DEPARTMENT OF THE INTERIOR
RAY LYMAN WILBUR, SECRETARY
UNITED STATES GEOLOGICAL SURVEY
W. C. MENDENHALL, DIRECTOR

GEOLOGIC ATLAS

OF THE

UNITED STATES

COATESVILLE-WEST CHESTER FOLIO

PENNSYLVANIA-DELAWARE

BY

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WASHINGTON, D. C.
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GEOLOGIC ATLAS OF THE UNITED STATES.

UNITS OF SURVEY AND OF PUBLICATION.

The Geological Survey is making a topographic and a geologic atlas of the United States. The topographic atlas will consist of maps called *atlas sheets*, and the geologic atlas will consist of parts called *folios*. Each folio includes topographic and geologic maps of a certain four-sided area, called a *quadrangle*, or of more than one such area, and a text describing its topographic and geologic features. A quadrangle is limited by parallels and meridians, not by political boundary lines, such as those of States, counties, and townships. Each quadrangle is named from a town or a natural feature within it, and at the sides and corners of each map are printed the names of adjacent quadrangles.

SCALES OF THE MAPS.

On a map drawn to the scale of 1 inch to the mile a linear mile on the ground would be represented by a linear inch on the map, and each square mile of the ground would be represented by a square inch of the map. The scale may be expressed also by a fraction, of which the numerator represents a unit of linear measure on the map and the denominator the corresponding number of like units on the ground. Thus, as there are 63,360 inches in a mile, the scale 1 inch to the mile is expressed by the fraction $\frac{1}{63,360}$, or the ratio 1:63,360.

The three scales most commonly used on the standard maps of the Geological Survey are 1:31,680, 1:62,500, and 1:125,000, 1 inch on the map corresponding approximately to one-half mile, 1 mile, and 2 miles on the ground. On the scale of 1:31,680 a square inch of map surface represents about one-fourth of a square mile of earth surface; on the scale of 1:62,500, about 1 square mile; and on the scale of 1:125,000, about 4 square miles. In general a standard map on the scale of 1:125,000 represents one-fourth of a "square degree"—that is, one-fourth of an area measuring 1 degree of latitude by 1 degree of longitude; one on the scale of 1:62,500 represents one-sixteenth of a "square degree"; and one on the scale of 1:31,680 represents one-sixty-fourth of a "square degree." The areas of the corresponding quadrangles are about 1,000, 250, and 60 square miles, though they differ with the latitude, a "square degree" in the latitude of Boston, for example, being only 3,525 square miles and one in the latitude of Galveston being 4,150 square miles.

FEATURES SHOWN ON THE TOPOGRAPHIC MAPS.

The features represented on the topographic maps comprise three general classes—(1) inequalities of surface, such as plains, plateaus, valleys, hills, and mountains, which collectively make up the *relief* of the area; (2) bodies of water, such as streams, lakes, swamps, tidal flats, and the sea, which collectively make up the *drainage*; (3) such works of man as roads, railroads, buildings, villages, and cities, which collectively are known as *culture*.

Relief.—All altitudes are measured from mean sea level. The heights of many points have been accurately determined, and those of some are given on the map in figures. It is desirable, however, to show the altitude of all parts of the area mapped, the form of the surface, and the grade of all slopes. This is done by contour lines, printed in brown, each representing a certain height above sea level. A contour on the ground passes through points that have the same altitude. One who follows a contour will go neither uphill nor downhill but on a level. The manner in which contour lines express altitude, form, and slope is shown in figure 1.

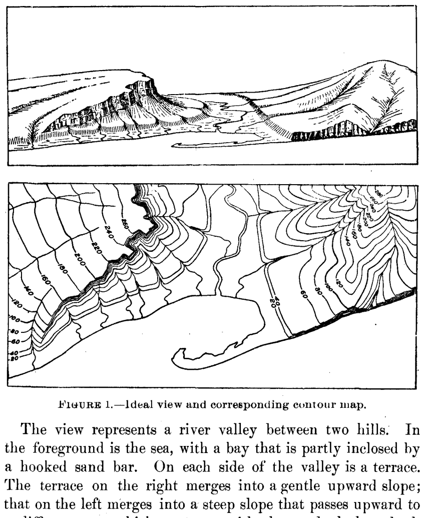


FIGURE 1.—Ideal view and corresponding contour map.

The view represents a river valley between two hills. In the foreground is the sea, with a bay that is partly inclosed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle upward slope; that on the left merges into a steep slope that passes upward to a cliff, or scarp, which contrasts with the gradual slope back from its crest. In the map each of these features is indicated, directly beneath its position in the view, by contour lines. This map does not include the distant part of the view.

As contours are continuous horizontal lines they wind smoothly about smooth surfaces, recede into ravines, and project around spurs or prominences. The relations of contour curves and angles to the form of the land can be seen from the map and sketch. The contour lines show not only the shape of the hills and valleys but their altitude, as well as the steepness or grade of all slopes.

The vertical distance represented by the space between two successive contour lines—the contour interval—is the same, whether the contours lie along a cliff or on a gentle slope; but to reach a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep slopes.

The contour interval is generally uniform throughout a single map. The relief of a flat or gently undulating country can be adequately represented only by the use of a small contour interval; that of a steep or mountainous country can generally be adequately represented on the same scale by the use of a larger interval. The smallest interval commonly used on the atlas sheets of the Geological Survey is 5 feet, which is used for regions like the Mississippi Delta and the Dismal Swamp. An interval of 1 foot has been used on some large-scale maps of very flat areas. On maps of more rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used, and on maps of great mountain masses like those in Colorado the interval may be 250 feet.

In figure 1 the contour interval is 20 feet, and the contour lines therefore represent contours at 20, 40, 60, and 80 feet, and so on, above mean sea level. Along the contour at 200 feet lie all points that are 200 feet above the sea—that is, this contour would be the shore line if the sea were to rise 200 feet; along the contour at 100 feet are all points that are 100 feet above the sea; and so on. In the space between any two contours are all points whose altitudes are above the lower and below the higher contour. Thus the contour at 40 feet falls just below the edge of the terrace, and that at 60 feet lies above the terrace; therefore all points on the terrace are shown to be more than 40 but less than 60 feet above the sea. In this illustration all the contour lines are numbered, but on most of the Geological Survey's maps only certain contour lines—say every fifth one, which is made slightly heavier—are numbered, for the heights shown by the others may be learned by counting up or down from these. More exact altitudes for many points are given in bulletins published by the Geological Survey.

Drainage.—Watercourses are indicated by blue lines. The line for a perennial stream is unbroken; that for an intermittent stream is dotted; and that for a stream which sinks and reappears is broken. Lakes and other bodies of water and the several types of marshy areas are also shown in blue.

Culture.—Symbols for the cultural features and for public-land land lines and other boundary lines, as well as all the lettering and the map projection, are printed in black.

FEATURES SHOWN ON THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic map as a base, the distribution of rock masses on the surface of the land and, by means of structure sections, their underground relations so far as known, in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or *magma*, within these channels—that is, below the surface—are called *intrusive*. An intrusive mass that occupies a nearly vertical fissure which has approximately parallel walls is called a *dike;* one that fills a large and irregular conduit is termed a *stock*. Molten material that traverses stratified rocks may be intruded along bedding planes, forming masses called *sills* or *sheets* if they are relatively thin and *laccoliths* if they are large lenticular bodies. Molten material that is inclosed by rock cools slowly, and its component minerals crystallize when they solidify, so that intrusive rocks are generally crystalline. Molten material that is poured out through channels that reach the surface is called *lava*, and lava may build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and contain, especially in their outer parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows are also usually made porous by the expansion of the gases in the magma. Explosions due to these gases may accompany volcanic eruptions, causing the ejection of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

Sedimentary rocks.—Rocks composed of the transported fragments or particles of older rocks that have undergone disintegration, of volcanic material deposited in lakes and seas, or of material deposited in such bodies of water by chemical precipitation or by organic action are termed *sedimentary*.

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits they form are called mechanical. Such deposits are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits composed of these materials are called organic if formed with the aid of life or chemical if formed without the aid of life. The more common rocks of chemical and organic origin are limestone, chert, gypsum, salt, certain iron ores, peat, lignite, and coal. Any one of the kinds of deposits named may be formed separately, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind, and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is *loess*, a fine-grained earth; the most characteristic of the glacial deposits is *till*, a heterogeneous mixture of boulders and pebbles with clay or sand.

Most sedimentary rocks are made up of layers or beds that can be easily separated. These layers are called *strata*, and rocks deposited in such layers are said to be *stratified*.

The surface of the earth is not immovable; over wide regions it very slowly rises or sinks with reference to the sea, and shore lines are thus changed. As a result of upward movement marine sedimentary rocks may become part of the land, and most of our land surface is in fact composed of rocks that were originally deposited as sediments in the sea.

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate, and their more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. The upper parts of these deposits, which are occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a considerable admixture of organic matter.

Metamorphic rocks.—In the course of time and by various processes rocks may become greatly changed in composition and texture. If the new characteristics are more pronounced than the old the rocks are called *metamorphic*. In the process of metamorphism the chemical constituents of a rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressure, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structural features may have been lost entirely and new ones substituted. A system of parallel planes along which the rock can be split most readily may have been developed. This acquired quality gives rise to *cleavage*, and the cleavage planes may cross the original bedding planes at any angle. Rocks characterized by cleavage are called *slates*. Crystals of mica or other minerals may have grown in a rock in parallel arrangement, causing lamination or foliation and producing what is known as *schistosity*. Rocks that show schistosity are called *schists*.

As a rule, the older rocks are most altered and the younger are least altered, but to this rule there are many exceptions, especially in regions of igneous activity and complex structure.

GEOLOGIC FORMATIONS.

For purposes of geologic mapping the rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone. If the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and the distinction between some such formations depends almost entirely on the fossils they contain. An igneous formation contains one or more bodies of one kind of rock of similar occurrence or of like origin. A metamorphic formation may consist of one kind of rock or of several kinds of rock having common characteristics or origin.

[Continued on inside back cover.]

When it is desirable to recognize and map one or more specially developed parts of a formation the parts are called *members* or by some other appropriate term, such as *lentils*.

AGE OF THE FORMATIONS.

Geologic time.—The largest divisions of geologic time are called *eras*, the next smaller are called *periods*, and the still smaller divisions are called *epochs*. Subdivisions of the Pleistocene epoch are called *stages*. The age of a rock is expressed by the name of the time division in which it was formed.

The sedimentary formations deposited during a geologic period are called a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

As sedimentary deposits accumulate successively the younger rest on the older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or their relations to adjacent beds have been changed by faulting, so that it may be difficult to determine their relative ages from their present positions at the surface.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them or were buried in surficial deposits on the land. Such rocks are said to be fossiliferous. A study of these fossils has shown that the forms of life at each period of the earth's history were to a great extent different from the forms at other periods. Only the simpler kinds of marine plants and animals lived when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived forms that did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. If two sedimentary formations are geographically so far apart that it is impossible to determine their relative positions the characteristic fossils found in them may determine which was deposited first. Fossils are also of value in determining the age of formations in the regions of intense disturbance mentioned above. The fossils found in the strata of different areas, provinces, and continents afford the most effective means of combining local histories into a general earth history.

It is in many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or lies upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

Symbols, colors, and patterns.—Each formation is shown on the map by a distinctive combination of color and pattern and is labeled by a special letter symbol.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations that are known to be of sedimentary or of igneous origin. The patterns of each class are printed in various colors. The colors in which the patterns of parallel lines are printed indicate age, a particular color being assigned to each system.

Each symbol consists of two or more letters. The symbol for a formation whose age is known includes the system symbol, which is a capital letter or monogram; the symbols for other formations are composed of small letters.

The names of the geologic time divisions, arranged in order from youngest to oldest, and the color and symbol assigned to each system are given in the subjoined table.

Geologic time divisions and symbols and colors assigned to the rock systems.

Era.	Period or system.	Epoch or series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent; Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene; Miocene; Oligocene; Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		Ћ	Peacock-blue.
Paleozoic	Carboniferous	Permian; Pennsylvanian; Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Є	Brick-red.
Proterozoic	Algonkian		A	Brownish red.
	Archean		Æ	Gray-brown.

DEVELOPMENT AND SIGNIFICANCE OF SURFACE FORMS.

Hills, valleys, and all other surface forms have been produced by geologic processes. Most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains that border many streams were built up by the streams; waves cut sea cliffs, and waves and currents build up sand spits and bars. Surface forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is built and afterward partly eroded away. The shaping of a plain along a shore is usually a double process, hills being worn away (*degraded*) and valleys filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wears them down, producing material that is carried by streams toward the sea. As this wearing down depends on the flow of water to the sea it can not be carried below sea level, which is therefore called the *base-level* of erosion. Lakes or large rivers may determine base-levels for certain regions. A large tract that is long undisturbed by uplift or subsidence is worn down nearly to base-level, and the fairly even surface thus produced is called a *peneplain*. If the tract is afterward uplifted it becomes a record of its former close relation to base-level.

THE GEOLOGIC MAPS AND SHEETS IN THE FOLIO.

Areal-geology map.—The map showing the surface areas occupied by the several formations is called an *areal-geology map*. On the margin is an explanation, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the explanation, where he will find the name and description of the formation. If he desires to find any particular formation he should examine the explanation and find its name, color, and pattern and then trace out the areas on the map corresponding in color and pattern. The explanation shows also parts of the geologic history. The names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and metamorphic rocks of unknown origin—and those within each group are placed in the order of age, the youngest at the top.

Economic-geology map.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic-geology map*. Most of the formations indicated on the areal-geology map are shown on the economic-geology map by patterns in fainter colors, but the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral product mined or quarried. If there are important mining industries or artesian basins in the area the folio includes special maps showing these additional economic features.

Structure-section sheet.—The relations of different beds to one another may be seen in cliffs, canyons, shafts, and other natural and artificial cuttings. Any cutting that exhibits these relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of the beds or masses of rock in the earth is called *structure*, and a section showing this arrangement is called a *structure section*.

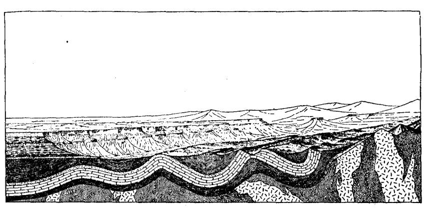


FIGURE 2.—Sketch showing a vertical section below the surface at the front and a view beyond.

The geologist is not limited, however, to natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks, after tracing out the relations of the beds on the surface he can infer their relative positions beneath the surface and can draw sections representing the probable structure to a considerable depth. Such a section is illustrated in figure 2.

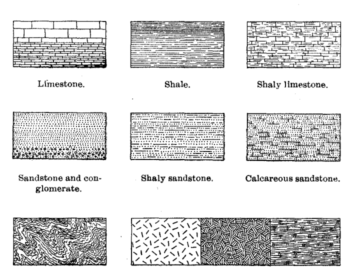


FIGURE 3.—Symbols used in sections to represent different kinds of rock.

The figure represents a landscape that is cut off sharply in the foreground on a vertical plane so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, made up of sandstone, which forms the cliffs, and shale, which forms the slopes. The broad belt of lower land is traversed by several ridges, which, as shown in the section, correspond to the outcrops of a folded bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the beds appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed, and by means of these observations their positions underground are inferred. The direction of the intersection of the surface of a dipping bed with a horizontal plane is called its *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called its *dip*.

In many regions the beds are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the materials that formed the sandstone, shale, and limestone were deposited beneath the sea in nearly flat layers the fact that the beds are now bent and folded shows that forces have from time to time caused the earth's crust to wrinkle along certain zones. In places the beds are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

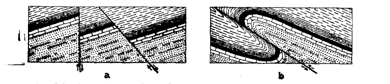


FIGURE 4.—Ideal sections of broken and bent strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted, and the form or arrangement of their masses underground can not be inferred. Hence that part of the section shows only what is probable, not what is known by observation.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of beds of sandstone and shale, which lie in a horizontal position. These beds were laid down under water but are now high above the sea, forming a plateau, and their change of altitude shows that this part of the earth's surface has been uplifted. The beds of this set are *conformable*—that is, they are parallel and show no break in sedimentation.

The next lower set of formations consists of beds that are folded into arches and troughs. The beds were once continuous, but the crests of the arches have been removed by erosion. These beds, like those of the upper set, are conformable.

The horizontal beds of the plateau rest upon the upturned, eroded edges of the beds of the middle set, as shown at the left of the section. The beds of the upper set are evidently younger than those of the middle set, which must have been folded and eroded between the time of their deposition and that of the deposition of the upper beds. The upper beds are *unconformable* to the middle beds, and the surface of contact is an *unconformity*.

The lowest set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and intruded by masses of molten rock. The overlying beds of the middle set have not been traversed by these intrusive rocks nor have they been affected by the pressure of the intrusion. It is evident that considerable time elapsed between the formation of the schists and the beginning of the deposition of the beds of the middle set, and during this time the schists were metamorphosed, disturbed by the intrusion of igneous masses, and deeply eroded. The contact between the middle and lowest sets is another unconformity; it marks a period of erosion between two periods of deposition.

The section and landscape in figure 2 are ideal, but they illustrate actual relations. The sections on the structure-section sheet are related to the maps in much the same way that the section in the figure is related to the landscape. The profile of the surface in each structure section corresponds to the actual slopes of the ground along the section line, and the depth to any mineral-producing or water-bearing bed shown may be measured by using the scale given on the map.

Columnar section.—Many folios include a *columnar section*, which contains brief descriptions of the sedimentary formations in the quadrangle. It shows the character of the rocks as well as the thickness of the formations and the order of their accumulation, the oldest at the bottom, the youngest at the top. It also indicates intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition.

THE TEXT OF THE FOLIO.

The text of the folio states briefly the relation of the area mapped to the general region in which it is situated; points out the salient natural features of the geography of the area and indicates their significance and their history; considers the cities, towns, roads, railroads, and other human features; describes the geology and the geologic history; and shows the character and the location of the valuable mineral deposits.

GEORGE OTIS SMITH,
Director.

January, 1924.

DESCRIPTION OF THE COATESVILLE AND WEST CHESTER QUADRANGLES

By F. Bascom and George W. Stose

INTRODUCTION

LOCATION AND AREA

The Coatesville and West Chester quadrangles are 14 miles west of Philadelphia, between parallels 39° 45′ and 40° and meridians 75° 30′ and 76°. They include one-eighth of a "square degree" and cover an area of about 458 square miles. This area embraces portions of Delaware, Chester, and Lancaster Counties, Pa., and New Castle County, Del., but is chiefly in Chester County. It sustains a population of nearly 130,000, of whom about one-half live in the principal towns—Wilmington, Del., and Coatesville, West Chester, Parkesburg, Kennett Square, Oxford, West Grove, Christiana, Atglen, and Avondale, Pa. The quadrangles take their names from the two largest towns, Coatesville and West Chester, 38 and 30 miles respectively west of Philadelphia. (See fig. 1.)

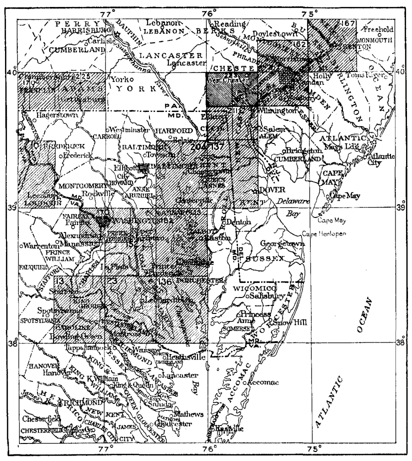


Figure 1.—Index map of southeastern Pennsylvania, Delaware, and parts of adjacent States

The location of the Coatesville and West Chester quadrangles is shown by darker ruling (No. 223). Published folios describing other quadrangles, indicated by lighter ruling, include Nos. 10, Harpers Ferry; 13, Fredericksburg; 23, Nomini; 70, Washington; 136, St. Marys; 137, Dover; 152, Patuxent; 162, Philadelphia; 167, Trenton; 170, Mercersburg-Chambersburg; 182, Choptank; 204, Tolchester; 211, Elkton-Wilmington; 225, Fairfield-Gettysburg.

CLIMATE, VEGETATION, AND CULTURE

In the Coatesville-West Chester district the rainfall is normally ample, reliable, and equably distributed throughout the year, an ideal condition for crops. The winds blow prevailingly from the north and northwest during the winter, spring, and autumn and from the south and southwest during the summer. Climatic records have been kept at West Chester and Coatesville for periods ranging from 25 to 71 years. These records show a mean annual temperature of about 52°, with a range from 13° to 107°; a mean annual rainfall of 49 inches; and a growing season ranging from 150 to 222 days.

The vegetation of the Coatesville-West Chester district is diversified and vigorous. The early forests have disappeared, but the district is well wooded with trees of second growth, among which are oaks in great variety, hickory, chestnut, walnut, beech, birch, maple, ash, locust, poplar, tulip tree, sycamore, linden, pine, hemlock, and cedar. Neat dwellings, spacious barns, and cultivated fields interspersed with woods create a pleasing landscape. The district is devoted to farming and dairying. The farm products are chiefly corn, oats, wheat, and other grains and potatoes. Much land is utilized as pastures for Holstein, Jersey, Guernsey, and other cattle. Milk is carried by autotrucks to the numerous local creameries or shipped by rail to Philadelphia.

The culture of mushrooms and carnations is extensively developed in an area which has been called the carnation belt and which includes West Grove, Avondale, Toughkenamon, and Kennett Square. The Chester loam, combined with "fish egg" lime sand and manure, makes a fertile soil for carnations, which are grown in greenhouses and shipped chiefly to Philadelphia. West Grove is said to have the largest rose-growing establishments in America.

Good dirt roads, hard-surfaced main highways, trolley lines, and excellent railway facilities are cultural features of the district. The Lincoln Highway traverses Chester Valley. The four tracks of the main line of the Pennsylvania Railroad follow Chester Valley with a branch line to West Chester and another from Pomeroy through Avondale; the Philadelphia, Baltimore & Washington line (Maryland division) passes through Wilmington, and another line of the Pennsylvania system (central division), with a West Chester branch, passes through Chadds Ford, Kennett Square, Avondale, West Grove, and Oxford. A narrow-gage road formerly connected Oxford with Peach Bottom on the Susquehanna and with Lancaster. The Baltimore & Ohio Railroad and the Wilmington division of the Philadelphia & Reading Railroad also traverse the district.

Trolley lines connect West Chester with Philadelphia, with Downingtown, Coatesville, Parkesburg, and Atglen, and with Lenape, Kennett Square, Avondale, and West Grove, but some of them are not now operating. Kennett Square, Hockessin, and Wilmington also are connected by trolley.

Aside from Wilmington, which lies partly in the Wilmington quadrangle, adjacent on the south, Coatesville and West Chester are the two largest towns. West Chester, on a relatively high and level upland, is primarily a residential borough of over 12,000 inhabitants. It is the capital of Chester County, the seat of a State normal school, and the center of a flourishing agricultural district. It contains extensive nurseries and other minor industries. Coatesville Borough, in Chester Valley, with a rapidly increasing population, now over 14,500, is an industrial center containing iron and steel works, boiler works, steel-plate mills, and brass and iron foundries.

APPALACHIAN HIGHLANDS

GENERAL CHARACTER

The Coatesville and West Chester quadrangles lie within the major physiographic division known as the Appalachian Highlands.* A consideration of the geographic and geologic character of this division will aid in a thorough understanding of the history of the district.

The Appalachian Highlands extend from the Atlantic Plain on the east and south to the Interior Plains on the west and north. They have been divided into well-marked provinces that form northeast-southwest belts, distinguished by characteristic rock formations, geologic structure, and topography. In the latitude of Pennsylvania these provinces are from west to east (1) the Appalachian Plateaus, comprising the Allegheny and Cumberland Plateaus; (2) the Appalachian Valley and Ridge province, comprising a southeastern group of valleys

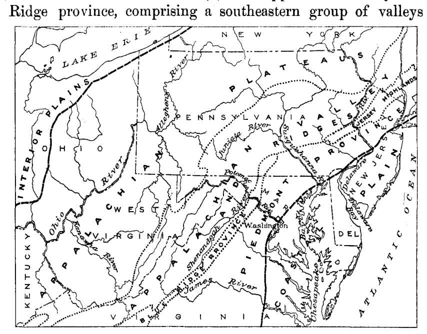


Figure 2.—Map of the northern Appalachian Highlands showing physiographic divisions and relations to Coastal Plain

and a northwestern succession of narrow ridges and valleys, lying between the eastward-facing escarpment of the Allegheny Plateau and South Mountain and the Reading Hills, the continuation in Pennsylvania of the Blue Ridge; (3) the Blue Ridge province; and (4) a group of plateaus which, stretching away eastward and merging into the Coastal Plain, constitute a broad upland known as the Piedmont province. The Coatesville-West Chester district lies entirely within the Piedmont province, on its southeast border. (See fig. 2.)

PIEDMONT PROVINCE

Geography.—The Piedmont province, which owes its name to its location at the foot of the Blue Ridge, merges on the northeast with the New England province. On the southwest it is terminated in Alabama and Georgia by the Gulf Coastal Plain, and on the east it is bounded by the Coastal Plain. The province has a mean width of 60 miles and a maximum width in its central portion of 120 miles.

The boundary between the Piedmont province and the Coastal Plain is defined in most places by a well-marked change in topography and geology. Topographically the change consists generally in the abrupt transition from an upland of diversified relief to a relatively smooth lowland. Geologically there is a transition from hard crystalline rock to gently dipping beds of unconsolidated clay, sand, and gravel of far more recent age. The formations of the Coastal Plain overlap the eastern border of the upland and in some districts extend far within the upland.

The eastern margin of the Piedmont province is everywhere marked by a decrease in the gradient of the streams that pass from upland to plain. So numerous are the falls or rapids at the margin of the upland that this boundary has been called the "fall line." Actually the "fall line" is a zone of appreciable width. North of Roanoke River the Coastal Plain is deeply embayed, and east of the "fall line" navigable streams flow into tidal estuaries, thus affording good shipping facilities; west of the "fall line" the streams cease to be navigable and occupy narrow, rocky channels. South of the Roanoke the "fall line" gradually rises in altitude until in the Carolinas and Georgia, although falls and rapids still mark its location and furnish power for factories, it lies considerably higher than the tide limit.

The position of the "fall line" at the head of navigation and at the source of water power has been so far dominant in determining the location of the large cities of the Atlantic States that a line passing through New York, Trenton, Philadelphia, Wilmington, Baltimore, Washington, Fredericksburg, Richmond, Petersburg, Raleigh, Columbia, and Macon is closely coincident with the "fall line" and in general marks the boundary between Piedmont Upland and Coastal Plain.

The Piedmont province is separable into two sections—the Triassic Lowland and the Piedmont Upland. The lowland is a narrow belt of country in the northern and western part of the province, underlain by relatively soft Triassic sandstone and shale. It is in general a less rugged country than the upland section but exhibits the same topographic features, though less strikingly. The Coatesville and West Chester quadrangles lie wholly within the Piedmont Upland, which is the dominating section of the Piedmont province.

There are certain general features common to the entire Piedmont region which make it a topographic unit: it consists, in brief, of a succession of gently sloping uplands of successively lower altitude, dissected by relatively narrow valleys and diversified by residual eminences (monadnocks) rising above the general level. If the valleys were filled, the uplands would be converted into a series of more or less undulating seaward-facing terraces, sloping gently eastward and southeastward toward the Atlantic. These terraces resolve themselves into several dissected upland plains or slopes representing either old peneplains or other topographic features produced in the early stages of peneplanation. Their character and history is narrated under "Geologic history."

Geology.—The rocks of the Piedmont province comprise metamorphic schists and gneisses of Archean and Algonkian age and associated intrusive igneous rocks; schists, quartzites, and limestones of Cambrian and Ordovician age, with associated igneous intrusives; and Triassic conglomerates, sandstones, and shales, with associated igneous intrusives.

The most ancient pre-Cambrian rocks, the Archean, are metamorphosed sandy and clayey sediments with rare limy beds. These rocks have been intruded by igneous material and also minutely injected by such material, which has produced a layering or fine banding, and they have also been folded and intensely metamorphosed. They are known in the Pennsylvania-Maryland region as Baltimore gneiss and Franklin limestone. Upon the eroded surface of this ancient complex there was deposited, in Algonkian time, a second series of sandy, clayey and limy beds, together with local but extensive

[1] All the descriptions are by F. Bascom except those of the Paleozoic sediments and their history, which are by G. W. Stose.

flows of lava. All these rocks have been closely folded and highly metamorphosed, being now represented by gneiss, schistose quartzite, marble, and schist. They are, moreover, in places intricately invaded and injected by granite and are cut by large and small masses of igneous rocks—gabbro, diorite, peridotite, and pyroxenite, the last two altered in most places to serpentine.

Upon the eroded and submerged surface of these ancient pre-Cambrian formations was deposited, in Paleozoic time, a thick series of sandstones, shales, and limestones, which in turn underwent deep burial, close folding, metamorphism, and in places injection by granitic magma. Thus these rocks, like those of the pre-Cambrian, are now in this region represented by quartzite, micaceous schist, phyllite, and marble. To the west, however, these rocks are progressively less folded and less altered, and they constitute the underlying rocks of the western portion of the Appalachian Highlands. In Triassic time, after uplift, erosion of the Paleozoic rocks, and resubsidence of the land, red sandy and clayey sediments were deposited, and in places masses of lava were poured out and the rocks were also invaded by sills and dikes of basalt.

On the extreme eastern border of the Piedmont province and in scattered areas near the eastern border the crystalline rock floor is concealed beneath unconsolidated beds of gravel, sand, and clay that were deposited along a former coast line during Cretaceous time. A thin covering of sand and gravel of late Tertiary and Quaternary age, left by erosion in scattered areas, overlaps these formations.

TOPOGRAPHY

RELIEF AND SURFACE FORMS

The Coatesville-West Chester district is on the southeastern border of a low dissected upland that slopes southeastward and does not possess a high relief. The highest hill, which reaches 860 feet above sea level, is in the northwest corner of the district; the lowest land lies in the extreme southeast, where Brandywine Creek leaves the district in a valley only 20 feet above sea level. There is a total relief, therefore, of 840 feet, sufficient to produce rugged and picturesque scenery in the neighborhood of the main drainage lines, with nearly level or gently undulating interstream areas.

The country owes its present aspect to remnants of a number of peneplains and berms that are described in the section on physiography. No vestige of the older of these peneplains—the Kittatinny-Schooley—is preserved in the Coatesville and West Chester quadrangles; the Harrisburg and Bryn Mawr partial peneplains dominate the landscape. The Harrisburg is preserved in the northwestern part of the West Chester quadrangle at 500 to 590 feet. The relatively high, slightly rolling country of the central southwestern portions of the Coatesville quadrangle preserves the Harrisburg peneplain at altitudes of 600 to 620 feet. Cochranville, Hayesville, and Oxford are located on it. From this prevailing level the Harrisburg rises to 700 feet in the higher summits of the South

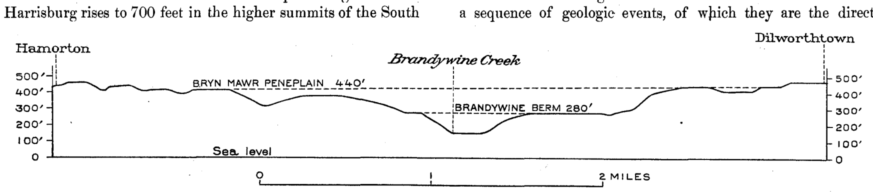


FIGURE 5.—Cross section of the valley of Brandywine Creek from Hamorton to Dilworthtown, showing stream terraces

Valley Hills and to 800 feet in the extreme northwest corner of the quadrangle, where it ascends toward the crest of a low arch which warped the Harrisburg peneplain at the time of the uplift and deformation of the Bryn Mawr peneplain. (See fig. 3.)

These remnants of an old peneplain are controlled in location and in form by the geology of the district—that is, they conform to the outcrop on the peneplain surfaces of the more resistant of the underlying rock formations, for it is to the resistant character of the rocks that they owe their preservation during later periods of erosion.

The dominant level upland of the West Chester quadrangle rises from 400 feet along the Pennsylvania-Delaware boundary line to 460 feet in the central and northern portions of the quadrangle. Unionville, Dilworthtown, Thornton, Marshallton, Rocky Hill, and West Chester are located on this well-defined upland, which is the remnant of the youngest peneplain, the Bryn Mawr. To the west, in the Coatesville quadrangle, the Bryn Mawr peneplain rises to an altitude of 560 feet. Although larger areas of this peneplain are preserved than of the older peneplains, it is everywhere submaturely dissected. The dissection, distributed through more than one erosion cycle, has produced a gentle slope from

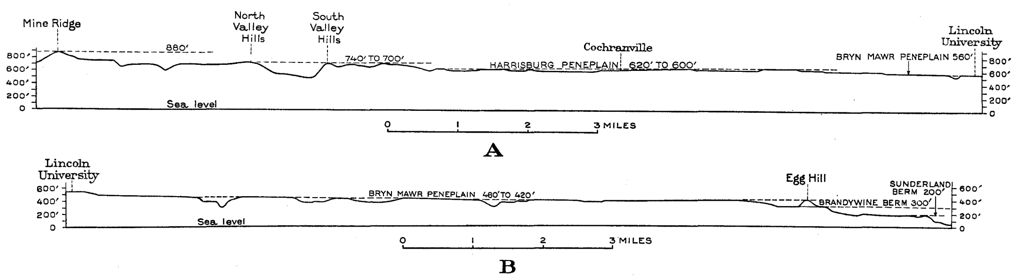


FIGURE 3.—Projected profiles across the Coatesville quadrangle, showing remnants of Harrisburg and Bryn Mawr peneplains

A, From Mine Ridge near northwest corner of quadrangle to Lincoln University; B, from Lincoln University to and beyond Egg Hill, in the Elkton quadrangle

400 to 200 feet, the Brandywine berm, and a steep descent from 200 feet to less than 100 feet at the bottoms of the master gorges, representing Pleistocene and Recent erosion. (See fig. 4.) The battle of the Brandywine took place on the Brandywine berm.

DRAINAGE

The streams of the district are tributary to Delaware and Chesapeake Bays through Delaware, Elk, and Susquehanna Rivers. Somewhat over three-fourths of the district drains through Delaware River; Ridley and Chester Creeks, on the east, empty directly into that stream; Brandywine Creek, which has the largest drainage basin in the area, and Red Clay and White Clay Creeks empty into the Delaware by way of Christiana River. Big Elk and Little Elk Creeks, which drain the southwestern border of the Coatesville quadrangle, form Elk River, which empties into Chesapeake Bay. Octoraro Creek, the East Branch of which drains the extreme western border of the Coatesville quadrangle, empties into Susquehanna River about 9 miles above its mouth.

None of these streams are navigable; all of them flow in rocky channels. Brandywine Creek has an average flow of 279 cubic feet a second.

The eight streams have in common four striking characteristics: (1) they pursue southeasterly, southerly, or southwesterly courses, transverse to the trend of the geologic formations, and thus pass from soft to hard rocks, through which alike they have cut their channels; (2) they all flow in terraced valleys—that is, they occupy gorges which are sunken in wide U-shaped valleys which are in turn cut in still wider shallow valleys (see fig. 5); (3) the main stream channels are more or less meandering, although at present the gradients are sufficient for vertical corrasion; (4) the tributary streams, on the other hand, flow in somewhat angular courses. These four features reveal a sequence of geologic events, of which they are the direct result. The southerly courses and the independence of rock structure are due to the original southwesterly tilt of the uplifted peneplains, which determined the direction of stream flow, and to the masking by planation, or concealment by sedimentation, of the underlying discordant rock structure, so that the courses of the streams became fixed early in their history. The terraced valleys are due to successive accelerations of valley cutting consequent upon slight uplifts of the peneplains. The meandering main channels are due to the original deficiency of slope of the uplifted peneplains.

In the angular courses of the tributary streams is seen that adjustment to rock structure which later subsequent streams are likely to reveal. The well-defined joint systems, or sets of parallel planes of parting, strike N. 75° E. and N. 40° E., N. 10° W. and N. 45° W., and by furnishing lines of least resistance have markedly influenced the courses of the subsequent streams.[2]

In apparent contradiction to what has been said, the best-defined valley and most marked topographic feature of the district is not a transverse valley but one that extends northeastward, parallel to the trend of the geologic formations. This is Chester Valley, a straight, narrow lowland between the North Valley and South Valley Hills, in the northern part of the Coatesville quadrangle. This valley is remarkable in the fact that it is not occupied by a master stream but is crossed by transverse streams, whose minor tributaries, flowing northeast or southwest, share Chester Valley but have not made it. The floor of the valley exactly conforms to the outcrop of formations composed of limestone; the North Valley Hills consist of hard, resistant quartzite, and the South Valley Hills are composed of fairly resistant mica-quartz schist; the valley floor has no stream gravel or other alluvial deposit, its slopes show no terracing, and the valley abruptly terminates to the northeast and the southwest where the limestone disappears. These phenomena indicate that Chester Valley does not owe its origin chiefly to stream cutting but to the differential weathering, with transportation by minor streams, of an uplifted peneplain, presumably the Honeybrook.

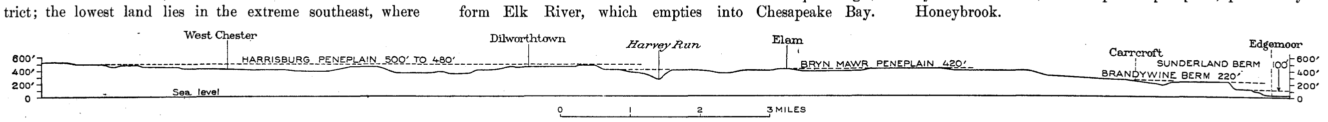


FIGURE 4.—Projected profile across the West Chester quadrangle through West Chester to Edgemoor, showing Bryn Mawr peneplain, Brandywine berm, and Pleistocene erosion slopes

GENERAL GEOLOGY

The rocks of the Coatesville and West Chester quadrangles comprise limestone, marble, quartzite, schist, and gneiss, of sedimentary origin, and diabase, granite, diorite, gabbro, pyroxenite, and peridotite, of igneous origin. The sedimentary rocks are classified as follows:

Quaternary (Pleistocene series):
- Talbot formation.
- Sunderland formation.
- Brandywine gravel.

Tertiary (Pliocene series):
- Bryn Mawr gravel.

Unconformity.

Ordovician:
- Conestoga limestone.

Unconformity.

Middle Cambrian.
- Elbrook limestone.

Unconformity.

Lower Cambrian:
- Ledger dolomite.
- Kinzers formation.

Lower Cambrian—Continued.
- Vintage dolomite.
- Antietam quartzite.
- Harpers schist.
- Chickies quartzite.

Unconformity.

Algonkian (Glenarm series):
- Peters Creek schist.
- Wissahickon formation.
- Cockeysville marble.
- Setters formation.

Unconformity.

Archean:
- Franklin limestone.
- Baltimore gneiss.

These rocks are shown in columnar form in the columnar section at the end of the text. A closely similar series of formations is present in the adjacent parts of Pennsylvania and Maryland, and some of them extend southward into Virginia and northward into Delaware, New Jersey, New York, and even New England.

SEDIMENTARY ROCKS

ARCHEAN SYSTEM

BALTIMORE GNEISS

Distribution.—The Baltimore gneiss appears in the crest of three anticlines that strike northeast and pitch southwest. The most northerly anticline forms the upland of West Sadsbury and Sadsbury Townships, in the northwestern part of the Coatesville quadrangle. This upland is the northeastern extension of Mine Ridge Hill, in the Quarryville quadrangle. The gneiss passes under Paleozoic sediments west of the Coatesville quadrangle.

The two more southerly anticlines pitch sharply to the southwest on the eastern border of the Coatesville quadrangle. In the northern one the Baltimore gneiss passes beneath a later pre-Cambrian (Glenarm) series in the vicinity of Clonmell and

[2] Bliss, E. F., and Jonas, A. I., Relation of the Wissahickon mica gneiss to the Shenandoah limestone and Octoraro mica schist of the Doe Run and Avondale region, Chester County, Pa.: U. S. Geol. Survey Prof. Paper 98, pl. 3, 1917.

Chatham. The southern anticline plunges under these rocks just east of Toughkenamon. The Glenarm rocks occupy the central and western portions of the Coatesville quadrangle. To the northeast the belt of Baltimore gneiss widens in the West Chester quadrangle but is interrupted in continuity by igneous intrusions and is covered over a considerable area by the younger Glenarm rocks. At the northwest corner of the West Chester quadrangle the Baltimore gneiss has a width of about 8 miles. The Baltimore gneiss underlies the relatively high rolling country that represents the surface of the Bryn Mawr and Harrisburg peneplains.

Character.— The Baltimore gneiss in this district is a medium-grained, finely or coarsely layered, compact rock composed mainly of quartz, feldspar, and biotite. The color varies with the content of biotite, ranging from a light gray and buff to dominantly dark gray. Hornblende is in some places associated with the biotite. This sedimentary formation is intricately injected by granitic pegmatite and by dikes and irregular masses of diorite, gabbro, and peridotite. (See pls. 1 and 2.) The pegmatite injection has been minute and intense and also on a grand scale, and to it is due much of the banded or layered character of the gneiss. The layering is conspicuously displayed on the West Branch of Brandywine Creek at the northern border of the Coatesville quadrangle. Gabbroic injections parallel the layers and break across them. Only the larger of the numberless dikes and other intrusive masses have been mapped. The light-colored invading layers consist of quartz, orthoclase, and sodic plagioclase. They are very irregular in width, swelling in places to considerable dimensions and decreasing elsewhere to paper thinness; alkali feldspar crystals in layers or dissociated from the layers reach 2 or 3 centimeters in diameter; crystals of hornblende, 1 centimeter in diameter, have also been developed, and the biotitic layers curve about these crystals or about aggregates of quartz and feldspar. The rock thus acquires a porphyritic character, and where silica is the dominant invading material and gives rise to anhedral quartz, the rock appears conglomeratic. Garnets, titanite, and zircon are accessory.

An old quarry near the railroad three-quarters of a mile north of Lenape shows the dark-colored fine-grained biotitic pseudo-conglomeratic type, which is also exposed 1 mile and $1\frac{1}{2}$ miles north and $1\frac{1}{2}$ miles northeast of Lenape and 1 mile south of Pocopson.

The light-colored finely layered type of normal gneiss shows granular quartz, microcline and other alkali feldspars, oligoclase (chiefly $Ab_{80}An_{20}$ to $Ab_{70}An_{30}$), a little andesine and orthoclase, and fine stringers of biotite, which by their aggregation produce the layering. Magnetite, apatite, and rounded grains of zircon and of titanite are accessory constituents, and epidote is secondary. The texture is inequidimensional (seriate porphyroid) with a more or less parallel arrangement of grains. The crystallization is fresh.

Locally the gneiss has been sheared into a mica schist, which breaks down rapidly upon exposure to weathering. This is the character of the rock at the Meredith and Black Horse feldspar quarries and in general on the northwest flank of the Sadsbury anticline. The gneiss bordering the thrust fault, just north of West Chester, has been mylonized into a compact schist with lens-shaped feldspar crystals.

In some places the gneiss contains graphite-bearing beds.[3] The gneiss overlying the Franklin limestone exposed at Brinton Bridge contains graphite, and about 6 miles east of Brinton Bridge, in Concord Township, on the eastern border of the West Chester quadrangle, in the vicinity of Ward, graphite-bearing gneiss shows in loose fragments in the fields, but its areal limits can not be exactly determined. In the Coatesville quadrangle graphite-bearing beds crop out in a railway cut near Valley station and in a road bank $2\frac{1}{2}$ miles west of Coatesville and a quarter of a mile north of the Lancaster pike (Lincoln Highway). Graphite-bearing beds are a minor feature of the Baltimore gneiss of the Coatesville-West Chester area, but they become areally and economically important to the north, in the Phoenixville and Honeybrook quadrangles, and similar graphite-bearing gneiss occurs in Sussex County, N. J.[4] The graphite-bearing gneiss as a rule is strongly micaceous, containing both muscovite and biotite, and quartz is more abundant than feldspar. The feldspar is orthoclase, microcline, and labradorite. Garnet, calcite, tremolite, and rounded zircons of a considerable size are accessory constituents. The ease with which these beds break down under weathering into a strongly hematitic or limonitic soil is characteristic of them.

[3] Several years ago the writer, in mapping the rocks of the Phoenixville quadrangle, Pa., separated the graphitic gneisses from the nongraphitic gneisses and proposed to apply to them the geographic name "Pickering gneiss," restricting the name Baltimore gneiss to the nongraphitic rocks, and that name and definition were published in an article by B. L. Miller in Economic Geology (vol. 7, p. 767, 1912). More recent work, however, on the pre-Cambrian gneisses of southeastern Pennsylvania and Delaware, has led the writer to consider the graphitic gneiss associated with recognized Baltimore gneiss as essentially a facies of that formation and not a distinct formation. In this folio and other reports in preparation, therefore, the graphitic gneiss is included in the Baltimore gneiss, and the name "Pickering gneiss" is dropped.—F. B.

[4] Wolff, J. E , New Jersey Geol. Survey Ann. Rept. for 1893, p. 365, 1894. Bayley, W. S., U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), 1908.

The Baltimore gneiss where thoroughly intruded by great masses of gabbroic material loses its distinctive layered character and presents the aspect of an igneous rock that has approximately the mineral composition of either a granite, quartz monzonite, granodiorite, or quartz diorite, the particular phase depending upon the original constitution of the sediment and the degree in which the rock has been affected by the igneous invasion. This massive pseudo-igneous phase of the Baltimore gneiss follows the contact with massive intrusions of gabbro, of which only a fraction probably appears in the surface outcrops, and is typically developed at Rocky Hill and northeast and west of Rocky Hill, where massive spheroidal boulders of a rusty yellow-gray on the weathered surface and a dark blue-gray on fresh fractures strew the fields. Very similar material is exposed in contact with gabbro in two quarries west of West Chester, on Chestnut Street and on the Copesville road, and is found on either side of the intrusive gabbro in the neighborhood of Chadds Ford. This rock, though superficially resembling gabbro, on examination proves to be irregularly saturated with a dark-blue quartz, to contain scanty pyroxene (hypersthene or augite), and in some places to retain such evidence of origin as rounded apatite grains. Gray feldspar and quartz distributed in layers are the chief primary constituents. The feldspar includes orthoclase, microcline, microperthite, and sodic plagioclase in extremely variable amounts. Garnets are very abundant. The texture is inequigranular, with evidences of strain. A similar rock is found in the Schuylkill River section, where gabbro intrudes the Baltimore gneiss. In mineral constitution and presumably in chemical composition this rock ranges from an alaskose to a quartz diorite with a wide range in the character of the feldspar and in the amount of quartz present. Briefly, the rock resembles an abridged differentiation series. In the rock at Dutton Mill, northeast of Rocky Hill, which grades into a true gabbro, the constituents are quartz > orthoclase > plagioclase $\lesseqgtr$ hypersthene. The injection of the gneiss by gabbro, displayed in the two quarries on the western outskirts of West Chester, has rendered the gabbro very quartzose and developed both augite and garnets in the gneiss.

It is believed that this rock did not originate from the solidification of an igneous magma produced by differentiation but is the result of the reaction of a gabbroic magma upon a siliceous gneiss. This view is based also on field relations: the rock is confined to contacts between gneiss and gabbro; the rock preserves more or less the texture as well as the constituents of the gneiss; in most places it weathers like a sediment; stages are found from simple injection through a reaction series to typical gneiss; the silica content varies greatly in a single mass; there is no persistent well-defined type. The rock was at first mapped separately from the Baltimore gneiss, but later it was thought that the facts did not justify separate mapping. Although spheroidal weathering has taken place in some localities, and although, where the injecting material dominates, because of its dark color the rock superficially resembles gabbro more than gneiss, its mineral and chemical constitution so closely affiliate it with the gneiss that it has been included in the areas mapped as gneiss.

About a mile southeast of Cheyney station, near the east edge of the West Chester quadrangle, north of the road to Locksley, a large boulder at the contact between gneiss and gabbro shows brecciated gneiss in a gabbroic cement.

On the southeast flank of the Sadsbury anticline granitic injections prevail, and exposures on Buck Run and fragments found in the fields have the appearance of a biotite granite gneiss. The segregation of the biotite in layers, the variation in granularity of the quartz-feldspar layers, the rounded shape of the zircon where present, the unlikeness of the texture of the rock to that of the igneous material of the Pennsylvania Piedmont, and the absence of spheroidal weathering—all have led to the belief that this is only a strongly injected facies of a sedimentary gneiss, which at other places may be a quartzose gneiss (south and east of Sadsburyville), a mica gneiss, or a mica schist.

In the immediate neighborhood of peridotite intrusions a recrystallization of the gneiss has taken place, with the development of hornblende. Thus here also the rock has an igneous aspect which masks its real origin.

No analyses of the Baltimore gneiss from the Coatesville-West Chester district are available, but the analyses in the next column represent the gneiss in the region east of this district.

The chemical constitution shown by analysis 2 reveals no indication of a sedimentary origin. The sample was a composite of the massive facies collected from six localities in the Philadelphia district and therefore shows a more balanced composition than is normal for a sedimentary formation. Analyses 1 and 3 show an excess of alumina over the 1:1 ratio necessary to satisfy the alkalies and lime, though not a greater excess than is found in igneous rocks, and in analysis 4 the percentage of silica borders on the excessive. Nos. 1 and 4 are graphite-bearing micaceous (biotitic) facies, and the presumption is strongly in favor of their sedimentary origin.

Analyses of Baltimore gneiss

	1	2	3	4
SiO_2	72.99	70.21	64.34	63.93
Al_2O_3	10.90	13.95	16.61	12.02
Fe_2O_3	.55	1.05	2.00	2.40
FeO	2.50	3.08	3.96	2.95
MgO	1.07	1.26	.38	2.44
CaO	1.88	3.10	3.32	4.00
Na_2O	3.34	3.27	2.84	3.15
K_2O	1.20	2.69	3.61	.84
$H_2O\pm$	1.47	.67	.80	1.30
CO_2		.11		.51
TiO_2	.84	.52	1.20	1.04
ZrO_2		Trace.		
P_2O_5	.18	.10	.19	
S		.09		
FeS_2	1.61			
Fe_7S_8				4.04
NiO		Faint trace.		
MnO		.11	.33	Trace.
BaO		.09		Trace.
Li_2O			Trace.	
SrO		Trace.		
Graphite	1.13			Not determined.
	99.66	100.30	99.58	98.62

1. Graphite-bearing gneiss, 1 mile east of Feasterville, Bucks County. F. A. Genth, jr., analyst, Pennsylvania Second Geol. Survey Rept. C6, p. 116, 1881.
2. Composite sample from Philadelphia district. W. F. Hillebrand, analyst, United States Geological Survey.
3. Gneiss near Paper Mills station, Pennypack Creek, Montgomery County. F. A. Genth, jr., analyst, op. cit., p. 117.
4. Graphite-bearing gneiss, Neshaminy Creek, Bucks County. F. A. Genth, jr., analyst, op. cit., p. 105.

NORMS

	1	2	3	4
Quartz	42.24	30.06	24.90	29.82
Orthoclase	7.23	16.68	21.13	5.00
Albite	28.30	27.77	24.10	27.25
Anorthite	8.62	15.01	15.57	15.85
Corundum	.92		2.35	
Hypersthene	5.47	6.99	5.09	6.45
Diopside		.22		3.13
Magnetite	.93	1.39	3.02	3.48
Ilmenite	1.52	.91	2.28	1.98
Apatite	.34	.34	.34	
Hematite				
Pyrite	1.61	.15		Fe_7S_8 4.04
Water	1.47	.67	.80	1.30
Carbon dioxide		.11		.51
Graphite	1.13			
	99.78	100.30	99.58	98.81

1. I(II).3.2″.4. Alsbachose. Quartz not excessive for Class I; excessive alumina; MgO < CaO; K_2O < Na_2O.
2. I(II).″4.(2)3.(3)4. Yellowstonose. Quartz not excessive for Class I; no excess alumina; MgO < CaO; K_2O < Na_2O.
3. I(II).″4.(2)3.3. Amiatose. Quartz not excessive for Class I; excessive alumina; MgO < CaO; K_2O < Na_2O.
4. II.3″.3.4″. Quartz bordering on excessive for Class II; no excess alumina: MgO < CaO; K_2O < Na_2O.

Thickness, correlation, and name.—The Baltimore gneiss forms at least a part of the floor upon which the later sediments were laid down, but no estimate can be made of its thickness. The gneiss is regarded as pre-Cambrian because it is in some places overlain unconformably by indubitably pre-Cambrian rocks (Glenarm series). In the Coatesville quadrangle it is flanked on each side of an anticline by Chickies quartzite, of Lower Cambrian age, and to the northeast of the Coatesville-West Chester district it underlies the Cambrian conglomerate which forms the basal member of the Chickies quartzite and which contains pebbles of the blue quartz that is a characteristic vein material in the gneiss and its igneous associates.

The early pre-Cambrian (Archean) gneiss of Maryland is known as the Baltimore gneiss, from the type locality on Jones Falls Creek in the city of Baltimore. Although the Baltimore gneiss of Pennsylvania is not stratigraphically continuous with the Baltimore gneiss of Maryland, similar stratigraphic relations and petrographic character have been recognized in the common designation.

The Baltimore gneiss is to be correlated with the Fordham gneiss of New York. (See correlation table at end of text.)

FRANKLIN LIMESTONE

Distribution.—The only exposure of the Franklin limestone in the Coatesville-West Chester district is in an old quarry (Harvey's) 1 mile north of Chadds Ford, on the west side of Brandywine Creek, opposite Brinton Bridge.

Character.—The rock is a banded marble and lies interbedded in quartzitic gneiss which is welded with the marble and finely plicated, with a general dip of about 45° SE. Both the marble and the gneiss contain graphite, and the marble in addition contains chondrodite. It is distinguished from all other limestones in the district by the presence of these two minerals. The marble is believed to be near or at the top of the Baltimore gneiss and generally younger than the main mass of that formation.

Thickness, correlation, and name.—At the outcrop mentioned, as in all other occurrences of the Franklin limestone in the Piedmont of Pennsylvania, the formation is not more than 50 feet thick.

This marble in Pennsylvania is correlated with the Franklin limestone of New Jersey because of its similar association with a pre-Cambrian graphitic gneiss and because of similar mineralization, which produced a large number of silicate minerals as well as graphite. In this locality chondrodite is the only notable silicate mineral present of the ninety-odd minerals listed from the type locality at Franklin Furnace, N. J. The crystalline limestone or marble of Sussex County, N. J., in the neighborhood of Franklin Furnace, was first called Franklin by Wolff and Brooks.[5]

ALGONKIAN SYSTEM

GLENARM SERIES

The Glenarm series, of late pre-Cambrian (Algonkian) age, unconformably overlies the Baltimore gneiss. Four formations of the series are present in the Coatesville and West Chester quadrangles—the Setters formation at the base, the Cockeysville marble, the Wissahickon formation, and the Peters Creek schist. The Setters formation and the Cockeysville marble, of highly variable thickness and areal extent, are not coextensive with the Wissahickon formation, which overlaps them and lies in places directly upon the Baltimore gneiss.

SETTERS FORMATION

Distribution.—The Setters formation occurs as a narrow marginal fringe on two anticlines in the Coatesville quadrangle and extends northeastward in the West Chester quadrangle until faulted out.

Character.—The formation consists chiefly of quartzite or quartzitic schist, and ranges from a compact almost white or buff quartzite to gray mica gneiss. There is considerable variation in the percentage of the primary constituents. Biotite with lesser amounts of muscovite may equal the sum of the quartz and feldspar or more rarely become the least abundant constituent; quartz and feldspar (chiefly orthoclase, microcline, and albite-oligoclase) are usually present in about the same proportions. Accessory constituents are hornblende, magnetite, apatite, garnet, zircon, titanite, and tourmaline. Broken tourmaline crystals are abundant in places.

The rock shows a cleavage parallel to the bedding with which the micas are alined. A pronounced gneissic facies of the formation crops out in the hill east of Avondale and also in the ridge at and northeast of West Grove, and at both these places it has been quarried for building stone. (See pl. 3.) It readily disintegrates into sand, and a sand pit has been worked in the formation just north of Toughkenamon.

A lower member of the Setters formation exposed in the most westerly of the quarries in the Avondale hill below the outcropping mica gneiss is somewhat different in its coarser grain and greater development of muscovite. It contains the same constituents—quartz, microcline, and albite-oligoclase feldspar and the light and dark micas—but micaceous minerals, which constitute perhaps 50 per cent of the rock, are so abundant as to render the rock more schistose than gneissoid.

About a mile northwest of Embreeville, in the West Chester quadrangle, an abandoned quarry exposes the quartzitic gneiss of the Setters formation. Here the rock, which was at one time quarried for use as a whetstone, contains about 80 per cent of quartz.

Analysis of mica gneiss member of Setters formation from Cromwells Bridge road 3 miles northeast of Towson, Md.

[Penniman and Browne, analysts, Maryland Geol. Survey, Baltimore County Rept., in press.]

		NORM	
SiO_2	62 66	Quartz	13.88
Al_2O_3	15.76	Orthoclase	58.94
Fe_2O_3	.71	Albite	6.81
FeO	3.77	Anorthite	5.56
MgO	1.54	Corundum	1.63
CaO	1.26	Hypersthene	7.60
Na_2O	.82	Apatite	.34
K_2O	9.97	Magnetite	.93
H_2O	1.59	Ilmenite	3.04
TiO_2	1.58	Miscellaneous	1.69
P_2O_5	.185		99.92
MnO	.032	I(II).4″.3.1(2).	
BaO	.072		
	99.919		

No representative of this division among igneous rocks reported.

Thickness, correlation, and name.—The Setters formation shows considerable variation in thickness, which is due to original variation in sedimentation. In the Doe Run region a thickness of 1,000 feet or more is probable. In the Avondale region the formation is somewhat thinner.

The rocks here designated Setters formation were correlated with the Cambrian Chickies quartzite by the Second Geological Survey of Pennsylvania and have formerly been considered of undetermined age by the writer. They are now, however, correlated with the Setters formation of Maryland because they lie conformably below the rocks identified as Cockeysville marble and above the Baltimore gneiss, in the stratigraphic position of the typical Setters formation.

The Setters formation obtains its name from Setters Ridge, Md., a conspicuous topographic feature due to the outcrops of a quartzitic member of the formation.

COCKEYSVILLE MARBLE

Distribution.—The Cockeysville marble is found in areas of very irregular outline, which owe their general northeast trend to the faulted structure of the rocks. The two largest areas are near Doe Run and Avondale. There are small outlying areas south of Landenberg, east of Corner Ketch, at Hockessin, east of Kennett Square, east of Mendenhall, northeast of Brinton Bridge, east of Birmingham, and at Embreeville. In five detached areas northeast of Embreeville limestone is exposed only in quarries that were at one time operated — the County Poorhouse quarry, Moses Bailey's quarry, Moses Woodward's quarry, George Marsh's quarry, and Cope's quarry.

Character.—The Cockeysville marble is typically a medium to coarse grained white saccharoidal rock, or a light blue-gray rock, in many places banded with flakes of golden-brown phlogopite. It is in general distinguished from the Cambrian and Ordovician limestones of Chester Valley by a lighter color and coarser grain and from the Archean Franklin limestone by a finer grain and the absence of graphite and the silicate minerals so characteristic of the Franklin.

A section of the Cockeysville marble at the Acme quarry, near Baker station, operated by the Pennsylvania Marble & Granite Co., shows the following beds:

Section of Cockeysville marble at Acme quarry, near Baker station

	Feet
Phlogopitic gray limestone, referred to by the quarrymen as "Avondale limestone"	10-30
Tremolite-phlogopite-quartz rock, locally called "bastard granite"	16-18
Very pure white granular limestone, locally called "fish-egg limestone"	10
Even-grained white magnesian marble, called "dolomite"	50

The more coarsely crystalline limestone is found at Mendenhall's quarry, 1 mile northeast of Mendenhall station. Some of the material there shows crystals a centimeter or more in diameter. The estimated total thickness is between 100 and 150 feet.

At Guest's quarry, $1\frac{1}{2}$ miles southeast of Doe Run village, the lower white marble beds contain tremolite.

Analyses of Cockeysville marble

	1	2	3	4
SiO_2	21.53	[a]2.40	3.92	1.950
$Al_2O_3+Fe_2O_3$	3.60	.29	1.25	.613
MgO	1.46			
$MgCO_3$		1.74	35.20	43.309
CaO	38.38			
$CaCO_3$		95.57	59.63	54.071
Na_2O	.33			
K_2O	1.18			
CO_2+H_2O	32.00			
Fe_7S_8	1.06			
P_2O_5				.003
S				.013
	99.54	100.00	100.00	99.959

[a] Insoluble residue.

1. Limestone, Cope's quarry, $1\frac{1}{4}$ miles northeast of Copesville. F. A. Genth, jr., analyst, Pennsylvania Second Geol. Survey Rept. C6, pp. 135–136, 1881.

2. "Fish-egg limestone," Acme quarry, Avondale, Pennsylvania Marble & Granite Co.

3. "Dolomite," Acme quarry, Avondale, Pennsylvania Marble & Granite Co. Analyses 2 and 3 furnished by the company.

4. Dolomite, Benjamin Swayne's quarry, $1\frac{1}{4}$ miles southwest of London Grove. A. S. McCreath, analyst, Pennsylvania Second Geol. Survey Rept. M3, p. 79, 1881.

No. 1 is a highly siliceous limestone; No. 2 is a very pure limestone; and No. 3 is a magnesian limestone with the percentage of magnesium carbonate a little below the standard percentage for a dolomite. No. 4 is a true dolomite.

Thickness, correlation, and name.—The Cockeysville marble is not of uniform thickness in its widely distributed areas of outcrops but presumably does not anywhere exceed 500 feet.

The crystalline limestone south of Chester Valley, here designated the Cockeysville marble, was somewhat doubtfully correlated by the Second Geological Survey of Pennsylvania with the Chester Valley limestone and was with that formation considered Siluro-Cambrian in age. Because of the stratigraphic position of this formation—above the Baltimore gneiss, from which it is separated only by the quartzose member of the series, the Setters formation, and below the Wissahickon gneiss—the marble is now correlated with the Cockeysville marble of Maryland, which has been assigned to the pre-Cambrian.

The Cockeysville marble obtains its name from the town of Cockeysville, 15 miles north of Baltimore, Md., where there are active quarries in the marble.

WISSAHICKON FORMATION

Distribution.—The Wissahickon formation has a wide distribution in the Coatesville-West Chester district. It forms the South Valley Hills, underlies the central and southern parts of the Coatesville quadrangle, and extends into the northern part and across the south-central part of the West Chester quadrangle.

Character.—The Wissahickon formation as mapped in this folio comprises two lithologic facies—a southern one known as oligoclase-mica schist and a northern one known as albite-chlorite schist.

The southern facies is separable into two members, which are not distinguished on the maps; the lower member is a biotite gneiss, abundantly injected by granitic and gabbroic pegmatites and by massive gabbro; the upper member is a muscovite gneiss. Where free from injected material the biotite gneiss is medium-grained schistose quartz-feldspar-biotite rock. Normally these constituents are evenly distributed through the rock and are equigranular; the feldspar is chiefly orthoclase and albite but also includes microcline and oligoclase. The biotitic layers, largely made up of minute overlapping scales of biotite with cleavage planes parallel to the gneissic banding, are spangled by larger brilliant plates of biotite and in some localities of muscovite. Even where it is most abundant the biotite in general does not exceed the sum of the quartz and feldspar, and the average distribution of the two latter constituents is about the same. Accessory constituents are magnetite, pyrite, apatite, zircon, garnet, titanite, staurolite, tourmaline, allanite, andalusite, and sillimanite. The garnets are commonly inconspicuous, but in some localities, as in the ridge forming the northwest side of Beaver Creek valley, on the left bank of Brandywine Creek north of the Delaware-Pennsylvania State line, they are abundant and average half an inch or more in diameter. The sillimanite occurs in almond-shaped nodules brought out in relief by weathering. Secondary constituents of the biotite gneiss are chlorite, epidote, a zeolite (probably scolecite), cordierite, hematite, and limonite. The rock is irregularly and abundantly jointed, with a rusty yellow, red, or brown stain on the joint planes.

Granitic pegmatization is not only a striking feature of the biotite gneiss but in a greater or less degree it is an almost constant feature. The biotite gneiss is invaded by many cross-cutting pegmatite dikes and is also intensely injected parallel to the bedding planes, as is illustrated south of London Grove; quartz-feldspar layers that show rapid and abrupt variation in width are injected between biotitic layers; the relative amount and distribution of the quartz and feldspar are highly variable; the feldspar is usually opaque and of a light-buff color and may be developed in euhedral crystals of a considerable size with quartz or dissociated from it and having the aspect of porphyritic crystals.

Where the biotite gneiss has been invaded by large masses of gabbro, hornblende or augite, or both, have developed in the gneiss in contact with the gabbro; orthoclase and an acidic plagioclase remain the dominant feldspars, but labradorite and labradorite-bytownite are locally present; although the rock has the constituents of a quartz monzonite it also has the aspect of a recrystallized sediment because of the fresh character of the feldspars and the rounded zircons and apatites. Such a local facies of the biotite gneiss is exposed in a small quarry $1\frac{1}{2}$ miles west of Centerville and also $2\frac{1}{2}$ miles northeast of Elam on the northeast side of the road. In addition to the exposed gabbro dikes the gneiss is thoroughly injected by dikes which do not appear at the surface but some of which are exposed in quarries or in roadside or railway cuts. About 1 mile and $1\frac{1}{4}$ miles northwest of Yorklyn, in a roadside cut, such gabbroitic injection of the biotite gneiss is finely displayed.

Injection along the layers of the biotite gneiss by gabbro is shown in a rock exposed $1\frac{1}{4}$ miles southeast of Elam and one-eighth of a mile southeast of the gravel pit. Here gneissic layers resembling an igneous rock in constituents and texture but still retaining some characteristics of a recrystallized sediment alternate with quartz-biotite-labradorite-hypersthene layers representing a gabbro pegmatite.

The most southerly syncline brings to the surface this biotite gneiss member of the Wissahickon formation south of Avondale, Kennett Square, and Chadds Ford, in a broad belt extending northeastward into the Chester quadrangle and southward into the Elkton and Wilmington quadrangles.

In the Elkton-Wilmington folio this biotite gneiss was described under the designation Baltimore gneiss. It was interpreted as Baltimore gneiss on the ground of the structural relations as they were then understood; but with the formations as now defined it becomes the basal member of the southern facies of the Wissahickon formation. A large quarry at Wooddale furnishes a good exposure of the gneiss. Here the rock is an even-grained quartz-feldspar-biotite gneiss,

[5] Wolff, J. E., and Brooks, A. H., The age of the Franklin white limestone of Sussex County, N. J.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 432, 1898.

which has been rendered more or less massive by proximity to a great gabbro intrusion, dikes from which are exposed in the quarry, and by injection by quartz diorite pegmatite. Folded beds dip 85° NW. to 90° and strike about N. 40° E. Pegmatization here, as well as in other localities, is later than the gabbro injection.

The muscovite gneiss member of the Wissahickon formation is distinguished from the underlying biotite gneiss in being excessively micaceous, dominantly muscovitic, and more schistose than gneissic. Where fresh the rock is of a blue-gray or warm yellow-gray color, brilliantly spangled with muscovite plates, which range in diameter from a millimeter to a centimeter. This muscovite gneiss, which prevails in the southwestern and the central to southern parts of the Coatesville quadrangle and the north-central part of the West Chester quadrangle, is characteristically crinkled or fluted, with a schistosity cutting across the fluting. A brown manganese oxide stain on joint planes and a characteristic weathering into sticklike fragments are distinctive features. The essential constituents are quartz, feldspar, and muscovite. The amount of quartz and feldspar varies greatly from place to place, but neither constituent is anywhere altogether absent. The quartz is fine grained; the feldspar, which is nowhere so abundant as in the underlying member of the formation, shows a considerable range of species. Orthoclase is generally present; the plagioclase feldspar may range from albite to bytownite; the calcic plagioclases are present in the gneiss which immediately overlies limestone.

In many localities garnets, large and small, crowd the rock; other metamorphic minerals are staurolite, tourmaline, andalusite and sillimanite. Accessory constituents are biotite, hornblende, apatite, zircon, titanite, and pyrite. Secondary constituents are epidote, chlorite, and calcite.

On the extreme southern border of the Coatesville quadrangle, on the road crossing Big Elk Creek, the two types of the Wissahickon formation—the muscovite gneiss and the underlying biotite gneiss—can be seen in contact.

The northern facies of the Wissahickon formation, the albite-chlorite schist, is distinguished from the muscovite gneiss primarily in degree of metamorphism and subordinately in mineral constitution. It is a resistant quartz-muscovite schist which forms the South Valley Hills in the Coatesville, West Chester, Phoenixville, and Norristown quadrangles.

The schist is typically a blue-gray or less usually a greenish-gray rock with lustrous smooth laminae, in some places wrapped about quartzose layers, and in others with very little if any quartz present. The surfaces of the laminae have almost a soapy feel, in contrast to the more gritty texture of typical muscovite gneiss. Locally the schist may be a fragile purplish slate. A dominating schistosity that usually dips steeply southeast obscures or obliterates the bedding. The weathered schists are of a rich rusty-yellow color owing to the oxidation and hydration of the ferrous oxide. Intercalated with the muscovite schist are beds studded with minute albite crystals, which are best seen in fractures transverse to the schistosity. The albite crystals are euhedral, nearly equidimensional, show no parallel arrangement, and include other constituents of the rock. These facts indicate that they are neither clastic in origin nor due to pegmatization but probably originated from the recrystallization of a sodium silicate constituent of the sediment as a result of hydrothermal metamorphism rather than metamorphism that was primarily dynamic. Such beds are exposed on the East Branch of Octoraro Creek a quarter of a mile north of Steelville at the fork of the road. They become increasingly less conspicuous to the northeast and increasingly dominant to the southwest, where they give character to the rock, which has accordingly been described in reports on Maryland areas as albite-chlorite schist[6] but which is in this district a typical muscovite schist.

The muscovite schist of the northern facies, like the muscovite and biotite gneisses, is a recrystallized sedimentary rock. In the muscovite schist recrystallization has not been carried to the same degree of perfection as in the gneisses on the southeast, and igneous intrusions, with one exception, which may be only apparent, are altogether lacking. The grain of the rock is finer, and the crystal boundaries, except those of the porphyroblastic albite, are not so clear-cut. Quartz and feldspar (chiefly orthoclase) occur in interlocking grains. Muscovite and chlorite are developed in association; limonite and, less usually, epidote are alteration products. Biotite, magnetite, ilmenite, tourmaline, and pyrite are accessory constituents. Pseudomorphs of limonite after pyrite in cubes 5 millimeters or more in diameter are a feature of the schist. Garnets and minerals that are produced by deep-seated metamorphism are absent.

The analyses given in the next column represent different facies of the Wissahickon formation at several localities in southeastern Pennsylvania. Analyses 1 and 2 show strong evidence of a sedimentary origin in the excess of silica, the very considerable excess of alumina above the 1:1 ratio necessary to satisfy the lime and alkalies, and the double relationship of the dominance of MgO over CaO and K_2O over Na_2O.

[6] Knopf, E. B., and Jonas, A. I., Stratigraphy of the crystalline schists of Pennsylvania and Maryland: Am. Jour. Sci., 5th ser., vol. 5, pp. 46, 59, 1923.

The value of these criteria in determining the origin of metamorphic rocks has been discussed by Bastin.[7]

In analyses 3 and 4 the evidence is not so strong, but it is quite sufficient to cast suspicion on an igneous origin for the rocks analyzed. No. 3 shows excessive quartz and alumina, and potassa is greater than soda. In No. 4 the silica is not excessive. There is a considerable excess of alumina, and MgO is dominant over CaO, but K_2O is less than Na_2O. The chemical evidence of a sedimentary origin for Nos. 5, 6, and 7 is very strong. Silica is abnormally low. Excess of alumina over the 1:1 ratio necessary to satisfy the alkalies and lime is very great. This criterion alone is sufficient proof of a sedimentary origin for the rock of which it is characteristic. The MgO exceeds the lime, and K_2O is excessively dominant relative to Na_2O.

Analyses of different facies of the Wissahickon formation

	1	2	3	4	5	6	7
SiO_2	66.13	60.33	59.01	56.40	43.81	43.10	39.35
Al_2O_3	15.11	20.85	17.02	19.76	27.52	30.86	31.92
Fe_2O_3	2.52	3.59	7.76	4.35	7.30	7.28	2.19
FeO	3.19	4.47	2.64	4.40	Trace.		9.00
MgO	2.42	2.07	.07	3.11	1.77	1.80	3.08
CaO	1.87	1.82	2.08	.09	.19		
Na_2O	2.71	1.38	2.44	5.82	.56	.66	1.98
K_2O	2.86	2.84	2.63	1.27	8.81	6.87	5.26
$H_2O\pm$	1.79	2.79	4.42	3.37	7.52	5.91	6.05
TiO_2	.82	1.41	1.34	1.05	3.78	3.28	1.20
P_2O_5	.22	.28	Trace.	.37	.13		.49
S	.03						
CrO	None.						
MnO	.20		.96	Trace.			
BaO	Trace.						
SrO	Trace.						
Li_2O					Trace.		
NiO+CoO							.06
	99.87	101.82	100.37	99.99	101.89	99.76	100.58

1. Composite sample, Philadelphia district. W. F. Hillebrand, U. S. Geol. Survey, analyst.
2. Muscovite gneiss, Tacony Creek, north of Jenkintown Junction. F. A. Genth, jr., analyst, Pennsylvania Second Geol. Survey Rept. C6, p. 122, 1881.
3. Albite-chlorite schist, 1½ miles northwest of Cully's station, Pennsylvania R. R., Columbia and Port Deposit branch. F. A. Genth, analyst. Pennsylvania Second Geol. Survey Rept. CCC, p. 271, 1880.
4. Muscovite gneiss, south of Hulmeville, Neshaminy Creek, F. A. Genth, jr., analyst, op. cit. (Rept. C6), p. 109.
5. Mica schist, between Gulf Mills and Hitner marble quarry. F. A. Genth, jr., analyst, op. cit. (Rept. C6), pp. 132–133.
6. Mica schist, between Gulf Mills and King of Prussia. F. A. Genth, jr., analyst, idem.
7. Mica schist, 1,222 feet from Bird-in-Hand Tavern, on road from Gulf Mills to Bryn Mawr. F. A. Genth, analyst, idem.

NORMS

	1	2	3	4	5	6	7
Quartz	31.02	33.96	30.33	11.46	4.08	10.62	
Orthoclase	16.68	16.68	15.57	7.78	52.26	40.59	31.14
Albite	23.06	11.53	20.44	49.25	4.72	5.24	16.77
Anorthite	8.34	7.23	10.29				
Corundum	4.49	12.85	6.43	8.77	17.03	22.44	22.95
Hypersthene	8.77	7.97		10.77			14.43
Magnetite	3.71	5.34	7.66	6.26			3.25
Ilmenite	1.52	2.74	2.58	1.98			2.28
Apatite	.34	.67		.34	.34		
Water	1.79	2.78	4.42	3.37			
Sulphur	.03						
Hematite			3.68		7.36	7.28	
$MgSiO_2$			.20		4.40	4.50	
P_2O_5							.49
TiO_2					3.78	3.28	
Miscellaneous							3.30
H_2O					7.52	5.91	6.05
	99.75	101.75	100.32	99.98	101.49	99.86	100.66

1. (I)II.3(4).2.3(4). No name; four representatives of this subrang in Washington's tables. Quartz excessive for Class II; excess of alumina; MgO > CaO; $K_2O > Na_2O$.
2. "II.3.2".''3. No name; four representatives of the type in Washington's tables. Quartz excessive for Class II; excess of alumina; MgO > CaO; $K_2O > Na_2O$.
3. (I)II.3(4).2(3).3''. No name; four representatives. Quartz excessive for Class II; excess of alumina; MgO < CaO; $K_2O > Na_2O$.
4. II.4''.1.4(5). Pantellerose; fifteen representatives in Washington's tables. Quartz not excessive; excess of alumina; MgO > CaO; $K_2O < Na_2O$.
5. "II."5.1.1". No name; one representative. Quartz abnormally low; excess of alumina; MgO > CaO; $K_2O \gg Na_2O$.
6. "II.4.1.1(2). No name; no representative. Quartz low; excess of alumina; MgO > CaO; $K_2O \gg Na_2O$.
7. II.5.1.2(3). Highwoodose; five representatives. Quartz abnormally low; excess of alumina; MgO > CaO; $K_2O \gg Na_2O$.

Comparison of the analyses of the muscovite gneiss and the less metamorphosed muscovite schist indicates that the two facies show certain differences in chemical constitution. They are both metamorphic derivatives of argillaceous sediments (pelitic foliates); Al_2O_3 is invariably more excessive in the schist than in the gneiss; the iron oxides are more excessive in the schist; K_2O is excessive in the gneiss—a chemical difference which might accompany the change in sedimentation from silty clay to finer, less silty clay with increasing distance from shore.

[7] Bastin, E. S., Chemical composition as a criterion in identifying metamorphosed sediments: Jour. Geology, vol. 17, pp. 445–472, 1909.

Thickness, correlation, and name.—It is not possible to estimate with any degree of accuracy the thickness of such a unit as the intensely folded Wissahickon formation, which contains no recognizable recurrent beds. There must be exposed on Susquehanna River a thickness of 8,000 to 10,000 feet of beds, which may, however, be repeated many times by close folding and faulting. The Wissahickon formation is considered to be pre-Cambrian because it has undergone deep-seated metamorphism, because of its intrusion and saturation by igneous rocks—granite, gabbro, peridotite, pegmatite, and their immediate differentiates, all of which, except the pegmatite, are entirely absent from the Paleozoic formations and are characteristic and abundant intrusives in known pre-Cambrian gneiss, and because of the number of joint systems found in the gneiss, one more than in the Paleozoic formations. Recently corroborative proof of the pre-Cambrian age has been found in the stratigraphic relations of the Wissahickon formation to pre-Cambrian subsilicic lavas in Maryland. The Wissahickon of this area is stratigraphically continuous with the formation of the same name in Maryland and has been correlated with the Manhattan schist of New York. It received the name Wissahickon because of type exposures on Wissahickon Creek, in eastern Pennsylvania near Philadelphia. The muscovite schist of the South Valley Hills in the Coatesville and West Chester quadrangles (and also of the Norristown quadrangle, described in the Philadelphia folio as the "Octoraro schist") is regarded by the Geological Survey[8] as the northern facies of the Wissahickon formation and referred with it to a pre-Cambrian age, because southwest of these quadrangles along the strike what appears to be the same formation is overlain unconformably by Lower Cambrian rocks. Under this view its present position above Cambrian and Ordovician formations must be due to a thrust fault, as shown in the structure sections.

An alternative hypothesis tentatively held by the writer is that this thrust fault lies between the gneiss belt of the Wissahickon and the muscovite schist of the South Valley Hills; that the schist is covered southwest of this area by the overthrust pre-Cambrian gneiss series and is exposed in these quadrangles by the removal through erosion of this overthrust cover, bringing the intersection of the fault plane with the surface of the country in this area between muscovite schist and muscovite gneiss about half a mile south of that shown on the map. This hypothesis rests upon the following observations:

1. The muscovite schist has manifestly undergone a different degree of metamorphism from that of the gneisses.

2. It is conspicuously free from the metamorphic minerals (garnet, staurolite, tourmaline, andalusite, and sillimanite) common to the gneisses.

3. The almost complete absence from the muscovite schist of the South Valley Hills of the igneous intrusions that are so abundant in the gneisses constitutes evidence of a so-called igneous unconformity.

4. The contact of the muscovite schist with the Ordovician limestone of Chester Valley is apparently conformable; this is indicated (*a*) by a lithologic gradation shown in the micaceous character of the upper limestone beds and the limy character of the lower beds of the mica schist in an apparent syncline at the Howellsville quarries, 1½ miles northeast of Paoli; (*b*) by the nature of the contact; where this can be observed, as at a small quarry 1½ miles northwest of Gulf Mills, in the Norristown quadrangle, it is either straight and parallel to the stratification of the two formations or there is a refolding of the beds in which both formations participate; (*c*) by failure to find evidence of the cutting out of limestone beds; south of Gulf Mills, in the Norristown quadrangle, the mica schist shows a synclinal structure with limestone exposed on both limbs and in the axis of the fold to the northeast, beyond Conshohocken; the syncline pitches southwest, and the schist is eroded to the northeast and widens to the southwest until concealed under the thrust fault of pre-Cambrian rocks; (*d*) by the similarity in chemical constitution respectively of the Martinsburg shale and the conformably (?) underlying limestone of the great valley and the mica schist of the South Valley Hills and underlying limestone of the Chester Valley, which constitutes a presumption in favor of a like age and relationship. Any one of these observations taken singly is capable of another interpretation, but the combined observations seem to the writer to point to similar relations between the mica schist and Cambrian and Ordovician formations and to the Ordovician age of the schist.

5. In the Norristown quadrangle, west, south, and east of Conshohocken, where the trace of the thrust plane emerges southeast of the South Valley Hills, it coincides with the northwest boundary of the belt of the Wissahickon gneiss, along which the Cambrian quartzite, the Cambrian and Ordovician limestones, and the muscovite schist of the South Valley Hills are successively cut off. If the presumption that these beds which are cut off by the fault constitute a conformable series is rejected and the last member of this series is included with

[8] Knopf, E. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pa.: U. S. Geol. Survey Bull. 799, pp. 34–35, 74–79, 1929.

the pre-Cambrian overthrust mass, the fault plane must be interpreted as abruptly and closely folded in a sharp anticline and syncline.

6. This fault has been traced southwestward from the Burlington, Germantown, and Norristown quadrangles, where it separates Wissahickon gneiss successively from pre-Cambrian, Cambrian, and Cambrian-Ordovician formations, across the Phoenixville, West Chester, and Coatesville quadrangles, where it separates a narrowing belt of steeply dipping phyllitic slate from the more coarsely crystalline flat to gently dipping gneiss.

PETERS CREEK SCHIST

Distribution.—The Peters Creek schist, the youngest of the pre-Cambrian sediments in the Coatesville-West Chester district, lies above the Wissahickon formation in the trough of a syncline that extends from the west edge of the Coatesville quadrangle northeastward into the West Chester quadrangle.

The boundaries between the Peters Creek schist and the muscovite gneiss member of the Wissahickon formation are not clear-cut. The crumpled muscovite rock on the south passes without stratigraphic break or abrupt lithologic change into a smooth muscovite-chlorite-quartz schist, and this in turn into a more fissile muscovite schist without definite demarkation.

Character.—The Peters Creek rock is a green mica schist, with yellow rust stains, fine grained, and finely laminated. It differs from the mica schist to the northwest of it in being nonfissile. Fine granular quartz layers are interleaved with layers of overlapping scales of muscovite; green chlorite blades are developed irregularly throughout the quartz layers and more scantily in the muscovite layers. Octahedral crystals of magnetite are freely distributed through the rock, or their former presence is indicated by rust-lined cavities.

The fine parallel lamination is presumably a secondary feature produced by pressure on a formation whose constituents responded to dynamic action by a completely parallel arrangement. The intensely crumpled bedding is thus obscured or obliterated except in some of the transition beds between the Peters Creek schist and the Wissahickon formation.

Thickness, correlation, and name.—On Susquehanna River the Peters Creek schist shows a thickness of 2,000 feet. In the Coatesville quadrangle the thickness is not determinable.

The Peters Creek schist of this area is stratigraphically continuous with the formation of the same name in Maryland. It obtains its name from Peters Creek, a tributary of Susquehanna River in southern Lancaster County, Pa., where there are fine exposures of the rock.[9]

CAMBRIAN SYSTEM

By George W. Stose

The lower three Cambrian formations are the Chickies quartzite, with the Hellam conglomerate member at its base, the Harpers schist, and the Antietam quartzite. The Hellam conglomerate member, although not so thick and prominent as it is in the Chestnut and Hellam Hills, to the west, is mappable throughout the area as a narrow band at the base of the Chickies formation. The Antietam quartzite can not be distinguished from the Harpers schist in most places in the North Valley Hills and is there not separately mapped. The remaining Cambrian formations are calcareous and consist of the Vintage dolomite, the Kinzers formation, the Ledger dolomite, and the Elbrook limestone.

CHICKIES QUARTZITE

Distribution.—The Chickies quartzite crops out in the North Valley Hills, a nearly continuous ridge along the north side of Chester Valley. It forms the crest of the ridge, with Harpers schist and Antietam quartzite on its south slope. The basal beds, comprising conglomerate, arkosic and pebbly schist, and shiny fissile black mica schist, form a narrow band along the north side of the ridge, and where the ridge is cut through by deep gorges these beds may be seen in section dipping steeply to the south. The conglomerate-bearing basal beds beneath the main quartzite rest unconformably on pre-Cambrian rocks. The formation also caps hilltops in the northwestern part of the Coatesville quadrangle. Here the beds are generally not so steeply inclined, and wider areas are covered by quartzite or white sand derived from its disintegration. At but few localities on the level upland can the rocks be seen in place, although masses of white quartzite strew the higher parts of the surface, and small masses and fragments of conglomerate, or quartz pebbles derived from its disintegration, are widely scattered where the Hellam conglomerate member crops out.

Character and thickness.—The Chickies quartzite is chiefly a vitreous to granular quartzite, in part massive and in part thin bedded, with interbedded quartzose schist and sandy mica schist. (See pls. 5 and 6.) At its base, and varying from place to place, lie conglomerate, pebbly granular sandstone, arkosic schist, and black mica schist, which together are mapped as the Hellam conglomerate member. Beds of fine to moderately coarse conglomerate and granular sandstone containing rounded grains and scattered pebbles of white, colorless, and clear blue quartz are present in most sections. The Hellam conglomerate member is not so noticeably conglomeratic in that part of the North Valley Hills within the Coatesville quadrangle as it is in places to the east and west. Several of its beds, however, carry large rounded grains and small pebbles of clear blue quartz, and its outcrop is generally marked by slabs or fragments of sandstone in which quartz pebbles can be readily seen. In the section along West Branch of Brandywine Creek above Coatesville the conglomerate member is not clearly distinguishable, but on the hill west of the creek conglomerate beds are conspicuous. Conglomerate is more plentiful in the hills in the northwest corner of the Coatesville quadrangle, and in that area thick masses of hard conglomerate are used in making stone fences. On the hills north of the Lincoln Highway, near Black Horse, conglomerate layers containing large grains and small and large pebbles of white and glassy blue quartz are interbedded with thin black tourmaline-bearing mica schist, quartzite, and quartzite schist, all of which are mapped as the Hellam conglomerate member.

The thickness of the formation in the Coatesville quadrangle is estimated to be about 500 feet, and that of the Hellam conglomerate member at the base is about 50 feet. The best section is that in the deep cut of the Pennsylvania Railroad west of Atglen (fig. 6). The three occurrences of quartzite in this section are explained as a double repetition by folding and faulting of a single heavy quartzite series in the midst of the formation. This interpretation is in accord with the measured section at Greentree, 5 miles to the southwest, and with other sections in the gorges through the North Valley Hills in the Coatesville quadrangle. The thickness in the gorge 2 miles southwest of Coatesville (see pl. 4) is 494 feet.

Section of Cambrian arenaceous rocks at Coatesville, Pa.

		Feet
Harpers schist and probably Antietam quartzite: Slivery micaceous quartzose schist and mica schist		278
Chickies quartzite:		
Thin quartzite and mica schist	270	
Vitreous quartzite and quartz schist	150	
Sheared quartzite and quartz schist (the lower part is conglomeratic west of the creek—Hellam conglomerate member)	137	
Gabbro (pre-Cambrian).		557
		835

The section at Greentree, 5 miles southwest of Atglen, is as follows:

Section of Cambrian arenaceous rocks at Greentree, Pa.

		Feet
Harpers schist and possibly Antietam quartzite: Dark-gray hard sandy schist, with quartz stringers		300±
Chickies quartzite:		
Covered; thin schist at base	300±	
Vitreous to granular white quartzite, angularly jointed	18	
Covered; quartzite fragments in soil	230±	
White sheared quartzite or quartz schist with pebbly beds and micaceous partings (Hellam conglomerate member)	94	
		642±
		942±

Age and correlation.—The Chickies quartzite was named from Chickies Rock, a cliff on the east side of Susquehanna River 5 miles above Columbia. The formation there is a massive-bedded quartzite, exposed in an anticline which is cut through by the river. A conglomerate at its base, which is not exposed in the river bluff but which comes to the surface in the Hellam Hills, west of the river, is composed of beds of coarse conglomerate with rounded pebbles as much as 3 inches across, fine conglomerate, and granular sandstone, with pebbly schist at the base. These beds (represented in part by arkose and mica schist) are everywhere present in the Coatesville-West Chester district. They compose the Hellam conglomerate member. The Chickies quartzite rests unconformably on pre-Cambrian rocks. It contains many *Scolithus linearis*, a fossil worm tube, which occurs in Cambrian and other Paleozoic rocks. Quartzite and shale that overlie the Chickies contain a Lower Cambrian fauna, and the Chickies is therefore regarded as of Lower Cambrian age.

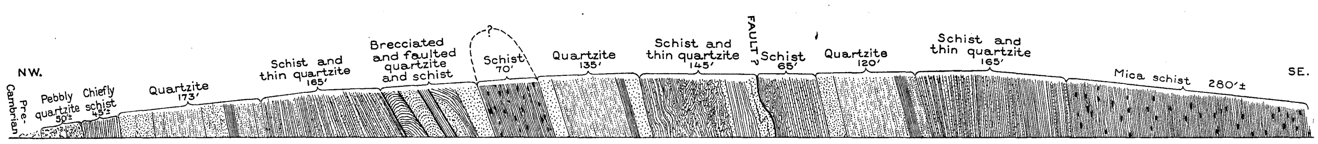


FIGURE 6.—Graphic section of the Cambrian quartzose rocks in the cut of the Pennsylvania Railroad west of Atglen

Measured by G. W. Stose and A. I. Jonas

Composite section of Chickies quartzite and associated rocks in Pennsylvania Railroad cut west of Atglen, Pa.

[By G. W. Stose and A. I. Jonas.]

		Feet
Harpers schist and Antietam quartzite: Mica schist with many quartz blebs or lenticular masses and a layer of porphyritic biotite schist at base		280
Chickies quartzite:		
Quartz schist, mica schist, and thin quartzites	115	
Quartz schist with layers of porphyritic biotite schist and thin quartzites	50	
Chiefly schist		165
Thin-bedded quartzite and quartz schist, thicker bedded at base	33	
Mica schist	10	
Vitreous quartzite, thick-bedded above, thin-bedded below	90	
Thick-bedded quartzite, thinner bedded toward top	40	
Chiefly quartzite		173
Biotite schist and thin quartzite beds		45±
Soft crumbly schistose sandstone containing coarse grains and small pebbles of glassy quartz, with partings of sericite schist (Hellam conglomerate member)		50±
		433±

The quartzite series comprises a main mass of thin-bedded quartzites 75 to 80 feet thick with more massive beds 15 to 25 feet thick and an upper group of thick and thin bedded quartzite 15 to 35 feet thick separated from the main mass by 10 to 15 feet of mica schist. This marked sequence occurs three times in the section, as shown graphically in Figure 6, and is believed to be repeated by faulting accompanied by crumpling and crushing at the points marked.

Another section, less well exposed and more obscured by folding and faulting, is that in the gorge of the West Branch of Brandywine Creek at Coatesville. A complete measurement could not be made because of the repetition of beds, difficulty in determining the dips, and obscure outcrops, but the following relations were observed:

HARPERS SCHIST

Distribution.—The Harpers schist forms the front of the North Valley Hills in the Coatesville quadrangle. It crops out as a rather straight band about a quarter of a mile wide. In the northwest corner of the quadrangle it appears only in a small lenticular area on the north flank of the Mine Ridge anticline, and in a narrow area to the north, repeated by faulting.

Character and thickness.—The Harpers schist is a gray sandy micaceous schist with some harder beds of quartz schist and thin-bedded quartzite. In the section at the Atglen cut of the Pennsylvania Railroad (given above) several thin beds of quartzite are interbedded with the schist and two beds of schist that are spotted with coarse porphyritic flakes of biotite are also present. The thickness measured in that section is 280 feet. In the gap at Coatesville the bedding in the Harpers schist is not determinable except where quartzite is interbedded with the schist, and the thickness was not measurable but is estimated to be about the same as at the Atglen cut. The overlying Antietam quartzite is not generally recognizable on the south flank of the Mine Ridge anticline and is not separately mapped there. On the north flank in the Coatesville quadrangle the beds are not sufficiently well exposed to be measured but are apparently considerably thicker, for a few miles to the north, at the west edge of the Barren Hills, the thickness is estimated to be 1,500 feet.

Age and correlation.—No fossils have been found in the Harpers schist in this area. The underlying Chickies quartzite contains *Scolithus*, and the overlying Antietam quartzite contains fragments of shells and trilobites of Lower Cambrian age. The Antietam quartzite grades downward into the Harpers schist, and the Harpers is probably also Lower Cambrian. It is the equivalent of the phyllite that overlies the Chickies quartzite at Chickies Rock and in the Hellam Hills, which in turn is correlated with the Harpers slate of South Mountain, Pa., and Harpers Ferry, W. Va.

[9] Knopf, E. B., and Jonas, A. I., Stratigraphy of the crystalline schists of Pennsylvania and Maryland: Am. Jour. Sci., 5th ser., vol. 5, p. 46, 1923.

ANTIETAM QUARTZITE

Distribution.—The Antietam quartzite probably occurs along the south face of the North Valley Hills from Coatesville eastward, but as it has been observed at only one place in the area and at a few other places to the east it has not been separately mapped in the North Valley Hills but is included with the Harpers schist. North of Thorndale, on a spur of the North Valley Hills, it is recognizable by its characteristic ferruginous quartzite beds. West of Coatesville, where the Conestoga limestone unconformably overlies the siliceous Cambrian rocks, the Antietam may be absent, having been eroded during pre-Conestoga time. On the north flank of the Mine Ridge anticline, in the northwest corner of the Coatesville quadrangle, the Antietam quartzite is present in two areas separated by a fault, and these areas are mapped.

Character and thickness.—The Antietam quartzite comprises gray laminated quartzite and quartzose schist, rust-spotted and stained on bedding surfaces. It normally overlies the Harpers schist and forms the top of the arenaceous series of Cambrian sediments. It is apparently very thin on the south flank of the Mine Ridge anticline, and its characteristic sandstone beds have been observed at but few places in the North Valley Hills. North of Thorndale a plunging minor anticline on the flank of the main Mine Ridge anticline exposes the Antietam quartzite on a spur at the north border of the Coatesville quadrangle. Here very thin beds of platy quartzite interbedded with sandy mica schist and shale, show the characteristic rust-stained depressions on bedding surfaces which, in less metamorphosed rock to the north, are seen to be molds and casts of fossil shells and trilobites. The observed thickness was not over 50 feet, but the formation may be much thicker.

In the extreme northwest corner of the Coatesville quadrangle a prominent hill is composed of rust-specked granular quartzite and schistose gray sandy beds with rusty laminae, characteristic of the Antietam. Its thickness there can not be determined, but on the flanks of Barren Hill, a few miles to the north, it is estimated to be 150 feet thick.

Age and correlation.—No recognizable fossils were found in the formation in these quadrangles, but a short distance to the north, in Barren Hill and Walsh Mountain, molds and casts of fossils were observed. In the Hellam Hills and Chickies Hill, north of Columbia, fragments of trilobites of the genus *Olenellus* and of shells of the genus *Obolella*, too poorly preserved to determine the species but of Lower Cambrian age, were found in this formation. The same fossils occur in the Antietam sandstone of South Mountain and of the Blue Ridge in Virginia, and as the formation has the same stratigraphic position it is considered to be the same as the Antietam sandstone of those regions.

VINTAGE DOLOMITE

Distribution.—The Vintage dolomite is represented on the map as a narrow band along the north border of the Chester Valley in the northeastern part of the Coatesville quadrangle, although it is exposed at only a few places. The formation is overlapped by the Conestoga limestone 2 miles southwest of Coatesville and does not crop out in Chester Valley beyond that point. A small area of the formation is infolded in a syncline of Antietam quartzite in the northwest corner of the Coatesville quadrangle.

Character and thickness.—The formation is deeply weathered in most places to a thick mantle of dark maroon-red residual clay soil and is covered by quartzite wash from the North Valley Hills. Where exposed, it consists of dark-blue glistening granular dolomite, generally having a wavy knotted texture due to impurities that weather in relief. In its typical exposures in the Lancaster Valley there is an impure white knotty marble at the base and coarse to fine grained massive light-gray dolomite in the upper part. The thickness of the formation in this area can not be measured but has been estimated from the width of its outcrop to be approximately 300 feet.

Age and correlation.—The Vintage dolomite is the basal calcareous formation of the Cambrian and Ordovician limestone series and resembles in character and is equivalent to the lower part of the Tomstown dolomite of the Cumberland Valley, south-central Pennsylvania. It was named from Vintage, a village in the Lancaster Valley, where most of the formation is excellently exposed in the Pennsylvania Railroad cut. In Lancaster Valley trilobites, shells, and cystid plates of Lower Cambrian age have been found in this formation and are especially plentiful in its upper layers.

KINZERS FORMATION

Distribution.—The Kinzers formation is mapped as a narrow band coextensive with and adjacent to the Vintage dolomite in the northeastern part of the Coatesville quadrangle. It likewise is overlapped by the Conestoga limestone 2 miles southwest of Coatesville and does not crop out in Chester Valley beyond that point. Its residual débris forms a small knoll northeast of Thorndale. Elsewhere it is represented by a low ridge of sandy micaceous soil.

Character and thickness.—The formation as exposed in the vicinity of Thorndale consists of interbedded highly micaceous limestone and calcareous mica schist. The more impure layers weather to slabby fragments of rust-stained laminated mica schist. Some of the fresh rock is a bluish laminated granular limestone spangled with mica. Elsewhere in the area it has disintegrated into a micaceous sand, which has been dug for building sand from Coatesville northeastward for over a mile, the outcrop now being marked by a line of elongated shallow sand pits. In the Pennsylvania Railroad cut at Vintage, near the type locality, the formation is composed of dark shale at the base overlain by dark banded argillaceous limestone, earthy dolomite, and spotted white and gray marble, in all 150 feet thick.

Age and correlation.—The Kinzers formation was named from Kinzers station, on the Pennsylvania Railroad in Lancaster Valley, where it is excellently exposed in railroad cuts. In that locality it contains the *Olenellus* trilobite fauna of Lower Cambrian age. Although its characteristic beds have not been observed in Cumberland Valley, the Kinzers is believed to represent the middle part of the Tomstown dolomite of that region.

LEDGER DOLOMITE

Distribution.—The Ledger dolomite occupies the central lowland portion of the Chester Valley from Coatesville northeastward to Downingtown. Its outcrop is about half a mile wide but tapers out 1 mile southwest of Coatesville, where it is overlapped by the Conestoga limestone. The formation crosses the extreme northwest corner of the West Chester quadrangle and is present in a small area in the lowland at the northwest border of the Coatesville quadrangle, north of the fault.

Character and thickness.—The formation is almost invariably granular crystalline light-gray to white dolomite, in places speckled or mottled with drab. It is generally a very pure carbonate rock of dolomite composition but locally contains beds of high-calcium marble. It commonly weathers to a characteristic deep-red granular soil, composed of residual clay and dolomite grains, which is very fertile. The subsoil surface of the dolomite is in places very irregular, owing to differential erosion. (See pl. 7.) In the western part of Coatesville about 130 feet of white granular dolomite of this formation, exposed in a quarry, is so massive and homogeneous that no bedding planes are observable. Similar dolomite has been quarried in the eastern part of Coatesville and at several places farther east. The estimated thickness of the formation is 600 feet.

Age and correlation.—The Ledger dolomite was named for exposures at Ledger, Lancaster County, Pa. It generally contains no visible fossils, but some weathered surfaces show concentric markings which are evidence of organic life, perhaps sponges or some similar low form. The formation is believed to represent the upper part of the Tomstown dolomite of Cumberland Valley and to be of Lower Cambrian age.

ELBROOK LIMESTONE

Distribution.—A narrow band of the Elbrook limestone occurs along the south side of Chester Valley in the northeastern part of the Coatesville quadrangle and the northwest corner of the West Chester quadrangle. It emerges from beneath the overlapping Conestoga limestone in the vicinity of Caln and is exposed along the Pennsylvania Railroad track as far as the southern part of Downingtown, where it passes out of the area.

Character and thickness.—The Elbrook is a finely laminated fine-grained marble, in part dolomite, in part limestone. The lamination, in places highly contorted, is more clearly observable on weathered surfaces. Muscovite and sericite spangle the cleavage and bedding planes in places. The formation generally weathers to shaly porous fragments and to a light-yellow ocherous soil, due to fine clayey impurities. At Gallagherville 15 feet or more of pure-white coarsely crystalline saccharoidal marble, in beds 2 to 3 feet thick, is included in the Elbrook formation because it seems to merge with the lower beds of that formation. It may, however, represent a locally pure calcitic part of the underlying Ledger dolomite. Both the white marble and the Ledger dolomite are quarried at Gallagherville, and the laminated phase of the Elbrook is quarried at Downingtown. The estimated thickness of the formation in this area is about 300 feet.

Age and correlation.—The Elbrook limestone in this area does not so closely resemble the limestone at Elbrook, near Chambersburg, Pa., as the Elbrook limestone of Lancaster Valley or even of other parts of Chester Valley. In the vicinity of Lancaster the laminated limestone is characteristically earthy and resembles the typical Elbrook in that it weathers to a yellow tripoli and light earthy soil. It contains no fossils, and the correlation with the typical Elbrook is based on lithology and stratigraphic position—that is, it lies between the Ledger (=upper part of Tomstown dolomite) beneath and the Conococheague limestone above. The Conococheague crops out east of Downingtown, north of the West Chester quadrangle. The Elbrook is of Middle Cambrian age.

ORDOVICIAN SYSTEM

By George W. Stose

CONESTOGA LIMESTONE

Distribution.—The impure limestone to which the name Conestoga has been applied underlies the larger part of the Chester Valley in this area. It occupies the full width of the valley in the western half of the Coatesville quadrangle. Its area gradually narrows from three-quarters of a mile to about a quarter of a mile at Coatesville and maintains this width to Downingtown, where it passes out of the West Chester quadrangle. Owing to its impure character it does not weather so readily as the purer limestones and makes low hills and ridges in the valley bottom, covered with micaceous sandy soil filled with slaty particles in places and broken by outcrops of micaceous limestone. On the south side of the valley it is largely concealed by phyllite and schist wash from the South Valley Hills.

Character and thickness.—The Conestoga is in general an impure thin-bedded blue to gray limestone. The purer limestone is generally granular and filled with mica flakes which lie parallel to the cleavage and generally to the bedding. The partings are dark, clayey, slaty, and micaceous, producing a marked banded and ribbed rock on weathering. Much of the limestone is dark and argillaceous. Some beds are so impure that they weather to shale, part of which is black and graphitic. Many of the basal beds are conglomeratic and contain pebbles and large masses of granular white to gray marble in a gray limestone matrix. This is especially well shown in an old quarry 2 miles northwest of Downingtown, north of the West Chester quadrangle (pl. 8), where the highly impure limestone grades down into purer limestone that gradually becomes less micaceous and resembles the folded, somewhat micaceous granular marble of the Conestoga quarried at Quarryville and is with difficulty distinguished from the underlying Elbrook limestone. Some beds contain much quartz sand and weather to a porous sandstone. A low ridge in the middle of the valley extending from Pomeroy westward is covered with sand derived from the disintegration of such sandy limestone. The thin-bedded limestones are generally so highly plicated that the thickness can not be estimated with assurance, but there is at least 500 feet of the formation and probably much more where the outcrop is widest.

Age and correlation.—No fossils have been found in the Conestoga limestone in Chester Valley. It is clearly unconformable on all the limestones there exposed, and in the vicinity of Norristown it overlies the Beekmantown limestone, of Lower Ordovician age. In Lancaster Valley fossils of Lower Ordovician age (probably Chazy) have been found in it. The formation is very widespread in Lancaster Valley and is typically exposed along Conestoga Creek, whence its name.

TERTIARY SYSTEM

BRYN MAWR GRAVEL

Character and distribution.—A thin deposit of yellow gravel, locally associated with a considerable thickness of sand and some clay, occurs on the upland north of Wilmington. The pebbles are mostly quartz and quartzite. Five small areas are mapped, ranging in altitude from 300 to 420 feet.

Age and correlation.—This gravel is the higher and therefore the older of two old upland gravel deposits. The name Brandywine, at first applied to both of these deposits, has been restricted to the lower gravel, and Bryn Mawr is applied to the upper gravel, which is regarded as probably of Pliocene age. Similar high-level gravel occurs in the neighborhood of Bryn Mawr, the type locality, northeast of this area.

QUATERNARY SYSTEM

BRANDYWINE GRAVEL

Character and distribution.—Gravel, sand, and clay thinly cover several flat terraces in the southeastern part of the West Chester quadrangle at altitudes of 220 feet or less. The most clearly defined deposit is that which caps the 220-foot terrace north of Edgemoor.

Age and correlation.—This gravel, containing pebbles less roughened than those of the Bryn Mawr gravel and occurring at a definitely lower level, is younger and probably of early Pleistocene age and is correlated with gravel on the upland at Brandywine, Md.

SUNDERLAND FORMATION

Character and distribution.—In northern Wilmington and farther west there are three areas of the Sunderland formation on terraces at 140 to 180 feet. The basal part of the formation is usually the coarser and contains pebbles and some boulders of quartz and crystalline rocks, many of which are decomposed. The coarser material is generally cross-bedded and probably stream-borne. Some large boulders are iceborne. The finer material is stratified and lenticular.

Age and correlation.—The formation is an alluvial deposit that lies on the highest of three low terraces in the Coastal Plain which are covered with such gravel. It was named from Sunderland, Md., where gravel of this terrace is well exposed. It is of early Pleistocene age.

TALBOT FORMATION

Character and thickness.—Clay, peat, sand, and gravel cover the lowland from Brandywine Creek to Edgemoor, in the southeast corner of the West Chester quadrangle. The deposit covers a terrace about 40 feet above sea level. The coarser material, including some cobbles and boulders, occurs at the base of the formation, and finer material at the surface. The pebbles are fresh and unweathered.

Age and correlation.—The formation is the lowest and youngest of the terrace gravels along the Coastal Plain and was named from Talbot County, Md., where it covers a wide, flat terrace. It is of late Pleistocene age.

IGNEOUS ROCKS

GENERAL FEATURES

The Coatesville and West Chester quadrangles contain igneous rocks of pre-Cambrian, Paleozoic, and Triassic age. The pre-Cambrian igneous rocks occur as batholiths, dikes, or minute sheetlike injections into pre-Cambrian gneisses. There are also dikes that intrude Paleozoic sediments and others that cut Triassic rocks. No volcanic rocks have been found in the quadrangles.

The plutonic pre-Cambrian igneous rocks, which are the most abundant, belong to the granite, gabbro, pyroxenite, and peridotite families. They are regarded as differentiates of a common magma and form an assemblage that shows an intimate intermingling of types and gradations between types. So closely do quartz gabbro, quartz diorite, and the metamorphosed invaded sedimentary gneiss resemble one another in color, constituents, and massive character, so irregular and confused are their contacts, that in the absence of good exposures the boundaries drawn have not the same significance as lines between well-defined sedimentary formations. The map represents the preponderance of one or another of the types rather than the exclusive occurrence of a single type.

These igneous rocks in places have a foliated texture. The foliation is due in part to the interlayering of several distinct igneous types and in part to the layered arrangement of the mineral constituents in single types. It is limited principally to the peripheries of the large intrusive masses or is found where smaller intrusive masses have yielded to compression.

Similar plutonic intrusions are associated with pre-Cambrian gneisses throughout the Atlantic provinces. They form an important part of the pre-Cambrian complex of the Adirondack Mountains; they appear in the Highlands of New Jersey, where they have been described under the names Byram gneiss, Losee gneiss, and Pochuck gneiss. They continue through Pennsylvania and Maryland. In Tennessee and the Carolinas similar rocks, probably belonging to the same period of intrusion, are termed the Cranberry granite and Roan gneiss.

The pre-Cambrian igneous rocks of Pennsylvania are all lime-rich. Alkaline feldspathoid minerals and even soda-bearing pyroxenes and amphiboles are altogether lacking. The igneous rocks of these quadrangles are part of a zone of lime-rich rocks, presumably differentiates from a single magma, which crop out west of an Atlantic zone of soda-rich igneous rocks in eastern New England.

GRANITE

Distribution.—Although in this district there is extensive granitic saturation of the pre-Cambrian gneisses and although there occur numerous pegmatite dikes, outcrops of massive granite are almost completely lacking. About 2½ miles north of Kennett Square a quarry has been opened in what appears to be a small mass of granite. In an old quarry near Wawaset station a massive light-colored granitic rock is exposed in the midst of gabbro.

Character.—The rock north of Kennett Square is light colored, medium to fine even grained, and of gneissoid texture. The constituents are quartz about 50 per cent, feldspar (orthoclase, microcline, and andesine) about 45 per cent, and biotite with accessory zircon and secondary muscovite about 5 per cent; the rock is specifically a quartz monzonite. The mass invades the Baltimore gneiss and the Setters formation.

The rock at the Wawaset quarry is medium fine grained and consists of quartz, feldspar (orthoclase, microcline, and andesine-labradorite), scanty biotite, and hornblende. This rock also is of a quartz monzonite type.

GABBRO

Distribution.—Gabbro occupies a large area in the southeastern part of the West Chester quadrangle and extends into the Chester and Wilmington quadrangles. Gabbro also appears at the surface in several large masses in the northern and central parts of the West Chester quadrangle and occurs in innumerable small intrusions throughout the Coatesville-West Chester district.

Character.—The intrusions that have the smallest mass have been least able to resist dynamic action and are the most altered. The original rock type is found in the larger masses. The normal type is a hypersthene gabbro (norite) or an augite gabbro, with or without quartz. The rock is medium grained, of a medium gray or bronzy color except where excessive secondary hornblende gives it a green color. The rock weathers to rusty brownish-gray spheroidal boulders. The principal constituents are feldspar (labradorite chiefly, labradorite-bytownite, and bytownite-anorthite) and pyroxene (hypersthene or augite or both). Accessory constituents are quartz, biotite, hornblende, garnet, apatite, zircon, titanite, ilmenite, magnetite, and pyrite. Secondary constituents are hornblende, scapolite, epidote, chlorite, magnetite, zoisite, muscovite, kaolin, calcite, and leucoxene. Where quartz is not present as an essential constituent, feldspar constitutes 45 to 50 per cent of the rock, the pyroxene or hornblende 40 to 45 per cent, and the accessory constituents 5 to 10 per cent.

The texture is holocrystalline and phanerocrystalline; the fabric is approximately equigranular, xenomorphic, equant, and tabular or prismoid. Where hornblende is developed, the tabular crystals have a parallel arrangement. The gabbro quarried near Wilmington is a more silicic type. It is lighter colored owing to abundant blue quartz (about 30 per cent) and dominant feldspar (about 60 per cent), with not more than 10 per cent of pyroxene. The feldspar is chiefly andesine of approximately the composition Ab_2An_1. Orthoclase and a plagioclase more calcic than the andesine are scantily present. Garnets are a characteristic accessory constituent, freely distributed throughout the rock and also peripherally developed about the pyroxene or amphibole constituent or even about the magnetite. The peripheral garnets owe their origin to chemical reactions between the feldspar and the ferromagnesian constituents.

Near Concordville the gabbro is porphyritic with phenocrysts of plagioclase laths half an inch in length.

The following analyses represent gabbro from the Pennsylvania Piedmont province, collected at localities adjacent to the Coatesville and West Chester quadrangles on the north, east, and south:

Analyses of gabbro

	1	2	3	4	5	6	7	8
SiO_2	64.26	58.57	55.16	54.03	49.67	48.68	48.02	44.04
Al_2O_3	15.88	16.10	17.51	16.71	18.19	14.39	20.01	20.01
Fe_2O_3	2.74	2.89	2.62	1.37	.33	4.00	1.13	4.22
FeO	1.44	6.12	5.83	7.70	12.84	10.09	7.29	8.61
MgO	2.80	2.33	4.35	5.66	2.12	6.32	10.05	5.01
CaO	7.44	7.39	8.50	8.84	9.70	9.23	11.42	11.86
Na_2O	3.43	2.11	1.83	2.99	2.74	2.81	.51	1.24
K_2O	.77	1.01	1.08	.67	.34	.47	.05	.15
H_2O+	.50	1.27	2.01	.53	.74	2.03	.57	1.90
H_2O-	.15	.21	.18	.14	.15	.46	.10	.11
TiO_2	.45	1.41	.64	.84	2.01	1.69	.23	2.24
ZrO_2	.02	.09	.02	Not est.	Trace.	Not est.	None.	.10
CO_2		None.	None.	.40	None.	None.	.25	None.
P_2O_5	.16	.37	.21	.13	.58	.29	Trace.	.52
FeS		Trace.	.03				.11	.25
S	Trace.			.09	.32	Trace.		
Cr_2O_3		None.	Trace.	Trace.			.08	None.
V_2O_3		.02	.04				.02	.05
NiO		None.	[a].01	Trace.		Trace.	.01	.01
MnO	.02	.18	.15	.13	.37	.22	.18	.28
BaO	None.	Trace.	Trace.	Trace.	Trace.	Trace.	None.	None.
SrO		Trace.	Trace.	Trace.		None.	None.	None.
Li_2O		Trace.	Trace.	Trace.		Trace.	None.	Trace.
	100.06	100.07	100.17	100.23	100.10	100.18	99.98	100.42

[a] (Ni,Co)O.

NORMS

	1	2	3	4	5	6	7	8
Quartz	24.00	21.60	13.50	4.68	2.70	2.82	0.60	2.10
Orthoclase	4.45	6.12	6.67	3.89	2.22	2.78	.56	1.11
Albite	28.82	17.82	15.20	25.15	23.06	19.39	4.19	10.48
Anorthite	25.85	31.41	36.42	30.30	36.14	27.52	51.99	48.87
Diopside	7.99	2.32	4.08	10.44	7.44	13.44	3.88	5.23
Hypersthene	3.30	11.50	16.70	20.50	21.40	22.00	35.65	19.18
Zircon								.18
Magnetite	3.25	4.18	3.71	2.09	.46	5.80	1.62	6.03
Ilmenite	.91	2.74	1.22	1.67	3.80	3.19	.46	4.26
Apatite	.34	1.01	.34	.34	1.34	.67		1.34
Hematite	.48							
Pyrite			.03	.18	.60		.11	.25
Water±	.65	1.48	2.19	.67	.89	2.49	.67	2.01
Miscellaneous	.04	.11	.05	.40			.31	.06
	100.08	100.29	100.11	100.26	100.05	100.10	99.99	100.60

1. ″II.4.3(4).4(5). Hornblende-grano-placerose-tonalose.
2. II.4.4.4. Biotitic hornblende-grano-bandose.
3. II.4.4.4. Biotitic hornblende-grano-bandose.
4. II(III).″5.″4.4(5). Augite-grano-hessose.
5. II(III).5.4″5. Augite-grano-hessose.
6. III.5.4.(4)5. Hornblende-grano-auvergnose.
7. ″III.5.5.(4)5. Grano-kedabekose.
8. II(III).5.(4)5.″5. Biotitic hornblende-grano-corsose.

1. Quartz gabbro, half a mile northeast of Devault, Pa., Phoenixville quadrangle. Specific gravity 2.890.
2. Quartz-biotite metagabbro, foundry on Stone Run, Cecil County, Md., Havre de Grace quadrangle. Specific gravity 2.902.
3. Quartz-biotite metagabbro, Porter Bridge, Octoraro Creek, Cecil County, Md., Havre de Grace quadrangle.
4. Gabbro, Radnor, Pa.
5. Gabbro, 1 mile northeast of Fontaine, Chester County, Pa. Honeybrook quadrangle.
6. Metagabbro, Roberts road, one-eighth of a mile west of Gulf Mills road, Bryn Mawr, Montgomery County, Pa., Norristown quadrangle.
7. Hypersthene gabbro (norite), McKensey's Mill, Cecil County, Md., Havre de Grace quadrangle.
8. Metagabbro, Stone Run, Cecil County, Md., Havre de Grace quadrangle.

All the analyses were made in the laboratory of the U. S. Geological Survey—No. 1 by R. C. Wells, No. 5 by W. T. Schaller; the others by W. F. Hillebrand. Nos. 2, 3, 4, and 8 were made for A. G. Leonard (Basic rocks of northeastern Maryland: Am. Geologist, vol. 28, pp. 146, 151–152, 159, 1901).

The application of the quantitative system of classification to the gabbro of the Pennsylvania Piedmont brings out the fact that the gabbroic intrusion is not of the same chemical composition throughout but ranges in basicity through two classes. The auvergnose is the typical hypersthene gabbro or norite. Tonalose and bandose are quartz gabbros and grade chemically and lithologically into quartz diorite. The quartz gabbro is dosalic—that is, the ferromagnesian or melanocratic constituents (pyroxene and iron oxide) are less than 37.5 per cent of the rock, and the salic or leucocratic constituents (quartz and feldspar) form more than 62.5 per cent of the rock. They are quardofelic—that is, feldspar is dominant over the quartz. The other types are salfemic or nearly so—that is, the salic and femic constituents have about the same percentage. They are perfelic—that is, feldspar is extremely dominant over the quartz; docalcic or percalcic; and persodic—that is, soda is invariably present in larger amount than potassa.

Age.—The gabbro intrusives are confined to pre-Cambrian formations and chiefly to the Baltimore gneiss and the Wissahickon formation. The protracted igneous activity of pre-Cambrian time ceased before Paleozoic time began, and the gabbro is late pre-Cambrian or post-Wissahickon.

SERPENTINE

Distribution.—Serpentine and related rocks appear at the surface in these quadrangles in many small isolated outcrops. Associated outcrops presumably represent disconnected exposures of a single large mass. At Westtown School drilled wells that are in the line of strike between outcrops of serpentine distant 1 and 2 miles to the southwest and northeast have penetrated serpentine which presumably is part of a continuous mass connecting these outcrops.

There are 46 mapped outcrops of serpentine and related rocks in the West Chester quadrangle and 9 in the Coatesville quadrangle. The largest area of serpentine is near Mount Cuba, 3 miles east of Hockessin; another lies 1 mile northeast of Unionville; and there are many small areas northeast of Mount Cuba and south, east, and northeast of Unionville.

Character.—Serpentine is one of the most readily recognized of rock types because of its softness, uniform texture, and characteristic green tints. The range in color, however, is considerable; in addition to many shades of yellowish green, grayish green, blue-green, and emerald-green there are varieties of reddish brown or buff or even white. Light colors and an earthy texture are usually associated; dark colors accompany a compact texture; grayish-green colors a fibrous texture due to the development of such minerals as talc, asbestos, or tremolite. The rock is traversed by numerous irregular and interrupted joint planes, whose surfaces are in many places slickensided.

A final alteration product of the serpentine is a rusty-yellow siliceous rock composed of cryptocrystalline quartz, jasper, chalcedony, or opal, colored by limonite and having a cellular or honeycomb texture due to the complete removal of the magnesium silicate. As it weathers less readily than other rocks, owing to its chemical stability, serpentine forms low hills and ridges in which bare rock is exposed or is covered only with a scanty depth of yellowish-green soil. The soil derived from serpentine and the general aspect of the country underlain by serpentine are distinctive. The sterility of the so-called honeycomb-rock soil, which is well known among farmers, is due as much to its thinness and inability to hold water as to its chemical composition, which is unfavorable for vegetation because of the absence of lime and the presence of magnesia. Thus even a small area of serpentine offers a notable contrast to the surrounding country. A cultivated and fertile soil may give place abruptly to a relatively barren soil that supports a scanty vegetation; ground pink (*Phlox subulata*), cat brier, cedars, and stunted pines characterize the serpentine hills, which are for the greater part left uncultivated.

The origin of serpentine from pyroxenite (a nonfeldspathic pyroxene-bearing rock) and from peridotite (a nonfeldspathic olivine-pyroxene rock) has long been recognized. Serpentine originating from a pyroxenite is likely to be somewhat fibrous and to have associated with it tremolite, anthophyllite, or smaragdite—minerals representing intermediate stages in the passage of pyroxene to serpentine. Serpentine originating from a peridotite is more massive and shows under the microscope a mesh texture due to the development of the serpentine along the periphery of the olivine and along a network of cracks in the olivine. Olivine cores may still remain where the alteration is not quite complete. Besides the associated minerals already mentioned, there is a considerable list of accessory and secondary constituents, among which chromic iron, magnetite, calcite, quartz, and talc (steatite) are the most common.

Chrome ore was mined in the "State line serpentines" southwest of the Coatesville-West Chester district as early as 1828, ceased to be mined about 1882, and was again mined in 1918, during the World War. Some of these chrome ore mines, notably Wood's mine, have been famous collecting ground for the rarer minerals associated with serpentine, such as brucite, clinochlore, deweylite, zaratite, picrotite, magnesite, hydromagnesite, and williamsite or precious serpentine.

The rock in the Mount Cuba area mapped as serpentine is in part pure serpentine of a pale-green color and smooth texture, containing magnetite crystals and lustrous scales of talc; in part a massive dark-green peridotite (wehrlite) composed of augite and serpentinized olivine; in part a medium-green peridotite of fibrous texture with a rough rusty-yellow weathered surface composed of tremolite, augite, and serpentinized olivine; and in part a massive green gabbro containing hypersthene, hornblende, and labradorite.

The dark mottled serpentine that forms a low ridge halfway between Westtown and Oakbourne stations is a peridotite (wehrlite) that originally contained augite and olivine, now serpentinized, with magnetite, calcite, and steatite as by-products.

The serpentine a mile west of Pleasant Grove, which is famous for the building stone that has been taken from a large quarry in it owned and operated by Joseph H. Brinton, is a pale, faintly mottled green rock of an unusually uniform character. A mesh texture, indicative of olivine as an original constituent, and traces of enstatite demonstrate the derivation of the serpentine from a peridotite, but as a rule the rock shows little trace of the original constituents; steatite and calcite are accessory minerals. Brinton's quarry exposes pegmatite intrusive in the serpentine. The pegmatite with associated hydrothermal injections, the peridotite, and the contact minerals presumably produced by this combination have made the quarry a hunting ground for mineral collectors. Among the minerals obtained here are chromite, anthophyllite, tremolite, asbestos, ripidolite, talc, magnetite and other iron oxides, amethystine quartz, aragonite, deweylite, saprolite, magnesite, beryl, tourmaline, apatite, and notably jefferisite.

The serpentine of the Pocopson schoolhouse area, three-quarters of a mile southwest of Lenape, is derived from a coarse-grained peridotite containing hypersthene, olivine, and tremolite and showing the poikilitic fabric. Just northeast of this area and in the line of strike is a sharply defined conical mass of peridotite which forms an abrupt hillock in otherwise flat land. The character of the rock, heavy and dark colored, and the nature of the exposure, an isolated mass apparently dropped and partly buried, have led the neighboring farmers to call it a meteorite. The rock is a partly serpentinized olivine-diopside peridotite (wehrlite). Olivine and diopside are present in about equal amounts, and the only accessory constituent is magnetite or ilmenite.

The serpentine $2\frac{1}{4}$ miles west of Pocopson schoolhouse, a grayish-blue rock, contains more steatite than serpentine. The serpentine area 1 mile northwest of Red Lion is a serpentinized pyroxenite, an actinolite-augite rock.

The large area of serpentinized peridotite 1 mile northeast of Unionville, is notable for the association with it of pegmatites and corundum. The corundum, which was at one time mined for abrasive uses, is reported to have occurred very irregularly in considerable granular masses and in euhedral crystals with albite, tourmaline, and margarite. The association of the corundum seems always to have been with the pegmatites in contact with peridotite. With the present exposures there is little basis for determining whether the corundum originated as a product of desilication of the pegmatite by the peridotite or as a product of crystallization from hydrothermal solutions charged with alumina. Loose crystals of corundum have been at times picked up in the soil but are now hard to find. This locality, known as Corundum Hill, has been famous as a source of mineral specimens. The minerals usually associated with metaperidotite and the minerals of pegmatite are found here; the more notable ones, in addition to corundum, are asbestos (mountain cork), clinochlore, talc, spinel, pyrite, magnetite, hematite, limonite, the alkali feldspars, margarite, tourmaline, muscovite, pattersonite, brucite, gibbsite, and jefferisite.

The outcrop of serpentine and steatite 2 miles north of Corundum Hill is said to have furnished material to the Indians for the manufacture of pots. The area mapped as serpentine half a mile south of Laurel, on the West Branch of Brandywine Creek, is in large part a fissile steatite or soapstone.

In West Bradford Township $2\frac{1}{4}$ miles northeast of Romansville there is a very small outcrop of a pale-green finely crystalline magnesite rock. The index of refraction (ω=1.72) indicates that the magnesite may contain a small percentage of siderite (iron carbonate). The rock is somewhat siliceous and owes its color to the presence of a chromic muscovite, fuchsite[10] (containing 3 per cent Cr_2O_3), and a little chlorite. The nature of the occurrence and the mineral constituents—quartz, magnesite, and fuchsite—suggest that the rock represents an extreme phase of alteration of a peridotite.

The serpentine near West Sadsbury schoolhouse, $1\frac{3}{4}$ miles north of Atglen, contains much actinolite and biotite and some talc or steatite. A mile north of Sadsburyville there is an area of dark-green serpentinized pyroxenite grading northward into gabbro; with the serpentine are associated tremolite, steatite, and magnetite.

[10] Wherry, E. T., U. S. Nat. Mus. Proc., vol. 49, pp. 465-466, 1916.

Composition of serpentine

	1	2	3	4
SiO_2	44.18	43.49	44.10	43.13
Al_2O_3	Trace.	-------	-------	-------
FeO	1.64	-------	-------	1.76
MgO	39.37	43.47	43.00	42.17
H_2O+	12.78	13.04	12.90	12.94
H_2O-	2.10	-------	-------	-------
	100.07	100.00	100.00	100.00

1. Serpentine, Mineral Hill, Middletown, Delaware County, Pa. F. A. Genth, analyst, Pennsylvania Second Geol. Survey Rept. C5, p. 120, 1885.
2, 3. Theoretical composition of serpentine.
4. Composition of serpentine with some of the magnesia replaced by ferrous oxide.

The pyroxenites and peridotites, from which serpentine is derived with the loss of alkalies and lime in the form of carbonates, are the least silicic of the igneous rocks of the Pennsylvania Piedmont province. They are considered to represent the gravitative accumulation of olivine and pyroxene crystals from a magma in the early stages of fractional crystallization, and unless there was partial refusion of these crystals they could not have moved freely from the horizon in which they accumulated.

Age.—Under this view of their origin the pyroxenites and peridotites will not have strictly intrusive relations, but they must be older than the later differentiates, the gabbro, diorite, granite, and pegmatite, and because they are limited in their association to pre-Cambrian rocks they are regarded as of pre-Cambrian age.

PEGMATITE

Distribution.—Pegmatite dikes are very numerous in the Coatesville-West Chester district, especially in the southeastern part of the Coatesville quadrangle and the southwestern part of the West Chester quadrangle. In general they strike northeast, parallel to the structure of the formations which they invade, and usually dip with the schistosity of the formations. The dikes vary greatly in width, and few individual dikes can be traced continuously for long distances. In many places the pegmatitic masses are exposed in a series of lenses rather than as a continuous dike. In addition to the dikes mapped there are innumerable paper-thin injections of pegmatite in the gneiss, which completely alter the character of the invaded rock. Such injections in the Wissahickon formation can be seen in the quarry on the East Branch of Brandywine Creek a quarter of a mile northeast of Copesville. A similar injection of the Baltimore gneiss is exposed in a road cut on the road leading from Kennett Square to Longwood, also 2 miles northwest of Kennett Square at the fork in the road. Pegmatite is characteristically associated with the ultrasubsilicic intrusive rocks. Such dikes cut the serpentine at Corundum Hill, northeast of Unionville, at Brinton's quarry, and at Mount Cuba. Pegmatite dikes also cut the formations of the Glenarm series and more sparingly the Cambrian rocks.

Character.—The pegmatite dikes of this region are granitic, quartz monzonitic, quartz dioritic, and gabbroic in constitution. They differ from the corresponding normal igneous types only in the remarkable coarseness of their crystallization, the irregularity of their texture, and the sporadic occurrence in them of rare minerals, due, it is believed, to the presence in this part of the magma of an extraordinary amount of water with small amounts of such volatile constituents as carbon dioxide, carbon monoxide, hydrogen, sulphur, chlorine, fluorine, and boron.

Pegmatite dikes are light-colored, owing to the prominence among their constituents of the silicic or light-colored minerals. The usual constituents are quartz, an alkali feldspar (orthoclase or more commonly microcline, microperthite, albite of later crystallization, or oligoclase), and muscovite or biotite. A sporadic but characteristic texture is the graphic, shown in a striking cuneiform pattern on the cleavage faces of the feldspars and produced by the interpenetration of quartz and feldspar during the crystallization period or in some places through a secondary replacement by quartz.

In general the texture of the pegmatites of this district is somewhat gneissoid. The usual accessory minerals are garnet, tourmaline, pyrite, and corundum. Corundum is a common accessory constituent where pegmatites have invaded peridotites, although it is not altogether limited to this combination, being also found with some pegmatites that invade gneiss. The alumina of the corundum may have been supplied by the hydrothermal solutions preceding, accompanying, or following the pegmatitic invasion, or it may have been liberated by the desilication of the aluminous silicates of the pegmatite through chemical interchange with the peridotite or with the sillimanite in the gneiss. If the desilication has taken place its products other than corundum should be found along the contact. In Brinton's quarry the vermiculite (jefferisite), anthophyllite, tremolite, and talc zones bordering narrow ramifying dikes of sodic feldspar or without the central zone of feldspar may represent such products. The reactions which might produce these minerals so commonly associated with pegmatitic intrusions in peridotites must be conceived of as taking place in connection with the movement of highly fluid pegmatitic solutions permitting exchange of material.

The pegmatite that cuts the Wissahickon gneiss in the Wooddale quarry contains quartz, microcline, oligoclase, and oligoclase-andesine as essential constituents, with accessory biotite, muscovite, and garnet. The feldspar, of which only about 10 per cent is microcline, constitutes about two-thirds of the rock, which is a quartz diorite.

A granite dike intrudes the gabbro on the northern outskirts of Wilmington and is exposed on Brandywine Creek in a road cut leading to Henry Clay Factory.

The pegmatite dikes have considerable economic importance; some of them have been quarried for corundum; many of them are quarried for feldspar and flint, and others for kaolin, a decomposition product, under favorable conditions, of the hydration of feldspar.

Age.— Pegmatite is intrusive only in the pre-Cambrian formations of this area but penetrates Cambrian-Ordovician formations to the northwest and presumably represents the dying out of igneous activity of pre-Cambrian time.

The chemical composition of the pegmatite shows it to be an extreme product of magmatic differentiation at the silicic end of the series; the pyroxenite and peridotite represent extreme differentiation at the subsilicic end of the series. These two groups of differentiates are associated in many places, and in such an association the pegmatite is the younger.

DIABASE

Distribution.—Two dikes of diabase extend across the Coatesville-West Chester district. The easterly one crops out north of Chatham and can be traced in a northeasterly direction intermittently across the West Chester quadrangle, which it leaves northeast of West Chester, and for many miles farther northeast. In fine exposures at West and East Conshohocken it has a width of about 30 feet and has been known as the Conshohocken dike. The second dike enters the Coatesville quadrangle south of Oxford, traverses the quadrangle, and is traceable many miles to the northeast. Good exposures in Downingtown have made it known as the Downingtown dike. It has been traced southwestward to Susquehanna River. Besides these two larger dikes there are three smaller dikes of the same character and trend north and northeast of Chatham.

Character.—The rock of these dikes is similar and of a uniform character; it is a medium to fine grained bronzy-green rock, weathering in spheroidal boulders with a rusty-yellow oxidized coat. In constituents and texture it is a typical diabase: plagioclase and pyroxene in about equal amounts are the primary constituents, and ilmenite, quartz, and apatite are accessory constituents. The secondary minerals are chlorite, delessite, biotite, calcite, and epidote. The plagioclase, which is labradorite-bytownite, forms a network of automorphic lath-shaped crystals; the pyroxene, which is the aluminous monoclinic species augite, is xenomorphic and fills the interstices of the feldspar network, making with the feldspar a fabric known as ophitic.

Analyses of diabase

Analyses			Norms		
	1	2		1	2
SiO_2	51.56	50.79	Quartz	10.14	3.78
Al_2O_3	17.38	14.19	Orthoclase	8.90	5.56
Fe_2O_3	6.57	3.84	Albite	18.34	15.72
FeO	3.85	7.44	Anorthite	33.08	27.52
MgO	3.42	7.88	Enstatite	8.60	-------
CaO	10.19	9.75	Diopside	-------	16.19
Na_2O	2.19	95	Wollastonite	6.96	-------
K_2O	1.46	1.89	Hypersthene	-------	22.02
$H_2O\pm$	2.15	1.95	Apatite	.34	.34
TiO_2	1.63	.70	Ilmenite	3.04	1.37
P_2O_5	.13	.15	Magnetite	7.66	5.57
Li_2O	Trace.	-------	Hematite	1.28	-------
MnO	-------	.48	H_2O	2.15	1.95
	100.53	100.01		100.49	100.02

1. Conshohocken dike at Gulf Mills, Montgomery County, Pa. F. A. Genth, jr., analyst, Pennsylvania Second Geol. Survey Rept. C6, p. 134, 1881.
2. Dike at Williamsons Point, Susquehanna River, Lancaster County, Pa. F. A. Genth, analyst, Pennsylvania Second Geol. Survey Rept. C8, p. 275, 1880.

By the quantitative system of classification the Conshohocken dike falls in Class II, order 4 (5), rang 4, and subrang ″4. It is dosalic, quardofelic, docalcic, and presodic. The name of this subrang is bandose; the micro-ophitic fabric and occurrence of augite as an abnormative constituent are recognized in the descriptive name augite-ophiti-bandose. The other dike falls into Class III, order ″5, rang 4, subrang 4. The rock is salfemic, perfelic, docalcic, and presodic and is named augite-ophiti-auvergnose. This subrang contains Triassic diabase and basalt from the Watchung Mountains, Orange, N. J., and other localities.

Age.—Both the Conshohocken and the Downingtown dikes may be traced into Triassic formations north of the area, which they intrude. They and all similar fresh diabase dikes of eastern Pennsylvania are of Triassic age. They are related to great masses of diabase that were extruded and intruded during Triassic time and are the youngest igneous rocks in the Coatesville and West Chester quadrangles.

STRUCTURAL GEOLOGY

GENERAL OUTLINE

The rocks of the Piedmont province have not remained undisturbed in the horizontal position in which they were formed. The Paleozoic and pre-Paleozoic rocks occur everywhere in positions acquired by folding or faulting and in outcrops due to the planation of the folds.

The severe compression from the east and southeast to which all the eastern continental shelf was subjected prior to, at about the middle, and toward the end of Paleozoic time, produced the type of structure which prevails in the Blue Ridge and Piedmont provinces and which is characterized in the Piedmont province by overturned anticlines and synclines striking northeast, with nearly isoclinal dips to the southeast, and by thrust faults which dip either approximately with the stratification or more gently and which reverse the normal succession of the formations by bringing older strata above younger. The severe compression that took place after as well as before faulting has folded both fault planes and bedding planes and has developed crystallization, schistosity, and fissility in the rocks.

Portions of the province are covered by Triassic sediments and by outliers of the sediments of the Coastal Plain. These sediments, deposited long after the period of severe compression, exhibit simplicity of structure and freedom from metamorphism, in striking contrast to the older formations. The Triassic sediments, for example, show little or very gentle folding but are tilted at a low angle to the northwest and cut by normal faults in many places. The faulting occurred in connection with crustal movements that brought about the uplift of the Triassic sediments and also involved the underlying rocks. Many such faults have been traced in the Paleozoic formations, but it is not always possible to trace them in the pre-Cambrian crystalline formations because of the absence of well-defined beds.

The Paleozoic and pre-Paleozoic sediments of the Piedmont province are folded in an anticlinorium which brings to the surface pre-Cambrian gneisses in the central portion of the province, wherever the Triassic cover has been removed by erosion. Successively on each flank of this anticlinorium Paleozoic sediments and pre-Cambrian schists and gneisses are exposed on the limbs and in the troughs and crests of subordinate synclines and anticlines.

STRUCTURE OF THE COATESVILLE AND WEST CHESTER QUADRANGLES

ARCHEAN AND ALGONKIAN ROCKS

The Coatesville and West Chester quadrangles are on the southeast flank of the major anticlinorium of the Piedmont province and contain three secondary anticlines and four secondary synclines striking northeast. At the northwest is the Sadsbury or Mine Ridge anticline, with pre-Cambrian gneiss in the arch and Paleozoic sediments on the limbs. Southeast of this fold is the Chester Valley syncline, in Paleozoic rocks. Thrust over this syncline and completely concealing the southeast limb are folded and compressed pre-Cambrian formations.

The large folds within the pre-Cambrian rocks are the Peach Bottom syncline, with Peters Creek schist in the trough and Wissahickon formation on the limbs; the Woodville anticline, with Baltimore gneiss in the arch and the Glenarm series on the limbs; the Willowdale syncline, in Setters formation and Cockeysville marble; the Avondale anticline, repeating the formations of the Woodville anticline; and finally the Landenberg syncline, a secondary synclinorium in the Wissahickon formation, bringing the Cockeysville marble to the surface in subordinate anticlines. These folds are either inclined or overturned with their axial planes dipping southeast and the limbs of the folds parallel or nearly so. The pitch of these folds is to the southwest, and in the Woodville and Avondale anticlines it is abrupt and brings the younger formations of the Glenarm series to the surface. Subsidiary folds and crumples appear on the limbs of the secondary folds. All the folds in pre-Cambrian formations are interrupted by igneous injections.

The Wissahickon formation, though apparently a conformable member of the Glenarm series, occurs in unconformable relations to the lower formations of the series and in places appears to lie directly upon the Baltimore gneiss. The absence of the Setters formation and the Cockeysville marble in such places may be due either to pre-Wissahickon erosion or to nondeposition of these formations, for there is undoubtedly considerable variation in the thickness of these sediments.

Thus, although there may be a hiatus in time between the deposition of the Cockeysville marble and that of the Wissahickon formation, and certainly a vast hiatus between the Baltimore sediments and the Wissahickon, there is no evidence that the rocks were folded between Wissahickon and Cockeysville time. The great unconformity between the Wissahickon and the Baltimore gneiss is simply obscured, where not obliterated, by intense post-Wissahickon folding and igneous injection.

CAMBRIAN AND ORDOVICIAN ROCKS

By George W. Stose

The Cambrian and Ordovician rocks of the Coatesville and West Chester quadrangles are restricted to the Mine Ridge anticline and the West Chester syncline. Metamorphism, which has nearly obliterated the original stratification of the pre-Paleozoic sedimentary rocks, including those which form the core of the Mine Ridge anticline, has not affected the Paleozoic rocks to the same degree. Bedding planes can generally be deciphered in the Chickies quartzite, especially in its Hellam conglomerate member, and in the Cambrian and Ordovician limestones, but in the Harpers schist and the Antietam quartzite, more especially on the south flank of the Mine Ridge anticline, metamorphism has developed schistosity to such a degree that it is about the only structure discernible in these recrystallized and closely folded rocks.

The Mine Ridge anticline is a broad-topped, steep-sided fold, which plunges west north of Quarryville and is there a double anticline with many minor wrinkles on its flanks. The steeply dipping quartzites on the south flank of the anticline, which appear at first glance to be a continuous sequence of monoclinal beds, are really closely folded. In the Pennsylvania Railroad cut west of Atglen and also in the gorge of the West Branch of Brandywine Creek at Coatesville the quartzite beds are repeated by folding and probably by minor faulting, as shown in the graphic section given in Figure 6. These minor folds plunge eastward and are manifest on the geologic map in the sharp bending of the outcrop of the Chickies formation near the Brandywine Creek gorge north of Coatesville and at several places to the southwest.

Just beyond the northern border of this district the Harpers and Antietam formations are similarly offset by a sharp fold, which is probably the expression of the same minor folding seen at Coatesville. The general dip of the quartzite beds on the south limb of the Mine Ridge anticline is about 60° SE., and the Harpers schist and Antietam quartzite thus pass normally beneath the limestones of Chester Valley. East of Thorndale, where the Vintage dolomite and Kinzers formation are exposed, they dip south and overlie the Antietam quartzite in normal relations. In Coatesville outcrops of the light-colored Ledger dolomite, the next succeeding formation, also dip steeply south on the flank of the anticline, and farther east the Elbrook limestone overlies the Ledger. These Cambrian formations are successively overlapped westward by the Ordovician Conestoga limestone, which occupies only a narrow strip of the southern part of the valley at Downingtown but west of Coatesville forms the surface of the whole valley from the schist hills on the north to the pre-Cambrian Wissahickon formation of the South Valley Hills. The Antietam quartzite has not been recognized west of Coatesville, and it may have been similarly eroded and overlapped by the Conestoga limestone. The Conestoga limestone is in most places so disintegrated and covered with soil that bedding can not be determined, but in an old quarry 2 miles southwest of Coatesville it dips steeply south.

The Paleozoic rocks on the north limb of the Mine Ridge anticline are present only in the extreme northwest corner of the Coatesville quadrangle. This limb of the fold is complex like the south limb, but the minor folds plunge westward, and the offsets of the formation are in the opposite direction. The minor folds are also much faulted. The Chickies quartzite, with its Hellam conglomerate member, where it is crossed by the Lincoln Highway on the top of Mine Ridge, lies in a minor syncline which is cut through near Black Horse, so that the underlying pre-Cambrian rocks are exposed. The outcrops are repeated to the north by a strike fault, and the Antietam quartzite and the overlying Vintage dolomite are inclosed in a minor synclinal fault block. The Antietam in a minor anticline in the extreme northwest corner of the quadrangle is in turn faulted against the Ledger dolomite of the lowland at Limeville, in the Honeybrook quadrangle. The structure as it may have appeared before faulting is suggested in Figure 7.

All the faults when first studied were considered overthrusts of the Appalachian type, but observations in the Lancaster Valley and in Welsh Mountain, to the north and northwest, have proved the prevalence there of normal faults of Triassic age.[11]

Although one of the faults on the north flank of Mine Ridge may be an overthrust associated with a minor fold that was so compressed that it broke, the larger displacements seem most certainly to be of the normal type, with movement on a nearly vertical plane and not caused by compression and they are so drawn in the structure sections. The angular area of Ledger dolomite at Limeville (see fig. 7) is beyond doubt part of a block that has been dropped with respect to the adjacent rocks. The fault on the south side of the Antietam quartzite ridge in the extreme northwest corner of the Coatesville quadrangle is also probably normal. The fault along the north side of the pre-Cambrian rocks at the north edge of the quadrangle, which forms the north boundary of the Cambrian arenaceous series of Mine Ridge west of the district, may be a thrust fault and is so shown in the structure section. The Antietam formation in the extreme northwest corner of the district may be described as an anticlinal horst between two normal faults.

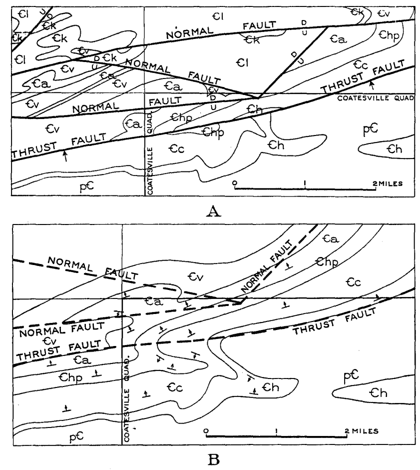


FIGURE 7.—Outline geologic map of the northwest corner of the Coatesville quadrangle and vicinity, showing (A) the faulted character of the rocks and (B) the postulated folded structure of the rocks before faulting

€l, Ledger dolomite; €k, Kinzers formation; €v, Vintage dolomite; €a, Antietam quartzite; €hp, Harpers schist; €c, Chickies quartzite; €h, Hellam conglomerate member; p€, pre-Cambrian rocks; D, downthrow of normal fault, U, upthrow; arrow indicates direction of movement of thrust fault

The Chester Valley syncline, which lies south of the Mine Ridge anticline, extends from Quarryville, 8 miles west of the Coatesville quadrangle, eastward to Schuylkill and beyond. Only the northwest limb of this syncline is exposed in the narrow Chester Valley, which is not over 1 mile wide in the Coatesville-West Chester district. The syncline is really much wider than 1 mile, but its southeast limb has been concealed by overthrusting of pre-Cambrian schists from the southeast. It was formerly believed (and the view is still held by the senior author; see p. 5) that these schists and phyllites, which make up the South Valley Hills, normally overlie the limestone in the syncline and are therefore younger than the limestones; but now they are generally believed to be of pre-Cambrian age and to be thrust over the limestones.

Although the Mine Ridge anticline probably existed as an upfold during the deposition of the Cambrian sediments, as indicated by the thinning of the sediments on its axis,[12] the major folding of the Paleozoic rocks and the overthrust faulting on the south side of Chester Valley probably occurred at or near the end of the Carboniferous period, when the whole Appalachian region is known to have suffered great compression and mountain building. The normal faulting occurred at or near the end of the Triassic period, when great blocks of the earth tilted and settled in an adjustment that took place under conditions of tension.

GEOLOGIC HISTORY

PRE-JURASSIC HISTORY

By F. Bascom and G. W. Stose

Although much is known of the pre-Cambrian rocks of the Coatesville and West Chester quadrangles and although the changes which they have undergone during their long history are now fairly well understood, very little can be said of the distribution of land and sea in pre-Cambrian time. Only the major events can be surmised; details are obliterated by subsequent events.

A conspicuous unconformity at the base of the Setters formation marks a long interval of time, separating the events that surrounded the deposition, folding, invasion by granite, and metamorphism of the Archean sedimentary series, which is now called Baltimore gneiss, from the events that affected in a somewhat similar way the Algonkian rocks. Little is known of the extent of the basins in which the Archean rocks were laid down, or of the position of the land masses from

[11] Stose, G. W., A new type of structure in the Appalachians: Geol. Soc. America Bull., vol. 35, pp. 465–480, 1924.

[12] Stose, G. W., and Jonas, A. I., Ordovician overlap in the Piedmont province of Pennsylvania and Maryland: Geol. Soc. America Bull., vol. 34, pp. 507–524, 1923.

which those sediments were derived. The same may be said of the Algonkian rocks, the Glenarm series. The record shows, however, that the earliest sediments were deeply buried, in some places folded, invaded by granite, and metamorphosed before they were uplifted and eroded and covered by the Algonkian sediments represented by the Setters formation, Cockeysville marble, Wissahickon formation, and Peters Creek schist.

Although it is inherently probable that life existed in these ancient times, as indicated by the occurrence of limestone and of graphite (carbon) widely disseminated through the rocks, it is not to be expected that rocks so thoroughly metamorphosed would yield recognizable fossils, either of vegetable or of animal origin, and none have been found.

It has been possible to distinguish and in most places map four formations in the Glenarm series. Alternation from sandy to limy sediments and a return to sandy and clayey sediments are clearly recognized. This sequence, nevertheless, is not everywhere present. In places the Cockeysville marble rests on the Baltimore gneiss; in other places the Wissahickon formation apparently rests on the Baltimore. In view of the fact that in places both the Cockeysville and the Wissahickon are known to be faulted against the Baltimore gneiss, it is best simply to suggest that overlap may exist. The rocks are so intensely metamorphosed, so closely folded, and so deeply covered by residual soil that their geologic relations can not be established with certainty. Attention is called to this condition here, simply for the faint light it may throw on the geologic history.

During the period of folding and uplift that succeeded sedimentation these formations were invaded by a series of intrusives, ranging from the ultrasubsilicic peridotite and pyroxenite through the subsilicic gabbro and diorite to the silicic granite and pegmatite. In Maryland lava and tuff are interbedded with the Glenarm series.[13] The source of this volcanic material is not known, but its presence harmonizes with the widespread occurrence of subsilicic intrusive rocks which are known to be of Algonkian age, for nowhere in this region are such subsilicic rocks found invading Paleozoic formations.

Just before the Cambrian period widespread erosion, continuing throughout a vast interval of time, reduced much of North America to a low level. The sea then advanced over part of this land, and Cambrian sediments were laid down in shallow seas.

During most of Paleozoic time such an epicontinental sea occupied much of what is now the Appalachian Highlands. A land mass east of this sea, which is called Appalachia, is believed to have contributed most of the sediment that accumulated. When the area was first submerged, in Lower Cambrian time, there were washed into this sea impure sand and soil derived from the disintegration of the rocks then at the surface. They accumulated as heterogeneous arkosic sand, clay, and quartz gravel in which the coarseness and quantity of the pebbles varied from place to place. These deposits were followed by purer quartz sand, and this in turn by clayey sand. These sandy deposits were later hardened into the Chickies quartzite, with its basal Hellam conglomerate member, the Harpers schist, and the Antietam quartzite.

Low forms of life existed in this epicontinental sea, and vertical tubes in the sand, the homes of sea worms, and casts of shells and fragments of trilobites in the rocks to-day bear testimony to this life. Later in Cambrian time, when the adjacent area was worn down so low that land sediments ceased to be washed into the sea, a great thickness of limy mud accumulated on the sea bottom, with occasional layers of clayey or sandy impurities and some beds of pure clay. These deposits later became hardened to the Vintage dolomite, the shale and impure limestone of the Kinzers formation, the Ledger dolomite, and the Elbrook limestone.

An interruption to otherwise continuous deposition of marine sediments occurred in early Ordovician time. Apparently the sea bottom was raised, particularly along an arch which is now known as the Mine Ridge anticline, and erosion began. (See fig. 8.) Upon resubmergence of the area later in Ordovician time, carbonaceous sediments came into the sea from some distant source, probably from the northeast, and mingled with the limy sediments, giving rise to dark impure limy silts with layers of black carbonaceous clay. Fragments of the older limestones were inclosed in the basal beds and formed coarse limestone conglomerates in many places. These impure limy silts were later hardened into the Conestoga limestone. Apparently the sea withdrew permanently from this region at the end of Conestoga time, for no later Ordovician beds nor Silurian or Devonian sediments have been found. The basin of deposition during these periods lay farther west.

Earth movements, at first mild and causing but slight deformation in early Paleozoic time, were more effective toward the end of the Carboniferous period, and the entire Appalachian region was compressed, faulted, and finally uplifted above the sea.

[13] Jonas, A. I., Pre-Cambrian rocks of the western Piedmont of Maryland: Geol. Soc. America Bull., vol. 35, pp. 355–364, 1924.

The Coatesville-West Chester district lies in the eastern portion of the compressed belt, where folding was very intense. Many of the folds were overturned toward the northwest. In places these broke, and extensive blocks of the crust were thrust northwestward on low-angle fault planes. The igneous intrusive that probably invaded the deeper part of the crust during this period of great deformation did not reach the Paleozoic rocks in large masses in this area, though they occur in the Paleozoic in distant parts of the Appalachian region. Only more intense local metamorphism and tourmaline crystals that are fairly abundant in the basal Paleozoic beds represent the advance effects of the approaching magma. It was during this stage of deep-seated deformation, intense compression, and subjection to the effects of near-by granitic magmas that the Paleozoic sediments were metamorphosed—sandstone to quartzite, limestone to marble, and shale to mica schist.

The uplift of these rocks no doubt began about the time that deformation began. The movement was slow, but erosion set in promptly on the first emergence of the sea bottom. How high the uplifted mountains may have risen, opposed as they were by agents of erosion, is not known. There must surely have ensued a vast interval of time during which the ancient Paleozoic mountains were slowly worn down to a low altitude. This interval probably stretched over the latest Paleozoic and much of early Triassic time.

In late Triassic time deposition began in a slowly sinking basin that developed nearly parallel to the coast line on the western border of the Piedmont province, some distance north and west of the Coatesville and West Chester quadrangles. Near the end of this period of sedimentation diabase dikes penetrated the rocks, and subsilicic lavas were erupted. Some of the dikes cut the rocks of the Coatesville-West Chester district. This igneous activity was accompanied by warping and tilting of earth blocks and normal faulting. Not only were the Triassic sediments affected by these movements, but areas now underlain by older rocks, including the Coatesville-West Chester district, were extensively block faulted.

POST-TRIASSIC HISTORY

The history of the Piedmont province after Triassic time is to be read chiefly in the present land forms. Sedimentation was thenceforth confined to the eastern margin of the province; erosion was active throughout the Appalachian Highlands.

Successive continental uplifts of the Piedmont region have produced a series of more or less extended peneplains, each in turn related to sedimentary deposits on its eastern margin. These sediments were furnished to a sea that advanced and retreated upon the margin of the eroded rocks. Thus there accumulated several thousand feet of sediments, which now constitute the Coastal Plain, bordering the Piedmont Upland.

All land surfaces are being reduced in altitude constantly, though slowly, by the weathering of the rocks, the mechanical wear of the streams, and the beating of waves on the shore. Weathering affects the whole surface, and its effects are noticeable only after long periods of time, but the other agencies are more pronounced in their operation and consequently soon produce a flat surface at or near drainage level. This flat surface is first developed along the seacoast and then extends inland along the main stream courses, spreading progressively up the tributary streams. The combined results of weathering, of the action of the streams, and of the beating of the waves is to cause a lowering of divides, the coalescence of flood plains, and the formation of a seaward-sloping lowland, or peneplain. Atmospheric agents of erosion, operative throughout an area and quickened at the seacoast and at the head of maximum corrasion, take part in this reduction of land surface. A long period of quiescence is necessary in order that uninterrupted erosion may reduce a highland area to a lowland with low divides. If such a period of quiescence is ended by continental uplift, the peneplaned surface becomes again a highland area, and erosion, which had been enfeebled and retarded by low declivity, is renewed and accelerated. New valleys are developed in the old flood plains, and eventually, if the period of continental stability is sufficiently long, a second peneplain is cut below the uplifted surface of the older peneplain, remnants of which may be left on the divides, preserved on resistant rocks. If there should be successive movements of uplift separated by long periods of quiescence, there will be developed a number of dissected peneplains, of which the oldest will have been most completely dissected and will be found therefore only in remnants and at the highest levels, and the youngest will have been the least eroded and will therefore appear most widely preserved and at the lowest levels, and those of intermediate age will be found at intermediate levels in various stages of preservation.

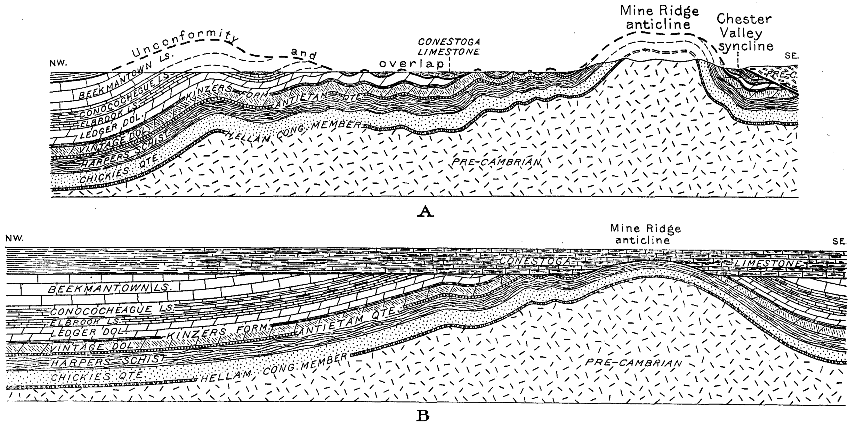


FIGURE 8.—Detailed sections across Mine Ridge anticline

A, Present conditions; B, conditions in Conestoga time

Any one of this succession of erosion surfaces may have been a completely developed peneplain or merely an approximation to a peneplain, the stage of development being dependent upon the length of the erosion period and the resistance of the rocks. Successive periods of continental stability are not likely to be of the same duration; where they are relatively brief and the rocks fairly homogeneous only the narrow marginal beginnings of peneplains are developed on the seacoasts and only narrow flood plains, or straths, along the main stream valleys. Such topographic features, marking the early stages of peneplanation, might later suffer complete obliteration through erosion or might be partly preserved as horizontal terraces paralleling the sea and sloping terraces paralleling the streams. A remnant of such a terrace produced in a relatively brief erosion cycle may be called a berm.[14]

The existence of successive erosion cycles, complete or partial, is proved not alone by berms or by vestiges of peneplains but also by deposits laid down on the submerged borders of the erosion surfaces. That periods of stability of varying length have alternated with periods of continental movement along the Atlantic border is indicated both by topographic features and by sedimentary deposits. Of the series of peneplains and berms which have successively developed there remain four berms and vestiges of three partial peneplains and two peneplains.

The period of freedom from land movements that followed the uplift at the end of Triassic time was longer, perhaps, than any subsequent period of quiescence. During this long period the divides in the Appalachian Highlands were probably pushed westward with the capture of northwestward-flowing streams, and interstream areas were reduced, at first vigorously, then slowly, until finally a plain of very low relief on its eastern margin, where sedimentation was taking place, spread away to the north and west, with but faint relief throughout the Appalachian Highlands.

[14] Berm is defined in the Standard Dictionary as follows: "*Civ. Engin.* A horizontal ledge part way up a slope; bench. *Fort.* A narrow level space at the outside foot of a parapet, to retain material which might otherwise fall from the slope into the ditch." It is proposed to give the term a geomorphic usage, confining it to terraces of a particular origin—that is, to terraces which originate from the interruption and rejuvenation of a drainage cycle in the mature stage of its development. These terraces are associated with land movements, which have brought about a change of permanent base-level. Every gradation between the typical berm and a widespread peneplain may be developed. Considerable latitude is therefore given in the use of this term, so that bermlike stages may be included under it. Those stages more nearly approaching the peneplain will be called partial peneplains.

This great plain, the oldest post-Newark erosion surface, recently named the Fall Zone peneplain,[15] is preserved only on that portion of the crystalline rock surface still buried beneath Lower Cretaceous sediments. Wherever the protecting deposits have been removed by erosion the peneplain surface has also been eroded.

During the following erosion cycle the uplifted Fall Zone peneplain was attacked, reduced, and finally obliterated in the Appalachian Highlands, and a peneplain was ultimately developed, remnants of which are still preserved in the level crests of Kittatinny and Schooley Mountains in New Jersey, northeast and southeast of the Delaware Water Gap. The resistant sandstone and gneiss that uphold these mountains maintain this surface at altitudes from 1,400 to 1,200 feet; the level-topped ridges of the Appalachian Valley conspicuously preserve the Kittatinny-Schooley peneplain[16] at altitudes rising to the southwest. Scant remnants are found in the Piedmont province at lower levels.

Plains as vast as the Fall Zone and the Kittatinny-Schooley peneplains are necessarily not of one age throughout; these plains are older in the extreme southeast, where the work of peneplanation first began and where Cretaceous sediments now lie upon their surfaces; they are younger in the north and west, where erosion was still going on in Lower or Upper Cretaceous time and was supplying sediments to their submerged eastern margins.

Thus the Fall Zone peneplain, begun in Jurassic time, was further developed in Lower Cretaceous time, while the ocean was advancing on the planed margin of crystalline rocks. The Kittatinny-Schooley peneplain, dating perhaps from the uplift that terminated Lower Cretaceous time, was developing during the remainder of Cretaceous time.

The end of the Kittatinny-Schooley period of erosion found the Coatesville-West Chester district a low featureless plain sloping toward the Atlantic Ocean.

At the beginning of Tertiary time the Kittatinny-Schooley peneplain was subjected to an uplift, which converted the plain into a low, unsymmetrical arch with its longest dimension in a northeasterly direction. Erosion was at once accelerated in this highland, the southeastern slope of which forms the Piedmont province, and continued at varying rates, finally removing in the Coatesville-West Chester district all remnants of the Schooley peneplain.

This early Tertiary erosion cycle was long enough to develop in the softer rocks along the courses of the Piedmont streams a partial peneplain, the Harrisburg, which is preserved in the Appalachian Valley on Delaware River just below Delaware Water Gap at an altitude of 800 feet, on Schuylkill River north of Reading at the same height, on Susquehanna River northeast of Harrisburg at 600 to 700 feet, and to the southeast at Safe Harbor at 900 feet, declining eastward to 800, 700, and 600 feet in the Coatesville quadrangle and to 590 and 540 feet in the West Chester quadrangle, and on Potomac River west of Hagerstown at 700 feet.

Immediately east and west of Harrisburg and to the northwest along Susquehanna River the interstream areas reach with great uniformity the 500 to 520 foot level and thus present evidence of still another period of partial peneplanation. The approximate peneplain that was formed in this period is named from the sediments which it carries on its seaward margin and which are now known as the Bryn Mawr gravel. The Bryn Mawr peneplain is the most recently developed and the most widely preserved of the partial peneplains of the Piedmont province. At altitudes ranging from 300 feet on the eastern margin to 400 feet inland from the "fall line" a thin and sporadic deposit of gravel with sand pockets is spread on its surface. This deposit, the Bryn Mawr gravel, is believed to be of late Tertiary, probably Pliocene age. During the development of this peneplain the sea overrode the West Chester quadrangle at least as far to the northwest as the present line of the Pennsylvania Railroad through Kennett Square and Chadds Ford. The uplift that followed Bryn Mawr time[17] brought the Coastal Plain above the sea and slightly deformed both it and the Piedmont Upland. This emergence is believed to mark the end of the Tertiary period.

The Quaternary period began with the resubmergence of the lower part of the Atlantic Plain. During this epoch open valleys with wide straths and gentle seaward slope were formed, remnants of which now appear as a well-defined sloping berm 300 to 200 feet in altitude bordering the larger rivers and associated tributaries up to the "fall line" and rising inland to a sloping surface 400 to 300 feet in altitude. These remnants of a once continuous erosion surface make up the Brandywine berm, named from sediments which lie upon its lower border in some places and are considered to be of early Quaternary age. During one of the periods of emergence of the Coastal Plain the whole Atlantic Plain was above sea and deep valleys were cut to the margin of what is now the continental shelf, such as the submerged parts of the valleys of the Hudson, Delaware, Susquehanna, and Potomac.

At lower altitudes than the Brandywine berm three relatively narrow berms appear on the extreme southeast border of the Piedmont province at altitudes of about 180, 80, and 40 feet. These berms carry sediments of Quaternary age and are named the Sunderland, Wicomico, and Talbot berms, from the deposits that received the same names from localities in Maryland where they are well developed.

Like the Brandywine berm, these berms border the major streams, but on the tributary streams straths were not formed, so brief was the erosion cycle; the uplifts were slight, slopes were merged, erosion cycles are not distinguishable, and berms are therefore not to be found.

The 180 to 200 foot Sunderland berm is recognizable in the southeastern part of the West Chester quadrangle west and east of Wilmington, where it carries a thin deposit of Sunderland gravel. In the extreme southeast corner of the quadrangle in the vicinity of Edgemoor the 40 to 20 foot Talbot berm is distinguishable as a lowland carrying sediments of Talbot age and cut back so close to the Sunderland as to obliterate the Wicomico berms. These berms border Delaware River, which is southeast of the quadrangle.

A final emergence brought the Piedmont province above estuarine waters and the Coastal Plain above the sea and established recent conditions. This uplift and the two just preceding terminated erosion cycles of so brief duration that the records are not as well defined in the Coatesville-West Chester area as they are in areas nearer to the sea; the stream gorges show the unbroken slopes of Pleistocene and Recent erosion.

Other cycles of erosion, more or less brief, may have existed during the long history of the Piedmont province without leaving as well-preserved records as those that have been named. The Mine Ridge peneplain, named from a possible remnant on Mine Ridge adjacent to the Coatesville quadrangle on the west, may represent one of these minor erosion cycles, the record of which is nearly obliterated.

ECONOMIC GEOLOGY

BUILDING STONE

The Coatesville and West Chester quadrangles are well supplied with stone suitable for use in building. The Baltimore gneiss, Setters formation, Cockeysville marble, Wissahickon formation, gabbro, serpentine, and Paleozoic limestones furnish fair building stone. The Chickies quartzite, which has been extensively quarried for glass sand and for silica brick, is also used to a minor extent as a building stone.

Baltimore gneiss.—Two large quarries have been intermittently operated in the Baltimore gneiss. A quarry in gabbroized gneiss at the south end of Chestnut Street, West Chester, is owned by the borough of West Chester. This quarry, opened in 1881, is known as M. & T. Farrell's quarry and produces a stone which is chiefly utilized for road metal but has also been used for house and foundation building. The stone is crushed at the quarry for road use. Both gabbro and gneiss are exposed in the quarry. A quarry in similar rock half a mile northwest of West Chester on the road to Copesville exposes gabbroized gneiss that is very garnetiferous and has the mineral constitution of a diorite. This quarry is owned by Josiah Howells, is operated intermittently by Patrick Corcoran, and supplies building stone for local use.

Setters formation.—Quartzite has been quarried from the Setters formation for local use in foundations south and southwest of London Grove, and gneiss has been quarried from the same formation just east of Green Lawn and used for road metal. The gneiss has also been quarried in the ridge northeast of West Grove and at several localities on the southeast face of the ridge between Avondale, Toughkenamon, and Kennett Square. The stone has an even grain and makes a fair building stone, for which it has had considerable local use. A sand pit just north of Toughkenamon is in this formation.

Cockeysville marble.—One of the most valuable stones of the district is furnished by the Cockeysville marble. This stone has been used for ornamental and monumental work, for building stone, for road metal, and for lime. It was extensively quarried for lime during the last quarter of the nineteenth century. There are at least 50 lime quarries in this formation in the Coatesville-West Chester district. Many of them were opened to furnish lime for the farmer upon whose property the limestone crops out and who burned his own lime. The quarries were not worked out, but most of them were abandoned.

Logan's quarry, 1 mile north of Upland, has had as long a history as any of these quarries. It was opened in 1818 and has been operated intermittently until 1910. The Pierce & Edwards, Hayes, Guest, Wood, Jones, and Hoopes & Darlington quarries were once famous in the Doe Run areas of limestone. Northeast from the Doe Run belt of the limestone in the West Chester quadrangle are the Embreeville quarry, the County Poorhouse quarry, Moses Bailey's quarry, Moses Woodward's quarry, George Marsh's quarry, and Cope's quarry. These are in isolated outcrops of the limestone with an overburden of several feet of gneiss. One mile south of Northbrook is Gawthorp's quarry hole in limestone. Elisha Bailey's quarry is in the limestone west of Upland.

Taylor's (two), Pusey's (two), Swayne's, Baker's (Acme), Bernard's, Story's, Quarll's, the Avondale quarries, and the Kennett Square quarries (McFarlan's) are among the well-known quarries of the Avondale area. Northeast of the Willowdale belt of the limestone (Avondale area) are the Thornbury and Brinton quarries; northeast of the Kennett Square belt of the limestone are the Sharpless and Mendenhall quarries. Jackson's quarry is in the Hockessin area. The Brown, David Nevin, Septimus Nevin, and Sharpless quarries are in the Landenberg area.

Among all these quarries there are only two that have been in systematic operation over a long period. One of them is a large quarry near Avondale, half a mile north of Baker station, originally known as Baker's, subsequently as the Acme quarry, later operated by the Avondale Marble Co., and finally, up to 1919, worked by the Pennsylvania Marble & Granite Co. This quarry was opened, like the others, for lime, but with the decline of the lime industry search was made for marble by means of diamond-drill holes, and at a depth of about 50 to 70 feet white dolomite marble of good quality was found which shows on testing very low absorption and high resistance to stain. This marble has been quarried to a depth of 50 feet. A section through the quarry is as follows:

Section in quarry at Baker station

	Feet
Limestone (locally called "Avondale limestone")	10–30
Gneiss or "bastard granite"	16–18
"Fish-egg" limestone	10
Dolomite	50

In connection with the quarry the company operates a mill where the marble is sawed and shaped for market. The marble has been used for monuments and in prominent buildings in Washington and in New York, New Jersey, and Pennsylvania.

The other quarry is about a mile northwest of Avondale, south of the railroad. It is known as the Avondale lime quarry and was owned and worked by Frank Williamson & Co. up to October, 1917, when it was closed and dismantled, and the property was sold.

Section in Avondale lime quarry

	Feet
Limestone (locally called "Avondale limestone")	50
Mica gneiss or "bastard granite"	10–12
"Fish-egg" limestone	6–12
Gray limestone	8–10
White dolomite.	

The presence of the dolomite marble is shown by drillings, but the rock has not been quarried. The first grade of the "fish-egg" limestone is used for glass sand, the second grade in asphalt paving and as a fertilizer, the third grade for nursery sand. The gneiss is used in foundations and buildings. The so-called "Avondale limestone" is used for foundations, facings, and general building purposes and has been used for churches in Delaware and Maryland.

Wissahickon formation.—Several quarries in the Wissahickon formation are operated intermittently, chiefly for road metal and subordinately for local building stone. Half a mile north of Wooddale station is a quarry, opened in 1886, operated by the Baltimore Standard Lime & Stone Co. The rock is an even-grained massive garnetiferous mica gneiss. The stone is suitable for building but has been utilized chiefly for road metal. Its value for road metal has been tested with favorable results for light traffic. There are gabbro and quartz diorite intrusions in the same quarry. The Park quarry, one-third of a mile north of Copesville on the east side of the East Branch of Brandywine Creek, is in an injection gneiss and supplies stone for local use. Another such quarry in the Wissahickon formation is 1 mile north of Northbrook and $1\frac{1}{4}$ miles south of Marshallton. There are small disused quarries in the Wissahickon formation, and their location is indicated on the areal-geology map. The mica schist member of the Wissahickon has had a small local use for stone walls and foundations.

Gabbro.—Half a mile north of the Baltimore & Ohio Railroad on the east bank of Brandywine Creek in Wilmington there are large quarries in the gabbro. The most northerly quarries are owned by the Brandywine Granite Co. and were opened in 1900. South of these are the quarries of Stewart & Donohue,

[15] Sharp, H. S., The Fall Zone peneplain: Science, new ser., vol. 69, pp. 544–545, 1929. Johnson, Douglas, Stream sculpture on the Atlantic slope, pp. 5–12, 14–22, 1931.

[16] It has been suggested that the peneplain which has been called Schooley in the Piedmont province is the Kittatinny peneplain faulted down in post-Cretaceous time (Stose, G. W., Geol. Soc. America Bull., vol. 38, pp. 493–504, 1927).

[17] Recent inspection of the Bryn Mawr and Brandywine gravels along the Potomac, Susquehanna, and Schuylkill Rivers has led M. R. Campbell (Nat. Acad. Sci. Proc., vol. 15, pp. 156–161, 1929) to entertain the hypothesis that the surface upon which the Bryn Mawr gravel rests was warped, when uplifted, forming a low anticline, the axis of which crosses the Potomac River near Great Falls, the Susquehanna River at Safe Harbor, and the Schuylkill River at Norristown. This deformation must have accompanied the uplift that preceded the development of the berm upon which Brandywine gravel was deposited, as that surface is not affected.

operated since 1902, the material from which has been used for paving, concrete work, building stone, and road metal. About $1\frac{3}{4}$ miles east of Wilmington, on the south side of the electric railroad, is the Shellpot quarry, opened in 1887, owned and operated by Philip T. Tyre, sr. The stone is used for curbing, for Belgian blocks, and for road metal.

Serpentine.—Serpentine had in the past considerable popularity as a building stone, and many of the serpentine areas now quarried for road metal were first quarried for building stone. Brinton's quarry, three-quarters of a mile north of Birmingham, is said to have furnished more stone than any other serpentine quarry in the United States. This quarry was opened in 1862 and has been operated with intermissions to the time of writing (1926). The stone is of a uniform color and even grain, and, because it is relatively free from the close and irregular jointing usual in serpentine rock, it can be sawed into cuboidal blocks. The Normal School buildings and many dwellings in and about West Chester are built of this stone. Churches have been built of it in Richmond, Va.; Washington, D. C.; Baltimore, Md.; Columbus, Ohio; South Bend, Ind.; and Jersey City, N. J. The stone has also been used for bridge work and other structures in Wilmington, Del.; in Lakewood and Asbury Park, N. J.; and in Connecticut. The occurrence of jefferisite in this quarry has recently become a matter of economic interest, as, when calcined, jefferisite makes a paint of a bright gold color, for which there is considerable demand.

Chickies quartzite.—The Chickies quartzite in the North Valley Hills is quarried north of Atglen, north of Pomeroy, and north of Coatesville, and at Parkesburg on the west branch of Buck Run. North of Pomeroy are four large adjacent quarries from which good hard stone has been taken for many years. Stone for the foundations of the Broad Street station, in Philadelphia, and other structures of the Pennsylvania Railroad was quarried here.

Cambrian and Ordovician limestones.—There are 10 or more quarries in the limestones in Chester Valley in the Coatesville and West Chester quadrangles, but all have been idle for years. Those west of Coatesville are in the impure Conestoga limestone. Those in and east of Coatesville are chiefly in pure dolomite of the Ledger formation, much of which was burned for lime. Their location is shown on the geologic maps.

ROAD METAL

As indicated in the preceding discussion, the Coatesville and West Chester quadrangles are adequately supplied with stone from which good road material may be obtained. Diabase, gabbro, diorite, serpentine, gneiss, and crystalline limestone are available, are adapted to use as road metal, and are being so utilized to a considerable extent.

In resistance to wear, in hardness, and in toughness, diabase and gabbro are superior to other road metal and can be used on roads subjected to heavy traffic. Crystalline limestone and serpentine, which are relatively soft but have good cementing properties, are suited to light traffic. Granite and gneiss lack the toughness and binding value requisite for top dressing of macadam roads but may be used as foundation stone; the foliated texture of gneiss and of schist renders them inferior to massive rocks in binding value. Quartzite, on account of its extreme hardness and lack of binding power, is not valuable as road material.

Laboratory tests of numerous samples of road material from this district, by the office of Public Roads of the United States Department of Agriculture,[18] showed that of the material tested, the only stone serviceable for heavy traffic is the gabbro at Wilmington. Stone of the same character may be obtained wherever gabbro crops out. For medium traffic the garnetiferous gabbro at Wawaset and hornblende schist (metagabbro) near Wooddale are suitable. Road metal for light traffic is furnished by the hypersthene gabbro from the Wilmington quarries, the gneiss from the quarry half a mile north of Wooddale, and some marble and crystalline limestone from Chester Valley. The crystalline limestone and marble south of Chester Valley are too coarsely crystalline to possess the requisite toughness.

FELDSPAR

The feldspar industry in Pennsylvania, though showing some fluctuation, has on the whole been declining, the production falling from 19,633 short tons in 1907–8 to 8,562 tons in 1920, when Pennsylvania, once the leading State, was fifth in rank, and to the output of only one company in 1921. In 1925, according to statistics collected by the Bureau of Mines, the output of crude feldspar in Pennsylvania was 1,330 long tons. Practically all Pennsylvania feldspar comes from Chester and Delaware Counties, where in 1913 there were nine large quarries in active operation, most of them within the Coatesville and West Chester quadrangles. The feldspar of these quadrangles is for the most part a potash feldspar (orthoclase and microcline), associated with quartz and muscovite in granitic pegmatite dikes.

The feldspar was ground at two mills within the district—near Brandywine Summit and at Toughkenamon—and at two other mills just south of the district or was shipped crude to East Liverpool, Ohio, or Trenton, N. J. The mill at Toughkenamon is still in operation. The quarries three-eighths of a mile southwest of Elam were the most productive in the State and were worked for about 30 years, until 1917. The dike that furnished the feldspar is about 70 feet wide and strikes N. 25° E., with a low southeasterly dip. The feldspar, which is orthoclase and microcline, occurs in fairly good crystals, some of them a foot in diameter, and is sufficiently pure for dental use. Quartz, muscovite, biotite, and garnet are the other constituents of the pegmatite; graphic granite is abundant; the biotite and garnet are so localized that the pure feldspar may be separated in quarrying.

Quarries $1\frac{1}{4}$ miles northwest of Toughkenamon, were worked continuously until 1921. The feldspar is microcline intergrown with albite; quartz and muscovite are the other constituents. In the largest pit microcline occurred in large crystals 1 to 2 feet in diameter. The pegmatite forms several distinct dikes. In London Grove Township near Avondale 20 to 30 quarries have been opened in pegmatite dikes. At a quarry three-quarters of a mile north-northeast of Chatham the feldspar is a pink microcline occurring in crystals of considerable size; massive quartz, muscovite, and biotite are the other constituents of the pegmatite. The pegmatite seems to occupy a pocket in the gneiss, and quarrying was done mainly by tunneling.

At a quarry near Baker station the dike has a width of about 25 feet, strikes N. 75° E., and dips about 50° SE. It is relatively fine grained and of the normal granitic type and gneissoid texture. The feldspar crystals are for the most part less than 4 inches in diameter, and the feldspar is rendered valueless along some planes by the presence of abundant biotite. Garnets are rare and small. The pegmatite dike three-quarters of a mile northeast of Baker station strikes N. 55° E. and dips southeast. The feldspar and the rock are like that of the dike to the north save that biotite is absent. Half a mile west of Upland feldspar has been quarried in a pegmatite dike about 35 feet wide, striking N. 50° E. and dipping 45° SE.

At a quarry $2\frac{1}{2}$ miles north of Pomeroy the feldspar, for the most part a pink microcline, is intimately intergrown with quartz producing the graphic texture. Greenish muscovite is the only other constituent of the pegmatite, which is practically free from iron-bearing minerals. The material, when quarried, was used for poultry grit, poultry dust, metal polish, and pottery, and mixed with a small portion of cement it was used for priming.

Three pits were opened in a pegmatite dike $1\frac{1}{2}$ miles south-southwest of Landenberg. The feldspar is a potash feldspar, and the pegmatite is of the usual granitic type.

The feldspar quarry at Embreeville, just north of the station, was first operated in 1885. Later it was for a long time idle; it was reopened in 1907 and almost continuously worked for some time, but it is idle at the present date (1926). The dike strikes about N. 20° E. and dips to the southeast. The quarry cut shows that the dike is confined to the Baltimore gneiss, which is overlain by the Wissahickon formation with what appears to be a fault contact. The feldspar is a white potash-soda-lime feldspar of which the following analysis[19] was furnished by Golding & Sons Co. This analysis gives a feldspar of approximately the composition $Or_3Ab_6An_1$.

Analysis of feldspar from quarry at Embreeville

SiO_2	67.46
Al_2O_3	21.76
Na_2O	5.96
K_2O	4.28
CaO	1.67
	101.13

The feldspar quarries northeast of Unionville are in pegmatite associated with or lying within serpentine areas. Other pits have been opened half a mile east of Chadds Ford, $1\frac{1}{4}$ miles southeast of Mendenhall, south and east of Fairville, a quarter of a mile north of Elam, and 1 mile southwest of Elam.

The decrease in the feldspar industry in Pennsylvania is apparently due in part to the exhaustion of the feldspar in some localities, in part to the inferior quality of the feldspar in other localities, and in part to the difficulties and cost of quarrying. There is always a demand for feldspar, though the market price may not greatly exceed the cost. High-grade feldspar is used chiefly for pottery, enamel ware, brick, and electrical ware. A low-grade feldspar is used in the manufacture of opalescent glass, emery and carborundum wheels, scouring soaps and window washes, and ready roofing, also for poultry grit. Very pure potash feldspar is used in the manufacture of artificial teeth.

KAOLIN

The kaolin of Pennsylvania is of two kinds—residual kaolin, which owes its origin to the decomposition in place of feldspathic rock or of argillites and which has therefore the same distribution as the parent rock, and transported kaolin, which is residual kaolin collected, sorted, and redeposited by water and which therefore occurs in beds. The kaolin of the Coatesville-West Chester district is almost exclusively residual and originates from the decomposition of the feldspar of pegmatite dikes. Pegmatite is therefore the source not only of "spar" and "flint" but of kaolin or clay.

Whether feldspar or kaolin is supplied by the pegmatite will depend chiefly upon whether conditions are favorable for the saturation of the pegmatite by ground water. Proximity and parallelism to drainage lines and a gentle dip rather than verticality or a steep dip are favorable conditions for saturation. Where such conditions exist the feldspar is more or less completely kaolinized. The removal of the alkali of the feldspar either through the formation of a soluble carbonate or through hydrolysis and the substitution for it of water are the changes essential to the formation of kaolin. The following equations indicate the general character of the two processes:

$$\underset{\text{feldspar}}{K_2O.Al_2O_3.6SiO_2} + \underset{\text{water, carbon dioxide carried in water}}{2H_2O + CO} = \underset{\text{kaolin}}{2H_2O.Al_2O_3.2SiO_2} + \underset{\text{quartz}}{4SiO_2} + \underset{\text{soluble carbonate of alkali}}{K_2CO_3}$$

$$\underset{\text{feldspar}}{K_2O.Al_2O_3.6SiO_2} + \underset{\text{water}}{3H_2O} = \underset{\text{kaolin}}{2H_2O.Al_2O_3.2SiO_2} + \underset{\text{quartz}}{4SiO_2} + \underset{\text{caustic potash}}{2KOH}$$

In this change quartz is a by-product; in addition the original feldspar is in many places intergrown with quartz and is everywhere closely associated with quartz as an accompanying essential constituent of the pegmatite. For these reasons residual kaolin is intimately mixed with granular quartz or sand. Additional impurities are undecomposed feldspar and muscovite, which is both an alteration product of the feldspar and an original constituent of the pegmatite. It is therefore necessary to refine the kaolin—that is, to separate it from these impurities. This can be accomplished by gravity methods, which leave the kaolin a pure buff-white. The following method, or some modification of it, is usually practiced. The raw material is thrown into agitators, where the coarse sand and feldspar are removed by sand wheels. The clay is then passed into float boxes, where the fine sand and the muscovite are separated by specific gravity; thence into large settling vats, from which it is pumped into bag presses and hung on open or covered racks to dry.

Residual kaolin is utilized chiefly in the manufacture of chinaware and paper. For both these purposes kaolin must burn to a white color. Transported kaolin is liable to be contaminated by iron oxide, which can not be removed in the refining process and which does not burn white. Of the other ingredients of chinaware (feldspar, flint, and ball clay or plastic clay), flint and in some localities feldspar can be supplied from the plant that furnishes the kaolin. Sand or "flint," as has been indicated, is a by-product of kaolin mills.

The kaolin deposits of this district are chiefly in the southern part of the West Chester quadrangle, in the neighborhood of Kaolin and Hockessin. The pegmatite dike that strikes northeast at the village of Kaolin has furnished a large amount of kaolin, which was first mined here in 1839. The purified product was shipped to East Liverpool, Ohio; Trenton, N. J.; and Canada. The separated sand was partly utilized in making silica brick. At present all these works are idle.

Kaolin was formerly worked near Hockessin to an average depth of 60 feet and a maximum of 120 feet. The clay was refined and shipped to East Liverpool and Trenton. A refining plant about three-quarters of a mile northeast of Hockessin station has obtained kaolin from localities about three-quarters of a mile south of Hockessin, half a mile west of Broad Run siding, and $1\frac{1}{4}$ miles northeast of Coatesville, in Chester Valley. At this last-named locality kaolin is a by-product of a sand pit that was first opened in 1878. The sand is removed in gravity troughs and settling vats and is shipped to Trenton and Wilmington. The purified kaolin, a lean white clay, is dried under pressure and shipped to the Hockessin plant, where it is mixed with the crude clay and refined a second time. It is used chiefly to give the other clays a better color.

About halfway between Avondale and Toughkenamon, north of the road, pits 70 feet deep have been dug in kaolin clay, which is found 6 feet below the surface. The clay was purified and dried in the usual way and shipped to Trenton and East Liverpool.

The only transported clay utilized in the Coatesville-West Chester district has been taken from pits 1 mile southeast of Elam. This discolored clay has been used in brickmaking.

QUARTZ ("FLINT")

The material that is commercially known as flint in eastern Pennsylvania is quartz. This mineral is the dominant constituent of the Chickies quartzite, an abundant constituent of pegmatite dikes, and a by-product of the kaolinization of the

[18] Goldbeck, A. T., and Jackson, F. H., The physical testing of rock for road building: U. S. Dept. Agr. Office Pub. Roads Bull. 44, pp. 37, 66, 1912.

[19] Hopkins, T. C., Clays and clay industries of Pennsylvania: Pennsylvania State College Ann. Rept., 1898-99, appendix, p. 15.

feldspar of the pegmatites. Weathered out of rocks, transported, and deposited it forms beds of sand. The feldspar and kaolin companies are therefore able to furnish flint. The sand separated from the kaolin is screened and ground, and the quartz of the pegmatite may also be ground and sold for flint. Southeast of Oxford the pegmatite is so quartzose that it is worked only for flint. The quartz as quarried is shipped to Trenton and there ground for use in the manufacture of chinaware and pottery. Sand is used for silica or fire brick and for concrete. A mile southeast of Elam there is a large sand pit with an exposure of 15 to 20 feet of yellow sand. The upper 8 to 10 feet is pebbly. At one time sand was taken from this pit and screened. This sand is transported material, deposited in Tertiary time by water. A stream-cut gully in the sand is filled with clay.

IRON ORE

No iron ore has been marketed from this region for many years, and only two mines have been found bearing testimony to earlier workings. Two abandoned pits $1\frac{1}{4}$ miles northeast of Doe Run village and 2 miles northwest of Upland are said to have yielded at one time considerable ore, which was hauled to the mills at Coatesville. Loose fragments of hematite show on the hill about half a mile southwest of Northbrook and a quarter of a mile south of the West Branch of Brandywine Creek.

SOILS

The soils of the Coatesville-West Chester district, with the exception of alluvial material in the creek bottoms, are residual—that is, they are derived directly from the underlying rocks by the disintegrating and dissolving action of atmospheric agencies and ground water. There exists, therefore, a close relationship between soil and rock, and with some allowance for wash on slopes and for variations in the same rock type, the areal distribution of the rocks indicates in a general way the areal distribution of the corresponding soils. Owing, however, to slight physical or chemical variation in a single rock formation and to close similarity between different geologic formations, a geologic unit may produce more than one type of soil, and one type of soil may be derived from two or more geologic units. The Bureau of Soils of the Department of Agriculture recognizes 22 types of soil in Chester County.[20] Of these the chief types found in the Coatesville-West Chester district are the Chester, Manor, Brandywine, and Hagerstown loams, Manor stony loam, De Kalb fine sandy loam and stony loam, Chester fine sandy loam, Cecil clay, Conowingo barrens, Rough stony land, and Meadow soil.

The Chester loam is derived from the Baltimore gneiss and included intrusive igneous rocks and from the more sandy facies of the Wissahickon formation, the biotite gneiss. It covers the eastern part of the Coatesville quadrangle south of Doe Run village and most of the West Chester quadrangle. It is essentially composed of a mellow brown silty surface loam 10 to 16 inches deep and of a brownish-yellow gritty clay subsoil to a depth of 36 inches. This soil is retentive of moisture and well adapted to general farming, producing good crops of corn, oats, wheat, and grass.

The Chester fine sandy loam is derived primarily from the Setters formation. It is found only in small scattered areas. It is a brown heavy fine sandy loam, a poor soil for staple crops but suited to light garden crops.

The Manor loam is derived from the decay of the muscovite facies of the Wissahickon formation and from the Peters Creek schist, and its areal distribution in a general way corresponds with that of these formations. On the hills where the rock is less thoroughly disintegrated and the soil more stony the Manor loam is replaced by the Manor stony loam, a less productive soil. The Manor loam, like the Chester loam, is a yellowish-brown silty loam 8 to 10 inches deep with a reddish-yellow clay subsoil to a depth of 36 inches. It is distinguished from the Chester loam by the presence of fragments of mica schist or of mica derived from the Wissahickon formation, in such abundance as to make the soil smooth or even unctuous. The soil is suited to the production of the staple crops, but the yield does not average so high as that from the Chester loam.

The Brandywine loam, also derived from the disintegration of the Wissahickon formation and differing from the Manor loam in containing a larger percentage of the unweathered rock, is found on the slopes of the West Branch of Brandywine Creek, of White Clay Creek and tributaries, of Elk Creek and tributaries, and of Octoraro Creek and tributaries southwest of Oxford. It is a thin or "hungry" soil and requires frequent fertilization if it is to be productive; its topography is unfavorable for cultivation, and it is more or less given up to woodland.

The Cecil clay is a brownish-red silty loam with a still deeper-red clay subsoil derived from the decomposition of the gabbro and is therefore the soil of Wilmington and vicinity. It is a productive type of soil and responds well to treatment with lime.

[20] Wilder, H. J., and others, Soil survey of Chester County, Pa.: U. S. Dept. Agr. Bur. Soils Seventh Rept., pp. 135-170, 1905.

The Conowingo barrens is a soil derived from serpentine rock exclusively. This rock, because of its chemical stability, does not weather readily, and the soil derived from it is therefore everywhere thin; in fact, in many places the bare rock is exposed. The soil is a yellowish-brown silty loam that becomes darker with increasing depth. Owing to its thinness it lacks not only capacity for holding water but also space for roots, and hence it has little value for agriculture. There are no large areas of this soil in the Coatesville-West Chester district, but numerous small serpentine ridges are conspicuous because of their sterility. On the bare rock there is no vegetation; with a slight depth of soil the hardy pink dwarf phlox flourishes; and with a greater depth there is a stunted growth of cedars, white pine, scrub oak, red oak, blackjack oak, and always the cat brier.

The De Kalb fine sandy loam, De Kalb loam, De Kalb stony loam, and Rough stony land are all derived from the weathering of the Cambrian formations and are confined to the North Valley Hills and the highlands of West Sadsbury and West Caln townships. These loams are alike in being sandy and owe their distinctive characters apparently to variations in the grain of the quartzite from which they are derived and in the completeness of the disintegration of the parent rock. The De Kalb fine sandy loam, which represents the complete disintegration of a fine-grained quartzite, is gray or more rarely yellow and is suited only to light farming or to garden crops. The De Kalb loam, though less productive than the Hagerstown or Chester loam, will, if wisely treated, produce the staple farm crops. The other two soils of the North Valley Hills occupy the steep slopes and are best utilized for woodland.

The Hagerstown loam is derived from limestone and is confined to Chester Valley. It is a dark-brown heavy, smooth, silty clay loam to a depth of 10 inches, where it changes to a lighter-brown heavy silt loam, which at a depth of 20 inches is replaced by a heavy silty yellow to brownish-red clay loam, which in turn at 30 inches grades into a silty clay. This soil is remarkably free from stone and immediately overlies undecomposed rock without transition through decayed rock. It represents the residual sand and clay after the carbonates have been removed in solution. The surface soil retains a small percentage of lime carbonate, which increases in amount with the depth of the soil and adds to its productivity. The Hagerstown loam is the most productive soil of the district and has made famous the products of Chester Valley farms.

On the east side of West Chester on the slopes of the west tributary to Chester Creek there is a patch of dark-colored clay loam that becomes less silty with increasing depth and represents fine wash material. Its thickness is not more than 3 or 4 feet. It has been named the Lickdale clay loam.

Meadow soil is the alluvial soil deposited by streams and therefore follows the stream courses. The largest areas of it are along the Brandywine Creek flats, where large herds of cattle are pastured. As it is somewhat too moist for crops, pasturage is the best use to which it can be put.

About 50 per cent of the soil of the Coatesville-West Chester district is the Chester loam, about 30 per cent the Manor loam, and 20 per cent the other soils above described. The Hagerstown loam is an exceptionally good soil. The Chester loam is above the average of soils in fertility, the Manor loam is an average soil, and the other soils, though less fertile, cover relatively small areas. The soil equipment of the district is therefore good.

WATER RESOURCES

SURFACE WATER

Ridley, Chester, Brandywine, Red Clay, White Clay, and Octoraro Creeks are sufficiently strong streams to furnish water power and water supply and have been abundantly utilized for both purposes.

Of these streams Brandywine Creek has its drainage basin most nearly confined to the Coatesville-West Chester district. Its headwater branches rise in the extreme northwestern part of Chester County, and its drainage basin occupies the central half of the West Chester quadrangle and about three-eighths of the Coatesville quadrangle. It has a drainage area of approximately 350 square miles and is utilized by the city of Wilmington as the source of water supply.

All the streams are fed by springs, which are abundant and strong and furnish private water supply throughout the farming districts.

GROUND WATER

As water carriers the rocks of the Coatesville and West Chester quadrangles fall into two classes—(1) metamorphic laminated rocks (the pre-Cambrian sedimentary and igneous rocks); (2) stratified rocks in which metamorphism has not been so great as to produce secondary planes of parting more effective as channels for ground water than the original planes of sedimentation (the Paleozoic sediments).

The conditions controlling the occurrence of water in the rocks of the first class are quite unlike those controlling its occurrence in unmetamorphosed stratified rock. Crystalline rocks, made up of closely interlocking grains, have a much lower porosity than unmetamorphosed sedimentary formations. Moreover, crystalline rocks do not have definite partings such as those furnished by the stratification planes of the sedimentary rocks and utilized by ground water as channels. Further, as crystalline rocks, even those made up of a series of metamorphosed sediments, do not show notable alternations of permeable and impermeable beds, all beds alike being crystalline and relatively impermeable, they contain no definite water-bearing zones.

Crystalline rocks are not, however, without openings suited to the flow of ground water. These are of four sorts—joints, faults, schistosity planes, and contacts. The joints are the chief water carriers of crystalline rocks, yet they are far less reliable than the openings due to the stratification of sedimentary formations. Joints are vertical, inclined, or horizontal fractures, which are very irregularly spaced and are a somewhat surficial phenomenon. Most metamorphic rocks contain two or more systems of intersecting parallel joints, which may be spaced from a few inches to 10 feet or more apart. Horizontal joints, such as are a common feature of granites, are spaced farther apart with increasing depth, and at a depth of a few hundred feet they disappear altogether. In all joints the opening is widened at the surface by weathering and rapidly decreases in width with increasing depth, becoming closed, and ultimately dying out. The joints with the greatest linear extension probably have also the greatest downward extension. The unreliability of joints as a source of water is due not alone to the disappearance below the surface of joints that appear at the surface, but also to the possible existence below the surface of joints that do not appear at the surface. It is important in obtaining water by means of drilled wells that master systems of joints should intersect, or that a system of horizontal joints should be present.

Faults constitute a special class of joints, on which there has been movement of one side of the fracture relative to the other. They are far less abundant than ordinary joints, but they are likely to furnish both wider and more persistent openings.

Schistosity planes are planes produced by pressure and are due to the parallel arrangement of the interlocking crystals (especially mica) of a rock. The openings are therefore of a capillary character, and although they assist in bringing about the saturation of the rock, they are not usually large enough to promote the movement of ground water.

Contacts, of course, are not peculiar to crystalline rocks, but they play a relatively more important part in crystalline rocks, where openings are few and irregular, than they do in sedimentary formations, where openings are numerous and determinable. Wherever an igneous rock has intruded another formation, the contact between the two formations is likely to furnish a channel for ground water. Along such contacts springs or streams fed by springs are likely to occur.

The gneiss, gabbro, and granite of the Coatesville-West Chester district usually show four systems of jointing, as shown in the table below. In addition each formation has a system of horizontal or nearly horizontal joint planes. With these conditions of jointing, water can probably be obtained, though not abundantly, throughout the area of pre-Cambrian crystalline rocks by means of drilled wells at no very great depth. If water is not obtained within 250 to 300 feet, there is little use in drilling deeper. The chances of a moderate supply before that depth is reached have been estimated to be about 9 in 10. The water, except in the limestone areas, should be soft.

Joint systems in rocks of Coatesville-West Chester district

Baltimore gneiss		Wissahickon formation		Gabbro		Granite	
Strike	Dip	Strike	Dip	Strike	Dip	Strike	Dip
N. 10° W.–N. 5° E.	85° SW. or SE.	N. 25°–55° W.	65°–80° NE.	N. 50°–70° W.	45° NE.	N. 65°–70° W.	----------
N. 85° E.	75° NW.	N. 65°–75° E.	60° NW.	N. 10°–20° W.	85° NE.	N. 10° W.	----------
N. 80°–85° E.	85° NW.	N. 30° E.	75° SE.	N. 80° E.	90°	N. 85° W.	90°
W.	75° SW.	N. 50° E.	50° SE.	----------	----------	----------	----------

Th. Paleozoic sediments furnish conditions for water circulation somewhat unlike those of the pre-Cambrian rocks. Like the pre-Cambrian rocks, they are crystalline and therefore less porous than the corresponding unmetamorphosed types—sandstone, limestone, and shale—and more nearly alike in porosity. They possess, however, definite planes of stratification as well as three systems of joints which serve as water channels, and water can be obtained from these formations at moderate depths.

PUBLIC WATER SUPPLIES

West Chester.—Water is supplied to West Chester by the municipal waterworks. The source of the supply is Chester Creek, which is fed by springs in the pre-Cambrian crystalline rocks. The plants are near Fernhill and at Milltown, 2 and 5 miles, respectively, below the head of the stream. The capacity of the plants is 2,500,000 gallons in 24 hours. The water is chlorinated at Milltown and pumped to a settling reservoir at Fernhill, whence it is served by gravity to about 12,000 people. An analysis of the untreated water at Fernhill (No. 1 in the table) shows it to have a low mineral content and comparatively little hardness.

In 1922 the borough drilled a well in the Baltimore gneiss about 100 yards southeast of the settling reservoir at Fernhill. At the depth of 238 feet water was obtained with a yield of 21 gallons a minute. As this yield was too small to add materially to the supply the well was abandoned at the depth of 240 feet. The well was 10 inches in diameter, and the water rose within 30 feet of the surface.

Coatesville.—The town of Coatesville is supplied with water by the borough. At one time the water was taken from Sucker Run, which had a flow of 1,500,000 gallons every 24 hours. The present supply is obtained from the headwaters of Rock Run, which has been dammed about 2½ miles northwest of Coatesville. From the reservoir the water goes to the purifying station near by, where it is chlorinated and sent by gravity to a settling reservoir on the North Valley Hills just west of the rolling mills on the West Branch of Brandywine Creek, whence it is served by gravity to nearly 15,000 people. Rock Run drains crystalline rocks of granitoid and gabbroic types, and therefore the water contains little dissolved mineral matter, as is shown by analysis 2 in the table.

Parkesburg.—The Parkesburg Water Co. supplies Parkesburg with water obtained from about 20 springs near the head of Glen Run, a tributary to the East Branch of Octoraro Creek, in Highland Township about 1½ miles south of Lenover. The capacity of the springs is estimated at 150,000 gallons in 24 hours. They are in the Wissahickon formation, and the water is described as medium soft. It issues clear and cold and is furnished without treatment to 2,500 people.

Atglen.—Water is supplied to Atglen by the Atglen Water Co., which owns springs that issue from gneiss 1½ miles northeast of Atglen and furnish a supply of about 6,000 gallons in 24 hours. The water is piped to a reservoir north of Atglen. It is soft and is served without treatment to 650 people.

Christiana.—The Christiana Gravity Water Co. furnishes Christiana with an abundant supply of soft water obtained from ten so-called springs at the headwaters of the East Branch of Octoraro Creek, 2½ miles north-northeast of Christiana. These springs were developed by excavating to a depth of 3 to 5 feet over an area of 4 to 6 by 10 to 16 feet, and the water is collected in a covered cement reservoir. The springs have a combined capacity of 130,000 gallons in 24 hours. The development of additional springs is contemplated.

Oxford.—The water supply for the borough of Oxford is obtained from two drilled wells owned by the borough. They are about 1 mile north of Oxford and are drilled in the Wissahickon formation. One of them is 4½ inches in diameter and 550 feet deep; the other is 6 inches in diameter and 1,000 feet deep. The water rises within 70 to 80 feet of the surface and is raised to the surface by air lift. The maximum yield from the combined wells is 120 gallons a minute and supplies a population of over 2,000 people. An analysis of water from the 1,000-foot well (No. 3 in the table) shows it to be fairly soft and of low mineral content.

West Grove.—The West Grove Water Co. supplies West Grove with soft water gathered from several springs and one drilled well 213 feet deep, in the Wissahickon formation, and from one dug well. The water is forced by three pumps with a combined capacity of 80 gallons a minute to reservoirs and supplies a population of nearly 2,000.

Avondale.—The Avondale water supply is furnished by springs in an abandoned limestone quarry a quarter of a mile southwest of Avondale station, which yield about 265 gallons a minute. Three pumps with a capacity of 147 gallons a minute force the water to a 392,000-gallon reservoir on the hill southwest of the quarry, from which it is supplied to nearly 1,000 people.

Kennett Square.—The town of Kennett Square is supplied with water by the municipal waterworks. The water is obtained from Spring Run, a tributary to Red Clay Creek at a point about 2 miles east of Kennett Square, in the Baltimore gneiss. The capacity of the plant is 500,000 gallons in 24 hours. The water, which is soft, is chlorinated and supplies about 2,500 people. A reservoir has recently been constructed and the pumping station rebuilt.

Wilmington.—Water is supplied to Wilmington by the city water department. The water is drawn from Brandywine Creek at a dam about 1 mile north of the south edge of the West Chester quadrangle and 4,800 feet upstream from the plant of the water department at Sixteenth and Market Streets, Wilmington.

Available flow of Brandywine Creek over period of 10 years

	Cubic feet per second	Million gallons daily
Maximum	402	260
Minimum	64	40
Average	279	180

The city owns one-half the rights of the stream and is entitled to one-half the available flow. The water is treated by preliminary filtration, sedimentation, and slow sand filtration. The chemical composition, which is fairly uniform throughout the year, is shown by analysis 4 in the table. The water is soft and has a low mineral content.

Other supplies.—The Octoraro Water Co. furnishes water to the Pennsylvania Railroad from Downingtown, in East Caln Township, to Shenk's Ferry, on Susquehanna River. The company has two plants—one at Pine Grove, on Octoraro Creek 3 miles west of Oxford, and the other 8 miles northeast of Pine Grove, on the West Branch of Octoraro Creek. The water is piped to six reservoirs along the railroad.

Pomeroy, Toughkenamon, and Landenberg have no public water supply but are dependent upon privately owned wells and springs.

PRIVATE WATER SUPPLIES

Springs and dug wells have chiefly, if not altogether, furnished the private water supply in the past, but drilled wells are becoming an increasingly important means of water supply in this region.

On the Du Pont estate at Longwood there are two drilled wells 360 and 600 feet deep, both finished with 8-inch steel casing. The 600-foot well, near the Red Lion Inn, penetrates the Setters formation and below 300 feet is in a medium to fine grained granite gneiss. The water rises in the well to a level 80 feet below the surface and is yielded under pump at the rate of 22 gallons a minute. Analysis 5 in the table shows that the water contains only a moderate quantity of dissolved mineral matter and is only slightly hard. Except for the large quantity of iron the water should be excellent for all ordinary uses.

On the highway from Longwood to Kennett Square, about 1½ miles southwest of Longwood, there are many privately owned drilled wells in the Baltimore gneiss, ranging from 40 to 72 feet in depth, in which the water rises within 37 to 20 feet of the surface. These wells yield from 7½ to 15 gallons a minute when pumped.

A 6-inch well about 1 mile southeast of the normal school at West Chester is 61 feet deep and extends through gabbro. The water rises in the well to a level 21 feet below the surface, and the well has a capacity of 18 gallons a minute.

At Westtown School, in Baltimore gneiss and serpentine, there are five drilled wells in the meadow south of the school grounds and one on the school grounds. The school-ground well is 240 feet deep and yields on pumping 100 gallons a minute.

About 1 mile northeast of Goshenville a privately owned drilled well 185 feet deep in the Baltimore gneiss furnishes water for a large estate.

ANALYSES

Analyses of waters from Coatesville and West Chester quadrangles

[Analyzed by Margaret D. Foster, except as indicated. Parts per million]

	1	2	3	4[a]	5
Silica (SiO_2)	8.7	6.0	24	6.7	24
Iron (Fe)	.09	[b].90	.13	.13	[c]2.2
Calcium (Ca)	4.8	6.6	5.4	17	16
Magnesium (Mg)	3.9	2.9	3.0	1.7	4.8
Sodium (Na)	2.4	3.1	5.7	5.4	8.8
Potassium (K)	.4	1.0	1.6		2.3
Bicarbonate radicle (HCO_3)	22	31	35	48	48
Sulphate radicle (SO_4)	5.2	5.5	7.8	9.7	8.5
Chloride radicle (Cl)	3.4	2.9	1.8	8.4	12
Nitrate radicle (NO_3)	4.6	.21	.44	---------	24
Total dissolved solids at 180° C	46	49	70	94	127
Total hardness as $CaCO_3$ (calculated)	28	28	26	49	60
Date of collection	May 6, 1922	Oct. 16, 1922	June 26, 1922	[a]	Nov. 16, 1922

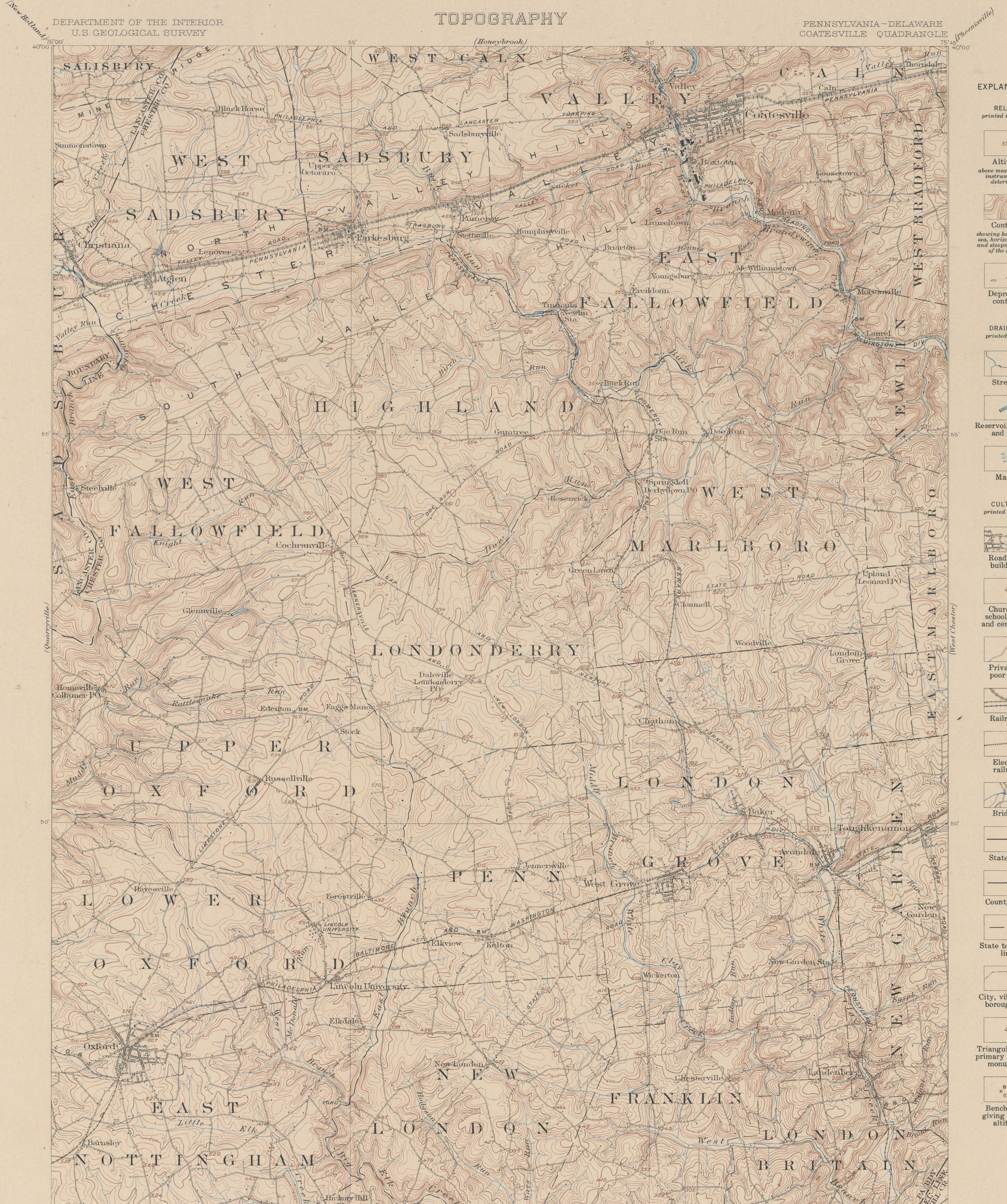
[a] Average of concordant analyses of samples collected Aug. 11, 1913, Aug 10, 1914, and May 19, 1915. Analyzed by James M. Caird, Troy, N. Y.
[b] Includes 0.84 part per million of iron precipitated at time of analysis.
[c] Includes 2.09 parts per million of iron precipitated at time of analysis.

1. Public water supply of West Chester; spring and stream half a mile northeast of Fernhill.
2. Public water supply of Coatesville; headwaters of Rock Run; collected at waterworks 2¼ miles northwest of Coatesville.
3. Public water supply of Oxford; 6-inch well, 1,000 feet deep.
4. Public water supply of Wilmington; Brandywine Creek; filtered.
5. Drilled well 600 feet deep at Red Lion Inn, near Longwood.

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

TOPOGRAPHY

PENNSYLVANIA–DELAWARE
COATESVILLE QUADRANGLE



EXPLANATION

RELIEF
printed in brown

Altitude
above mean sea level instrumentally determined

Contours
showing heights above sea, horizontal form, and steepness of slope of the surface

Depression contours

DRAINAGE
printed in blue

Streams

Reservoir or pond and dam

Marsh

CULTURE
printed in black

Roads and buildings

Church or schoolhouse and cemetery

Private or poor road

Railroads

Electric railroad

Bridges

State line

County line

State township line

City, village, or borough line

Triangulation or primary traverse monument

Bench mark giving precise altitude

H. M. Wilson, Geographer.
Frank Sutton and Robt. D. Cummin, in charge of section.
Topography by Robt. D. Cummin and A. C. Roberts.
Control by C. B. Kendall.
Surveyed in 1903–1904.
SURVEYED IN COOPERATION WITH THE STATE OF PENNSYLVANIA.

APPROXIMATE MEAN DECLINATION 1930.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Mar. 1906, reprinted 1931.

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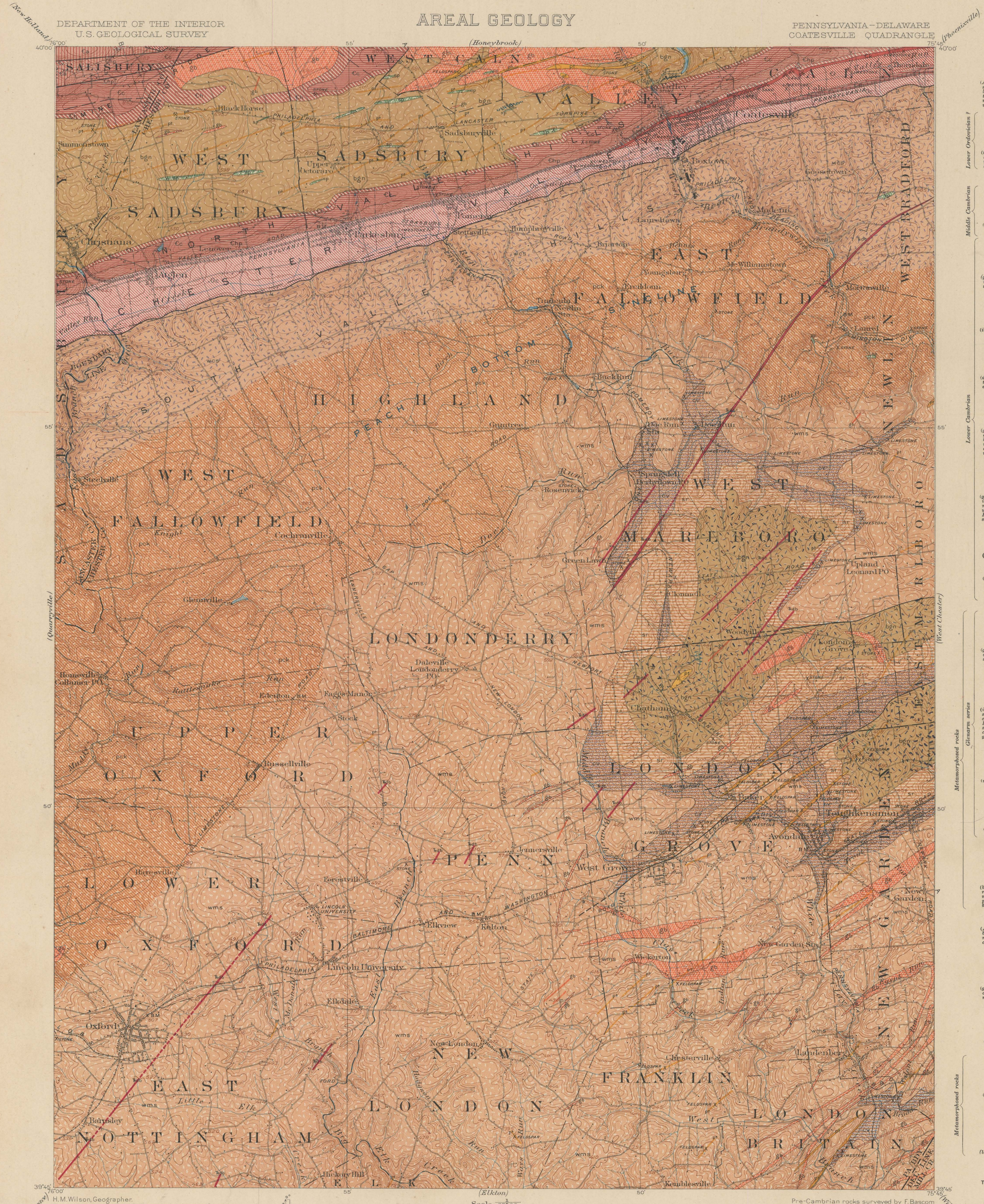
U.S. GEOLOGICAL SURVEY

AREAL GEOLOGY

PENNSYLVANIA–DELAWARE
COATESVILLE QUADRANGLE



EXPLANATION

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines; subaerial deposits by patterns of dots and circles; metamorphism is indicated by hachures)

ORDOVICIAN — *Lower Ordovician ?*

Oc — **Conestoga limestone** *(thin-bedded blue to white granular limestone, with micaceous laminations and dark slaty partings; limestone conglomerate at base)*

UNCONFORMITY (EROSION AND OVERLAP)

CAMBRIAN — *Middle Cambrian*

€e — **Elbrook limestone** *(fine-grained earthy laminated white crystalline limestone and dolomite)*

CAMBRIAN — *Lower Cambrian*

€l — **Ledger dolomite** *(gray to white pure granular crystalline dolomite and some limestone)*

€k — **Kinzers formation** *(impure micaceous limestone and mica schist; poorly exposed)*

€v — **Vintage dolomite** *(dark-blue dolomite with knotty texture due to impurities; poorly exposed)*

€a — **Antietam quartzite** *(gray laminated quartzite and quartzose schist with ferruginous beds at top; mapped only in northwestern part of area; where present in North Valley Hills mapped with Harpers schist)*

€hp — **Harpers schist** *(gray sandy schist and thin quartzites; overlying Antietam quartzite not generally recognizable and where present in North Valley Hills is mapped with Harpers schist)*

€c, €h — **Chickies quartzite with Hellam conglomerate member at base** *(thin-bedded to massive quartzite and quartz schist; thin mica schist and conglomerate, and Hellam conglomerate member, €h, at base)*

UNCONFORMITY

ALGONKIAN ? — *Metamorphosed rocks — Glenarm series*

pck — **Peters Creek schist** *(green, finely laminated nonfissile quartzitic muscovite-chlorite schist)*

wcs, wms — **Wissahickon formation** *(in northern part, albite-chlorite schist facies, wcs, in part muscovite schist; south of Peach Bottom syncline, oligoclase-mica schist facies, wms, in part muscovite gneiss and in part biotite gneiss)*

cv — **Cockeysville marble** *(white or light-gray saccharoidal marble)*

sr — **Setters formation** *(buff quartzite and gray biotite-quartz-feldspar gneiss)*

UNCONFORMITY

ARCHEAN ?

bgn, bgg — **Baltimore gneiss** *(biotite or hornblende gneiss, a recrystallized sediment, in part massive with little banding; in part graphite-bearing muscovite biotite gneiss, bgg)*

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs; metamorphism is indicated by hachures)

TRIASSIC

Ꞇdb — **Diabse** *(granular to fine-grained; generally weathered to small rounded rusty ironstone masses)*

PRE-CAMBRIAN

pt — **Pegmatite** *(coarsely crystalline orthoclase, quartz, and mica; only larger dikes shown)*

Metamorphosed rocks

sp — **Serpentine** *(more or less altered peridotite and pyroxenite; includes some magnesite; intrusive masses and dikes)*

gb — **Gabbro** *(large intrusive masses and dikes)*

Fault

T *Overthrust side of thrust fault*

⚒ *Active quarry*
x *Abandoned quarry*
⛏ *Sand pit*

H. M. Wilson, Geographer.
Frank Sutton and Robt. D. Cummin, in charge of section.
Topography by Robt. D. Cummin and A. C. Roberts.
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1 ½ 0 1 2 3 4 Miles

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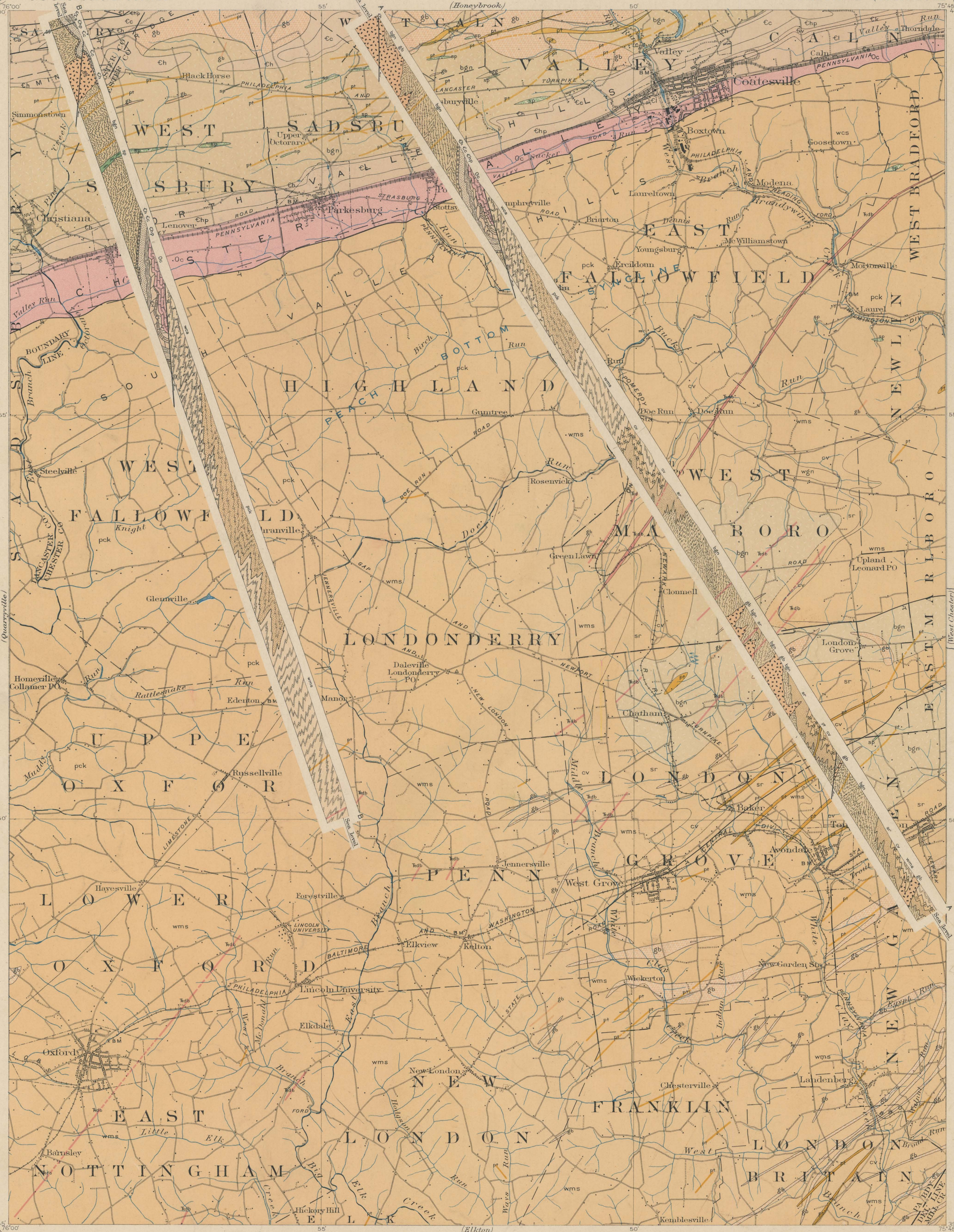
Pre-Cambrian rocks surveyed by F. Bascom in 1902-1923.
Cambrian and Ordovcian rocks surveyed by G. W. Stose in 1922-1923.

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

STRUCTURE SECTIONS

PENNSYLVANIA–DELAWARE
COATESVILLE QUADRANGLE



EXPLANATION

SEDIMENTARY ROCKS

SHEET SYMBOL — SECTION SYMBOL

ORDOVICIAN

Lower Ordovician ?

Oc — **Conestoga limestone** (thin-bedded blue to white granular limestone, with micaceous laminations and dark slaty partings; limestone conglomerate at base)

UNCONFORMITY (EROSION AND OVERLAP)

CAMBRIAN

Middle Cambrian

€e — **Elbrook limestone** (fine-grained earthy laminated white crystalline limestone and dolomite)

Lower Cambrian

€l — **Ledger dolomite** (gray to white pure granular crystalline dolomite and some limestone)

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UNCONFORMITY

ARCHEAN ?

bgn — **Baltimore gneiss** (biotite or hornblende gneiss, a recrystallized sediment, in part massive with little banding; in part graphite-bearing muscovite-biotite gneiss, bgg)

IGNEOUS ROCKS

TRIASSIC

Ꞧdb — **Diabase** (granular to fine-grained; generally weathered to small rounded rusty ironstone masses)

PRE-CAMBRIAN

pt — **Pegmatite** (coarsely crystalline orthoclase, quartz, and mica; only larger dikes shown)

Metamorphosed rocks

sp — **Serpentine** (more or less altered peridotite and pyroxenite; includes some magnesite; intrusive masses and dikes)

gb — **Gabbro** (large intrusive masses and dikes)

Fault

T, Overthrust side of thrust fault

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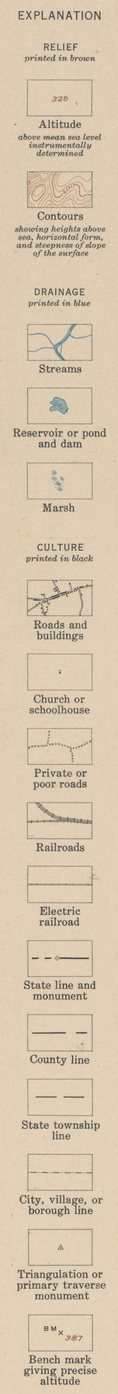
U.S. GEOLOGICAL SURVEY

TOPOGRAPHY

PENNSYLVANIA-DELAWARE
WEST CHESTER QUADRANGLE



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APPROXIMATE MEAN DECLINATION 1900.

Scale 1/62500

Miles — Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of May 1904, reprinted 1931.

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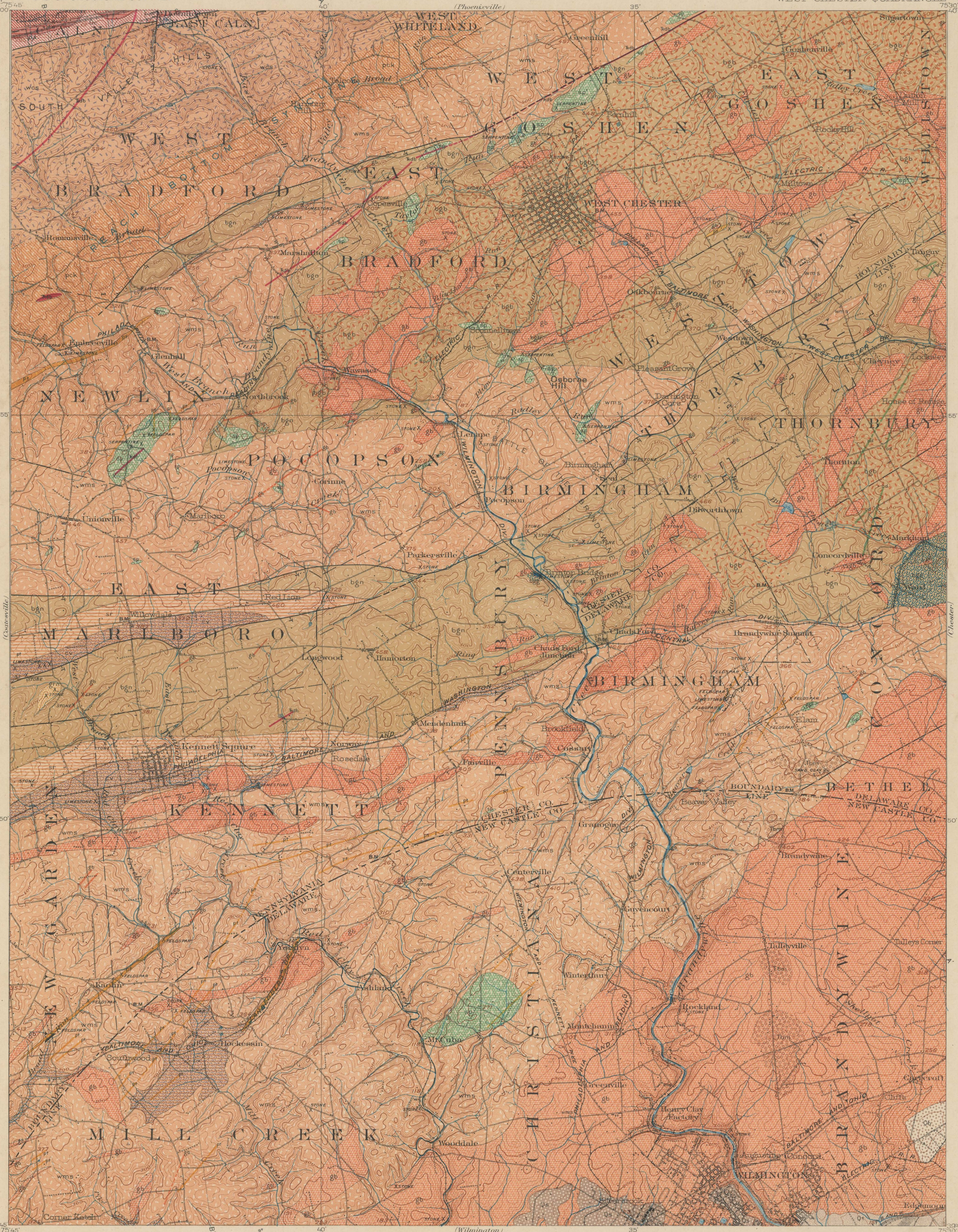
U.S. GEOLOGICAL SURVEY

AREAL GEOLOGY

PENNSYLVANIA-DELAWARE
WEST CHESTER QUADRANGLE



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APPROXIMATE MEAN DECLINATION 1930

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Edition of Aug. 1931.

Pre-Cambrian rocks surveyed by F. Bascom in 1902-1923.
Cambrian and Ordovcian rocks surveyed by G.W. Stose in 1922-1923.

EXPLANATION

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines; subaerial deposits by patterns of dots and circles; metamorphism is indicated by hachures)

QUATERNARY — *Pleistocene*

Qt — **Talbot formation** *(gravel and sand on terraces 60 to 40 feet above sea level)*

Qs — **Sunderland formation** *(gravel and sand on terraces 180 to 100 feet above sea level)*

Qb — **Brandywine gravel** *(thin gravel on terrace 220 feet above sea level)*

TERTIARY ? — *Pliocene ?*

Tbm — **Bryn Mawr gravel** *(chiefly thin gravel on uplands 400 to 300 feet above sea level)*

UNCONFORMITY

ORDOVICIAN — *Lower Ordovician ?*

Oc — **Conestoga limestone** *(thin-bedded blue to white granular limestone, with micaceous laminations and dark slaty partings; limestone conglomerate at base)*

UNCONFORMITY
(EROSION AND OVERLAP)

CAMBRIAN

Middle Cambrian

Ce — **Elbrook limestone** *(fine-grained earthy laminated white crystalline limestone and dolomite)*

Lower Cambrian

Cl — **Ledger dolomite** *(gray to white pure granular crystalline dolomite and some limestone)*

UNCONFORMITY

ALGONKIAN ? — *Metamorphosed rocks, Glenarm series*

pck — **Peters Creek schist** *(green, finely laminated nonfissile quartzitic muscovite-chlorite schist)*

wcs, wms — **Wissahickon formation** *(in northern part, albite-chlorite schist facies, wcs, in part muscovite schist; south of Peach Bottom syncline, oligoclase-mica schist facies, wms, in part muscovite gneiss and in part biotite gneiss)*

cv — **Cockeysville marble** *(white or light-gray saccharoidal marble)*

sr — **Setters formation** *(buff quartzite and gray biotite-quartz-feldspar gneiss)*

UNCONFORMITY

ARCHEAN ?

fl — **Franklin limestone** *(white, somewhat banded, usually graphite-bearing crystalline marble)*

bgn, bgb, bgg — **Baltimore gneiss** *(biotite or hornblende gneiss, a recrystallized sediment; in part massive, with little banding; in part graphite-bearing muscovite-biotite gneiss, bgg ; in places heavily injected with gabbro, bgb)*

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs; metamorphism is indicated by hachures)

TRIASSIC

Trdb — **Diabase** *(granular to fine-grained; generally weathered to small rounded rusty ironstone masses)*

PRE-CAMBRIAN

pt — **Pegmatite** *(coarsely crystalline orthoclase, quartz, and mica; only larger dikes shown)*

Metamorphosed rocks

sp — **Serpentine** *(more or less altered peridotite and pyroxenite; includes some magnesite; intrusive masses and dikes)*

gb — **Gabbro** *(large intrusive masses and dikes)*

od — **Older diabase** *(dikes of fine-grained labradorite-hornblende rocks)*

grn — **Granite gneiss** *(gneissoid even-grained quartz-orthoclase-andesine-biotite rocks)*

Fault
T, *Overthrust side of thrust fault*

⚒, *Active quarry*
X, *Abandoned quarry*
✂, *Sand or clay pit*

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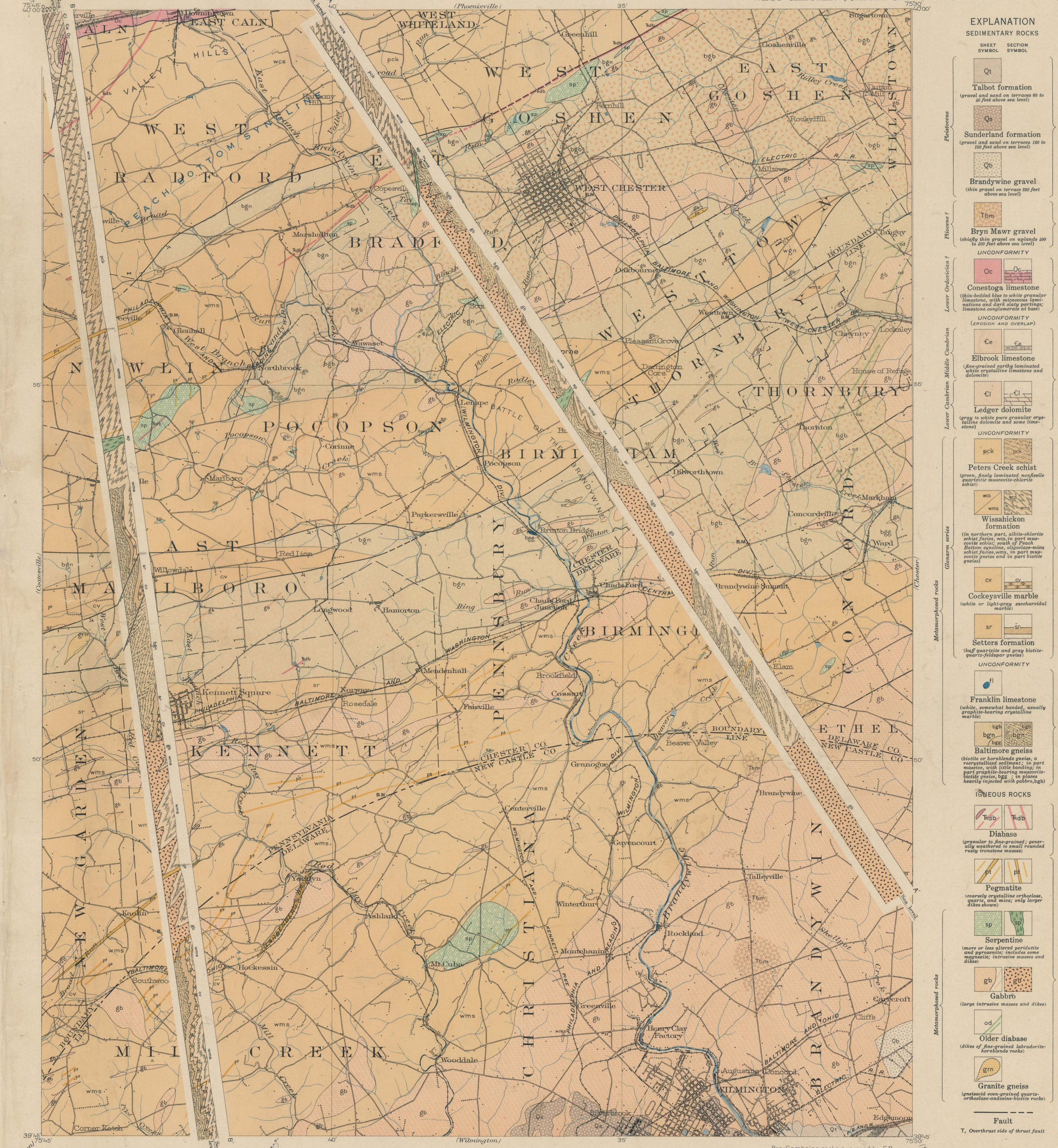
STRUCTURE SECTIONS

PENNSYLVANIA-DELAWARE
WEST CHESTER QUADRANGLE



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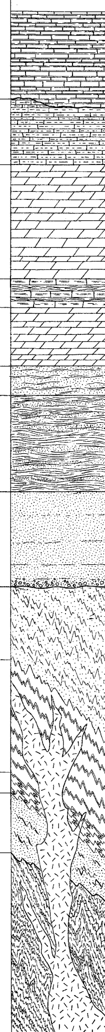
Pre-Cambrian rocks surveyed by F. Bascom in 1902-1923.
Cambrian and Ordovcian rocks surveyed by G.W.Stose in 1922-1923.

COLUMNAR SECTION

GENERALIZED SECTION OF ROCKS EXPOSED IN THE COATESVILLE AND WEST CHESTER QUADRANGLES.

SCALE: 1 INCH = 500 FEET.



System.	Series.	Formation.	Symbol.	Section.	Thickness in Feet.	Character of Rocks.
ORDOVICIAN	LOWER ORDOVICIAN ?	Conestoga limestone.	Oc		500+	Thin-bedded blue to gray granular limestone with thin dark shale and impure limestone partings; limestone in part conglomeratic at base.
		UNCONFORMITY				
CAMBRIAN	MIDDLE CAMBRIAN	Elbrook limestone.	€e		300±	Finely laminated fine-grained impure marble, weathering shaly.
	LOWER CAMBRIAN	Ledger dolomite.	€l		600	Granular, crystalline light-gray to white dolomite.
		Kinzers formation.	€k		150	Micaceous limestone and calcareous mica schist.
		Vintage dolomite.	€v		300±	Massive knotty granular glistening dark-gray dolomite.
		Antietam quartzite.	€a		150	Gray laminated quartzite, rust spotted and contains fossil molds.
		Harpers schist.	€hp		280–1000±	Gray sandy micaceous schist with thin quartzite beds.
		Chickies quartzite with Hellam conglomerate member.	€c €h		500	Vitreous to granular quartzite, massive and thin bedded, some quartz schist and mica schist; conglomerate-bearing beds at base.
		UNCONFORMITY				
ALGONKIAN (?)	GLENARM	Peters Creek schist.	pck		2000±	Green fine-grained laminated chloritic mica schist.
		Wissahickon formation.	wcs wms		5000–8000±	Biotite gneiss and muscovite schist, injected by granite and gabbro.
		Cockeysville marble.	cv		200+	Medium to coarse grained white saccharoidal marble, banded with phlogopite.
		Setters formation.	sr		1000±	Quartz schist, quartzite, and mica gneiss.
ARCHEAN (?)		Baltimore gneiss and Franklin limestone.	bgn fl			Contorted, banded gneiss, in part graphitic, injected by granite, gabbro, and serpentine. Franklin limestone is a banded white coarsely crystalline marble containing graphite.

Correlation chart

Age	Central Maryland	Eastern Pennsylvania	Southeastern New York
Ordovician	Cocalico shale. Conestoga limestone.	Cocalico shale (dark-gray shale, containing graptolites of normanskill type; gray, green, and purple slate; and green impure sandstone). Conestoga limestone (dark slaty limestone, coarse limestone and marble conglomerate, and thin-bedded granular blue limestone; probably of Chazy age).	Hudson schist (mica schist consisting of biotite and quartz, accompanied by garnet, staurolite, fibrolite, and kyanite). [The schist in the New York City area, formerly regarded as Hudson schist, is now regarded by most authors as of pre-Cambrian age and named Manhattan schist.]
Cambrian and Ordovician	Calcareous series, formerly known as Shenandoah limestone, now usually divided into several formations.	Calcareous series, formerly known as Shenandoah limestone, now divided into Beekmantown limestone, Conococheague limestone, Elbrook limestone, Ledger dolomite, Kinzers formation, Vintage dolomite (medium to fine grained white, gray, and blue limestone, dolomite, and marble, shale, and sandy limestone conglomerate).	"Wappinger limestone" (fine-grained crystalline dark-gray limestone ranging in age from Trenton to Lower Cambrian).
Lower Cambrian	Arenaceous series: Antietam schist. Harpers phyllite. Chickies formation, with Hellam conglomerate member at base.	Arenaceous series: Antietam quartzite. Harpers schist or phyllite Chickies quartzite, with Hellam conglomerate member at base.	Cheshire ("Poughquag") quartzite (silicified sandstone).
	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY
Algonkian (?) (Glenarm series)	Peach bottom slate Cardiff conglomerate. Peters Creek schist (chloritic sericitic quartzite with interbedded chlorite-muscovite schist). Wissahickon formation. Cockeysville marble (coarse grained granular magnesian marble with calcareous mica schist phase). Setters formation (mica schist and mica gneiss with intercalated quartzite member).	Peach Bottom slate. Cardiff conglomerate. Peters Creek schist (chloritic sericitic quartz schist and chlorite-muscovite schist). Wissahickon formation (thoroughly crystalline quartz-feldspar-mica gneiss and mica schist. A mica schist facies was formerly known as the "Octoraro schist" and regarded as Ordovician in age). Cockeysville marble (coarsely crystalline marble, associated with gneiss and penetrated by pegmatite). Setters formation (quartzite and quartz schist, in some places dominantly a mica gneiss).	Manhattan schist (thoroughly crystalline sediments formerly supposed to be the equivalent of the "Hudson River slates" but of different physical and petrographic character; now regarded as of pre-Cambrian age). Inwood limestone (magnesian crystalline limestone, formerly supposed to be the equivalent of the "Wappinger limestone" of Paleozoic age, but now regarded as of pre-Cambrian age). Lowerre quartzite (few exposures and probably very thin; formerly believed to be the equivalent of the Cheshire quartzite, but now regarded as of pre-Cambrian age).
	UNCONFORMITY	UNCONFORMITY	
Archean (?)	Baltimore gneiss (medium-grained quartzose gneiss, altered sedimentary rock).	Franklin limestone (coarsely crystalline white marble with graphite and numerous silicate minerals). Baltimore gneiss (medium to fine grained banded sedimentary gneiss, penetrated by igneous rocks; in some places thoroughly granitized).	Marble (crystalline and very impure and tremolitic). Fordham gneiss (chiefly granitic and quartzose banded sedimentary gneisses and schist with igneous intrusives).

PLATE 1.—BALTIMORE GNEISS INJECTED BY PEGMATITE AND GABBRO IN THIN LAYERS
Road cut on east side of West Branch of Brandywine Creek half a mile north of Coatesville, Coatesville quadrangle

PLATE 2.—BALTIMORE GNEISS CLOSELY FOLDED AFTER INJECTION BY PEGMATITE AND GABBRO
About 2½ miles north of Bryn Mawr, Norristown quadrangle

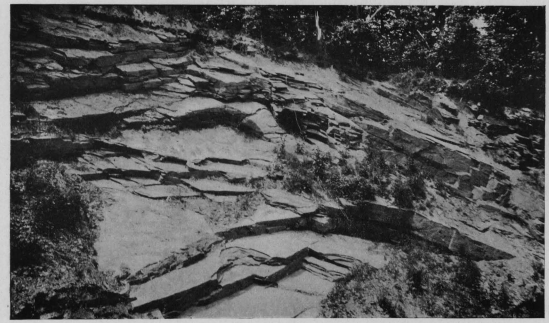


PLATE 3.—THIN-BEDDED MICACEOUS QUARTZITE OF THE SETTERS FORMATION
Quarry at Avondale, Coatesville quadrangle

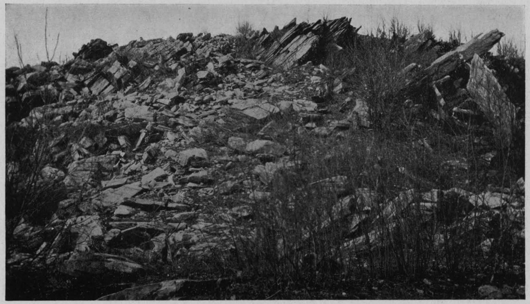


PLATE 4.—SCHISTOSE CHICKIES QUARTZITE, SCHISTOSE PLANE DIPPING SOUTHEAST
Exposed in small gorge in North Valley Hills 2 miles west of Coatesville, Coatesville quadrangle

PLATE 5.—THICK EVEN-BEDDED CHICKIES QUARTZITE IN LOWER PART OF THE FORMATION
Pennsylvania Railroad cut 1 mile west of Atglen, Coatesville quadrangle

PLATE 6.—THIN-BEDDED CHICKIES QUARTZITE ABOVE THE THICK BEDS
Pennsylvania Railroad cut 1 mile west of Atglen, Coatesville quadrangle

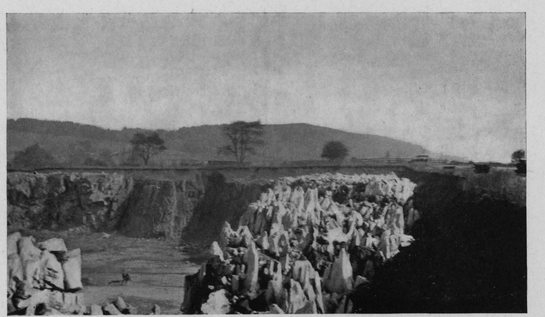


PLATE 7.—KARREN STRUCTURE PRODUCED BY SUBSOIL SOLUTION OF LEDGER DOLOMITE EXPOSED IN QUARRY STRIPPING
Quarry of Charles Warren Co., at Cedar Hollow, near Devault, Phoenixville quadrangle

PLATE 8.—LIMESTONE CONGLOMERATE INTERBEDDED WITH THIN-BEDDED DARK LIMESTONE NEAR BASE OF CONESTOGA LIMESTONE
In small quarry 2 miles west of Downingtown, Phoenixville quadrangle. The conglomerate is composed of angular fragments of white marble in a limestone matrix

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