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GEOLOGY AND MINERAL RESOURCES OF THE HONEYBROOK AND PHOENIXVILLE QUADRANGLES, PENNSYLVANIA

BY

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GEOLOGY AND MINERAL RESOURCES OF THE HONEYBROOK AND PHOENIXVILLE QUADRANGLES, PENNSYLVANIA

By F. Bascom and G. W. Stose [1]

ABSTRACT

The Honeybrook and Phoenixville quadrangles comprise an area of 456 square miles in the Piedmont province of southeastern Pennsylvania. This report describes the topography, areal geology, geologic structure, geologic history, and mineral resources of this area.

Topography.—The surface is chiefly a low rolling upland above which rise low mountains composed of Cambrian quartzites. The upland has a general altitude of 750 feet, and the mountains rise to 1,000 feet, with a few higher peaks. Limestone lowlands about 500 feet in altitude enter the western and southern sections of the area. The 750-foot level represents the Harrisburg peneplain, and the higher level represents dissected and somewhat lowered remnants of the Schooley peneplain. The area is crossed by the Schuylkill River, which has an altitude of 120 to 140 feet and is bordered by terraces at 200 to 240 feet.

Areal geology.—The rocks of the area comprise pre-Cambrian crystalline rocks, Lower Paleozoic sedimentary rocks, Triassic sedimentary rocks, and Triassic intrusive diabase. The crystalline rocks include the sedimentary Pickering gneiss, which is graphite-bearing, the Franklin limestone, and the Wissahickon formation, and igneous rocks that are intrusive in them. The igneous rocks include gabbro, pyroxenite and peridotite largely serpentinized, granodiorite, anorthosite, quartz monzonite, and metadiabase. The Paleozoic sedimentary rocks have at their base a Lower Cambrian quartzose sequence—Chickies quartzite with the Hellam conglomerate member at the base, Harpers phyllite, and Antietam quartzite. Above these is a carbonate sequence consisting of Vintage dolomite, Kinzers formation, Ledger dolomite, Elbrook limestone, and Conococheague limestone, of Cambrian age, and the Beekmantown limestone, of Ordovician age. The Conestoga limestone, which unconformably overlies the Elbrook limestone and older Paleozoic rocks, is probably also of Ordovician age. The Triassic rocks embrace the Stockton, Lockatong, and Brunswick formations, a thick series of red sandstone, arkose, conglomerate, and shale of terrestrial origin. These are cut by large intrusive bodies and dikes of diabase, which also invade the Paleozoic rocks in places.

[1] The pre-Cambrian rocks were surveyed by F. Bascom; the Paleozoic rocks by G. W. Stose; the Triassic rocks by E. T. Wherry, supplemented by G. W. Stose, who revised some of the boundaries and mapped the baked shale at the diabase contact. The interpretation of the geologic structure of the Paleozoic and Triassic rocks is by G. W. Stose and that of the pre-Cambrian rocks is by F. Bascom.

Geologic structure.—The Paleozoic and pre-Cambrian rocks are closely folded and faulted. The pre-Cambrian rocks form the cores of three major anticlines, on the flanks of which are Cambrian quartzites that dip westward and northwestward under the Paleozoic carbonate rocks. These anticlines are faulted in a complicated manner. The northern fold—the Welsh Mountain anticline—is not only overthrust northward onto the limestones of the valley but is apparently also upthrust on a high-angle fault on its south side. The middle fold—the Barren Hills anticline—is apparently locally overthrust southward onto the limestones of Chester Valley. The southern upfold—the Mine Ridge anticline—terminates eastward in an elongate fault block which is apparently upthrust on parallel high-angle faults on each flank. Chester Valley, south of these uplifts, encloses Paleozoic limestone in a syncline that is overridden on its south side by the Wissahickon formation apparently overthrust along the Martic fault.

The Triassic rocks overlie the Paleozoic rocks in the northern part of the area and overlap the folds and faults of the older rocks diagonally. The Triassic rocks are not folded but are tilted uniformly northwestward and are block-faulted.

Mineral resources.—The chief mineral resources are stone, lime, white clay, and sand. Magnetic iron ore, low-grade limonite, iron ore, and graphite deposits were formerly mined in the area, also small amounts of zinc and lead. Sand, gravel, feldspar, and flint deposits have been worked in a small way.

INTRODUCTION

By F. Bascom

Location and area.—The Honeybrook and Phoenixville quadrangles are west of Norristown, south of Reading, and in greater part north of Chester Valley. They are crossed in the northeast by the Schuylkill River, 16 miles northwest of Philadelphia, and they lie between 40° and 40°15′ north latitude and 75°30′ and 76° west longitude. They cover one-eighth of a "square degree" and contain about 456 square miles. (See fig. 1.)

This area embraces portions of Chester, Berks, Lancaster, and Montgomery Counties, Pa., and maintains a population of over 60,000. Pottstown, Royersford, Spring City, Phoenixville, Malvern, Downingtown, and Honeybrook are the principal towns in the quadrangles.

Climate, vegetation, and culture.—The climate of the Honeybrook and Phoenixville quadrangles is clement, without extremes of temperature, precipitation, or wind velocity. At Pottstown, on the northern border of the Phoenixville quadrangle, the mean annual temperature for a period of 12 years was 53.02°, and at Coatesville, 1 mile to the south of the Honeybrook quadrangle, the mean annual temperature for a period of 31 years was 51.9°.

The mean annual total precipitation at Pottstown for a period of 32 years was 44.90 inches, including an average annual snowfall of 31.9 inches in which 10 inches of snow equals about 1 inch of rain.

July, with a record of 5.44 inches, was the month of greatest mean annual rainfall. At Phoenixville the mean annual rainfall during a period of 12 years was 44.64 inches, with July the month of greatest mean annual rainfall, having a record of 5.30 inches. Rainfall is evenly distributed throughout the growing season, which is of good length. The average date of the first killing frost is in the third

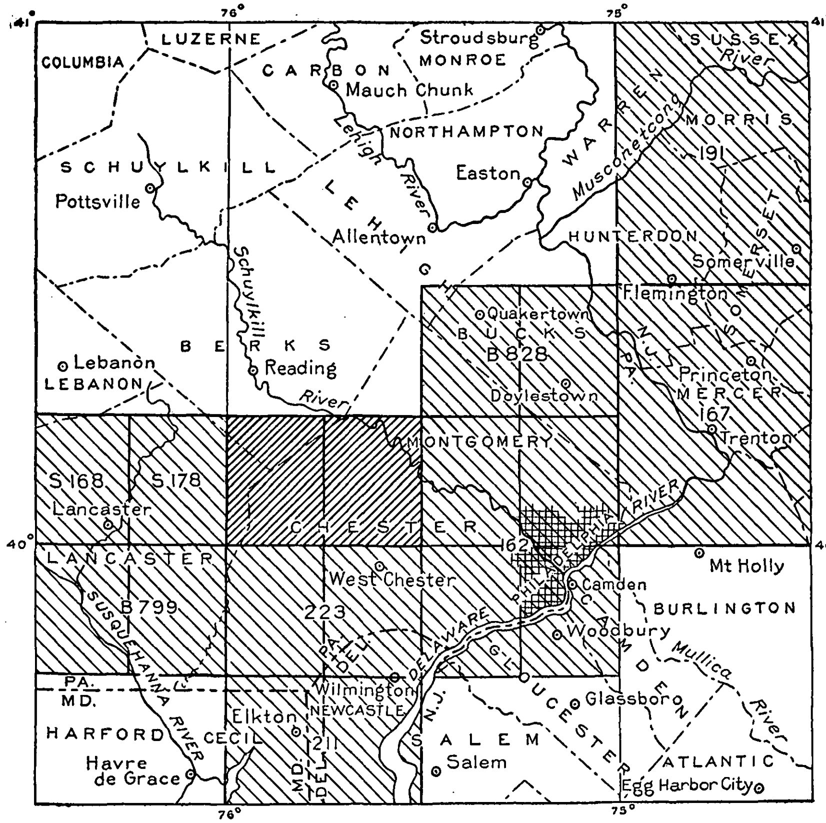

FIGURE 1.—Index map of Honeybrook and Phoenixville quadrangles and vicinity. Honeybrook and Phoenixville quadrangles are shown by close ruling. Other areas are described in the following reports. Folios of the Geologic Atlas of the United States: 162, Philadelphia; 167, Trenton; 191, Raritan; 211, Elkton-Wilmington; 223, Coatesville-West Chester. Bulletins of the United States Geological Survey; B 799, McCalls Ferry-Quarryville district, Pa.; B 828, Quakertown-Doylestown district, Pa.-N. J. Topographic and Geologic Atlas of Pennsylvania, Pennsylvania Geol. Survey: S 168, Lancaster quadrangle; S 178, New Holland quadrangle.

week of October, and that of the last killing frost is in the second week of April. The prevailing winds blow from the northeast during the summer and from the northwest during the winter and spring.

The soils, which are described in detail on pages 132–135, with the exception of the stony loam of Barren Hills, Welsh Mountain, Thomas Hill, Mount Pleasure, and North Valley Hills, average well in fertility and drainage. The climate and soil conditions are favorable for agriculture. The native vegetation is varied and vigorous throughout the summer. On the stony lands with rugged topography, there are light forests of oak, birch, beech, maple, poplar, sycamore, and cedar. The rolling uplands are arable. At present much land is kept in woodland and pasture, but under more intense cultivation the district would be capable of high development as an agricultural region.

Conestoga, Pequea, and Chester Valleys are famous for their farm products. Dairying is carried on extensively; the milk is taken to numerous local creameries or shipped by rail to larger centers.

The district is traversed by good roads, in large part hard-surfaced. This is notably true in the southern section: the Lancaster Pike, now known as the Lincoln Highway, traverses Chester Valley and connects Downingtown with Philadelphia and Lancaster. The Conestoga Pike, the Pottstown and West Chester Pike, the Harrisburg and Downingtown Pike, and the State road bring Downingtown into easy communication with the north, west, and south.

The main line of the Pennsylvania Railroad connects Downingtown with Philadelphia and with Chicago; the New Holland, Frazer, and West Chester branches unite Honeybrook, Phoenixville, and West Chester, respectively, with the main line. The Philadelphia & Reading Railroad (Wilmington division) crosses the Honeybrook quadrangle from north to south, with a branch road to St. Peters. Both the Pennsylvania Railroad (Schuylkill division) and the Philadelphia & Reading Railroad (Reading division) follow the Schuylkill River, uniting Philadelphia, Phoenixville, Pottstown, Reading, and the northwest. Bus or trolley lines link Downingtown with towns in Chester Valley, to the southwest, and with West Chester and other towns, to the south.

The Schuylkill Navigation Co.'s canal, which nearly parallels the Schuylkill River, is used for the transfer of anthracite coal and a small amount of miscellaneous freight from the upper part of the Schuylkill River Basin to tidewater at Philadelphia.

The larger towns of the area, Pottstown (population in 1930, 19,430), Phoenixville (12,029), and Downingtown (4,548), are located at the northern, eastern, and southern borders, respectively, of the Phoenixville quadrangle. Pottstown contains iron foundries, blast furnaces, car works, nail factories, and rolling mills, and is the seat of the Hills School for boys. In Phoenixville is the huge Phoenix Iron & Steel Works. Downingtown contains iron works, flour, paper, woolen, and knitting mills, machine shops, and brickyards. Royerford (3,719) and Spring City (2,963) aggregate over 6,600 inhabitants. Honeybrook (654) maintains a candy factory, a box factory, a printing plant, and the Honeybrook Vocational School.

Malvern (1,551), served by the main line of the Pennsylvania Railroad, is a suburban residential town; the smaller towns of the quadrangle are for the most part rural in character.

GEOGRAPHY

By F. Bascom

The Honeybrook and Phoenixville quadrangles lie within the geographic division known as the Appalachian Highlands. (See fig. 2.)

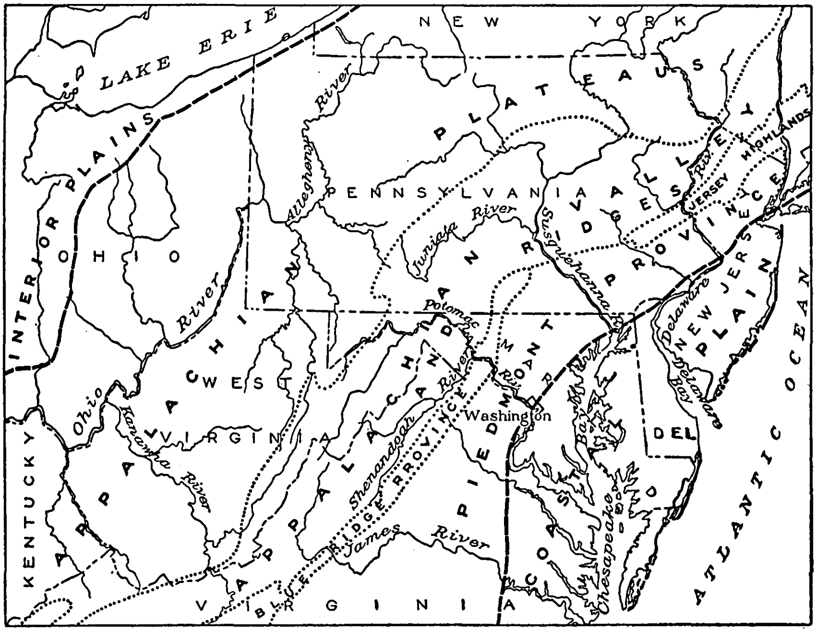

Figure 2.—Map of the Appalachian Highlands, showing physiographic divisions and relations to the Atlantic Coastal Plain. The Jersey Highlands, including the Reading and Boyertown Hills, are the northern representative of the Blue Ridge province. South Mountain in Pennsylvania forms the north end of the Blue Ridge province.

It is desirable to consider the geographic and geologic character of this division in order that the history of that small portion of the area which includes these quadrangles may be thoroughly understood.

The Appalachian Highlands extend from the Atlantic Plain division to the Mississippi lowlands and from Canada to the Gulf Coastal Plain. They are composed of several well-marked provinces which extend lengthwise of the division from northeast to southwest and within each of which there is a similarity of formations, structure, and topography. The Allegheny and Cumberland Plateaus, now known as the Appalachian Plateaus, form the westernmost of these provinces. The Valley and Ridge province, comprising in Pennsylvania a group of valleys and a succession of narrow ridges, lying between the Allegheny Front, or escarpment, of the Appalachian Plateaus, and the Blue Ridge, constitutes the central province. The eastern provinces of the division are the Blue Ridge province, comprising the mountains that border the Appalachian Valley, and the Piedmont province (a region of undulating uplands and lowlands) sloping eastward toward the Coastal Plain province of the Atlantic Plain.

The Honeybrook and Phoenixville quadrangles are wholly within the Piedmont province. This province, as its name signifies, is located at the foot of mountains—the Blue Ridge. Extending northeastward until it merges into the New England upland and southwestward until it merges into the East Gulf Coastal Plain, the province curves parallel to the Atlantic coast, with a mean width of 60 miles and a maximum width in its central portion of 120 miles.

The Piedmont province includes two sections. A belt in the north and northwest consists of relatively open level country on less resistant rocks (Triassic sandstone and shale, and Paleozoic limestone from which the Triassic cover has been eroded) intersected by a considerable hilly area (underlain by conglomerate or ridge-making igneous rock). This belt is known as the Piedmont lowlands. The more rugged country comprising the remaining and greater portion of the province, with deeper valleys and more abrupt hills, constitutes a section known as the Piedmont upland.

On the east the upland is separated from the Continental Shelf by a belt of the Atlantic Plain 250 miles in width. From the Connecticut coast north, the entire plain is submerged, with the minor but notable exception of Cape Cod, and the eastern border of the New England upland coincides with the coast line. From Connecticut southward, the plain is only partly submerged, and the upland is separated from the coast line by the Coastal Plain, which slopes gently seaward and gradually increases in width toward the south. The boundary between upland and plain is usually defined by a well-marked change in topographic features and geologic formations. Topographically the change consists generally in the transition from a diversified upland to a relatively undiversified lowland. Geologically there is a transition from hard crystalline rock of great age to unconsolidated clay, sand, and gravel of relatively recent age. All these Coastal Plain formations overlap the eastern border of the upland, and in some districts they are even found far inland and somewhat obscure the passage from upland to plain. Though remnants of Coastal Plain formations have been mapped in the quadrangles immediately to the south of the area here described, they have not been recognized in the Honeybrook and Phoenixville quadrangles.

For the most part, the margin of the upland is indicated by a change in the character of the streams that pass from upland to plain. An increased velocity at the upland margin succeeded by an abrupt decrease in velocity is characteristic of this passage, and so many falls or rapids mark the margin of the upland that this boundary has been called the "Fall Line", a term imperfectly descriptive of the boundary, which is actually a zone of appreciable width. East of this zone navigable streams, leading to tidal estuaries, afford good shipping facilities; west of it the streams are not navigable and occupy narrow, rocky channels. In the southern extension of the upland the Fall Line or Fall Zone gradually rises until in the Carolinas and Georgia, although falls and rapids still mark its location and furnish power for factories, it lies considerably above the tide limit. The position of this Fall Zone 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, Augusta, and Macon in general marks the boundary between upland and plain.

Although the Piedmont province exhibits great diversity of scenery, there are certain general features common to the entire province which make it a topographic unit. It comprises, in brief, gently sloping uplands of moderate and successively decreasing elevation as the Fall Zone is approached, dissected by gorgelike but not deep valleys and diversified by isolated eminences (monadnocks) rising above the general level of the uplands. If the valleys were filled, the uplands would become part of a series of undulating benches or terraces sloping eastward and southeastward toward the Atlantic. These uplands are remnants of several partly developed erosion surfaces and one extensively developed and uplifted erosion plain, or peneplain. Their origin and history are related in the section on historical geology.

When a highland area is reduced by erosive agents to a relatively smooth seaward-sloping lowland—that is, to a peneplain—and this peneplain is uplifted by continental movement, erosion will be accelerated; old valleys, which survive the uplift, will be deepened, and new valleys will develop; flood plains will mature and coalesce, until eventually, if the period of continental stability is sufficiently prolonged, a new erosion surface will be cut below the surface of the peneplain, and remnants of the peneplain will be left only at the headwater divides and on the more resistant rocks in interstream areas.

If there should be a succession of movements of uplift separated by long periods of quiescence, there will be developed a series of erosion surfaces, of which the oldest may be completely removed in the development of later surfaces or may be preserved only at low levels by burial beneath sediments; the intermediate may be preserved on a lowered surface only in the most resistant rocks remote from drainage lines; and the youngest will be widely preserved on lower levels. If, on the other hand, relatively brief periods of stability should intervene between periods of land movement, then only the beginnings of peneplains would be developed and these would consist in seaward slopes and flood-plain (strath) valleys. Upon uplift and renewed erosion such topographic features marking the early stages of peneplanation might either suffer complete obliteration through subsequent prolonged erosion or, if this later erosion is not prolonged, they might be preserved as sea terraces and river terraces—that is, berms.[2] If the movement of uplift is very slow, erosion and uplift may be so perfectly balanced that peneplanation is for the time being retarded and proceeds only when stability is established. The movement of uplift may be purely vertical, or it may be accompanied by deformation or warping of the uplifted surface.

A succession of continental movements alternating with periods of stability have characterized the Atlantic border of North America such as to produce one authentic peneplain of somewhat narrow extent, one incipient peneplain, and several rock terraces or berms. All trace of a hypothetical peneplain, the oldest and most extended erosion surface, known as the Fall Zone peneplain,[3] has been destroyed in the Appalachian Highlands. In the Fall Zone, where it passes under Lower Cretaceous sedimentary rocks, recent denudation has uncovered the ancient surface in small areas, and its intersection with later peneplains forms an angle of great linear extent and marked topographic expression. (See description and references, p. 103.) The theory of the existence of this erosion surface postulates the extension of the Coastal Plain some 150 miles beyond its present inner margin and the consequent superposition of the drainage from a Coastal Plain cover, a suggestive but unproved hypothesis.

The surviving erosion surfaces of eastern Pennsylvania have been subjected to the critical scrutiny of physiographers ever since the

[2] Bascom, F., U. S. Geol. Survey Geol. Atlas, Coatesville-West Chester folio (no. 223), p. 11, 1932; Geomorphic nomenclature; Science, new ser., vol. 74, pp. 172–173, August 14, 1931.

[3] Shaw, E. W., Ages of peneplains of the Appalachian Province: Geol. Soc. America Bull., vol. 29, pp. 575–586, 1918. Benner, G. T., The physiographic interpretation of the Fall Line: Geog. Review, vol. 17, pp. 278–286, 1927. Sharp, H. S., The Fall Zone peneplain: Science, new ser., vol. 69, pp. 544–545, 1929. Johnson, D. W., A theory of Appalachian geomorphic evolution: Jour. Geology, vol. 39, pp. 497–508, 1931.

appearance of Davis' famous paper entitled "The rivers and valleys of Pennsylvania."[4] Stose,[5] Knopf,[6] Ashley,[7] Campbell,[8] and Johnson[9] have made notable contributions to this subject. There is fair agreement as to the identity of the Schooley peneplain, perhaps the oldest surface still preserved and certainly the latest erosion surface deserving the designation peneplain. Traces ("lowered vestiges")[10] of this oldest authenticated peneplain are still preserved in summit areas rising to altitudes in the Appalachian Valley province of 1,400 feet (Kittatinny or Blue Mountain) and 1,200 feet (Schooley Mountain) and on the highest hilltops of the Piedmont province to 1,000 feet.

The next younger erosion surface, upon which complete agreement among physiographers has yet to be reached was named the Harrisburg[11] by Campbell and later renamed by him the Chambersburg.[12] Remnants of this surface at 800 to 700 feet dominate interstream areas in the northeastern Pennsylvania Piedmont south of Blue (Kittatinny) Mountain on both sides of the Schuylkill, Delaware, and Susquehanna Rivers (Wind Gap, Allentown, Slatington, and Lebanon quadrangles). From these altitudes the surface descends to 660 and 600 feet 8 to 6 miles northeast and east of Harrisburg, rising westward (Harrisburg, Carlisle, Newville, Shippensburg, and Chambersburg). Ashley[10] would include the lower surface (520 feet) in the near neighborhood of Harrisburg, as well as the higher surface at 600 feet or more, as the Harrisburg surface sub-

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[4] Davis, W. M., Nat. Geog. Mag., vol. 1, pp. 184–253, 1889.

[5] Stose, G. W., Physiographic studies in southern Pennsylvania: Jour. Geology, vol. 12, no. 6, pp. 473–484, 1904; Possible post-Cretaceous faulting in the Appalachians; Geol. Soc. America Bull., vol. 38, pp. 493–504, 1927; High gravels of Susquehanna River above Columbia, Pa.; Idem, vol. 39, pp. 1073–1086, 1928; Is the Bryn Mawr peneplain a warped surface? Am. Jour. Sci., 5th ser., vol. 19, pp. 177–184, 1930; Geology of the Middletown quadrangle, Pa.: U. S. Geol. Survey Bull. 840, pp. 46–49, 1933.

[6] Knopf, E. B., Correlation of residual erosion surfaces in the eastern Appalachian Highlands: Geol. Soc. America Bull., vol. 35, pp. 653–658, 1924. Knopf. E. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pa.: U. S. Geol. Survey Bull. 799, pp. 91–118, 1929.

[7] Ashley, G. H., Age of the Appalachian peneplains: Geol. Soc. America Bull., vol. 41, pp. 695–700, 1930; Studies in Appalachian Mountain sculpture: Idem, vol. 46, pp. 1395–1436, 1935.

[8] Campbell, M. R., Geographic development of northern Pennsylvania and southern New York: Geol. Soc. America Bull., vol. 14, pp. 277–296, 1903; Geomorphic value of river gravel: Idem, vol. 40, pp. 515–532, 1929; Late geologic deformation of the Appalachian Piedmont as determined by river gravels: Nat. Acad. Sci. Proc., vol. 15, no. 2, pp. 156–161, 1929; Alluvial fan of Potomac River: Geol. Soc. America Bull., vol. 42, pp. 825–852, 1931; Chambersburg (Harrisburg) peneplain in the Piedmont of Maryland and Pennsylvania: Idem, vol. 44, no. 3, pp. 553–573, 1933.

[9] Johnson, D. W., op. cit.; Stream sculpture on the Atlantic slope, 133 pages, Columbia University Press, 1931.

[10] Ashley, G. H., Studies in Appalachian Mountain sculpture: Geol. Soc. America Bull., vol. 46, p. 1399, 1935.

[11] Campbell, M. R., Geographic development of northern Pennsylvania and southern New York: Geol. Soc. America Bull., vol. 14, pp. 277–296, 1903.

[12] Campbell, M. R., Chambersburg (Harrisburg) peneplain in the Piedmont of Maryland and Pennsylvania: Geol. Soc. America Bull., vol. 44, no. 3, pp. 553–573, 1933.

jected to reduction by differential erosion. Others, however,[12 13] have considered that the lower surface is separated in time and duration from the upper surface. With this interpretation confusion has arisen in usage as to which of the two surfaces should take the name Harrisburg.

The writer is in agreement with Campbell and Stose as to the correlation of the surface adjacent to Chambersburg with the upper surface in the neighborhood of Harrisburg. The surface near Chambersburg,[13a] with an altitude of 750 feet, is, like the surface east of Harrisburg, developed on Martinsburg shale. It has been maintained at an altitude commensurate with its position relative to the edge of the Continental Shelf owing to the exceptional hardness of the shale, fortified locally by a hard coarse-grained thick-bedded sandstone member. Campbell[12] states that the Chambersburg surface fulfills the requirements of a type locality "in an almost ideal manner", while it is "obvious that the retention of the name Harrisburg will in the end result in much greater confusion and tend to throw doubt upon the validity of the surface itself as well as upon its name." With this conclusion the writer as a student of the area is in complete accord. Stose and others, however, dissent from this conclusion. The term Harrisburg will be used in this report.

Some 25 miles south and southeast of Harrisburg the upland rises and northeast of Westminster, Md., reaches a maximum altitude of 1,000 feet. From this altitude the surface descends on the south and southeast to 750 and 700 feet and in the southeastern Piedmont, where it is represented by well-preserved remnants, to 500 feet.

The 700-foot level, which this upland attains in the Honeybrook area, is coincident with the surface described by the writer[14] under the name Honeybrook. If the Harrisburg erosion surface has been warped, as profile sections across the uplands from Havre de Grace to Harrisburg on each side of the Susquehanna River have convinced the writer is the case, the name Honeybrook is no longer needed. The 700- to 760-foot plain in the neighborhood of Honeybrook, upon which that town is located, is part of the northwestern slope of the supposedly warped surface (Wind Gap, Slatington, Honeybrook, Phoenixville, and Coatesville quadrangles).

There are two lower erosion surfaces at Harrisburg between the upland surface and the city of Harrisburg, one at an altitude of 520

[12] Campbell, M. R., Chambersburg (Harrisburg) peneplain in the Piedmont of Maryland and Pennsylvania: Geol. Soc. America Bull., vol. 44, no. 3, pp. 553–573, 1933.

[13] Stose, G. W., High gravels of Susquehanna River above Columbia, Pa.: Geol. Soc. America Bull., vol. 39, pp. 1073–1086, 1928. Knopf, E. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pa.: U. S. Geol. Survey Bull. 799, pp. 91–118, 1929.

[13a] Stose, G. W., U. S. Geol. Survey Geol. Atlas, Mercersburg-Chambersburg folio (no. 170), pp. 16, 17, 1909.

[14] Bascom, F., Cycles of erosion in the Piedmont province of Pennsylvania: Jour. Geology, vol. 29, pp. 540–559, 1921.

to 540 feet and the other at 420 to 450 feet. The 520- to 540-foot terrace, or berm, is the conspicuous level surface to be seen from the city, a surface which has been considered to be an integral part of the uplands [15] or has been interpreted as the surface to which the name Harrisburg was originally given [16] and which seems to the writer to preserve evidence of a distinct and relatively short period of erosion. As this berm is capped on its seaward margin by the Bryn Mawr gravels,[17] which distinguish it from the older upland, it is appropriately named the Bryn Mawr berm. It is the oldest and most widely developed of the berms in the Piedmont province, and, like the upland surface, was apparently so warped [17a] by the low arching of the highland south of Harrisburg that it rises to an altitude of 600 and 640 feet west of Safe Harbor and thence descends eastward to 500 and 400 feet north of Havre de Grace. The warping of these surfaces is questioned by Stose.[17b]

The lowest erosion surface at Harrisburg is the 420- to 450-foot level sloping toward the Susquehanna River. This berm is developed bordering the streams, and along the margin of the Coastal Plain it has altitudes from 300 to 200 feet with a gentle seaward slope. Near the Fall Line it carries Brandywine gravel and has therefore been named the Brandywine berm. More recently Campbell [18] has called it the Shepherdstown berm from gravel well developed at Shepherdstown, W. Va.

A later series of land movements apparently brought the whole Continental Shelf above the sea, when the valleys, now submerged, were cut to the edge of the Continental Shelf. The submerged valleys of the Hudson, Delaware, Susquehanna, and Potomac, extending across the Continental Shelf, are evidences of this period of uplift and valley erosion.

Below 200 feet on the extreme border of the Piedmont province, at levels of about 180, 80, and 40 feet, are three narrow berms. These berms carry sediments of Pleistocene age and are in some localities of purely fluvial origin and independent of coastal movement. They have been known as the Sunderland, the Wicomico, and the Talbot,

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[15] Ashley, G. H., Studies in Appalachian Mountain sculpture: Geol. Soc. America Bull., vol. 46, pp. 1395–1436, 1935.

[16] Johnson, D. W., A theory of Appalachian geomorphic evolution: Jour. Geology, vol. 39, no. 6, pp. 497–508, 1931.

[17] This name, Bryn Mawr, was first used for these gravels in 1880. Later they were called the Lafayette and still later renamed the Brandywine, which was subsequently separated into the high-level or early Brandywine (Pliocene?) and the low-level or late Brandywine. It is now proposed to reinstate the old name Bryn Mawr for the early Brandywine and to confine the term Brandywine to the late Brandywine (Pleistocene).

[17a] Campbell, M. R., Late geologic deformation of the Appalachian Piedmont as determined by river gravels: Nat. Acad. Sci. Proc., vol. 15, no. 2, pp. 156–161, 1929.

[17b] Stose, G. W., Is the Bryn Mawr peneplain a warped surface?: Am. Jour. Sci., 5th ser., vol. 19, pp. 177–184, 1930.

[18] Campbell, M. R., Chambersburg (Harrisburg) peneplain in the Piedmont of Maryland and Pennsylvania: Geol. Soc. America Bull., vol. 44, no. 3, p. 558, 1933.

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from localities in Maryland where the deposits were first noted. The river gorges in the Piedmont province below the Brandywine berm were cut while these seaward berms were developing. The consecutive and more or less complete development of a peneplain (Schooley), an incipient or partial peneplain (Harrisburg), and two berms (Bryn Mawr and Brandywine) signifies a long erosion history for this region and one subject to interruption.

The successive dissection of an older peneplain through the development of a younger partial peneplain and several berms is made possible only by such oscillations of the continental border as are also recorded in the Atlantic Plain by sedimentation and erosion.

The possibly warped and sloping surfaces of the peneplain, partial peneplain, and berms of the Piedmont province, do not conform to the underlying rock formations, which have highly complex structure, nor do the master streams of the province, which rise either in the western province (Appalachian Plateaus) of the Appalachian Highlands or on the inland border of the Piedmont province, pursue courses consequent upon the slope of the uplands—that is, to the south and southwest, independent of the character of the rock floor. Instead they empty into estuaries heading at the eastern margin of the Piedmont province, or, after crossing the Coastal Plain, empty directly into the Atlantic or into the Gulf of Mexico. The Delaware, Susquehanna, and Potomac are such master streams that pursue southerly courses across the Valley and Ridge and the Blue Ridge provinces. At the Triassic lowlands these streams turn to the southeast and continue in that direction to the Fall Line, where they make a right-angle turn and follow first southwesterly and then southerly directions to the sea. This remarkable change of direction in the Fall Zone is further discussed in the section on historical geology. The tributary or subsequent streams, on the other hand, show adjustment to the constitution of the rock floor, and by means of them the differences in rock character and complexity of rock structure are finding expression. The main drainage lines of the province, however, do not accord with the general trend of the highlands, which is northeast and southwest, in harmony with the strike of the rocks, and which has controlled the courses of the subsequent streams.

South of an east-west line drawn north of New Brunswick, N. J., the interstream areas are covered by a mantle of residual soil and are characterized by an absence of rock ledges. North of this line the rock is mantled by glacial drift, dropped by continental glaciers of Pleistocene time and varying in depth from 200 feet to the vanishing point. Rock ledges become an increasingly prominent feature toward the north, and valleys were developed not through stream work alone but also by means of glacial erosion and glacial deposition.

The discordance of underground structure with the level or undulating surfaces of the seaward-facing berms, the presence of residual eminences, the terraced valleys, the nonadjustment of the master streams to the rock formations, the deep rock mantle, and the absence of rock ledges all have their explanation in the history of the province, which is outlined in the section on historical geology.

TOPOGRAPHY

By F. Bascom

RELIEF

The Honeybrook and Phoenixville quadrangles lie partly in the Piedmont Lowlands and partly in the Piedmont Upland. The northwestern third of the two quadrangles, or lowland section, is conspicuously less rugged than the southern two-thirds, or upland section, but each section, one more faintly than the other, shows the features of the physiographic unit of which it is a part. These features have been described above in some detail; their specific character in the Honeybrook and Phoenixville quadrangles will now be briefly emphasized.

The maximum measure of the relief of the Honeybrook and Phoenixville quadrangles is 1,000 feet. The maximum altitude occurs in the Welsh Mountains at 1,080 feet and the minimum in the channel of the Schuylkill River at 80 feet. This relief is distributed through the successive levels of one peneplain, one incipient peneplain, and two berms with connecting slopes.

The Schooley peneplain is represented by the resistant Cambrian quartzite of Welsh Mountain (1,000 to 1,080 feet), Thomas Hill, and Barren Hills (900 to 960 feet). Two remnants are also found on the less resistant shale and sandstone of the Brunswick formation on hills in the northwest, remote from the main drainage lines.

In the vicinity of Honeybrook quartz monzonite and granodiorite maintain the Harrisburg surface at a level of 700 to 800 feet. The quartz monzonite of East Nantmeal, in the Phoenixville quadrangle, also preserves remnants of the Harrisburg surface at 600 feet. The level crests of the North Valley Hills at 600 feet are a conspicuous remnant of that incipient peneplain. The lowered crests (540 to 600 feet) of the South Valley Hills also represent the Harrisburg surface.

The Bryn Mawr berm is not a prominent level in these quadrangles, which are too remote from the sea and main drainage lines for the conspicuous development of a berm. It is, however, preserved on the less resistant rocks at 500 feet, notably terracing Allegheny and Conestoga Creeks and the headwaters of Pequea Creek.

The uplands of Chester and Schuylkill Valleys preserve at 300 feet remnants of the Brandywine erosion epoch. The Schuylkill River Valley and inner gorge represent Pleistocene and Recent erosion.

These dominant features due to erosion cycles terminated by continental movements are somewhat modified by the more or less resistant character of the underlying rocks. The Paleozoic sedimentary rocks, the pre-Cambrian crystalline rocks, and the Triassic sedimentary rocks have each their distinguishing topography.

In the south and in the west, where Paleozoic sedimentary rocks crop out with a prevailing northeast strike, the highlands and valleys all have a similar definite trend. This is shown in Welsh Mountain, Thomas Hill, Mount Pleasure, Barren Hills, North and South Valley Hills, and in Conestoga, Pequea, and Chester Valleys.

The three spurs of the Barren Hills projecting into Pequea Valley owe their development to the existence of three secondary folds that bring resistant quartzite to a higher horizon in the crests of the folds.

The central portion of the quadrangles, underlain by massive igneous rocks without definite trend, is characterized by irregular hills and valleys showing little parallelism. The more pronounced valleys in this portion are for the most part in the weaker pre-Cambrian gneiss and in general follow the strike of the gneiss.

The northern third of the district, underlain by Triassic formations, which are not folded and offer a nearly uniform resistance to erosion, exhibits an open, level topography, changing to rugged hills where underlain by conglomerate or intruded by igneous rock.

DRAINAGE

The Schuylkill River and its tributaries, Allegheny Creek, Beaver Run, Pigeon, French, Pickering, and Valley Creeks, drain almost one-half of the area. Conestoga and Pequea Creeks, tributary to the Susquehanna River, drain about one-fourth, and the remainder is drained by Crum, Ridley, Chester, and Brandywine Creeks, tributary to the Delaware River. The general course of the Schuylkill, transverse to the trend of the underlying rocks and crossing indifferently hard and soft materials, has been thought to be consequent by superposition upon Cretaceous and Tertiary sedimentary rocks that formerly extended far inland and rested upon a submerged floor—the surface of the Fall Zone peneplain. (See pp. 103–104.)

The initial declivity was not great, and the Schuylkill River established meanders, which upon the next uplift became incised. The Schuylkill has its headwaters in the anthracite regions of Schuylkill County and empties into the Delaware 100 miles to the southeast, draining an area of 1,915 square miles. From source to mouth the

Schuylkill has a fall of 800 feet, most of which is above Reading. In the 24 miles, including meanders, of its course in the Honeybrook and Phoenixville quadrangles, the river descends only 40 feet, or 1⅔ feet to a mile. The courses of the tributaries to the Schuylkill have been shaped by the slope of the valley of the main stream, modified by rock formations.

The headwaters of Crum, Ridley, and Chester Creeks drain a very small area in the southeast corner of the Phoenixville quadrangle. Valley Creek, tributary to the Schuylkill River, contests with them the watershed of the South Valley Hills; with a shorter course to base level and flowing on less resistant rock through much of its course, Valley Creek is shifting the divide slightly to the southeast. On the southwest, in Chester Valley, Valley Creek contests the divide with a stream of nearly equal strength, also known as Valley Creek, flowing southwestward into the East Branch of Brandywine Creek; the course of this stream to its base level is shorter than that of the Schuylkill tributary, but its base level is higher and the advantage is with the Schuylkill tributary.

The East and West Branches of Brandywine Creek and their tributaries drain nearly a third of the remaining area, contesting the divide with the tributaries of the Schuylkill on the northeast and of the Susquehanna on the west. They are strong streams, whose courses transverse to the strike of the formations were established in consequence of the slope of an uplifted peneplain.

The headwaters of Conestoga and Pequea Creeks drain fertile limestone valleys on the western slope of the district.

In striking discordance with the southeast courses of the streams, the most sharply defined valley, which is also the most conspicuous topographic feature of these and the adjoining quadrangles, trends southwest and northeast, parallel to the general strike of the rock formations. This is Chester Valley, a singularly narrow, straight valley, 60 miles long, confined between the North and South Valley Hills, with a drainage pattern inherited from the erosion surface now preserved only in the level summits of these hills. The valley contains no master stream but is crossed by transverse streams whose tributaries are lowering the floor of the valley but have not sunk their courses deeply. It is clear that some agency other than stream work has been operative in the production of the valley. The floor of the valley exactly conforms to the outcrop of limestone, terminating in the northeast with the disappearance of the limestone and losing its distinctive character in the southwest with the widening and change of direction of the limestone outcrop. The quartzite of the North Valley Hills and the quartzose mica schist of the South Valley Hills are relative insoluble; the imestone is soluble. The valley floor shows no terracing such as might be produced by an earlier longitudinal stream, and it carries no recent stream gravel or other alluvial deposits.

These phenomena combine to indicate that Chester Valley was not primarily developed through stream work but rather through solution and differential weathering of the rocks beneath the early erosion surface, with transportation of the dissolved limestone by underground drainage and by surface drainage tributary to strong transverse streams. That solution has nearly kept pace with stream work is indicated by the low and gentle divides within the valley. Where the limestone has been stripped of soil the karrenfels surface, characteristic of differential solution of limestone, is a marked feature. (See pl. 10, *B*.)

During the early history of erosion in this region the limestone was protected from attack by a cover of the schist, which, retreating under later erosion, has controlled the width of the valley, and, because of the steep accordant dip of limestone and schist, given rise to its notably straight boundary. Topographically Chester Valley, because of this differential erosion, belongs to the lowland division of the Piedmont province.

GEOLOGY

ROCKS OF THE PIEDMONT PROVINCE

By F. Bascom

The rocks of the Piedmont province include crystalline igneous material and metamorphosed and unmetamorphosed fragmental material, both consolidated and unconsolidated.

The most widespread formations are of sedimentary origin and include some of the earliest material known to have been laid down in the sea and some of the most recent. The first sediments that were deposited in the Atlantic epicontinental sea were sandy, clayey, and limy; later the sequence was repeated and followed by clayey and sandy sediments. Consolidation produced clayey sandstones, sandstones, limestones, and shales. Pressure, folding, and injection converted them into hard crystalline banded gneisses, with associated graphitic beds and lenses of marble, a quartzose gneiss, a marble, and a mica gneiss and schist. The older graphitic gneiss is now known in the Pennsylvania Piedmont as the Pickering gneiss (see p. 23), the associated marble as the Franklin limestone, and the later (Glenarm) series as the Setters formation, Cockeysville marble, Wissahickon formation, and Peters Creek schist. The pre-Cambrian and post-Cambrian movements that metamorphosed these sedimentary rocks were accompanied by the intrusion of bosses, sills, and dikes of molten material, which further altered the squeezed sedimentary beds and which consolidated as granite, quartz monzonite, granodiorite, quartz diorite, quartz gabbro, gabbro, pyroxenite, and peridotite.

With the beginning of Paleozoic time there were deposited successively upon these formations sandy, sandy and clayey, limy, and clayey sediments. This deposition, taking place in Cambrian and Ordovician time, extended over the major portion of the Piedmont region, if not throughout the region. The folding, faulting, and accompanying metamorphism to which they have since been subjected have converted the sandy materials into quartzite, the sandy and clayey materials into mixed quartzites, phyllites, and mica schists, the limy materials into marble and calcareous schist, and the clayey materials into slates and phyllites.

These formations, which were widespread though not continuous throughout the Piedmont belt, are respectively designated in the Pennsylvania Piedmont (*a*) the Chickies quartzite, with the basal Hellam conglomerate member, Harpers phyllite, and Antietam quartzite; (*b*) the Vintage dolomite, Kinzers formation, and Ledger dolomite; and (*c*) the Elbrook, Conococheague, Beekmantown, and Conestoga limestones. (See pl. 6.)

These sedimentary formations and the associated igneous intrusives constitute the foundation of the Piedmont province, in considerable part concealed beneath post-Paleozoic formations. They are uncovered in detached belts trending northeast and southwest. They have been folded in synclinoria and anticlinoria, made up of compressed more or less isoclinal anticlines and synclines with dominant southeast dips, have a steeply dipping southeast cleavage, and are cut by many faults, both normal and reverse.

After a period of uplift and prolonged erosion upon the central and northeastern portions of the crystalline floor there were deposited in a shallow subsiding inland basin coarse and fine ripple-marked sands, sandy muds, and muds, which are in many places sun-cracked and bear the tracks of animals or are locally rich in vegetable matter. After this deposition, which took place in Triassic time, igneous material was intruded between the beds of sediment as sills, or intersected them as dikes, or was poured out in lava flows. The consolidation and uplifting of these sediments took place without metamorphism. The uplift was accompanied by abundant normal faulting and a tilting sufficient to produce gentle west and northwest dips. These formations wherever they occur in the Piedmont province have a very uniform constitution and character and are known in Pennsylvania and New Jersey, where they underlie the Piedmont Lowlands, as the Stockton, Lockatong, and Brunswick formations. The contemporaneous igneous material occurring as sills, dikes, and lava flows is diabase and basalt. These igneous rocks resist erosion and therefore form bold ridges whose level tops are remnants of old erosion surfaces or whose summits rise as monadnocks above such surfaces. Among these eminences are the Palisades in New York and New Jersey, First and Second Watchung Mountains and Sourland Mountain in New Jersey, and Haycock Mountain, Rock Hill, Mount Monocacy, Gibraltar Hill, and many other lesser hills in Pennsylvania.

On the extreme eastern border of the Piedmont province and in scattered outlying areas near the eastern border, the crystalline floor is concealed beneath unconsolidated beds of gravel, sand, and clay, which were deposited in a marine estuary or along a former coast line during Cretaceous and early Tertiary time. These are the Patuxent and Patapsco formations of the Lower Cretaceous; the Raritan, Magothy, Matawan, and Monmouth of the Upper Cretaceous; and the Rancocas and Manasquan of the early Tertiary. Overlapping these formations and left by erosion in scattered areas are deposits of sand and gravel of varying thickness belonging to the Tertiary and Quaternary periods. They show that the eastern border of the province, while submerged beneath sea waters during a part of these periods, also received subaerial fluvial deposits. They are the Chesapeake, Bryn Mawr, Bridgeton, Brandywine, Pensauken, Sunderland, Wicomico, and Talbot formations.

ROCKS OF HONEYBROOK AND PHOENIXVILLE QUADRANGLES

PRE-CAMBRIAN ROCKS

By F. Bascom

Pre-Cambrian formations cover much of the central and southeastern portions of the Honeybrook and Phoenixville quadrangles and are a part of a complex of more or less metamorphosed sedimentary and igneous rocks, which extends from Newfoundland to Alabama and constitutes an important component of the eastern border of the continental plateau. These formations are not stratigraphically continuous throughout this belt but over large areas are concealed under Paleozoic, Triassic, Cretaceous, or Recent sedimentary deposits.

In the Honeybrook and Phoenixville quadrangles the pre-Cambrian formations and associated intrusives may be listed as follows:

Igneous rocks:
- Metadiabase.
- Quartz monzonite.
- Anorthosite.
- Granodiorite, including quartz diorite.
- Gabbro.
- Serpentine (metapyroxenite and metaperidotite).

Sedimentary formations:
- Wissahickon formation.
- Franklin limestone.
- Pickering gneiss.
- Baltimore gneiss (possibly present southeast of Chester Valley).

The distribution of these rocks is shown on plate 1.

SEDIMENTARY ROCKS

PICKERING GNEISS[19]

Distribution.—Pickering gneiss, the oldest formation known to be present in the Honeybrook and Phoenixville quadrangles, underlies a large part of the central and western portions of the area.

The Baltimore gneiss, a nongraphitic gneiss widely exposed south and east of the Phoenixville quadrangle, may occur in the southeast corner of that quadrangle, south of the Chester Valley; a small area of such gneiss, heavily injected with gabbro and of somewhat massive character, was observed south of the serpentine area in the southeast corner of the Phoenixville quadrangle but has not been separated on the map from the injecting gabbro.

Because of lack of exposure of fresh material and the great similarity of the disintegrated material the monzonitic, dioritic, and granitic gneisses bordering and injecting the Pickering gneiss cannot be easily separated from it, and the boundary lines drawn can be only approximately accurate.

Areas underlain by the Pickering gneiss are strewn with fragments of vein quartz, pegmatite, and decayed gneiss, but areas underlain by quartz monzonite or granodiorite are relatively free from rock fragments, with here and there a rounded exposure of the underlying intrusive rock. As the igneous rock is approached the Pickering gneiss becomes more massive in character. The largest area of Pickering gneiss extends eastward from Barren Hills, in the Honeybrook quadrangle, and northeastward from Lyndell, in the Phoenixville quadrangle, expanding to 3½ miles in width along the West Chester pike and continuing with approximately this width to the Triassic cover.

Two other areas extend westward from Pughtown and in the neighborhood of Loag; several small areas occur in the western part of the Honeybrook quadrangle.

[19] When the rocks of the Honeybrook and Phoenixville quadrangles were mapped the writer separated the graphitic gneisses from the nongraphitic gneisses and proposed to apply to the former the geographic name Pickering gneiss, restricting the name Baltimore gneiss to the nongraphitic rocks, and the name and definition of Pickering gneiss were published in an article by B. L. Miller (Econ. Geology, vol. 7, p. 67, 1912). In the Coatesville-West Chester folio (no. 223), published in 1932, the graphitic gneiss was included in the Baltimore gneiss and the name Pickering gneiss was discarded. Later, however, in accordance with a decision by the committee on geologic names of the United States Geological Survey, the name Pickering gneiss was restored to designate the pre-Cambrian graphitic sedimentary rocks associated with the Franklin limestone.

Character and stratigraphic relations.—The Pickering gneiss is essentially a medium-grained siliceous rock with varying constituents and with graphite more or less abundantly present in linear scales parallel to a gneissic texture.

Graphite-bearing beds are the distinctive feature of the Pickering gneiss. They are usually yellowish or reddish owing to the oxidation of the iron compounds. Although the characteristic constituents are dominantly quartz and less commonly feldspar (orthoclase and microcline), biotite, and hornblende, the beds vary so greatly in the proportions of these constituents that quartz schist, quartz-feldspar gneiss, mica schist, hornblende schist, and rarely calcareous schist make up a varying series of beds characterized by the presence of the significant and in many places abundant accessory constituent graphite. Other accessory constituents are muscovite, calcite, magnetite, pyrite, pyrrhotite, allanite, titanite, zircon, scapolite, diopside, and garnet. Metamorphic minerals are epidote and zoisite; decomposition products are hematite, limonite, chlorite, kaolin, and other clay minerals. The prevalent decomposed condition of these beds, contrasting with adjacent relatively fresh and massive granite, gabbro, and diorite gneiss, is their most persistent and distinctive feature. These beds have been the source of limonite, which was formerly mined, and red soils are a clue to the presence of the graphite-bearing gneiss. Pyrite and pyrrhotite, of which the formation contains a considerable amount, are the immediate sources of the limonite ore and one cause of the ready disintegration of the gneiss, rendered mechanically weak by the presence of graphite. The association of pyrite and pyrrhotite with graphite is presumably a causal relation; the carbonaceous material, by its reducing action on the iron sulphates, caused their precipitation as sulphides, and from these sulphides the limonite deposits were formed by oxidation and segregation. Wherever the gneiss has been exposed to the action of the atmosphere and ground water, all the constituents have been oxidized or hydrated except quartz and graphite. The feldspar, according to original composition, has become one of the clay minerals, and the iron compounds have become hematite or limonite. Open cuts in the formation, such as occur at Pettinos Bros.' mine at Uwchland, near the center of the Phoenixville quadrangle, show the brilliant residual products of the gneiss. Bright moss-green epidote layers or lenses alternate with wine-colored clay (kaolin), white clay, and an impure deep-red clay; all of the material is rich in graphite and soft enough to be cut with a pick. The mining and crushing of the graphite formation is, except in a few places, rendered much easier because of the decomposed character of the material. At the Chester mine some of the best ore—a red graphitic earth—is known as loam ore.

The Pickering gneiss has not only been closely folded by the dynamic action that recrystallized and metamorphosed the formation, but it has been fractured, and the fractured surfaces moved upon each other so that faults and slickensided surfaces are characteristic features. It has also been intruded along planes parallel or transverse to the bedding by subsilicic and silicic dikes. The larger dikes have been mapped, but there are numberless smaller irregular dikes and lens-shaped intrusions that have only local exposures and are scarcely mappable. Many of the pegmatites (persilicic dikes) are parallel to and included between the beds of the gneiss, from which they are distinguished by their coarse-grained texture; they range in width from a few inches to several feet and are composed largely of microcline and quartz.

The constituent of the Pickering gneiss which has given to that formation its economic importance is the graphite. Graphite may occur in disseminated grains or in linear scales or plates in the gneiss; it also occurs in small veins in the gneiss and in some pegmatite and dacite dikes. Graphite is not evenly disseminated throughout the formation: some beds contain little or no graphite, while other beds contain so high a percentage of the mineral that they have been profitably worked. In content of graphite the beds so worked range from 3 to 16 percent, but the average content is perhaps not more than 6 percent; in thickness they range from 5 to 100 feet. Graphite-rich beds may be sharply separated from barren beds, or there may be a gradual diminution in the amount of graphite.

A dozen quarry locations in graphitic beds are indicated on the geologic map (pl. 1) extending from Uwchland northeastward to the area where the gneiss is concealed under the Stockton formation.

The beds may be cut off by faults or by dikes, or their content of graphite diminishes, or the graphite-bearing layers are lens-shaped. For these reasons graphite-bearing beds cannot be traced for long distances. A quarter of a mile south of Eagle and Uwchland a graphite-bearing bed 75 to 100 feet thick strikes almost due east (N. 85° E.). Here a group of three mines were operated from an early date to 1920, since when operations have not been resumed. The same bed, if persistent, lies north of the Anselma mine and reappears in the mines worked by the Chester and Federal Graphite Cos. It may be that the same bed appears in the mine of the Phoenixville Graphite Co., but if so it is less rich in graphite. The graphite occurs in anhedral flakes—that is, without crystal boundaries—arranged in layers parallel to the planes of gneissic or schistose structure. Few of the individual flakes exceed one-eighth of an inch in diameter, but they may form aggregates measuring an inch or more in diameter.

The occurrence of graphite in pegmatite dikes is naturally more sporadic than the occurrence just described. Pegmatites are so abundant, however, that in almost every mine they furnish part of the yield of graphite. Like the other minerals of the pegmatite, its graphite is coarser-grained than the graphite of the gneiss and is more commonly massed in considerable aggregates and confined to the outer portions of the pegmatite. It is not impossible that carbon was an original constituent of the pegmatitic magma, but the fact that, so far as known in this region, pegmatitic graphite is confined to the pegmatites traversing graphite-bearing beds makes it appear probable that the highly heated, vapor-saturated magma, which intruded the sedimentary rocks during the period of metamorphism, picked up carbonaceous material there and precipitated it in crystalline form simultaneously with the solidification and crystallization of the other constituents of the pegmatites. The graphite of the pegmatite, although occurring in large masses, is said not to be of equal economic value with the graphite of the gneiss; it is so readily reduced to a powder that it is either lost altogether or recovered in the form of dust, the least valuable form of graphite.

The graphite that occurs in dacite dikes is also to be explained as a constituent picked up from the intruded rock. Only fragments of the dike rock were found, and therefore, it is not possible to say whether the graphite was confined to the contact.

The occurrence of graphite in veins is still more sporadic and of no economic importance in the Honeybrook and Phoenixville area. At the Chester graphite mine near Chester Springs there is a vein of pure graphite between 2 and 3 inches wide filling a joint seam. The graphite is arranged in curved folia radiating from the wall rock and assuming forms somewhat resembling pressure columns. The folia break up into flakes upon grinding with pestle and mortar. With the flake graphite in these veins there seems to be some "amorphous" graphite. The graphite of the veins is believed to represent the deposit of volatilized graphite from the sedimentary beds.

This graphite is presumably of organic origin—that is, derived from the carbonaceous remains of plant and animal life. The materials of the Pickering gneiss and the Franklin limestone accumulated in a shallow interior sea. Under these conditions plant life and lowly forms of animal life would flourish and their remains be buried with the accumulating sediments. When this region was later subjected to earth movements, the pressure, which compressed and folded the sediments, and the heat, arising from friction and igneous intrusions, changed the beds of loosely aggregated fragmental debris into hard rock composed of closely interlocking crystalline grains and at the same time converted the amorphous carbon into crystalline flakes of graphite.

Thickness, name, and correlation.—There are no means of estimating the thickness of this formation, the oldest of the sedimentary series, deeply eroded and meagerly exposed. The rocks unconformably underlie material known to be of Lower Cambrian age and are therefore pre-Cambrian. This graphite-bearing formation was early called the Pickering gneiss because Pickering Creek lies almost wholly within the gneiss area, and within the drainage basin of this creek are located most of the graphite mines and the most persistent graphite-bearing beds. (See pp. 126–127.) The Pickering gneiss is provisionally correlated with the pre-Cambrian gneiss and schist of Sussex County, N. J., which, together with gneiss of igneous origin, have previously been included under the name "Pochuck gneiss".[20]

FRANKLIN LIMESTONE

Distribution.—The Franklin limestone is found only in small isolated lenses associated in every case with the graphite-bearing beds of the Pickering gneiss. There are 11 such lenses located as follows: (1) 1 mile west of Eagle (Phoenixville quadrangle), (2) at Uwchlan (exposed in mines only), (3) in the Chester Springs graphite mines, and (4) 1 mile east of Hallman (central eastern part of Phoenixville quadrangle), (5) at Kimberton (2 miles north of Hallman), (6) 1½ miles southwest from Kimberton, (7) 1 mile south of Pughtown, (8) 1¾ miles southeast of Pughtown (central-northern part of Phoenixville quadrangle), and (9–11) 1¼, 1½, and 4½ miles west of Pughtown. About three-quarters of a mile northeast of Loag limestone may have been quarried from a pit. At the French Creek iron-ore mines Franklin limestone is the formation in large measure replaced by the iron ore, and the old shaft of the mine to the depth of 250 feet penetrates the limestone. Near the border and in the northeastern part of the Honeybrook quadrangle Franklin limestone and Pickering gneiss have been reached by the shaft of an iron-ore pit half a mile northeast of Pine Swamp School.

Character and stratigraphic relations.—The Franklin limestone is a white, coarsely crystalline limestone or marble. The crystal grains show lustrous rhombohedral cleavage surfaces, which may be striated by parallel planes of parting produced by the pressure to which the rock has been subjected. This marble is characterized, wherever it

[20] Spencer, A. C., U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (no. 161), 1908. Recently the name Pochuck gabbro gneiss has been restricted to the gabbro gneiss, and the sedimentary gneisses that formerly were included under Pochuck are now known as Pickering gneiss. Bayley, W. S., Pre-Cambrian geology and mineral resources of the Delaware Water Gap and Easton quadrangles, Pa. and N. J.: U. S. Geol. Survey Bull. — (in preparation).

occurs, by the presence of a considerable number of silicate minerals. The area of similar limestone at Franklin Furnace, in Sussex County, N. J., is famous for the variety of minerals which it contains—91 distinct species of minerals have been noted from that locality. In the Honeybrook and Phoenixville quadrangles graphite is the important accessory constituent of the marble; other accessory constituents are quartz, feldspar, pyrite, muscovite, epidote, zoisite, and penninite.

All outcrops of this limestone contain some graphite, and the occurrence at Uwchland contains a high percentage of this mineral. Here the graphite occurs in large hexagonal flakes evenly distributed throughout the rock and constituting about 20 percent of it. The flakes average one-fourth of an inch in diameter. This bed of limestone, which is not more than 10 feet thick, does not crop out at the surface but has been mined and may be seen in an open cut. Lenses or horses of limestone occur in the underground workings. No limestone crops out at the Chester Spring mines, but calcareous graphitic gneiss is found in the mines.

About the middle of the nineteenth century, when lime was extensively used as a fertilizer and hauling over long distances was an additional expense, every outcrop of limestone was quarried, and in the immediate vicinity of the quarry the stone was burned to lime for local use. With changed conditions the quarries have been abandoned, grown over or filled in with refuse, and forgotten by the present generation of farmers.

Occurrences of this character do not furnish structural details. At the outcrops 1 mile east of Hallman and 1½ miles west of Pughtown the rock strikes N. 40° E. and N. 65° E. and dips 35° and 50° SE., respectively. These dips and strikes conform in general with those of the Pickering gneiss.

Chemically the Franklin limestone is sharply separated from the Pickering gneiss, and it has been separated in the mapping. It may, however, be considered as essentially a part of that formation, like the mica schist and quartz-feldspar gneiss; in the underground workings near Uwchland it is closely united to the other members of the formation by intermediate calcareous mica schists.

It is more or less contemporaneous with the Pickering gneiss, with which it is interbedded and which it apparently overlies. Calcareous muds grading into fairly pure calcareous material accumulated adjacent to, overlying, or alternating with fine mechanical deposits. On metamorphism these deposits bcame gneiss, mica schist, calcareous schist, and marble, which make up the Pickering gneiss and the Franklin limestone.

Thickness, correlation, and name.—The thickness of the formation cannot be determined because of the nature of the outcrops. The limestone bed at the Uwchland mines is not more than 10 feet thick, and the surface outcrops show but an insignificant amount of limestone, but it is impossible to say how much has been removed by erosion. Less than 100 miles to the northeast the Franklin limestone has a considerable extension and presumably considerable thickness, and the associated gneiss is relatively unimportant. From New Jersey southwestward early pre-Cambrian calcareous deposits diminish in amount, whereas the associated gneiss increases. Neither gneiss nor limestone has been reported farther south.

The Franklin limestone of Pennsylvania and New Jersey, the Pickering gneiss of Pennsylvania, and the graphitic gneiss of New Jersey are comparable in lithology and age to the Grenville series of the Adirondacks and Canada—a complex of limestone, gneiss, and schist with intrusive igneous rocks—and have been correlated with that series.[21]

The limestone was first called Franklin by J. E. Wolff and A. H. Brooks [22] in describing the limestone of Sussex County, N. J., in the neighborhood of Franklin Furnace.

WISSAHICKON FORMATION

Distribution.—In the southeast corner of the Phoenixville quadrangle an area of some 2½ by 10 miles is underlain by schistose and gneissic rocks, which continue northeastward into the Norristown quadrangle and southward into the West Chester quadrangle and which are limited in the Phoenixville quadrangle by igneous intrusives on the southeast and Paleozoic limestone on the northwest. These gneissic and schistose rocks have been elsewhere [23] designated the Wissahickon formation, which comprises two lithologic facies—the oligoclase-mica schist on the southeast and the blue-gray albite-chlorite schist of the South Valley Hills. The steep northwest slope of the South Valley Hills and a few small and scattered abandoned quarries furnish the only exposures of these two facies in this area.

Character.—The main body of the Wissahickon formation, in the Chester quadrangle to the southeast, the oligoclase-mica schist, is a coarse-grained rock with quartz, feldspar (orthoclase and more sodic plagioclase), biotite, and muscovite as chief constituents and magnetite, pyrite, apatite, zircon, tourmaline, garnet, titanite, staurolite,

[21] U. S. Geol. Survey Geol. Atlas, Passaic folio (no. 157), p. 6, 1908; Raritan folio (no. 191), p. 5, 1910.

[22] U. S. Geol. Survey 18th Ann. Rept., pt. 2, p. 432, 1898.

[23] U. S. Geol. Survey Geol. Atlas, Coatesville-West Chester folio (no. 223), p. 4, 1932.

andalusite, sillimanite, and zoisite as accessory constituents. The occurrence of muscovite in relatively large crystals gives the rock a characteristic spangled appearance not possessed by the finer-grained smooth fissile albite-chlorite schist of the South Valley Hills. This character, the coarser crystallization, the prevalence of potash feldspar, and abundant garnets serve to distinguish it from the albite-chlorite schist.

The albite-chlorite schist is characterized by a pronounced lamination of a slaty rather than a schistose type. The fresh laminae are of a lustrous blue-gray or green-gray color, which under the action of weathering alters to a reddish yellow.

The chief constituents of the schist are muscovite, quartz, feldspar, and chlorite. Biotite (not everywhere present), magnetite, limonite, tourmaline, apatite, and pyrite are subordinate constituents. Quartz occurs in interlocking grains which show undulatory extinction and other pressure effects in their form and arrangement. Orthoclase, sporadically present, is not uniformly an important or characteristic constituent.

Intercalated with albite-free laminae are laminae 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. Albite crystals are similarly present in the contiguous Conestoga limestone in places. These facts indicate that the albite crystals 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 metamorphism in the presence of thermal solutions in Paleozoic time rather than metamorphism that was primarily dynamic in character.

These albite crystals, neither conspicuous nor important in this region, become increasingly dominant to the southwest, where they give character to this member, which has accordingly been designated the albite-chlorite schist. Chlorite is prevalent throughout the formation, associated with wavy lamellae of muscovite. Pyrite cubes, more or less altered to limonite, and cavities left by the disappearance of the pyrite are characteristic. The crystalline texture of the schist is neither so coarse nor so sharply defined as in the gneiss.

The strike of the schistosity is N. 65°–70° E. and the dip 85°–90° SE. The strike of the gneiss in the neighborhood of the schist is N. 55°–60° E. and the dip 85°–90° NW.

Analyses of two facies of the Wissahickon formation of southeastern Pennsylvania

	1	2	3	4		1	2	3	4
SiO_2	66.13	43.81	43.10	39.35	P_2O_5	0.22	0.13	....	0.49
Al_2O_3	15.11	27.52	30.86	31.92	S	.03	....	....	....
Fe_2O_3	2.52	7.30	7.28	2.19	CrO	None	....	....	....
FeO	3.19	Trace	....	9.00	MnO	.20	....	....	....
MgO	2.42	1.77	1.80	3.08	BaO	Trace	....	....	....
CaO	1.87	.19	....	....	SrO	Trace	....	....	....
Na_2O	2.71	.56	.66	1.98	Li_2O	....	....	....	....
K_2O	2.86	8.81	6.87	5.26	NiO-CaO	....	....	....	.06
$H_2O\pm$	1.79	7.52	5.91	6.05					
TiO_2	.82	3.78	3.28	1.20		99.87	101.39	99.76	100.58

1. Composite sample of mica gneiss, Philadelphia district. W. F. Hillebrand, U. S. Geol. Survey, analyst.
2. Mica schist, between Gulf Mills and Hitner marble quarry. F. A. Genth, Jr., analyst, Pennsylvania Geol. Survey Rept. C_6, p. 109.
3. Mica schist, between Gulf Mills and King of Prussia. F. A. Genth, Jr., analyst, idem.
4. Mica schist, 1,222 feet from Bird-in-Hand Tavern, on road from Gulf Mills to Bryn Mawr. F .A. Genth, analyst, idem.

These analyses show convincing evidence of a sedimentary origin in the very considerable excess of alumina over the 1:1 ratio necessary to satisfy the alkalies and lime and in the dominance of MgO over CaO and of K_2O over Na_2O. Silica is excessive in No. 1 and abnormally low in Nos. 2, 3, and 4, as would be characteristic of sedimentary rather than igneous rocks.

A comparison of the analyses of the gneiss and schist discloses certain differences in chemical constitution. They are both metamorphic derivatives of argillaceous sediments. SiO_2 is very low in the schist in contrast to the gneiss; Al_2O_3 and the iron oxides are excessive in the schist as contrasted with the gneiss—a chemical difference that might accompany the change of sedimentation from silty clay to finer, less silty clay with increasing distance from shore.

Thickness, correlation, and name.—It is impossible to determine with any degree of accuracy the thickness of either unit of such a formation as the Wissahickon, intensely folded and without recognizable recurrent beds. An aggregate thickness of some 8,000 feet has been reported exposed on the Susquehanna River.[24]

The oligoclase-mica schist, or mica gneiss, has been considered to be of pre-Cambrian age, chiefly because of the high-rank metamorphism which it has undergone and because of its intrusion and saturation by igneous rocks—granite, gabbro, pyroxenite, peridotite, and their associated differentiates—unknown in recognized Paleozoic formations and characteristic of pre-Cambrian gneisses.

The age of similar intrusives in the Maryland Piedmont, however, has recently been interpreted by Cloos and Hershey [25] to be Paleozoic

[24] Knopf, E. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pa.: U. S. Geol. Survey Bull. 799, p. 23, 1929.

[25] Cloos, Ernst, and Hershey, H. G., Structural age determination of Piedmont intrusives in Maryland: Nat. Acad. Sci. Proc., vol. 22, no. 1, pp. 71–80, January 1936.

(post-Conestogan). The method used by Clöos (the relation of intrusives to cleavage planes developed in Paleozoic formations) if extended into the southern Pennsylvania Piedmont may prove a similar age for these intrusives; hence they have little value for exact age determination. The character of the crystallization of the oligoclase-mica schist, in contrast to that of the albite-chlorite schist, may be due to saturation by thermal solutions and the age thus remain an open question.

This does not apply to the intrusives north of Chester Valley in the Honeybrook and Phoenixville quadrangles. The facts that in this area the igneous rocks are overlain by basal Lower Cambrian sediments and that these sediments contain pebbles derived from fragments of these intrusives establish their pre-Cambrian age.

The Wissahickon formation is exposed only south of Chester Valley, and nowhere is it in contact with the Pickering gneiss. Therefore its age relative to that formation is not known.

The interpretation of a part of the albite-chlorite schist facies of the Wissahickon formation as of post-Cambrian rather than pre-Cambrian age has been presented elsewhere.[26] The possibility must be recognized that the two facies of the Wissahickon formation may both be of Paleozoic age. The Wissahickon has been correlated,[27] because of similar character and associations, with the Manhattan schist of New York, the age of which is also still an open question.[28]

The Wissahickon received its name because of type exposures on Wissahickon Creek, in eastern Pennsylvania north of Philadelphia.

IGNEOUS ROCKS

In the Honeybrook and Phoenixville quadrangles there are representatives among the pre-Cambrian igneous rocks of the usual magmatic differentiation types—the silicic, subsilicic, and ultrasubsilicic. These rocks occur as deep-seated batholiths, as lenses, and as dikes in pre-Cambrian gneisses and are not found in younger formations.

The plutonic or deep-seated pre-Cambrian igneous rocks may be grouped under the quartz monzonite, granodiorite, anorthosite, gabbro, and pyroxenite-peridotite families. They represent the chemical differentiation of a common magma and form a complex that shows an intimate mingling of three distinct types and gradations between the types. Because of such gradations and intermingling of

[26] Bascom, F., and Stose, G. W., U. S. Geol. Survey Geol. Atlas, Coatesville-West Chester folio (no. 223), pp. 5–6, 1932.

[27] Bascom, F., and Miller, B. L., U. S. Geol. Survey Geol. Atlas, Elkton-Wilmington folio (no. 211), p. 5, 1920. Knopf, E. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pa.: U. S. Geol. Survey Bull. 799, pp. 70–71, 1929.

[28] Fettke, C. R., The Manhattan schist of southeastern New York State and its associated igneous rocks: New York Acad. Sci. Annals, vol. 23, pp. 245, 257, 1914.

types a perfectly accurate representation of the distribution of the members of such a complex is not possible, and the boundaries drawn have not the same significance as the lines drawn between well-defined sedimentary formations. The areas outlined represent the preponderance of one or another of the three types rather than the exclusive occurrence of a single invariable type.

Of the igneous origin of these rocks, some of which were formerly grouped with sediments, there is no reasonable doubt: chemically, mineralogically, and texturally they are ordinary plutonic rocks differing from normal igneous rocks only (and not everywhere) in the possession of a foliated texture. This texture is the combined result of the interlayering of differentiated magmas (injection gneisses) and of the layer arrangement of the mineral constituents of a single product of differentiation, and it is more common on the peripheries of the large intrusive masses and in the smaller intrusions. The central portions of the larger batholiths are usually massive, with the texture of an unaltered plutonic rock. The order of intrusion of the igneous material is not plainly indicated in these quadrangles. In the adjacent quadrangles to the east and southeast (Chester) the succession is distinctly gabbro, serpentine, and granite. In this area the succession is interpreted as gabbro with associated pyroxenite and peridotite differentiates, granodiorite, including quartz diorite, and quartz monzonite with the associated crystal-aggregate differentiate, anorthosite, and finally diabase, penetrating as dikes pre-Cambrian formations exclusively.

Similar plutonic intrusives are found associated with pre-Cambrian gneisses throughout the Atlantic belt. They form an important part of the pre-Cambrian complex of the Adirondacks, and they appear in the Highlands of New Jersey, where they have been described under the names Byram gneiss (granite), Losee gneiss (diorite), and Pochuck gneiss (gabbro).[29] The Cranberry granite and Roan gneiss of Tennessee and North Carolina are assigned to the pre-Cambrian period of intrusion but possibly include material of later age.[30] In Maryland a study of the inclusions has suggested a Paleozoic age for similar intrusives.[31]

SERPENTINE, METAPYROXENITE, AND METAPERIDOTITE

Distribution.—The ultrasubsilicic serpentine, metapyroxenite, and metaperidotite, representing extreme products of differentiation, occur chiefly in relatively small dikelike lenses included as xenoliths in

[29] U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (no. 161), pp. 4, 5, 1908.
[30] Idem, Cranberry folio (no. 90), pp. 2, 3, 1903.
[31] Cloos, Ernst, and Hershey, H. G., op. cit.

pre-Cambrian formations. There are some 16 such occurrences in the Honeybrook and Phoenixville quadrangles. Eight outcrops in the Honeybrook quadrangle are located 1¼ miles south of Cambridge, 1½ miles, 1¾ miles, and 3 miles southwest of Cambridge, 2 miles northwest of Cambridge, 1½ miles northeast of Cambridge, and 1 mile southwest and 1¼ miles northeast of Loag. The first five of these are associated with gabbroic material; the rest are lenticular xenoliths in silicic crystalline rocks.

The outcrops in the Phoenixville quadrangle are located at Milford Mills, near the western border of the quadrangle, half a mile and 1½ miles northeast of Milford Mills, a quarter of a mile northeast of Lionville station on the Philadelphia & Reading Railroad, at Hallman station, 1 mile west of Hallman station, 1¼ miles southeast and 1½ miles south of Wilson's Corners. A larger area is located 1½ miles south and southwest of Malvern, on the southeastern border of the quadrangle.

In general these lenses extend in a northeasterly or easterly direction and are usually but not invariably associated with gabbro. The pyroxenite and peridotite associated with gabbro are presumably crystal differentiates of gabbroic magma. Those included in the silicic rocks are interpreted as xenolithic inclusions brought into their present position by rising currents or caught in the flowage of a magma intruding gabbro. That they are not true dikes is inferred from their inconsistently coarse crystallization, the absence of reaction zones, and the improbability of the injection of an ultrafemic crystal differentiate in a liquid condition in view of the question whether such differentiations were ever completely liquid.

It has been suggested [32] that an ultrasubsilicic magma may be so thoroughly hydrated that it becomes a serpentine magma, which may intrude solid formations and, because of its water-saturated condition, solidify as a coarsely crystalline serpentine rock.

The serpentinized peridotites of these quadrangles, however, with serpentine as a secondary product only and in some occurrences not extensively developed, must have been brought to their present position as a crystal aggregate rather than as a fluid magma—a crystal mush, perhaps, included upon consolidation of the enclosing formation rather than intruding it. Thus the presence of a plutonic igneous rock in an outcrop that has a width of a few feet and a length of a few hundred feet might find an explanation.

Character.—These intrusives fall into two groups—the olivine-free, or pyroxenite, and the olivine bearing, or peridotite. Representa-

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[32] Hess, H. H., Ultramafic magmas [read before section of Volcanology, Am. Geophys. Union, Apr. 28, 1937].

tives of the pyroxenite group are found exclusively in the Honeybrook quadrangle. It is questionable whether some of these rocks did not originally contain more or less olivine, now represented only by the serpentine and linear magnetite. The peridotite group includes the occurrences of the Phoenixville quadrangle and the rock outcropping 1½ miles southwest of Cambridge in the Honeybrook quadrangle. Neither pyroxenite nor peridotite occurs in these quadrangles unaltered. The occurrences differ only in the degree of alteration, which reached its consummation in the production of serpentine rock.

The metapyroxenite is a medium- to coarse-grained rock with considerable variation in color and texture. The exposures do not usually show any of the original pyroxenic constituents, which are completely replaced by some member of the amphibole group. The amphibole may be anthophyllite, tremolite, actinolite, or green hornblende. Talc, chlorite, epidote, and calcite are other secondary constituents and biotite (or vermiculite) and magnetite are usual accessory constituents. With further metamorphism the rock was completely serpentinized. Those metapyroxenites that are characterized by tremolite (1½ miles and 1¾ miles southwest of Cambridge) are dark green and massive, with lustrous broad blades of the amphibole constituent, with or without poikilitic texture; those which are more completely serpentinized (1 mile southwest of Loag and 2 miles northwest of Cambridge) are dark blue green and thoroughly massive, with scattered brilliant blades of talc or of some lustrous amphibole.

The metaperidotite is a coarse-grained dark-colored massive rock showing lustrous blades of actinolite or hornblende with an irregularly pitted weathered surface. The constituents are hypersthene or diopside and actinolite, making up 50 to 75 percent of the rock, and olivine, serpentine, talc, and magnetite. This is not an abundant type. Alteration has usually culminated in the production of serpentine, which is characterized by dominantly green or greenish colors, notably low hardness, uniform texture, and a dull surface with lustrous slickensides and is a readily recognized rock.

The distinctive low hill or ridge form of the serpentine outcrops is evidence of the chemical stability of the rock, and the sterility of these hills and ridges demonstrates the highly magnesian character of the thin soil covering. The most extended exposure of serpentine lies south and southwest of Malvern, bordering the gabbro in the southwest corner of the Phoenixville quadrangle.

Analyses and norms of pyroxenite and peridotite from the Piedmont province

Analyses				Norms			
	1	2	3		1	2	3
SiO_2	53.21	48.62	43.87	Quartz	----	----	----
Al_2O_3	1.94	2.66	1.64	Orthoclase	0.56	0.56	----
Fe_2O_3	1.44	6.73	8.94	Albite	1.05	1.57	4.19
FeO	7.92	6.88	2.60	Anorthite	4.45	6.12	2.22
MgO	20.78	19.44	27.32	Diopside	48.24	32.17	22.46
CaO	13.12	10.29	6.29	Hypersthene	41.95	39.82	33.90
Na_2O	.11	.20	.50	Olivine	.31	----	16.80
K_2O	.07	.06	----	Magnetite	2.09	9.74	8.35
H_2O+	.87	3.28	7.64	Ilmenite	.46	1.06	.15
H_2O-	.14	.25	1.08	Hematite	----	----	3.20
TiO_2	.26	.57	.12	Apatite	----	1.68	----
ZrO_2	----	None	----	Chromite	----	.67	.67
CO_2	.10	Trace	----	Pyrite	.03	----	----
P_2O_5	----	.75	Trace	Water	1.01	3.53	8.72
FeS_2	.03	----	----	Miscellaneous	.36	----	----
S	----	None	----				
Cr_2O_3	.20	.46	.44		100.51	100.58	100.66
V_2O_3	.03	----	----		V.	(IV)V.	"V.(I)2_2.
NiO	.03	.05	----		I.$_1$ 2."2	(I)$_2$.$_1$2."2	(I)2.I
MnO	.22	.19	.19				
BaO	----	None					
	100.47	100.43	100.63				

1. Websterite, Oakwood, Cecil County, Md. W. F. Hillebrand, analyst. Williams, G. H., Am. Geologist, vol. 6, pp. 35–49, 1890. Leonard, A. G., Basic rocks of northeastern Maryland: Idem, vol. 28, pp. 146, 151, 152–159, 1901. An unaltered pyroxenite from the southeastern Piedmont; essential constituents hypersthene and diallage.
2. Pyroxenite, one-third mile south of Honeybrook, Chester County, Pa. W. T. Schaller, analyst. An altered pyroxenite from the Honeybrook quadrangle; chief constituents tremolite and serpentine.
3. Peridotite, Johnny-Cake Road, Md. T. M. Chatard, analyst. A serpentinized peridotite from the southern Piedmont; essential constituents olivine, bronzite, and diallage.

According to the quantitative classification of igneous rocks, the two pyroxenites belong to the same class, section, rang, and subrang, varying only in the order. No. 1 falls in order I and no. 2 is transitional between orders I and II. The rocks are therefore perfemic, perpolic (websterite type), or dopolic (pyroxenic type), perpyric, domiric, and domagnesic. This means that they are rich in femic constituents, and of these constituents the femic silicates are the dominant ones; that of these silicates the pyroxenes are extremely dominant; that magnesia and ferrous iron exceed in amount the femic lime; and that magnesia is dominant over the ferrous iron. The websterite in mineralogy and texture is a granocecilose. The other pyroxenite may be called a granochesterose.[33]

The peridotite differs only in section and subrang from no. 2; it is also perfemic, dopolic, and domiric, but dopyric and permagnesic—that is, pyroxene is dominant but not extreme and the magnesia content, slightly higher than in the pyroxenites, is sufficient for the crystallization of olivine.

GABBRO

Distribution.—Gabbro, norite, and quartz norite, are found in the Honeybrook and Phoenixville quadrangles in many areas of small extent and are mapped as gabbro. There are 23 such areas, exclusive of the dikes. In the southeast corner of the Phoenixville quadrangle, south of Chester Valley and the South Valley Hills, there is an area

[33] It is suggested that the name chesterose be given to the subrang of which this type is at present the only representative. The name is taken from the county which contains this and many other outcrops of pyroxenite of an apparently similar character.

of gabbro which is part of a large mass extending into the Norristown and West Chester quadrangles. This intrusive may not be of the same age as the gabbro north of Chester Valley. The other areas lie north of Chester Valley and the North Valley Hills, and here the gabbro appears to have intrusive relations with the Pickering gneiss and to be intruded by the granodiorite. The greater diameter of all areas trends east and west.

Character.—The gabbro, medium-grained and everywhere highly altered, ranges in color from a medium-gray rock, which can scarcely be distinguished in the hand specimen from diorite, to a dark-green rock, which is characterized by an abundance of green hornblende. Intermediate types are of a brown color, and all types weather to rusty-brown spheroidal boulders.

The subsilicic rock in the southeast corner of the Phoenixville quadrangle and that on the eastern border south of Williams Corner is a hypersthene gabbro or norite and locally contains quartz in sufficient quantities to place it among the quartz norites. The chief constituents of these norites are hypersthene, feldspar, and, in some specimens, quartz. The feldspar is an andesine-labradorite. Accessory constituents are apatite, zircon, and ilmenite. The secondary constituents are chlorite, zoisite, and leucoxene. The chlorite with some magnetite forms reactionary rims about the hypersthene. The light-colored constituents (quartz and feldspar) range in amount from 40 to 55 percent and the dark-colored constituents range from 45 to 60 percent. The texture is subhedral, granular, slightly modified by a foliated texture.

Typical gabbro contains less quartz than the norite, and augite takes the place of part or all of the hypersthene. Secondary hornblende is associated with the augite, and in some specimens the augite has completely disappeared through alteration to hornblende. Biotite is also a constituent of the gabbro. The feldspar is a variety of labradorite, usually the more calcic labradorite-bytownite (Ab_1An_3), and is in large part altered to zoisite or epidote. As in the norites, the accessory minerals are apatite, zircon, and ilmenite, and in addition titanite, pyrite, and garnet.

In the gabbro of the southwestern part of the Honeybrook quadrangle the essential constituents have been replaced by alteration products—the pyroxene by hornblende, which in turn may be altered to chlorite; the feldspars by zoisite and epidote. This alteration is associated with and productive of a foliated texture. The fresh material has a subhedral granular texture, with inequigranular, equant crystals.

The gabbro injects the Pickering gneiss, as can be seen in the Phoenixville quadrangle, and is thoroughly injected by the granodiorite, which contains large lenticular inclusions of altered gabbro striking with the foliation of the granodiorite. These xenoliths are a conspicuous feature of the granodiorite.

Analyses and norms of gabbro from the Piedmont province

Analyses	1	2	Norms	1	2
SiO_2	54.03	49.67	Quartz	4.63	2.70
Al_2O_3	16.71	18.19	Orthoclase	3.89	2.22
Fe_2O_3	1.37	.33	Albite	25.15	23.06
FeO	7.70	12.84	Anorthite	30.30	36.14
MgO	5.66	2.12	Diopside	10.44	7.44
CaO	8.84	9.70	Hypersthene	20.50	21.40
Na_2O	2.99	2.74	Apatite	.34	1.34
K_2O	.67	.34	Ilmenite	1.67	3.80
H_2O+	.53	.74	Magnetite	2.09	.46
H_2O-	.14	.15	Pyrite	.18	.60
TiO_2	.84	2.01	Water	.67	.89
ZrO_2		Trace	CO	.40	
CO_2	.40	None			
P_2O_5	.13	.58		100.26	100.05
S	.09	.32		II(III).	II(III).
MnO	.13	.37		"5."4.4(5).	5.4."5.
BaO	Trace	Trace			
	100.23	100.10			

1. Neighborhood of Radnor, Norristown quadrangle. W. F. Hillebrand, analyst.
2. 1 mile northeast of Fontaine, Honeybrook quadrangle. W. T. Schaller, analyst.

The gabbro is a normal type, closely resembling the gabbro of the Norristown quadrangle (from the neighborhood of Radnor and Bryn Mawr, Pa.), and poorer in quartz and richer in feldspar than the gabbro of the Elkton-Wilmington district, to the southwest.

The rock is dosalic transitional to salfemane, perfelic, docalcic, and persodic approaching the dosodic. This means that quartz and feldspar are dominant, with feldspar preponderating; feldspathic lime is considerably greater in amount than the sum of the alkalies, and of the alkalies soda is extremely dominant. Augite is a critical mineral and with the textural prefix the name of the rock becomes augitic granohessose.

GRANODIORITE

Distribution.—Granodiorite, an intrusive igneous rock intermediate between quartz monzonite, by which it is intruded, and quartz gabbro (including gabbro), which it intrudes, is intermediate also in distribution. It has a greater extent than the gabbro and a smaller extent than the quartz monzonite. The larger area of granodiorite is in the Phoenixville quadrangle south of Pickering Valley and north of Chester Valley. At Devault a fault brings the granodiorite to the margin of Chester Valley; elsewhere it is separated from the valley by the Cambrian quartzites forming the North Valley Hills.

The Paleozoic sedimentary rocks rest upon the granodiorite. With the Pickering gneiss on the north the granodiorite has intrusive relations. At Lyndell a drill hole penetrated granodiorite between depths of 1,000 and 1,330 feet below the surface. West of Wilson's Corner gabbro surrounds an area of granodiorite, and south of Mar-

A. THOMAS HILL VIEWED FROM THE EAST.
Shows northward dip slope of Chickies quartzite and steep back slope.

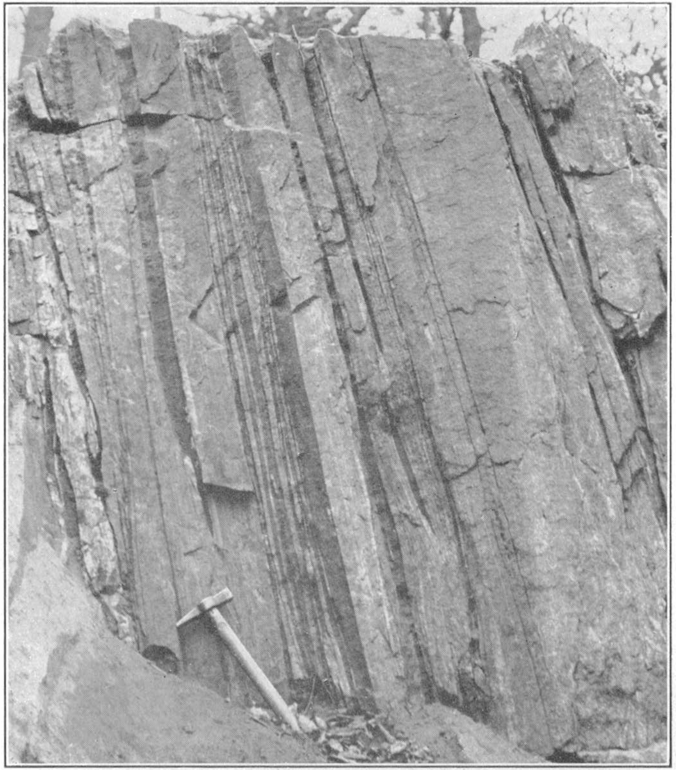
B. LAMELLAR INJECTION OF GABBRO BY GRANITIC MATERIAL.
Road cut on east side of West Branch of Brandywine Creek, half a mile north of Coatesville.

A. INJECTION OF LAMINATED GABBRO BY GRANODIORITE AND PEGMATITE.

One-third of a mile north of Siousca, east side of West Branch of Brandywine Creek.

B. NEAR VIEW OF EXPOSURE SHOWN IN *A*.

Illustrates details of the injection of the gabbro by the granodiorite and pegmatite.



A. INJECTION OF LAMINATED GABBRO BY GRANODIORITE AND PEGMATITE, FORMING AN INJECTION GNEISS.

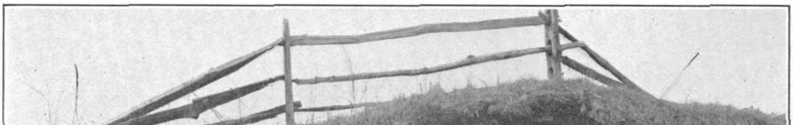
One-third of a mile north of Siousca, east side of West Branch of Brandywine Creek. Photograph by E. H. Watson.

B. LENTICULAR XENOLITH OF GABBRO INCLUDED IN GRANODIORITE.

One-third of a mile southeast of Wagontown. Photograph by E. H. Watson,

A. IRREGULAR GABBRO XENOLITH IN GRANODIORITE.

Road cut one-third of a mile southeast of Wagontown. Photograph by E. H. Watson.



B. GABBRO-GRANODIORITE-PEGMATITE INJECTION GNEISS.

Shows creep at surface. One-fourth of a mile south of Wagontown. Photograph by E. H. Watson.

tin's Corner, in the Honeybrook quadrangle, gabbro encloses an area of granodiorite and is deeply injected on the east and south by the granodiorite. Such an injection is finely exposed on the east side of the West Branch of Brandywine Creek one-third of a mile northwest of Siousca. The exposure is strongly layered, owing to the injection of laminated or foliated gabbro by granodiorite, which is in turn injected by light-colored pegmatite. (See pls. 2, *B*, 3, *A*, *B*, and 4, *A*, *B*.) This relationship of gabbro and granodiorite is also shown in a cut on the Wagontown-Siousca Road about a third of a mile southeast of Wagontown (pl. 5, *A*) and in a cut on the west side of the road south from Wagontown (pl. 5, *B*). In this exposure the formation exhibits strong creep. In all these localities the granodiorite has become a composite gneiss by injection (gabbro, syntectite of gabbro and granodiorite, granodiorite, and pegmatite) and flowage.

East of the East Branch of Brandywine Creek the granodiorite is a quartz-andesine rock with numerous syntectic xenoliths, such as that south of Dorlan, composed chiefly of quartz, chlorite, epidote, hornblende, and magnetite, and with large xenoliths of less altered gabbro to the east and northeast.

The granodiorite that underlies the Cambrian formations northwest of Chester Valley is more or less injected with pegmatite, as is indicated by the fragments in the field. These are chiefly quartzitic pegmatite and quartz, showing the blue color that characterizes the quartz pebbles of the conglomeratic member of the Chickies quartzite. If these pegmatites are the source of the pebbles of the Cambrian conglomerate, the pegmatitization must represent pre-Cambrian activity.

Similar pegmatitic material shows at the entrance to the Pennsylvania Railroad cut southeast of Christiania, on the northwest border of the Coatesville quadrangle.

The blue quartz is everywhere associated with the gabbro injected by the granodiorite.

Character.—The granodiorite is a medium-grained quartz-feldspar-mica rock, usually light-colored owing to the paucity of ferromagnesian constituents, and pinkish or greenish in tone owing to abundant altered feldspar. The rock is invariably gneissic, but in the absence of contrasting constituents—that is, where not injecting gabbro or injected by pegmatite or both—this texture is not conspicuous. The feldspar is orthoclase and a sodic plagioclase that is albite or andesine. It is commonly almost completely altered to zoisite and epidote or to sericite and kaolin; muscovite is also a secondary product of the feldspar; the biotite is chloritized. Accessory minerals are magnetite, ilmenite (showing alteration to leucoxene), rounded apatite, garnet, titanite (abundant), zircon, and pyrite.

The texture is anhedral with a more or less parallel arrangement of the minerals, which exhibit the granulation that is evidence of crushing. Granodiorite, with quartz diorite facies, differs from quartz monzonite in the decrease in orthoclase, in the absence of microperthite and microcline, and in the increased calcic character of the plagioclase, which is chiefly andesine, or less commonly oligoclase-andesine or andesine-labradorite. The plagioclase is usually saussuritized, and an increase in saussuritization accompanies an increase in lime. The feldspar ranges roughly from 40 to 60 percent and quartz from 5 to 15 percent.

Hornblende (frequently a blue hornblende) is the most abundant of the ferromagnesian constituents and is in some specimens obviously, and in all specimens presumably, secondary to pyroxene. The pyroxene is either a pale-green augite, a bright-green aegirite, or hypersthene. Biotite is associated scantily with the hornblende or pyroxene. The ferromagnesian minerals range from 10 percent to approximately 55 percent.

The texture is that common to rocks that have crystallized slowly and uninterruptedly—the subhedral granular. An inconspicuous foliated texture has been produced since the solidification of the rock by subsequent pressure, which has brought about a partial reorientation of the mineral constituents in layers. This rearrangement has chiefly affected the hornblende and biotite.

Separation of granodiorite and quartz monzonite in the field is difficult. The texture and constituents are the same, with the dominance in granodiorite of the soda-lime feldspars. Granodiorite is slightly darker than quartz monzonite, owing not so much to a larger amount of the sodic plagioclase as to a slightly finer grain and the more even distribution of the femic constituents.

Analyses and norms of granodiorite from Phoenixville quadrangle

Analyses			Norms		
	1	2		1	2
SiO_2	69.10	64.26	Quartz	27.30	24.00
Al_2O_3	15.05	15.88	Orthoclase	5.56	4.45
Fe_2O_3	.74	2.74	Albite	41.39	28.82
FeO	2.81	1.44	Anorthite	12.51	25.85
MgO	1.63	2.80	Corundum	1.43	----
CaO	2.86	7.44	Diopside	----	7.99
Na_2O	4.92	3.43	Hypersthene	8.32	----
K_2O	.89	.77	Magnesium silicate	----	3.30
H_2O+	1.76	.50	Apatite	.67	.34
H_2O-	.07	.15	Magnetite	1.16	3.25
TiO_2	.26	.45	Ilmenite	.46	.91
ZrO_2	Trace	.02	Hematite	----	.48
CO_2	Trace	----	Pyrite	.12	----
P_2O_5	.24	.16	Water	1.83	.65
S	.08	Trace	Miscellaneous	.02	.04
MnO	.12	.02			
BaO	.02	None		100.77	100.08
				I (II). "4.2".(4)5.	"II .4.3(4).4(5).
	100.55	100.06			

1. Granodiorite 3 miles east of Aldham station. W. T. Schaller, analyst.
2. Granodiorite half a mile northeast of Devault. R. C. Wells, analyst.

The analyses and the norms calculated from them indicate a plagioclase which conforms to the mineral composition indicated by optical tests—andesine and andesine-labradorite—and also show the close approach of the rock to the gabbroitic type. No. 2, which most closely approaches the gabbro, is a typical quartz diorite in appearance, notwithstanding the presence of a somewhat calcic andesine. The rock has been termed a granodiorite in the general description because of the presence of orthoclase in varying amount.

The rock symbols indicating class, order, rang, and subrang show that the rock has crystallized from a transitional magma. The type at Aldham (no. 1) is persalic transitional to dosalic—that is, quartz and feldspar are unmistakably dominant. It is quardofelic approaching the quarfelic—that is, feldspar is dominant over quartz. It is intermediate between the domalkalic and the alkalicalcic—that is, the alkalies dominate. It is persodic transitional to the dosodic—that is, soda is obviously the dominant alkali. Biotite is present as an occasional constituent but in such insignificant amount that the mode may be considered normative; the texture is megascopically subhedral granular. The rock name is therefore granolassenose-mariposose.

The type at Devault (no. 2) is dosalic approaching the persalic, quardofelic, alkalicalcic transitional to domalkalic, and dosodic transitional to persodic—that is, quartz and feldspar are dominant constituents, and of these constituents feldspar is dominant; the sum of the alkalies is not notably unequal to the feldspathic lime, and of the alkalies soda is dominant. Augite is the only original femic mineral in the mode and, though usually altered to hornblende, deserves mention as a critical mineral. The texture is that usual to deep-seated rocks.

The granodiorite has been called gneiss by the State Surveys of Pennsylvania and New Jersey and has not been distinguished from gneisses such as the Pickering and Baltimore, which have been held to be highly injected and metamorphosed sediments. The quartz monzonite and granodiorite belong to the class of igneous rocks that are commonly but inaccurately known as granites: they are intermediate between granite and quartz diorite. The dominant feldspar in the true granite is a potash feldspar, orthoclase or microcline; the dominant feldspar in the quartz diorite is a soda-lime feldspar, oligoclase or andesine. Quartz monzonite contains about equal amounts of potash feldspar and of soda-lime feldspar, not exceeding the ratio of 5 to 3. Perthite is likely to be a characteristic constituent of the quartz monzonite type.

Granodiorite also contains both potash and soda-lime feldspar, in a proportion, however, that does not exceed 3 to 5. The norms calculated from the analyses of this rock show a ratio between the potash and soda-lime feldspar which falls below that required for a granodiorite, and the rock should therefore technically be designated quartz diorite. The formation as a whole, however, shows a larger percentage of orthoclase than is indicated by these analyses and is therefore designated granodiorite. It is possible that it constitutes a portion of the formation in the adjoining quadrangles to the east, southeast, and south described under the designation Baltimore gneiss, a designation not supported by continuity of outcrop with the Baltimore gneiss of Maryland, which has been considered to be of sedimentary origin.[34]

ANORTHOSITE

Anorthosite is one of the four representatives of the gabbro family present in the Honeybrook and Phoenixville quadrangles. Gabbro and the associated quartz norite and norite are considered the oldest genuine intrusives and as such have been discussed above. The description of the anorthosite is introduced at this point because of its inferred origin, age, and relations to the quartz monzonite.

Distribution.—The anorthosite is found in an oval area, about 6 miles long and 3⅓ miles wide, in the central-eastern part of the Honeybrook quadrangle. This mass is a typical representative of the domical class of anorthosite occurrences, with more than 80 percent of labradorite having a composition between Ab_1An_1 and Ab_1An_2. It is penetrated by subsilicic dikes and by a pegmatite, but it is markedly a unit without interlayering of subsilicic material.

Character.—The anorthosite is a medium- to coarse-grained rock, exceedingly tough and usually of a prevailing blue-gray color. This color, which is a characteristic feature of the rock, varies from a delicate light blue gray, passing into white on the joint seams, to a very dark blue gray. Greenish-white and pink or purplish-gray tints occur but are less characteristic colors for the anorthosite. The rock weathers into large spheroidal boulders with smooth surfaces unlike the rough, pitted, weathered surface of rocks containing ferromagnesian constituents.

The feldspar that constitutes from 65 to 100 percent of the rock is dominantly a plagioclase, ranging from andesine-labradorite to bytownite-anorthite, and in small part an orthoclase. The plagioclase feldspar shows a prevailing alteration to zoisite, which in aggregates of microscopic individuals constitutes in some places the bulk of the rock and is the source of the blue color. Associated with zoisite in subordinate amount are clinozoisite, epidote, kaolin, and sericite. Colorless augite, partly or completely altered to hornblende and actinolite, occurs in amounts reaching 35 percent but is not everywhere present. The highest percentage is found only on the periphery of the anorthosite mass. The main body of the rock is almost free from augite or hornblende. The hornblende, in turn, is altered to epidote, associated with actinolite, calcite, and magnetite.

[34] Knopf, E. B., and Jonas, A. I., Maryland Geol. Survey, Baltimore County, Geology of the crystalline rocks, p. 150, 1929.

The accessory minerals are quartz, apatite, titanite, magnetite, ilmenite, and very rarely garnet.

Chlorite, biotite, and leucoxene are further decomposition products of the peripheral ferromagnesian constituents. The texture is subhedral, inequigranular, inequant, and diverse.

Analysis and norm of anorthosite half a mile west of Forest, Pa.

[W. T. Schaller, analyst]

Analysis		Norm	
SiO_2	52.86	Quartz	0.54
Al_2O_3	26.68	Orthoclase	5.56
Fe_2O_3	1.03	Albite	37.73
FeO	.74	Anorthite	50.04
MgO	.38	Diopside	1.94
CaO	10.93	Hypersthene	.23
Na_2O	4.44	Magnetite	1.39
K_2O	.92	Ilmenite	.46
H_2O-	.11	Apatite	.67
H_2O+	1.49	Water	1.60
TiO_2	.25	S	.05
ZrO_2	Trace	MnO	.02
CO_2	Trace	BaO	.03
P_2O_5	.33		
S	.05		100.26
MnO	.02		I.5.″4. (4) 5.
BaO	.03		
	100.26		

This rock falls into the class, order, rang, and subrang that contain the labradorite-rich rocks, the anorthosites, and among them the anorthosite mass of the Adirondacks. Like these anorthosites, it is extremely rich in feldspar and quartz (persalic), in comparison with the femic (dark-colored) constituents and extremely rich in feldspar (perfelic) as compared to quartz. The anorthite molecule dominates over the alkali molecules in the feldspars (docalcic), and the albite molecule over the orthoclase molecule (persodic). The name of the subrang is labradorose; with a normal granitic texture and without abnormative primary constituents the rock is a granolabradorose.

The anorthosite is surrounded, save on the southeast, where Cambrian quartzite is faulted against it, by quartz monzonite, which is both finer-grained and more silicic than the anorthosite and unlike it in color. There is no change in the grain of the anorthosite in the neighborhood of the quartz monzonite, and no evidence of intrusive relations on the part of the anorthosite mass.

The quartz monzonite is not intruded by gabbro, of which it is supposedly a crystal differentiate. The quartz monzonite, granodiorite, quartz diorite, anorthosite, and gabbro are manifestly differentiates of a single magma.

An isolated and insignificant outcrop of anorthosite south of the road at the French Creek Dam may be indicated by one or two boulders at this locality.

The coarse-grained, nonprotoclastic texture, the essentially monomineralic composition of the anorthosite, the nonoccurrence of dikes or flows of similar composition, and the absence of evidence of intrusive relations to any igneous body all point to an origin of the anorthosite due to the gravitative separation of the femic constituents of a crystallizing gabbroic magma, leaving the plagioclase crystals in suspension, submerged and surrounded by a residual magma of granitic composition.[35]

The anorthosite is penetrated by several pre-Triassic diabase dikes and a smaller number of pegmatitic dikes.

QUARTZ MONZONITE

Distribution.—The quartz monzonite of the Honeybrook and Phoenixville quadrangles occupies the larger part of the central area of pre-Cambrian crystalline rocks overlain on the south and west by Paleozoic rocks and on the north and east by Paleozoic and Triassic sedimentary beds. The quartz monzonite area is in part bounded by and also contains inclusions of the Pickering gneiss; it is injected by dikes of pegmatite and diabase, both Triassic and pre-Triassic; it surrounds an anorthosite boss (6 by 3¼ miles) save on the south, where a thrust fault brings quartzite against the anorthosite border. There are several outlying masses of quartz monzonite. Two of considerable extent occur east and northeast of Honeybrook and are intrusions in the granodiorite. Two occur as intrusions in the Pickering gneiss west of Pughtown and east of Matthews, in the Phoenixville quadrangle. There are also some lenticular areas between the granodiorite and Pickering gneiss and possibly two north of the Cambrian quartzite ridge in the granodiorite; these must also be intrusions.

Character.—The quartz monzonite is medium-grained and, when fresh, of a medium dark-gray color; when weathered it is of a lighter yellowish-gray color, mottled by the abundant dark-colored constituents. Though for the most part massive, the quartz monzonite may possess a foliated texture very similar to that of the Pickering gneiss, from which it is distinguished by a larger percentage of the darker-colored minerals and a more uniform distribution of constituents.

Feldspar, quartz, pyroxene, amphibole, and biotite can be seen in the hand specimen. The feldspar, which averages about 55 percent of the rock, with a range from 45 to 85 percent, is represented by the species orthoclase, microperthite, microcline, and, in some specimens less abundantly, in others in equal amounts, by albite, oligoclase, or andesine. Microperthite, an intergrowth of orthoclase and albite or oligoclase, is very characteristic of the monzonite and is the most

[35] Bowen, N. L., The problem of the anorthosites: Jour. Geology, vol. 25, no. 3, pp. 209–243, April–May 1917. Smith, I. F., Genesis of anorthosites of the Piedmont of Pennsylvania: Pan-Am. Geologist, vol. 38, pp. 29–50, August 1922.

abundant feldspar. The feldspar is fresher than the feldspar of the subsilicic types, and where altered the decomposition products are kaolin, sericite, albite, muscovite, and zoisite.

The percentage of quartz is in places remarkably low; the range is approximately from 5 to 45 percent. The ferromagnesian constituent is more commonly augite, but it may be diopside, aegirite, biotite, or hornblende (secondary), and it ranges from 5 to 40 percent of the rock. The pyroxene is altered to hornblende and chlorite and the biotite to chlorite.

Accessory minerals are magnetite, ilmenite, zircon, apatite, pyrite, rutile, and garnet. The texture is subhedral, with an inequigranular fabric and inequant tabular and diverse grains. The quartz monzonite rarely grades locally into a more silicic type, the granite. An example of this gradation occurs half a mile northwest of Wallace.

Analyses and norms of quartz monzonite

[R. C. Wells, analyst]

Analyses			Norms		
	1	2		1	2
SiO_2	77.33	64.64	Quartz	37.98	8.70
Al_2O_3	11.47	15.92	Orthoclase	27.80	36.14
Fe_2O_3	1.47	1.14	Albite	30.39	37.20
FeO	.27	4.65	Anorthite	1.11	5.56
MgO	.03	.23	Diopside		4.40
CaO	.19	2.12	Hypersthene		5.15
Na_2O	3.59	4.38	Magnetite	.23	1.62
K_2O	4.65	6.06	Ilmenite	.30	.76
H_2O-	.18	.04	Hematite	1.28	
H_2O+	.52	.43	Pyrite		.12
TiO_2	.17	.42	Miscellaneous	.07	.13
ZrO_2	Trace	Trace	Water	.70	.47
P_2O_5	Trace	Trace			
S	Trace	.06		99.87	100.25
MnO	Trace	.03		I. 3(4). 1. 3	I (II). (4)5. (1)2.3
BaO	.04	.10			
	99.91	100.22			

1. Left bank of East Branch of Brandywine Creek, 2½ miles north of Downingtown.
2. South of Ludwigs Corners, north slope of Black Horse Hill, Phoenixville quadrangle.

In the terms of the quantitative system of rock classification this rock crystallized from a persalic magma transitional to the dosalic—that is, the rock is rich in quartz and feldspar, which are dominant constituents. The rock also represents a magma transitional between the quardofelic and perfelic—that is, feldspar in relation to quartz is extremely dominant but close to the border line of simple dominance. The magma is also transitional in the relation of the alkalies to the feldspathic lime—that is, the alkalies are dominant (domalkalic), approaching extreme dominance (peralkalic). The magma is sodipotassic—that is, the alkalies are present in nearly equal amounts. It is this magmatic characteristic in connection with the persalic character that makes the resulting rock a quartz monzonite, a rock type possessing about equal amounts of potash and soda feldspars.

The rock symbols indicating class, order, rang, and subrang are given in the table. The subrangs are yellowstonose (1) and pulaskose (2); the texture of the rock is megascopically hypidiomorphic granular; there are no primary abnormative constituents; the name of the rock is therefore granopulaskose.

METADIABASE

The Honeybrook and Phoenixville quadrangles are intricately traversed by numerous dikes, which range in width from a few inches to many feet. These dikes are alike in being dark-colored, fine grained to aphanitic, and of a diabasic type but are unlike in representing two widely separated periods of intrusion, with corresponding difference in the degree of metamorphism.[36]

The more numerous but less extended dikes traverse pre-Cambrian formations only and are presumably of pre-Cambrian age; they strike about N. 60° E., nearly due east, or more rarely about N. 55° W. A smaller number of dikes usually strike about N. 15° E. and intrude pre-Cambrian, Paleozoic, and Triassic formations; they are of Triassic age. In some outcrops the dikes of the two periods are easily distinguished; in others they bear a close resemblance. The pre-Cambrian dikes are as a rule bluish gray, in contrast to the clear gray of the Triassic dikes; they are softer than the Triassic dikes and break with a less clear-cut conchoidal fracture; the diabasic (ophitic) texture, which in the younger dikes is easily detected with a hand glass, is blurred in the older dikes.

The pre-Cambrian metadiabase dikes are scattered throughout the pre-Cambrian complex, to which they are confined, and are therefore, as the map shows, limited to the central portion of the quadrangles. They are for the most part of a blue-gray color, but there are more altered types which are bluish to yellowish green, with further decrease in hardness and with a somewhat schistose fracture. The exposed surface may show a brownish-yellow oxidized crust that is a quarter of an inch thick in some places. Where the rock is porphyritic, it is mottled with thickly set phenocrysts of opaque white lath-shaped feldspars, which may measure a centimeter in length and in some occurrences are a striking feature; in other occurrences they produce merely a blurred outline. All diabase dikes occurring in the Honeybrook quadrangle, with the exception of the two dikes crossing Conestoga Valley, are pre-Triassic. The same is true of the diabase dikes of the Phoenixville quadrangle, with the exception of the long interrupted dike striking northeast from Downingtown and the nearly parallel dike to the east. The strike, color, and extent of alteration serve to separate these pre-Triassic dikes from very similar Triassic diabase.

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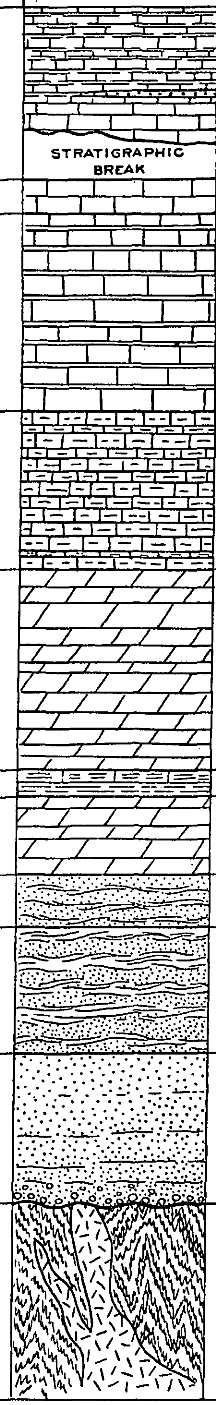
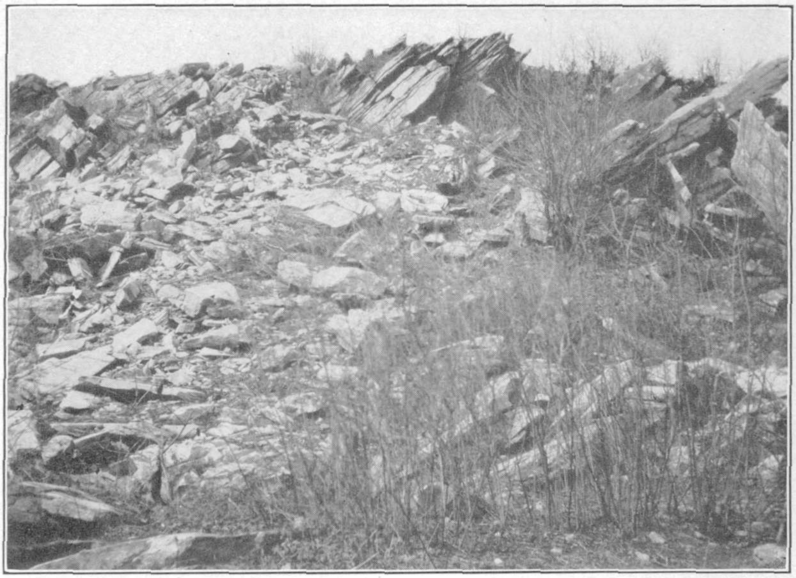
[36] Jonas, A. I., Pre-Cambrian and Triassic diabase in southeastern Pennsylvania: Am. Mus. Nat. History Bull. 37, art. 3, pp. 173–181, 1917.



System.	Series.	Formation.	Symbol.	Section.	Thickness in Feet.	Character of Rocks.
ORDOVICIAN	LOWER ORDOVICIAN	Conestoga limestone (Chester Valley only). (UNCONFORMABLE ON ELBROOK LIMESTONE AND LEDGER DOLOMITE)	Oc	STRATIGRAPHIC BREAK	500-800	Upper part, thin-bedded blue to gray granular limestone with thin dark argillaceous partings; thin dark phyllite and mica schist in middle part; lower part, thicker pure granular limestone, containing quartz grains and limestone conglomerate near base.
		Beekmantown limestone.	Ob		100+	Light-blue pure limestone and finely laminated magnesian limestone.
CAMBRIAN	UPPER CAMBRIAN	Conococheague limestone.	€cg		1000±	Variable interbedded dark and light, pure to magnesian limestone and lenticular dolomite, with beds of sandy limestone and *Cryptozoon* reefs.
	?					
	MIDDLE CAMBRIAN	Elbrook limestone.	€e		800±	Finely laminated fine-grained impure limestone and marble, weathering buff, shaly, and earthy.
	LOWER CAMBRIAN	Ledger dolomite.	€l		1000±	Massive-bedded granular, crystalline, light-gray to white dolomite.
		Kinzers formation.	€k		130-30 cv	Dark shale at base; dark argillaceous banded and nodular limestone above. In Chester Valley, micaceous limestone and calcareous mica schist.
		Vintage dolomite.	€v		600-200 cv	Massive knotty granular glistening dark-gray dolomite.
		Antietam quartzite.	€a		450-100 cv	Gray laminated quartzite, rust spotted and contains fossil molds. Not generally separable from Harpers phyllite in Chester Valley.
		Harpers phyllite.	€hp		800-500 cv	Gray sandy phyllite and mica schist with thin quartzite beds.
		Chickies quartzite with Hellam conglomerate member.	€c €h		1000-500 cv	Vitreous to granular quartzite, massive and thin-bedded, some quartz schist and mica schist; conglomerate-bearing beds at base.
		UNCONFORMITY				
PRE-CAMBRIAN		(Wissahickon formation south of Chester Valley in overthrust relations.)	(wcs)		(1000±)	(Mica gneiss and blue-gray chloritic mica schist, injected by gabbro and serpentine.)
		Pickering gneiss and Franklin limestone.	pgn pgg fl			Contorted, banded gneiss, in part graphitic, pgg, injected by granite, quartz monzonite, diorite, gabbro, and serpentine. Franklin limestone is a banded white coarsely crystalline marble containing graphite.

GENERALIZED SECTION OF PRE-TRIASSIC ROCKS EXPOSED IN THE HONEYBROOK AND PHOENIXVILLE QUADRANGLES.

Scale, 1 inch=1,000 feet. Figures followed by cv show thickness of formations in Chester Valley.



A. CHARACTERISTIC EXPOSURE OF CHICKIES QUARTZITE IN NORTH VALLEY HILLS, 1½ MILES WEST OF COATESVILLE.

B. CHICKIES QUARTZITE EXPOSED IN PENNSYLVANIA RAILROAD CUT, 1 MILE WEST OF ATGLEN.

Shows thin-bedded character at right, thicker-bedded at left.

The ophitic texture and the mineral constituents (labradorite and augite) characteristic of diabase are preserved in these ancient rocks, though always obscured by more or less extended alteration. The originally lath-shaped plagioclase is altered to aggregates of zoisite grains with albite or scanty muscovite, which blur the crystal boundaries; the violet-colored augite is altered peripherally to pale-brown hornblende, to biotite, or to chlorite and epidote, and the ilmenite is altered to leucoxene. Many stages in this alteration occur, nowhere is the rock unaltered, and in some occurrences little of the original constituents remains.

Originally feldspar and augite were present in about equal amounts in the nonporphyritic material. In the porphyritic dikes feldspar constitutes about 65 percent of the rock, with 35 percent of augite.

The yellowish-green dikes are those in which the replacement of the original constituents is most nearly complete. The fine-grained dark-colored rock cropping out on the hill 1¼ miles north of Anselma, in the Phoenixville quadrangle, is composed of labradorite altered to zoisite, augite altered to hornblende, and phenocrysts of biotite. The texture is subhedral granular rather than ophitic.

The pre-Cambrian intrusion that has been traced from Cornog (southeast of the station) nearly to Ludwigs Corners, where it is buried under the Cambrian quartzite debris, has a different aspect and character from the diabase dikes just described. The rock is quarried at Cornog by the Keystone Trappe Rock Co. and is commercially known as trap rock. It is fine-grained but not aphanitic. Where exposed in surface outcrops it has a green color; where exposed in the quarry it is a light gray green, irregularly jointed and traversed by calcite veins. A pocket containing masses of calcite was opened up in quarrying.

The original constituents of the rock were presumably feldspar, pyroxene, biotite, titanite, and ilmenite. The feldspar, which appears to be andesine, is altered to aggregates of zoisite and epidote. The pyroxene, which may have been augite, is completely replaced by pale-green or colorless hornblende, associated with chlorite or epidote. The biotite, which remains unaltered, occurs in aggregates. The titanite shows a leucoxenic aspect. Pyrite is an accessory constituent and calcite a secondary constituent. Recrystallized pegmatite with large blue quartz crystals is a characteristic feature, together with siliceous feldspathic injections.

This dikelike gabbroic injection in the Pickering gneiss is an inclusion in the injecting quartz monzonite.

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PEGMATITE

The most silicic differentiate of the igneous intrusives and the youngest, except the Triassic diabase, is the pegmatite. Pre-Cambrian formations are saturated with this siliceous material, both as dikes and as veins. Some of the more conspicuous dikes in the Honeybrook quadrangle occur west and southeast of Honeybrook; west, northwest, and northeast of Fontaine; 1¼ miles south of Cornog; and northeast of Cornog, where a quartzose pegmatite following a fault extends from the terminus of the Cambrian quartzite nearly to the isolated quartzite hill in the Phoenixville quadrangle.

These dikes are confined to pre-Cambrian formations. The pegmatites are composed chiefly of quartz and feldspar in the proportion of about 50 to 45; both constituents show pressure effects, and the feldspar (potash-soda feldspar, chiefly orthoclase) is kaolinized, with the accompanying development of sericite or muscovite; magnetite is also a common constituent of the pegmatite and occurs both as grains and in irregular veins.

The veins of blue quartz are apparently so exclusively associated with the injection of the gabbro by the granodiorite that they serve as an indication of such contacts.

PALEOZOIC ROCKS

By G. W. Stose

The Paleozoic rocks in this area are sedimentary rocks of Cambrian and Ordovician age. They comprise the following formations, named in order of age, beginning with the oldest: Chickies quartzite with basal Hellam conglomerate member, Harpers phyllite, Antietam quartzite, Vintage dolomite, Kinzers formation, Ledger dolomite, Elbrook limestone, Conococheague limestone, all of Cambrian age; Beekmantown limestone and Conestoga limestone, of Ordovician age. (See pl. 6.) These rocks occur in three separated areas. The two northern areas form the eastern part of the wide Lancaster Valley; one includes Welsh Mountain and the lowland between it and the red hills of Triassic rocks on the north, and the other includes the Barren Hills and the lowland to the west. The third area occupies Chester Valley, which crosses the southern part of the Phoenixville quadrangle diagonally from its southern edge west of Downingtown to its eastern edge north of Malvern. The distribution of these formations at the surface is shown on the geologic map (pl. 1).

The exposed limestones in the northernmost area terminate in a wedge point west of Elverson but are believed to continue beneath alluvium to the east edge of the Honeybrook quadrangle. The limestones of the middle area terminate north of Sadsbury, and the quartzose rocks form the Barren Hills and its eastward extension. All the formations in Chester Valley are thinner than they are in the northern areas (see pl. 6), largely owing to the fact that the southern area is south of the Mine Ridge uplift, which apparently was actively rising during early Paleozoic time and formed a partial barrier so that sediments were not carried as freely to the southern part of the basin. This local uplift was particularly marked in pre-Conestoga time, for the formations down to the Ledger dolomite were eroded in places at that time and were overlapped by the Conestoga limestone.

CAMBRIAN SYSTEM

CHICKIES QUARTZITE

Distribution and character.—The Chickies quartzite, the lowest formation of Cambrian age, is a pure quartzite and sericitic quartz schist so resistant to erosion that it makes prominent hills. In the northern part of the area it forms the crest of Welsh Mountain, Thomas Hill (pl. 2, *A*), Mount Pleasure, and another outlying hill to the east. In the middle of the area it forms the Barren Hills and their extension to the east and south. A long eastward prong extends to the East Branch of Brandywine Creek at Cornog, with an outlier of the formation farther east at Font. Southward the Barren Hills of Chickies quartzite extend to Sadsbury, and two outlying hills of the formation occur to the southeast.

In Chester Valley the Chickies makes a low ridge bordering the north side of the limestone valley. It enters the south border of the Phoenixville quadrangle west of Downingtown and extends as a narrow belt eastward to the vicinity of Whitford post office. Here the main belt of the formation swings north and joins a wider belt of the formation along the north edge of the limestone valley that extends to the east edge of the quadrangle. It makes more prominent hills west and east of Devault but is faulted out at Devault. The Chickies also extends westward on the north limb of the Mine Ridge anticline to Corner Ketch, at the west edge of the Phoenixville quadrangle. East of Whitford a low discontinuous sandy ridge, an upfaulted anticline of the Chickies formation, lies out in the valley and extends to the prominent hill north of Mill Lane.

The formation is quartzose throughout. It is chiefly a thick-bedded light-colored vitreous quartzite with water-clear or bluish grains. (See pl. 7, *A*, *B*.) The upper part is thin-bedded fine quartzite with sericitic partings, which in places develop into a sericitic quartz schist. These beds disintegrate into a fine white siliceous clay, which is extensively quarried around Narvon, in Welsh Mountain. These upper beds are crossed at right angles by parallel straight tabular markings which are filled worm burrows, called *Scolithus* tubes. At the base of the formation are coarse-grained quartzite with scattered round quartz pebbles and conglomerate beds with interbedded black slate. These basal beds are mapped separately as the Hellam conglomerate member, chiefly for purposes of showing the structure. The formation in the Welsh Mountain and Barren Hills areas is estimated to be abont 1,000 feet thick, of which the Hellam conglomerate comprises 200 to 400 feet.

A partial section, showing the variable character and sequence of the beds, is exposed at the William Mason quarry, on Welsh Mountain 1½ miles southeast of Beartown, as follows:

Partial section of Chickies quartzite at William Mason quarry, southeast of Beartown

	Feet
Quarry:	
Crumbly granular quartzite	20
Very white soft sandstone, weathering bluish and crumbly, with some white clay	20
Crumbly quartzite	20
Harder white quartzite containing numerous *Scolithus* tubes; weathers somewhat crumbly	20
Very white quartzite, weathering crumbly, with glassy quartz grains, in part coarse, and white clay	15
Railroad cut:	
Thin-bedded quartzite	10±
Quartzite beds, 3 feet thick, with black shale partings as thick as 6 inches	15
Thick-bedded white grainy *Scolithus*-bearing quartzite; weathers buff	10
Thin-bedded, cross-bedded laminated quartzite; weathers dirty gray	20±
Thinner-bedded *Scolithus*-bearing quartzite; weathers rusty	40±
Massive-bedded quartzite, granular below, vitreous above; weathers rusty	55±
Hellam conglomerate member:	
Crumbly arkosic quartzite	25±
Massive white grainy quartzite; weathers rusty	40±
Grainy arkosic quartzite, crumbly and containing considerable white clay	20
Fine arkosic conglomerate, crumbly in part	40±
	370±

Another partial section measured at the Silica Sand quarry is as follows:

Partial section of Chickies quartzite at Silica Sand quarry, Welsh Mountain, 1½ miles east of Narvon

	Feet
Buff-weathering sandstone	20±
White-weathering sandstone	50±
White-weathering *Scolithus*-bearing quartzite, some granular	40±
Thinner-bedded white quartzite	12
Thick-bedded hard white quartzite	30
Shaly parting	½
Thinner-bedded white grainy quartzite, much jointed	22
Hellam conglomerate member:	
Thicker-bedded rusty-weathering coarse-grained much-jointed quartzite with some fine conglomerate	25
Thin-bedded white grainy quartzite and conglomerate of rice-sized pebbles of white quartz and scattered blue quartz	40
Crumbly rusty grainy sandstone	20
	260+

More clayey sericitic beds are shown in the section from the Whittaker clay mine, at Narvon:

Section of Chickies quartzite at Whittaker clay mine, Narvon

	Feet
Quarry:	
Grainy white sandstone, grains of vitreous quartz in sugary matrix, with quartz seams	30
Crumbly laminated white sandstone, some rust-stained	80
White clay, with 3-inch streak of yellow clay in midst; thin laminated white clayey sandstone at top	160±
White banded clay with some yellow layers	60±
Slope above quarry:	
Covered with fragments of *Scolithus*-bearing quartzite (details in part shown in Harvison quarry section given below)	260±
Massive, very vitreous quartzite	50±
Granular white quartzite (crest of ridge)	40±
	680

Partial section of Chickies quartzite at Harvison quarry, Narvon

	Feet
Thin-bedded grainy white quartzite; quartz grains coated with white clay	30
Clay containing quartz fragments	10
Thin-bedded quartzite	5
Greenish clay with schistose structure and containing fragments of bluish quartz	15
Vitreous quartzite (part of unexposed section at Whittaker clay mine)	50±
	110±

At Font, the easternmost occurrence of Chickies in the Barren Hills anticline, the exposure is too poor to show the thickness of beds, but the sequence there is as follows:

Sequence of Chickies quartzite at Font

White *Scolithus*-bearing sandstone and sand.
White crumbly granular sandstone containing tourmaline.
Dark ferruginous-banded granular sandstone.
Dark feldspathic sandstone.
Crumbly blue-quartz pebble conglomerate.
Crumbly dark-banded porous granular sandstone and crumbly conglomerate with ½-inch blue-quartz pebbles and vein quartz.
White sand with wash of conglomerate, vein quartz, and tourmaline-bearing quartzite.

In the Chester Valley area the formation is much thinner, and the rock is much more metamorphosed and drawn out to a schist, contains much mica and tourmaline, and is complicated by close folding. The general sequence of beds in this area is as follows:

Sequence of Chickies quartzite in Chester Valley

Buff-weathering sandy gray schist and schistose quartzite.
Sheared white sericitic quartzite with particles of white clay, formerly feldspar, much mica, and scattered tourmaline crystals, with a thick bed of harder vitreous quartzite in the midst.
Thick hard vitreous *Scolithus*-bearing quartzite.
Slabby schistose conglomerate with blue-quartz pebbles and soft sandy mica schist, 50 feet.

A fairly good section of the Chickies and overlying Harpers phyllite was measured at Coatesville, just south of this area, as follows:

Section of Cambrian quartzose rocks at Coatesville, Pa.

	Feet
Harpers phyllite: Silvery 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
	557

A better-exposed section, but complicated by folding, necessitating interpretation of structure, is that at Atglen, in the Coatesville quadrangle (see pl. 7, *B*), as follows:

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 phyllite 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 quartzose schist		165
Thin-bedded quartzite and quartz schist, thicker bedded at base	33	
Mica schist	10	
Vitreous quartzite, thick-beded above, thin-bedded below	90	
Thick-bedded quartzite, thinner bedded toward top	40	
Chiefly quartzite		173
Hellam conglomerate member:		
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	50±	
		95±
		433±

In the sandy ridge north of Exton the Chickies is disintegrated to white sand and clay, which has been extensively quarried. The general character of these beds is shown by the following section:

Partial section of Chickies quartzite at quarry of Whiteland Silica Co., 1 mile northwest of Exton

	Feet
Platy to crumbly paper-white quartzite with sericite partings, some finely pebbly, and white clayey sand	40±
Hard blocky white quartzite; weathers rusty, with thin argillaceous layers; passes into unweathered blue-gray vitreous quartzite	20±
Thin platy to paper-white sandstone with dark spots	12
White powdery clayey sand with schistose structure and crumbly; quartz eyes and stringers; contains chlorite and tourmaline crystals in lower part	50±
Harder white platy quartzite with scattered quartz pebbles and beds of fine conglomerate containing tourmaline crystals	10±
Crumbly white laminated sandstone interbedded with white powdery clay and some white pebbly beds	30±
	162±
Similar white clayey sand and yellow clayey sand below, unmeasured.	

East of Devault, where the beds are overturned toward the south by the Devault overthrust, the basal beds are exposed as follows:

Section of basal part of Chickies quartzite east of Devault

	Feet
Schistose conglomerate, arkose, and fine green sericitic schist with tourmaline crystals	15
Hard conglomerate with coarse grains of blue quartz and banded purple quartzite	13
Crumbly blue-quartz congloremate, ½-inch pebbles, and banded dark-purple and light-gray quartzite	32
	60

The same conditions prevail in the sandy ridge northwest of Planebrook, where the following partial section was measured:

Section of Chickies quartzite in sand pit northwest of Planebrook

	Feet
Thin-bedded crumbly white glistening *Scolithus*-bearing sandstone	20±
Somewhat harder, thicker *Scolithus*-bearing white sandstone; crumbles to white sand	70
Thin-bedded vitreous blue to white quartzite	10
Massive white to bluish quartzite	6±
	106±

Age and correlation.—The relation of this quartzite to the overlying formations is the same as that of the Chickies quartzite at Chickies Rock, on the Susquehanna River north of Columbia, and the formation is therefore called the Chickies quartzite.[37] The basal beds contain conglomerates and black slate, similar to the Hellam conglomerate member, but the conglomerates are not as coarse nor the beds as thick and numerous as those in the type locality in the Hellam Hills, west of the Susquehanna River. No fossils except *Scolithus* tubes have been found in the formation in this area. The long, straight worm tubes have been named *Scolithus linearis*, and this simple fossil is not known from rocks older than the Cambrian. The Chickies quartzite lies at a lower horizon than the Antietam quartzite in a conformable sequence, and the Antietam contains fossils of Lower Cambrian age. Therefore the Chickies is regarded as Lower Cambrian.

HARPERS PHYLLITE

Distribution and character.—The Harpers phyllite overlies the Chickies quartzite and occupies the slopes of ridges composed of the

[37] Stose, G. W., and Jonas, A. I., Geology of the Middletown quadrangle, Pa.: U. S. Geol. Survey Bull. 840, p. 17, 1933.

quartzite and valleys between the quartzite ridges. It makes a rather wide belt on the north slope of Welsh Mountain from the west edge of the Honeybrook quadrangle eastward but thins to a narrow band as a result of overthrusting and ends against the fault 2 miles southwest of Elverson. A similar narrow band lies on the northwest slope of Thomas Hill. On the west slope of the Barren Hills the Harpers phyllite makes a wavy band half a mile wide that weaves in and out around the axes of minor folds that plunge westward under the limestone. In Chester Valley it makes a narrow belt on the south slope of the North Valley Hills from a point west of Downingtown to Devault and again east of Devault. A small inlier is enclosed next to the fault on the north limb of the Mine Ridge anticline west of Dowlin.

The Harpers phyllite is a greenish-gray to dark-gray sandy argillaceous rock that has been recrystallized under pressure and differential movement, so that it is now a fine-grained micaceous schistose rock or phyllite. Its cleavage planes sparkle with fine mica. The bedding planes are in most places completely destroyed by the cleavage developed in the rock. The thickness therefore cannot be accurately determined. In the Welsh Mountain and Barren Hills areas it is estimated to be 800 feet thick. In Chester Valley it is probably not over 500 feet thick. The overlying Antietam quartzite is so thin in the western part of Chester Valley that it has not been separately mapped west of Exton, although it is clearly recognizable in the minor anticline 2 miles west of Downingtown.

Age and correlation.—The Harpers phyllite nowhere contains fossils. This phyllite is the same as that which lies above the Chickies quartzite at Chickies Rock and is the same as the less metamorphosed phyllite or shale that underlies the Antietam quartzite at Harpers Ferry, W. Va. It is therefore called Harpers phyllite, from the type locality of the Harpers shale. It underlies conformably rocks that carry a Lower Cambrian fauna and is therefore regarded as of Lower Cambrian age.

ANTIETAM QUARTZITE

Distribution and character.—The Antietam quartzite, which overlies the Harpers phyllite and is the highest quartzose formation of Cambrian age, is resistant to erosion and makes a line of prominent hills in front of the hills of Chickies quartzite. On the north flank of Welsh Mountain it makes hills that are discontinuous because of faulting. These culminate in the high hill east of Beartown, at the plunging end of an anticline. Three small outliers of the formation, north of the fault, lie west and north of Elverson. The hills and spurs that form the west and southwest fringe of the Barren Hills are composed of Antietam quartzite that has a wavy outcrop around the westward-plunging ends of minor anticlines of the Barren Hills uplift.

In Chester Valley quartzites of Antietam type have been recognized at several localities. Slabby rusty laminated quartzite with fossil shells (*Obolella*) in the rusty layers and weathering to a dark-brown manganese-stained soil, characteristic of the upper Antietam, occurs in the hill north of Mill Lane. Similar ferruginous quartzites west of Barton and northwest of Sidley are mapped as Antietam. The formation is believed to be present in Chester Valley west of Exton, in the upper part of the formation mapped as Harpers, but it is here too thin to be a distinct mappable unit. Typical rust-specked quartzite, like the fossil-bearing topmost beds of the Antietam, were seen in the minor anticline 2 miles west of Downingtown.

The Antietam is a light-gray fine-grained quartzite, grading downward into Harpers phyllite by the addition of dark argillaceous matter. The upper beds of the formation are coarse-grained and calcareous and are laminated so that the rock breaks into slabby fragments, on the bedding surfaces of which are molds and casts of trilobite spines and brachiopod shells. These are usually stained with a bright rust color due to the oxidation of the contained iron. The deep-red residual soil from these beds is also a source of iron ore, once extensively mined in the region. The Antietam quartzite in Welsh Mountain and the Barren Hills is estimated to be 450 feet thick. It is probably not over 200 feet thick in Chester Valley and less than that west of Exton.

Age and correlation.—The Antietam quartzite contains *Scolithus* tubes throughout the formation, and its upper beds contain fragments of trilobites and shells. These have been identified by Walcott as *Olenellus thompsoni*, *Camarella minor*, *Obolella* cf. *O. crassa*, and *Hyolithes communis*, of Lower Cambrian age. The formation here mapped has the same stratigraphic position and contains some of the same fossils as the Antietam quartzite on Antietam Creek in Maryland, and the same name is here used.

VINTAGE DOLOMITE

Distribution and character.—The Vintage dolomite, which overlies the Antietam quartzite and is the first carbonate formation of the Cambrian, makes a lowland at the foot of hills composed of the Antietam quartzite. It crops out as a band half a mile wide around the hill of Antietam quartzite north of Beartown, in the valley of Conestoga Creek, and north of the foothills on the side of Welsh Mountain. It was not seen north and northeast of Elverson but probably underlies the lowland northwest of Thomas Hill and Mount Pleasure and southeast of Hopewell, as mapped, especially around the small Antietam quartzite outlier. West of the Barren Hills uplift it makes a zigzag belt around the serrate foothills of Antietam quartzite but ends abruptly south of Compass against an east-west fault. In Chester Valley the Vintage makes a narrow band around the anticlinal hill of Harpers phyllite and Antietam quartzite 2 miles west of Downingtown, and eastward a very narrow belt of it can be traced as far as Whitford post office, where it is cut out by a fault. It has not been seen farther east except in the fault block north of Mill Lane. It is, however, probably present above the Antietam quartzite between the two parallel faults west of Bacton, as shown on the map.

The Vintage dolomite is seldom exposed because of the thick cover of quartzite wash from the adjacent hills. It is a thick-bedded gray glistening dolomite at the base, dark-blue knotty dolomite with blebs of coarser crystalline dolomite in the middle, and thin-bedded mottled blue limestone at the top. The basal beds merge downward, through cream-white argillaceous to sandy dolomite with mica on the bedding planes, into ferruginous calcareous beds at the top of the Antietam. The thickness of the formation west of the Barren Hills and north of Welsh Mountain is estimated to be 600 feet. In the Chester Valley it probably is not over 200 feet thick.

Age and correlation.—The Vintage dolomite was named[38] from Vintage station, on the Pennsylvania Railroad 4 miles west of the Honeybrook quadrangle, where the character and relations of the formation are well displayed in the railroad cut. No fossils were collected from the Vintage in this area, but the few fossils reported from it near Lancaster are of Lower Cambrian age.

KINZERS FORMATION

Distribution and character.—The Kinzers is a thin shaly formation and makes a narrow line of hills in the limestone lowland. Linear ridges of shale are not as prominent and persistent here as those in the vicinity of York and Lancaster, where the shale is much thicker. North of the Welsh Mountain anticline the Kinzers has not been observed and apparently was not deposited in that part of the region. This anticline probably rose as a barrier in the early Cambrian sea, and the deposition of the Kinzers formation was restricted to the basin south of it. West of the Barren Hills the Kinzers makes linear hills that form loops around the plunging ends of minor folds. These are offset by east-west faults. Several isolated inliers of the formation are brought to the surface on minor anticlines in the area of Ledger dolomite. In Chester Valley the band is even narrower

[38] The Vintage dolomite, Kinzers formation, and Ledger dolomite were fully described in Pennsylvania Geol. Survey Atlas of Pennsylvania, no. 178, New Holland quadrangle, 1926.

and the rocks are poorly exposed, but the formation is apparently continuous from the south edge of the Honeybrook quadrangle to a point north of Exton, where it is cut out by a fault. Small areas of the formation are mapped in the fault blocks at Bacton and north of Mill Lane, although the beds are not exposed there.

The formation, where its full thickness is present, comprises a lower member of dark shale with thin-bedded impure dolomite, weathering to buff dense tripoli, at the base, and an upper member of irregularly banded dark argillaceous limestone and nodular limestone with white marble lenses or nodules surrounded by wavy argillaceous layers.

The section of the formation at the type locality, 3 miles west of the Honeybrook quadrangle, is as follows:

Section of Kinzers formation in Pennsylvania Railroad cut at Kinzers, Pa.

	Feet
Top not exposed; elsewhere largely sandy dolomite weathering to dense, tough tripoli	45±
Dark-blue limestone with wavy argillaceous partings	10
Thick-bedded light-gray dolomite	12
Dark-blue limestone with wavy argillaceous partings	6
Spotted white marble ("leopard rock") with wavy buff dolomitic layers	8
Blue limestone banded with slightly wavy siliceous layers	10
Highly siliceous banded dark-blue limestone, weathering to buff siliceous reticulate skeleton	8
Impure thick-bedded dolomite, weathering to dense, tough buff tripoli	3
Spotted white marble ("leopard rock") evenly banded with buff dolomite	8
Wavy-banded blue limestone with many wavy argillaceous partings	10
Fissile dark-gray shale, weathering spheroidal	50±
Impure dolomite weathering to dense, tough buff tripoli and containing trilobite spines and *Salterella*	7
	177±

Massive light-blue dolomite, weathering white (Vintage).

Most of the different kinds of rock that compose the formation can be found in the outcrops west of the Barren Hills, but in Chester Valley it is represented only by sporadic outcrops of impure limestone that weathers to shaly mica schist. The thickness of the formation west of the Barren Hills is about 130 feet. In Chester Valley it is probably not over 30 feet thick.

Age and correlation.—Numerous fossils have been collected from the Kinzers formation in the vicinity of York and Lancaster. These include *Olenellus* and other trilobites of Lower Cambrian age. A cornucopialike fossil, *Salterella*, is plentiful in the formation west of the Barren Hills, and a few fragments of trilobites have also been found in that area. The formation was named from Kinzers station, on the Pennsylvania Railroad 3 miles west of the Honeybrook quadrangle.

LEDGER DOLOMITE

Distribution and character.—The Ledger dolomite, which overlies the Vintage dolomite in the area north of Welsh Mountain and overlies the Kinzers formation in the southern areas, makes a lowland valley with deep rich soil. North of Welsh Mountain it crops out as a band from a quarter of a mile to a mile wide across the west half of the Honeybrook quadrangle. West of Beartown a small area of the formation at the plunging end of a minor fold is repeated by faulting. West of the Barren Hills it makes a wide area between the zigzag line of hills of Kinzers formation and the west border of the Honeybrook quadrangle. In Chester Valley it occupies most of the limestone floor as far northeast as Whitford post office. Here a medial tongue of overlying Conestoga limestone expands in width eastward, so that the Ledger is restricted to the north half of the limestone valley. This area extends northeastward to a point north of Warren Tavern. A parallel area of the formation, which lies north of a low ridge of Cambrian quartzite north of Exton, extends eastward to Bacton. The formation appears again in an anticline south of Devault, where it crops out in an area 1½ miles long.

The formation is in general a pure granular dolomite that weathers with a rough granular surface and disintegrates eventually to a deep-red granular clay soil. It is massive-bedded and gray to blue in color, finely speckled in places. The lower beds are generally light gray to white, and in the area north of Welsh Mountain these beds are so conspicuously pure and white that they have been separately mapped and make a narrow band along the base of the formation. The thickness cannot be measured because of incomplete exposures but is estimated at 1,000 feet.

A section showing the sequence of beds of the formation near Morgantown is as follows:

Section of Ledger dolomite and adjacent beds southeast of Morgantown

Elbrook limestone: Very impure limestone weathering to cherty sandstone (basal bed).

Ledger dolomite:
- Dolomite and white marble.
- Impure limestone, dolomite, marble, and thin sandy beds in recumbent fold, overturned to south (may be basal Elbrook, infolded).
- Shaly impure dolomite.
- Impure dolomite, weathered pitted.
- Massive dark dolomite.
- Shaly dolomite.

Ledger dolomite—Continued.
- Thick-bedded dark dolomite with some light beds.
- Concealed (valley of Conestoga Creek).
- Impure dolomite.
- White finely granular dolomite, thinner bedded below (basal beds that are mapped).
- Irregular contact (unconformity?).

Vintage dolomite:
- Thin-bedded mottled blue limestone.
- Thick-bedded dolomite.

The pure dolomite is very massive in the Charles Warner Co.'s quarries at Cedar Hollow, southeast of Devault, and at Knickerbocker. The following thick beds are present in the Knickerbocker quarry:

Section of Ledger dolomite in Charles Warner Co.'s quarry at Mill Lane

	Feet
Finely laminated gray granular dolomite, weathers crumbly and dirty looking; some light and dark bands at base	100±
Banded dolomite, in part deeply weathered and stained	100±
Massive dolomite	40
Porous cherty layer	1±
Very massive dolomite, crushed and badly stained	100±
	341±
Gray dolomite with folded siliceous parting and porous chert; contains spongelike fossils.	

Age and correlation.—No fossils except spongelike markings have been found in the formation. These occur at the Knickerbocker quarry and probably represent sponges related to *Archeocyathus*, of Lower Cambrian age. The Ledger conformably overlies the Kinzers formation, which in places contains an abundance of Lower Cambrian fossils. It was named from Ledger, 2 miles west of the Honeybrook quadrangle.

ELBROOK LIMESTONE

Distribution and character.—The Elbrook limestone is characterized by light-yellow earthy soil and generally makes low hills that stand above the rest of the limestone valley. North of Welsh Mountain the Elbrook outcrop is generally about a mile wide and extends from the west edge of the Honeybrook quadrangle to Morgantown, beyond which it becomes narrower and ends about 2 miles to the east, where it is overlapped by Triassic rocks. West of the Barren Hills the syncline is not deep enough to contain the Elbrook. In Chester Valley a narrow belt of laminated limestone and marble, believed to be Elbrook, is mapped along the south edge of the valley from a point south of Downingtown to a point north of Whitford station, where it is overlapped by the Conestoga limestone. This narrow band appears again from beneath the Conestoga limestone south of Planebrook and extends to the east edge of the quadrangle, where it becomes much wider. South of Devault a larger area of the formation extends from Bacton to the east edge of the quadrangle, where it merges into the area south of Mill Lane.

The Elbrook is in general a thin-bedded fine-grained dove-colored to light-blue earthy limestone which weathers to shaly buff limestone and soft buff tripoli. Some beds in this area are cream-colored to pure-white fine-grained marble (pl. 8, *B*), with sericite and mica on the partings, and some are so dense, fine, and even-grained that they may be classed as lithographic stone. The formation weathers to a light-buff or yellow fine earthy soil with many shaly fragments and makes low hills and excellent agricultural land. The prevalence of beds of marble is shown in the partial section of the formation northeast of Morgantown, as follows:

Partial section of Elbrook limestone along Conestoga Creek, northeast of Morgantown

	Feet
Dark to pink and white marble.	
Pure dense blue limestone, less pure at top and with some dolomite and marble (quarry rock)	25±
Dolomite footwall	3±
White marble	30±
White marble, weathering buff, impure marble, and mottled blue limestone	60±
Blue limestone and buff to white marble, interbedded	30±
Buff-banded blue limestone	30±
White marble, seamed with siliceous impurities	15±
Finely laminated dense thick-bedded cream-colored marble stained pink; some beds ripple marked; some white and gray banded; some dense fine-grained lithographic stone	35±
Blue limestone with impure banding	15±
Earthy dolomite, weathered dirty-looking, and thin white laminated marble	10±
Thick blue limestone, buff-banded	10±
Earthy dolomite, weathers sandy	10
	273±
Folded and minutely crinkled cream-colored marble with fine impure laminations.	
Shaly earthy light-gray marble.	
Thick earthy buff marble.	

In the area north of Welsh Mountain there is a hard sandy limestone or cherty sandstone at the base of the Elbrook which makes quartzose ledges and leaves many resistant fragments and large chert blocks in the soil and therefore forms a linear ridge. This cherty bed makes a good marker for the base of the formation, and it has therefore been mapped. The ridge is especially prominent just east of

Churchtown and farther east, where a 5-foot bed of ripple-marked calcareous gray to reddish sandstone or siliceous limestone and earthy dolomite that weathers with a thick brown earthy coating is exposed in places, and fences are made of weathered slabs, 3 to 4 feet long, of these hard cherty rocks.

In Chester Valley white marble beds predominate in the formation and are also thicker and coarser. The mica coating the parting planes is also coarser, indicating a greater degree of metamorphism. In the area south and southeast of Devault beds of fine-grained earthy laminated and shaly limestone, typical of the Elbrook, are present with the coarser marble.

The Elbrook limestone is estimated to be 800 feet thick in this area.

Age and correlation.—The formation is correlated with the Elbrook limestone[39] near Chambersburg, which has the same general lithologic character and occupies the same stratigraphic position. It is possible that the ripple-marked reddish sandstone at the base, north of Welsh Mountain, represents the Waynesboro formation of southern Pennsylvania. No fossils have been found in the Elbrook in this area. The few fossils found near the type locality are of Middle Cambrian age. In central Pennsylvania fossils assigned to the Upper Cambrian are reported from the upper part of the formation.

CONOCOCHEAGUE LIMESTONE

Distribution and character.—The Conococheague limestone, which normally overlies the Elbrook, is present only in two small areas in these quadrangles. The largest of these areas is west and northwest of Churchtown. This area is overlapped by Triassic rocks, a tongue of which divides it into two separate exposures. Another small area lies south of the Triassic rocks just northwest of Morgantown. The formation has not been identified in Chester Valley.

The Conococheague limestone is characterized by its variability, beds of dark and light limestone, pure dove-colored limestone, and lenticular dolomite alternating with one another. It is also marked by the presence of very sandy limestone that weathers to porous sandstone and of impure banded limestone that weathers to an earthy siliceous reticulate network and to buff shaly particles in the soil. There are also pure light-gray to blue limestones that are colonies of *Cryptozoon* heads, which have fine concentric wavy laminations and enclose associated oolite and edgewise conglomerate. A mile northwest of Morgantown two *Cryptozoon* reefs occur, each 10 to 15 feet thick, composed of wavy blue limestone in concentric *Cryptozoon* heads 2 to 4 inches across.

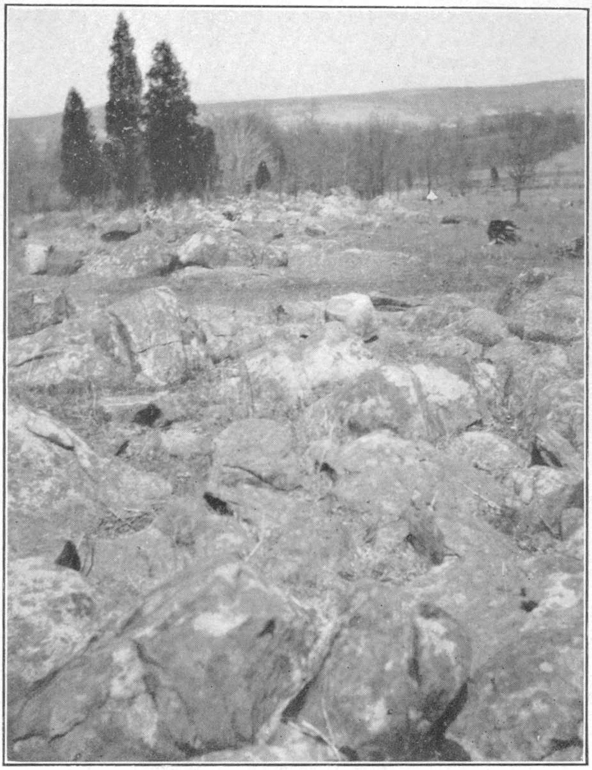
[39] The names Elbrook, Conococheague, and Beekmantown limestones were first applied in this region in U. S. Geol. Survey Geol. Atlas, Mercersburg-Chambersburg folio (no. 170), 1909.

A. LIMESTONE CONGLOMERATE NEAR BASE OF CONESTOGA LIMESTONE.

Two miles west of Downingtown.

B. CRINKLED THIN-BEDDED IMPURE BANDED WHITE MARBLE IN ELBROOK LIMESTONE.

Half a mile east of Morgantown.



A. FIELD STREWN WITH RESIDUAL TRIASSIC DIABASE BOULDERS.
Forms a low ridge 1 mile west of Churchtown.

B. DIABASE WEATHERING ALONG JOINTS INTO SPHEROIDAL BOULDERS.
At St. Peters. Photograph by E. T. Wherry.

The formation in the adjacent New Holland quadrangle is estimated to be about 1,000 feet thick. In most places in this area, however, only a small part of this total thickness is present.

Age and correlation.—This formation has the same lithologic character as the Conococheague limestone of the Chambersburg area and was named from its outcrop on Conococheague Creek in that area. The sequence of associated formations at the two places is also the same, and at both it carries characteristic *Cryptozoon* forms. These are fossil algae, two varieties of which have been recognized in the formation. In the Chambersburg area the formation also contains trilobites and other fossils of Upper Cambrian age. These beds are included by E. O. Ulrich in his lower Ozarkian.

ORDOVICIAN SYSTEM

BEEKMANTOWN LIMESTONE

Distribution and character.—Only the small east end of a large area of the Beekmantown limestone enters the Honeybrook quadrangle 2 miles northwest of Churchtown. The Beekmantown is generally a pure light-blue finely laminated limestone with some dark-blue magnesian beds, both of which weather to a light-gray, white, or cream-colored chalky surface. The formation, where fully present, is about 2,000 feet thick, but only about 100 feet occurs in this area.

Age and correlation.—The Beekmantown limestone throughout the Great Valley contains poorly preserved fossils, chiefly gastropods, which may be best seen on the weathered surface of the limestone. Similar fossils have also been found in the formation in the Lancaster Valley. By means of these fossils the formation has been correlated with the limestone at Beekmantown, N. Y.

CONESTOGA LIMESTONE

Distribution and character.—The Conestoga limestone is present in the Honeybrook-Phoenixville area only in Chester Valley. A long, narrow strip of the formation lies along the south edge of the valley, occupying the deepest part of the syncline. This comes into the quadrangle south of Downingtown and extends to a point south of Exton, where it expands to nearly a mile in width. Here a synclinal arm of the formation extends southwestward in the middle of the valley to Downingtown. A small separate area of the formation, west of the north-south normal fault that passes through Downingtown, is an outlier of this syncline. The main belt of the formation continues northeastward along the south side of the valley to the east edge of the Phoenixville quadrangle north of Malvern.

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The Conestoga in the Phoenixville quadrangle is a thin-bedded to shaly micaceous impure blue limestone with argillaceous shaly partings. Mica coats most of the bedding and cleavage planes. The lower part of the formation is generally thicker bedded and purer and is extensively quarried in places. Some of the basal beds are a coarse limestone conglomerate in a dark argillaceous matrix, which was seen chiefly in a small quarry 2 miles west of Downingtown. (See pl. 8, *A*.) Here several thick beds of conglomerate contain large pebbles and irregular masses of coarse white marble in an argillaceous limestone matrix. With the conglomerate are associated thin beds of granular light-gray ribbed limestone, 1 inch thick,

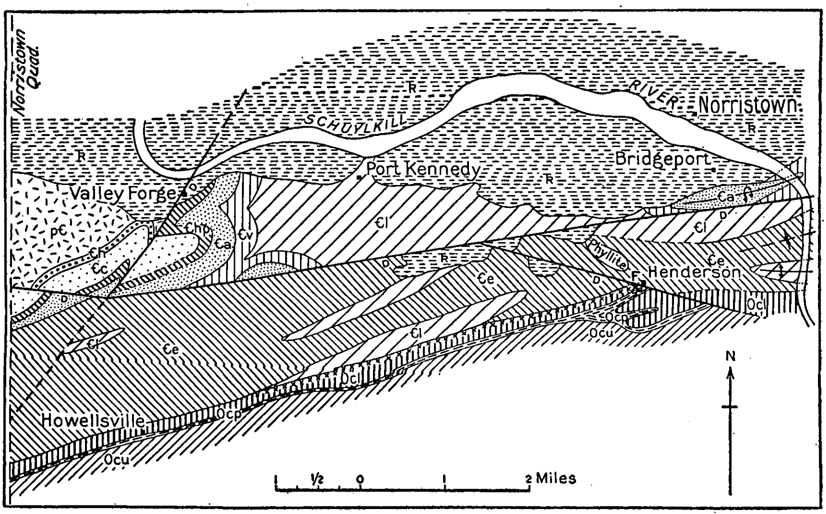

FIGURE 3.—Reconnaissance geologic map of Chester Valley east of Phoenixville quadrangle. By G. W. Stose and A. I. Jonas. ℞, Triassic redbeds; Ocu, upper part of Conestoga limestone; Ocp, phyllite in Conestoga limestone; Ocl, lower part of Conestoga limestone (basal chert marked by xxx); Єe, Elbrook limestone; Єl, Ledger dolomite; Єv, Vintage dolomite; Єa, Antietam quartzite; Єhp, Harpers phyllite; Єc, Chickies quartzite; Єh, Hellam conglomerate member; pЄ, pre-Cambrian rocks. D, Downthrow of faults. F, Fossils.

with dark slaty partings half an inch thick and finely banded dark slaty limestone; also some dark earthy dolomite, weathering to light-blue color. Many particles of residual slate derived from the limestone are found in the soil.

East of Whitford in Chester Valley a thin dark graphitic phyllite with thin sandy schist layers appears within the Conestoga limestone and has been traced eastward to the longitude of Frazer, where it is concealed by soil and mountain wash. The beds are again observed north of Knickerbocker and were traced eastward to the edge of the Phoenixville quadrangle. The schist thickens eastward and makes a line of discontinuous hills, which become more prominent east of Valley Store, and these higher hills extend to Henderson, in the Norristown quadrangle. This line of hills separates the thin-bedded blue argillaceous limestone above, which is more characteristic of the Conestoga in the Lancaster area, from thick-bedded granular crystalline dark- and light-gray purer high-calcium limestone of the lower part of the formation. These purer granular beds are extensively quarried around Howellsville and eastward. (See fig. 3.) In the W. E. Johnson quarry, just east of Howellsville, about 250 feet of limestone is quarried. The lower 20 feet or more, which is fine, even-grained, and dove-colored to buff, is tentatively assigned to the Elbrook. The rest of the limestone, 230 feet thick, is believed to be Conestoga. It is massively bedded dark- and light-gray coarsely granular limestone and white marble, finely laminated and banded by darker layers, with mica-coated partings. Although the apparent dip is uniformly 70°–80° S., minute plications of the real bedding within the layers are observable on some weathered surfaces, and the beds are probably intricately folded throughout. The schist exposed above the pure limestones in the large old quarry west of Howellsville has thin parallel smooth parting planes, which are slip cleavage and not bedding. It dips 80° S., parallel to the cleavage in the adjacent limestone. The schist shows no remnant of the folded bedding, which has been destroyed by intense crumpling and internal movement, although close folding is observable in the pure thick-bedded limestone below and in the thin-bedded limestone above. The thickness of this schist is stated by Miller [40] to be 115 feet, but this is probably not the true thickness because of the close folding. Although the phyllite was not observed west of Whitford, thicker-bedded granular limestone is generally present to the west in the lower part of the formation, and in places, as at the quarry west of Downingtown, it is conglomeratic.

In the Pennsylvania Railroad cut south of Ackworth the section is as follows:

Section of Conestoga limestone in Pennsylvania Railroad cut south of Ackworth

	Feet
Upper thin-bedded argillaceous beds:	
Thin-bedded highly micaceous blue limestone, closely folded and contorted; estimated thickness	300
Highly micaceous thicker bedded granular crystalline limestone	60±
	360±
Sharp contact, probably representing phyllite beds to east.	

[40] Miller, B. L., Age of the schists of the South Valley Hills, Pa.: Geol. Soc. America Bull., vol. 46, p. 742, 1935.

	Feet
Lower purer limestone beds:	
Thick white marble and laminated dark limestone, internally folded	120±
Coarse white marble, thin-bedded limestone, and thin dark dolomite beds	50±
Brecciated limestone bed, cemented by calcite and quartz; fault(?).	
Granular crystalline blue limestone and thin buff limestone, partly concealed by railroad tracks	150±
	320±
	680±

The lower part of this section may be repeated by faulting, indicated by the brecciated layer.

South of Downingtown the following section was measured.

Partial section of Conestoga limestone in quarry south of Pennsylvania Railroad in Downingtown

	Feet
Conestoga limestone:	
Upper beds: Highly micaceous limestones, south wall of quarry and hill to south.	
Lower purer beds:	
Very massive blue marble streaked with white; some beds closely folded and lenticular. Upper layers dark and light ribbon-banded	80±
Very massive-bedded bluish granular crystalline limestone, streaked with white and weathering ribbed. Some shaly micaceous partings at base	35±
Hard bluish to white laminated crystalline limestone with shaly micaceous layers	5
White coarse saccharoidal marble	1
Hard laminated bluish crystalline limestone with 2-foot lenticular magnesian limestone	5
Shaly-weathering laminated white granular crystalline limestone with dark streaks	35±
Finely laminated white granular crystalline limestone with black streaks and 4-inch lenticular magnesian limestone layers	5
White marble highly banded with fine dark streaks, crumpled near base	6
	172±
Sharp wavy contact.	
Elbrook limestone(?):	
White saccharoidal marble alternating with buff magnesian layers. Some beds weather buff like Elbrook. Some residual banded chert at surface	20
Thick-bedded white granular saccharoidal marble, finely laminated on weathering, with fine buff magnesia layers, some weathering roughly granular	23
White granular saccharoidal marble with fine bluish laminations and interbedded fine-grained magnesian limestone.	

Southwest of Downingtown, in the Coatesville quadrangle, coarsely crystalline micaceous limestone, in places conglomeratic and containing beds of very sandy limestone which weathers to porous sandstone and light sandy soil, forms a line of hills in the northern part of the belt of Conestoga limestone in Chester Valley and evidently represents the lower member of the formation. Similar granular limestone and conglomerate occur in the lower part of the formation north of Mine Ridge, in the New Holland and Quarryville quadrangles. This is especially well shown at Lime Valley, on Pequea Creek in the Quarryville quadrangle, where at the base of the formation 40 feet of massive white, coarsely crystalline, pure limestone,

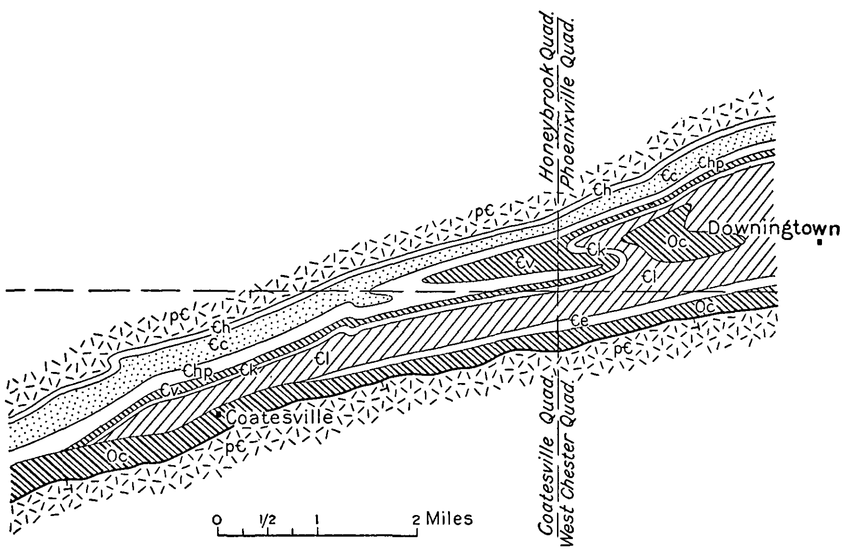

FIGURE 4.—Generalized geologic map of part of Chester Valley showing overlap of Conestoga limestone. Oc, Conestoga limestone; Ꞓe, Elbrook limestone; l, Ledger dolomite; Ꞓk, Kinzers formation; Ꞓv, Vintage dolomite; Ꞓhp, Harpers phyllite; Ꞓc, Chickies quartzite; Ꞓh, Hellam conglomerate member; pꞒ, pre-Cambrian rocks.

in part conglomeratic, is quarried and is overlain by thin dark graphitic shale and impure dark argillaceous limestone. This area is north of the Mine Ridge anticline.

The thickness of the Conestoga in this area is estimated at 500 to 800 feet.

Age and correlation.—The Conestoga limestone was named from Conestoga Creek, in the Lancaster area.[41] In Chester Valley in the Phoenixville quadrangle and eastward the Conestoga rests on Elbrook limestone and Ledger dolomite. At Coatesville,[42] just south of the Honeybrook quadrangle, it overlaps successively the Ledger, Kinzers, and Vintage formations, down to the Harpers phyllite, on

[41] Pennsylvania Geol. Survey, Atlas of Pennsylvania, no. 168, Lancaster quadrangle, 1930.
[42] U. S. Geol. Survey Geol. Atlas, Coatesville-West Chester folio (no. 223), 1932.

which it rests as far west as Quarryville. (See fig. 4.) It is thus seen to be an unconformable formation younger than Elbrook that transgresses older eroded formations down to the Lower Cambrian Harpers phyllite.

The Conestoga limestone was formerly believed to be of Chazy age or younger, because fossils collected near the supposed base of the Conestoga northeast of York were identified as of Chazy age, and also it was supposed to overlie beds containing fossils of Beekmantown age at Henderson, in the Norristown quadrangle. (See fig. 3.) The fossils found near York have recently been redetermined by G. A. Cooper to be of Lower Cambrian age, and the beds in which they occur are therefore upper beds of the Kinzers formation, which there underlies the Conestoga. The fossils from the Norristown quadrangle were obtained from a layer of limestone similar to the lower beds of the Conestoga in that area but largely replaced by silica in the form of clusters of radiate quartz crystals in geode cavities. Large masses as much as 4 or 5 feet in diameter of this quartz chert are strewn along the basal contact of the Conestoga limestone for 3 miles west of Henderson, but fossils have been found preserved in this very unfavorable rock only at Henderson. In fact, all the known fossils were collected by Lewis Woolman and J. E. and H. G. Ives in 1899 from a small quarry at Henderson station, now abandoned and largely filled up. They are on file in the Museum of the Academy of Natural Sciences, Philadelphia, and in the laboratory of Bryn Mawr College and have recently been reidentified by E. O. Ulrich and A. F. Foerste as follows:

A coiled cephalopod closely similar to *Tarphyceras seelyi* (Whitfield).
Several orthoconic cephalopods.
Eoconia aff. *E. etna* (Billings).
Hormotoma cf. *H. gracilens* Whitfield.
An *Ophileta*-like gastropod.
Maclurites aff. *M. oceanus* Billings.
Maclurites cf. *M. speciosus* Billings.
Coelocaulis? sp.

All these forms indicate the upper Canadian of Ulrich, Beekmantown of Geological Survey usage, probably equivalent to the Cotter dolomite of Missouri.

The Conestoga limestone in Chester Valley is therefore apparently of Beekmantown age, probably in part equivalent in time to the Beekmantown limestone north of the Mine Ridge uplift in the western part of the Honeybrook quadrangle and the adjacent New Holland quadrangle. The fact that the Conestoga limestone is so entirely different in lithologic character from the Beekmantown indicates that the Chester Valley basin in which it was deposited was separated from the sea to the north in which the Beekmantown was deposited by a partial barrier represented by the Mine Ridge uplift. This barrier was no doubt rising during the deposition of the Cambrian limestones, because the Vintage, Kinzers, Ledger, and Elbrook formations south of the uplift are all thinner than the same formations north of it. In post-Elbrook time the barrier rose still higher, temporarily draining the Chester Valley arm of the sea, for these Cambrian formations were in part eroded and their edges truncated before the deposition of the Conestoga, which entirely overlaps them in the Coatesville quadrangle and there rests on the Harper and Antietam formations. (See fig. 5.)

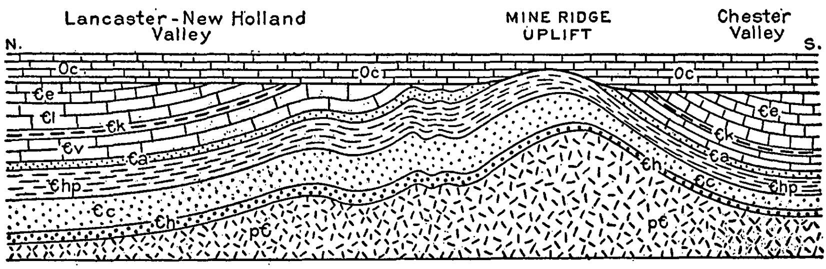

FIGURE 5.—Ideal section across Mine Ridge uplift, showing deposition of Conestoga limestone unconformably on older rocks. Shows pre-Conestoga anticlinal uplift and erosion of the older formations and overlap of the Conestoga limestone onto the Harpers phyllite on the crest of the fold. The pre-Conestoga formations are also thinner on the crest of the uplift and in Chester Valley, showing incipient elevation and shallowing of the sea during deposition. Oc, Conestoga limestone; Ꞓe, Elbrook limestone; Ꞓl, Ledger dolomite; Ꞓk, Kinzers formation; Ꞓv, Vintage dolomite; Ꞓa, Antietam quartzite; Ꞓhp, Harpers phyllite; Ꞓc, Chickies quartzite; Ꞓh, Hellam conglomerate member; pꞒ, pre-Cambrian rocks.

MESOZOIC ROCKS

TRIASSIC SYSTEM

By F. BASCOM, with the aid of field notes by E. T. WHERRY

Newark group in general

Extent.—The Triassic formations described in this bulletin are a part of an occurrence of the Newark group that extends with unbroken continuity from the Hudson River southward through New Jersey, Pennsylvania, and Maryland into Virginia. Detached areas in Nova Scotia, Massachusetts, Connecticut, Virginia, and North Carolina make a belt of discontinuous occurrences over a thousand miles long; this belt was probably never a continuous one, and portions of it are now widely separated.

Constitution and structure.—Newark rocks, wherever they occur, are remarkably uniform in character. They comprise great thicknesses of alternating conglomerates, sandstones, and shales, for the most part of a reddish-brown color, with intercalated sills, lava flows, and dikes of basaltic composition. The intrusive rocks or dikes are without question younger than the formations which they intrude; however, they doubtless had their source in the same magma from which the Triassic lava issued; they are known from contacts farther to the east to be pre-Cretaceous and to have been deeply eroded before Cretaceous time. They are essentially of Triassic igneous material and are discussed with the Triassic igneous rocks (pp. 76–78).

The prevailing structure is homoclinal—that is, the beds dip in the same direction without repetition—and normal and vertical faults are common. In New Jersey the prevailing dip of the formations is westward at low angles; in Pennsylvania the dips are northwest; in New England and Nova Scotia and in the most easterly areas in Virginia and North Carolina the dip is to the east. The aggregate thickness of the sedimentary rocks is considerable, though less than the great width of territory in which there are homoclinal dips would indicate. Strike faults so repeat the outcrops of the strata that the actual thickness has been only approximately determined.

Age.—The age of the Newark group is believed to be Upper Triassic, with the possibility that it may include the early Jurassic, but its precise equivalence is still undetermined. A comparison of fossil plants, crustaceans, and vertebrates of the Newark with similar forms of the Jura and Trias of Europe establishes a correspondence within general limits, but a correlation of exact horizons is not practicable.

The Newark strata did not share in the folding that occurred at the end of Carboniferous time and therefore must be of later date; they are, however, clearly older than the lowest Cretaceous formations, which overlap them unconformably. They are thus separated from earlier and later deposits by intervals of upheaval and erosion of unknown duration, but their position in geologic history cannot be determined more closely than by the general correlation of fossils above indicated.

Subdivisions.—The rocks of the Newark group in eastern Pennsylvania and New Jersey have been classified in three formations—the Stockton, Lockatong, and Brunswick—the last-named the youngest. These subdivisions are clearly separable along the Delaware River and northeastward in New Jersey, where they were first established and named.

The Stockton formation in general comprises arkosic sandstone with some red-brown sandstone and red shale, in irregular succession and presenting many local variations in stratigraphy. It lies unconformably on Paleozoic and pre-Paleozoic crystalline rocks. The sandstones are in places cross-bedded, and the finer-grained rocks exhibit ripple marks, mud cracks, and raindrop impressions, which indicate shallow-water conditions during deposition. The arkose, a sandstone containing more or less feldspar or kaolin derived from granite or gneiss, indicates proximity at the time of deposition to a shore of pre-Cambrian crystalline rocks.

The Lockatong formation consists chiefly of dark-colored fine-grained hard and compact argillaceous rocks. Some beds are massive, and others are flaggy. They show mud cracks and other evidences of shallow-water deposition, but their materials are clay and very fine sand; some of the beds contain also carbonaceous material.

The Brunswick formation, in its typical development, consists mainly of a great thickness of soft red shale with local and thin layers of sandstone. Northward and westward the sandstone increases in amount and coarseness. It overlaps irregularly older Triassic formations and Paleozoic and pre-Paleozoic formations.

The three formations are not sharply separated by abrupt changes of material but usually merge into one another through beds of passage which appear to vary somewhat in thickness and possibly also in stratigraphic position in different areas.

Newark group in Pennsylvania

The Newark group in Pennsylvania occupies a belt extending across the southeastern portion of the State from the Delaware River to the Maryland line south of Gettysburg. This belt is 32 miles wide near the Delaware, 10 miles near the Schuylkill, 12 miles near the Susquehanna, and 14 miles at the Maryland border; it overlaps irregularly Paleozoic and pre-Paleozoic formations. In some portions of the area its margin is determined by faults. Over wide areas in the east and west the dips are to the north and northwest, but in the central districts there are flexures of considerable amount and extent. The numerous normal faults mostly extend northeast, with the downthrow on the east side of the fault plane. One such fault extending through Bucks and Montgomery Counties has a vertical displacement of several thousand feet. The thickness of the Newark group in eastern Pennsylvania, allowing for repetition by faulting, is estimated at 20,000 feet, but in no single vertical section does this total thickness occur owing to deposition in a basin deepening to the west.[43]

Newark group in Honeybrook and Phoenixville quadrangles

In the Honeybrook and Phoenixville quadrangles the rocks of the Newark group cover an area of about 180 square miles, extending across the northern portion of the quadrangles. At its greatest width, on the east margin of the Phoenixville quadrangle, the belt of Newark rocks is about 10 miles wide, and from this width it narrows to 5½ miles in the central portion of the area and widens again slightly to 7 miles on the western border. There are three outliers of the Stockton in Conestoga Valley, Caernarvon Township, which

[43] U. S. Geol. Survey Geol. Atlas, Fairfield-Gettysburg folio (no. 225), p. 9, 1929.

rest on Elbrook and Conococheague limestones, and inliers of pre-Triassic crystalline rocks north and northeast of Elverson. The irregular southern margin is due in part to faulting but in greater part to unequal erosion of material laid down on an uneven floor. Presumably the formations extended originally a mile or two farther south but have been removed by erosion. They were deposited upon eroded pre-Cambrian gneisses and Paleozoic quartzite and limestone.

The relatively soft shales of the Brunswick, which cover the northeastern portion of the district, give rise to an open rolling country with a maximum altitude of 434 feet and an average altitude between 200 and 300 feet. The Cambrian quartzite inlier, the quartzose conglomerate member of the Brunswick, the resistant Lockatong formation, and the Stockton sandstone, covering the western and southeastern portions of the Newark area, produce a rugged topography with a maximum altitude of 1,044 feet. This country is heavily wooded, thinly settled, and somewhat difficult of traverse.

The general structural relations of the sedimentary rocks and the igneous masses are illustrated by the structure sections on plate 1. These sections show the general dip, the order of succession, the relation of the intercalated sheets, and the origin of the more prominent topographic features. The igneous masses crossed by the sections are intruded sheets and crosscutting bodies.

STOCKTON FORMATION

Distribution.—The beds of the Stockton formation crop out along the southern border of the belt of Newark rocks. The area of outcrop extends nearly east and west, with a maximum width of 2½ miles west of Phoenixville, a minimum width of three-fourths of a mile east of Pughtown, and an average width of 2 miles. There are three outliers in Conestoga Valley where the Stockton caps hills.

Like the other formations of the Newark, the Stockton is intruded by igneous material and is further interrupted in the eastern portion of the area of outcrop by inliers of pre-Cambrian and Paleozoic crystalline rocks, which form hills of considerable height.

Character.—The rocks of the Stockton formation are chiefly conglomerate and arkosic sandstone with a few layers of red shale, and in part red shale with a few beds of sandstone. The sandstone and conglomerate are conspicuously micaceous and arkosic. In the eastern section of the area the basal beds are conglomerates composed of pebbles ranging from 1 inch to 3 inches in diameter in a matrix of smaller fragments of quartz, feldspar, and mica. Above these beds are yellow or gray sandstones, which in some places have interbedded red shales. At the top occur thick beds of dark-red shale with only sparse yellow sandstones. (See section, p. 72.) Toward the western part of the area, where the Lockatong is absent and the Brunswick immediately overlies the Stockton, the shales thin out and the conglomerate becomes more prominent, still characterized, however, by the presence of feldspar and mica fragments and therefore separable from the conglomerate of the overlying Brunswick formation, which rarely contains feldspar pebbles.

Local features.—In the Honeybrook quadrangle the Stockton, in the neighborhood of the diabase which intrudes it for a distance of 10 miles, is an indurated, highly arkosic fine-grained gray conglomerate, not readily separated on casual examination from the adjacent pre-Cambrian gneiss, from which it is distinguished by rounded quartz and feldspar grains. This indurated conglomerate member of the Stockton formation and the Cambrian quartzite, in contact in the neighborhood of Elverson, are not very dissimilar: the former contains pebbles of Cambrian quartzite and is free from sericite; the Cambrian contains only blue quartz pebbles and shows considerable sericite.

A quarry operated by the Phoenixville Iron Co. on the Schuylkill River near the northern boundary of the Stockton formation shows the yellowish-gray arkosic sandstone with shaly red layers typical of the top of the Stockton. Half a mile northwest of Corner Stores, in the Phoenixville quadrangle, is an abandoned copper mine (the Morris mine) in the Stockton. Close to the southern border of the Stockton, 1½ miles south of Phoenixville, are the Frank Showalter quarries in a pink to white sandstone, strongly cross-bedded and dipping 10° NE. The stone is utilized for building. Other quarries in the vicinity are located at the angle of the Montgomery & Chester Electric Railroad in the southern suburbs of Phoenixville, on the Pickering Valley Railroad near French Creek, and on French Creek west of Phoenixville. The quarries are worked as needed for rough building stone. At the old Warwick iron-ore mine, in the Honeybrook quadrangle, there is an open pit about a quarter of a mile in diameter and several abandoned shafts. Conglomerate typical of the Stockton formation is exposed here, somewhat arkosic and containing pebbles 3 inches in diameter. It is metamorphosed and indurated with the precipitation of secondary silica; hematite, magnetite, garnet, calcite, chalcopyrite, and actinolite occur in fissures and cavities. On Garner's farm, 1 mile southeast of Hopewell, is another abandoned iron-ore pit that was worked during the year 1895. The pit penetrates the pre-Cambrian gneiss below the Stockton. Other pits have been dug in the Stockton, prospecting for iron ore west of Elverson and for copper half a mile south of Edwards School on a tributary to Little Conestoga Creek. Many small quarries have been opened at the localities indicated on the map and worked as the stone has been needed for road metal or rough building material. In the dump heap of material from iron-ore pits three-quarters of a mile west of Joanna, opened in 1890, there are concretions of psilomelane reaching 6 inches in diameter.

The soil of the Stockton is, in the main, a light red brown but may also be yellowish, especially where derived from the more feldspathic sandstone. The variable character of the beds in the upper part of the formation is shown in the section on page 72.

Thickness.—The thickness of the Stockton formation in this area is estimated to range from 1,000 feet on the west to 3,000 feet on the east, allowance being made for repetition of the beds by possible strike faulting. Although in some regions any estimate of the thickness of the Newark group is rendered uncertain by the existence of numerous strike faults, the almost continuous exposure of the Stockton formation along the Schuylkill River shows so few faults that these figures are believed to be fairly reliable.

Fossils.—The Pennsylvania Railroad Co. (Frazer branch) has tunneled through the Stockton formation for about a quarter of a mile on the east bank of the Schuylkill River in Montclare. When the fresh material was taken out there were found two species of *Unio*, a fresh-water mollusk, and three other species of Lamellibranchiata thought by Lewis [44] to be of a marine type. At several localities, notably three-quarters of a mile northeast of Sheeder and a quarter of a mile east of Coventryville, in the Phoenixville quadrangle, and 2 miles northwest of Churchtown, in the Honeybrook quadrangle, silicified wood is found in considerable abundance; it has been studied by Wherry [45] and referred to three species—*Araucarioxylon virginianum*, *A. varnartsdaleni*, and *Brachyoxylon pennsylvanianum.*

Name and correlation.—The Stockton formation received its name from the borough of Stockton, Hunterdon County, N. J., some 19 miles northwest of Trenton, on the Delaware River. The formation is exposed in numerous quarries in the neighborhood. The Stockton of the Phoenixville quadrangle is correlated with the same formation in New Jersey, with which it is stratigraphically continuous. It is also to be correlated with the New Oxford, with which it is continuous to the southwest and which is its approximate equivalent.

Because the Lockatong thins westward and disappears near the western border of the Phoenixville quadrangle, the upper limits of the two formations cannot be proved to be the same, hence a new name was introduced.[46]

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[44] Lewis, H. C., Science, new ser., vol. 3, p. 295, 1884.

[45] Wherry, E. T., Silicified wood from the Triassic of Pennsylvania: Acad. Nat. Sci. Philadelphia Proc., July 1912, pp. 366-372.

[46] Kümmel, H. B., New Jersey Geol. Survey Rept., 1896, pp. 35-40, 1897; Jour. Geology, vol. 5, pp. 543-544, 1897. Stose, G. W., and Bascōm, F., U. S. Geol. Survey Geol. Atlas, Fairfield-Gettysburg folio (no. 225), p. 9, 1929.

LOCKATONG FORMATION

Distribution.—The Lockatong formation crops out in a narrow belt enclosed between the Stockton on the south and the Brunswick on the north. The belt is 1¼ miles wide on the Schuylkill River at the eastern border of the district and narrows westward, pinching out just north of Coventryville. Its area of outcrop is crossed by a narrow dike and by at least one dip fault.

Character.—The special distinction of the dominantly argillaceous beds of the Lockatong is their hardness and dark color. There is considerable variation, however, both in color and composition. Dull-red sandstones, green, purple, and black shales and argillites, and argillaceous limestones are comprised in the Lockatong formation, in a succession that varies locally.

The base of the formation is drawn at the top of the uppermost bed of the arkosic sandstone of the Stockton formation.

Local features.—The southern boundary of the Lockatong formation is marked by a change in the soil from the light reddish and yellowish browns of the Stockton to darker shades of the same color. The boundary between the Lockatong and Stockton is easily drawn, as the top of the Stockton is an arkosic sandstone, readily separable from the somber purple shales of the Lockatong. A quarter of a mile northeast of Montclare there is a large quarry, now idle, in shale typical of the Lockatong formation showing abundant sun cracks and rain prints. The Lockatong is also characteristically exposed in cliffs along the Schuylkill River from the entrance of the canal northward. The hard red shales at the top of the formation here contain concretions which reach half an inch in diameter. Two joint systems also show here, one striking N. 30° W., and the other N. 85° W. The strike of the beds is S. 85° W. and the dip 13° NW. The following partial section shows the general character of the formation and of the underlying beds of the Stockton:

Section of Lockatong formation and upper part of Stockton formation along Pennsylvania Railroad northwest of Phoenixville

[Measured by G. W. Stose]

	Feet
Brunswick formation: Soft red sandstone and shale.	
Lockatong formation:	
Platy jointed blocky wavy-banded fine-grained calcareous sandstone, blue when fresh; weathers buff; brown plant remains on bedding surfaces	8
Thin blue to olive and buff shaly sandstone; well bedded; smooth bedding surfaces; fucoids near middle	33
Very crumbly shaly yellow fine-grained sandstone	20
Dark-red to chocolate-brown hard shaly fine-grained sandstone	15

	Feet
Lockatong formation—Continued.	
Crumbly yellow shale (largely concealed by railroad fill).	
Red to buff mottled calcareous breccia, blue when fresh	3
Blue sparkling dense calcareous shale	3
Gray to olive shale	(?)
Shaly red sandstone	8
Massive red sandstone, 1- to 3-foot beds	23
Hackly red shaly sandstone	12
Lenticular red sandstone	8
Thick-bedded red sandstone	6
Dark crumbly shale	5
Tunnel (concealed)	(?)
Stockton formation:	
Red crumbly shale	15
Thick purplish sandstone	18
Crumbly red sandstone	15
Thick blocky red sandstone	24±
Crumbly red sandstone.	
White to yellow massive granular sandstone, cross-bedded and lenticular	30±
Soft crumbly red shale.	
White to yellow sandstone.	
Concealed.	
Red crumbly shale and interbedded red sandstone.	
Rusty light-gray to yellow cross-bedded arkosic sandstone	40
Crumbly red shale.	
Red sandstone.	
Thick, poorly bedded white to rusty arkosic sandstone.	

Thickness.—The average dip of the Lockatong is 15°, and as the width of outcrop on the Schuylkill River is about 6,000 feet, the thickness of the formation is about 1,500 feet. No strike faults are to be seen in the continuous exposure of this formation along the east bank of the Schuylkill River, so that considerable reliance can be placed on this measurement. In the Philadelphia district, to the east, the Lockatong is estimated to be 2,000 to 3,000 feet thick. Although faults known to be present have slightly increased the apparent thickness, there seems no reason to doubt that a thickening of the beds occurs in this direction. Westward from the Schuylkill River the width of outcrop of the Lockatong formation gradually decreases until northwest of Coventryville the formation disappears. This thinning westward is due to the disappearance of the lower beds and a progressive change of the upper argillaceous beds to the quartzite conglomerate at the base of the Brunswick formation.

Fossils.—The Philadelphia & Reading Railroad has cut a tunnel under a bend of the Schuylkill River north of Phoenixville, known as the Black Rock tunnel, three-eighths of a mile long, through the middle beds of the Lockatong. In this tunnel the following minerals have been found in the Lockatong: Brookite in minute crystals, fine crystals of calcite, dolomite and ankerite, pyrite, smoky quartz, and sphalerite. When the tunnel was in process of construction in 1857 a considerable amount of fossiliferous material was taken out, an extensive collection of which was made by Charles M. Wheatley. Part or all of this material is now in the American Museum of Natural History in New York City. The plant material was studied by the late Dr. F. H. Knowlton, of the United States Geological Survey, and the following tentative identifications were made:

Equisetum rogersi (Bunbury) Schimper.
Ctenophyllum grandifolium? Fontaine.
Anomozamites?
Stems, etc.

The vertebrate remains were examined by the late Dr. O. P. Hay, of the United States National Museum, and the following forms were recognized:

Amphibia: Eupelor (Mastodonsaurus) durus.
Fish: Turseodus acutus.
Reptiles:
  Clepsysaurus pennsylvanicus.
  Paleoctonus appalachianus.
  Rutiodon caroliniensis.

These forms indicate Upper Triassic time.

C. M. Wheatley also identified *Rutiodon caroliniensis* and further reported *Chelichnus wymanianus* footprints, *Dichynodon rosmarius* and *Rhabdopelix longispinus*. In addition to these forms one freshwater lamellibranch (*Myacites pennsylvanicus* Lea), a crustacean (*Estheria ovata* Lea), and a fish (*Catopterus gracilis* J. H. Redfield) may be certainly stated to have occurred there, but a large number of other forms, reptilian bones, teeth, tracks, and coprolites, fish, and crustaceans, many of which were given names by Wheatley and other writers when first discovered, are not known to have been preserved and, having never been adequately studied and identified, need not be listed here.

Name and correlation.—The Lockatong formation in New Jersey was named from Lockatong Creek, Hunterdon County, in the falls of which it is exposed. The Lockatong of the Phoenixville quadrangle is correlated with the New Jersey formation, with which it is stratigraphically continuous.[47]

BRUNSWICK FORMATION

Distribution.—The area of outcrop of the Brunswick formation is about three times that of the other two formations of the Newark

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[47] Kümmel, H. B., New Jersey Geol. Survey Ann. Rept. 1896, pp. 40–47, 1897; Jour. Geology, vol. 5, pp. 544–547, 1897.

group. It has a width of 6¾ miles on the eastern border of the district, 6½ miles on the western border, and 3 miles in the central part.

Character.—The Brunswick formation, like the Lockatong, undergoes a progressive change westward. Its easternmost exposures show a great succession of comparatively soft red siliceous shales or fine-grained argillaceous sandstones, with a few yellowish or greenish beds of the same type of material. In the vicinity of the Schuylkill River lenses of coarse sandstone appear, which increase both in amount and coarseness westward and finally become the dominant rock. The western equivalent of the main body of shale is mainly conglomeratic with well-rounded quartzite pebbles, usually less than an inch but in places exceeding a foot in diameter, embedded in a cementing material of clay and red iron oxide, which stains both pebbles and matrix. The boundary drawn between the prevailing shale and prevailing conglomerate beds is only approximately correct; the change from one to the other is always gradual; there are conglomerate beds among the shales and shale beds in the conglomerate. In the neighborhood of the northern boundary of the Brunswick limestone pebbles begin to appear and the rock grades imperceptibly into a limestone conglomerate. North of the Honeybrook and Phoenixville quadrangles this becomes a conspicuous formation made up of rounded and subangular fragments of blue and gray limestone ranging from 2 inches to a foot in diameter. The interspaces are filled with finer limestone debris and fragments of a green shale or schist. The cementing material is usually red clay or in some places a yellow clay.

In mapping the Brunswick formation the demarkation between conglomerate and sandstone is based on the size of the included particles. All rocks containing pebbles about one-eighth of an inch in diameter and larger are classed with the conglomerates; material composed of finer debris than this is mapped as sandstone and shale. Toward the west end of the Newark area, where the Lockatong is absent, the Brunswick and Stockton have been separated on the basis of the presence in the Stockton of debris from the disintegration of gneissic rocks, whereas in the Brunswick such material is practically absent, and the pebbles appear to have been derived from the degradation of quartzites, presumably of middle or later Paleozoic age, which have now disappeared from the region.

Local features.—Cross-bedding is not uncommon in the sandy layers of the Brunswick. Most of the numerous quarries in this formation are abandoned, and none are continuously operated. The red shale is used chiefly for ballast and road metal. The hard gray shale is utilized for walls, for dam breasts, and as a rough building stone. A highly siliceous residual clay in the Brunswick formation has been utilized in brickmaking by the Spring City Brick Co., whose plant is on the right bank of the Schuylkill River half a mile south of Spring City. The Joseph S. Garber Brick Co., on the Philadelphia and Reading turnpike east of Pottstown, is making brick from a crumbly red shale.

Quarries at Sanatoga station and 1½ miles northeast of the station expose a hard dark greenish-gray shale with black layers. These shales, which display sun cracks, rain prints, and ripple marks, are of the Lockatong type. The section along the river to the south of Sanatoga station shows, however, that the dark shales are not part of the Lockatong formation brought up by a fault but are interbedded with shale typical of the Brunswick formation.

Section from north to south along Schuylkill River north of Sanatoga station

	Feet
Red shale	150
Greenish-gray shale	400
Hard red shale	200
Gray shale	20
Red shale	40
Gray shale	40
Red shale	500

These measurements should be divided by 4 to get the true thickness of the beds.

There are several minor faults in the section, with an aggregate throw of 85 feet. Of two diabase dikes, one, 8 feet wide, occupies a vertical fault fissure and has altered the shales for a foot on each side of the contact; the other dike is the continuation of the dike at Downingtown, which is a remarkably persistent intrusive, also filling a fault fissure, and can be traced across the country for many miles. This exposure gives it a width of 270 feet. The Sanatoga quarries and other quarries on the contact of this dike with the shale show the effects of the intrusion in a change to a dark-gray or purple color, in the filling of cracks with calcite and epidote, in lenses of chalcocite and cuprite close to the contact, and in the development of cleavage parallel to the dike (N. 65° E.).

The shale exposed in Custer's quarry, on Pigeon Creek southeast of Parkerford, displays these effects of igneous intrusion although the dike does not crop out at the surface. Numerous small faults with a throw of a foot or less accompany the Downingtown fault.

On the east side of the Schuylkill River, 2 miles northwest of Royersford, there are three minor faults. The first (from the south), heading to the west, has a downthrow of 10 feet on the south side. The second, 100 feet northwest of the first, with a shear zone 1 foot wide, has a downthrow of 20 feet. Both of these faults are reverse faults. The third, a quarter of a mile to the northwest, is a vertical fault with a downthrow of 5 feet on the south side.

A quarter of a mile northwest of Sanatoga station and 650 feet from the east end of the Philadelphia & Reading Railroad cut, a lens of green shale is impregnated for about 6 feet with chalcocite, which also has replaced plant remains. Chrysocolla and malachite occur as associated alteration products. A mile northwest of Sanatoga station, in a railway cut, a 4-foot bed of gray shale exposes a sun-cracked surface; the cracks are filled with hardened red clay, which in turn is dissected by a network of cracks.

In the Honeybrook quadrangle many quarries are opened in the pebbly sandstone beds of the Brunswick formation, especially along Beaver Run and the Philadelphia & Reading Railroad. The material is used for bridge piers and building stone.

Thickness.—The Brunswick formation is estimated to have a total maximum thickness of about 16,000 feet, after making due allowance for repetition by strike faulting. This is exclusive of the diabase sheets, which are 1,800 feet thick. Only about half of this thickness is present in the Honeybrook-Phoenixville area, the remainder being developed north from Pottstown. Although at first sight these figures appear unduly large, they are entitled to considerable weight. Many railroad cuts and natural river-channel cuttings offer fine sections through the beds, and the few minor faults that occur can have but a negligible influence in increasing the apparent thickness. Furthermore, the essential continuity of the several diabase dikes that cross the area also indicates the absence of any extensive faults. The reduction, 5 percent, which has been made from the thickness computed from dip and width of outcrop is therefore regarded as ample to cover all possible repetition of beds.

Name and correlation.—The Brunswick, like the other members of the Newark group, received its name from a locality in New Jersey where it is typically developed, and the Brunswick of the Honeybrook and Phoenixville quadrangles may be correlated with the New Jersey formation on the ground of stratigraphic continuity.

To the southwest it may be correlated with the Gettysburg, though its exact equivalence, owing to the absence of the Lockatong, is not established.[48]

TRIASSIC IGNEOUS ROCKS (DIABASE)

The igneous rocks of Triassic age in the Honeybrook and Phoenixville quadrangles are exclusively intrusive. A considerable and very

[48] Kümmel, H. B., New Jersey Geol. Survey Rept. 1896, pp. 47–55, 1897; Jour. Geology, vol. 5, pp. 547–549, 1897. Stose, G. W., and Bascom, F., U. S. Geol. Survey Geol. Atlas, Fairfield-Gettysburg folio (no. 225), pp. 10–11, 1929.

irregular intrusive body, from half a mile to over a mile in width, traverses the quadrangles in a more or less U-shaped course. This intrusive body gives rise to a rugged country, well-wooded and strewn with boulders. The Triassic formations are altered for 500 feet or more on each side of the intrusion: The shales are baked to a hard resistant black or dark-purple porcellanite, and the sandstones are altered to a hard white sandstone. These bordering zones of altered rocks have been mapped by Stose. One of the principal falls of French Creek is caused by a ledge of hardened baked shale on the southern contact of the dike.

In addition to this conspicuous intrusion there are several relatively narrow dikes. Among the lesser dikes are two, approximately 300 and 200 feet wide, traversing the limestone of Conestoga Valley, in a considerable area east of Conestoga station, and many small dikes 5 feet or more in width on the northern border of the Honeybrook quadrangle; several small and inconspicuous dikes crossing the Pequea Valley; in the Phoenixville quadrangle a continuous dike, exposed in the Pennsylvania Railroad cut near Downingtown and on the East Branch of Brandywine Creek in Downingtown. This dike strikes N. 66° E., changing to N. 15°–20° E. on the northeast and traversing the crystalline rocks and the Triassic sedimentary rocks to the extreme northern edge of the quadrangle. It ranges in width from 200 feet on the Pennsylvania Railroad cut to 500 feet 0.3 mile southwest of Slonaker, 125 feet at the fault south of the Schuylkill River, and 100 and 150 feet near the northern border of the quadrangle. It is somewhat intermittent in outcrop; both topography and soil seem to indicate the absence of the diabase at the surface at recurrent intervals and its reappearance at intervals in the line of the strike. That there has been movement along the fissure filled by the Downingtown dike is evident at the Triassic boundary, which is offset about 300 feet. In the crystalline rocks this fault cannot be detected, nor can contact metamorphism be detected in rocks that were so thoroughly metamorphosed before the intrusion of the dike. The Triassic material of whatever sort that has been intruded by the dike shows alteration in contact with the diabase. The shale is baked—that is, it is hardened and darkened and in some places shows the development of spherical concretions reaching 5 millimeters in diameter. Quarries have been opened along the contact of diabase and baked shale to obtain the hardened shale for road material. The dike is itself faulted 1½ miles west of Linfield, near the Schuylkill River.

Smaller dikes in the Phoenixville quadrangle are exposed on the Schuylkill River one-third of a mile northwest of the Downingtown dike (8 feet wide), on the bend of the river southeast of Linfield (21 feet wide), near Coventry (10 feet wide and striking N. 35° W.), 1 mile east of Knauertown (indicated only by scattered boulders), and a quarter of a mile southwest of Knauertown.

The rock of these intrusions has the usual constituents and texture of diabase. The essential constituents are labradorite and an augite that is violet-colored in thin section; accessory constituents are magnetite, apatite, quartz, and pyrite; secondary constituents are delessite and chlorite. The rock is fresh, and the augite shows only slight alteration to these secondary minerals. The texture is ophitic, and the grain ranges from medium-fine in the wider dikes to aphanitic in the narrower dikes.

In an abandoned quarry at St. Peters, on the east side of French Creek, the diabase contains segregations of pyroxene 3 inches long, and stilbite is developed on the joint planes.

The usual spheroidal weathering is a feature of the diabase. (See pl. 9, *A*, *B*.)

CENOZOIC ROCKS

QUATERNARY SYSTEM

By G. W. Stose

RIVER TERRACE GRAVEL AND RECENT ALLUVIUM

Terrace gravel and recent alluvium are present in the flood plain and near the banks of the Schuylkill River throughout the area, but only the deposit of river gravel and sand northeast of Royersford, at an altitude of 220 feet, has been mapped by E. T. Wherry, who surveyed that part of the area. This deposit is thick enough to be dug for sand.

Wide alluvial flats border the river for long distances above and below Pottstown, and gravel on terraces up to an altitude of 160 feet occurs on the inside of most of the meander curves, such as those at Fricks Lock, at Linfield, and north of Phoenixville.

OLD STREAM GRAVEL

Old stream gravel has been observed at two places in Chester Valley, one northeast of Sidley and the other southwest of Mill Lane. (See map, pl. 1.) This gravel is composed of rounded pebbles, mostly of white quartz but some of dark quartzite, 1 inch to 2 inches in size, enclosed in finer gravel and sand. The deposit near Sidley has also been dug for sand. The significance of these gravel deposits in Chester Valley is not apparent in the Phoenixville quadrangle, but to the east, in the Norristown quadrangle, their origin is clearer. Figure 6 shows the distribution of these gravel deposits in the Norristown quadrangle, copied from the geologic map in the

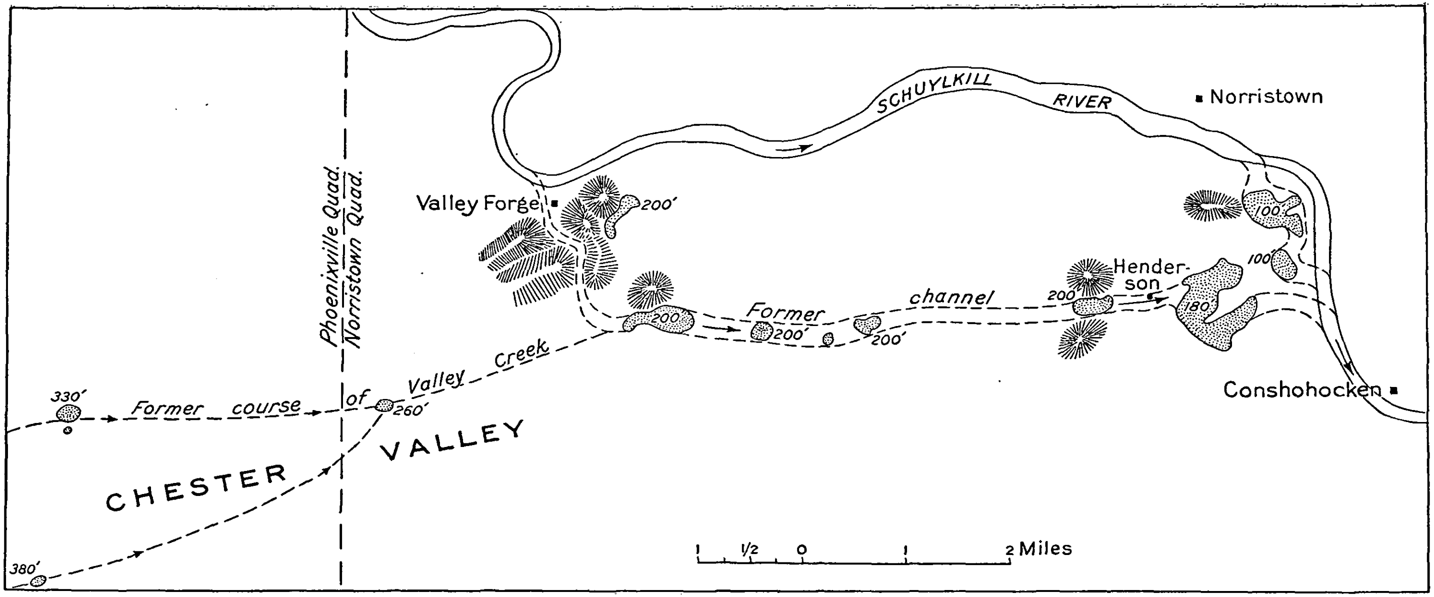

FIGURE 6.—Sketch map of Quaternary terrace-gravel deposits in the Phoenixville and Norristown quadrangles, showing probable former course of the Schuylkill River at 200-foot level and of Valley Creek. Mapping in Norristown quadrangle by F. Bascom; interpretation by G. W. Stose.

Philadelphia folio.[49] They have a uniform altitude of 200 feet and are distributed along a course that was evidently the old channel of the Schuylkill River when it flowed at this level, about 140 feet higher than its present level. At that time the river continued its general southeasterly course beyond Valley Forge, cutting a rocky channel through the Cambrian quartzite hills south of Valley Forge before turning eastward in Chester Valley. Flowing over a Cambrian quartzite barrier and between hills of phyllite, the river was retarded in its down-cutting, so that a tributary flowing on the softer Triassic shales to the north cut its channel deeper and eventually captured the river and diverted it eastward at Valley Forge. The terrace gravels in the Norristown quadrangle are best shown in the railroad cut half a mile west of Henderson station. Here a deposit 40 feet thick of white sand and clay, with numerous round white quartz pebbles as much as 3 inches in diameter, forms a terrace. The level-topped terrace is preserved from erosion in a saddle between hills of phyllite, into which the railroad grade is cut 40 feet.

Valley Creek, which drains the adjacent part of Chester Valley, was then, as now, a tributary of the Schuylkill, and remnants of its gravelly bed are preserved at altitudes of 260 feet in the Norristown quadrangle and 330 to 380 feet near Sidley and Mill Lane, in the Phoenixville quadrangle. When the river was diverted eastward at Valley Forge, Valley Creek followed the old course of the river northward through the rocky gap at Valley Forge, which it still follows. This gap is too large to have been carved in this hard quartzite by so small a stream, but it could readily have been cut by the Schuylkill River.

STRUCTURAL GEOLOGY

GENERAL FEATURES

By F. Bascom

The rocks of the Piedmont province are not found in undisturbed horizontal position but on the contrary show by their vertical or steeply inclined positions evidence of severe compression.

The eastern part of the Continental Shelf was subjected to compression at least three times—before the beginning, at about the middle, and toward the end of Paleozoic time—and this compression closely folded the originally horizontal beds and in some places fractured them and thrust older beds along the fractured planes over and upon younger and originally overlying beds.

Thus was produced the type of structure which prevails in the Piedmont province. It is characterized mainly by anticlines and synclines that strike northeast and are overturned to the northwest so as to give nearly isoclinal dips to the southeast; also by thrust

[49] U. S. Geol. Survey Geol. Atlas, Folio 162, 1909.

faults that have low dips and strike approximately with the formations, and reverse the normal succession by bringing older strata above younger strata. Both folds and thrust faults are cut by normal faults. The compression, which took place both after and before the thrust faulting, has folded fault planes as well as bedding planes and has also developed crystallization, fissility, and schistosity in the rocks.

A central belt of the province is covered by Triassic sedimentary rocks which were deposited after these periods of severe compression and which therefore differ from the older formations in their freedom from metamorphism and in their simplicity of structure.

The Triassic sedimentary rocks rarely show very gentle folding but more commonly have a monoclinal dip at a low angle to the northwest, with numerous nearly vertical normal faults. The faulting presumably involved in some degree both the underlying and the adjacent Paleozoic and pre-Paleozoic rocks. Such faults have been traced in the Paleozoic formations, but because of the absence of well-defined beds it is not possible to trace them for any great distance in the pre-Paleozoic crystalline rocks.

The Honeybrook and Phoenixville quadrangles lie partly in the central belt, where the older rocks are overlain by Triassic sedimentary rocks, and partly southeast of this belt.

STRUCTURE OF THE PRE-TRIASSIC ROCKS

By G. W. Stose

The main structural features of the area are chiefly preserved in the Paleozoic rocks because they are made up of parallel layers that fold under pressure, and these rock layers now show great arches and troughs that have been truncated by erosion. Although the pre-Cambrian rocks were also affected by the forces that produced these folds, they are not made up of parallel layers that can be folded. Moreover, the effects of the later folding are difficult to distinguish from the results of pre-Cambrian deformation and of intrusion by igneous rocks. The relation of the major folds in this area to the South Mountain uplift and the Great Valley is shown in figure 7. The general structure of the area is shown by the structure sections on plate 1. The major structural features of the area are the Welsh Mountain anticline, Barren Hills anticline, Mine Ridge anticline, Chester Valley syncline, and Martic overthrust. (See fig. 8.) The structural features of the region have recently been described in detail.[50]

[50] Stose, G. W., Structure of the Honeybrook uplift: Geol. Soc. America Bull., vol. 48, pp. 977–1000, 1937.

WELSH MOUNTAIN ANTICLINE

The Welsh Mountain fold is a massive anticline exposing largely pre-Cambrian rocks in the Honeybrook quadrangle. The oval area of pre-Cambrian anorthosite surrounded by quartz monzonite east of Honeybrook apparently marks the center of greatest uplift and the deepest erosion, thereby exposing the deepest-lying rocks in the

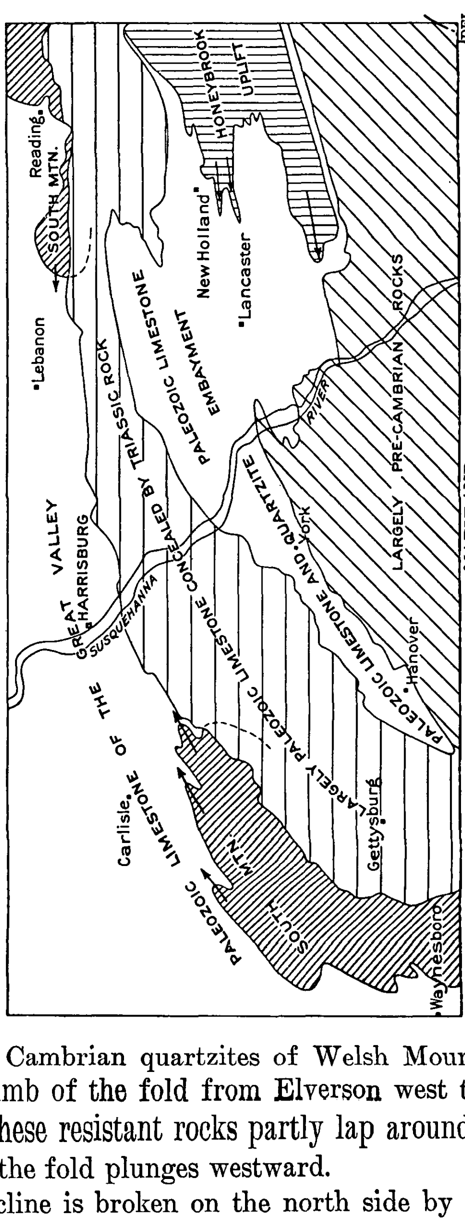

FIGURE 7.—Map of southeastern Pennsylvania showing relation of Honeybrook uplift to South Mountain uplift and Appalachian Valley. The limestones of the Appalachian Valley encroach on the Piedmont by passing around the plunging end of the South Mountain uplift and occupy a wide embayment.

area. The Cambrian quartzites of Welsh Mountain dip north on the north limb of the fold from Elverson west to Narvon. At the southwest these resistant rocks partly lap around the pre-Cambrian core where the fold plunges westward.

The anticline is broken on the north side by a thrust fault, and throughout most of its length the Chickies quartzite is thrust over

Vintage dolomite. At Beartown an anticline of Antietam quartzite rises out of the limestone in front of the overthrust. (See fig. 9.) The Chickies quartzite in the overthrust mass is locally overturned, as, for example, on the mountain side above Narvon, where it dips 60°–80° S. West of Elverson the Hellam conglomerate member at the base of the Chickies quartzite is locally thrust over the Vintage dolomite and a small anticline of Antietam quartzite. This fault is named the Elverson overthrust.

At the west end of the anticline, in the New Holland quadrangle, two long, narrow anticlines of Antietam quartzite, representing the plunging end of the uplift, make long ridges that extend several miles westward into the limestone. These anticlines are faulted on

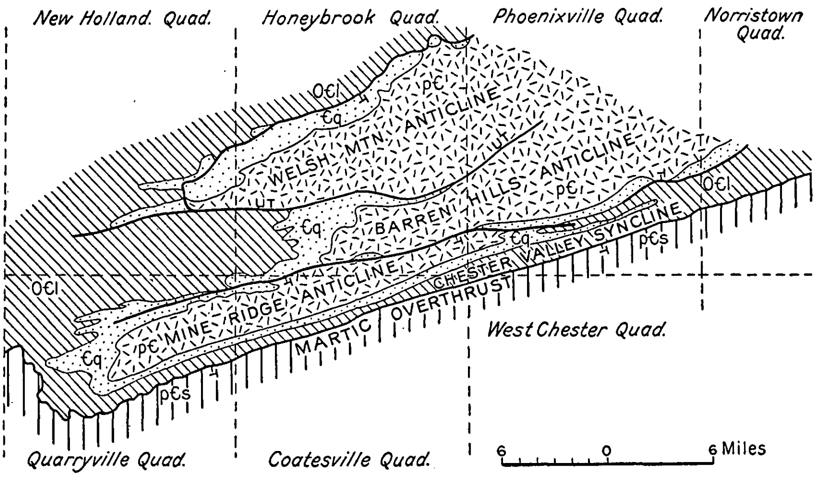

FIGURE 8.—Generalized geologic map of the region, showing the larger structural features. OЄl, Cambrian and Ordovician limestones; Єq, Cambrian quartzites and phyllite; pЄ, pre-Cambrian rocks in the anticlinal uplifts; pЄs, pre-Cambrian schists south of Chester Valley, overthrust on the limestones of Chester Valley. T. Overthrust side of thrust fault; UT, upthrust side of high-angle compression fault.

both sides and were apparently isoclinal folds so tightly compressed that some of the softer rocks on their flanks were faulted or squeezed out.

The anticline is terminated abruptly on its south side by a great high-angle fault, named the Brandywine Manor fault, which brings the Ledger dolomite south of South Hermitage to the level of the pre-Cambrian rocks in the Welsh Mountain anticline and which brings the Chickies quartzite at Brandywine Manor adjacent to the anorthosite in the core of the anticline. This fault appears at first sight to be a normal tension fault, with a downthrow of at least 3,000 feet on the south, but more probably it was formed by compression during the upheaval of the Welsh Mountain anticline. It is believed to be an upthrust of the pre-Cambrian core of the anticline on a steep break. This is discussed more fully below, under the heading "Brandywine Manor fault."

Thomas Hill is a continuation of the Chickies quartzite on the north limb of the Welsh Mountain anticline, detached from the main fold by the invasion of Triassic diabase. It is similarly

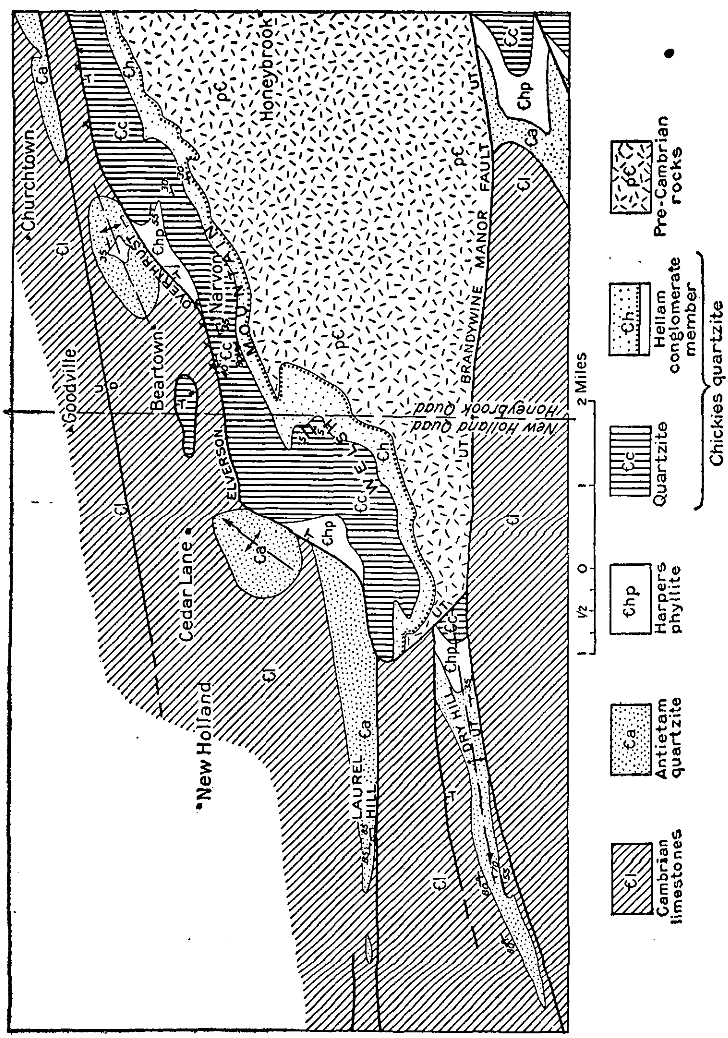

FIGURE 9.—Geologic map of western part of Welsh Mountain anticline, showing Elverson overthrust and Brandywine Manor upthrust. The Elverson overthrust on the north side apparently unites at the west end with the Brandywine Manor upthrust on the south side, and this upthrust mass tore loose from the two attenuated faulted anticlines at the west plunging end of the fold. T, Overthrust side of thrust fault; UT, upthrust side of high-angle compression fault. D, Downthrow, and U, upthrow, on normal faults. Numerous iron-ore banks are shown along the Elverson overthrust.

broken by a fault on its north side, and Chickies quartzite is overthrust on Vintage dolomite in the valley to the northwest and overrides a minor anticline of Antietam quartzite 1 mile north of Elverson. (See fig. 10.) The quartzite on the north limb of the fold is cut out by the overthrust east of Thomas Hill but reappears in a synclinal fold in the low hills to the northeast. Mount Pleasure is a similar northward-dipping plate of Cambrian quartzite resting on pre-Cambrian rocks, and the repetition of this sequence is apparently due to a sharp fold and to a split of the main Elverson overthrust. (See fig. 10.) The Cambrian quartzite is cut out by the Elverson overthrust southeast of Mount Pleasure but occurs again in the small hill on the border line of the Honeybrook and Phoenixville quadrangles, 1 mile northwest of St. Peters. This hill is similarly capped by a northward-dipping plate of Cambrian quartzite resting on pre-Cambrian rocks, but the Elverson overthrust and the overridden limestone north of it are concealed by overlapping Triassic rocks. The sporadic occurrence of the Cambrian quartzite along the front of the overthrust on this part of the uplift is due to its preservation in minor synclines or downfolds, the overthrust having cut into the pre-Cambrian rocks in the intervening anticlinal nodes.

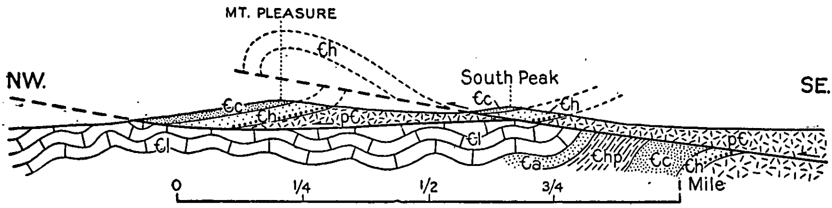

FIGURE 10.—Cross section through Mount Pleasure, showing split in Elverson overthrust. (See pl. 1.) Єl, Cambrian limestones; Єa, Antietam quartzite; Єhp, Harpers phylite; Єc, Chickies quartzite; Єh, Hellam conglomerate member; pЄ, pre-Cambrian rocks.

The structure in this part of the area is obscured by alluvium, especially in the lowland adjacent to the Triassic rocks from Hopewell to Kenneys. The swampy lowland southwest of Mount Pleasure has no rock exposures, but small remnants of the Stockton formation are found on higher land on its borders. The soil in the lowland is reported by Wherry to give an acid reaction and to support a vegetation characteristic of acid soil, which he regards as evidence of the presence of the Stockton formation in the lowlands. However, an acid soil would be produced in poorly drained and swampy lowland even if it were underlain by limestone, especially where the drainage came from sandy slopes of the adjacent Stockton and Chickies. Fragments of Vintage dolomite occur on the flanks of the anticline of Antietam quartzite in the lowland southwest of Thomas Hill, and the dolomite is therefore assumed, from structural reasoning, to underlie the lowland all along the northwest foot of Thomas Hill and the swampy area southwest of Mount Pleasure. No doubt this area was once covered by the Stockton formation, but the Stockton is believed to have been eroded from the lowland area and the limestone floor exposed, and it is so shown on the geologic map.

BRANDYWINE MANOR FAULT

The Brandywine Manor fault has been traced across the Honeybrook quadrangle and 5 miles eastward in the Phoenixville quadrangle to Font. The minimum vertical throw is over 3,000 feet. The Cambrian quartzites and phyllite in the western part of the Barren Hills terminate against the fault almost at right angles. West of the Barren Hills the Vintage dolomite, Kinzers formation, and Ledger dolomite are successively brought into contact with the pre-Cambrian rocks in the uplifted mass. At Brandywine Manor the anorthosite body, believed to have been the deepest-lying rock of the pre-Cambrian in the area, is faulted against the Cambrian quartzites to the south. These quartzites, which are on the north limb of the Barren Hills anticline, strike east, are closely folded but apparently in part dip steeply south, and therefore are overturned, and are highly schistose, the cleavage dipping 45°–60° S. At Cornog the anorthosite is sheared to a mylonite, and the quartzite is converted to a quartz-sericite schist, the schistosity dipping 60° S. East of Cornog the fault is marked by a thick sheared quartz vein and sheared quartzite, the schistosity here also dipping 60° S. At Font the last evidence of the fault consists of a remnant of Cambrian quartzite preserved on the south side of the fault, which makes a prominent hill crossed by the Pottstown road.

The Brandywine Manor fault appears at first sight to be a normal tension fault with downthrow to the south. The absence of brecciation along the fault and the presence of highly schistose rocks and mylonite indicate that the faulting occurred under compression and not under tension, and that it is not a normal tension fault of Triassic age. The southward-dipping schistosity along the fault suggests that the rocks to the south were overthrust on those to the north—that is, that younger rocks, Cambrian quartzites and limestones, are thrust over pre-Cambrian rocks. Such a structure is not impossible, but it is exceptional in the Appalachians.

At the west end of Welsh Mountain the Elverson overthrust, on the north side of the uplift, cuts across the end of the Cambrian quartzites into the pre-Cambrian and joins the Brandywine Manor fault, thus completely cutting off the Welsh Mountain uplifted block at its west end, which was here torn loose from the elongated westward-plunging folds of the anticline. It appears, therefore, that the Elverson overthrust becomes a tear fault at its west end, with a steep upthrust that increases in throw toward the south, where it joins the Brandywine Manor fault, and that the Brandywine Manor fault is probably an upthrust of pre-Cambrian rocks of the Welsh Mountain mass on a steep southward-dipping plane. (See figs. 11 and 12.) It is possible that the plane of schistosity dipping 45°–60° S. represents the original inclination of this fault plane, up which the pre-Cambrian rocks rose, but it seems more likely that the fault plane was steeper or vertical and that the southward-dipping schistosity was produced by later minor northward movement of the Barren Hills block.

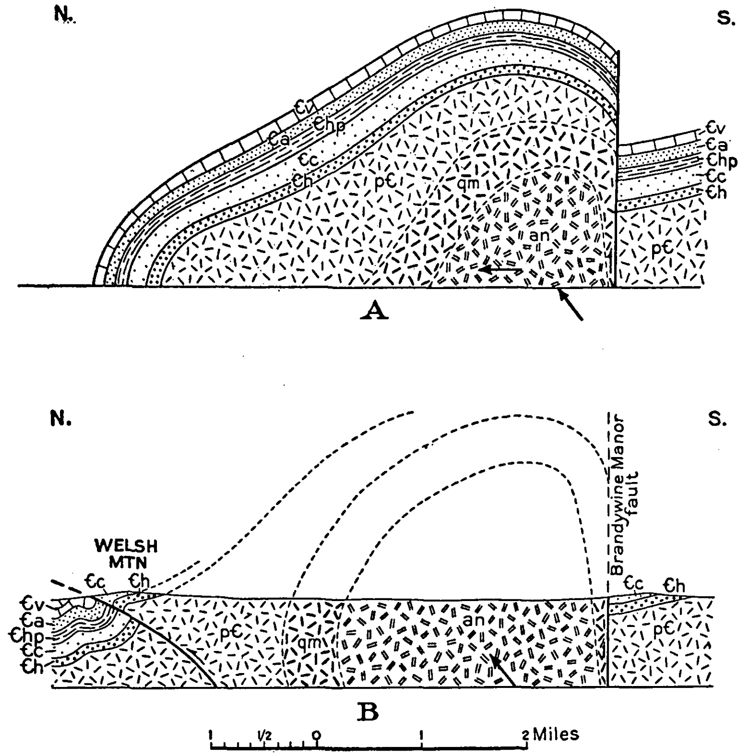

FIGURE 11.—A, Hypothetical cross section of Welsh Mountain anticline in early stage of uplift showing upthrust of pre-Cambrian rocks on Brandywine Manor fault and forward movement of the uplifted mass, resulting from a diagonal upthrust from below. B, Cross section of the anticline after further upthrusting and overthrusting. Ꞓv, Vintage dolomite; Ꞓa, Antietam quartzite; Ꞓhp, Harpers phyllite; Ꞓc, Chickies quartzite; Ꞓh, Hellam conglomerate member; an, anorthosite; qm, quartz monzonite; pꞒ, undifferentiated pre-Cambrian rocks.

BARREN HILLS ANTICLINE

The Barren Hills anticline lies between the Welsh Mountain anticline on the north and the overthrust Mine Ridge anticline on the south. Although it is an anticline, it occupies a depression between these two major uplifts. The Barren Hills are composed of Cambrian quartzites on the north limb of the fold, and the quartzites are overlain by the Cambrian limestones in the Pequea Valley, in the southwestern part of the Honeybrook quadrangle, where the anticline plunges westward. The winding course of the narrow band of Kinzers formation clearly marks three westward-plunging minor anticlines, two of which are broken on their south limbs by faults.

These breaks are apparently steep upthrusts from the north, similar to the Brandywine Manor fault and possibly induced by that movement. The southern fold is cut off by an overthrust from the south,

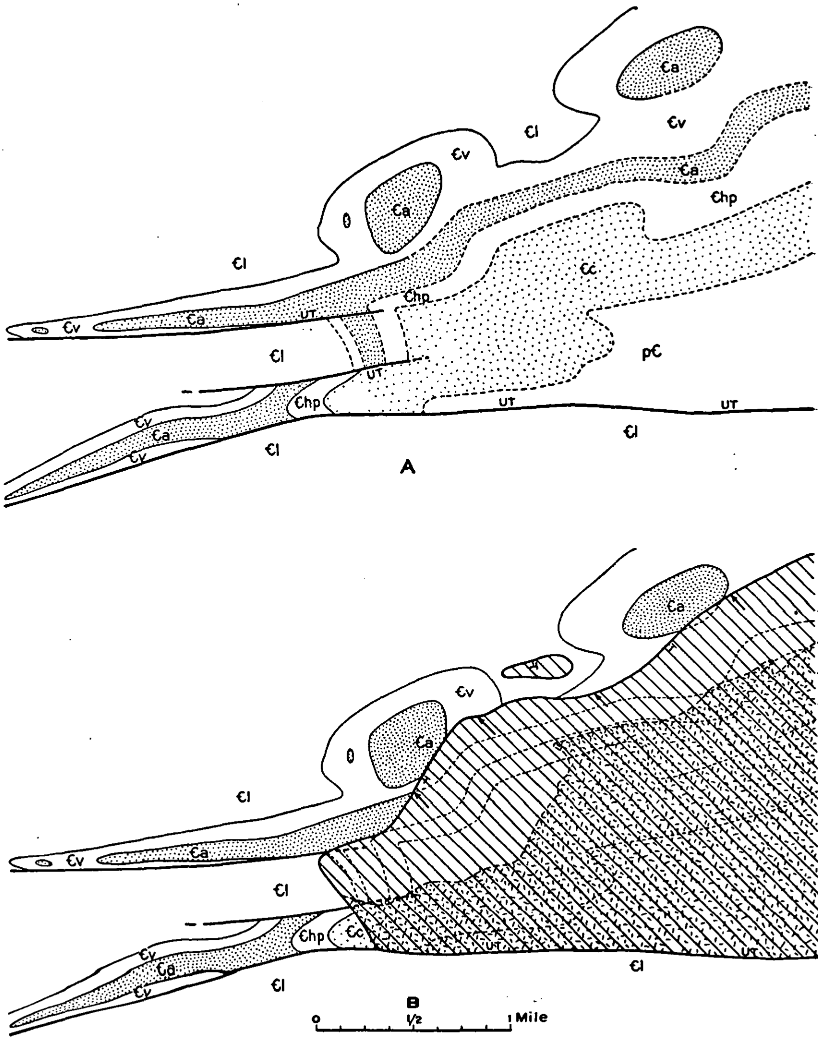

FIGURE 12.—Maps of Welsh Mountain anticline, showing hypothetical stages of folding and faulting. A, Hypothetical early stage of uplift. B, Hypothetical later stage of uplift, showing overthrusting and upthrusting. Ruled pattern, overthrust block; hachured pattern, pre-Cambrian rocks. Overridden structure shown by dashed lines. Ꞓl, Younger Cambrian limestones; Ꞓv, Vintage dolomite; Ꞓa, Antietam quartzite; Ꞓhp, Harpers phyllite; Ꞓc, Chickies quartzite; pꞒ, pre-Cambrian rocks. T, Overthrust on low-angle fault; arrows show direction of movement. UT, Upthrust on high-angle fault.

probably produced by drag from the northward movement on the Gap overthrust of the Mine Ridge anticline. Southeast of Limeville, at the south edge of the Honeybrook quadrangle, the Chickies quartzite is thrust over Ledger dolomite on this fault, and it is therefore named the Limeville overthrust. The Cambrian quartzites of the Barren Hills are folded but in general dip westward, plunging off the anticline.

Farther east the anticlinal character of the Barren Hills fold is shown chiefly by two long, narrow bands of Cambrian quartzite that are enclosed in downfolds on the north and south borders of the anticline. The narrow band of Chickies quartzite extending from Brandywine Manor eastward to Cornog marks the bordering syncline on its north side. This syncline is again shown farther east by the infolded Cambrian quartzite that makes a prominent hill at Font, in the Phoenixville quadrangle. The syncline on the south margin of the anticline is represented by the southward-dipping Chickies quartzite that makes the ridge west of Wagontown and by the narrow belt of southward-dipping quartzite that extends eastward from Corner Ketch to Devault. West of the longitude of Whitford post office the deeper part of this syncline is overridden by rocks thrust from the south on the Gap overthrust. East of this point the Cambrian quartzites and overlying limestones in the syncline are faulted against Ledger dolomite that forms the valley to the south. This relation appears to be due to a normal fault with downthrow to the south, against which the Gap overthrust terminates. North of Bacton another nearly parallel normal fault offsets the quartzites eastward, and near Bacton the quartzites are adjacent to Ledger dolomite on this fault. The rocks in the lowland are so poorly exposed that the relations are not clear, but both the normal faults as here interpreted are indicated by iron-ore pits, cherty fault breccia, and springs.

Northeast of Sidley the limestone lowland swings northward and forms a wide embayment that extends to Devault. Here the quartzites are entirely cut out by a fault, and pre-Cambrian rocks on the north abut against Elbrook limestone on the south for about a mile. The Ledger dolomite exposed in the Cedar Valley quarries a quarter of a mile south of Devault is only gently folded, and the limestones in this embayment may have been dropped adjacent to the pre-Cambrian rocks by a normal fault, but the fault trace appears to be gently curved and not straight and angular, as normal faults in the Appalachians generally are. The attitude of the quartzites at their terminations on each side of Devault indicates a sharp local upfold of these beds with north-south axis, which is truncated by the fault. Just east of Devault these quartzites are overturned and dip 50° N., indicating an overthrust from that direction. Also the folds in the limestone trend east-west, which does not accord with the structure in the uplifted rocks to the north, as it should if it is a dropped normal-fault block. From the data available it is concluded that a minor anticline on the flank of the Barren Hills uplift is locally overturned and thrust southward onto the limestone along a fault plane that dips northward. The erosion of the overthrust mass, if the fault plane were bowed up, would give rise to the limestone embayment. (See fig. 13 and structure sections *A–A′* and *B–B′*, pl. 1.) This fault is called the Devault overthrust.

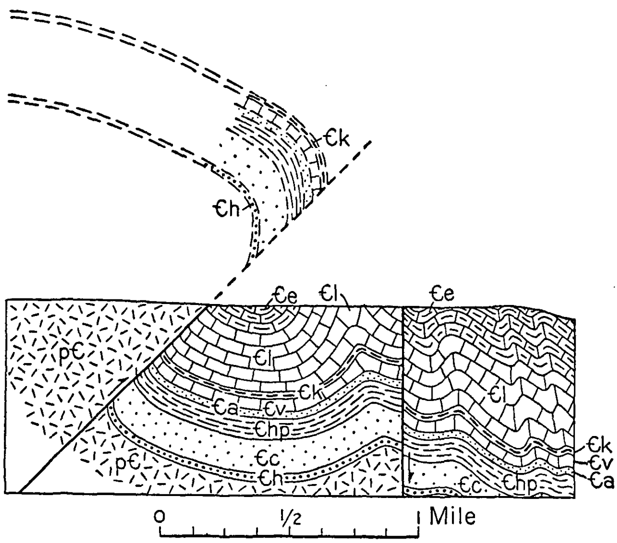

FIGURE 13.—Section across Devault overthrust showing theoretical interpretation. €e, Elbrook limestone; €l, Ledger dolomite; €k, Kinzers formation; €v, Vintage dolomite; €a, Antietam quartzite; €hp, Harpers phyllite; €c, Chickies quartzite; €h, Hellam conglomerate member; p€, pre-Cambrian rocks.

MINE RIDGE ANTICLINE

The Mine Ridge anticline is best shown southwest of the Honeybrook area in the Quarryville quadrangle, where it has been mapped and described by Knopf and Jonas.[51] It is broken on its north side by an overthrust, which at Gap, in the Quarryville quadrangle, carries the Chickies quartzite over the Vintage dolomite. This fault, here called the Gap overthrust, enters the Honeybrook quadrangle near Sadsbury, where pre-Cambrian rocks in the core of the Mine Ridge anticline are thrust over Chickies quartzite. The Cambrian quartzites on the north flank of the fold terminate against the fault southeast of Limeville, in the Coatesville quadrangle.[52] (See fig. 14.) An infold of Cambrian quartzite on the anticline enters the quadrangle for a short distance east of Sadsbury township.

[51] Knopf, E. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pa.: U. S. Geol. Survey Bull. 799, pp. 72–73, 1929.

[52] Bascom, F., and Stose, G. W., U. S. Geol. Survey Geol. Atlas, Coatesville-West Chester folio (no. 223), 1932.

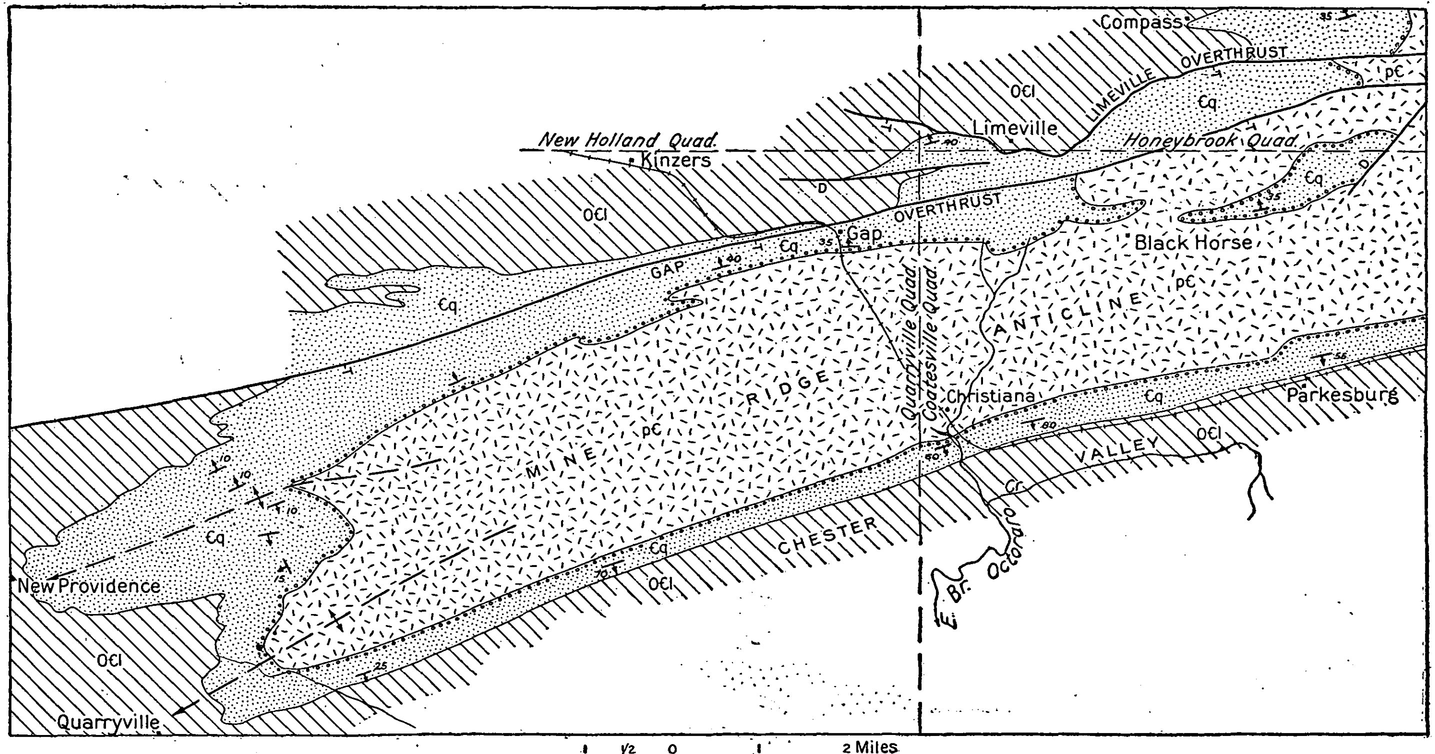

FIGURE 14.—Geologic map of western part of Mine Ridge anticline and Chester Valley syncline, showing Gap and Limeville overthrusts. O-Cl, Cambrian and Ordovician limestones; -Cq, Cambrian quartzites and phyllite; p-C, pre-Cambrian rocks. T, Overthrust side of thrust fault. D, Downthrow side of normal fault.

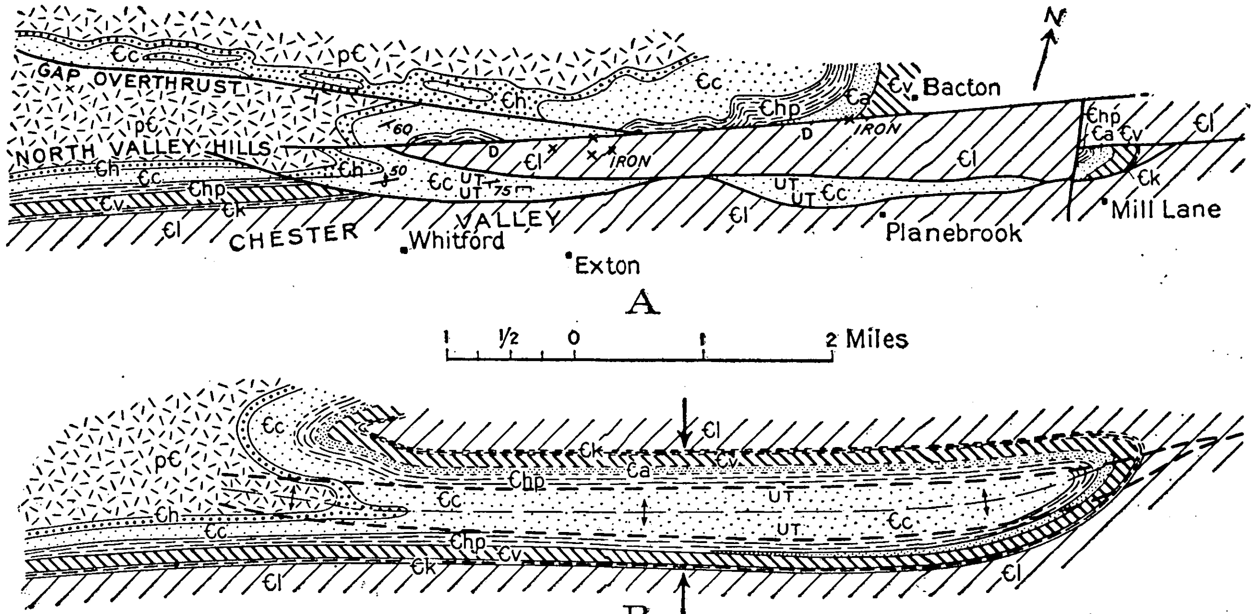

FIGURE 15.—A, Geologic map of faulted Mill Lane anticline, northeast of Exton. The main part of the anticline is represented by schistose quartzite in a narrow fault block, terminating at the east end in a plunging fold. B, Theoretical restoration of anticline before faulting. €l, Ledger dolomite; €k, Kinzers formation; €v, Vintage dolomite; €a, Antietam quartzite; €hp, Harpers phyllite; €c, Chickies quartzite; €h, Hellam conglomerate member; p€, pre-Cambrian rocks. UT, Upthrust side of steep-angle fault. D, Downthrow side of normal tension fault.

The anticline, limited on the north by the Gap overthrust, is well shown in the southwestern part of the Phoenixville quadrangle, south of Corner Ketch, and eastward to the longitude of Whitford. The pre-Cambrian rocks in the core of the anticline are flanked on the south side by a belt of Cambrian quartzites which is much narrower than the belt on the north limb, because the formations are much thinner here, the Antietam quartzite being so thin that it is not mappable but is included with Harpers phyllite. North of Whitford the anticline plunges eastward and the quartzites swing around the end of the pre-Cambrian rocks. The folding here was apparently very intense and was complicated by overthrusting. This is especially shown by the narrow attenuated fault block of Chickies quartzite that tapers to a point northeast of Exton and is continued

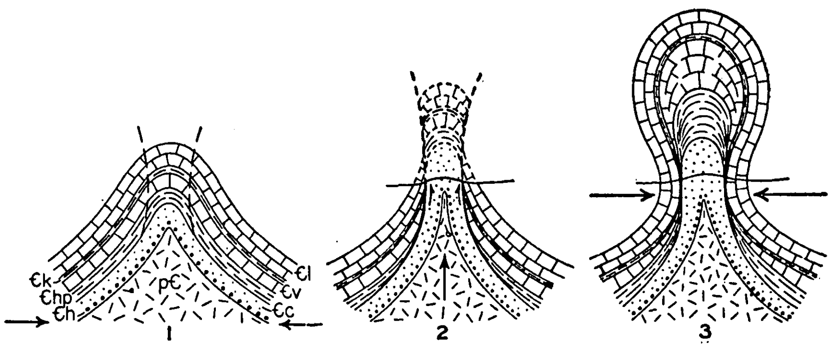

FIGURE 16.—Theoretical cross sections showing progressive stages in development of Mill Lane anticline. 1 and 2 show the quartzites in an isoclinal anticline upfaulted on both sides and sheared through the overlying Ledger dolomite. 3 shows the same result if the softer beds on the limbs of the fold were squeezed out (not supported by the evidence). Ꞓl, Ledger dolomite; Ꞓk, Kinzers formation; Ꞓv, Vintage dolomite; Ꞓhp, Harpers phyllite; Ꞓc. Chickies quartzite; Ꞓh, Hellam conglomerate member; pꞒ, pre-Cambrian rocks.

eastward in a similar fault block of Chickies quartzite that ends in the low hill north of Mill Lane. In this hill the Chickies is overlain by Harpers phyllite, fossiliferous beds of Antietam quartzite, Vintage dolomite, probably Kinzers formation, and Ledger dolomite in normal sequence at the plunging end of the fold, which is therefore called the Mill Lane anticline. Near Mill Lane these formations stand vertical, cross the narrow fault block diagonally, and are cut off abruptly on both sides by the bounding faults. (See fig. 15.)

In a previous paper[53] this fold was included with other examples of a horst between two parallel normal faults of later, probably Triassic, age. The evidence here seems to favor the view that the whole movement took place under compression, while the anticline

[53] Stose, G. W., New type of structure in the Appalachians: Geol. Soc. Ameirca Bull., vol. 35, pp. 475–479, 1924.

was rising. Evidence of great compression is indicated by the overturning of the quartzite on the south limb of the anticline, which dips 50° N. half a mile north of Whitford, and by the schistose structure of the quartzite and the extensive development of mica on parting planes. The evidence does not seem to favor an overthrust on the north side and a normal tension down-fault on the south side. This elongated fold is apparently an anticlinal horst of Cambrian quartzite which has been upthrust along steeply dipping fault planes on both sides and which now protrudes through the limestone. (See fig. 16.) Or it might have resulted from the development of an isoclinal anticline, so greatly compressed laterally that the beds between the heavy quartzite and the massive dolomite were squeezed out on the flanks and forced upward into the crest of the fold. (See fig. 16, section 3.) The presence and attitude of the formations at the crest of the fold as exposed in the Mill Lane hill do not support the latter explanation.

CHESTER VALLEY SYNCLINE

The long, narrow Chester Valley syncline enclosing Cambrian and Ordovician limestones extends from Quarryville northeastward for 75 miles to the Delaware River at Trenton. In part of this area the syncline is less than 1 mile in width, but in the Phoenixville quadrangle it ranges from 1 to 2 miles or more in width. It enters the Phoenixville area southwest of Downingtown and trends northeastward to the east edge of the quadrangle north of Malvern. In the southeast corner of the Honeybrook quadrangle a minor anticline that brings up Harpers phyllite and Antietam quartzite makes a low, narrow ridge that extends 2 miles into the valley as a spur of the North Valley Hills. The axis of the syncline is near the southern margin of the valley, where the Conestoga limestone is enclosed. A minor synclinal depression in the middle of the valley is indicated by the narrow infold of Conestoga that extends southwestward from a point near Exton to Downingtown. This minor syncline is also represented by the detached area of Conestoga limestone west of Downingtown. North of Exton and eastward to the low hill north of Mill Lane the Chester Valley syncline is divided by a narrow belt of Cambrian quartzite brought up in the tightly compressed Mill Lane anticline, which is an attenuated fold of the Mine Ridge anticline, as described above. North of Mill Lane Elbrook limestone is enclosed in the syncline, and at Devault it is cut off by pre-Cambrian rocks overthrust from the north. The Conestoga limestone overlies the Elbrook in the deeper southern part of the syncline east of Mill Lane.

The Chester Valley syncline throughout its length is here interpreted as cut off on its southeast side by the Martic overthrust, which carries pre-Cambrian schists over the syncline and conceals its southeast limb. Because of its structural importance the Martic overthrust is described separately.

MARTIC OVERTHRUST

The great Martic overthrust has been traced from the Delaware River southwestward for many miles. It was first described in detail and named by Knopf and Jonas [54] in their report on the McCalls Ferry-Quarryville region. In that area the pre-Cambrian schists clearly overlie unconformably the Cambrian and Ordovician limestone formations, which here wrap around the southwestward-plunging end of the Mine Ridge anticline and are therefore overthrust from the south on these younger rocks. The overthrust enters the Phoenixville quadrangle south of Downingtown and passes out of the quadrangle north of Malvern. The pre-Cambrian schists of the overthrust mass are more resistant than the Paleozoic limestones of Chester Valley and form a dissected plateau 200 feet higher than the valley floor. Some geologists [55] interpret this contact as marking a normal sedimentary sequence instead of a thrust fault and consider the Wissahickon formation south of it to be metamorphosed Ordovician shale. The fault interpretation is based on a broad study of the contact from the Delaware River across Pennsylvania into Maryland. The evidence of overthrusting consists of the unconformable relation of schist of the Wissahickon formation to the underlying formations, shown chiefly northwest of Quarryville, the prevalence of springs, vein quartz, and iron-ore deposits along the contact, and the greater metamorphism in general of the schists of the Wissahickon than of the adjacent limestones of Chester Valley. The relations shown in the only known exposure of this contact, in the Pennsylvania Railroad cut 1 mile west of New Providence, in the Quarryville quadrangle, are believed by the writer [55a] to favor the fault theory. Schists similar to the Wissahickon have been continuously followed from this area into Maryland, where they are interbedded with volcanic rocks and marble and are overlain by arkose and quartzite which culminate in thick quartzite that caps Sugarloaf Mountain and is generally considered to be Cambrian. The schists in Maryland are therefore probably pre-Cambrian. The available evidence thus favors the fault interpretation.

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[54] Knopf, E. B., and Jonas, A. I., op. cit., p. 74.

[55] Miller, B. L., Geol. Soc. America Bull., vol. 46, pp. 715–756 and 2021–2031, 1935. Mackin, J. H., Jour. Geology, vol. 43, pp. 356–385, 1935. Bascom, F., U. S. Geol. Survey Geol. Atlas, Coatesville-West Chester folio (no. 223), p. 5, 1932.

[55a] Stose, G. W., Age of the schists of the South Valley Hills: Geol. Soc. America Bull., vol. 46, pp. 2021–2026, 1935.

DOWLIN AND MILL LANE CROSS FAULTS

West of Downingtown the Chester Valley syncline and the Mine Ridge anticline are cut by a north-south cross fault along which the outcropping formations are offset. The movement on the fault appears to be largely horizontal, the block on the east side having moved south half a mile with respect to that on the west. Not only the formations are offset in this direction but also the Gap overthrust and the Martic overthrust. It passes near Dowlin and is named Dowlin cross fault. The movement on this fault was later than the general deformation of the region and probably of late Triassic age, but the Triassic dike in West Downingtown is not noticeably offset.

A similar nearly parallel cross fault cuts the rocks west of Mill Lane and is named the Mill Lane cross fault. It noticeably cuts off the Mill Lane anticline and offsets the upthrust faults that bound it, but this effect was probably produced by a vertical rather than a horizontal movement, as the limestone formations are apparently not offset in the same direction. The fault furthermore appears to terminate in the east-west normal fault at Sidley and does not noticeably affect the Martic overthrust at the south.

AGE OF STRUCTURAL FEATURES

The structural features above described are known to have been produced later than early Ordovician time, because the Conestoga limestone is involved in them. The rocks were folded, broken, and overthrust during a period of great compression and mountain making, and the structural features are therefore believed to have been formed during the Appalachian revolution at the end of Carboniferous time, when most of the mountain building of the Appalachians occurred. Earlier in Paleozoic time there was minor upfolding, such as the incipient rising of the Mine Ridge anticline indicated by the thinning of the early Cambrian sedimentary rocks on its crest and in the Chester Valley basin to the south. (See fig. 5.) Also, this area was gently uplifted in pre-Conestoga time, and some of the surface rocks were eroded, so that when the Conestoga limestone was deposited, it overlapped the eroded edges of formations down to the Ledger dolomite and, in the Coatesville region, down to the Harpers phyllite. (See fig. 4.) The Downingtown and Mill Lane faults are of somewhat later date and may be of late Triassic age. Probably some of the east-west normal faults also are late Triassic, because similar nearly parallel normal faults in the vicinity of King of Prussia, 5 miles east of the Phoenixville quadrangle, affect the Triassic sedimentary rocks and are therefore of late Triassic age.

STRUCTURE OF THE TRIASSIC ROCKS

By G. W. Stose

The Triassic rocks in the northern part of the area are not folded, like the pre-Triassic rocks to the south, because they were deposited after the folding took place. They are, however, tilted gently northward, which is the result of a general uplift of the southern region relative to the region on the north. The downward movement was accompanied by and culminated in a great down-faulting of the north edge of the Triassic basin along a line of eastward-trending normal faults, 5 miles or more north of this area. This tilting was accompanied by more or less fracturing and normal faulting of the Triassic rocks, and some of these faults extend into the older rocks south of the Triassic area. This tilting and faulting occurred after the red Triassic sediments were deposited and after they were intruded by the larger molten masses of diabase. The fault south of Joanna, in the Honeybrook quadrangle, occurred later than the diabase intrusion, for the Triassic rocks here adjacent to the diabase are red and are not baked by the diabase, as they would be if the diabase had intruded them. Several small faults cut the south margin of the Stockton formation and offset it. The fault 2 miles west of Phoenixville offsets the basal contact of the Triassic nearly half a mile. The zinc mines south of Phoenixville apparently lie along minor normal faults of this character. These faults are not the result of compression, but rather of release from such stresses, or of actual tension in the rocks, allowing the broken blocks to be adjusted by settling and tilting.

Small normal faults have been observed in outcrops of the Triassic rocks. A fault is exposed in the Philadelphia & Reading Railroad cut on the left bank of the Schuylkill River near Linfield. Another small fault in the Reading Railroad cut in the northern part of Phoenixville, photographed by E. T. Wherry, is illustrated in plate 10, *A*. Figure 17 is drawn from a pencil sketch of this fault. The offset of the Triassic basal contact by faults is clearly shown in places. Figure 18 shows the offset of the base of the Stockton formation at Sheeder and near Williams Corner.

The great east-west diabase dike north of Elverson apparently followed an irregular fault break, for it has cut through and displaced the Stockton formation. East of Elverson the base of the formation south of the dike is in places separated more than 3 miles from the base of the main mass of the Stockton north of the dike. The top of the Stockton is also offset by the dike northeast of St. Peters. East-west faults near King of Prussia, east of this area, offset and drop the Triassic rocks. Probably some of the normal east-west faults in the vicinity of Bacton are also of late Triassic

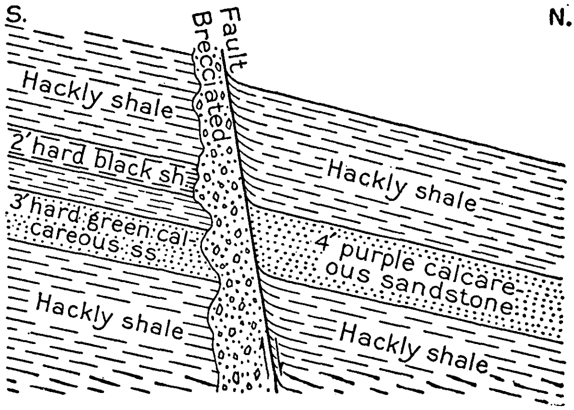


FIGURE 17.—Sketch of minor normal tension fault in Triassic rocks in Philadelphia & Reading Railroad cut, Phoenixville.

age. The Dowlin transverse fault, although it cuts only pre-Triassic rocks, is probably of late Triassic age, as stated above. The movement here seems to have been chiefly a horizontal shear and not a vertical movement. The great Brandywine Manor fault, although

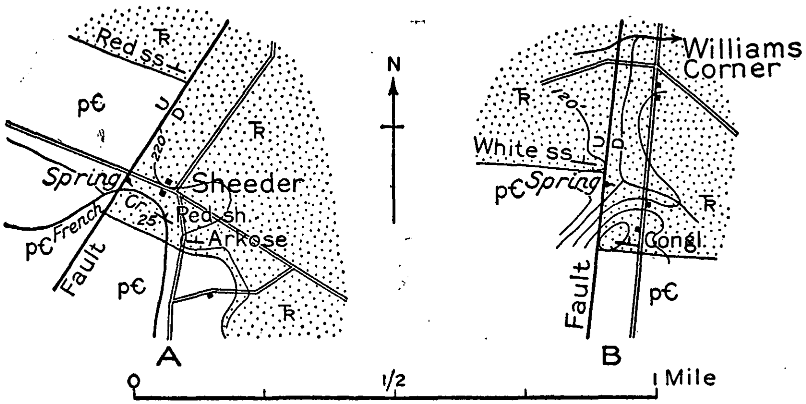
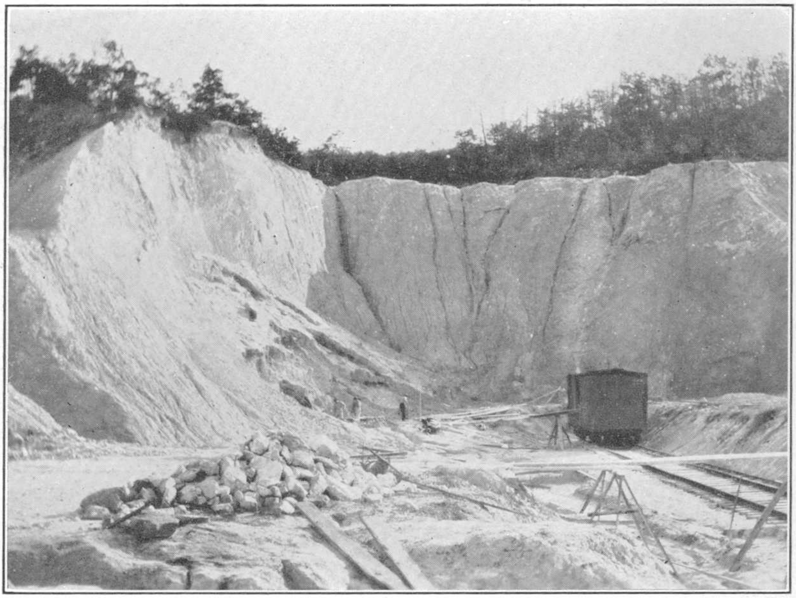


FIGURE 18.—Plans of normal tension faults in the Triassic rocks. A, At Sheeder. B, at Williams Corner. ₮, Triassic rocks; pЄ, pre-Cambrian rocks. D, Downthrow, and U, upthrow.

it has previously been considered to be a normal fault, is closely associated with the uplift of the Welsh Mountain anticline and appears to have been formed under compression at the time of the general uplift and not in late Triassic time.

A. FAULT IN TRIASSIC REDBEDS AT LINFIELD.
Photograph by E. T. Wherry.

B. KARRENFELS DUE TO SUBSOIL SOLUTION OF LEDGER DOLOMITE.
Exposed by stripping. Cedar Hollow quarry, near Devault.



A. WHITE SILICEOUS CLAY DERIVED FROM DISINTEGRATED SCHISTOSE CHICKIES QUARTZITE.

Diller mine near Narvon.

B. CHICKIES QUARTZITE MINED FOR SAND.

Shows gently dipping beds. Mason quarry on Welsh Mountain, 2 miles northwest of Honeybrook.

HISTORICAL GEOLOGY

By F. Bascom

From evidence furnished by the rocks the conclusion has been reached [56] that in early geologic (pre-Cambrian) time there existed three great continental masses—Archi-America, or the North American-Greenland platform; Archi-Eurasia, or the Eurasian platform; and Archi-Gondwana, or the African-Indian-Australian platform.

Archi-America, the pre-Cambrian ancestor of the North American continent, extended considerably to the east of the present Atlantic border and far to the northeast, including Greenland and reaching England. It was perhaps never completely and certainly not continuously above sea level throughout its extent; interior and bordering epicontinental seas, in which sediments accumulated, appeared, disappeared, and reappeared. In the period of greatest submergence more than 50 percent of ancestral America was below water. During this and other periods of less but still great submergence pre-Cambrian America, including what is now the American continent, was only a group of islands. The present continental form of North America, which is more nearly coextensive with ancestral America and yet leaves submerged a considerable percentage of the ancient platform, is of relatively recent development.

The oldest rocks of the Honeybrook and Phoenixville quadrangles originated as sediments deposited in an early pre-Cambrian epicontinental sea, the exact limits of which are not established but which must have been located near the Atlantic border of pre-Cambrian America and must have extended as far north and south as the limits of the Piedmont province.

In this pre-Cambrian sea were laid down sand, mixed sand and clay, clay carrying carbon, and calcareous beds of minor extent and thickness. To the southeast this basin continued to exist as a basin of deposition for a long period, preceding a widespread change in the relation of the epicontinental sea to land, when these sediments, consolidated by concentration and pressure, were later intruded by granitic and gabbroitic igneous masses and associated dikes and lifted above the sea. The compression and heat to which these early sedimentary beds were thus subjected produced the crystallization exhibited by the Pickering gneiss and the Franklin limestone and the high degree of crystallization of the schist and gneiss of the Wissahickon formation.

The next sedimentation of which there is record in this district took place at the beginning of Cambrian time, during the island stage of continental growth. A portion of the Atlantic margin of ancestral

[56] Ruedemann, Rudolph, The existence and configuration of pre-Cambrian continents: New York State Mus. Bulls. 239–240, pp. 65–152, 1922.

America formed a long and relatively narrow island (the largest of several islands) which extended north and south between 50° and 30° north latitude approximately. It extended eastward to the present edge of the continental plateau and possibly beyond, possessing possibly a width somewhat less than half its length. This ancestor of the American continent has been named Appalachia, and the epicontinental sea to the west of it has been called the Appalachian sea. Appalachia contributed the detrital material, and the Appalachian sea was the basin to which the materials were brought, in which they accumulated, and where, as will be seen, they were eventually folded, lifted, and eroded, forming the Appalachian Highlands.

The Paleozoic era began with deposition in a narrow epicontinental sea on the submerged western margin of Appalachia, communicating at the south with the open ocean and advancing northeastward and eastward. At first gravel and sand, followed by fine material, were brought down by the streams and accumulated to a depth of not more than 3,000 feet. The relative fineness and moderate thickness of this terrigenous material do not indicate lofty mountains as the source of Cambrian sediments.

As the sea deepened several thousand feet of calcareous material accumulated, including 1,000 feet of pure dolomite. Later the sea shallowed, and in the east gentle folding brought these deposits to the surface and exposed them to erosion, while in the west terrigenous deposits, clay and fine sand from a deeply denuded land surface, were laid down. Upon renewed subsidence calcareous deposits, probably continuous with the terrigenous sediments on the west, progressed over the eroded edges of earlier deposits. Further consolidation with uplift converted these Paleozoic deposits into limestone, dolomite, and shale. This emergence, which affected pre-Paleozoic as well as Paleozoic formations and was not accompanied in the Honeybrook and Phoenixville quadrangles by igneous intrusions, took place at the end of Ordovician time, when continental movement contracted the Appalachian sea and brought part of the submerged western border of Appalachia above water.

There is no record of further sedimentation during Paleozoic time in the Piedmont province of Pennsylvania, but the presence of Silurian and Devonian sedimentary rocks to the northeast (Green Pond Mountain formation) and west is ground for inference that the late Ordovician uplift (Taconic revolution) was followed during Silurian and Devonian time by partial or slight submergence and sedimentation on the western border of Appalachia but probably not in this area. The character of the sedimentation may be inferred from the Silurian and Devonian of New Jersey, to the northeast. The beds are for the most part terrigenous mud, gravel, and sand, which may represent confluent delta deposits on a coastal plain;

red sand and clay, with calcareous sediments, followed by silt and sand deposits, a shallowing of the sea, and final emergence of the continental area.

Beginning in middle Devonian time and continuing into Permian time there took place along the Atlantic border earth movements that united Appalachia with land masses to the north and south and finally expelled the sea from the entire Appalachian district, uniting Canada and the Great Lakes region with the Atlantic border region, but still leaving, on the cessation of these movements, about 25 percent of the present continental plateau submerged.

The great compressive forces that were the cause of the earth movements acted in a northwesterly direction and compressed the sediments that had been accumulating in the Appalachian sea into a wide trough fold, made up of long, narrow, secondary folds trending northeast, at right angles to the compressive force. Overturned folding and thrust faulting in the southeast, where the crowding of the oceanic segment on the continental segment was severest, passed, toward the northwest, first into close folding and then into open folding in the Appalachian Valley, with gradual progression to horizontality at the northwestern border of the Appalachian Highlands.

This prolonged period of dynamic action left its record in the rocks of the Appalachian Highlands. The effect was greatest in the southeast, where the folding was closest, and least in the northwest, where the formations dip gently.

The Honeybrook and Phoenixville quadrangles are in the southeastern area of considerable metamorphism. The pre-Cambrian rocks, which have been subjected to at least three periods of dynamic action and to igneous intrusion, show the highest degree of metamorphism among the formations of the Honeybrook and Phoenixville quadrangles. Formations that were originally sand and mud, later consolidated to sandstone and shale, have by recrystallization become gneiss, with a schistose texture obscuring the original stratification. The carbon present in the mud has crystallized into graphite. The calcareous material, at first consolidated into dark-colored, impure, "amorphous" limestone, then a crystalline limestone, has become a coarsely crystalline white marble, with the impurities crystallized as silicate minerals and the carbon as graphite.

The Cambrian and Ordovician rocks have been subjected to only two periods of dynamic action and have undergone only relatively minor igneous intrusions in these quadrangles. They do not, therefore, show so high a degree of metamorphism as the pre-Cambrian rocks. The sandstone, formed from beach sand, has become by induration a quartzite or, where the beds were made up of less pure sand, a quartzite schist, a mica schist, or even a fine-grained gneiss.

The calcareous rock is a finely crystalline blue limestone in the northern part of the area; farther to the southeast it is a more coarsely crystalline white marble. The fine argillaceous sediment has become a finely crystalline mica schist.

The great Permian uplift was very slow, and erosive forces never ceased to act upon and to modify the rising continent. While this region stood high at the end of the Paleozoic emergence, the crests of arched sedimentary rocks were already reduced and the troughs modified. This reduction of the height of land continued and this region was well advanced toward a peneplain, when a gradual warping of Appalachia in Triassic time developed a slowly subsiding basin, located in the western border of the Piedmont province nearly parallel to the coast line and involving the northern third of the Honeybrook and Phoenixville quadrangles. This warping raised Appalachia on the east and progressively tilted the Triassic basin to the northwest. Thus on the southeast border of this basin there were prevailing shallow-water conditions, oscillating shore lines, and a rising source of detrital material. These conditions brought the greatest thickness of sediments near the present northwest boundary of the basin, where the highest beds of the Triassic overlap pre-Paleozoic and Paleozoic formations. These beds are missing on the southeast border.

Streams from the eastern rising land brought gravel to this basin, forming confluent deltas that spread out northwestward, enclosing local fluctuating lakes. Fine gravel, sand, and sandy clay were contributed to this basin. Later in Triassic time, with progressive tilting and possibly faulting owing to the increasing load of sediments, confluent deltas growing on the northwest border of the basin rested directly upon the old denuded formations. Streams eroding Silurian quartzite on the northwest furnished quartz gravel, boulders, and pebbles, and contiguous Paleozoic limestones contributed limestone fragments.

Near the end of Triassic time, but before Newark sedimentation terminated, igneous material was intruded in sheets and dikes and in other regions was extruded as lava flows, which were in turn buried under sediments. This igneous action was the precursor of earth movements in this region that further warped the floor of the Triassic basin and caused a general dislocation of the Newark sedimentary rocks, resulting in their being broken, faulted, and tilted.

After Triassic time the history of the Appalachian Highlands, including the Honeybrook and Phoenixville quadrangles, is chiefly one of erosion. Sedimentation was confined to the eastern margin of the Piedmont province and to the Atlantic Coastal Plain, while erosion was going on throughout the Highlands division. Successive coastal uplifts accelerating erosion were followed by longer or shorter periods of quiescence and continuous erosion, when eastward-flowing streams widened and leveled their valleys and deposited their sediments on the sea margin. A series of erosion surfaces was thus developed; each surface in turn was lifted and partly dissected, and the detrital material was laid down on its submerged margin. The sea alternately advanced upon a submerged margin or retreated from an uplifted margin and was a subordinate agent of planation. It is not safe to say how far inland such post-Triassic sedimentation was carried, but certainly it went as far as the farthest inland remnant of sedimentation; that it was possibly much farther inland is a hypothesis recently advanced by Johnson [57] on the evidence of regional superposition of drainage.

While the land was being lowered by erosion sediments, separated by unconformities indicating changes in sea level, were accumulating to the depth of 1,500 to 2,500 feet and collectively underlie the Coastal Plain, which borders the Piedmont province.

The quiescent period immediately following the post-Newark uplift was the first and the longest of a series of such periods. The rock floor beneath the Coastal Plain sediments is a remnant of a surface produced during this period of erosion.

Because the change in slope ("Fall Line angle") that marks the junction of the oldest peneplain surface of which vestiges are still preserved (Schooley) with this old rock floor is more sharply angular than would be expected as the product of warping, because the Schooley peneplain possesses a remarkable linear extent and coincides to an improbable degree with the inner margin of the Coastal Plain, and, finally, because the degree of preservation of the Schooley peneplain (Kittatinny-Schooley) is greater than could be expected in a surface as old as the crystalline floor of the Coastal Plain, the existence of a pre-Schooley (Fall Zone) peneplain continuing the singularly uniform and extensive southeast slope of the rock floor has been inferred.[58]

During the following erosion cycle the supposed upraised Fall Zone peneplain, if existent beyond the Coastal Plain, was completely obliterated in the Appalachian Highlands, and there was developed the Schooley peneplain, traces of which—that is, vestiges reduced by erosion—are still preserved in the level-topped ridges of the Appalachian Highlands.

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[57] Johnson, Douglas, Stream sculpture on the Atlantic slope, New York, Columbia Univ. Press, 1931.

[58] Shaw, E. W., Age of peneplains of the Appalachian province: Geol. Soc. America Bull., vol. 29, p. 586, 1918. Sharp, H. S., The Fall Zone peneplain: Science, new ser., vol. 49, pp. 544–545, 1929. Ashley, G. H., Age of the Appalachian peneplains: Geol. Soc. America Bull., vol. 41, pp. 655–700, 1930. Johnson, Douglas, Stream sculpture on the Atlantic slope, pp. 3–22, 1931.

Plains as vast as the Fall Zone and 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 sedimentary beds 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 Schooley peneplain, dating perhaps from the uplift that terminated Lower Cretaceous sedimentation, was developing during the remainder of Cretaceous time. Toward the end of the Cretaceous period Schooley peneplanation was interrupted by continental movements, which warped the peneplain into a low unsymmetrical domelike ridge with its greatest extension in a northeast-southwest direction.

With the uplift that ended Cretaceous time erosion was renewed on the Cretaceous surface, and an incipient peneplain, the Harrisburg erosion surface, was carved in Tertiary (Miocene) time on the softer rocks along the courses of the master streams. Remnants of this surface are preserved in the Honeybrook quadrangle at an altitude of 720 feet, and to the northeast, southeast, and southwest. Large areas of this surface have an impressive extent in the western and northern two-thirds of the Slatington quadrangle. Remnants are also preserved along the Delaware River (near Delaware Water Gap), the Schuylkill River (north of Reading), the Susquehanna River (northeast of Harrisburg), and the Potomac River (west of Hagerstown) and their larger tributaries.

The Martinsburg shale, which is chemically stable and with corrasion retarded by reason of low altitude (600 to 800 feet), has widely preserved the Harrisburg surface. The best-preserved remnant of this surface is south and west of Chambersburg, where it is upheld by Martinsburg shale with an indurated sandstone member. These remnants, as is to be expected in a younger erosion surface, have a larger areal extent near the sea and are everywhere lower than the associated remnants of the older surface.

After the uplift that ended the Harrisburg subcycle the rejuvenated streams developed wide, flat valleys or straths, and before erosion was carried further an upward movement with possibly a low arching brought this incomplete cycle to an end and left its record in the berm that parallels the main streams and carries a thin cover of gravel of late Tertiary(?) (Pliocene?) age, the Bryn Mawr gravel.

This suggested warping, affecting the Harrisburg as well as the Bryn Mawr surface, is believed by some geologists to account for the slope of the land surface on each side of an axis that curves northeast and crosses the Susquehanna River in the neighborhood of Safe Harbor.[59]

A brief period of land stability and erosion is recorded in the Brandywine berm, which parallels the sea and lies between the Bryn Mawr berm and the inner valleys of the larger streams.

In Pleistocene time, owing to glacial and interglacial conditions, oscillations of sea level or advances and retreats of the sea upon the land, are supposed to have occurred, bringing during the period of maximum glaciation the whole Continental Shelf above water and permitting valleys to be cut by the master streams, the Delaware, Susquehanna, and Potomac, across the Atlantic plain to the edge of the Continental Shelf.

Upon the disappearance of the ice these lower stream courses became submerged. The extreme margin of the upland was brought below the open sea or below estuarine waters, when sediments of the Sunderland, Wicomico, and Talbot formations were laid down on three successive beaches or terraces, wave-cut where developed on the seacoast or estuary- and current-cut where developed in a stream-meander belt.

These terraces raised above the sea form gravel-covered berms, which merge in passing up the tributary streams and are collectively expressed in the gorges cut below the Brandywine berm. On the master streams they persist as terraces.

In Recent time a partial emergence of the Atlantic plain brought above the sea the margin of the Piedmont Upland and the sedimentary beds on its border which form the Coastal Plain and established essentially present conditions. Thus the features described in the section on geography record in part the geologic history of the region. The inclined or warped seaward-facing erosion surfaces with discordant rock structure record alternate uplift and erosion; the residual hills consist of more resistant rocks or are more remote from drainage lines; the terraced valleys record brief periods of stability and erosion. The deep mantle of soil and the rarity of rock ledges are evidences that this region has been long exposed to the action of subaerial erosive agents and has never been stripped of the residual decayed rock by a continental glacier such as has covered the area to the northeast.

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[59] Campbell, M. R., Late geologic deformation of the Appalachian Piedmont as determined by river gravels: Nat. Acad. Sci. Proc., vol. 15, no. 2, pp. 156–161, 1929. Stose, G. W., Is the Bryn Mawr peneplain a warped surface?: Am. Jour. Sci., 5th ser., vol. 19, pp. 177–184, March 1930.

MINERAL RESOURCES[60]

By F. Bascom

The mineral products that have been quarried or mined in the Honeybrook and Phoenixville quadrangles are stone (granite, limestone, and sandstone) utilized for building stone, the manufacture of lime, agricultural lime, monuments, Belgian blocks, and road metal; also sand, gravel, clay, flint, feldspar, iron ore, lead, zinc, copper, and graphite.

In spite of explicit admonition as to the futility of the project, a well was at one time drilled for oil in the Pickering gneiss west of Lyndell, with no favorable results.

The water supply throughout the area is constant and good. The soils vary considerably in fertility.

STONE

Many stone quarries have been opened in the Honeybrook and Phoenixville quadrangles, but for the most part the quarried stone has been used for road metal, for concrete, or for rough building stone only. The granite (including quartz monzonite, granodiorite, quartz diorite, gabbro, and diabase) is capable of furnishing good building stone, and the limestone formations have also supplied stone for that purpose. The sandstones of the Stockton and Brunswick formations and the Chickies quartzite have been used for bridge piers and in a minor way for other building purposes.

A few openings, long abandoned, have been made in the Pickering gneiss for local use as road material or foundation walls. The Wissahickon formation has locally furnished stone suitable for use in buildings.

At Aldham, on the Frazer branch of the Pennsylvania Railroad 3½ miles south of Phoenixville, a quarry was opened in 1889 and operated intermittently. Both trap rock (a diabase dike 50 feet wide) and gneiss with pegmatite dikes were quarried here. The gneiss was used for building stone, for concrete, and for roads. It is a strong, hard, and highly tough rock, with alkaline feldspars, and is considered a superior stone. The quarry is owned by the William K. Williams estate, of Phoenixville, and was leased to the Aldham Stone Co., Inc., which ceased operations about 1920. About 1930 it was operated a short time by Warren Brothers, and in 1936 the Public Works Administration took some stone from it for road improvement.

[60] The kind assistance of R. W. Stone, geologist, Department of Internal Affairs, Harrisburg, Pa., in checking and amplifying this section is gratefully acknowledged. In addition to working on the text, Mr. Stone devoted several days in the field to this purpose.

A. Sugerman & Sons opened a quarry in gneiss half a mile north of Devault in 1920 and have produced crushed granite continuously since then. In 1937 the face of the quarry is 70 feet high, and a working pit in the floor is 25 feet deep. The daily output for roads, railroad ballast, and general concrete construction purposes is 500 to 600 tons. Hollow concrete building blocks are made in a plant at the quarry. A pegmatite dike crosses the quarry.

At Cornog a quarry in gabbroic gneiss cut by pegmatite dikes was opened by Harry Rhodewalt in 1907 and leased in 1913 to John Galt, who has operated it many years under the name Keystone Trappe Rock Co. The beds stand nearly vertical and strike northeast. The present quarry face is 150 feet high, and the daily output of crushed stone averages 1,000 tons. The product is used for roads, railroad ballast, and general construction.

The French Creek Granite Co. operates a quarry at St. Peters which was opened in 1885 and has been active almost continuously since that date. The stone is diabase, known as black granite, and is used for monuments, Belgian blocks, building stone, and road material. The Elverson Bank Building and numerous residences have been built of it, and it was used in the subway in Philadelphia. The quarry is 60 to 80 feet deep, 100 feet wide, and 300 feet long. Layers 10 to 20 feet thick supply large blocks, which are dressed down, but most of the output consists of blocks measuring about 2 by 2 by 5 feet. The principal product is rough and polished monument stock.

At Traprock, on the northern border of the Honeybrook quadrangle, there are three large quarries in the diabase—one on the west side of the valley about 300 yards long, 150 yards wide, and 75 feet deep, and two adjoining quarries on the east side, above and east of the railroad, with a large open cut through the spur to the north and a face 50 feet and more in height. These were opened in 1893 and developed by the John T. Dyer Co., of Norristown, for crushed stone for road metal. Operation of the quarries was discontinued about 1933.

A very large quarry on Sixpenny Creek, 2 miles east of Traprock, operated by the John T. Dyer Quarry Co., of Norristown, has a face as much as 265 feet high and 200 yards long and when operating at capacity has produced 3,000 tons of crushed trap rock a day; the stone is shipped from Monocacy. The property is leased from the A. Louise C. Brooke estate.

The Chickies quartzite was in very early days used in a small way as building stone, and in recent years it has been almost continuously used for that purpose. The stone is obtained from Wirth's quarry, in the quartzite half a mile southeast of Fisherville. This quartzite was formerly quarried near Narvon and Downingtown for ganister, and where softened or disintegrated has been dug in several places for silica sand.

In Chester Valley across the southern part of the Phoenixville quadrangle between Devault and Downingtown can be counted at least 150 abandoned pot kilns formerly used for burning lime. These kilns and adjacent quarries denote an early industry supplying local need. Consolidating interests resulted in the development of large operations. The Knickerbocker Lime Co.'s quarry at Mill Lane, for ex-

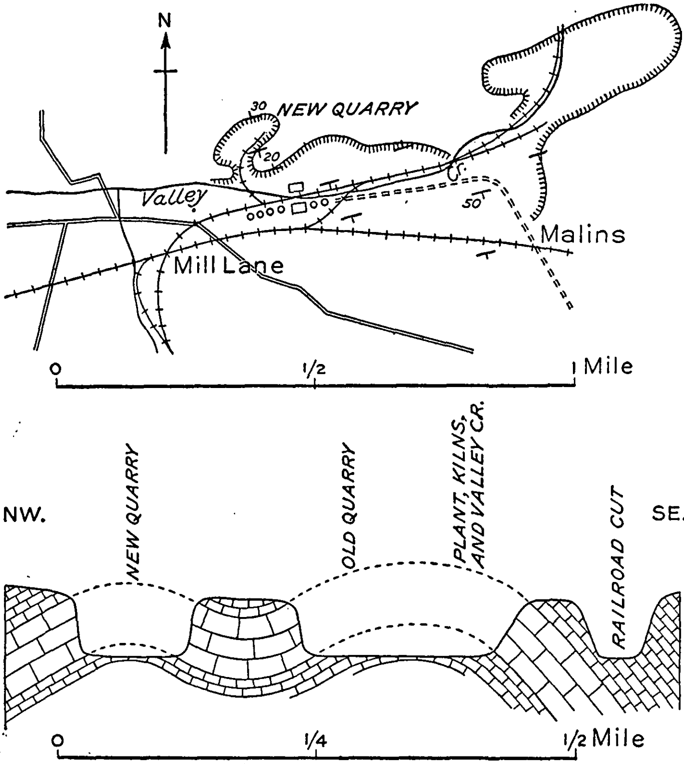

FIGURE 19.—Sketch plan and section of Knickerbocker quarry at Mill Lane. By G. W. Stose. About 500 feet of thick-bedded Ledger dolomite is exposed in old quarries along railroad and repeated in an anticline in new quarries to the north.

ample, had an almost continuous opening for more than a mile in the same beds and about 75 to 100 feet deep. (See fig. 19.) By further consolidation, in 1937 limestone or dolomite is quarried in three places in Chester Valley in the Phoenixville quadrangle and burned at two places. The operators are the Warner Co. at Devault, the Chester Valley Lime Co. at Planebrook, and John U. Trego near Bradford Hills.

The Warner Co. has a large operation in Cedar Hollow three-fourths mile southeast of Devault. Quarrying began here before the

Revolutionary War. Several small quarry operations located side by side were combined in the early eighties. The Whiteland Lime Co., previously known as the Pennsylvania Lime & Fluxstone Co., became a Warner Co. property in 1905. In 1928 the Warner Co. purchased the Van Sciver Corporation and with it came the Knickerbocker plant at Mill Lane. This large plant, 3 miles southwest of Cedar Hollow, is connected by railroad with a quarry adjacent to the Cedar Hollow plant. The Knickerbocker plant was operated by the Warner Co. until May 1931, when it was closed and perhaps definitely abandoned.

In 1937 the Cedar Hollow quarry is about three-quarters of a mile long, has a maximum width of one-third of a mile, and yields more than 2,000 tons of stone daily. The company operates 1 rotary and 10 shaft kilns and an exceptionally efficient crushing plant. Crushed stone is sold for roads and general concrete work. As much as 1,000 tons of hydrated lime a day is shipped in rush periods, and stone is dried and pulverized for agricultural and chemical use. This stone (the Ledger dolomite) is practically inexhaustible.

The Chester Valley Lime Co., originally Maxwell, Smalley & Kerbaugh, quarries about 500 tons of dolomite daily at Planebrook. About 65 tons of hydrated lime is made daily, and the rest of the stone is pulverized for agricultural use and road dust.

John U. Trego's Bradford Hill quarry is 1½ miles east of Downingtown, between the Philadelphia & Reading and Pennsylvania Railroads. Formerly known as the Baldwin quarry, it was reopened in 1931 by Mr. Trego and has been operated continuously since then, producing crushed stone for general use. Building stone also is sold. The output of crushed stone is about 200 tons daily.

The Dougherty quarry, 1 mile east of Mill Lane, operated in recent years by Samuel Given, is now abandoned. Quarries near Exton have long been idle.

In Pequea Valley, in the southwestern part of the Honeybrook quadrangle, numerous small limestone quarries were opened many years ago, and the stone was burned for agricultural lime. Some of these were at Pequea, 2 miles north and 1 mile south of Cains, and at Limeville. The only active quarry in this area in 1937 is on the farm of Charles Robinson at Limeville, operated by Harold Robinson. The quarry is in a white to blue thick-bedded siliceous magnesian limestone. This quarry was opened about 100 years ago. The stone is burned in two kilns and either sold as lump lime or ground and sacked for agricultural use.

In the Conestoga Valley only two limestone quarries were being worked in 1937. Amos J. Stoltzfus is quarrying limestone 2 miles west of Morgantown beside the highway and burning it in three kilns. In a modern plant the lime is pulverized and packed in barrels and bags. The product is sold as "Maxwell's Hill blue stone lime for all agricultural purposes."

Just north of the crossroads three-quarters of a mile east of Morgantown, Walter Stoltzfus is taking limestone from an old quarry in which the beds dip 70° and pulverizing it in a small plant for use raw on the soil.

Numerous quarries have been opened in the Newark formation to provide stone for building and for roads, but practically all are now idle. In recent years, instead of quarrying stone, some builders have dressed blocks from old stone walls or abandoned barns for use in new construction, as at Geiger's Mills.

A short mile northeast of Sanatoga a quarry operated by C. J. Wilson, producing 100 to 150 tons of crushed stone a day for roads and concrete, is in shale and sandstone hardened by intrusive trap. Trap and baked sediment are mixed in the product.

The Stowe Trap Rock Co., of Philadelphia, is operating a quarry 1 mile south of Sanatoga in tough Triassic sandstone cut by a vertical 10-foot dike of diabase or trap. The product is 75 tons of crushed stone daily for roads and concrete. Flags suitable for rustic walks are saved for that use. Some of them are ripple-marked. A black shaly bed in this quarry yields highly slickensided lumps that resemble anthracite in appearance.

A mile north of Spring City along the road to Pennhurst State School several small excavations have yielded sandstone and conglomerate for building stone, boundary walls, and in 1937 to the Public Works Administration for filling and grading.

Old sandstone quarries in Royersford and Spring City and near Phoenixville and other places have been abandoned.

At the north end of Montclare, high on the road ascending a hill, are quarries in gray shale and sandstone typical of the Lockatong formation. For 40 years Andrew Wilson has produced rough stone here for building, and operation was in progress in 1937.

Native stone in these quadrangles used for the main walls of buildings includes granite or gneiss, diabase or trap rock, quartzite, sandstone, limestone, and marble. The following notes on this area[61] furnish a more or less complete review of the building stones and their use.

At St. Peters, at the falls of French Creek three-quarters of a mile north of Knauertown, the French Creek Granite Co. is quarrying diabase or "black granite" for monuments. The quarry has been in operation since 1885 and now has a pit from 20 to 50 feet deep well down in unaltered rock. The

[61] Stone, R. W., Building stones of Pennsylvania: Pennsylvania Geol. Survey Bull. M15, pp. 95–100, 1932.

product is rough-faced and polished monument stock and paving blocks. Polished surfaces are black, and the fresh fracture is dark gray. Some of the rubble from quarrying and dressing large blocks is sold occasionally for building stone, but the freight rate and the dark color of the stone make the demand small. From 30 to 75 men are employed.

Near the surface the rock shows typical spheroidal weathering due to disintegrating along joints. The resulting rounded blocks are hard but not suited for monument stock, and the interstices are filled with residual sandy material. At depth, however, the rock is perfectly sound, very massive, with few joints in evidence, and breaks with regular but slightly curving fracture.

Quarrying and squaring the rough blocks is done with compressed-air drills. The blocks are raised from the quarry to the rough-dressing ground by derricks with long booms and after being squared are moved to the shop on small flat cars. About 25 men work in the quarry and yard, and about 25 in the finishing department. Two men were making paving blocks. Some of the rough pieces from squaring the large blocks are sold for building stone, but the principal output of the company is polished monument stock. Specimens of this "black granite" can be found in many prominent cemeteries, especially in the Philadelphia district, in Baltimore, Brooklyn, New York City, and Cleveland, Ohio.

This trap is the country rock along the St. Peters branch of the Reading Railroad from St. Peters to Elverson, and the surface is strewn with large boulders of it. Some have been gathered in fences and used for foundation walls. The National Bank and some houses at Elverson are built of the stone, which is called "French Creek granite."

Phoenixville and Spring City are built on Triassic shale and sandstone, and buildings of native stone are rare.

In the hilly country between Phoenixville and Honeybrook and from Birchrunville to Sadsburyville the bedrock is mostly granite, gabbro, and gneiss. One quarry at Cornog is getting out crushed stone, but I know of none that makes building stone. In this area one finds stone fences made by assembling boulders from the fields, and foundations from the same source, and maybe including two or three different kinds of rock. As this surface material of different kinds of rock is usually in rather small blocks, some are iron-stained, colors differ, etc., a wall built of it does not look well, so stone houses in this district commonly have an exterior coat of plaster. A. Sugerman & Sons at Devault are producing crushed monzonite but can furnish nice building stone if wanted, for some of this granitic rock breaks with parallel flat faces.

Chickies quartzite forming a ridge or line of hills along the north side of Chester County Valley is mostly a tough quartzite but contains some softer, micaceous layers. It tends to make rock floes in places, and this readily available material was used in the early days for building purposes. Two miles northwest of Downingtown and just below Fisherville are an old mill, barn, and house (the Edge place) built of native stone, mostly quartzite. Records show there was a building here between 1720–27, probably the wing of the house next to the road. The adjoining part of the house was built in 1768 and the mill maybe about 1784. The main part of the present residence was built in 1800 and the stone porch was added in 1925, using stone from partitions of the old barn. Much of the stone in these buildings probably was taken from the banks of Beaver Creek without quarrying. Some blocks expose micaceous faces with small black tourmaline needles. The large door stones and all the rest of the old masonry are in fine condition.

Mr. Edward A. Wirth, of Downingtown, has been quarrying Chickies quartzite in the end of the ridge at Fisherville. The beds strike N. 60° E. and dip 35° SE. As much difficulty has been found in drilling this very hard rock, it is broken out by barring and working sticks of dynamite into the cracks. Large blocks are then mauled to one-man size. Small black tourmaline crystals are common, and green chlorite (?) is developed along some seams. Rough stone is delivered to the user by auto truck. The East Downingtown High School and three or four houses near it are built of this stone, as are also three new houses near Wirth's limestone quarry, 1 mile northwest of Downingtown, the William J. Mitchell house, half a mile north of Thorndale, and the Josiah Phillips house, two doors from the Baptist Church at Downingtown. Green rough- to smooth-surfaced rustic flags, micaceous and with small black tourmaline crystals, are also produced for walks and terraces.

A quarry owned by Edward A. Wirth, 1 mile northwest of Downingtown on the Horseshoe Pike, provided limestone for building purposes. The quarry has been opened for 500 feet along the strike of beds dipping 50° S. and is 20 feet deep. The joints are vertical or at a slight angle to the bedding and from a few inches to 2 feet apart. The stone is light gray with faint blue markings. Garages, a church, and some houses at the east end of Coatesville are of this stone; also the East Downingtown public school.

A blue, fine-textured limestone from a quarry near Downingtown, opened in 1831, was used in building Villanova College, Villanova station, and railroad bridge abutments and piers.

According to Geology of Pennsylvania, 1858, page 215: "A little south of the Valley Turnpike, about 13½ miles east of Downingtown, is the extensive quarry of superior white marble which has for many years supplied Philadelphia with the beautiful article employed in so many of its public and private edifices. It is on the farm of John R. Thomas. The beds on this quarry are slightly contorted. The portion worked for the marble separates into two bands. The rock occurs in massive beds, chiefly white, with sometimes a bluish tinge, and is quarried with great facility. It has been much used in the construction of the Girard College and other public buildings which adorn Philadelphia and the neighboring towns."

These old quarries, now owned by George Thomas 3d, are half a mile southeast of Whitford. One now used for a swimming pool is about 250 feet long, 75 feet wide, and 20 feet above water. Another, now used for a trash dump, is about twice as large, and a third, parallel but narrower, is smoothly grassed. The large dumps likewise now are all grassed over. The beds dip at high angles, up to 70°. Pure-white marble was only part of the product, for nearby houses and barns are mostly bluish marble.

Founders Building, Girard College, built in 1832, is designed after the Parthenon. The walls are marble in coursed ashlar, blocks being 20 to 30 inches thick and up to 9 feet long. They are weathered to gray, stained muddy color in places, and fresh, clean, and blue on the northeast corner, where rainwashed. The 36 fluted columns of 11 drums each, resting on 9-foot round pedestals, have been patched in several places where a fluting has broken. The surfaces shed sand easily, which consists of angular grains of calcite and rare mica flakes. The steps are blue-gray banded marble in blocks 10 feet long. Many of them are cracked along the bedding and some have patches set in.

Perhaps "other public buildings" include the old Customs House and Girard Bank. In July 1927 I viewed the front of the Customs House at Fifth and

Chestnut Streets, Philadelphia, and found that while the steps are in good condition (possibly not the original steps) and the square sawed blocks of the front wall are in fair shape, the eight fluted columns are badly spalled. Likewise the old Girard Trust Co. Bank on Third Street below Chestnut at the Stock Exchange Place has a marble front including a portico with broad steps and six columns. The building was closed and for sale in 1927, and much of the marble in a sorry state. Many of the corners and edges are rounded, some faces are slightly spalled, and the fluting of the pilasters is chipped and cracked. It also is very noticeable that the bases of some of the columns are cracked and patched with inlays where pieces have broken out. The window sills are in particularly bad condition. These buildings suggest that some at least of the Chester Valley marble is not durable in the atmosphere of downtown Philadelphia. In 75 years it has deteriorated sadly. On the other hand, thousands of white marble doorsteps in Philadelphia that have been scrubbed frequently are in excellent condition after 50 or more years of constant exposure to the same atmosphere and the abrasion of passing feet.

Marble is well exposed along the Pennsylvania Railroad west of Valley Creek, east of Downingtown.

Between Malvern and Devault are several large limestone quarries. The wing of a church on the Lincoln Highway at Frazer and a home next door are built of limestone from the Mill Lane quarry.

The following list shows the producers of stone and other nonmetalliferous mineral products in these quadrangles in 1937:

A. Sugerman & Sons, Devault. Crushed stone (granite).
Warner Co., Devault. Crushed stone and lime.
Keystone Trappe Rock Co., Cornog. Crushed stone (granite).
French Creek Granite Co., St. Peters. Monument stock (diabase).
John T. Dyer Quarry Co., Monocacy. Crushed stone (diabase).
Chester Valley Lime Co., Planebrook. Lime, ground limestone.
John U. Trego, Bradford Hill. Crushed limestone.
Charles Robinson, Limeville. Lime.
Amos J. Stoltzfus, Morgantown. Lime.
Walter Stoltzfus, Morgantown. Ground limestone.
C. J. Wilson, Sanatoga. Crushed sandstone and diabase.
Stowe Trap Rock Co., Sanatoga. Crushed sandstone.
Andrew Wilson, Montclare. Sandstone.
Edward A. Wirth, Fisherville. Quartzite.
Whitaker Clay Co., Narvon. White clay.
Diller Clay & Stone Co., Narvon. White clay.
A. T. Harris, Honeybrook. Silica sand.

CLAY

Residual clay is supplied in the Honeybrook and Phoenixville quadrangles through the disintegration of sericitic Cambrian quartzite and shale of the Brunswick formation. In the Honeybrook quadrangle the clay quarries are with one exception located in the quartzite of Welsh Mountain, at or near Narvon.

An area of residual clay lies along the north slope of Welsh Mountain in eastern Lancaster County, 4 miles west of Honeybrook.[62] Welsh Mountain is made up of resistant Chickies quartzite, of Lower Cambrian age. The upper portions of the Chickies are thinner-bedded and weather to a white clay, above which lies the Harpers phyllite, a greenish schist that weathers to a speckled gray clay. The Whitaker Clay Co. is working in 1937 the pit opened in 1902 by L. H. & A. J. Whitaker and Cyrus Silknetter. The pit is about 1,000 feet southwest of the station on a switch from the Pennsylvania Railroad. The pit is cut into the north slope of the ridge, and the beds dip 30° SE. into the ridge. At the entrance to the pit quartzites carrying a 10-foot bed of white clay are to be seen, but in the quarry these give way to a main clay bed about 60 feet thick. The main clay is gray and speckled and shows a schistose structure. It carries some sandier layers and some quartz veins. It is probably derived from schistose phases of the upper Chickies quartzite or from the overlying Harpers phyllite. The thinner, whiter bed in the quartzite is probably derived from the weathering of feldspathic quartzite. Tests made on the main clay show that it has 2.26 percent air shrinkage. At cone 8 (1,290° C.) its fire shrinkage is 10.79 percent, its absorption 1.3 percent, and its color buff. At cone 15 (1,430° C.) it is overfired. This indicates that it is not suitable for china manufacture. It is sold extensively to steel mills and for filler in linoleum and other products. The company has a well-equipped grinding plant which loads directly into railroad cars. The output is about 2,500 tons a month.

The clay from this pit is chiefly kaolinite with minute flakes of muscovite; there is also a small percentage of quartz, rarely rutile and zircon crystals, and less rarely tourmaline crystals.

The Diller Clay & Stone Co. of Lancaster operates a similar pit about 2,000 feet west. This pit also cuts into the quartzite and schist of the ridge, but the structure is less evident and more complex. In 1937 this company was working a 25-foot face of massive gray clay. The clay is dug by hand and shoveled on a long belt, which conveys it to the rotary cylindrical dryer at the mill. The clay passes through a well-equipped pulverizing plant and is shipped in sacks. It is used in steel-mill practice, in molding compounds for foundry use, and as a filler. Operations began here about 1914. This material is crushed and screened through a 200-mesh sieve. The 90 percent which passes through is 71.21 percent SiO_2, 21 percent Al_2O_3, and 1.39 percent Fe_2O_3.

[62] Leighton, H., The white clays of Pennsylvania: Pennsylvania Topog. and Geol. Survey Bull. 112, pp. 14–16, 1934.

The Narvon clay is a very white clay, containing a high percentage of free silica in a finely divided form. Its dry strength is very low, and it fires to a dark-gray color. It may be used as a no. 2 refractory or filler for paint. A sample of Narvon white clay from this pit showed the following properties:

Properties of Narvon white clay from pit of Diller Clay & Stone Co.

Green clay

Plasticity rating,[63] 60; linear drying shrinkage, 4 percent.

Fired clay

	Cone				
	1	5	7	9	11
Temperature ° C	1, 160	1, 205	1, 250	1, 285	1, 325
Linear shrinkage percent	1. 0	4. 0	6. 0	7. 0	9. 0
Absorption do	27. 1	18. 4	13. 8	14. 0	6. 0
Porosity do	40. 3	30. 0	24. 5	24. 0	12. 4

Fired color, dark gray.
Pyrometric cone equivalent, cone 26, 1,595° C.

The Walters property has never been opened up. It lies half a mile west of the other properties.

Two miles east of Narvon the Diller Sand & Clay Co. opened a sand quarry in 1901. (See pl. 11, *A*.) The clay is made up of about equal parts of quartz, muscovite, and kaolinite, with rutile, zircon, titanite, tourmaline, and epidote as rare accessory constituents. The clay was utilized for foundry facings and the sand in concrete work and for lining steel furnaces. The output was about 30 tons of clay and 60 tons of sand a day. This operation was discontinued in 1914.

The Welsh Mining Co. opened three quarries for sand and clay. One, three-quarters of a mile southeast of Narvon, was abandoned because the clay bed, about 30 feet thick, dipped so steeply that an excessive amount of stripping would be required. The other two are 1½ miles east of Narvon. One of them was worked by Paxton-Taggart, Inc., of Philadelphia, for molding sand, but operation stopped in 1932.

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[63] The plasticity rating shows the plasticity and working properties of the clay as compared with those of well-known commercial clays.

100 represents the most plastic American and English ball clays.
90 good ball clays and the best plastic fire clays.
80 good plastic fire clays and the best shales and kaolins.
70 workable shales and fire clays.
60 short, sandy shales, kaolins, and surface clays.
10 to 50 flint fire clays, semiflint clays, and lean, sandy clays.

Ratings from 70 to 100 percent represent good working properties. Ratings from 10 to 50 represent clays of perceptible plasticity but too short to work alone by any wet process of manufacturing.

On land owned by Israel R. Berry half a mile northwest of Cedar Knoll station and just above a schoolhouse a large and deep pit, now partly filled with water, is the site of an active production of kaolin which began in the 1880's. Production ceased before 1912. The kaolin is derived from the hydration of feldspar and was discovered in the process of well-digging.

In the Phoenixville quadrangle, on the north side of the Philadelphia and Reading turnpike at the east end of Pottstown, the Joseph S. Garber Brick Co. had a plant, started in 1889, which produced about 9,000 bricks a day. The clay utilized in the brickmaking was a crumbly red shale, which was dug to the depth of 5 feet or more. The site is now occupied by residences. The site of a brickyard at the south end of Spring City that used river clay is now occupied by a sewage-disposal plant.

FELDSPAR

Pegmatites are the common source of feldspar (orthoclase, microcline, and less abundantly plagioclases). The feldspar quarries formerly worked in Pennsylvania are for the most part in Chester and Delaware Counties, in the extreme southeastern part of the State.[64]

In the Honeybrook and Phoenixville quadrangles feldspar has been quarried at few localities. At Cornog a small quarry along the railroad just below the Keystone quarry was once worked by Harry Rhodewalt. The feldspar was shipped for use in the manufacture of pottery. Two pits in a pegmatite dike, about 1 mile northeast of Brandywine Manor, were at one time productive. One of these pits on Mrs. Isaac Reiter's farm was worked for road stone about 1919.

Feldspar was quarried many years ago on the C. Hackett farm, 2 miles southeast of Honeybrook. The spar at these localities is so heavily impregnated with quartz that it cannot be sold to potteries at present.

SAND, GRAVEL, AND GANISTER

The Cambrian quartzite by disintegration furnishes relatively pure sand. Sand was dug or quarried in the Phoenixville quadrangle many years ago by George D. Johnson 1½ miles north of Whitford post office; by the Chapman Mineral Co. 1 mile northwest of Bacton; and by the Whiteland Silica Co. 1¼ miles north of Whiteland. Some of the sand of the Whiteland Co. averages as high as 99.66 percent of SiO_2, but most of it is not pure enough for glass making and was used for smelting in copper and nickel refineries and in

[64] See also Stone, R. W., and Hughes, H. H., Feldspar in Pennsylvania: Pennsylvania Topog. and Geol. Survey Bull. M13, 1931.

reverberatory-furnace bottoms. For these purposes it was at one time in considerable demand.

The Whiteheat Products Co., at Planebrook, formerly quarried sand for the manufacture of silica bricks and artificial stone, but this industry was discontinued at least 20 years ago. The Whiteland Silica Co. also worked a large sand quarry for the manufacture of firebrick, 1 mile northwest of Exton in the Chickies quartzite, until about 1920. The Sidley Silica Co. operated a crushing plant on the summit of the North Valley Hills 1 mile north of Sidley and shipped silica to be processed elsewhere. These pits and plants are now idle.

Other abandoned sand pits in the Chickies quartzite are 1½ miles north of Downingtown, a large old sand pit 1 mile northwest of Whitford post office, 1½ miles southeast of Lionville, several sand pits 1 mile northeast of Exton, two pits 1¼ miles northwest of Planebrook, and two pits half a mile west of Bacton.

In the quartzite of the North Valley Hills, 1¼ miles north of Downingtown, quarries were opened by the Harbison-Walker Refractories Co. in 1917, and later a firebrick plant with six 40-foot kilns was built on Brandywine Creek 1 mile north of the town. The Chickies quartzite is thick-bedded and dips 55° S. 20° E. Pure quartzite, very hard and about 25 feet thick, is exposed along the strike for several hundred feet. Beneath this band the rock is softer and less pure and contains narrow schistose bands. After several years of continuous operation, the rock having proved unsatisfactory, all work stopped about 1930. The brick plant also has been idle for several years.

The Harbison-Walker Refractories Co. opened a quarry for ganister in Welsh Mountain at Narvon in the winter of 1921, but this operation was short-lived.

Quarries in the Chickies formation were opened on the south side of Welsh Mountain 2 miles northwest of Honeybrook. (See pl. 11, *B*.) The Welsh Mountain Mining & Kaolin Co. opened one of these quarries in 1890, and in 1908 it was producing 100 tons of silica sand daily for firebrick, furnace lining, and concrete work. The only one of these quarries operating in 1937 is that of A. T. Harris, of Honeybrook. Originally opened by Budding & Smart, in the course of 40 years the quarry has attained considerable size. The rock is ground to sand and sold for use in steel and copper furnaces and for building sand. This plant has shipped as much as 400 cars in a month.

The only gravel pit seen in the area was opened on the property of B. F. Kern, just south of a cemetery on the northern outskirts of Royersford, and operated by the Keystone Cement Brick & Tile Co.

for the manufacture of concrete building blocks and drain pipe. The work was discontinued probably more than 20 years ago. An examination of the abandoned pit suggests that gravel was only a small part of the deposit.

FLINT

A quarter of a mile east of Devault, in the Phoenixville quadrangle, there is a silica quarry in a quartz vein following the overthrust fault. It has not been worked in 30 years. Half a mile southwest of West Pikeland, on the Lewellen farm, a quartz vein has been quarried for flint. There is also an abandoned flint quarry in a vein of quartz about a mile southeast of Lionville. At Cornog, in the Honeybrook quadrangle, vein quartz along the Brandywine Manor fault striking northeast was at one time quarried and the stone crushed for use in making sandpaper. The quarry is behind John Galt's house and is owned by the Harry Rhodewalt estate, Glenmoore.

The Harbison-Walker Refractories Co. has a flint mine in Welsh Mountain a quarter of a mile southeast of Narvon, where a vitreous quartzite high in silica was crushed. The product was utilized for fire-brick sand; the mine is now idle.

One-third of a mile south of Brandywine Manor flint boulders in the field were broken and shipped to Philadelphia for glass making many years ago. Boulders and blocks of vein quartz are common between Brandywine Manor and Cornog.

MAGNETITE ORE

As early as the first half of the nineteenth century magnetite iron ore was mined at several localities in the Honeybrook and Phoenixville quadrangles.

This ore is everywhere associated with Triassic diabase in pre-Cambrian limestone (Franklin), in Cambrian limestone (Ledger dolomite), or in a calcareous Triassic conglomerate (Stockton formation), and there can be no doubt that the deposit had its origin in connection with hydrothermal action at the time of the injection of the diabase. The intrusion of the diabase magma must have been accompanied or followed by an invasion of hot vaporous and gaseous solutions, which dissolved the limestone and precipitated the magnetite and associated minerals and calcite in the passages thus obtained. The character and appearance of the ore, the mineral associations, and the relations of ore, limestone, and diabase are similar wherever the ore has been mined.

The principal mines in the magnetic ore are, in the Phoenixville quadrangle, the French Creek mines, at the terminus of the St.

Peters branch of the Philadelphia & Reading Railroad; and in the Honeybrook quadrangle, the Warwick mine, half a mile southeast of Warwick station (St. Marys), on the same railroad; the Hopewell mine, 1 mile northwest of Warwick station; the Jones mine, three-quarters of a mile east of Joanna; the Kinneys mine, three-quarters of a mile southeast of Joanna; and the Bylers mine, about 1 mile northwest of Morgantown.

French Creek mines.—On the hillside east of St. Peters station, in the valley of French Creek, there are two old mines known as the Kleim or lower mine, and the Elizabeth copper mine, or upper mine. About 100 yards to the east are the Crossley iron-ore pits, now filled in. These mines were first opened in 1850 and were operated continuously until 1851. Later the Elizabeth mine (no. 1) was worked for iron by the E. & G. Brooke Iron Co. and the Phoenix Iron Co. in equal shares. In 1895, with ore still in sight, mining operations were discontinued, partly because the iron ore, containing pyrite and chalcopyrite, was not high-grade ore and the present methods of roasting the ore to rid it of sulphur were not then perfected, and partly because the present efficient methods of dewatering mines did not then exist.

Mining was resumed in the Elizabeth mine by the E. & G. Brooke Iron Co., of Birdsboro, Pa., in the later part of 1913 and continued to 1928. The old shaft of the Elizabeth mine was vertical to a depth of 240 feet, whence a 45° inclined slope extended 180 feet farther down the footwall of the ore body, with crosscuts to ore-body levels. In 1914 this shaft and slope were remodeled into a compound shaft and continued for 100 feet along the footwall, reaching a total vertical depth of 485 feet. There are levels at 80, 130, 200, and 240 feet along the upper vertical portion and three levels along the lower slope. In 1918 mining was continued through a new three-compartment inclined shaft 100 feet back in the footwall (gneiss). This shaft dips 43° for the first 800 feet and continues to 1,400 feet with a 33° dip. Levels in this shaft are 300, 420, 530, 650, 750, 850, 950, 1,050, 1,150, 1,250, and 1,350 feet from the shaft collar. The magnetite deposits of French Creek are fully described by Smith.[65]

The total production of ore from 1914 to 1928 is reported to be 876,140 tons. All operations ceased in 1928, and it is reported that the ore is exhausted.

The ore body, which is discontinuous and variable in thickness, averaging about 75 feet, lies between a hanging wall and footwall of pre-Cambrian gneiss in the upper levels, and a hanging wall of pre-Cambrian gneiss and a footwall of Triassic diabase in the lower

[65] Smith, L. L., Magnetite deposits of French Creek, Pa.: Pennsylvania Geol. Survey, 4th ser., Bull. M-14, 52 pp., 5 pls., 1931.

levels. The diabase comes in from the southeast side at 500 feet (vertical) from the surface and cuts out the gneiss, replacing it as footwall. Apophyses from the diabase mass have at some points found their way along the hanging wall and penetrate the ore, pinching out before reaching the footwall. The hanging wall (gneiss) is laminated and straight; the footwall of diabase is undulating and eventually, with the pinching out of the limestone bed and ore, comes directly into contact with the gneiss.

The ore, which occurs as a lens between hanging wall and footwall, pinches out very irregularly. It contains much interstitial calcite, derived from the replaced limestone.

The principal ore mineral is magnetite, and its character is platy, pseudomorphic in part after calcite and in part after foliated hematite, which is a subordinate ore mineral. The associated primary metallic minerals include octahedral pyrite, containing from less than 1 percent to 1.75 percent of cobalt,[66] chalcopyrite, sphalerite, pyrrhotite, and bornite. The replacement of foliated hematite by magnetite is characteristic of the Cornwall ore of Pennsylvania. Oxidation of these minerals has produced hematite, malachite, chrysocolla, and erythrite. The gangue minerals include apophyllite in colorless and pink crystals, calcite, byssolite, actinolite, tourmaline, and garnet; graphite is found in both gneiss and unreplaced limestone. These gangue minerals are typical of contact metamorphism.

The analysis of a sample containing conspicuous octahedral pyrite and considerable chalcopyrite from the French Creek iron mines, furnished by the writer, shows 0.19 percent of cobalt, 15.30 percent of copper, and 0.04 percent of arsenic. This analysis was made by R. C. Wells and reported June 26, 1923.

The pre-Cambrian graphite-bearing gneiss of the hanging wall is manifestly an extension of the Pickering gneiss exposed south of the Triassic cover. Like the Pickering gneiss elsewhere, it is a sedimentary formation granitized by lit-par-lit injections of pegmatite, quartz monzonite, granodiorite, and gabbro and carrying here as elsewhere limestone lenses (Franklin) and disseminated graphite.

A pre-Cambrian pink orthoclase-bearing pegmatite occurs irregularly in veins and pockets in gneiss, limestone, and ore, and specimens from earlier mining, showing ore and pegmatite and limestone in contact, suggest a pre-Cambrian age for the ore; but the underground conditions, which have been described, the mineral associations, and the "look" of the ore, all of which are very similar to those of the Triassic Cornwall (Pennsylvania) type of magnetic iron ore rather than the pre-Cambrian Franklin Furnace (New Jersey) type of ore, strongly indicate its Triassic age.

[66] Genth, F. A., Am. Jour. Sci., 3d ser., vol. 40, p. 114, 1890.

Other mines and prospects.—The Kleim mine was also dewatered by the E. & G. Brooke Iron Co. with a view to renewing operations. Unfortunately the limestone below the 1,250-foot level has been intersected by a gabbroic dike and thus rendered inaccessible to solutions from the later diabase intrusion.

About three-quarters of a mile south of the French Creek mines and just north of Knauertown shafts were at one time sunk in search for iron ore, but the deposits were not sufficiently promising to justify mining.

At the Warwick mine, 3½ miles east of Elverson Church and 2¾ miles west of Knauertown, the geologic relations are similar to those at Knauertown, except that at the latter place there is evidence of more vigorous igneous action. The Warwick mine was reported by Rogers, writing in 1853, to have been worked for 120 years and to have produced 12,000 tons in 1853. The ore body occurs near the surface in the Stockton formation, at or near the base of an undulating conglomerate bed of variable thickness (1 to 17 feet), and was reached by stripping a few feet of weathered rock or by shafts at a depth of 60 feet at the most. The conglomerate is cut by several small dikes from the neighboring diabase body. At present only an open shallow pit, with undulating walls, about a quarter of a mile in diameter, and several old shaft holes can be seen.

The surface rock, a coarse conglomerate, has been metamorphosed and indurated, with the introduction of silica and the precipitation or crystallization, in fissures and cavities, of hematite, magnetite, chalcopyrite, calcite, actinolite, byssolite, and garnet. Rogers mentions also epidote spherules and serpentine. The induration of the conglomerate and the aspect and associations of the ore indicate hydrothermal action in connection with the intrusion of the massive diabase and lesser dikes. The porous and calcareous conglomerate offered a channel of escape and conditions for cooling and crystallization for the gaseous solutions.

Two other quests for iron ore were made long ago in this neighborhood: The Leighton mine, south of Warwick (St. Marys) village, and the Steels pits, about 2 miles northeast of the village. Little is to be seen at these localities now.

About 1¼ miles west of Warwick, on the east side of Thomas Hill, is the Hopewell iron mine, which is at the border of a diabase intrusion in pre-Cambrian gneiss. This mine was early worked for many years and later was worked between 1877 and 1880. An attempt to reopen it was made in 1907, and in November 1911 it was reopened by the Elverson Ore & Stone Co., of Coatesville. In 1914 the mine was closed down, and in 1917 the ore was reported exhausted. There is at present an open pit and a shaft 75 feet in depth. The ore, of which about 1,000 tons a month was mined, was shipped to the Warwick furnace of the Eastern Steel Co., Pottstown, Pa. The ore body forms a bed in the gneiss averaging 30 feet in thickness, starting at the diabase contact and dipping 35°–40° NW., away from the diabase. The Pickering gneiss forms both hanging wall and footwall and is included in the ore body. A small number of minerals deposited by hydrothermal action have been found at this mine—garnet, epidote, pyrite, sphalerite, magnetite, quartz, and chalcedony.

Two other abandoned ore pits in Warwick Township are located half a mile and 1¼ miles northeast of Pine Swamp schoolhouse. At the first locality the ore is in Franklin limestone associated with Pickering gneiss; at the second locality the ore appears to be in Pickering gneiss underlying the Stockton formation. This pit was worked in 1895 by the Phoenix Iron Co.

In Caernarvon Township, Berks County, west of the mines just described, which are in Warwick Township, Chester County, are the Jones and Kinney mines, east and southeast of Joanna. The Jones mine has also been known as the Warwick mine because it was at one time worked by the Warwick Iron Co. At present only waste dumps and water-filled pits are to be seen. Both mines are on the contact of Triassic diabase with Cambrian limestone and calcareous shale, overlapped on the north by the Stockton formation. The limestone is not only intruded by the great mass of diabase but is injected by minor dikes. Associated with the ore are pyrite, chalcopyrite, chalcocite, bornite, cuprite, melaconite, and copper. Associated hydrometamorphic minerals are calcite, aragonite, malachite, chrysocolla, cerusite, aurichalcite, and gypsum. Contact minerals in the limestone are actinolite, byssolite, serpentine, ripidolite, talc, and graphite. Neither of these mines has been operated for many years. The following analyses of the ore from the Jones mine show the composition of that type of ore.

Analyses of iron ore from Jones mine[1]

	1	2
Iron	42.75	44.07
Sulphur	.59	1.56
Phosphorus	.01	.02
Alumina, lime, and magnesia	11.45	----------
Silica	22.21	8.48

[1] Mineral Resources of the United States, 1887.

The iron ores of the Warwick, Hopewell, and Jones mines like those of the French Creek mines are of the Cornwall type; the possibility has therefore been considered that other limestone lenses carrying ore might be located along the diabase-gneiss contact.

The E. & G. Brooke Iron Co. has prospected with a magnetometer for ore along the northeastern contact of diabase and gneiss, but no favorable results have thus far been reported.

The Bylers mine, about 3 miles west-southwest of the Jones mine and 1 mile northwest of Morgantown, is also located on the contact of diabase and Cambrian limestone (with green shale layers). This mine was opened in about 1860 and was worked for 15 years by the E. & G. Brooke Iron Co., of Birdsboro. Mining was abandoned because of the difficulty of keeping the mine free from water, rather than because of the exhaustion of ore. There is a pit about 500 feet in diameter and 70 feet deep; the waste dump shows ore of the same type as that at the Jones mine.

A quarter of a mile east of the Bylers mine, pits were sunk in quest of iron in 1878 on the farm of Jacob S. Wertz at the contact of diabase and the Stockton formation, but no ore was found.

LIMONITE ORE

There are depressions, probably old limonite pits, in the Phoenixville area 1 mile northwest of Swedesford Road, 1 mile north of Exton, 1½ miles northeast of Exton, and 1 mile northwest of Whitford post office.

In Union township in the Honeybrook quadrangle, Berks County, about 4 miles northeast of Joanna Heights, at the five quarries indicated on the map, pits were at one time sunk for limonite ore or ocher or "paint." They did not prove profitable and have been abandoned. Other abandoned limonite ore pits in the Honeybrook area are located 1½ miles north of Elverson on the northwest foot of Thomas Hill, three pits 1 to 2 miles east of Churchtown, at the north foot of Welsh Mountain, and two pits half a mile west of Narvon at the north foot of Welsh Mountain.

LEAD AND ZINC

Phoenixville was at one time much interested in lead and zinc mining; but with the exception of a little sporadic development these ores have not been mined in this vicinity for more than 65 years. Mining ceased, it is reported, before 1870.

The mines were located as follows: West of Williams Corner and about 1½ miles south of Phoenixville, on the eastern border of the Phoenixville quadrangle, a group of lead and zinc mines; the Morris mine, 1 mile north; the Wheatley and Chester County mines, half a mile west of Williams Corner; the Montgomery mine, half a mile farther west; and the Charlestown and Buckwater mines, 1¼ and 1½ miles west, the Brookdale and Roberts mines, half a mile south, and the Pennypacker mine, 1½ miles south of Williams Corner. (See fig. 20.) Within 2 to 4 miles east of Williams Corner, in the Norristown quadrangle, adjacent on the east, similar ore deposits have been mined at six localities.

All these mines are in lead, zinc, and copper veins that strike northeast and dip southeast and penetrate pre-Cambrian granodiorite and quartz monzonite and the Triassic Stockton formation. The dominant material of the veins is quartz, and associated with it are many metallic and nonmetallic minerals. The lead minerals include galena, anglesite, cerusite, pyromorphite, and mimetite; the zinc minerals, sphalerite and calamine; the copper minerals, malachite, cuprite, azurite, chalcopyrite, chalcocite, and native copper; associated minerals are wad, sulphur, silver, hematite, limonite, pyrite, siderite, calcite, dolomite, ankerite, fluorite, and barite. These are the minerals found in the waste dumps.

The ore veins, which cut Triassic shale (Stockton) and in some places cut diabase dikes (Wheatley vein), are of late Triassic or post-Triassic age. The primary ore minerals (galena, sphalerite, chalcopyrite, chalcocite, and pyrite) and the gangue minerals (siderite, calcite, dolomite, ankerite, fluorite, and barite), like those of the magnetic iron ores, are hydrothermal in character; they have presumably been carried upward in heated solutions from which they have been precipitated in veins. The remaining associated minerals are of secondary origin—anglesite, cerusite, pyromorphite, mimetite, sulphur, and silver, derived from the galena; calamine and probably sulphur and silver, from sphalerite; malachite, cuprite, azurite, copper, hematite, limonite, and also sulphur and silver from chalcopyrite, chalcocite, and pyrite; and wad, presumably derived from a gangue mineral containing manganese. Galena, pyromorphite, sphalerite, and chalcopyrite were the commercially important minerals.

The late Triassic diabase dikes, which traverse the formation, like the ore-bearing veins, indicate the presence of some deep-seated source of igneous material. Both dikes and veins follow joint or fault fissures and intersect the strike and dip of the sedimentary rocks. These mines were being worked during the middle of the nineteenth century (1851–69) and are described in detail by H. D. Rogers.[67] The underground workings are at present inaccessible, and the veins are traceable by vein material, such as quartz and iron oxides, rather than by outcropping ore bodies.

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[67] Rogers, H. D., Geology of Pennsylvania: Pennsylvania Geol. Survey Final Rept., vol. 2, pp. 699–705, 1858. See also Miller, B. L., Lead and zinc ores: Pennsylvania Topog. and Geol. Survey Bull. 67, 1923, and Bull. M-5, 1924.

In January 1917 the Wheatley mine was reopened by the Eastern Mining & Milling Co., with Constant Minieri as president and general mine manager, and the old 250-foot inclined shaft was retimbered. On account of coal shortage, operations were stopped, but they were resumed in November 1918 and continued until 1920. At that time there were two shafts about 400 feet apart, connected by two tunnels at depths of 140 and 200 feet, and about 900 feet of tunnels, winzes, and raises. In August 1919 about 500 tons of ore had been mined, assaying $15 to $66 to the ton, and the daily hoisting was reported to be about 20 tons.

Shaft no. 1 produced mostly zinc ore; shaft 2 lead-silver ore. A carload of ore shipped on trial to the Pennsylvania Smelting Co., of Carnegie, Pa., was valued at $55 a ton.

In 1918 and 1919 the mine on the Chester County lode was unwatered and further developed, and a small concentrating plant was erected, and in 1920, 100 tons of concentrates were shipped, averaging 79 percent of lead and 7½ ounces of silver to the ton.

Except for the brief development of the Chester County lode and the shipment of ore by the Eastern Mining & Milling Co., apparently none of these mines have been operated in many years, and the property, in part or in whole, is now reported to be utilized by a golf club.

COPPER

Copper was once mined, as recalled by the oldest inhabitant, south of Phoenixville and half a mile northwest of Corner Stores at the Morris lode. The site was on the south side of Route 23, just inside the borough line, in the grounds of a country club; the mine has long been abandoned and is inaccessible. Galena, anglesite, pyromorphite, barite, and chalcopyrite are minerals reported to be found in the waste dumps of this mine.

Genth [68] reported that he found traces of gold in the chalcopyrite from the Chester County mines near Phoenixville. This presumably means an unworkable amount. Gold has also been reported in association with chalcocite in a diabase sheet in the adjoining Montgomery County.[69]

GRAPHITE [70]

Graphite has been mined intermittently from an early date in the gneiss of Pickering Valley, in the Phoenixville quadrangle. Many

[68] Genth, F. A., Minerals of Pennsylvania: Pennsylvania 2d Geol. Survey Rept. B, p. 2, 1875.

[69] Wherry, E. T., The Newark copper deposits in southeastern Pennsylvania: Econ. Geology, vol. 3, no. 8, p. 732, 1908.

[70] For fuller description see Miller, B. L., Graphite deposits of Pennsylvania: Pennsylvania Topog. and Geol. Survey Rept. 6, 1912.

graphite-mining companies have had a brief existence, succeeding earlier companies and in turn succeeded by later companies; graphite properties have thus changed hands with a rapidity which renders it difficult to keep abreast of the history of the graphite industry in Chester County.

In 1935–36 no graphite mines were in operation in Chester County. The most recent graphite production reported from this county was that by the Graphite Products Co. at Byers, in 1920. The mills

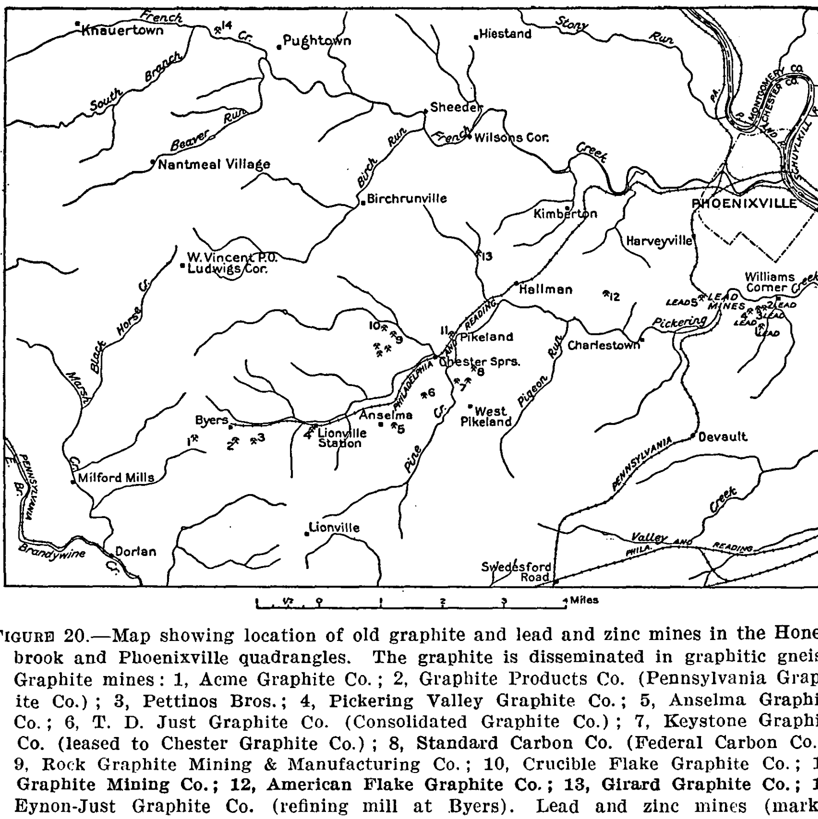

FIGURE 20.—Map showing location of old graphite and lead and zinc mines in the Honeybrook and Phoenixville quadrangles. The graphite is disseminated in graphitic gneiss. Graphite mines: 1, Acme Graphite Co.; 2, Graphite Products Co. (Pennsylvania Graphite Co.); 3, Pettinos Bros.; 4, Pickering Valley Graphite Co.; 5, Anselma Graphite Co.; 6, T. D. Just Graphite Co. (Consolidated Graphite Co.); 7, Keystone Graphite Co. (leased to Chester Graphite Co.); 8, Standard Carbon Co. (Federal Carbon Co.); 9, Rock Graphite Mining & Manufacturing Co.; 10, Crucible Flake Graphite Co.; 11, Graphite Mining Co.; 12, American Flake Graphite Co.; 13, Girard Graphite Co.; 14, Eynon-Just Graphite Co. (refining mill at Byers). Lead and zinc mines (marked lead): 1, Brookdale mine; 2, Wheatley mine; 3, Chester County mine; 4, Montgomery mine; 5, Charlestown mine.

are now more or less in ruins. Graphite is doubtless still to be found at some of the mines, but the future of the graphite industry is dependent upon the availability of higher-grade imported ore, and it is problematical whether mining will ever be resumed in Chester Valley.

The mines are for the most part located in a belt of locally calcareous graphite-bearing gneiss, a facies of the Pickering gneiss, which extends from Byers to Charlestown and northeast. (See fig. 20.) The history of graphite mining in this belt, given by localities, beginning at the southwest end of the belt, has been as follows:

1.[71] The first attempt to mine graphite at a locality five-eighths of a mile west-southwest of Byers station (Uwchland post office) was made in 1882 by the Eagle Plumbago Co. on property adjoining the site of the present mine. The ore was hauled to concentrating mills at Lionville. This enterprise was early abandoned. In May 1906 the Continental Graphite Co. was incorporated, and in the following December a mill was erected and a tunnel cut into the hill. In 1909 this company discontinued operations and sold out to the Acme Graphite Co., which rebuilt the mill and operated the mine until December 1910. Later the property was sold to John C. Hill, of New York, but the old name was retained. The mine has long been idle.

The graphite-bearing beds are coarsely crystalline calcareous gneiss and a micaceous gneiss striking N. 85° E. and dipping 45° S. An inclined shaft follows the dip of the beds, with east and west drifts.

2. A quarter of a mile south of Byers station (Uwchland post office), is one of the oldest graphite mines in Pickering Valley. The mine was worked first in the seventies by the Pennsylvania Graphite Co., and in 1880, when the company name was changed to the Pennsylvania Graphite Mining & Manufacturing Co., it was the only graphite mine operating in the county. In 1881 the property was sold to the Pennsylvania Plumbago Co. In 1889 the American Plumbago Co., which at that time owned the adjoining mining property (Pettinos Bros.), leased and worked one of the open cuts. This company soon gave up the lease, and Bullitt, Edmonds & McIntyre purchased the property and put up the mill that now stands on the hill close to the inclined shaft sunk by them. In 1903 the property was bought by J. P. MacLearn, who organized the Pennsylvania Graphite Co. and operated the mine until 1904, when the United States Graphite Co. leased the property at a high rental and 10 percent royalty on sales and built an expensive new mill at the foot of the hill near the road. In 1907, however, this company ceased operations, with expenses exceeding the value of sales, and in the summer of 1908 the lease was annulled for nonpayment of rental, and an injunction was issued restraining the United States Graphite Co. from using the name because of the prior use of it by a Michigan company. The Imperial Graphite Co., newly incorporated, took over the new mill, the old mill and mine remaining idle. In 1910 these were sold to the Acme Graphite Co., which had purchased the property to the west. This

[71] Numbers heading paragraphs refer to locations on figure 20.

company operated the mine during the summer and fall of 1910 and closed it in December. Until 1915 the mine was idle, with the Pennsylvania Graphite Co. again in possession (since 1911) and maintaining a watchman, who kept the water pumped out. In 1915–19 the Graphite Products Co. (John A. Lilly in charge) operated this mine. In 1920 the mine ceased to be operated, and the mill has since been destroyed by fire.

The graphite-bearing beds, a coarsely crystalline calcareous gneiss and a micaceous gneiss, aggregate about 75 feet in thickness, of which only 10 feet is rich enough to pay for working. The beds strike about N. 85° E. and dip 45° SE. They are cut by faults and by abundant pegmatite veins which are, for the most part, barren of graphite. It has been claimed that the ore averages 10 percent of graphite, but a more exact statement is that it ranges between 4 and 8 percent, rarely reaching 10 percent. The percentage of graphite in the ore is very irregular. An inclined shaft follows the dip to a depth of 70 feet (vertically 154 feet), with drifts to the east aggregating 900 feet, and to the west aggregating 800 feet, of which only 300 feet is accessible owing to caving in of the walls. There are in addition several open pits, earlier abandoned but in 1918 reopened for the quarrying of the ore, operating in 1920 and closed soon afterward.

3. The oldest graphite mine in Pickering Valley and in Chester County is on property for a long time owned by Pettinos Brothers, a quarter of a mile east of the Pennsylvania Graphite Co.'s mines. It was first operated in 1860, when it was known as the Phoenix graphite mine. In 1894 the property was first leased and subsequently purchased by the Pettinos Brothers and was operated continuously for 4 years. After 1899, when the mill was destroyed by fire and rebuilt, the mine was operated intermittently. From 1910 to 1912 the plant was in active operation. The ore was concentrated in the mill on the premises and shipped to the refining mill of Pettinos Brothers in Bethlehem. In 1913 the mill was again burned and was not at that time rebuilt. In 1915 the property was leased to the Tonkin Graphite Co., which built a new mill and operated the mine until 1918, when it was leased to E. C. Hargrave, who operated the mine a short time. Operations ceased in 1920 and have not been resumed up to the present time (1936), and the mill is rotted down.

The graphite is found in the eastward extension of the beds in which it is mined to the west (at localities 1 and 2) and ranges, it is claimed, from 5 to 6 percent. The calcareous gneiss or crystalline limestone, which occurs as horses and as footwall, is about 10 feet thick (70 feet below the surface). There is a large open cut in which the rock is so thoroughly disintegrated that neither the original rock nor the original structure can be seen. Kaolin, quartz, limonite, marcasite, pyrite, chloropal, chlorite, epidote, zoisite, and tremolite are secondary minerals. There are also several small pits and one shaft. The ore was most recently obtained from an open cut and is in some places a high-grade ore but is uneven in range. Both here and on the property to the west the ore is weathered to a degree that renders it easily worked.

4. About one-eighth of a mile west of Lionville station, on property belonging to J. H. Dewees, a prospecting shaft was sunk and a drift cut into the hill. No mill was erected, and the mine was soon abandoned. The property was leased to the Pickering Valley Graphite Co. but not utilized for mining.

5. About one-eighth of a mile east of Anselma village is the mine and mill of the National Graphite Co., later reorganized under the name Anselma Graphite Co. The mine was first opened in 1905 but was operated for only a short time. In 1910 it was worked once more and again soon abandoned. The property was later purchased by John A. Lilly, and in 1936 the mine and mill had long been idle.

Here the graphite-bearing rock is hard and undecomposed, consisting largely of quartz and graphite and some kaolin. The separation of the graphite from the quartz proved an obstacle not easily overcome. The ore mined in 1905 was reported to carry 6 to 8 percent of graphite. In 1906 the plant averaged 1 ton of graphite daily, separated by the dry method. The footwall of the mine is a fine-grained pre-Cambrian diabase dike, the hanging wall a coarse-grained and very quartzose gneiss.

6. Three-quarters of a mile northeast of the Anselma mine prospecting along the strike of the same graphite-bearing beds was carried on by the Consolidated Graphite Co., but no mining or milling was done. The T. D. Just Graphite Co. leased a property in this vicinity, erected a mill about 1912, and operated pretty steadily up to the fall of 1919, when operations ceased and the property reverted to the bondholders. It was subleased by them to Harry Schmehl, who for a year operated a mill refining ore from this and the neighboring property (7) and recovering graphite from old crucibles. The ore on this property was dug with pick and shovel in the deeply weathered rock of an open cut. In 1916 the T. D. Just Co. opened a new mine and erected a mill near Chester Springs, and in 1918 these were still in operation, but by 1920 operation had ceased.

7. Five-eighths of a mile south-southeast of Chester Springs is a mine opened in 1896 by the Philadelphia Graphite Co. In 1901 the mine changed hands, but operations were continued under the same name. In 1903 it again changed hands, and a new company was

organized, the New Philadelphia Graphite Co. Later the Keystone Graphite Co. took possession and leased the property in 1907 to the Chester Graphite Co., which operated the mine and mill until the fall of 1910, when the lease was given up. The property has been idle since that date with the exception of 2 years (1916–17), when it was leased to Harry Schmehl.

The graphite-bearing beds are reported to be about 20 feet thick, and the ore carries about 6 to 10 percent of graphite. The rock is a decomposed gneiss and coarsely crystalline limestone striking N. 25° E. and dipping 35° SE. A feature of the occurrence is pegmatite dikes which, near the contact with the gneiss, contain graphite in large flakes or as amorphous powder in small pockets. Beside the shaft there are two open cuts in which the ore is soft enough to be worked with pick and shovel.

The Chester Graphite Co., known later as the Paragon Graphite Works, refined crystalline graphite obtained from Alabama, Ceylon, and elsewhere and manufactured a high-grade product (nearly 100 percent graphite) suitable for flake graphite and graphite lubricants. The mill and property of this company were just west and across the road from the old mine. This plant, exclusively engaged in refining and manufacturing, was the only one active in Pickering Valley in 1920.

8. About three-quarters of a mile east of Chester Springs and a quarter of a mile northeast of the Keystone Graphite Co.'s property are the mill and mine of the Federal Carbon Co., successors to the Federal Graphite Co., by which the mine was operated and abandoned before 1900. In 1903 the mill was destroyed by fire and rebuilt. In July the company was reorganized as the Federal Carbon Co., and in 1911 the mine was pumped out and put into condition for operating. The Federal Carbon Co. was succeeded by the Standard Carbon Co., which operated the mine intermittently and closed it in 1918.

The ore beds are the continuation of those formerly mined by the Chester Graphite Co. and strike N. 45° E. and dip. 35°–40° SE. The gneiss is decayed and contains 3 to 7 percent of graphite, with pegmatitic and aplitic granitic injections containing graphite in contact with the gneiss. The workings consist of an open cut, a vertical shaft, and a tunnel.

9. Three-quarters of a mile northwest of Chester Springs there is a graphite mine which was opened in September 1903 by driving a tunnel 400 to 500 feet into the hill. The ore carried an average of 4 to 5 percent of graphite and yielded 8 tons of finished material daily from 200 tons of raw material. Flake graphite for crucibles

was produced. The mill and mine were first operated by Wayne C. P. Parker and subsequently by Charles W. Snyder. In 1904 the property was purchased by the Sterling Graphite Co., which erected a mill in 1906–7 and began operations in the fall of 1907. The mine was operated intermittently. In 1910 the property was sold to the Rock Graphite Mining & Manufacturing Co., which operated intermittently up to November 1916. Since that time the mine has been idle. About 30 tons of rock is reported to yield 1 ton of graphite.

The ore rock is a gneiss which has undergone but little decomposition and is composed of quartz, feldspar, biotite, graphite, and pyrrhotite. The beds strike nearly north and dip east. The ore was mined in an open pit, with only a few feet of weathered material at the surface.

10. Adjoining the Rock Graphite Mining & Manufacturing Co.'s property on the northwest is the mining property of the Crucible Flake Graphite Co., locally known as the Parker Graphite Co. (Wayne C. P. Parker). The company was incorporated in 1905. A mill with expensive machinery and electric power was erected in 1906 and closed in 1907. In 1918 the property was again operated as Rock Crucible Graphite Co. and new machinery installed. The mill was shut down in the fall of 1919, and the machinery was removed in the spring of 1920. Since then the mine has been idle.

The graphite-bearing rock is the same as that on the adjoining property.

One mile north of Matthews the Biggs Mining Co. had a brief existence.

11. The Graphite Mining Co. has owned property at Pikeland, where a little ore has been mined and refined elsewhere. There is no mill on the property.

12. About 2½ miles northeast of the Federal Carbon Co.'s property and 1 mile northwest of Charlestown is the property of the Phoenix Hill Graphite Co., later known as the American Flake Graphite Co. (1908). This company started the mine and mill in 1908 and operated intermittently until the spring of 1911. Since that time the mine has been idle and the mill dismantled. It was reported that only 9 to 10 tons of rock was required to yield 1 ton of concentrate.

An open cut shows a fine-grained gneiss, with numerous pegmatite veins carrying little or no graphite, striking N. 10°–15° E. and dipping 35°–50° SE.

13. Half a mile northwest of Hallman station, on C. C. Walker's farm, a graphite mine was opened and a mill equipped in 1905 by the Husbands Graphite Co. The plant was operated 1 year and in

1907 passed into the hands of the Girard Graphite Co., which worked it about a year. In the spring of 1911 the property was sold by the sheriff and the mill dismantled. Since then the plant has been idle.

The graphite occurs in a calcareous limonitic gneiss, originally pyritiferous. Large flakes of graphite, a quarter of an inch in diameter, have been found here. A limonite ore pit and an outcrop of Franklin limestone occur just west and north of the graphite mine.

14. In the French Creek Valley, a quarter of a mile southeast of Coventryville, on the north side of the creek, are the mine and concentrating mill of the Eynon-Just Graphite Co., with the refining mill at Byers. As owners of this mill the Eynon-Just Co. succeeded the Imperial Graphite Co., which took over the new mill from the United States Graphite Co. and found itself with a mill and no mine. The Eynon-Just Co. bought the property near Coventryville in June 1911 and in December reported a daily output of 50 tons of hard rock averaging 15 percent of graphite. The ore bed is 24 feet thick. The graphite was separated in a mill at the mine and finished in a mill at Byers.

SOILS

Eighteen types of soils have been recognized in the Honeybrook and Phoenixville quadrangles.[72] Of these only six types have sufficient areal extent to be of importance, six others are stony phases of these important types, five cover a very small area, and the remaining one is the alluvial soil of the valley bottoms.

The soils formed from the disintegration of pre-Cambrian rocks are known as the Brandywine loam, the Manor loam and the Manor stony loam, the Chester loam and the Chester stony loam, the Conowingo clay and Conowingo barrens, and the Lickdale clay loam.

The Brandywine loam is derived from the weathering of the granodiorite but has been given by the soil survey a very small area. It has been limited to the decayed gneiss between Cedar Knoll and Reeceville, southward in the Honeybrook quadrangle. It is a brown sandy loam with a high content of finely divided mica, and sharp, gritty fragments of the gneiss. Both the mica and the rock fragments increase with depth, forming a very loose-textured subsoil. The soil has good drainage and is moderately productive for general farming. It is termed a "hungry" soil because of the way in which it "eats up" fertilizers.

On the South Chester Valley Hills mica schist of the Wissahickon formation supplies a yellowish-brown silty loam known as the Manor

[72] U. S. Dept. Agr. Bur. Soils Field Operations for 1905, pp. 97–174, 1907.

loam and an associated stony phase, the Manor stony loam, occupying steep slopes. This soil is only moderately productive as compared with the Hagerstown and Chester loams. It is best adapted to staple farm products. Its topography is a gently rolling highland with good surface drainage.

The Chester loam, derived from the decay of pre-Cambrian crystalline rocks, including practically all the igneous intrusives, is the principal soil type of the Honeybrook and Phoenixville quadrangles. Covering in general all the area between the Triassic formations on the north and the Paleozoic formations on the south, its continuity is broken only by many small areas of the Chester stony loam, distinguished merely by the presence of either boulders or small stones. It is a somewhat coarse-textured mellow medium-brown loam with a subsoil of a brownish-yellow gritty loam and is well adapted to the growing of corn, oats, wheat, and grass. A smooth, rolling topography characterizes it.

South of Malvern, chiefly in Willistown Township, is an area of Conowingo clay and associated small areas of Conowingo barrens. This soil is derived from the disintegration of serpentine and gabbro and is a brownish-gray silty loam with a pale-yellow or greenish subsoil, or both soil and subsoil may be reddish. This soil requires draining, liming, and fertilizing in order to be made productive. The topography of the soil is rather smooth, broken only by ridges of outcropping residual serpentine which are coincident in large part with the Conowingo barrens.

The Lickdale clay loam is a very rare and unimportant soil occurring only in a small area east of Rockville, between Brandywine Manor and Ford, and in four still smaller scattered patches. It is a fine clay loam which has accumulated by washing from higher land. Natural drainage is poor, and the soil is not adapted to tilling.

The Cambrian quartzite produces by decay four types of soil which are distinctive and nearly coterminous with the quartzite hills and ridges. They are the Dekalb fine sandy loam, Dekalb loam, and the stony phases, the Dekalb stony loam and Rough stony land. Of these only the two first named are important. They differ only in the fineness of sand, which constitutes over 80 percent of the soil. These soils are inferior to the Chester loam but with careful treatment will produce a moderate yield of the staple crops. The rugged topography of the Dekalb soils is also less favorable to tillage than the topography of the Chester loam.

The Cambrian and Ordovician limestones of Chester, Pequea, and Conestoga Valleys produce a distinctive and fertile soil, called the Hagerstown loam, consisting of a dark-brown heavy smooth silty clay loam. This soil and subsoil represent the residual sand and clay after the soluble carbonates have been removed in solution. The soils immediately overlie undecomposed rock without gradation through decayed rock and are very free from rock fragments. A small percentage of lime carbonate is found in the surface soil and increases in amount in the subsoil. The Hagerstown loam is the most arable soil of the quadrangles and is exceptionally productive, requiring only a moderate application of fertilizers. The distribution of this soil coincides with the three well-marked limestone valleys, and the topography is that of a rolling lowland.

The Triassic formations of the northern third of the quadrangles produce by their decay the Penn loam with the stony phases, the Penn stony loam, and the Rough stony land; the Dekalb shale loam and the Lansdale silt loam.

Penn loam and Penn stony loam cover practically all of the Triassic area, their continuity being interrupted only by irregular patches of the Dekalb shale loam, Lansdale silt loam, and Rough stony land. Penn loam is a loose medium-brown loam with a light-brown or rarely reddish-brown clay-loam subsoil. It is characterized by a dark Indian-red phase. Along the Schuylkill River and 1 to 2 miles back from the river the Penn loam is a medium-brown loam with enough medium and coarse sand to make a coarse loam. The subsoil is a light-brown to gray loam, containing a large amount of coarse sand. The Penn loam is suited to the staple farm products, corn, potatoes, grains, and grass. The topography is that of a thoroughly dissected lowland with few and small level areas. Rough stony land and Penn stony loam cover the area north and east of St. Peters. They correspond very closely in character, but on account of its rugged topography Rough stony land is distinctly inferior in agricultural value. They are both derived in part from the disintegration of diabase and in part from the disintegration of the conglomerate of the Brunswick formation.

East of the Schuylkill River the Lansdale silt loam is the dominant soil. On the west side of the Schuylkill River the two chief areas of Lansdale silt loam lie south of Spring City and south of Phoenixville. It is distinguished from the Penn loam by a larger percentage of silt. It is a mellow silt loam, which excels the Penn loam in productivity. It is well drained, and its topography does not differ from that of the Penn loam. The Dekalb shale loam covers the bluffs on the Schuylkill River north of Phoenixville, with a long, narrow ridge extending westward, where it is derived chiefly from the disintegration of the compact blue shale of the Lockatong formation. It covers considerable areas north and west of Pottstown, where it is derived from the red shale of the Brunswick formation. It consists of brown, blue-brown, or red-brown medium silty loam, containing 5 to 50 percent of broken stone. Bedrock lies in many places very near the surface, but where the soil is sufficiently deep, potatoes can be grown to advantage upon it. The topography is hilly with steep slopes, and the soil is subjected to either excessive drainage or seepage.

The alluvial soil along the larger streams, subject to overflow and kept in too moist a condition for tillage, has been termed Meadow and is best adapted for pasturage.

The limestone valleys have been carefully cultivated, but elsewhere intensive methods of farming have not been practiced, and much land is left to grass or in pasture or in woodland. The greater part of the areas covered by the Dekalb loam, sandy loam, and stony loam, the Manor stony loam, the Rough stony land, and a large part of the Chester stony loam are woodland. The forest trees are oak, of which there are many varieties, hickory, walnut, beech, birch, maple (several varieties), poplar, tuliptree, sycamore, linden, locust, hemlock, pine, and cedar. Formerly the chestnut was abundant.

SURFACE WATER

With a mean annual rainfall of 45 inches, the principal streams of the Honeybrook and Phoenixville quadrangles are perennial. The quadrangles are drained by numerous small tributaries of the Schuylkill and Susquehanna Rivers. The Schuylkill, which crosses the northeast corner of the Phoenixville quadrangle, is the only river in the area and the only stream serviceable for navigation. Many of the creeks have sufficient head for water power, as the numerous mill dams testify, and are also sources of domestic water supply.

The area is well provided with hillside springs, which furnish water to many farms. Copious springs supply the Orphans' Home, half a mile south of Chester Springs. Five springs of soft water, some of them large enough to form streams, emerge 1½ miles north of Matthews, at the Briggs Graphite Mining Co.'s plant.

GROUND WATER[73]

Grouped by conditions that control the occurrence of ground water, the rocks of the Honeybrook and Phoenixville quadrangles fall into three classes—(1) relatively unmetamorphosed stratified

[73] See also Hall, G. M., Ground water in southeastern Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. W-2, 1934.

rocks; (2) metamorphosed stratified rocks; (3) massive igneous rocks and extremely metamorphosed stratified rocks (gneisses).

The Newark group, consisting of conglomerates, sandstones, and shales, belongs to the first class. This series of stratified formations contains beds (conglomerate and sandstone) that are likely to be water-bearing. In some places, where such water-bearing beds are confined beneath relatively impermeable shale beds, the water may be under sufficient pressure to be raised somewhat above the level at which it enters the beds, and any well in which the water rises above the water table, or local ground-water level, may properly be regarded as an artesian well.

In order to have artesian conditions the water-bearing bed must also in one or more directions be connected with areas of outcrop at higher altitudes, and must be saturated up to a higher level than that of the local water table at the well site. If the bed is saturated up to a higher level than the surface of the ground at the well site, a flowing artesian well may be obtained. No flowing wells, however, have been observed in this area.

The sandstone, arkose, and conglomerate of the Stockton formation are water-bearing, and wherever these beds are reached by drilling artesian water may be obtained. The shales and argillites of the Lockatong are relatively impermeable, but interbedded sandstones in them may furnish some water. The Brunswick formation, although consisting chiefly of shale, contains beds of coarse sandstone which are water-bearing.

In general in the northern or Triassic lowland area of the Honeybrook and Phoenixville quadrangles, water may be obtained in rocks that can be drilled with comparative ease, and the chances of obtaining a supply of water can generally be predicted with little doubt.

The Paleozoic formations fall into the second class of water-bearing rocks. The finely crystalline stratified rocks are less permeable to water than the noncrystalline clastic rocks of the Newark group. Water may be obtained in the Chickies quartzite and at the base of the Chickies. It may also be obtained from limestones at their base, but this water will be hard and will be subject to all the impurities of surface water, owing to the solubility of limestone and the dependent fact that water in limestone moves through relatively large channels and is accordingly not filtered by the rock. In general in Paleozoic formations occupying narrow belts water can probably be obtained by drilling, but the supply will not be inexhaustible.

The pre-Cambrian crystalline rocks represent the third class of water-bearing formations and furnish still another set of conditions.

These rocks, made up of closely interlocking grains, are the least permeable of the three classes of rocks of the area. Moreover, unlike the rocks of the other two classes, they possess no definite planes of parting, such as stratification planes, along which ground water may circulate. The metamorphosed stratified rocks show no alternations of permeable and impermeable beds but are relatively impermeable throughout and therefore supply no water-bearing zones. The crystalline rocks, however, have openings of four sorts that are suited to the flow of ground water—joints, faults, planes of foliation, and contacts. Joints, which are the chief water carriers of crystalline rocks, are vertical, inclined, or horizontal fractures, are spaced very irregularly, and generally do not extend far below the surface and are generally less uniform than the bedding planes of stratified rocks. Parallel joints may be from a few inches to 10 feet or more apart; there are usually two or more intersecting systems of such parallel joints in metamorphic rocks. Horizontal joints, which characterize granites, decrease in number with increase in depth and disappear altogether at a depth of a few hundred feet. Joint openings are widened at the surface by weathering and abruptly decrease in width with increase in depth, becoming first a closed joint and ultimately disappearing altogether. Joints that have the greatest linear extension probably have also the greatest downward extension. The unreliability of joints as water carriers is due not alone to their disappearance at depths but also to the possible existence of deeper joints whose character cannot be calculated. The most successful wells drilled in crystalline rocks are those which strike intersecting master systems of joints or a system of horizontal joints, or both.

Faults are fractures along which movement has taken place. They are less abundant than joints but are rarely absent in metamorphic rocks and are likely to furnish wider and more persistent openings than joints.

Planes of schistosity, or foliation planes, are produced by pressure, which effects the flattening and parallel arrangement of the interlocking crystals of the rock. The openings along these planes are very minute, and although they are a factor in bringing about the saturation of the rock they are not usually large enough to permit free movement of ground water.

Contacts, of course, are not peculiar to crystalline rocks, but as water channels they are relatively more important in some crystalline rocks, where other openings are few and irregular, than in most stratified rocks, where openings are generally numerous and regular. Where an igneous rock has intruded another formation the contact between the two formations may furnish a channel for ground water, and springs are likely to occur along such contacts.

The igneous rocks of the quadrangles have four intersecting systems of parallel joints, as does also the Wissahickon formation. Because of these intersecting joint systems water can probably be obtained from the crystalline rocks by drilled wells of no very great depth. If water is not obtained within 200 or 300 feet there is no use in drilling deeper. The water obtained will be soft except in the Pickering gneiss associated with limestone lenses. This statement is true of all the pre-Cambrian rocks of the quadrangle, covering nearly one-half of the area.

The general character of spring water in the pre-Cambrian rocks is indicated by the following analysis of water from springs at Honeybrook:

Analysis of water from springs owned by the Honeybrook Water Co., Honeybrook, Pa.

[Margaret D. Foster, analyst, U. S. Geological Survey]

	Parts per million
Silica (SiO_2)	6.2
Iron (Fe)	.71
Calcium (Ca)	1.6
Magnesium (Mg)	.9
Sodium (Na)	1.7
Potassium (K)	.8
Carbonate radicle (CO_3)	0
Bicarbonate radicle (HCO_3)	9.0
Sulphate radicle (SO_4)	1.5
Chloride radicle (Cl)	2.0
Nitrate radicle (NO_3)	Trace
Total dissolved solids at 180° C	20
Total hardness as $CaCO_3$ (calculated)	7.7

The mineral content of this water, which issues from quartz monzonite, is low, and the water is soft. Analysis of the mineral content of a water supply, however, gives no indication of its sanitary quality, which is dependent upon the amount of possible pollution by organic matter.

PUBLIC WATER SUPPLIES

The following notes on public water supplies in this area were prepared for the department of health, department of internal affairs, in March 1937, by H. E. Moses:

Malvern, Chester County: This is an industrial and residential community with a population of 1,500 and has a municipal waterworks. The supply is obtained from one dug well 18 feet in diameter by 18 feet deep and three springs. The water is treated with chlorinated lime. Storage is in two standpipes, each 15 feet in diameter by 8 feet high, capacity 107,000 gallons.

Honeybrook, Chester County: The population is 650, with a municipal waterworks. The supply is obtained from one drilled well 8 inches in diameter and 102 feet deep. The storage reservoir has a capacity of 900,000 gallons. The supply is untreated.

Royersford, Montgomery County, and Spring City, Chester County: These two communities are on opposite sides of the Schuylkill River and are served with a public water supply by the Home Water Co., which serves a total population of about 6,000. The supply is obtained from the Schuylkill River, and the filter plant is on the west bank of the river in Chester County about 2 miles above Spring City. In 1917 a filtration plant was installed, having a rated capacity of 2,000,000 gallons daily. Alum and lime are used as chemicals, and the water is treated with chlorine gas. Activated carbon is also used as a taste and odor control agent. Storage of 3,000,000 gallons is provided in a reservoir on the Spring City side.

Pottstown, Montgomery County: This borough and vicinity is furnished with a public water supply by the Pottstown Gas & Water Co., the water being used by about 23,000 persons. The Schuylkill River is the source of supply, with the pumping station and filtration plant on the east bank of the stream about 1½ miles above the upper borough line. The filtration plant was installed in 1908 and extended in 1927. It has a rated capacity of 6,000,000 gallons daily. Alum and lime are used as chemicals, and the water is treated with chlorine gas. There are two storage reservoirs—Stowe Reservoir, capacity 17,000,000 gallons, and Washington Hill Reservoir, capacity 4,000,000 gallons.

Phoenixville, Chester County: The public supply is furnished by a municipal waterworks to some 13,000 persons. The supply is obtained from the Schuylkill River, and the filtration plant, which was built in 1914, is on the west bank of the river above the town near Cromby station. The plant has a capacity of 3,000,000 gallons daily. Alum and lime are used as chemicals, with disinfection by the use of ammonia-chlorine. The filtered water is stored in an open reservoir having a capacity of 9,000,000 gallons.

Downingtown, Chester County: This borough has a municipal waterworks serving some 5,000 persons. The water is filtered in a plant built in 1924, having a daily capacity of 1,500,000 gallons. Two sources of supply are used, Copeland Run and Beaver Run. On the latter stream there is a pumping station through which the water is pumped to the filtration plant, located on Copeland Run. Alum and soda-ash are used as chemicals, with ammonia-chlorine for disinfection. There is one storage reservoir of 3,300,000 gallons capacity along Copeland Run just below the filtration plant.

PRIVATE WATER SUPPLIES

Private water supplies are obtained from springs, dug wells, and drilled wells. In recent years new supplies have been sought chiefly from drilled wells. Drilled wells in the Stockton formation provide private water supplies in Phoenixville and Montclare.

Springs issue in Chester Valley and along the south slope of the North Valley Hills. The following analyses are typical of water from these two sources.

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Analyses of spring water from Chester Valley and North Valley Hills

[Margaret D. Foster, analyst. Parts per million.]

	1	2
Silica (SiO_2)	10	9.1
Iron (Fe)	.16	.02
Calcium (Ca)	40	2.1
Magnesium (Mg)	22	1.4
Sodium (Na)	2.4	2.5
Potassium (K)	1.4	1.5
Carbonate radicle (CO_3)	0	0
Bicarbonate radicle (HCO_3)	211	6.8
Sulphate radicle (SO_4)	7.5	1.8
Chloride radicle (Cl)	2.7	3.4
Nitrate radicle (NO_3)	11	5.3
Total dissolved solids at 180° C	204	34
Total hardness as $CaCO_3$ (calculated)	190	11

1. From spring in Conococheague limestone on W. W. Atturbury's estate, 1¼ miles north of Frazer.
2. From spring in lower member of Cambrian Chickies quartzite on Three Springs Farm, owned by the Misses Hopkinson and Huntzinger, Malvern, near Bacton.

The water of no. 1 is hard, as is to be expected, though not dissimilar in this respect from water supplied elsewhere. The water of no. 2 is soft, with a low mineral content, an excellent water on the basis of mineral content.

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