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GEOLOGY AND MINERAL RESOURCES

OF THE

QUAKERTOWN-DOYLESTOWN DISTRICT
PENNSYLVANIA AND NEW JERSEY

BY

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By F. Bascom, E. T. Wherry, G. W. Stose, and A. I. Jonas

INTRODUCTION

By F. Bascom

LOCATION AND GENERAL RELATIONS OF THE AREA

The Quakertown and Doylestown quadrangles, in this bulletin called the Quakertown-Doylestown district, lie mainly between the Delaware and Schuylkill Rivers, in southeastern Pennsylvania, north of Philadelphia; the northeast corner of the Doylestown quadrangle, inclosed by the Delaware River, embraces a small portion of western New Jersey northwest of Trenton. (See fig. 1.) The area lies chiefly in Bucks County but includes portions of Montgomery and Lehigh Counties, Pa., and a small part of Hunterdon County, N. J.

This area as shown on the map (pl. 1) extends from latitude 40° 15′ to 40° 30′ N. and from longitude 75° to 75° 30′ W. and includes one-eighth of a "square degree" of the earth's surface, which in this latitude amounts to 455 square miles.

The district lies almost wholly in the Piedmont Lowlands of the Piedmont province; the extreme northwest corner of the Quakertown quadrangle is part of an upland region which is regarded as a southern extension of the New England Upland and has been called the Reading prong of the New England Upland.

In Pennsylvania this lowland area adjoins on the southeast the Piedmont Upland of the Piedmont province, and in New Jersey it adjoins in this direction the Atlantic Plain with no intervening upland.

GENERAL GEOGRAPHY AND GEOLOGY OF THE REGION

Appalachian Highlands.—The eastern section of the United States is separable into two great natural divisions—the Atlantic Plain, bordering the sea with a maximum width of 250 miles and extending beneath the sea to the edge of the continental plateau,

[1] The Triassic sedimentary rocks were surveyed by E. T. Wherry and the Triassic diabase and pre-Cambrian rocks by Eleanora Bliss [Knopf] and Anna I. Jonas, the preliminary survey of the Paleozoic rocks was made chiefly by F. Bascom and E. T. Wherry and the final survey by G. W. Stose. F. Bascom was in charge of the field work and inspected the results.

and the Appalachian Highlands, extending from the Atlantic Plain to the Mississippi lowlands and from Canada to the Gulf plains.

The Appalachian Highlands (see fig. 2) embrace seven physiographic provinces, of which the most easterly—the Piedmont—adjoins the Atlantic Plain and includes the area described in this bulletin. This province is separated from the valley and mountains of the western Appalachian Highlands on the southwest by

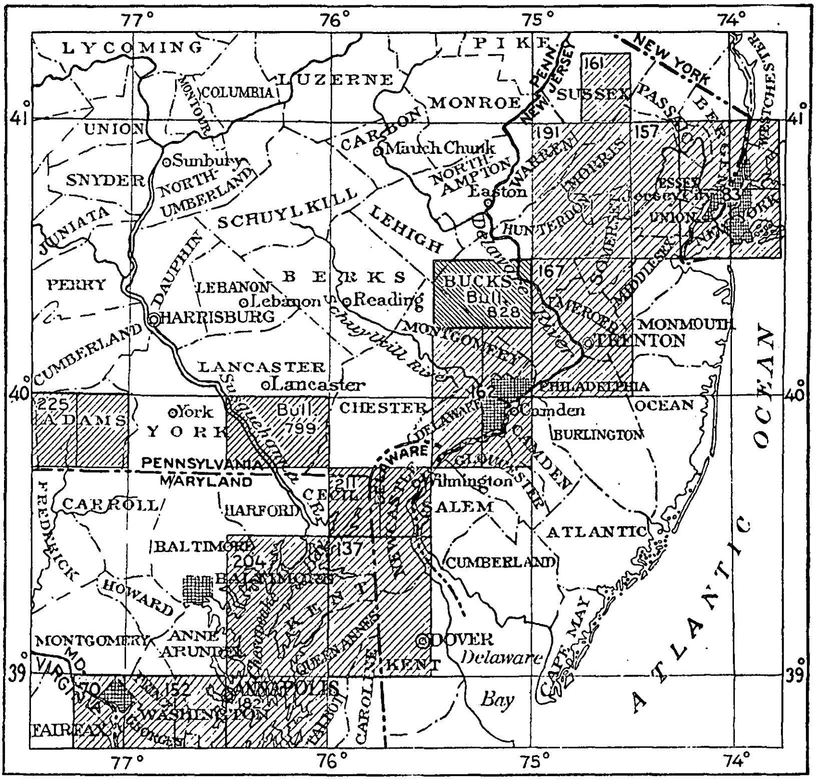

FIGURE 1.—Index map of eastern Pennsylvania, western New Jersey, and parts of Delaware and Maryland. The location of the Quakertown and Doylestown quadrangles is shown by the darker ruling. Other quadrangles, indicated by lighter ruling, are described in Geologic Folios 70, Washington; 83, New York City; 137, Dover; 152, Patuxent; 157, Passaic; 182, Choptank; 161, Franklin Furnace; 162, Philadelphia; 167, Trenton; 191, Raritan; 204, Tolchester; 211, Elkton-Wilmington; 225, Fairfield-Gettysburg; and in Bull. 799, Geology of the McCalls Ferry-Quarryville district, Pa.

the Blue Ridge province and on the northeast by a series of upland plateaus that stretch away to the east.

Piedmont province.—The Piedmont province owes its name to its location at the eastern foot of the Appalachian Mountains and includes the Piedmont Upland and the Piedmont Lowlands. Northeastward it merges into the New England Upland and southwestward it passes into the 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 lowlands comprise those small contiguous portions of the Piedmont province underlain by relatively weak Triassic shale or by soluble Paleozoic limestone and dolomite. Among the limestone-dolomite areas are Chester Valley and the adjacent rolling agricultural plains about Lancaster, Pa., and similar plains about Frederick, Md.

The lowland area underlain by Triassic formations is a narrow strip of country (10 to 30 miles wide) extending 300 miles along the northern and western border of the province and distinguished from the adjacent upland by the more level open character of the

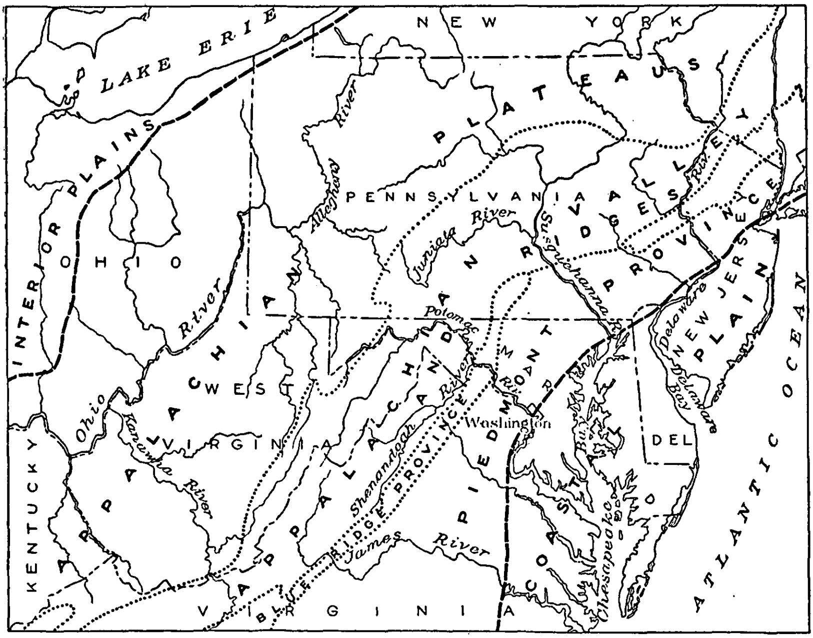

FIGURE 2.—Map of the northern Appalachian Highlands, showing physiographic divisions and relations to the Coastal Plain. The division northeast of the Blue Ridge province, separated from it by a part of the Piedmont province, is an extension of the New England Upland, and between it and the Coastal Plain are the Piedmont Lowlands, which form a section of the Piedmont province

country. The valleys are not so deep as in the uplands, the hills are not so abrupt, and the relief is less. Triassic formations do not everywhere produce lowlands; west of the Schuylkill River, where the Triassic rocks are locally sandy and conglomeratic and relatively resistant, a rugged upland is developed. In the southern Piedmont detached areas of weak Triassic rocks are not differentiated from the rest of the Piedmont, because the peneplain surface, of which they are a part, lies close to base level and has never been sufficiently uplifted to stimulate erosion.

The Piedmont Upland constitutes the remaining and major portion of the province.

Although the Piedmont province exhibits a varied scenery, there are certain general features common to the entire region that make it a topographic unit; it consists, in brief, of a succession of uplands sloping toward the sea, dissected by relatively narrow valleys and diversified by residual eminences rising above the general level. If the valleys were filled, the uplands would be converted into a broad stairlike series of seaward-facing terraces or a succession of plateaus sloping eastward, southeastward, and southward, toward the Atlantic. The lowlands of the Piedmont province, developed on weaker rocks, exhibit these features in a less marked degree.

The plateaus and terraces are resolved into five incomplete upland plains, representing old peneplains, partial peneplains, and four narrow terraces. Remnants of the oldest and now the highest peneplain are preserved in the even-crested, high ridges of the Appalachian Valley and Ridge province. The crest of Kittatinny Mountain, just north of this area, standing at an altitude of 1,600 feet and composed of resistant sandstone and conglomerate, is regarded as a typical remnant and has given its name to this peneplain. Remnants of the Kittatinny peneplain are found eastward at lower levels on the tops of mountains in the Piedmont province, and apparently the peneplain passes under recent sediments (Patuxent) on the eastern border of the Piedmont province. The peneplain is preserved only where it is buried beneath later deposits. Where the protecting deposits have been removed by erosion the surface of the peneplain has been dissected, so that the unmodified surface does not exist unless in the immediate vicinity of the deposits. This surface emerges from beneath the cover of sediments at an altitude of about 120 feet in New Jersey and at 400 feet in Maryland.

The even-crested summits of ridges lower than those on which the Kittatinny peneplain are preserved are remnants of a later and almost equally extensive plain, which is preserved at a height of 1,000 to 1,100 feet in Schooley Mountain, New Jersey, and has been called the Schooley peneplain.[2] This peneplain also extends eastward into the Piedmont province and is believed to pass under sediments (Patapsco) at an altitude of 100 feet in New Jersey. Southwestward in Maryland it passes beneath the sedimentary cover at 320 to 380 feet.

The highest upland within the Appalachian Valley proper represents a peneplain less well defined in the Appalachian Valley than the two preceding plains on the ridge tops but showing a considerable development at 700 to 800 feet in the Piedmont province. Because of its development about Honeybrook, 15 miles south of Reading,

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

it has been called the Honeybrook peneplain. This peneplain apparently passes under deposits of Upper Cretaceous age on the Atlantic Plain.

The next lower upland of the Appalachian Valley proper lies in general at an altitude of about 600 feet. This upland is conspicuous northeast of Harrisburg and may be traced northeastward to the Delaware River, southwestward to the Potomac River, and eastward on the Piedmont Upland, where the remnants have an altitude of 500 feet. It is the dissected remnant of a peneplain known as the Harrisburg peneplain and apparently passes beneath Tertiary deposits on the Atlantic Plain.

Immediately east and west of Harrisburg, along the Susquehanna River, the interstream areas rise rather uniformly to heights of 500 to 540 feet and show a period of partial peneplanation. The less widespread partial peneplain produced in this epoch is named the Bryn Mawr peneplain from the sediments known as the Bryn Mawr gravel (formerly "early Brandywine" or "Lafayette") which it carries on its seaward border. The Bryn Mawr peneplain is a conspicuous plain in parts of the Piedmont province, where it maintains a slope over wide areas from 450 to 400 feet and passes under Bryn Mawr gravel at 400 feet. From the Bryn Mawr peneplain there is a gentle seaward slope to the highest of three seaward-facing escarpments at 200 feet. This terrace plain is also well developed between the Bryn Mawr surface and the stream gorges. It takes its name from the Brandywine ("late Brandywine") formation, which is found upon its surface. It was perhaps during the epoch that followed the development of the Brandywine sloping plain, of which now only a terrace plain or berm [2a] remains, that the

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2a *Berm* is defined in the Standard Distionary as follows: "*Civ. Engin.* A horizontal ledge part way up a slope; bench. *Fort.* A narrow level space at the outside foot of a parapet, to retain material which might otherwise fall from the slope into the ditch."

At the suggestion of Laurence LaForge this term is here given a geomorphic usage; it will be used to distinguish those terraces which result from the interruption of an erosion cycle with rejuvenation of a stream in the mature stage of its development. Dissection, following upon elevation of the land, will leave remnants of the earlier broad valley floor of the rejuvenated stream as a terrace, or *berm,* and remnants of the uplifted abrasion platform as a seaward-facing terrace, or *berm.* In different localities every gradation between relatively narrow berms and widely developed peneplains may occur. Considerable latitude should be given, therefore, in the use of this term, so that it may include bermlike forms as well as typical berms; whereas those forms more nearly approaching the peneplain will be called partial peneplains.

Such a distinction as the following between berms, partial peneplains, and peneplains might be considered: Berms, paralleling streams and seacoast, only cross divides on weak formations; partial peneplains cross divides on rocks of medium resistance or on decayed resistant rocks; peneplains are widespread over divides on resistant as well as nonresistant rocks.

Strath is defined in the Standard Dictionary as follows: "(Scot.) A wide, open valley, usually a river course; distinguished from a glen." This has been its usage by Geikie in "Scenery of Scotland," p. 156. In the Kittanning folio strath is used to designate an old broad valley floor uplifted and dissected into such remnants as are here termed berms. It is to be noted that strath as a geomorphic term was first used for a broad valley floor unrejuvenated, and it is still so used in Great Britain.

whole Atlantic Plain was above the sea, and valleys were cut to the edge of the continental plateau. The seaward extensions of the valleys of the Hudson, Delaware, Susquehanna, and Potomac, now submerged, were cut on this uplifted surface. Recent inspection of the Bryn Mawr and Brandywine gravels along the Potomac, Susquehanna, and Schuylkill Rivers has led Campbell[3] to present the hypothesis that the surface upon which the Bryn Mawr gravel rests is deformed in a low anticline the axis of which crosses the Potomac River near Great Falls, the Susquehanna River at Safe Harbor, and the Schuylkill River at Norristown. Such a deformation, if it occurred, must have accompanied the uplift that preceded the development of the berm upon which Brandywine gravel was deposited, for that surface is not affected.

On the extreme border of the Piedmont province occur three relatively narrow berms separated by weakly defined escarpments at about 80, 40, and 20 feet above sea level. These berms carry materials of more recent age (Pleistocene) and have been named from localities in Maryland, where the deposits were thought to be typically developed, in descending order, the Sunderland, Wicomico, and Talbot. The gorges in the Piedmont province, which lie below the Brandywine berm, were cut and the river bottoms of the master streams of the Appalachian Highlands were widened during these erosion cycles.

Most of the master streams of the province, rising either in the western part of the Appalachian Highlands or on the inland border of the Piedmont province, pursue courses that are dependent upon the seaward slope either of a pre-Kittatinny peneplain,[3a] of which no trace remains, or of the Kittatinny and later peneplains and are quite independent of the structure and character of the rock floor. They empty into estuaries that head at the eastern margin of the Piedmont province, or else they cross the Coastal Plain and empty directly into the Atlantic or into the Gulf of Mexico. The Delaware, Schuylkill, Susquehanna, and Potomac are such streams that have cut gorges transverse to the strike of the rock formations.

The courses of the tributary or secondary streams, on the other hand, are in a large measure adjusted to the unequally resistant rocks that form the floor upon which the streams flow, and the valleys produced by them, together with the ridges left between the valleys, show marked conformity to geologic structure. The general trend of the highlands of the Piedmont province, which is northeastward in harmony with the strike of the rocks, is in accord with the courses of the tributary streams rather than with the main drainage lines of the province.

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

[3a] Johnson, D. W., unpublished manuscript.

GEOGRAPHY

By F. Bascom

SURFACE FEATURES

The Quakertown-Doylestown district lies almost wholly within the Piedmont province and in that subdivision of the province known as the Piedmont Lowlands. (See fig. 2.) The northwest corner of the Quakertown quadrangle, an area of about 5 square miles, is part of an upland region, which geologically may be regarded as either the northward extension of the Blue Ridge province or the southern extension of the New England Upland. Though in alinement with the Blue Ridge province it has been held to be more closely related to the New England Upland and has been called the Reading prong of that upland.

The higher elevations of the district sweep in curving lines from southwest to northeast and are conspicuously controlled by the strike of the rock formations. The crystalline rocks (pre-Cambrian quartz monzonite and Triassic diabase), conglomerate and baked shale (Brunswick formation), and a hard blue shale (Lockatong formation) are the resistant beds of the area and maintain the highest levels in the quadrangles. The lowest altitude, where the Delaware River leaves the Doylestown quadrangle, is 80 feet above sea level and 880 feet below the top of Haycock Mountain, the highest altitude of that quadrangle. This relief does not find expression in a rugged, hilly country. Gentle slopes are the rule, and save on the massive crystalline rocks abrupt hills are the exception.

The dominant scenic features of the quadrangles are three ridges sweeping to the northeast. The most southerly ridge is upheld by resistant shale (Lockatong formation) and is 620 feet in altitude. The next one, along the crest of which lies Ridge Road, is not more than 560 feet high and is due to relatively resistant beds (baked shale) in a normally weak shale (Brunswick formation). The most northerly ridge, upheld by diabase (Triassic intrusive), rises to a height of 700 feet with hills that reach 800 and 900 feet. The characteristic rugged, hilly country of the crystalline rocks (pre-Cambrian) appears in the extreme northwest corner of the Quakertown quadrangle. In a country with so little diversity of land forms, the topographic remnants of surfaces induced by successive erosion intervals are neither conspicuous nor easily separated, but the Quakertown and Doylestown quadrangles show traces of six of the erosion cycles of the Piedmont province—the Schooley, Honeybrook, Harrisburg, Bryn Mawr, Brandywine, and Sunderland.

The Schooley is represented by only three remnants, preserved on relatively resistant rock. One remnant is on Haycock Mountain, in the northwest corner of the Doylestown quadrangle, 960 feet in altitude, composed of diabase. The other two remnants are in Lower Milford Borough, in the northwest corner of the Quakertown quadrangle at altitudes of 920 and 900 feet. These remnants are preserved on relatively resistant quartzose conglomerate (Brunswick). Chestnut Hill and another hill to the southwest, each 880 feet in altitude, part of a group of quartz monzonite hills, are possibly remnants of the Schooley peneplain lowered by erosion or by warping.

There are residual surfaces of the Honeybrook peneplain in the high hills in the northwest corner of the Quakertown quadrangle at a level of 700 to 740 feet. This level of erosion is also found on the diabase in the vicinity of Haycock Mountain and in the central part of the Quakertown quadrangle, 1½ miles southwest of Smoketown. Rock Hill, in the diabase area, is a low monadnock or unreduced hill on this peneplain. Mount Pleasant, in the Doylestown quadrangle, is a flat remnant of the Honeybrook peneplain at a slightly lower level on relatively nonresistant shale (Brunswick).

As is to be expected, the Harrisburg and Bryn Mawr levels of erosion are more widely preserved than the earlier peneplains. The Harrisburg is preserved on the resistant diabase and on hard shale (Lockatong) in interstream areas at a level of 600 feet. The Bryn Mawr is also preserved on diabase, on hard shale (Lockatong) in the outer Delaware Valley, and on the quartzite (Cambrian) of Buckingham Mountain at a level of 500 feet. Quakertown is located on the Bryn Mawr surface dissected by Tohickon Creek. The Quakertown-Doylestown area, which lies northeast of the assumed axis of the low anticline of the warped Bryn Mawr plain, was apparently little affected by this deformation.

The Brandywine and Sunderland remnants occur on the easily eroded shale (Brunswick formation) bordering the main streams and have the character of slopes rather than level surfaces. The Brandywine slopes from 440 to 400 feet and the Sunderland from 320 to 300 feet. The valley bottoms that lie below 300 feet were cut in post-Sunderland time.

DRAINAGE

Nearly three-fourths of the Quakertown-Doylestown district is drained by the Delaware River and the remainder by the Schuylkill. The divide is very closely contested by the eastern tributaries of the Schuylkill and the western tributaries of the Delaware. The Delaware has apparently been rejuvenated by an inconsiderable uplift which did not affect the Schuylkill, to the south, and which has given the advantage of gradient to the tributaries of the Delaware working under conditions otherwise common to the two basins.

In many places only a small fraction of a mile separates rival streams, and in other places the tributaries of the two river systems interfinger. In the Doylestown quadrangle the southwest tributaries of Tohickon Creek, tributary to the Delaware, are contesting this divide with the Northeast Branch of Perkiomen Creek, a strong tributary to the Schuylkill. Among the former streams Deer Run, which has a shorter course to base level and thus double the gradient of its rival, threatens to capture the headwaters of the Northeast Branch of Perkiomen Creek.[3b]

The Delaware River and Neshaminy and Perkiomen Creeks flow southeastward in a direction determined by the slope of the uplifted peneplains. The tributary streams tend to pursue southwest or northeast courses parallel to the strike of the rock formations with small right-angled tributaries normal to the strike. The region is well drained and free from natural ponds and swamps.

POPULATION, CLIMATE, VEGETATION, AND CULTURE

The population of the area, estimated to be about 53,000, is distributed in more than a hundred small villages and on farms. In 1930 there were no towns in the quadrangles with a population of 5,000 or more. Quakertown (4,883), Doylestown (4,577), Perkasie (3,463), and Sellersville (2,063) are the largest towns.

The mean annual temperatures for the Quakertown-Doylestown district, estimated from observations at Quakertown covering the periods 1875–1905 and 1917–18 and at George School 12 miles southeast of Doylestown, for 1907–18, are as follows:

For Quakertown the mean temperature is 49.6° F., the highest temperature 105°, in July and August, and the lowest temperature −15°, in February, 1899 and 1918. This is 4.4° lower than the mean annual temperature of Philadelphia and 2.5° lower than the mean annual temperature of Reading, 30 miles to the west, estimated for a period of 40 years. July is the hottest month, with a mean annual temperature of 72.5°. January, with a mean annual temperature of 27°, is the coldest month. At George School, 15 miles south of the latitude of Quakertown, the mean annual temperature is 51.5° and the lowest temperature recorded is −14°, in February, 1918. July is the hottest month, with a mean temperature of 73.6°, and February has the lowest mean temperature, 29.7°.

The average date of the first killing frost in the vicinity of Quakertown is October 7 and of the last killing frost April 30. The average date of the first killing frost at George School is October 14 and of the last killing frost April 25. The warm winds from the Coastal Plain reach the region of George School, which is separated by no

[3b] Cf. Davis, W. M., A river pirate: Science, vol. 13, pp. 108–109, 1889.

highland from the plain, more directly than they do Quakertown and lengthen the growing year in the former place.

The mean annual precipitation at Quakertown, from records covering the same period of years as the observations of temperature, is 44.56 inches; the greatest precipitation in 24 hours was 5.94 inches (May), and the average number of days in the year in which there is precipitation of 0.01 inch or more is 109. The month of greatest mean annual precipitation is July, and the month of least precipitation is November.

At Doylestown, between 1889 and 1918, the mean annual precipitation was 49.31 inches, with July and November the months of greatest and least annual precipitation. At George School the mean annual precipitation for the 12 years 1907–1918 was 40.37 inches, and August and November were the months of greatest and least annual precipitation. The rainfall in the Quakertown-Doylestown district is fairly equally distributed throughout the year and is never less than 3 inches in any month. Droughts are rare, and vegetation thrives throughout the summer. The prevailing winds are southerly from May to September inclusive and northerly during the rest of the year.

The Quakertown-Doylestown district shows little diversity in soil, owing to the uniform underlying rock formations. The greater part of the area is covered by a silty loam conspicuously characterized by an Indian red or reddish-brown color. This soil (Penn silt loam), the origin and character of which are further described under the heading " Soils " (p. 55), is adapted to general farming but is somewhat deficient in organic matter and is subject to wash. When this deficiency is overcome the soil is very productive and especially adapted to grass and grain.

A belt of heavy red or brown clay loam crosses the quadrangles, marking the outcrops of the diabase. This soil is characterized by many boulders and by a rough topography, which renders it difficult to put the land under cultivation. Where the land has been cleared and cultivated the soil produces good crops. Peach trees are said to thrive upon it.

There are no heavy forests in this area, but a light growth of several kinds of trees—oak, hickory, maple, and formerly chestnut. This region is beyond the suburban district and is distinctly agricultural in its interests. Markets are good and accessible, and farming here should become intensive.

Railways crossing the district are the Perkiomen Railroad, the Belvidere branch of the Pennsylvania Railroad, and the Bethlehem and Doylestown branches of the Philadelphia & Reading Railway. The last-named road terminates at Doylestown. The Lehigh Valley Transit Co's. electric line connects Quakertown, Perkasie, Sellersville, Souderton, and Hatfield with Philadelphia and Allentown. Doylestown is connected by trolley lines with Easton and Philadelphia and with Bristol. Through roads leading from Philadelphia to Easton by way of Doylestown, from Philadelphia to Allentown and Bethlehem by way of Quakertown, and from Trenton to Easton following the west bank of the Delaware River are hard surfaced for automobile traffic. The Delaware division of the Pennsylvania Canal parallels the Delaware River from Trenton to Phillipsburg.

Quakertown, the largest town in the area, has cigar and cigar-box factories, silk mills, a harness factory, and a foundry.

Doylestown, the second largest town in the area, is the county seat of Bucks County. It contains shoe factories, hosiery, silk, and worsted mills, flour and saw mills, creameries, manufactories of agricultural implements, spokes, and brick and tile, and foundries.

Perkasie has silk mills, brick and tile works, lumber mills, stone crushers, and manufactories of cigars, tags, and novelties.

DESCRIPTIVE GEOLOGY

STRATIGRAPHY

By F. Bascom

The geologic formations of the Quakertown-Doylestown district comprise Archean crystalline rocks of sedimentary origin; igneous rocks of pre-Cambrian age; sedimentary rocks of Cambrian and Ordovician age; sedimentary and igneous rocks of Triassic age; and gravel of Quaternary age. The distribution of these formations is shown on Plate 1. The character and sequence of the sedimentary rocks are graphically shown in the columnar section forming Plate 2.

ARCHEAN SYSTEM

SEDIMENTARY ROCKS

GRAPHITIC GNEISS

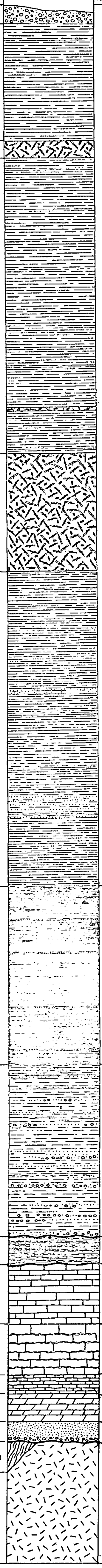
Distribution.—The graphitic gneiss, which is an extensive formation in the quadrangles lying to the southwest, has a very scanty distribution in the Quakertown quadrangle. The gneiss is exposed in only two small areas in the Quakertown quadrangle and nowhere in the Doylestown quadrangle. These exposures are in the northwest corner of the Quakertown quadrangle, where the Triassic cover has been eroded from the underlying pre-Cambrian and Paleozoic formations. Here the gneiss occurs as a narrow lens in the gabbro and as an oval area in the quartz monzonite.

Character and thickness.—The graphitic gneiss in this area is a metamorphosed graphite-bearing sediment of considerable mineralogic and textural variability. It is typically a medium-grained crystalline quartz-feldspar rock conspicuously spangled with scales of graphite and biotite and in most places thoroughly injected with acidic pegmatite and hornblendite. Quartz is usually a dominant constituent. The feldspar may be orthoclase, microcline, or a sodic plagioclase and is usually altered to kaolin, sericite, epidote, or zoisite. Biotite, which occurs in minute scales, may be present in excess or may be almost absent. Accessory constituents are graphite, muscovite, garnet, zircon, sillimanite, titanite, pyrite, pyrrhotite, magnetite, calcite, allanite, scapolite, diopside, and tremolite. Secondary constituents are epidote, sericite, kaolin, zoisite, chlorite, limonite, and hematite. Although essentially a quartz-feldspar-biotite rock, the gneiss shows so great a variation in the proportion of these constituents that it is identified rather by characteristic accessory constituents, structure, and decomposition products. Such characteristic accessory constituents are graphite and muscovite; characteristic structure consists of gneissic banding and many closely placed and irregular joints; a characteristic decomposition product is a reddish graphitic clay, where the iron sulphides and oxide have changed to limonite and hematite and feldspar has changed to clay, quartz has been partly sorted out, and graphite is the chief original constituent remaining. In their prevalent decomposition, foliation, and complex jointing the rocks of this formation are in contrast with the adjacent relatively fresh and massive igneous rocks.

The small areas underlain by pre-Cambrian gneiss in the Quakertown quadrangle reveal little geologic structure. The strike, where it can be observed, is northeast, and the dip of the schistosity or gneissic banding southeast. The gneissic banding, schistosity, and disintegration of the exposed rock obscure the record of the closely overturned folding which the formation has doubtless undergone. It is impossible to estimate the thickness of the formation owing to the impracticability of recognizing recurrent beds.

Name and correlation.—The graphitic gneiss of the Quakertown quadrangle is separated by a broad belt of overlying Triassic formations from the noteworthy graphite-bearing gneiss of southeastern Pennsylvania, which is an extensive formation to the southeast and which has furnished most of the graphite mines in the State. The largest of these mines are in the Pickering Creek Valley, Chester County, where the gneiss contains beds that are persistently rich in graphite.

Elsewhere the formation is entirely free from graphite or has only a thin bed containing an inconsiderable amount of the mineral. This is the more typical gneiss and is a well-recognized formation known as the Baltimore gneiss. The Archean graphite gneiss of the



SYSTEM		GROUP AND FORMATION		THICKNESS IN FEET	DESCRIPTION OF ROCKS
TRIASSIC	Newark group	Brunswick formation	Ŧbc, Ŧb, Ŧd, Ŧb, Ŧd, Ŧb	12,000	*Soft bright-red shale and fine sandstone metamorphosed to hard dark baked shale adjacent to large intrusive masses of diabase,* Ŧd; *coarse quartzose conglomerate,* Ŧbc, *at top*
		Lockatong formation	Ŧl	3,000-3,500	*Hard dark-red to dark-gray or black shale and argillite and hard impure limestone. Locally metamorphosed to hard baked shale*
		Stockton formation	Ŧs	3,000	*Chiefly yellow arkosic sandstone with some conglomerate and red argillaceous sandstone and shale*
		UNCONFORMITY			
ORDOVICIAN		Cocalico phyllite	Oc	500+	*Chiefly dark shaly phyllite, some red and green, and thin quartzite, slate, and arkosic sandstone*
		UNCONFORMITY			
		Beekmantown(?) limestone	Ob	1,000±	*Massive dark-colored dolomite and light-blue magnesian limestone*
CAMBRIAN		Conococheague limestone	Ꞓc	900±	*Blue limestone, light-blue and dark-gray dolomite, thin sandstone, chert with shaly and siliceous partings, and Cryptozoon reefs*
		Elbrook limestone	Ꞓe	500+	*Fine-grained light-gray limestone, weathering shaly, earthy, and buff; some black chert and flint*
		Tomstown dolomite	Ꞓt	500±	*Massive dark-blue dolomite and some chert*
		Hardyston quartzite	Ꞓh	300±	*White vitreous quartzite with pebbly arkosic beds at base*
		UNCONFORMITY			
PRE-CAMBRIAN		Graphitic gneiss and intrusive rocks	ggn, qm, gb		*Graphitic sedimentary gneiss cut by quartz monzonite, gabbro, and pegmatite*

Vertical scale

2,000 1,000 0 2,000 6,000 FEET

COLUMNAR SECTION OF THE ROCKS OF THE QUAKERTOWN-DOYLESTOWN DISTRICT

Quakertown quadrangle, on the northwest side of the Triassic belt, showing very similar characters and associations, is presumably an equivalent formation or perhaps a part of the same great formation. The graphitic gneiss is provisionally correlated with the pre-Cambrian graphitic gneiss and schist of Sussex County, N. J.,[4] on the ground of lithologic character, associations, and general stratigraphic relations.

PRE-CAMBRIAN IGNEOUS ROCKS

GENERAL FEATURES

Most of the pre-Cambrian rock exposed in the Quakertown quadrangle forms part of an igneous complex of wide extent that is composed dominantly of three types—granite (quartz monzonite), diorite (quartz diorite), and gabbro (quartz gabbro). A gneissic texture where present in these rocks is due either to minute parallel injection or to parallel orientation of mineral constituents brought about by pressure, or to both, and is for the most part limited to the peripheries of the larger intrusive masses and to the smaller intrusive bodies. The greater part of the large intrusions is massive and exhibits the textures of unaltered igneous rocks. Similar plutonic intrusions are associated with pre-Cambrian gneisses throughout the Appalachian region. They form a noteworthy part of the pre-Cambrian complex of the Adirondacks and appear as pre-Cambrian intrusions in southeastern New York; they are found in the highlands of New Jersey, where they have been described as Byram gneiss, Losee gneiss, and Pochuck gneiss; in Pennsylvania they appear throughout the Piedmont Upland on both sides of the Piedmont Lowlands. The Cranberry granite and Roan gneiss of Tennessee and North Carolina are similar rocks belonging to the same general period of intrusion. Quartz monzonite and quartz gabbro are the only types represented in the Quakertown area.

QUARTZ MONZONITE

Quartz monzonite is the more widespread of the two types of pre-Cambrian igneous rocks in the Quakertown quadrangle. It is the dominant formation of the small highland area in the northwest corner of the quadrangle. In a few places it is concealed under faulted remnants of Cambrian quartzite or Cambrian and Ordovician limestone, or it is invaded by gabbro, diabase, and pegmatite.

[4] Wolff, J. E., New Jersey Geol. Survey Ann. Rept. for 1893, p. 365, 1894. Bayley, W. S., U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), p. 6, 1908; Raritan folio (No. 191), p. 8, 1914.

The quartz monzonite is a medium-grained light-gray to buff rock, locally coarse grained and highly feldspathic and quartzitic. Quartz, feldspar, and hornblende or biotite are the usual essential constituents. Augite rarely exceeds hornblende or biotite in amount, and muscovite is exceptionally a primary constituent. Accessory constituents are magnetite, zircon, apatite, and allanite. Secondary constituents are chlorite, epidote, kaolin, sericite, glaucophane, and leucoxene. The quartz ranges from 10 to 50 per cent, and the average is about 40 per cent. Feldspar, which makes up from 40 to 75 per cent of the rock and averages about 50 per cent, is dominantly orthoclase, microperthite, and microcline and very subordinately albite-oligoclase or oligoclase. Microperthite, the intergrowth of orthoclase and albite, is the characteristic feldspar. The feldspar is relatively fresh; its decomposition products are kaolin, sericite, and epidote. The quartz monzonite is in some places quite free from hornblende, augite, and biotite, but where such constituents are present hornblende is the more common and in some specimens constitutes as much as 20 per cent of the rock. Biotite may occur with the hornblende or alone but in few specimens constitutes more than 10 per cent of the rock.

Magnetite is nowhere abundant. In many places it is titaniferous and is altered to leucoxene. North and northwest of Chestnut Hill glaucophane is a conspicuous secondary constituent of the rock. For the most part the rock is made up of somewhat tabular mineral grains of diverse size and diverse arrangement, in part showing crystal boundaries. In some places pressure has brought about a parallel arrangement of grains.

Analyses of quartz monzonite from Pennsylvania and New Jersey

	1	2	3	4
SiO_2	77.07	73.64	64.64	58.75
Al_2O_3	12.61	12.82	15.92	17.16
Fe_2O_3	.71	.65	1.14	5.18
FeO	.73	1.55	4.65	3.94
MgO	Trace.	.12	.23	.91
CaO	.87	1.08	2.12	.62
Na_2O	3.43	2.47	4.38	5.22
K_2O	4.06	6.22	6.06	5.40
H_2O+	.62	.68	.43	.73
H_2O-	.23	.14	.04	.35
TiO_2	.12	.17	.42	.65
ZrO_2			Trace.	
CO_2	Trace.	.38		.13
P_2O_5	Trace.	.04	Trace.	.20
S		None.	.06	
MnO	.09	.03	.03	.10
BaO		.04	.10	
	100.54	100.03	100.22	99.84

Analyses of quartz monzonite from Pennsylvania and New Jersey—Continued

Norms calculated from analyses

	1	2	3	4
Quartz	39.60	31.98	8.70	1.86
Orthoclase	23.91	36.70	36.14	31.69
Albite	28.82	20.96	37.20	48.21
Anorthite	4.45	5.56	5.56	2.22
Corundum	1.02			1.22
Diopside			4.40	
Hypersthene ($FeSiO_3$)	.66	2.01	5.15	4.28
Apatite				.34
Magnetite	.93	.93	1.62	7.66
Ilmenite	.30	.46	.76	1.22
Pyrite			.12	
Water	.85	.82	.47	1.08
Miscellaneous			.13	.13
	100.54	99.91	100.25	99.91
Symbol	I.3'.(1)2.3	I."4.(1)2.(2)3	I(II).(4)5.(1)2.3	(I)II.5.1.3(4)

1. Byram gneiss (quartz monzonite). Quarry a mile west of Hibernia, N. J. U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 9, 1914. W. T. Schaller, analyst.
2. Quartz monzonite. West end of Furnace Hill, Boyertown quadrangle, Pa. R. C. Wells, analyst.
3. Quartz monzonite. South of Ludwigs Corner, Phoenixville quadrangle, Pa. R. C. Wells, analyst.
4. Micaceous Byram gneiss (monzonite). Van Nest tunnel on Delaware, Lackawanna & Western Railroad near Oxford, N. J. U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 9, 1914. W. T. Schaller, analyst.

Analyses 1 and 4 represent quartz monzonite from adjacent quadrangles northeast of the Doylestown quadrangle, and analyses 2 and 3 represent the same quartz monzonite respectively 14 miles southwest and 4 miles west of the Quakertown quadrangle. There is considerable variation in the percentage of silica and therefore of the quartz present in the rock. The more constant ratios are those of the alkalies, which by their relative proportion indicate the persistence of microperthite as a characteristic constituent. Quartz and feldspar are the dominant constituents of the rock, and feldspar either equals or more commonly is in excess of the quartz. The alkalies are invariably in excess of the lime and are present in about equal amounts. This criterion is the one upon which the separation between quartz monzonite, granodiorite, and diorite is made; in the latter types soda is dominant or extremely dominant over potash. These analyses indicate progressive differentiation, which is carried further in some portions of the granitic magma, producing syenite and monzonite or granodiorite and diorite.

GABBRO

Gabbro is intrusive in the quartz monzonite and is exposed in five localities, in three of which it occurs as narrow dikes along the southwestern border of the quartz monzonite. A small triangular area on the northern border of the quadrangle continues into the adjacent Allentown quadrangle, and an intrusive mass enters the Quakertown quadrangle from the Boyertown quadrangle, where it has considerable extent.

The rock is medium grained and ranges from a medium-gray rock very similar to diorite to a dark-green rock characterized by an abundance of green hornblende and readily distinguished from diorite. There are intermediate types of bronzy color. All types weather to spheroidal boulders with rusty brown exteriors.

The essential constituents are feldspar and pyroxene or hornblende, and quartz is generally present. Magnetite, titanite, apatite, garnet, zircon, corundum, pyrite, biotite, and muscovite are accessory constituents. Secondary constituents are kaolin, sericite, epidote, zoisite, chlorite, talc, glaucophane, quartz, limonite, and leucoxene. The feldspar is orthoclase, oligoclase-andesine, andesine, andesine-labradorite, labradorite, and labradorite-bytownite, the last two being the dominant species. The proportions of the salic and the femic constituents range in general from 30 per cent salic and 70 per cent femic to 85 per cent salic and 15 per cent femic. The pyroxene is either augite, hypersthene, or diopside.

The gabbro, like the other plutonic rocks, has a granular texture, and the mineral grains in places show their characteristic form, but where the intrusion is small or dikelike in character, the texture is more commonly foliated with a parallel arrangement of the crystals, especially the hornblende. Although the gabbro is typically a massive bronzy-green quartz-feldspar-pyroxene rock, locally the pyroxene may be replaced by hornblende. Where this constituent makes up 50 per cent of the rock, if primary quartz is absent, the specific gravity of the rock increases, the texture becomes gneissoid, and the color dark green. Hornblende gabbro of a more massive type is also found west of Zionsville and south of Sigmund, in the Boyertown quadrangle, west of this district. The other extreme in content of silica is reached in the gabbro in which quartz constitutes about 25 per cent of the rock.

Analyses of gabbro from Pennsylvania and New Jersey

Analyses			Norms calculated from analyses		
	1	2		1	2
SiO_2	49.67	43.98	Quartz	2.70	
Al_2O_3	18.19	12.01	Orthoclase	2.22	6.67
Fe_2O_3	.33	6.60	Albite	23.06	14.15
FeO	12.84	12.20	Anorthite	36.14	16.40
MgO	2.12	5.46	Nephelite		5.68
CaO	9.70	11.99	Diopside	7.44	34.20
Na_2O	2.74	2.93	Hypersthene	21.40	
K_2O	.34	1.10	Olivine		7.38
H_2O+	.74	1.04	Apatite	1.34	.67
H_2O-	.15	.29	Magnetite	.46	9.51
TiO_2	2.01	2.25	Ilmenite	3.80	4.26
ZrO_2	Trace.		Hematite		
CO_2	None.	.18	Pyrite	.60	
P_2O_5	.58	.28	Water	.89	1.33
S	.32		Carbon dioxide		.18
MnO	.37	.05			
BaO	Trace.				
	100.10	100.36		100.05	100.43
Symbol				II(III).5.4.″5	III″.(5)6.3.4

1. Gabbro. 1 mile northeast of Fontaine, Honeybrook quadrangle, Pa. W. T. Schaller, analyst.
2. Pochuck gneiss. Pardee mine, Franklin Furnace quadrangle, N. J. U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 8, 1914. W. T. Schaller, analyst.

The two gabbros differ in basicity; one is a quartz-pyroxene gabbro, the other a hornblende gabbro. In one quartz and feldspar are dominating constituents, and in the other quartz and feldspar about equal the other constituents; in one feldspar is abundant, and in the other feldspar is dominant over nephelite; in one feldspathic lime is dominant over the alkalies, and in the other alkalies and feldspathic lime are about equal; in one soda is abundant as compared with potash, and in the other soda is the dominant alkali.

The two rocks are essentially alike in showing the increase in lime and decrease in potash and silica which distinguish them from quartz diorite and determine the presence of labradorite and pyroxene as essential constituents. There is a perfect transition between the gabbro and the quartz diorite and quartz monzonite of the Phoenixville quadrangle.

PEGMATITE

Fine-grained pegmatite is exposed in a small area of pre-Cambrian rocks occurring at the south end of Buckingham Mountain, in the Doylestown quadrangle. In the bottom of a sand quarry at the southeast base of the mountain the basal arkosic beds of the Hardyston quartzite merge almost imperceptibly into underlying fine granular pegmatite of the pre-Cambrian floor. The pegmatite is composed largely of pink orthoclase interspersed with limpid to milky quartz and some magnetite in irregular grains and veinlets. That part of the rock near the contact with the arkose consists of bands of quartz and feldspar with grains of magnetite and is apparently slightly assorted regolith. Some of this rock is greenish and waxy in appearance, owing to the alteration of the groundmass to pinite. Small dikes of pegmatite also occur in the mountainous area in the northwest corner of the Quakertown quadrangle, and a deposit of magnetite associated with one of them was formerly mined.

CAMBRIAN SYSTEM

By G. W. Stose

HARDYSTON QUARTZITE

Distribution and character.—There are five small areas of Cambrian quartzite, herein identified as Hardyston quartzite, in the northwest corner of the Quakertown quadrangle and two larger areas in the Doylestown quadrangle. Buckingham Mountain, in the southeastern part of the Doylestown quadrangle, is the largest of these areas, and Little Buckingham Mountain is also composed of this quartzite. The small areas in the vicinity of Hosensack, in the Quakertown quadrangle, are parts of fault blocks.

The chief rock of the formation is a fine-grained white vitreous quartzite. In the Quakertown quadrangle the exposures are poor and much broken and shattered by faulting, so that the detailed character of the formation can not be determined. In the Doylestown quadrangle, where exposures are better, the sequence of beds can be observed. The main mass of Buckingham Mountain is made up of thick-bedded vitreous white quartzite in two benches, which generally give rise to two ledges along the ridge. The upper bench is less vitreous and coarser grained than the lower and contains at the top a layer of closely packed clean white quartz pebbles about the size and shape of white navy beans. Masses of this conspicuous rock strew the surface along the whole west foot of the mountain.

The only place in the Doylestown quadrangle where the base of the formation is exposed is on the east slope of Buckingham Mountain near its south end. Here fragments of conglomerate, composed of conspicuous pebbles of red feldspar and quartz and closely resembling granite in appearance, strew the surface and disintegrate into gravel. These basal beds are well exposed in a sand and gravel pit. The basal layer is composed of bluish-purple crumbly coarse arkosic sandstone containing scattered fragments of red feldspar and round quartz pebbles 1 inch or less in diameter. It rests on a red and green banded sandy clay regolith containing large residual fragments of red feldspar derived from a coarse red feldspar pegmatite exposed in the bottom of the pit. The conglomerate is overlain by harder purplish sandstone. These basal beds, which have a thickness of about 20 to 25 feet, are overlain at the top of the pit by 25 feet of thin-bedded white quartzite containing numerous thin green clay partings. Massive vitreous white quartzite, which composes the middle of the formation, is quarried on the slope 100 feet above.

The outcrops are too poor to furnish good detailed sections, but the formation is made up approximately as follows:

Section of Hardyston quartzite on Buckingham Mountain

	Feet
Massive white vitreous quartzite, with layer of conglomerate containing bean-shaped pebbles at the top	165+
Thinner-bedded white quartzite, lower part containing green clay partings	100±
Purplish quartzite and conglomerate of quartz and pink feldspar pebbles in highly feldspathic matrix	25
	290±

Age and correlation.—The Cambrian quartzite of Buckingham Mountain closely resembles the quartzite of the Reading and Durham Hills, which include the mountain area in the northwestern part of the Quakertown quadrangle. That quartzite, called Hardyston, which also has a basal purple arkosic conglomerate similar to that in

Buckingham Mountain, comprises all the Lower Cambrian sandy sediments in the Reading and Durham Hills. The distinctive conglomerate of beanlike pebbles near the top of the quartzite on Buckingham Mountain is similar to a bed at the top of the Antietam quartzite of South Mountain, and a fragment of poorly preserved *Olenellus*, a trilobite that occurs in the Antietam quartzite, was found by E. T. Wherry in the upper quartzite beds of Buckingham Mountain. The quartzite of Buckingham Mountain therefore appears to represent not only the Chickies quartzite with its basal Hellam conglomerate member of the York-Lancaster area, but also the younger fossiliferous Antietam quartzite. The quartzite of the Quakertown-Doylestown area is thus more closely allied in scope to the Hardyston, and that name is here used. The formation was named from Hardyston, N. J. Near the type locality in New Jersey it is a hard ferruginous arkosic quartzite, ranging from nearly 0 to 200 feet in thickness and containing in places conglomeratic beds with pebbles of quartz, feldspar, and granite. It contains fossil trilobites, species of *Olenellus*.

TOMSTOWN DOLOMITE

Distribution and character.—In the Reading region the Tomstown dolomite overlies the Hardyston quartzite. This dolomite has not been observed above the quartzite of Buckingham Mountain in the Doylestown quadrangle and probably is not present there, although this can not be positively stated because the rocks in the lowland at the foot of the mountain are largely concealed by wash. Its apparent absence in that locality may be due in part to faulting, of which there is some indication. Several small areas of limestone and dolomite in the northwest corner of the Quakertown quadrangle are believed to be Tomstown. The chief area is along Hosensack Creek, 1 mile east of Hosensack. This rock, which is well exposed in a quarry south of the creek, is a massive dark-blue dolomite with some chert. It is much broken and crushed in a fault block, and the fragments are recemented by calcite. The Hardyston quartzite, which normally should lie to the south of the dolomite, is cut off by a fault that drops the Triassic sandstone next to the dolomite. It is overlain by thin-bedded white marble which weathers to buff earthy, shaly fragments and is believed to be part of the Elbrook limestone.

No other outcrops of Tomstown dolomite were observed in the area, but the lowland adjacent to the Hardyston quartzite in the small fault block in the valley of Hosensack Creek north of Hosensack is underlain by red clay that is probably derived from the Tomstown dolomite and is so shown on the map. A similar narrow valley adjoining the Hardyston quartzite on the Perkiomen Railroad to the northwest is also believed to contain Tomstown dolomite.

The thickness of the Tomstown dolomite can not be determined because of the broken character of the outcrops. About 100 feet is exposed at the old quarry, and it is probably 500 feet or more thick.

Age and correlation.—No fossils have been found in the Tomstown dolomite in this area. The formation has the same lithologic character as the Tomstown dolomite of the South Mountain area in Franklin County, Pa., and similarly overlies Lower Cambrian quartzite. It is overlain by fine-grained marble and shaly, earthy limestone similar to the Elbrook limestone of the Cumberland Valley. Tomstown dolomite is recognized in the near-by Reading area with similar relations. This formation is therefore regarded as the Tomstown dolomite, which was named from Tomstown, Franklin County, Pa.

ELBROOK LIMESTONE

Distribution and character.—The southeastern part of Buckingham Valley from Furlong to Lahaska station, in the Doylestown quadrangle, is underlain by limestone that is believed to be the Elbrook. It is deeply covered with a residual buff earthy clay soil that contains many fragments and masses of black flint and chert. Similar shaly, earthy limestone and marble occur in the fault block 1 mile east of Hosensack, in the Quakertown quadrangle.

Several quarries and road cuts expose parts of the formation. In the roadway west of Lahaska station shaly light-gray fine-grained, finely laminated limestone crops out and weathers to buff earthy platy fragments. In the quarry just north of Furlong the following beds are exposed:

Section of Elbrook limestone in quarry north of Furlong, Pa.

	Feet
Gray dolomite and hard siliceous dark limestone	10±
Finely laminated magnesian limestone and dolomite weathering to white coating; contains black flint in large irregular rough-surfaced masses, some banded and mottled white, which have partly replaced the dolomite	20±
Concealed	30±
Light-blue, finely laminated earthy limestone; weathers shaly and buff; sun cracks, ripples, and other markings on bedding planes; contains scattered glassy quartz grains	15
Thick-bedded fine-grained dove-colored marble, finely laminated in part; weathers white; some blue wavy slate partings	30

Similar thin-laminated impure limestone, which weathers shaly and contains quartz grains, is exposed in a quarry 1 mile to the northeast and also near the foot of Buckingham Mountain, 1 mile east of Buckingham post office. Along the southeast margin of the valley adjacent to Little Buckingham Mountain large masses of rough chert and hard cemented quartzite breccia in the soil suggest a probable fault. It may be that the Tomstown dolomite, which should normally occur here between the Elbrook limestone and the Hardyston quartzite, is faulted out.

The exposures of the formation are too few to determine its thickness. Its base has not been seen and may be faulted out along its eastern margin. It dips northwest, and its top is placed just below sandy beds that form a low ridge and are classed as the base of the overlying Conococheague. The formation is estimated to be at least 500 feet thick.

Age and correlation.—No fossils have been found in the Elbrook limestone in this area. As it underlies the Conococheague formation and has beds that are lithologically similar to the Elbrook limestone, which underlies the Conococheague in the Cumberland Valley, it is regarded as that formation. The Elbrook limestone was named from Elbrook, Franklin County, and in the type region contains fossils of Middle and Upper Cambrian age.

CONOCOCHEAGUE LIMESTONE

Distribution and character.—Buckingham Valley, in the southeastern part of the Doylestown quadrangle, is underlain for the most part by the Conococheague limestone. An area of the same formation is mapped in the lowland northwest of Chestnut Hill in the Quakertown quadrangle; although there are no rock exposures within that quadrangle, the Conococheague limestone is quarried in this lowland 1 mile north of the border.

The Conococheague limestone weathers to a deep clay soil containing slabby sandstone and fragments of shale at certain horizons. It does not generally crop out in ledges but is exposed in many quarries, most of which have been abandoned. The formation comprises chiefly massive dense blue limestone and massive light-blue dolomite with thin wavy argillaceous partings and black cherty layers 1 to 1½ inches thick. The best exposure is in a quarry south of Lahaska. About 70 feet of beds there exposed consist of alternations of light-gray pure limestone containing *Cryptozoon* reefs and dark siliceous banded limestone with sandy beds, oolite, edgewise conglomerate, black chert, and small black phosphatic nodules. The alternation of beds consists of a repetition of a more or less systematic sequence about 5 feet thick, as follows: At the top, thin dark-banded siliceous limestone, weathering shaly, oolitic in places; light-gray pure limestone, *Cryptozoon*-bearing bed, about 3 feet thick; thin black siliceous limestone containing some black flint and small black phosphatic nodules in places. Repetition of a sequence of similar beds occurs in all the exposures of the formation. In quarries northeast of the area, in the Lambertville quadrangle, ripple marks are said to be a feature of this limestone. The lower part of the formation contains many beds that weather to rough yellow chert, green slaty fragments, slabby sandstone, and cherty limestone with wavy laminations like Cryptozoa. Some very sandy layers weather to slabby porous sandstone pitted by holes from which limestone pebbles have been dissolved. These harder layers, which resist erosion and form low hills in the middle of the valley, are considered the base of the formation.

Although most of the observed dips are to the northwest, a minor sharp fold is exposed east of Lahaska, and it is probable that there are other folds which are not exposed. The thickness is therefore difficult to determine. In Chester Valley, to the southwest, the Conococheague limestone has a thickness of approximately 900 feet, and it probably has about the same thickness in the Doylestown quadrangle.

Age and correlation.—In an abandoned quarry at Limeport, in the Lambertville quadrangle, 3 miles northeast of Aquetong, fossils were found in this formation that were determined by E. O. Ulrich to be *Solenopleura jerseyensis* (Weller) and *Lingulepis acuminata* (Conrad). These forms are referred by Ulrich to the lower part of his "Ozarkian system," and the formation is thus regarded by him as younger than Cambrian, but it is classed as Upper Cambrian by the United States Geological Survey. This is the age also of the Conococheague limestone on Conococheague Creek, in the Cumberland Valley. The Cryptozoa found in this formation in the Doylestown quadrangle also are similar to those found in the Conococheague limestone of southern Pennsylvania. (See pl. 3, *B*.) The name Conococheague limestone is therefore applied to the formation.

ORDOVICIAN SYSTEM

By G. W. Stose

BEEKMANTOWN (?) LIMESTONE

Distribution and character.—The limestone on the northwest side of Buckingham Valley, in the eastern part of the Doylestown quadrangle, is tentatively regarded as Beekmantown. It forms two separate areas, one between Buckingham and Holicong and the other northeast of Aquetong.

The formation is chiefly massive-bedded fine-grained dark dolomite and light-blue magnesian limestone. It is exposed in numerous quarries adjacent to the hills of Triassic sandstone west of the valley. In an old quarry west of Holicong the limestone is fine grained and siliceous and weathers buff, earthy, and laminated, much like the limestone mapped as Elbrook. It also contains black flint, which has in part replaced the dolomite.

The formation is estimated to be about 1,000 feet thick.

Age and correlation.—The formation is correlated with the Beekmantown limestone largely because it lies above the Conococheague limestone and is composed of massive limestone and dolomite like the Beekmantown of the Lancaster Valley. Apparently no fossil Cryptozoa are present. The Beekmantown limestone generally contains a fauna of gastropods and other fossils of Lower Ordovician age, but none were found in this area.

The limestones here described as Elbrook, Conococheague, and Beekmantown are a part of what was formerly called the Shenandoah limestone of Pennsylvania and Virginia. They are part of the old Auroral limestone of H. D. Rogers and of Formation No. 2 of the Second Geological Survey of Pennsylvania.

COCALICO PHYLLITE

Distribution and character.—The formation herein mapped as Cocalico phyllite occurs at only one place in the area—west of Furlong, at the southwest end of the area of Paleozoic formations in the Doylestown quadrangle.

The formation does not make ledges and has not been quarried; it is represented chiefly by loose fragments of rock on the surface. It is composed chiefly of dark shaly phyllite, most of which is blue to gray, hard, and platy, but some is black, fissile, smooth, papery, and shiny. There is also some reddish-gray phyllite, light-green siliceous blocky slate, thin beds of gray quartzite, and laminated hard gray to buff arkosic granular sandstone which contains crystals of pyrite and weathers rusty and porous. The sandstones are sufficiently resistant to make a fairly prominent hill southwest of Furlong.

The thickness of the formation can not be determined, but it is estimated to be more than 500 feet.

Age and correlation.—No fossils have been found in the formation in this area, and its stratigraphic relation to the other Paleozoic formations is not known because it is apparently in fault contact with them. It closely resembles the Cocalico shale of the Lancaster Valley except that it is more metamorphosed. A band of purple and green shale with thin quartzite is most certainly the same as the similar characteristic rocks, probably in part of volcanic origin, near the base of the Cocalico in the type locality. At Cocalico Creek, northeast of Lancaster, from which the formation was named, the shale unconformably overlies the Beekmantown limestone, and the anomalous relation in the Doylestown area may also be due to unconformity instead of faulting. A few poorly preserved graptolites obtained from the shale in the Lancaster area were at first considered by Ulrich to be of Normanskill type and therefore of upper Chazy age but later were regarded by him as probably of lower Trenton age.

TRIASSIC SYSTEM

SEDIMENTARY ROCKS

By E. T. Wherry

NEWARK GROUP

GENERAL FEATURES

Almost the entire area of the Quakertown and Doylestown quadrangles is underlain by rocks of the Newark group, which includes all the sedimentary rocks of Triassic age. Igneous rocks are associated with the sediments, and both are on the whole notably uniform in character over large areas. The sedimentary beds comprise sandstone, arkose, and conglomerate, soft red shale that becomes hard and gray where metamorphosed by igneous action, and dark-red, green, purple, or black argillite, which owes its hardness to its original composition rather than to any metamorphic action. The igneous rock is almost everywhere a dark bluish-gray diabase occurring in sills and dikes.

In the Doylestown quadrangle, as in most other regions, the Newark rocks have on the whole a fairly uniform dip, averaging from 10° to 15° NW. In the Quakertown quadrangle, however, the beds are folded into a series of pronounced but gentle anticlines and synclines, the axes of which have a general northwest trend. A fault of many thousand feet displacement crosses the Doylestown quadrangle in an east to northeast direction and has greatly increased the width of the Newark belt. There are, no doubt, other faults also parallel to the strike which repeat beds and somewhat increase the apparent thickness of the formations. On the other hand, in the folded area west of Quakertown extensive repetition of beds by such normal faults can hardly have occurred, and the true thickness of strata represented should be determinable by measurements. The floor on which the Newark strata were deposited has been brought to the surface by the great Furlong fault east of Doylestown. It there consists of pre-Cambrian gabbro and pegmatite and Paleozoic sandstone, limestone, and shale, similar to but less metamorphosed than the Paleozoic formations exposed in the Piedmont region southeast of the Newark belt.

The Newark group comprises the Stockton, Lockatong, and Brunswick formations, which are described below in detail, beginning with the oldest.

STOCKTON FORMATION

Distribution and character.—The Stockton formation crops out in the Doylestown quadrangle in a belt about 4 miles wide, beginning at the Chalfont fault line south of Doylestown and extending northeastward beyond the edge of the quadrangle east of Lumberville. There is also a small area at Newville, which is the northern edge of a large area in the Germantown quadrangle. The Stockton formation is not exposed in the Quakertown quadrangle.

The Stockton formation is chiefly arkosic sandstone and ranges from coarse conglomerate through sandstone of different sizes of grain to the finest argillaceous shale. The conglomerate and coarser sandstone are made up chiefly of well-rounded grains of nearly colorless quartz, with some more or less angular fragments of feldspar in all stages of kaolinization and here and there conspicuous flakes of muscovite mica. The cementing material is argillaceous, with sufficient finely divided iron hydroxides to give it and the rock as a whole a pronounced yellow color. The finer-grained sandstones and the argillaceous beds are similar in composition, even the finest clay of the shales containing much more quartz than kaolinite and also some feldspar and mica; but in these beds the argillaceous cement contains the iron oxide hydrohematite (turgite), which imparts to the rocks a bright and highly characteristic red color. Locally the iron oxide has been reduced, apparently by organic matter, and the fine sandstones and shales are brownish, greenish, or even black.

The several rock types above described are not superimposed upon one another in any definite sequence. The coarser conglomerates are not, as a rule, at the very bottom of the formation and do not lie on the eroded edges of the underlying rocks from which their materials have been derived; they occur instead at several horizons in the lower third of the formation, interbedded with finer-grained sediment.

Along the strike, also, rapid variations in character of sediment are evident. Coarse-grained beds in many places grade rapidly into fine-grained beds, and ridges formed by hard members of the formation rarely persist for a distance of a thousand feet. These variations, as well as the cross-bedded structure of the coarser beds, indicate that the strata were deposited in rapid and shifting currents. Moreover, the water in which the sediments accumulated was shallow, as is proved by raindrop pits and sun cracks preserved in places on bedding planes of shaly beds.

The soils over the conglomerate and sandstone beds are inclined to be yellow in color and gravelly in texture, although over the red sandstones and shales they are mostly brownish red and more loamy.

The dip of the Stockton is rather uniformly 10° NW., indicating the presence of about 3,500 feet of strata. It is possible that faulting parallel to the strike has repeated the strata, and that this thickness is a low overestimate. Trap dikes that cross the Stockton belt, however, show no evidence of interruption by such faults. It is probable that the Stockton formation in this area is at least 3,000 feet thick.

Fossils and age.—The fossils that have been found in the Stockton formation are all of vegetable origin. The feldspathic sandstone beds contain impressions of fragments of wood or thin streaks of carbonized residue. In many places the wood is silicified and the structure so well preserved as to admit of study in thin section under the microscope. The trees are all araucarian conifers. Although three species have been distinguished in the Newark group of Pennsylvania, only one of them, *Araucarioxylon vanartsdaleni* Wherry, has been found in the area under consideration. Silicified wood is most abundant west of Center Hill, southwest of Spring Valley, and south of Doylestown.

Near Holicong, in the eastern part of the Doylestown quadrangle, impressions of plants have also been found in the shaly beds. The most abundant of these forms consist of striated stems, identified by David White and F. H. Knowlton as a species of *Schizoneura*, and a single leaf of a cycad, which appears to represent a *Cycadites* related to *C. tenuinervis* Fontaine. (See pl. 4, *B*.)

The most abundant fossil plants occur in a road quarry a short distance northeast of the village of Carversville. The black shale here closely resembles beds in the overlying Lockatong formation; but as the shale is interbedded with feldspathic sandstone it is placed in the Stockton. Impressions of leaves of two or three species of cycads and branches of five species of conifers have been found. Although a large quantity of fossiliferous material has been crushed and used as road metal, other plants could probably be obtained by quarrying with the purpose of seeking fossils. The species identified include cycads (*Podozamites formosus* A. P. Brown, *P. angustifolius* (Schenk) Schimper?, and *Zamites velderi* Brown) and conifers (*Palissya diffusa* (Emmons) Fontaine, *P. obtusa* Brown, *P. tenuifolia* Wherry, *Cheirolepis muensteri* Schenk, and *C. latus* Brown).

Unfortunately none of these fossils are adequate to establish the exact geologic age of the Stockton beds, and all that can be safely inferred from them is that this formation belongs in some part of the Triassic system. In the absence of definite paleontologic evidence to the contrary, the Stockton formation, with the rest of the Newark group, is classified as Upper Triassic.

Local features.—The Stockton formation is not well exposed in this area, and most of its features have to be made out from chance roadside outcrops. The coarse conglomerate beds several hundred feet above the base of the formation are fairly well shown in the vicinity of Pebble Hill, southeast of Doylestown. A local development of limestone-pebble conglomerate occurs half a mile west of Holicong and also just east of Lahaska. The pebbles, which have evidently been derived from the underlying limestone strata, are an inch or two in diameter, subangular, and cemented by gray to red argillaceous material. Near Lumberville there are several quarries in a fine-grained brownish-red sandstone, of considerable value as a building stone. This building stone occurs in lens-shaped bodies chiefly near the top of the Stockton formation. Elsewhere the formation yields only poor exposures of the softer red shale and yellowish sandstone members.

The Stockton beds on the whole are rather soft and weather readily, and the area they underlie is in general therefore one of low relief. Some of the coarser strata form fairly distinct ridges, trending parallel to the strike, in a northeasterly direction.

LOCKATONG FORMATION

Distribution and character.—Beginning in the southeast corner of the Quakertown quadrangle, north of the Chalfont fault near Hatfield, the Lockatong formation extends northeastward in a strip somewhat more than 5 miles wide, crossing the Delaware River into New Jersey between Tumble, N. J., and Lumberville, Pa. The formation is also exposed south of the Chalfont and Furlong faults and extends almost across the Doylestown quadrangle.

The Lockatong comprises a series of hard dark argillaceous beds that grade downward into the uppermost greenish shales and feldspathic sandstones of the Stockton formation. Some of the beds are thin and shaly; others are thick and are more properly termed argillite. (See pl. 4, *A*.) The rocks are so fine grained that a microscopic examination of thin sections is generally necessary to determine their mineral composition. The dominant mineral is quartz, but feldspar, as a rule in fairly fresh condition, is occasionally seen. Both muscovite and biotite micas are present, together with an obscure flaky material, perhaps to be classed as kaolinite. The cement appears to be largely opaline silica, in view of the fact that treatment of the hardest rock with sodium hydroxide solution reduces it to a soft mud. The color ranges from dark red to purplish, greenish, or blackish gray, and even to dull black. The red and purplish colors are due to ferric oxides, the green to ferrous compounds, and the black to carbonaceous matter. In many places there are minute crystals of calcite, and many highly calcareous beds occur, both red and dark gray and in places distinctly crystalline.

The cross sections of some of the grains of calcite in the argillites suggest that they are pseudomorphic after glauberite, a double sodium-calcium sulphate, as the result of an alteration brought about by the action of percolating waters. As these grains of calcite are more characteristic of the Brunswick formation, a fuller description will be given in connection with that formation. Other minerals are locally developed in the Lockatong beds. Tiny cubes of pyrite, usually coating joint planes, are common in the more carbonaceous rocks, and thin films of crystalline barite have been observed in similar situations, where the source of the barium is probably the feldspar grains of the sediments.

The Lockatong beds were evidently deposited in quieter water than the Stockton beds. That the water was shallow is indicated by the presence of numerous sun cracks and a few ripple marks. The general character of the formation is indicated by the following section:

Section of Lockatong formation in cut on the Philadelphia & Reading Railway south of Wycombe station, in the southeast corner of the Doylestown quadrangle

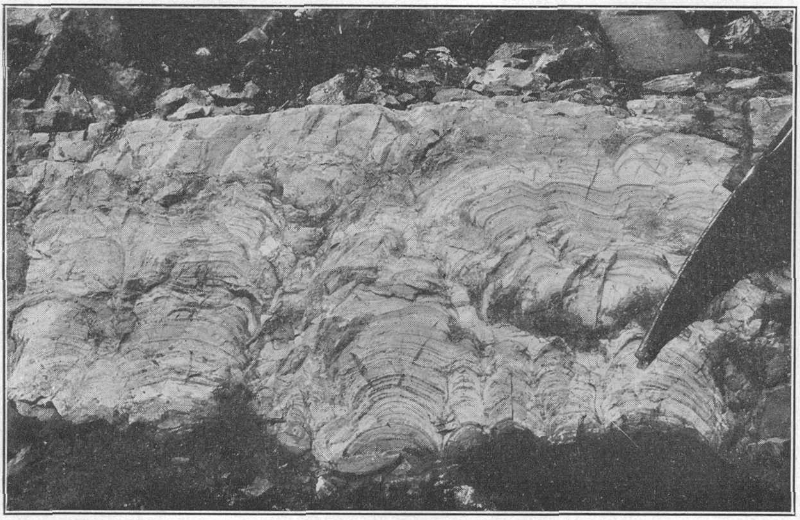
	Feet
Soft red shale of Brunswick formation at top.	
Hard dark-red and brown shale	400
Hard brown to green shale with limestone band	25
Gray and brown argillite	600
Hard brown to green shale with calcareous beds	20
Gray and brown argillite	650
Black argillite with magnesian limestone bands	50
Brown shale	600
Dark-red shale	450
Green and yellow sandy shale	60
Hard red shale	190
Arkosic sandstone of Stockton formation at base.	
	3,045

The soils that overlie this formation are inclined to be dark brown and loamy but are commonly so full of slabs and flakes of unaltered rock as to make them rather unproductive.

In the belt northwest of Doylestown the average dip of 10° NW. indicates a thickness of over 4,000 feet. There are, however, indications in several exposures of strike faults that seem to have caused a slight duplication of beds, and an estimate of 3,500 feet is probably more nearly correct. The section measured south of Wycombe, in the southern belt, gives a total thickness of a little more than 3,000 feet. There is local evidence of faulting here, although the amount of possible repetition would be very small, and there is some suggestion of a fault at the north edge of the Lockatong which has cut out some of the beds rather than repeated them. As this belt of the formation is nearer the southern margin of the Triassic basin

A. DIABASE WEATHERING INTO ROUNDED BOULDERS BY EXFOLIATION, PHILADELPHIA & READING RAILWAY CUT AT ROCK HILL, QUAKERTOWN QUADRANGLE

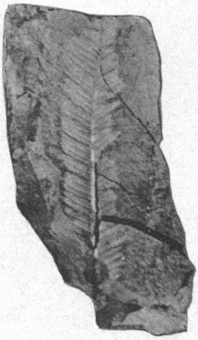
Photograph by E. T. Wherry



B. *CRYPTOZOON PROLIFERUM*, FOSSIL ALGAE IN CONOCOCHEAGUE LIMESTONE, BYCOT, DOYLESTOWN QUADRANGLE

Head of geologic hammer at right. Photograph by E. T. Wherry

A. WELL-BEDDED SHALES OF THE LOCKATONG FORMATION IN QUARRY ON DELAWARE RIVER 1 MILE WEST OF LUMBERVILLE, DOYLESTOWN QUADRANGLE



B. FOSSIL LEAF OF *CYCADITES* SP. FROM THE STOCKTON FORMATION NEAR HOLICONG, DOYLESTOWN QUADRANGLE

C. KETTLE ROCK, A LARGE HOLE RESEMBLING A POTHOLE FORMED IN HARD DIABASE ON SPRING MOUNTAIN, QUAKERTOWN QUADRANGLE than the northern strip, it would be expected to be somewhat thinner, and 3,000 feet may be regarded as a reasonable estimate of thickness at this place.

Fossils and age.—The Lockatong is by far the most fossiliferous formation of the Newark group, but owing to its small area and poor exposure within these quadrangles very few specimens were found. In the calcareous beds near Wycombe, the stratigraphic positions of which are given in the section tabulated above, the shells of small crustaceans and fish bones and fish scales are not uncommon. The shells are believed to represent the widespread Triassic ostracode *Estheria ovata* Jones and the scales a species of the ganoid fish *Semionotus*. In other regions east and south of the Quakertown and Doylestown quadrangles these and other crustaceans and fishes, also cycads, conifers, and other plants and the bones and tracks of reptiles, have been collected.

Although these fossils were at one time assigned to the age of the Rhaetic or uppermost Triassic of Europe, they are now believed to be somewhat older and to be more closely related to those found in the Keuper, which lies directly above the Muschelkalk in Germany and is classified as Upper Triassic.

Local features.—The Lockatong formation is rather more resistant to weathering than the Stockton, and its outcropping beds give rise to broad plateaulike ridges, with characteristic northeasterly trend, corresponding to the strike in the area north of Doylestown. One of the most pronounced of these ridges, Plumstead Hill, extending southwestward from Lumberville and Point Pleasant on the Delaware River, owes its relief in part to the fact that the rocks are here metamorphosed by a sill of diabase. Near the igneous rock the sediments have become extensively recrystallized, and it is difficult to distinguish the metamorphosed argillite from diabase. The metamorphosed argillite is well exposed in the quarry across the Delaware River from this point, just north of the station at Byram, N. J. Good exposures of the nonmetamorphosed beds in this area occur along Tohickon Creek northwest of Point Pleasant; some of the rock here is so hard as to ring when struck.

The best exposures of the Lockatong in the region occur southeast of Doylestown along Neshaminy Creek and in the cuts on the Philadelphia & Reading Railway south of Wycombe, around Rushland. A section of the beds in the railway exposures is given on page 28. At Dark Hollow the strata are so black that they have been prospected for coal. The amount of carbonaceous matter present, however, is far too small to be of value as a fuel. Hard beds in the formation are quarried at several places in the area, the rock being crushed and sold as "trap rock" because of its hardness.

33309—31——3

BRUNSWICK FORMATION

Distribution and character.—The Brunswick formation is present toward the northwest side of the Triassic area. Except for the small area of pre-Triassic rocks in the northwest corner and the small triangle of Lockatong formation toward the southeast corner, the whole of the Quakertown quadrangle is occupied by Brunswick beds and the associated intrusive diabase. The northwest third of the Doylestown quadrangle is also occupied by these beds, and there are small patches of them in the southern part of that quadrangle south of the Chalfont and Furlong faults.

The change which occurs at the top of the Lockatong formation is even more gradual than the change from the Stockton below into the Lockatong. It is so gradual, in fact, that no two geologists would be likely to agree as to where the line between the Lockatong and Brunswick formations is to be drawn. The hard dark-red shales of the Lockatong gradually become softer and brighter, and after a few hundred feet of transitional beds, which might be included with either formation, soft red shale and fine sandstone beds prevail, and these are classed as Brunswick formation. Microscopic study shows that most of the grains consist of quartz; feldspar and mica are very sparingly present in the typical rocks, although near the northwestern margin of the basin they locally become prominent. The cement is argillaceous, with the hydrohematite form of ferric oxide present in such amount that the color is a rather brilliant red. Locally lenses of green or even black shale occur, but they are nowhere so hard or so extensive as the similarly colored rocks of the Lockatong.

Near the great diabase sill that traverses the northwestern part of the Doylestown quadrangle and the central part of the Quakertown quadrangle the soft red shales are extensively metamorphosed. As the diabase is approached the beds are harder and darker and resemble the rocks of the Lockatong formation; still nearer the diabase the iron oxide is magnetite, the color is gray, more or less mottled or spotted, and silicification has produced a rock but little inferior to diabase itself in resistance to weathering. Tabular black crystals of tourmaline have developed in these altered rocks in some places, and zeolites have crystallized in fissures. Rudely spherical aggregates of secondary epidote form prominences several inches in diameter on the weathered surfaces of the rock, and their residual fragments accumulate in the rain channels. Similar spheres are in places formed by chlorite.

Another characteristic feature of the beds of the Brunswick formation consists of cavities at several horizons, the form and angles of which suggest that they are molds of crystals of glauberite, a double sodium-calcium sulphate. The position of these crystals on the parting surfaces of the beds indicates that the glauberite crystallized out in the mud as the body of water in which deposition occurred was gradually drying up.

Toward the northwest corner of the Quakertown quadrangle the beds of red shale and sandstone are replaced along the strike by coarse conglomerate. Near the transition zone they are fine grained, with grains of quartz and flakes of mica or shale in a matrix of consolidated red mud, but near the margin of the Triassic area they become coarse, with well-rounded quartz boulders a foot or more in diameter and with limestone pebbles, angular or at most subangular, locally abundant. Where this rock has been metamorphosed by diabase it changes in aspect: the red-mud cement becomes gray, and reaction rims of garnet, epidote, and hematite appear around the fragments of limestone.

The conditions of deposition of the Brunswick beds in general were not greatly different from those of Lockatong time. Cementation, however, was less marked, and oxidation was more thorough, for the iron is generally in the ferric condition. Ripple marks, rain prints, and locally sun cracks again indicate shallow water. The coarse marginal facies of the formation suggest accumulation on alluvial fans, over which poured torrents from adjacent mountains on the northwest, thus depositing coarse material and forming fanglomerates.

The general character of the beds of the Brunswick formation is shown by the following section, measured along the Philadelphia & Reading Railway southeast of Quakertown.

Section along Philadelphia & Reading Railway from a point near Shelly station to a point near Souderton, in the Quakertown quadrangle

	Feet
Diabase sill 1 mile south of Shelly station, at top.	
Dull-red shale, slightly altered	250
Soft red shale, poorly exposed	2, 400
Hard red, brownish, and greenish shale	400
Soft red shale, poorly exposed	1, 000
Hard dark-red to gray altered shale	200
Diabase sill (not included in total)	(30)
Very hard gray altered shale	700
Large diabase sill (not included in total)	(2, 000)
Very hard gray shale, intensely altered	375
Gray shale, softer, not well exposed	375
Hard gray and greenish to dull-red altered shale	250
Tunnel through hard shale like preceding	450
Dull-red, somewhat altered shale	150
Soft red shale, not exposed, about	275
Hard red shale	50
Black and dark-green shale	20
Hard red to grayish sandstone	100

	Feet
Hard red shale (to Sellersville station)	120
Soft red shale, poorly exposed	450
Gray to black shale, with fragments of plants	50
Hard red to gray shale	100
Soft red shale, poorly exposed (to Derstines station)	100
Soft red shale with some hard beds	40
Green to black shale, weathering yellow	10
Dull-red to brown shale	15
Green to black shale	20
Red shale, alternately hard and soft beds	125
Soft red shale, poorly exposed (to Telford station)	370
Same, no exposures, approximately	375
Alternations of red shale and sandstone	250
Hard dark-red sandstone	70
Black and dark-green shale	20
Dark-red hard sandstone	10
Greenish-gray to yellow shale	5
Alternations of hard and soft red shale	35
Soft red shale, not exposed, approximately	500
Alternations of hard and soft red shale	125
Green, gray, and black shale	60
Alternations of hard and soft red shale	250
Soft light-red to yellowish shale	25
Gray and greenish shale	5
Alternations of hard and soft red shale	90
Soft red shale, poorly exposed	235
Top of Lockatong formation, marked by gray-brown soil.	
Total thickness of Brunswick formation	10, 450

Thicknesses of different kinds of rock represented in the section

	Feet
Soft red shale	5, 720
Alternating hard and soft shale	915
Hard red shale and sandstone	450
Green, gray, and black shale	615
Altered shale	2, 750
	10, 450

In the northern part of the Doylestown quadrangle the dip averages 10° NW. and the width of the formation is more than 5 miles. A very considerable thickness of strata is therefore represented by the Brunswick formation. The continuous section given in detail above, which represents a total of 10,450 feet, started not at the top of the formation but at the edge of a body of diabase that intrudes the upper portion. Evidence obtained in the Boyertown quadrangle, which adjoins the Quakertown quadrangle on the west, indicates that at least an additional 2,000 feet of beds lies above this diabase intrusion, so that the total thickness of the formation would exceed 12,000 feet. Where the beds are monoclinal the apparent thickness may be greater or less than the real, owing either to repetition or to concealment of beds by normal strike faults. A number of such faults are in fact exposed in several of the railroad cuts examined in measuring the above section. In most of them, however, the throw is extremely small, and moreover the slickensides, which give evidence of the direction of movement, are horizontal rather than vertical. There is as much evidence of local omission of beds as there is of repetition by such faulting, so that but slight reduction, if any, in the estimate of thickness can be made on the ground of faulting. This thickness has also been checked by measurements made on the limbs of anticlinal and synclinal folds, where duplication by strike faults is not at all likely to occur. The Brunswick formation in the Quakertown and Doylestown quadrangles is therefore estimated to be 12,000 feet thick.

Except on or near the conglomerate beds, or in the vicinity of the diabase, the soil of the Brunswick is loamy, without much coarse rock material, and bright red to brown. It represents the best farming soil of the Triassic belt. The soil of the altered rocks near the diabase is, however, gray and very stony and of much less value for agriculture. The abundance of pebbles in the soils on the conglomerate hills is also a detriment to cultivation.

Fossils and age.—Fossils are exceptionally rare in the Brunswick formation. At one locality in these quadrangles, however, in the cut on the Philadelphia & Reading Railway south of Sellersville station, impressions of a fossil plant are abundant. As the botanic relations of this plant are unknown, it has been given a generic name after the formation and a specific name expressing doubt—namely, *Brunswickia dubia* Wherry. Many years ago reptilian remains, to which the name *Clepsysaurus pennsylvanicus* was given, were found near Hosensack. Elsewhere in the Brunswick a few other fossil plants and also reptilian teeth, bones, and tracks have been found. None of these fossils are of any value in determining the exact age equivalence of the Brunswick, but in view of its close stratigraphic relations with the Lockatong formation it also is referred to the Upper Triassic.

Local features.—The Brunswick is on the whole the least resistant of the formations of the Newark group, and, except in the vicinity of the diabase intrusions, the country underlain by it is gently rolling, without ridges pronounced enough to bring out the strike of the beds, as in the other two formations. The metamorphic action of the diabase has, however, markedly indurated the rocks, and north of Perkasie, in the east-central part of the Quakertown quadrangle, and thence well across the Doylestown quadrangle there is a pronounced flat-topped ridge of altered shale that follows the strike closely. In the southwestern part of the Quakertown quadrangle also curving ridges of hard shale bring out the sharp folding which the beds have there undergone. The highest altitudes on this formation occur at the northwest margin, where the conglomerate facies are developed, reaching a maximum altitude of 925 feet at a point 1.4 miles west of Locust Valley, near the north edge of the quadrangle.

The best exposures of the unaltered beds of the Brunswick formation are those in the cuts on the Philadelphia & Reading Railway from Sellersville to Souderton, as detailed in the section already given. An idea can be obtained here of the abundance of soft red shale, the local development of darker beds containing carbonaceous matter, the presence of sandstone or harder shale layers alternating with the softer ones, and other features.

The altered rocks in the upper part of the same section can be seen from Perkasie northward to Quakertown and also in the cuts of the Perkiomen Railroad in the southwestern part of the Quakertown quadrangle. Prospect pits for copper or other metals supposed to be present and the quarries for so-called "trap rock" are also good places to study the character of the metamorphosed rocks. In Young's quarry, north of Hendricks, not only is the hardening and darkening evident but there has also been a transfer into crevices of bituminous material from the plant remains that have left their impressions in the rocks. In prospect pits across Perkiomen Creek from Young's quarry, as well as farther northeast, north and east of Mechanicsville, the shales show extensive development of secondary minerals, including garnet, epidote, and zeolites, and associated with them are copper sulphide minerals, especially chalcopyrite and bornite. Zeolites are most abundant at the quarries near Green Lane. In the most northern of these quarries a small diabase dike cuts diagonally through the strata.

East of Tylers Port another prospect shows abundant epidote, calcite, and zeolites. Northwest of Perkasie and for many miles farther northeast the epidote nodules are a conspicuous feature of the altered rocks. Epidote, chlorite, and copper minerals are also conspicuous in the quarry 2 miles east of Quakertown. In the Doylestown quadrangle the altered rocks occur only in the northwest corner, and aside from the epidote nodules there are no noteworthy features.

The cavities left by the dissolving of crystals of glauberite, which in many places have been filled by calcite, are most abundant in the upper part of the Brunswick, northeastward from Spinnerstown, in the northwestern part of the Quakertown quadrangle. They are also well shown in quarries along the Philadelphia & Reading Railway southeast of Quakertown and in cuts farther south. This mineral has plainly crystallized in the mud while it was soft and while the bodies of water in which deposition occurred were drying up.

The best exposures of the conglomerate facies of the formation occur in the hills northwest of Spinnerstown, where metamorphism by the adjacent masses of diabase has hardened the rocks so that they resist weathering and crop out prominently. Where pebbles of limestone or calcite have been present, they have dissolved out, resulting in a strikingly cellular formation. The soil here and farther northeast is full of the pink-stained quartz pebbles that have weathered from these beds, and the streams have carried quantities of these pebbles southeastward over the red-shale plain. Areas in which well-defined deposits of this material have accumulated are indicated on the map as mountain wash.

IGNEOUS ROCKS

By Anna I. Jonas

DIABASE

Distribution and geologic relations.—Diabase is widely exposed in the Quakertown-Doylestown district. The largest area is formed by the sill which extends from Haycock Mountain southwestward through Rock Hill to the western edge of the area near Perkiomenville. Southward from this point it follows a curved course, trending southeast to Spring Mountain and then swinging west. This main sill is connected by a narrow offshoot at Applebachsville that curves northwest and west and by another irregular mass that extends northward through Milford Square with a large area around Shelly, at the northern edge of the quadrangle. An outlying mass of curved outline occurs a mile north of Spinnerstown.

The Byram sill crops out in a small area that crosses the Delaware River at Byram and can be traced 2½ miles southwestward. A small area of diabase occurs at Clayton, northeast of Buckingham Mountain.

The more notable dikes are the Plumstead Hill dike, which extends from Chalfont northeastward and eastward to Centre Hill, and the Newville-Bridge Point dike.

The main igneous mass, the Haycock-Rock Hill sill, has an average width of 2½ to 3 miles from Haycock Mountain southwest to Smoketown. It lies parallel to the bedding of the Brunswick shales, which dip about 10°–15° W. The southeast boundary of the diabase sill is in general parallel to the strike of the underlying shale throughout. The northern boundary is parallel to the strike of the overlying shale as far west as a point 1 mile south of Trumbauersville. The northeastern part of the sheet has a thickness of 1,500 to 1,800 feet, estimated on the assumption that near Rock Hill the diabase conforms in dip with that of the overlying shale.

The marked extension of the diabase northwest of Tylers Port is the result of the crosscutting and rising of the diabase into the shale. The diabase intrusion has uplifted the overlying beds in the Pennsburg syncline (see fig. 3) and cut them off from their eastward continuation in the Quakertown syncline, where, from Butter Creek northwestward, the diabase cuts across the shale at right angles to the strike. This crosscutting body passes northwestward in a thin dike that curves to the western edge of the Quakertown quadrangle south of Hosensack. A branch of the crosscutting body extends north of Trumbauersville and near Milford Square sends out a sill to the east that connects with the large diabase area near Shelly. This mass is also a crosscutting body, which rises through the lower shales of the Brunswick formation to the horizon of the conglomerate of that formation at Zion Hill. At its contact with the shale exposed in the cut of the Philadelphia & Reading Railway on the northern edge of the Quakertown quadrangle the diabase dips 80° SE., cutting the gently dipping shale. The curved area of diabase north of Spinnerstown occurs at the same horizon as the Shelly area—that is, in the upper shales and conglomerate of the Brunswick—and the Spinnerstown mass is probably continuous underground with the Shelly mass but rises higher in the shale in the synclinal fold, where it is exposed.

A narrow sill parallels the northwestern border of the main sheet in the Pennsburg syncline, and dikes occur near Pennsburg. There is also a dike at Rich Hill and another east of Richlandtown. East of California a dike connects the Shelly crosscutting mass with the main sill at Applebachsville.

The curve of the main diabase sill southwest of Tylers Port is caused by the folding of the rocks. At Perkiomenville the sill is folded into an anticline, and it curves southeastward to Spring Mountain. Here its western curve is the result of the Zieglerville syncline.

No trace of interbedded basalt flows has been found in the area. The intrusive nature of the diabase is shown by the effects of its action on the bounding shale, both at the lower and upper contacts. Thus the shale has been changed in color from red to dark blue or grayish green and has been converted into a hard crystalline aphanitic rock not easily distinguishable from fine-grained diabase. The shale is metamorphosed for as much as 330 feet from the diabase contact. The railroad cut south of Salford station affords a good opportunity for studying the gradation from altered to unaltered shale. At 10 feet north of the contact the shale is dense greenish gray and crystalline. A hard blue shale resembling a fine-grained diabase is exposed 90 feet north of this green shale. Half a mile farther north the color has become deep purple and the rock is softer; in another half mile the rock has resumed its red color and the unaltered condition of the Brunswick formation. At this locality, as well as elsewhere near the diabase contact, round shotlike nodules of chlorite pseudomorphic after cordierite are developed in the shale. Such a rock has been called a spilosite. In some places nodules of green epidote are developed in the baked shale and on weathering stand out in relief. With a microscope the indurated shale is seen to be a fine-grained hornfels composed chiefly of quartz with scanty feldspar. Minute granules of magnetite are abundant. Nodules of cordierite appear in ordinary light as dark knots in a light quartz groundmass. Much of the cordierite has been replaced by pinite and chlorite.

The Byram sill, which is 5 miles long and about half a mile wide, invades the Lockatong formation and hence occurs at a lower horizon than the Haycock-Rock Hill sheet, and no relation has been established between them. Lewis[5] considers the Byram sill continuous with the Rocky Hill sill of New Jersey and the Palisades, although it is separated from them by several normal faults that have caused repetitions of a large part of the Triassic rocks and included diabase sheets.

The small area at Clayton is the west end of the sill of Solebury Mountain that thickens to the northeast in New Jersey in Sourland Mountain.

The contact effects of the Byram sill on the neighboring shale are not so noticeable as those produced on the Brunswick shales by the Haycock-Rock Hill sill, partly because the Byram sill is much thinner but largely because there is a difference in the shales. The shale of the Lockatong formation is a black carbonaceous shale in which effects of baking are not readily evident. The shale of the Brunswick formation, on the other hand, is soft and red, and the heat of the diabase deoxidizes the red iron oxide and thus turns the rock blue and bluish black.

As the diabase is hard and resistant to weathering, it gives rise to hilly country, for the most part thickly strewn with large spheroidal boulders, which unfit it for cultivation and cause it to be left largely in forest. The rock generally weathers by exfoliation, giving rise to spheroidal boulders. (See pl. 3, *A*.) The Haycock-Rock Hill sill forms a broad hilly area, which at Haycock Mountain rises 450 feet above the level of the shale. The baked shale on the edges of the diabase is almost equally resistant. It holds up the flanks of the diabase areas and is included topographically in what is locally called "The Ridge," which extends southwestward from Haycock Mountain to Perkiomenville. Within the diabase area are upland

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[5] Lewis, J. V., Structure and correlation of Newark trap rocks of New Jersey: Geol. Soc. America Bull., vol. 18, p. 196, 1907.

valleys or flats the surface of which is covered by diabase boulders that obstruct the drainage. These areas are swampy, and small ponds have developed along the stream courses; Ridge Valley Creek flows through such an area.

Character and composition.—The diabase of the greater part of the Haycock-Rock Hill sill is a light-gray medium to coarse grained crystalline rock. The diabase of the center of the sill is so coarse grained that it is quarried and marketed as a "granite." The edges of the sill, the dikes, and the thinner Byram and Clayton sills are dense, fine grained, and greenish black. The constituents of both varieties are the same, feldspar and augite being the only minerals discernible in the hand specimen. Feldspar preponderates in the coarser-grained rock and augite in the fine-grained variety. Augite occupies angular spaces between the interlocking lath-shaped feldspar, producing an ophitic texture.

The feldspar is for the most part repeatedly twinned plagioclase with the composition of acid labradorite. Augite is the common green-brown to yellow variety, and in some specimens it is slightly frayed and altered to chlorite or to uralitic amphibole. It contains inclusions of plagioclase, which was among the first minerals to crystallize. Biotite, magnetite, and micrographic quartz and orthoclase are present in small amount. Olivine has not been found in the diabase of this area.

No analysis has been made of the diabase of the area, but several from adjoining regions are quoted below.

Analyses of diabase from localities near the Quakertown and Doylestown quadrangles

	1	2	3	4
SiO_2	56.78	46.87	51.56	51.68
Al_2O_3	14.33	13.36	17.38	15.87
Fe_2O_3	5.76	9.79	6.57	1.46
FeO	9.27	2.71	3.85	8.43
MgO	1.58	4.35	3.42	7.84
CaO	5.26	14.70	10.19	11.08
Na_2O	3.43	4.64	2.19	1.86
K_2O	1.75	2.01	1.46	.34
H_2O+	.10	----------	[a] 2.15	.15
H_2O-	.33	----------		.16
TiO_2	1.44	1.98	1.63	.72
P_2O_5	.36	----------	[b] .13	.12
MnO_2	.25	----------	----------	.15
Li_2O	----------	----------	Trace.	----------
	100.64	100.41	100.53	99.86

[a] Loss.
[b] Phosphoric acid.

1. Quartz diabase (tonalose, II.4.3.4). About 450 feet from the upper surface of the sheet, Rocky Hill, N. J. Am. Jour. Sci., 4th ser., vol. 8, p. 267, 1889. A. H. Phillips, analyst.
2. Diabase (kilauose, III.5.2.4). Birdsboro, near Reading, Pa. U. S. Geol. Survey Nineteenth Ann. Rept., pt. 6 (continued), p. 222, 1898. H. Fleck, University of Pennsylvania, analyst.
3. Diabase (bandose, II.4.4.3). Conshohocken, Pa. Pennsylvania Second Geol. Survey Rept. C6, p. 134, 1881. F. A. Genth, jr., analyst.
4. Diabase (auvergnose, III.5.4."5). Rocky Ridge, Frederick County, Md. U. S. Geol. Survey Bull. 148, p. 90, 1897. A. E. Schneider, U. S. Geol. Survey, analyst.

QUATERNARY SYSTEM

By F. Bascom

Mountain wash.—In the northwestern part of the Quakertown quadrangle there are several remnants of gravel deposits on stream divides and on hilltops. This gravel was washed from the disintegrated Triassic conglomerate that forms the adjacent high hills in Lehigh County and was deposited on a plain at the foot of these hills. It is composed largely of round quartz pebbles stained red on their surfaces, in red sandy soil. The gravel was deposited largely in Pleistocene time, and its remnants stand above the present stream level.

Alluvium.—Alluvium covers the low bottom lands and flood plains of the larger streams. It is largely a light clay loam and conceals the underlying rock formations. The low islands and flat flood plain of the Delaware River are the best examples of this alluvium, but similar deposits occur in the lowlands along its larger tributaries. The alluvium has not been mapped.

STRUCTURE

By G. W. Stose, E. T. Wherry, and F. Bascom

The Quakertown-Doylestown district lies almost entirely within the belt of Triassic lowland on the northwest side of the Piedmont province, and the structure of the Triassic rocks therefore dominates the area. Only at the extreme northwest corner and near the southeast corner of the area are pre-Triassic rocks exposed, where the structure of the pre-Triassic rocks may be studied.

STRUCTURE OF THE PRE-TRIASSIC ROCKS

NORTHWEST CORNER OF THE AREA

The pre-Cambrian and Cambrian rocks in the northwest corner of the Quakertown quadrangle are part of a complex anticlinal uplift that forms the Reading and Durham Hills, to the west. Two faulted anticlines of the anticlinorium enter the quadrangle, one forming the hills in the extreme northwest corner and the other the Chestnut Hill line of hills. Pre-Cambrian rocks form the core of both folds, and remnants of Cambrian quartzite and limestone lie on their flanks. These folds were formed during the period of Paleozoic compression, but they have since been broken by post-Triassic normal faults into great blocks that have been depressed on their northwest sides. The Cambrian rocks are preserved mostly on the downthrown northwest sides of the fault blocks. The Hardyston quartzite in the extreme corner is on the depressed northwest side of one of these fault blocks, and the quartzite 1 mile farther south is on the depressed northwest side of the other block. Northwest of Chestnut Hill the limestone lowland seems to be part of a sunken block or graben on this fault line, having been dropped between two divergent faults.

In the vicinity of Hosensack and along Hosensack Creek the Cambrian rocks on the south side of the southern anticline are much broken by faults, which are offshoots of the Triassic boundary fault later to be described. The rocks have been broken into triangular blocks, which have been displaced so that the Cambrian rocks in them are repeated and offset many times.

EAST OF DOYLESTOWN

The Paleozoic rocks exposed in the southeast corner of the Doylestown quadrangle are brought to the surface on the uplifted southeast end of a northwestward-tilted Triassic fault block, the former covering of Triassic red sandstone having been removed by erosion. The Paleozoic limestones are poorly exposed in the lowland of Buckingham Valley, and the attitude of the beds is observable mostly in quarries. The dips are almost universally northwestward, ranging from 15° to 45°, but east of Lahaska a minor fold is seen. Probably there are many other minor folds which are not exposed. The Cambrian quartzite on Buckingham Mountain also dips to the northwest, and in a quarry on the east slope of the south end of the mountain pre-Cambrian rocks are exposed beneath nearly flat-lying basal Cambrian conglomerates, probably representing the crest of an anticlinal fold. The Paleozoic rocks are apparently folded into an anticline, the axis of which is Buckingham Mountain. This folding took place during the period of compression in late Paleozoic time. Younger rocks appear successively westward from the mountain, but the succession is somewhat broken by faults. The area of Cocalico shale at the south end of the Paleozoic area trends across the strike of the limestone formations, apparently in fault relation. There may also be a minor fault along the west side of Buckingham and Little Buckingham Mountains, separating the Cambrian quartzite from the Elbrook limestone. These faults are apparently normal faults of Triassic type, but a fault between the Cocalico shale and the limestone, if one exists, could not have been formed at the end of the Triassic period, because it does not affect the Triassic beds at its ends—that is, it passes under the Triassic beds and is older. The discordant relations may be due to unconformity and not to faulting.

STRUCTURE OF THE TRIASSIC ROCKS

Folds.—The structure of the Triassic strata of these quadrangles is in general monoclinal, the dips averaging 10° NW. over long distances both along the strike and across it. Everywhere through the northern two-thirds of the Doylestown quadrangle the strike is N. 45°–60° E. and the dip 10°–12° NW. South of the great fault south and southeast of Doylestown the strike is less constant, and near the fault the dips are locally steep to the south, a maximum of 75° S. being exposed south of Furlong. The exposures in this part of the area are not sufficiently numerous, however, to enable any definite system of folds to be traced. There is apparently a low anticline at Newville which brings the Stockton formation to the surface with a general northwesterly dip, but in the vicinity of the fault the dips are variable, and a few miles north of the fault they have become monoclinal.

In the Quakertown quadrangle the monoclinal structure prevails only in the northeastern portion, for elsewhere the beds are folded in distinct synclines and anticlines, all of which plunge northwestward, the synclines deepening in that direction. (See fig. 3.) The northeasternmost of these folds, around Quakertown, is obscured by the irregularity of the intruded mass of diabase, but it appears to be a syncline with the axis trending northwestward just south of Steinsburg. It is here called the Quakertown syncline. Near Spinnerstown, on the south side of this syncline, the dips into the syncline, are as high as 30° NE. West of Spinnerstown there is an anticline, which is also obscured by intrusions of diabase. It is here called the Hazelbach Creek anticline.

More extensive and plainer folds appear in the southwestern part of the quadrangle. Pennsburg is near the axis of a syncline that trends southeastward through Red Hill to Green Lane. On the north limb of the Pennsburg syncline the dips are locally as steep as 30° SW., and on its south limb 8°–15° NE. A pronounced anticline occurs at Perkiomenville and involves the diabase sheet as well as the sedimentary beds to the east. North of the axis of the Perkiomenville anticline the dips are mostly 10°–12° NW. and south of it from 15° to more than 30° SW. At Branchville this fold passes into the Chalfont normal fault, which lies north of Hatfield. (See fig. 3.) Zieglerville is near the axis of another syncline in which the dips are somewhat greater on its north than on its south side. This is called the Zieglerville syncline.

The great diabase sill in the upper part of the Brunswick formation is involved in these folds, and, although it differs somewhat in thickness from place to place and locally cuts across the beds to some extent, the general shape of its outcrop outlines these folds most plainly.

Faults.—The Triassic rocks of these quadrangles are traversed by a fault having many thousands of feet throw and by several somewhat smaller faults, which are more prominent east of the area. There are also a large number of very minor slips observable in rock

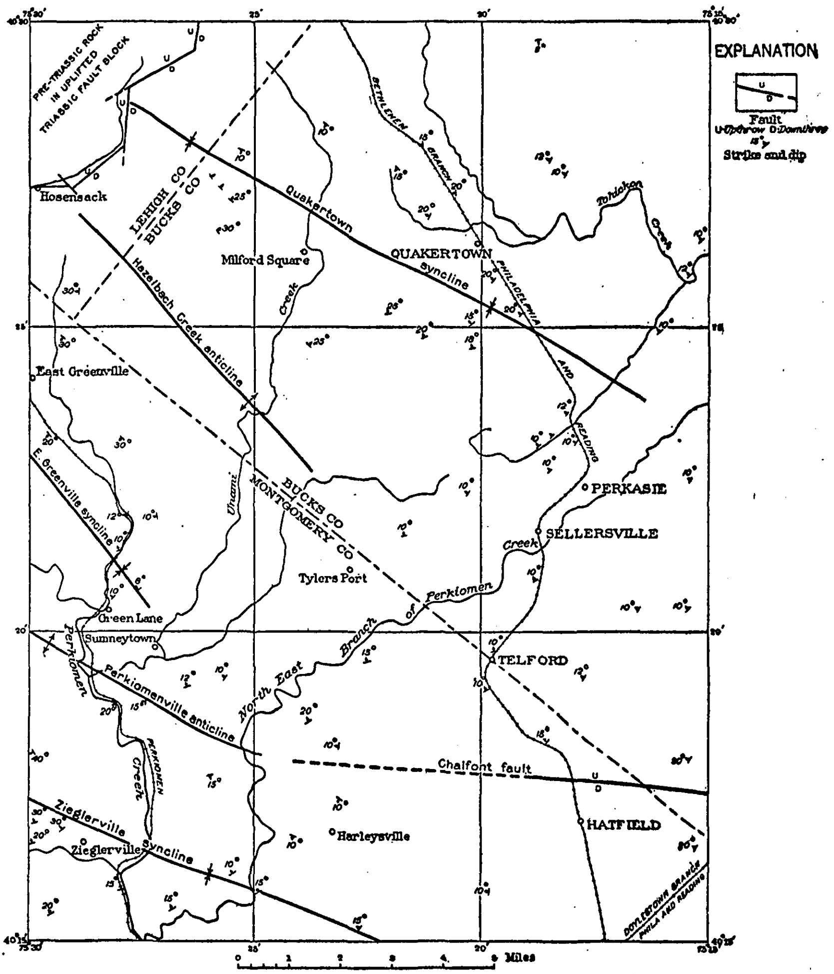

FIGURE 3.—Axes of structure of the Triassic beds in the Quakertown quadrangle

exposures. The most extensive fault in the area is a continuation of the Brookville-Flemington fault of New Jersey into the southeastern part of the Doylestown quadrangle. It passes through Furlong and will be referred to here as the Furlong fault. It brings the rocks that underlie the Triassic rocks against beds fairly high in the Brunswick formation, and the displacement is therefore the sum of the thickness of the Stockton, 3,000 feet; the Lockatong, 3,500 feet;

and at least 5,000 feet of the Brunswick—a total of at least 11,000 feet. The fault apparently terminates 1½ miles southwest of Furlong against an eastward-trending fault that passes through Chalfont and will be referred to here as the Chalfont fault. The displacement on this fault is not so great, and it diminishes rapidly westward, so that in the south-central part of the Quakertown quadrangle the fault apparently dies out by passing into the anticline that crosses the western boundary of the quadrangle at Perkiomenville. Eastward the fault apparently passes between Forrest Grove and Pineville and probably joins the fault that trends northeastward through Hopewell, N. J.

The course of the Furlong fault is marked throughout much of its extent by a fault breccia. At the southeast base of Buckingham and Little Buckingham Mountains the breccia is composed of fragments of quartzite cemented by iron and silica. Where the fault lies in the Triassic rocks they are so shattered and sheared by the fault and there is so great a development of micaceous minerals and increased susceptibility to weathering that at many exposures it is impossible to tell what Triassic formation is represented.

In the neighborhood of Chalfont the fault is represented only by marked jointing in the shale, and farther west it can be traced only by changes in soil where unlike formations are brought together.

Small faults of apparently only a few feet throw can be seen in nearly every extensive exposure of Triassic rocks, especially in railroad cuts. In most of them, however, the slickensided surfaces show that horizontal rather than vertical movement has taken place. There are, of course, many places where the rocks are concealed and where more extensive faults might be present, but there is not a single place where a recognizable bed of any magnitude has been definitely repeated by faulting; nor are diabase sills offset except by the larger faults. This fact is brought out because, in view of the enormous thickness of beds determined by computing from dips and width of outcrop, it would be reasonable to suspect extensive repetition of beds by normal strike faults. Strong evidence against this suggestion, however, has already been mentioned in the paragraph devoted to the distribution and thickness of the Brunswick formation. In the Boyertown quadrangle, to the west, the upper beds of the Brunswick are thrown into a series of folds with more or less parallel northwestward-trending axes, and measurements on the limbs of these folds show approximately the same thickness throughout.

The nature of the northwest boundary of the Triassic rocks is a matter of much interest. The Stockton rests on pre-Triassic rocks at the southeast margin of the Triassic belt and is seen again in the same relation north of the great Furlong fault. At the north edge of the Triassic belt the Stockton does not appear, the uppermost beds of the Brunswick formation abutting against pre-Triassic rocks. The evidence as to the nature of this boundary in the Quakertown quadrangle is inadequate because of the lack of good exposures. The pre-Triassic formations near Hosensack are greatly broken up by Triassic block faulting, and it is reasonable to assume that the contact of the Triassic against the older rocks is also the result of faulting. This is most certainly the relation of the beds at most other places along this contact to the northeast and southwest. At a few of these places the floor on which these Triassic rocks rest is exposed in fault blocks along this contact, and there the youngest Triassic sedimentary beds are seen to overlap on pre-Triassic rocks. It is probable that such overlapping occurs also in the Quakertown area and that the Triassic rocks lie on the Cambrian limestone, but this relation is apparently not exposed at the surface.

A normal fault with the downthrow on the southeast side which crosses the northwest corner of the Quakertown quadrangle is known to have considerable extent southwestward. This and other similar normal faults in pre-Triassic rocks are probably of late Triassic age, and the displacement of the rocks along them probably occurred during the deepening of the basin in which the Triassic rocks were being deposited. This deepening was more pronounced on the northwest side of the basin, so that the latest strata to be deposited—that is, the uppermost Brunswick beds—overlapped the younger Triassic rocks in that direction.

HISTORICAL GEOLOGY

By F. Bascom

Pre-Cambrian North America, ancestor of the present continent, extended considerably to the east of the present Atlantic border, and at different periods of its history interior areas were submerged under epicontinental seas. At one time nearly half of the continent was below water.

PRE-CAMBRIAN SEDIMENTATION AND INTRUSION

The earliest formations of the Quakertown-Doylestown district were laid down in pre-Cambrian time in one of such interior seas. The sediments were composed of sand and clay carrying carbon, which indicates shallow water and vegetal growth, and locally included limy beds of small thickness and extent.

There is no record in this district of further sedimentation preceding the widespread change in the relation of land to sea, when these sediments were consolidated, uplifted, and intruded by granitic and gabbroitic igneous masses and their associated dikes. The compression and the heat to which these sediments were thus subjected produced a large part of the metamorphism exhibited by the graphitic gneiss, the product of this early period of sedimentation.

CAMBRIAN AND ORDOVICIAN SEDIMENTATION

The next sedimentation of which there is record in this district took place while there existed on the Atlantic border a land mass that has been named Appalachia and on the western border of Appalachia an inland sea, known as the Appalachian sea. At the beginning of Cambrian time the advancing sea worked over the residual arkosic material and deposited a mixture composed of red and green clay, red feldspar and quartz sand, and coarse pebbles of rounded quartz. This material was followed by a very pure white sand, which was brought down by the streams from the highlands to the southeast and accumulated to a depth of about 2,000 feet. The relatively fine character and insignificant thickness of this terrigenous material indicate only moderate height of the land to the southeast, which was the source of the Cambrian sediments, during the period of its deposition. After this sand was washed from the land several thousand feet of limy material accumulated in the sea. Scattered grains of quartz and thin layers of clayey and sandy sediments in the limestone indicate only slight contribution of material from the land at this time. The deposition of lime mud continued apparently into the Ordovician period, when fine black clay mud was brought into the basin from some distant source, probably from the northwest. Thus were formed the Tomstown dolomite, the Elbrook, Conococheague, and Beekmantown(?) limestones, and the Cocalico shale.

SILURIAN AND DEVONIAN PERIODS

At the end of Ordovician time crustal movement along the Atlantic border contracted the Appalachian sea and brought the submerged western border of Appalachia once more above water. This movement was accompanied by minor folding and possibly some faulting of the Cambrian and Ordovician sediments and of the underlying pre-Paleozoic formations. It was not accompanied by igneous intrusions in this region. Farther northeast, in Pennsylvania and in adjacent parts of New Jersey and New York, the folding was more marked and was followed by erosion before the succeeding Silurian sediments were laid down on the truncated edges of the older beds.

The Quakertown-Doylestown district shows no record of further submergence and sedimentation during Paleozoic time, but the presence of Silurian and Devonian sediments northeast and west of the district gives some ground for inference that submergence and sedimentation persisted during part of Silurian and Devonian time throughout the western border of Appalachia. The character of the sedimentation may be inferred from the Silurian and Devonian sediments to the northeast in New Jersey. They are for the most part shore deposits—gravel and sand that may represent confluent delta deposits on a coastal plain, red sand, and clay—but there was a period of calcareous sedimentation followed by deposits of silt and sand, with a shallowing of the sea and a final emergence of the continental area.

LATE PALEOZOIC FOLDING AND UPLIFT

Beginning in Middle Devonian time and continuing into Permian time there took place along the Atlantic border earth movements which 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 and leaving, on the cessation of these movements, only a small fraction of the continental plateau still submerged. The great compressive forces that accompanied the earth movements acted in a southeasterly direction and crowded the sediments that had been accumulating in the Appalachian sea into a great synclinorium made up of long, narrow anticlines and synclines trending northeastward. Overturned folding and thrust faulting in the southeast, where the crowding of the oceanic segment on the continental segment was severest, passed into close folding and then into open folding in the Valley and Ridge province, and the beds gradually assumed horizontality in the northwestern border of the Appalachian Highlands.

During this prolonged period of dynamic action the character of the sediments underwent further alteration. The alteration was greatest in the southeast, where the folding was closest, and least in the west, where the formations dip only gently. The Quakertown-Doylestown district is in a central area of only moderate metamorphism and also in an area where later deposition has almost completely covered up these pre-Cambrian and Paleozoic sediments. The pre-Cambrian sediments, which have been subjected to three periods of dynamic action and to igneous intrusion, show the highest degree of metamorphism among the formations of the Quakertown and Doylestown quadrangles. The sand and mud, at first consolidated into impure sandstone and shale, have by recrystallization become gneiss, with the original stratification obscured by secondary schistosity. The carbon present in the muds has crystallized out in flakes of graphite. The limy material occasionally included in the clay but not appearing in the Quakertown-Doylestown district has become by metamorphism a marble.

The Cambrian and Ordovician sediments have been subjected to only two periods of dynamic action and have not suffered igneous intrusion. They are therefore less completely metamorphosed than the pre-Cambrian material. The conglomerate, formed from the pebbly deposit, has been indurated. The sandstone, formed from beach sand, has become a quartzite but has not been so completely recrystallized as the Chickies quartzite of the southeastern Piedmont Upland. That formation is made up of interlocking quartz grains with quartz schist, mica schist, and gneissic facies. The quartzite of these quadrangles is made up of sand grains in a siliceous cement with pebbly and shaly beds. The limestones—Tomstown, Elbrook, Conococheague, and Beekmantown (?)—are for the most part imperfectly or very finely crystalline. Limestones of the same age in southeastern Pennsylvania are, on the other hand, true marbles, being completely crystalline. The Cocalico phyllite is not sufficiently crystalline to be called a schist, nor is it for the most part sufficiently indurated to be designated a slate, but it is characterized by the fissility and luster of the phyllite, in which finely crystalline muscovite has developed.

The movement of uplift, which resulted in the Appalachian synclinorium, was very slow, and erosion never ceased to modify the rising land. Although the land stood high at the end of Paleozoic emergence, the crests of the folded sediments were already reduced and the troughs modified.

TRIASSIC SEDIMENTATION, INTRUSION, AND FAULTING

The reduction of the height of the land continued and was carried on by streams flowing eastward into the Atlantic as well as by streams flowing westward.

Planation was well advanced when the Triassic sediments began to be deposited in a slowly subsiding basin located in the central Piedmont region, nearly parallel to the present coast line and crossing the Quakertown-Doylestown district. The subsidence was in the nature of a progressive tilting of the basin to the northwest, which brought about an overlap of beds on the northwestern border, the greatest thickness of the sediments being developed near the present northwestern boundary, a receding shore and prevailingly shallow water on the southeast, and a rising source of sedimentary material farther to the southeast. The highest beds of the Newark are thus absent on the southeastern border, but on the northwestern border they overlap pre-Paleozoic or Paleozoic formations. Streams from the eastern rising land brought gravel to the basin, forming confluent deltas that spread out northwestward. Fine gravel, sand, and sandy clay were later contributed to the basin. Still later in Triassic time, with progressive tilting, confluent deltas growing on the northwestern border rested directly upon the old eroded formations. Streams eroding Devonian quartzite on the northwest furnished gravel, boulders, and pebbles, and near-by Paleozoic limestones contributed fragments of limestone. Near the end of Triassic time, but before Newark sedimentation was completed, igneous material was intruded in sheets and dikes and extruded as lava flows. This igneous action was the precursor of earth movements in this region, which produced a general dislocation of the Newark sediments and resulted in their being broken into blocks that were faulted and tilted and to some extent warped and gently folded. This faulting and tilting of the blocks brought up the Paleozoic sediments east of Doylestown, which by their differential erosion have formed Buckingham and Little Buckingham Mountains. Here the older beds of the Newark group rest on the Paleozoic rocks. The Quakertown and Doylestown quadrangles are on the western border of the Newark basin, where the youngest beds of the Newark in places rest directly on the pre-Paleozoic and Paleozoic rocks.

POST-TRIASSIC UPLIFT AND EROSION

Since Triassic time the history of this region has been chiefly a history of erosion. Sedimentation was confined to the eastern margin of the Piedmont province and the Atlantic Plain, while erosion was going on throughout the Appalachian Highlands. Each continental movement of uplift accelerating erosion was followed by a period of quiescence and continuous erosion, during which eastward-flowing streams eroded their valleys and deposited their sediments on the margin of the sea. When these quiescent periods were of great length, peneplains were produced. Each peneplain in turn was lifted, with or without warping, and dissected, and the detrital material was laid down on its submerged eastern margin.

During relatively brief periods of stability intervening between periods of land movements, only narrow marginal beginnings of peneplains were developed along the seacoast and only narrow flood plains up the stream valleys. After uplift some of the topographic features marking such an early stage of peneplanation suffered complete obliteration through subsequent prolonged erosion, but where later erosion was not prolonged sloping terraces, paralleling the sea and streams, were preserved. Such terraces or remnants of relatively brief erosion cycles have been called berms. As a consequence of these alternating periods of upward movement and stability a series of peneplains and berms have been developed in the Piedmont province.

The Quakertown-Doylestown district, which lies within the Piedmont Lowlands and therefore lacks formations so diversely resistant as those of the Piedmont Upland, does not reveal a complete record of its erosion history. The Triassic formations, which are uniformly less resistant than the crystalline rocks of the upland, preserve a record of the later erosion cycles only. The region undoubtedly suffered the same succession of uplifts and periods of quiescence accompanied by erosion that characterized the upland. All evidences of the older cycles of erosion have been obliterated in this region. A later uplift and erosion interval (Schooley), probably in early Cretaceous time, is feebly represented in a few detached summits at about 880 feet above sea level.

Late Cretaceous erosion is recorded in the Honeybrook peneplain, preserved at about 720 to 740 feet level in more extended areas and closely associated with the Schooley remnants. At the beginning of Tertiary time uplift renewed erosion, and the Harrisburg peneplain, which now stands at an altitude of 600 feet, was developed; in late Tertiary time there was cut into the uplifted Harrisburg surface the Bryn Mawr peneplain, which is still preserved at an altitude of 500 feet over considerable areas in these quadrangles.

In Pleistocene time the three successive uplifts and four erosion intervals have left a meager record in stream terraces or berms and gorges in the quadrangles.

ECONOMIC GEOLOGY

By F. Bascom, E. T. Wherry, and G. W. Stose

BUILDING STONE

The principal building stone of the Quakertown-Doylestown district is the brownstone that is obtained from the upper beds of the Stockton formation near Lumberville, at the eastern edge of the Doylestown quadrangle. Some beds of the Lockatong formation are also suitable for building stone or flagstone, but only small local quarries have been opened for this material.

The diabase of the northern part of the Quakertown quadrangle, commercially known as "trap rock" or as "granite," is also used to some extent for building stone, and the blocks are split and shaped by laborious hand methods with the use of iron wedges. As a rule definite quarries are not opened for this purpose, but the larger boulders which strew the surface over much of the area occupied by the diabase are utilized. The stone is resistant to wear, but its color is too dark for popular usage.

ROAD METAL

The Quakertown-Doylestown district is amply supplied with stone from which good road metal can be obtained. Three qualifications are essential for the best service as road metal—a degree of hardness that enables the stone to resist the abrasive action of traffic, a degree of toughness that enables it to resist rupture due to the impact of traffic, and finally good cementing or binding power that enables the rock powder and the freshly fractured stone to cement firmly. Diabase, gabbro, quartz monzonite (granite), quartzite, sandstone, limestone, and hardened shale can be obtained within the quadrangles.

In resistance to wear, in hardness, and in toughness, diabase and gabbro are superior to other rocks for road metal and can be used on roads that carry heavy traffic. Limestone, which is relatively soft and has high cementing value, is suited to light traffic only. Granite and gneiss lack the toughness and binding value requisite for top dressing of macadam roads but may be used as foundation stone; the foliated texture of gneiss renders it inferior to granite in binding value. Quartzite fails in cementing value and sandstone in resistance to frost.

Diabase, popularly known as trap rock, is distinctly the best road material in the quadrangles, and of this rock there is an abundance; it is quarried for this purpose at eight or more localities. The "gneiss" and "syenite" from Vera Cruz, half a mile north of the Quakertown quadrangle, are similar to the quartz monzonite of the Quakertown quadrangle and second to diabase and gabbro in value for road metal.

The sedimentary formations of the quadrangles have been largely utilized for road metal; extensive quarries are operated for this purpose, and material is shipped considerable distances. The limestones of the area east of Doylestown have been so utilized. The purer limestones have been burned for lime, but the dolomite and harder impure limestones have been crushed for road metal. The larger quarries are described under the heading "Limestone." The Hardyston quartzite of Buckingham Mountain is also locally used for this purpose. The brecciated quartzite along the boundary fault at the east foot of the mountain has been crushed and used on the roads, and at a quarry near the south end of the mountain white vitreous quartzite blocks on the mountain slope are crushed to 2 inches or less and so used.

The feldspathic beds of the Stockton formation in many places are so thoroughly weathered as to be little more than sand at the surface, and this sand is frequently dug and applied to the near-by roads. The results are not favorable, however, and only the cheapness of the method leads to its use. Just northeast of Carversville a hard black shale near the top of the Stockton formation has been used to a slight extent for road metal. The hard rock of the Lockatong is much better suited to road making, though it does not stand heavy traffic. There are several extensive quarries in this formation, both in the unaltered shale and in the shale altered by the diabase. The quarries near Line Lexington are in unaltered beds, but the rock is hard and has sufficient cementing power to form a fair road surface. Near Point Pleasant, on the Delaware River, an altered rock is similarly used. There are several quarries in the area of Lockatong formation at the south edge of the Doylestown quadrangle, the largest being that at Rushland station, where the rock contains calcareous bands and being also very hard yields good surfacing material. This rock, like other phases of the Lockatong, is sold as "trap rock," although this term should properly be restricted to diabase.

The Brunswick formation is for the most part poorly adapted to road making, because it is too soft; small local quarries are, however, frequently opened at points where the low cost of excavating the material is considered more important than permanence of road surface. Some of the harder beds yield tolerable road metal, even where unaltered. The best road material in this formation is obtained at places where the beds have been altered by diabase, as at Green Lane and Hendricks, on Perkiomen Creek. This rock is very hard and contains sufficient calcareous and argillaceous material to furnish good binding power. Like the Lockatong, it is known in the trade as "trap rock."

LIMESTONE

Limestone has been extensively quarried in Buckingham Valley in the Doylestown quadrangle and to a small extent in the northwest corner of the Quakertown quadrangle. Much of the limestone was burned in kilns and field piles for local use as fertilizer, and some has been used for lime plaster.

The larger quarries are in the Conococheague limestone. A more or less continuous line of old quarries extends from Centreville northeastward into the Lambertville quadrangle. They are generally long and shallow pits which follow purer beds that were worked for lime, lying between dolomite and siliceous banded beds. A less continuous line of shallow quarries follows the Elbrook limestone from Furlong northeastward along the foot of Buckingham Mountain. This rock is in general a fine-grained magnesian limestone that weathers into shaly fragments. A large number of small inactive quarries are in massive dolomite and limestone in the Beekmantown (?) limestone between Centreville and Holicong. One at Holicong is a deep hole with vertical walls and is filled with water. Other quarries in the Beekmantown (?) limestone extend northeast of Aquetong.

Limestone has been quarried at two places east of Hosensack, in the northwest corner of the Quakertown quadrangle. The southern quarry is in dark dolomite of the Tomstown dolomite; the northern one is fine-grained earthy marble of the Elbrook limestone.

Only a few of these quarries show signs of recent working, and most of those have been active only in the winter and other dull seasons, or when local road construction created a demand.

SAND AND GRAVEL

The Hardyston quartzite disintegrates into sand, which is dug in a few small pits on Buckingham Mountain. At the south end of the mountain there is a pit in the disintegrated basal arkosic beds of the Hardyston quartzite, from which coarse sand and some building blocks are obtained. The Stockton formation generally disintegrates into sand and gravel, which is locally dug for use at several places around Doylestown. The gravel is conspicuously exposed on Pebble Hill, 1 mile southeast of Doylestown.

IRON ORE AND UMBER

Iron ore in the form of magnetite was once mined in a small way in pegmatite half a mile south of Dillingerville, in the northwest corner of the Quakertown quadrangle. The mine was abandoned in 1913.

Umber was mined on a small scale in the Doylestown quadrangle at the fault contact at the southeast base of Buckingham Mountain, where the road crosses the middle of the mountain.

COPPER

Minute amounts of copper minerals occur at many places in the Triassic rocks. The primary mineral appears to be chalcopyrite in most places, but this is usually weathered at the surface into bright-green films of malachite. These films have attracted considerable attention, and numerous prospect pits have been sunk in the hope of finding valuable deposits of ore. One of the oldest copper prospects in the United States lies half a mile west of Schwenksville. The largest amounts of copper appear to have been found in three mines near Woxall (Mechanicsville), but even here not enough was obtained to pay for the cost of operations. The rock at these localities is a highly metamorphosed shale, with secondary calcite, zeolites, epidote, pyroxene, and other minerals; the copper minerals are chalcopyrite and bornite, with their alteration products malachite and azurite. There is every reason to suppose that the copper came from the diabase magma that produced the metamorphic effects. The reason for the concentration of the minerals in these particular places appears to be that the rocks there are shattered along a zone of slight faulting near the axis of the anticlinal fold of the beds, and the solutions could circulate there freely. There is no reasonable expectation that deposits of copper ores of real commercial value exist in the area.

GOLD

Still less promising than the copper prospects are those which have been directed toward supposed gold ores in the Triassic rocks. The most extensive operation for this purpose was that near Tylers Port and Naceville, in the center of the Quakertown quadrangle. No credible assays showing more than the merest traces of gold were ever obtained, and there is no reason to expect that deposits worthy of attention exist. The rock at this locality is a much altered shale with zeolites and other secondary minerals, and it is, of course, possible that a minute amount of gold was brought in by the metamorphosing solutions, but the Triassic diabases have nowhere been found to have introduced any appreciable quantities of this or any other precious metal. At Rock Hill, farther northeast, weathered gold-colored biotite in the diabase has been mistaken for gold, but no trustworthy assays showed gold in the rock.

SOILS

By F. Bascom

The soil survey of Montgomery County,[7] which gives typical results for the adjacent portions of Bucks and Lehigh Counties, shows that 13 types of soil may be recognized in the Quakertown and Doylestown quadrangles. Of these the Chester loam, the Penn silt loam, the Dekalb shale loam, and the Lansdale silt loam are the only soils that have sufficient acreage to be of significance in the agricultural development of this district. The other soils either cover very small areas (the Dekalb, Hagerstown, Manor, and Cecil loams and Meadow soil) or are stony phases of the loams (the Chester, Dekalb, and Cecil stony loams and Rough stony land).

The Chester loam, which is derived from the disintegration of granite, gneiss, and associated intrusive rocks, covers the northwest corner of the Quakertown quadrangle, in Lehigh County. Its continuity is interrupted by small patches of Chester stony loam, Rough stony land, Dekalb loam, and Hagerstown loam. It is a mellow brown silty loam, practically free from stones save for angular fragments of flint. The subsoil is a heavy silty loam of a light

[7] U. S. Dept. Agr. Bur. Soils Field Operations, 1905, pp. 97–133, 1906.

ashy-brown or yellowish-brown color. The Chester loam is an excellent soil for agriculture; it is adequately drained but has a texture suitable for the retention of sufficient moisture, and it is adapted to the growth of all the staple crops. Its topography in the Quakertown quadrangle is marked by high, rolling, well-drained land.

The Paleozoic formations east of Doylestown produce by their decay the Dekalb loam, Dekalb stony loam, and Rough stony land, which cover Buckingham Mountain and the hill to the southwest, and the Hagerstown loam, which is confined to the limestone valley of Watsons and Lahaska Creeks and the limestone valley in the northwestern part of the Quakertown quadrangle, with a small patch of Manor loam west of Bushington (Furlong).

The Dekalb loam, Rough stony land, and Dekalb stony loam, derived from the decay of the Cambrian quartzite, are gritty sandy loams with subsoils of the same color and texture. Both soils and subsoils contain many fragments and large boulders of quartzite. The topography and stony character of these soils render them unadapted to tillage, and they are usually left to forest growth.

The Hagerstown loam, derived from the disintegration of the Paleozoic limestone, is one of the most productive soils of the quadrangles. It ranges from a heavy brown silt loam to a silty clay loam, mellow and easily worked. The subsoil is of much the same character but friable and open, notably free from stones and without gradation into solid rock through decayed rock. A very small percentage of lime carbonate remains in the surface soil and increases in amount with depth. This soil has good natural drainage combined with a texture suited to the retention of sufficient moisture and, when properly farmed, yields excellent crops. The topography of the Hagerstown loam is that of a rolling open valley.

The Manor loam, which occurs southwest of the Hagerstown loam in Buckingham Valley and which is derived from the disintegration of the Cocalico shale, is a brownish-yellow loam containing small amounts of minutely divided mica and fragments of mica schist. The Manor loam is well drained, with a sufficiently retentive texture, and gives moderate yields of the staple crops. Its topography consists of rolling hills and gentle slopes.

The great intrusive masses of diabase in the quadrangles disintegrate into the Cecil clay loam, Cecil stony loam, and Rough stony land. The Cecil clay loam, which has the smallest areal extent of the three soils, is a reddish-brown silty clay loam with a subsoil of reddish heavy clay loam. The topography is such that the surface drainage is everywhere good and in places so excessive as to produce gullies. The subsoil is able to hold a reserve of moisture, and the soil is productive. The Cecil stony loam and Rough stony land are distinguished from the Cecil clay loam and from each other only by the increasing amount of stony material. The stone content of the Cecil stony loam is 40 to 70 per cent, and there are few large boulders. In the Rough stony land this stone content includes many large boulders and some rock ledges. The rough topography and the stony character of both these soils, which cover the greater part of the area occupied by diabase, render them unsuitable for tillage.

The rest of the Quakertown-Doylestown district, which is more than three-fourths of the whole area, with the exception of the flood plains of the larger streams, is covered by the Penn silt loam, the Dekalb shale loam, and the Lansdale silt loam. These loams are derived from the disintegration of the Triassic sandstone and shale and cover about equal portions of the area.

The Penn silt loam is a red or reddish-brown silty loam with a heavier red or brown silt loam subsoil, grading at greater depths into a red silty clay loam. Fragments of sandstone or shale are present in both soil and subsoil. The natural drainage is variable, ranging from excessive drainage, producing drought, to seepage. The Penn loam gives fair yields of the staple crops.

The Dekalb shale loam is typically a slate-colored or blue-brown silty loam, with a silty clay loam subsoil of a lighter color. Both soil and subsoil contain fragments of sandstone and shale. A stony phase of this soil is in some places associated with it. The drainage is generally good, but the two extremes of drought and seepage may occur with this soil as with the Penn loam. The Dekalb shale loam differs from place to place in its adaptation to staple crops. Where the soil is thin on steep slopes or where there is seepage, it is adapted to pasturage. With favorable topography and good drainage this soil yields good staple crops.

The Lansdale silt loam consists of a drab or light-colored silt loam with a heavy silty loam to silty clay subsoil. This soil is well drained and at the same time is capable of retaining sufficient moisture for crops. It is a better producer of staple farm products than the Dekalb shale loam and a little better than the Penn loam. The topography of the Penn, Dekalb, and Lansdale loams is very similar—hilly country, with open valleys and steep slopes bordering the streams. Deep plowing and thorough cultivation will increase the productivity of these soils and prove the equivalent of a considerable fraction of the amount of fertilizer ordinarily used.

The Meadow soil occupies a small area, covering only the bottom lands or flood plains of the larger streams. It is alluvial in character and therefore variable and subject to overflow. It is most commonly a clay loam, in some places covered by a wash of stone and fragments of shale. It is too uncertain a soil for cultivation but is admirable for pasturage. Its topography is low and flat.

Agricultural interests dominate these two quadrangles. A vigorous growth of forest trees of the common varieties covers the stony land. The oak takes the lead in the number of varieties and individuals. Other trees are the walnut, hickory, beech, birch, tulip, maple, poplar, locust, sycamore, linden, cherry, dogwood, hemlock, cedar, and pine. The chestnut tree has yielded to the blight. There are some indications, however, of its return by means of shoots from the old stumps, and these shoots show more or less immunity to the blight.

WATER RESOURCES

By F. Bascom

SURFACE WATER

The Quakertown-Doylestown district, like all the Piedmont region, is amply supplied with streams that possess a flow sufficient to furnish water power or water supply. The Delaware River and Tohickon, Perkiomen, Northeast Branch of Perkiomen, and Neshaminy Creeks are such streams. The country is also dissected with tributary streams fed by springs, which furnish private water supplies throughout the rural districts.

GROUND WATER

With regard to the conditions that control the occurrence of ground water, the rocks fall into three classes—relatively unmetamorphosed stratified rocks, metamorphosed stratified rocks, and massive igneous rocks and gneisses.

The Quakertown-Doylestown district, except a small area in the northwest corner of the Quakertown quadrangle and a triangular belt in the region of Buckingham Mountain in the Doylestown quadrangle, is underlain by stratified formations. The Newark group of conglomerate, sandstone, and shale contains beds that are likely to be water bearing. Such beds would be sandstones that are exposed somewhere at the surface, where they obtain their water supply, and are elsewhere buried between relatively impermeable beds, such as shale, which prevent the water from draining away.

The conglomerate and sandstone of the Stockton formation are permeable water-bearing beds that are interbedded with impermeable shale, and where the permeable beds are reached by drilling, water may be obtained. The dip of the Stockton is fairly uniformly 10° NW., giving an aggregate of about 3,500 feet of beds. This thickness is probably nowhere to be found in any one vertical section, for the beds are known to overlap one another westward, and water could be obtained at much less depth at determinable horizons.

The fine-grained shales and argillites of the Lockatong formation are relatively impermeable, and no serviceable water-bearing beds occur among them.

The Brunswick formation consists largely of shale but contains a small amount of sandstone. About 200 feet of sandstone, distributed in three beds, 100, 70, and 10 feet in thickness, occurs in the south-central part of the Quakertown quadrangle. The 100-foot bed appears in a northeastward-trending belt on the southeast slope of the ridge traversed by Ridge Road. The other two beds are exposed just south of Souderton. These sandstone beds are probably water bearing. There may be other sandy beds in the Brunswick which do not appear in the section exhibited along the Philadelphia & Reading Railway, for the character of the beds may change parallel to the strike. Water may be obtained at the base of the conglomerate member of the Brunswick, and even in the shale beds water that has moved along joint and bedding planes may be obtained by drilling.

In general in the area underlain by the Newark water may be obtained by drilling through relatively soft rocks to water-bearing sandstones whose horizon can be determined with considerable accuracy.

The Paleozoic formations, which form Little Buckingham and Buckingham Mountains and underlie the lowland on the northwest foot of these highlands, fall into the second class of water-bearing rocks. These crystalline or more or less indurated rocks are less permeable to water than the sandstones of the Newark group, but with the exception of the Cocalico shale they are to some degree permeable. Water may be obtained in the Cambrian quartzite and at its base and also in the Cambrian and Ordovician limestones and at their base. The water in the limestone is somewhat hard and is liable to pollution from the surface because it moves through relatively large solution channels in the limestone and is accordingly not filtered by the rock.

The pre-Cambrian crystalline rocks that underlie a small area in the Quakertown quadrangle fall into the third class of water-bearing rocks and furnish still another set of conditions. These rocks are made up of closely interlocking grains and are the least porous, with the exception of the shales, of the three classes of rocks. Moreover, they possess no definite planes of parting along which ground water may circulate, such as are furnished by stratified rocks. Irregular openings for the circulation of water are furnished, however, by joints and faults, and if these planes intersect one another near the surface, water may be obtained from such rocks by drilling, but the amount is likely to be small.

TOWN WATER SUPPLIES

Quakertown is supplied with water by the Quakertown Water Co., a public-service corporation. The water is obtained from four drilled wells and from Hickon Creek at a point about 1½ miles northeast of Quakertown. Hickon Creek is fed by springs. Three of the wells are 150 feet deep and are in Brunswick shale. One is between 125 and 130 feet deep. The water is treated with chlorine and supplied to approximately 5,000 people. The analysis of a sample of mixed water from the public supply is given in the table below.

Analyses of waters from public supplies of Quakertown and Doylestown collected October 7, 1922

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

	Quakertown	Doylestown
Silica (SiO_2)	31	22
Iron (Fe)	.14	.08
Calcium (Ca)	145	24
Magnesium (Mg)	39	5.7
Sodium (Na)	20	7.9
Potassium (K)	2.1	1.1
Carbonate radicle (CO_3)	0	0
Bicarbonate radicle (HCO_3)	144	76
Sulphate radicle (SO_4)	418	21
Chloride radicle (Cl)	6.4	5.4
Nitrate radicle (NO_3)	1.7	14
Total dissolved solids at 180° C	769	136
Total hardness calculated as $CaCO_3$	522	83

The water of the Quakertown supply is characterized by a high mineral content and an undesirable hardness. The hardness is sufficient to render the water unfit for many industrial uses and unsatisfactory for domestic use, and it can not be so treated as to make it satisfactory. Otherwise, so far as dissolved mineral constituents are concerned, the water would be classed as satisfactory. The source of the calcium sulphate in the water is probably the double salt of calcium and sodium sulphate, glauberite, a mineral which occurs more or less abundantly at several horizons in the Brunswick formation, particularly in the neighborhood of Quakertown.

The Perkasie Water Supply Co., a corporation, supplies Perkasie with water. The sources of supply are springs in the cut on the Philadelphia & Reading Railway 1.1 miles north of Perkasie tunnel, and three deep wells south and two springs east of the summit of Rock Hill at altitudes of 520 feet.

The town of Sellersville is supplied with water by the Sellersville municipal waterworks, which obtains the water from springs and drilled wells, with a capacity of 150,000 gallons a day. The plant owns a settling basin 3 miles north of the town and a reservoir 1 mile north of the town. The spring water is soft; the water from the wells is hard and is used only when the springs cease to give a sufficient supply during dry weather. The water is reported to be pure and is furnished without treatment to approximately 2,000 people.

The Doylestown Borough Water Department supplies a population of 4,500 with water obtained from three springs and two wells about 1 mile east of Doylestown station. The wells are 4 inches in diameter and are 175 and 125 feet deep. The capacity of the plant is 400,000 gallons daily. The water is served without treatment. An analysis of a sample of mixed water from the public supply of Doylestown is given in the preceding table. This water is characterized by moderately low mineral content and hardness.

The other towns and villages of the Quakertown and Doylestown quadrangles have no public water supplies. Privately owned wells and springs supply the householders with water.

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