestone thins to the north and northwest. Locally it may be thin or absent where: (1) marine shales, sandstones and thin coals were laid down when depositional conditions changed; (2) post-deposition solution channels were filled with clay and sandstone; or (3) the formation was removed by erosion after deposition.

Since it is easily identified, the Vanport Limestone serves as an excellent marker bed for correlation purposes and determining structure. The limestone is of economic importance as a source of flux stone for the steel industry, cement, agricultural limestone, aggregate and roadstone (O'Neill, Jr., 1964). It has been extensively quarried in the Watershed at Annandale, Branchton, Cowanville, Coaltown and Prospect.

Clarion Formation - (50 feet average thickness). This formation includes those rocks occurring in the interval between the base of the Brookville underclay and the base of the Vanport Limestone (Carswell and Bennett, 1963; Poth, 1963).

The rocks in the interval consist of tan and black, clayey to sandy shale, channel sandstones and three economically important coal beds and their associated underclays. These coal beds are, in descending order, the Scrubgrass, Clarion and Brookville. Since the coals are extremely variable, discrepancies in correlations and nomenclature result because their complex stratigraphy is not well understood.

1. Scrubgrass coal. The lenticular Scrubgrass coal is either absent or very thin over much of the Watershed. Where present, the coal lies 6 feet or less below the base of the Vanport Limestone. The Scrubgrass coal outcrops in Cherry, Mercer, Slippery Rock and Venango Townships. It is about 14 inches thick in the northern part of the Watershed, and in the Barkeyville quadrangle it is more than 28 inches thick. The coal has been strip mined in this area with the underlying Clarion coal.

   Near Annandale Station, the Scrubgrass coalesces with the Brookville and Clarion coals to form a single bed. At Goff's Station the Scrubgrass includes only the upper 2½ inches of bony coal (Patterson and Van Lieu, 1969).

2. Clarion coal. The Clarion coal is present in the northern and eastern parts of the Watershed where it is 14 to 42 inches thick. Information concerning its occurrence in the remainder of the Watershed is sparse. The Clarion coal is 42 inches thick in areas of the Eau Claire, Barkeyville and Hilliards quadrangles.

   In an area bordered by the towns of Eau Claire, Murrinsville, Boyers, and Hilliards, the Clarion, Brookville and Scrubgrass

coals coalesce. This single bed, called the Clarion, was mined extensively by underground mines, now abandoned. The coal has also been strip mined in other areas to the north and west.

3. Brookville coal. The Brookville coal is considered to be the first coal bed present above the Homewood Formation. In the Watershed this coal has a reported thickness ranging from 12 to more than 48 inches.

Conemaugh Group

Only the basal portion of the Conemaugh Group is present in the Watershed. About 75 feet thick, the group outcrops in the eastern and southern parts of the area.

The Conemaugh Group is underlain by the Upper Freeport coal of the Allegheny Group. In ascending order the section in the Watershed includes: the medium to coarse grained massive Mahoning Sandstone, the freshwater Mahoning Limestone, the Mahoning coal and the Mahoning red shale.

The Mahoning coal is thin where it has been measured in the Watershed - generally less than 14 inches thick. It is of little economic importance. A thickness of more than 14 inches has been reported by Patterson and Van Lieu (1969) to occur on several hill tops near Portersville in the Portersville Quadrangle.

Structure

A part of the Appalachian foreland, the Slippery Rock Watershed is located at the northeastern end of the Pittsburgh-Huntington basin. This large northeast-southwest trending down-fold of strata (synclinorium) has many smaller folds superimposed on its flanks. Regional dip in the Watershed is generally 1 degree or less southward - ranging 14 to 23 feet per mile. Although this gentle dip is interrupted by minor folds, it rarely exceeds 2 or 3 degrees.

The Homewood anticline is the largest structural feature in the Watershed. This southwest plunging anticline trends northeastward from Homewood in Beaver County and enters the southwest part of the Watershed in the vicinity of Ellwood City. From this point the axis of the anticline continues north-northeast across Lawrence County in the direction of Energy. It passes southeast of Rose Point and con-

tinues into Butler County to a point one mile south of Slippery Rock. Although not clearly defined, the axis of the anticline has been extended by Sherill and Matteson (1939) northeasterly to Kennerdell school in the Hilliards quadrangle. The Darlington syncline parallels the Homewood anticline on the northwest (Patterson, 1963; Poth, 1963; Patterson and Van Lieu, 1964).

The effect of the Homewood anticline has been to raise the Lower and Middle Kittanning coals 20 to 50 feet. This structure may have preserved the coals in the lower part of the Allegheny Group from erosion by restricting the courses of Wolf Creek and Slippery Rock Creek (Patterson and Van Lieu, 1969).

Other structural features include the Henderson Dome, which is located at the extreme northern end of the Watershed in Worth Township, Mercer County, and an unnamed anticlinal fold that extends southward from Eau Claire to North Washington along the eastern border of the Watershed. Other minor anticlines and synclines, parallel to the Homewood anticline, occur in southeastern and northeastern Lawrence County along the Butler County Line.

Differential compaction of shales, silts and coals may account for the many local reversals of regional dip in the Watershed. Vertical or nearly vertical fractures exist in the rocks of the Watershed. It has been suggested by Poth (1963) that the valleys are controlled by zones with a greater density off fractures than adjacent areas. These fracture concentrations provide a zone of increased permeability in the valley rocks and adjoining areas.