DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS
OF THE
UNITED STATES

TRENTON FOLIO

NEW JERSEY–PENNSYLVANIA

BY

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GEOLOGIC ATLAS OF THE UNITED STATES.

The Geological Survey is making a geologic atlas of the United States, which is being issued in parts, called folios. Each folio includes topographic and geologic maps of a certain area, together with descriptive text.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds—(1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those of the most important ones are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval*. Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

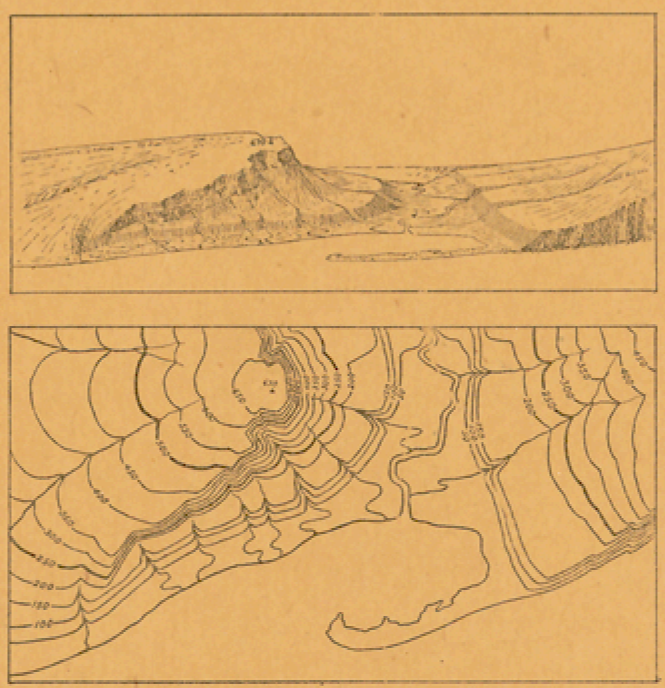

FIGURE 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay that is partly closed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle hill slope; that on the left is backed by a steep ascent to a cliff, or scarp, which contrasts with the gradual slope away from its crest. In the map each of these features is indicated, directly beneath its position in the sketch, by contour lines. The map does not include the distant portion of the view. The following notes may help to explain the use of contour lines:

1. A contour line represents a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contour lines are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above the sea—that is, this contour would be the shore line if the sea were to rise 250 feet; along the contour at 200 feet are all points that are 200 feet above the sea; and so on. In the space between any two contours are all points whose elevations are above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, and that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above the sea. The summit of the higher hill is marked 670 (feet above sea level); accordingly the contour at 650 feet surrounds it. In this illustration all the contour lines are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contour lines. The accentuating and numbering of certain of them—say every fifth one—suffices and the heights of the others may be ascertained by counting up or down from these.

2. Contour lines show or express the forms of slopes. As contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing around spurs or prominences. These relations of contour curves and angles to forms of the landscape can be seen from the map and sketch.

3. Contour lines show the approximate grade of any slope. The vertical interval between two contours is the same, whether they lie along a cliff or on a gentle slope; but to attain a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

A small contour interval is necessary to express the relief of a flat or gently undulating country; a steep or mountainous country can, as a rule, be adequately represented on the same scale by the use of a larger interval. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is in regions like the Mississippi Delta and the Dismal Swamp. For great mountain masses, like those in Colorado, the interval may be 250 feet and for less rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. For a perennial stream the line is unbroken, but for an intermittent stream it is broken or dotted. Where a stream sinks and reappears the probable underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are represented by appropriate conventional signs in blue.

Culture.—The symbols for the works of man and all lettering are printed in black.

Scales.—The area of the United States (exclusive of Alaska and island possessions) is about 3,027,000 square miles. A map of this area, drawn to the scale of 1 mile to the inch would cover 3,027,000 square inches of paper and measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and a linear mile on the ground by a linear inch on the map. The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to the inch" is expressed by the fraction $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; they are $\frac{1}{250,000}$, $\frac{1}{125,000}$, and $\frac{1}{62,500}$, corresponding approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale of $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale of $\frac{1}{125,000}$, about 4 square miles; and on the scale of $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map of the United States is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ represents one square degree—that is, a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ represents one-fourth of a square degree, and each sheet on the scale of $\frac{1}{62,500}$ one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, though they vary with the latitude.

The atlas sheets, being only parts of one map of the United States, are not limited by political boundary lines, such as those of States, counties, and townships. Many of the maps represent areas lying in two or even three States. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet are printed the names of adjacent quadrangles, if the maps are published.

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or magma, within these channels—that is, below the surface—are called *intrusive*. Where the intrusive rock occupies a fissure with approximately parallel walls it is called a *dike*; where it fills a large and irregular conduit the mass is termed a *stock*. Where molten magma traverses stratified rocks it may be intruded along bedding planes; such masses are called *sills* or *sheets* if comparatively thin, and *laccoliths* if they occupy larger chambers produced by the pressure of the magma. Where inclosed by rock molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. Where the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and as a rule contain, especially in their superficial parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows also are usually porous, owing to the expansion of the gases originally present in the magma. Explosive action, due to these gases, often accompanies volcanic eruptions, causing ejections of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

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

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

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

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

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

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

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

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressures, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structures may have been lost entirely and new ones substituted. A system of planes of division, along which the rock splits most readily, may have been developed. This structure is called *cleavage* and may cross the original bedding planes at any angle. The rocks characterized by it are *slates*. Crystals of mica or other minerals may have grown in the rock in such a way as to produce a laminated or foliated structure known as *schistosity*. The rocks characterized by this structure are *schists*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are many important exceptions, especially in regions of igneous activity and complex structure.

FORMATIONS.

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

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

AGES OF ROCKS.

Geologic time.—The time during which rocks were made is divided into *periods*. Smaller time divisions are called *epochs*,

DESCRIPTION OF THE TRENTON QUADRANGLE.

By F. Bascom, N. H. Darton, H. B. Kümmel, W. B. Clark, B. L. Miller, and R. D. Salisbury.

INTRODUCTION.

By F. Bascom.

LOCATION AND AREA.

The Trenton quadrangle, described in this folio, lies between 40° and 40° 30′ north latitude and 74° 30′ and 75° west longitude. This is one-fourth of a square degree and is equivalent in this latitude to approximately 911.94 square miles or about 34.50 miles from north to south and 26.43 miles from east to west.

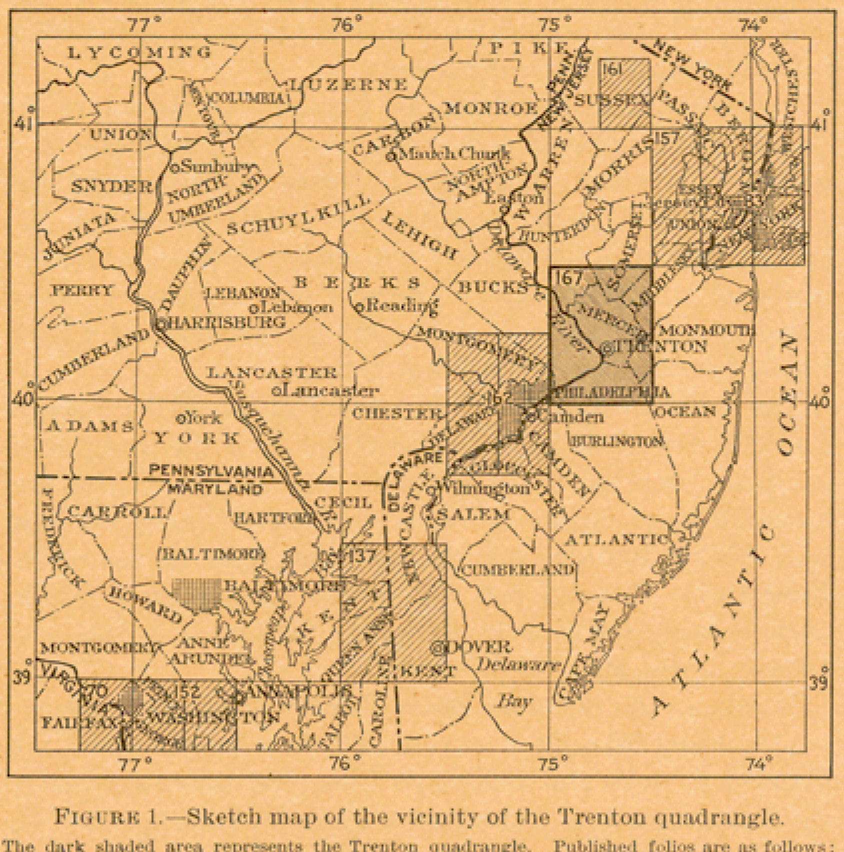

FIGURE 1.—Sketch map of the vicinity of the Trenton quadrangle.

The dark shaded area represents the Trenton quadrangle. Published folios are as follows: Nos 70, Washington; 83, New York City; 137, Dover; 152, Patuxent; 157, Passaic; 161, Franklin Furnace; 162, Philadelphia.

It lies in two States, New Jersey and Pennsylvania, and embraces in whole or in part nine counties, Hunterdon, Somerset, Mercer, Middlesex, Monmouth, Ocean, and Burlington counties in New Jersey; Bucks and Philadelphia counties in Pennsylvania. (See fig. 1.) The population of this area does not exceed 150,000.

GENERAL GEOGRAPHY AND GEOLOGY.

The Atlantic border region, of which the Trenton quadrangle is a part, embraces two distinct physiographic provinces—a mountain and plateau district and a coastal plain. The Trenton quadrangle comprises portions of the plateau and of the plain provinces, each of which is characterized by special topographic features which record the physiographic history of the province.

The first of these is known as the Appalachian Province and is separable into three geographic divisions which extend throughout its length. The Appalachian (formerly called Allegheny and Cumberland) Plateau forms the western division; the Greater Appalachian Valley, comprising a group of valleys and ridges, constitutes the central division; and the Appalachian Mountains, which border the Greater Valley, and the group of plateaus stretching away to the east in the vast upland known as the Piedmont Plateau, form the eastern division. A portion only of this eastern division forms a part of the Trenton quadrangle.

PIEDMONT PLATEAU.

GEOGRAPHY.

The Piedmont Plateau owes its name to its location at the southeastern foot of the Appalachian Mountains. Curving parallel to the Atlantic coast line, and extending northeast until it merges into the New England Plateau and southwest to Alabama, it possesses a mean width of 60 miles and a maximum width in the central portion of 120 miles. The Appalachian Mountains, which form its northwest border, although more or less distinct from it topographically, are united with it in one physiographic division, because they have had essentially the same geologic and physiographic history.

To the south these mountains are chiefly represented by the Cohutta Mountains of Georgia, the Great Smoky Mountains of Tennessee and North Carolina, and the Blue Ridge of North Carolina, Virginia, and Maryland. To the north the Blue Ridge is continued in South, Neversink, Lehigh, and Musconetcong mountains of Pennsylvania and in the Highlands of New Jersey and New York.

Physiographically, the boundary between the Appalachian Mountains and Piedmont Plateau is not a sharply defined line, but is crossed by physiographic features possessing similar and contemporaneous origins. Although topographically there is usually a more or less abrupt passage from a trenched upland to an area of level-topped mountain ridges, geologically there is no transition, the same geologic formations and structures appearing in both Mountains and Plateau.

On the east the Plateau is separated from the margin of the continental shelf by a belt of coastal province 250 miles in width. The greater part of this is under water in the region discussed. The land portion, which is called the coastal plain, dips gently eastward under the sea; it increases greatly in width toward the south.

The boundary between Plateau and Plain is defined by a well-marked change in the topographic features and geologic formations. Topographically, the change consists generally in an abrupt transition from a diversified upland to a relatively undiversified lowland; and geologically in a transition from consolidated and for the most part crystalline rock to unconsolidated clays, sands, and gravels of more recent age. The Coastal Plain formations, however, always overlap the eastern margin of the Plateau and in some districts are found far inland and somewhat obscure the passage from Plateau to Plain.

The margin of the Plateau is also indicated by a change in the character of the streams which pass from Plateau to Plain. This passage is always characterized by an abrupt decrease in stream velocity, and is so frequently marked by falls or rapids that the boundary has been called the "fall line." This term, however, is imperfectly descriptive of the boundary, which is actually a zone of appreciable width. East of it navigable streams lead to tidal estuaries affording good shipping facilities; westward they cease to be navigable and occupy narrow, tortuous channels. In the southern extension of the Plateau the fall line gradually rises, until in the Carolinas and Georgia—although falls and rapids still mark its location and furnish power for factories—it lies considerably above the tide limit.

The position of this fall line at the head of navigation and at the source of water power has been a dominant factor in determining the location of the large cities of the Atlantic States. A line passing through New York, Trenton, Philadelphia, Wilmington, Baltimore, Washington, Fredericksburg, Richmond, Petersburg, Raleigh, Columbia, Augusta, and Macon marks in a general way the passage from Plateau to Plain.

While the Plateau exhibits diversity of scenery, there are certain general features common to the entire region which make it a topographic unit. The province is, in brief, a sloping upland of moderate elevation, dissected by relatively shallow open valleys that usually become more rugged and narrow on the eastern border, and diversified by isolated eminences that rise above the general level. The valleys have been formed by recent stream cutting since the Plateau peneplain was carved. If they were filled in, the upland would be converted into an elevated plain, or plateau, sloping east and southeast toward the Atlantic, or south toward the Gulf of Mexico. The isolated eminences are remnants left unreduced by the erosion which produced the peneplain, now a plateau.

On the New England Plateau Mount Monadnock, a typical residual prominence, has furnished to physiographic literature the term monadnock, by which similar residual hills are designated. In New Jersey the upland has a relief on its western edge of about 800 feet, with a few monadnocks rising a little above that height, and on its eastern margin a range from sea level to an altitude of about 60 feet. The Pennsylvania upland descends from an altitude of 900 feet to an average elevation of 200 feet in the neighborhood of Philadelphia, the monadnocks, Long Hill, Gibraltar Hill, and other similar prominences, rising 100 to 200 feet above the surface. In Maryland the western edge of the upland reaches an altitude of 700 feet and slopes to an eastern margin 300 feet above tide level, in the vicinity of Baltimore; Rocky Ridge and State Ridge are monadnocks on this upland. In Virginia, North and South Carolina, and Georgia, the Plateau slopes southeastward and southward from summits 500 to 1500 feet in height along its western border to an eastern margin having an altitude of 300 to 500 feet. Southwest, Brushy, South, and many other mountains rise as monadnocks.

The plane surface which, sloping gradually from western border to eastern margin, forms the Plateau, does not owe its even contour to the underlying rock formations, for they possess highly complex structures. The larger streams, which have cut into the plateau, converting it into a diversified upland, maintain courses which are quite independent of the structure and character of the rock floor. The tributary or subsequent streams, on the other hand, show adjustment to the constitution of the rock floor and by means of them the heterogeneity of rock character and complexity of rock structure are finding expression. The general trend of the highlands, which is northeast and southwest in harmony with the strike of the underlying rocks, does not accord with the main drainage lines of the Plateau, but with the courses of the subsequent streams. The main streams of the Plateau, rising either in the Appalachian Mountains or on the inland border of the Piedmont district, pursue courses consequent upon the slope of the upland, that is, to the east, southeast, and south, and either empty into estuaries heading at the eastern margin of the Plateau, or, crossing the Coastal Plain, empty directly into the Atlantic or into the Gulf of Mexico. The Delaware, Susquehanna, and Potomac are examples of such master streams which have carved rugged valleys in the Plateau transverse to the strike of the rock formations.

South of an east and west line drawn just north of New Brunswick, N. J., the interstream areas are covered by a mantle of residual soil and are characterized by an absence of rock ledges. North of this line the rock mantle is glacial drift, the depth of which varies where it is present from a fraction of an inch to 200 feet. Rock ledges become an increasingly prominent feature toward the north, and contours are controlled not by stream work alone, but by ice erosion and deposition.

The discordance of underground structure with the level contour of the Plateau, the presence of residual eminences, the flatly convex valleys, the nonadjustment of the master streams to the rock formations, the deep rock mantle and absence of rock ledges, all have their explanation in the history of the Plateau, which will be outlined under the heading "Physiographic record," page 20.

GEOLOGY.

The rocks of the Piedmont Plateau include both highly metamorphosed crystalline material and unmetamorphosed fragmental material. The oldest formation is presumably of igneous origin; that is, it consolidated from a molten condition. Since consolidation it has been subjected to pressure and metamorphism, which have given it a banded structure. Such rocks are composed chiefly of quartz and feldspar and are known as gneisses. In the Pennsylvania Piedmont this material is part of a composite formation known as the Baltimore gneiss.

The later formations are chiefly of sedimentary origin; that is, the materials of which they are composed were accumulated beneath the sea, consolidated by pressure and cementing materials, and subsequently uplifted with or without folding. These facts are indicated by their constitution, their structure, and their mutual relations. They include some of the oldest materials known to have thus accumulated and some of the most recent.

The first sediments that were deposited in this Atlantic belt were of arkosic and argillaceous character, and their deposition took place in pre-Paleozoic time. The subsequent compression and folding to which the arkose and argillites were subjected developed from them a hard, crystalline, finely banded gneiss composed largely of quartz and feldspar, and a mica gneiss with interbedded mica schist facies. These gneisses have been differently named in different parts of the Plateau. In the Pennsylvania Piedmont the quartz-feldspar gneiss is intimately associated with a massive gneiss and forms with it the Baltimore gneiss; the mica gneiss is known as the Wissahickon.

The pre-Cambrian crustal movements which metamorphosed these formations were accompanied by the intrusion of bosses, irregular masses, sills, and dikes of molten material, which further altered the squeezed sediments and which consolidated as granite, gabbro, pyroxenite, and peridotite.

With the opening of Paleozoic time arenaceous, arenaceous-argillaceous, calcareous, and argillaceous sediments were successively deposited upon these gneisses. This deposition, taking place in Cambrian and Ordovician time, extended over a considerable part but not all of the Piedmont region.

The intense folding, faulting, and accompanying metamorphism to which these sediments were subjected before the close of Paleozoic time converted the arenaceous materials into quartzite, the arenaceous-argillaceous sediments into interbedded quartzites and mica schists, the calcareous material into marble and calcareous schists, and the argillaceous material into slates and micaceous schists. These formations, which are widespread though not continuous throughout the Piedmont belt, are respectively designated in the Pennsylvania Piedmont the Chickies quartzite, the Shenandoah limestone, and the Octoraro schist. These crystallized sediments and the associated igneous intrusions constitute the foundation of the Piedmont Plateau, but are uncovered only in detached belts trending northeast and southwest. They have been folded in synclinoria and anticlinoria made up of compressed anticlines and synclines with dominant isoclinal southeast dips and a steep southeast cleavage dip, and have further suffered thrust faulting. These geologic formations and structures are not confined to the Plateau, but also appear in the Appalachian Mountains, into which the Plateau merges on the west without geologic change, the Mountains and Plateau forming a geologic unit.

Upon the central and northeastern portions of this eroded crystalline floor there accumulated, in a shallow inland estuary, coarse and fine ripple-marked sands and sun-cracked mud which in places shows the tracks of animals or is locally rich in vegetable matter. Contemporaneously with this deposition, which took place in the Triassic period, igneous material was intruded between the beds of sediment, or traversed them in the form of dikes, or was poured out in lava flows. The consolidation and uplifting of these sediments took place without metamorphism. The uplift was accompanied by abundant normal faulting and tilting sufficient only to produce gentle northwest dips. These formations, wherever they occur on the Piedmont Plateau, possess a very uniform constitution and character and are known in Pennsylvania and New Jersey, where they cover a large part of the Plateau, as the Stockton and Lockatong formations and the Brunswick shale. The contemporaneous igneous material, occurring in the form of lava flows, sills, and dikes, is diabase and basalt. This rock resists erosion and forms bold ridges whose level tops are a part of the Piedmont slope or whose summits rise as monadnocks above the plain. Such eminences are the Palisades in New York and New Jersey, First, Second, and Sourland mountains in New Jersey, and Haycock Mountain, Rock, Long, Gibraltar, and many other lesser hills in Pennsylvania.

On the extreme eastern border of the Piedmont Plateau and in adjacent outlying areas the crystalline floor is concealed beneath unconsolidated gravel, sand, and clay, which were deposited in a marine estuary and along a former coast line during Cretaceous time. These are the Patapsco and Raritan formations of the Lower Cretaceous and the Magothy formation and Matawan, Monmouth, and Rancocas groups of the Upper Cretaceous. Overlapping these formations and left by erosion in scattered areas are thin coverings of sand and gravel belonging to the Tertiary and Quaternary periods. These show that the eastern border of the Plateau was intermittently submerged beneath estuarine waters during these periods. They are the Cohansey sand and the Lafayette formation of the Tertiary and the Bridgeton, Pensauken, and Cape May gravels and sands of the Pleistocene.

COASTAL PROVINCE.

By F. Bascom and B. L. Miller.

GEOGRAPHY.

The Coastal Province forms the eastern margin of the North American continental plateau and is, in geologic and geographic features, essentially unlike the Piedmont Plateau. Its western limit coincides with the eastern boundary of the Piedmont Plateau and has already been characterized as the "fall line." Eastward its limits are defined by the steep slopes at the margin of the continental shelf, which form an escarpment varying in height from 5000 to 10,000 or more feet. This declivity generally begins at a depth of 450 to 500 feet below sea level, but in common practice the 100-fathom line is regarded as the boundary of the continental shelf. The descent from that line to greater ocean depths is very rapid; off Cape Hatteras the bottom falls away to 9000 feet within 13 miles, a grade as steep as that found on the flanks of the greater mountain systems. In striking contrast to this is the comparatively flat ocean bottom stretching away to the east with but few and slight irregularities.

Seen from its base the escarpment forming the edge of the continental shelf would have the appearance of a high mountain range with an even sky line, broken here and there by notches produced by streams which at some time flowed across the shelf.

The Atlantic Coastal Province is divided into two parts by the present shore line—(1) a submarine portion known as the continental shelf and (2) a subaerial portion known as the Coastal Plain. In some places the dividing line is marked by a low sea cliff, but more commonly the two districts grade into each other without perceptible topographic change, separated only by the shore line. Their relative areas have been frequently altered in past geologic time by a shifting of the shore line eastward or westward, owing to local or to general depressions or uplifts. Such changes are still in progress.

That at some period the entire width of the continental shelf was above water is shown by the fact that old river valleys, the continuation of valleys of existing streams, have been traced entirely across the shelf, in which they have cut deep gorges. The channel of Hudson River is well defined, extending uninterruptedly to the edge of the shelf, over 100 miles east of the present mouth of the river. The same facts have been observed for Chesapeake Bay, the continuation of the Susquehanna channel.

The combined width of the submarine and subaerial portions of the Coastal Province is uniform along the entire eastern border of the continent and is approximately 250 miles. In the south the subaerial portion expands to 150 miles, while the submarine portion dwindles in width and along the eastern border of Florida almost disappears. Northward the submarine portion increases in width, while the subaerial portion diminishes, disappearing north of Massachusetts through the submergence of the entire Coastal Plain Province. Off Newfoundland this submarine province is about 300 miles in width.

From the fall line the Coastal Plain, or subaerial portion, has a gentle slope to the southeast, generally not over 5 feet to the mile, except in the vicinity of the Piedmont Plateau, where the slope is locally as great as 10 to 15 feet to the mile. The submarine portion, or continental shelf, is even more monotonously flat, as marine erosion and submarine deposition have smoothed out the irregularities due to earlier subaerial erosion. The continental shelf bears the sand bars which fringe the Atlantic coast and the sand flats and marshes which almost unite the bars to the Coastal Plain.

The moderate elevation of the Coastal Plain, which in few places reaches 400 feet and is as a rule less than half that amount, has prevented the streams from cutting valleys of any considerable depth. Throughout the greater portion of the plain, therefore, the relief is inconsiderable, the streams flowing in open valleys which lie at only slightly lower levels than the broad, flat divides. The drainage is largely simple, most of the streams being consequent on the uplift of the plain from the sea and lying wholly within the Coastal Plain. The master streams may be the extension of streams which rise in the Piedmont or Appalachian districts and are therefore complex.

Conspicuous features of the plain are its numerous bays and estuaries and the marshes bordering the stream courses. All of these features represent submerged valleys carved during a time when the province stood at a higher level than the present. Chesapeake Bay, the old valley of the Susquehanna, and Delaware Bay, the extended valley of the Delaware, together with such tributary streams as Patuxent, Potomac, York, and James rivers, are chief among similar bays and estuaries. Some of the streams which have their sources in the Appalachian or Piedmont provinces are turned at the fall line in a direction roughly parallel to the strike of the formation or the old coast line. The Delaware is a conspicuous illustration of such a deviation. Otherwise the structure of the geologic formations and the character of the materials have had but slight effect upon stream development except locally.

GEOLOGY.

The structure of the Coastal Plain is extremely simple. Upon a floor of crystalline and fragmental rocks, the continuation of the Piedmont Plateau, rest overlapping beds possessing a southeast dip of a few feet to the mile, uniform with the slope of the rock floor. The materials of these beds are bowlders, pebbles, sand, clay, and marl, for the most part unconsolidated, though locally indurated. Their total thickness varies from a maximum of 50 feet in the neighborhood of the fall line to 2246 feet at the coast line (at Fort Monroe, Va.).

In age the formations range from Jurassic to Recent. Since the deposition of the oldest formation there have been many periods of deposition alternating with erosion intervals. The sea advanced and retreated differently in different parts of the province so that few formations can be continuously traced through the entire Coastal Plain. Unlike conditions thus prevailed synchronously in distinct portions of the district and produced great diversity in the character and thickness of the deposits of a single period. A full representation of the successive stages may be found within the Coastal Plain, but may not be seen in any one section. Their general character and the distinctive terms applied to them have been given in the discussion of the geology of the Piedmont Plateau.

TOPOGRAPHY.

By F. Bascom.

RELIEF.

The Trenton quadrangle lies about equally in the Piedmont Plateau and the Coastal Plain. The eastern margin of the Piedmont Plateau is characterized by a low escarpment, the base of which is marked by the 20-foot contour line. The Pennsylvania Railroad tracks follow tolerably close to the base of this escarpment, departing from it only in the neighborhood of Bristol. The top of the escarpment is the level of the 60-foot contour. Between this and the 80-foot contour line there is a second faint escarpment that extends nearly parallel to the first scarp, from which it is separated by a terrace in general not more than half a mile in width. To the northwest the level of the second terrace is maintained with a slight upward slope until the base of a third and steeper escarpment is reached some 3½ miles northwest of the first terrace. This escarpment, like the first, is the continuation of one at the same level which crosses the adjacent portion of the Germantown quadrangle. Its base is defined by the 120-foot contour and its summit by the 200-foot contour line. It is a well-marked and persistent topographic feature from the western edge of the quadrangle to Langhorne, which is located upon its summit and overlooks the low and smooth plain separating it from the Delaware basin. East of Langhorne the scarp is more or less broken by the tributaries of the Neshaminy and its summit is reduced to 180 feet. At 2¼ miles west of Trenton it turns abruptly north and reaches the Delaware at Yardley. A still higher terrace, the dissected remnants of which extend several miles to the south and southeast, is defined by the 180-foot contour line in the vicinity of Newtown. This terrace is apparently to be correlated with the high terrace extending southwestward from Somerton to Swarthmore in the Philadelphia district.

North of these escarpments the plateau gradually ascends to a height of 540 feet. This slope is interrupted by eminences trending northeast and southwest which rise above the general level of the plateau. Such eminences are Rocky Hill, Mount Rose, Sourland and Jericho mountains, and Goat Hill. All these monadnocks are composed of more resistant material than that which characterizes the plateau.

In contrast with the Piedmont Plateau, that portion of the Coastal Plain included within the Trenton quadrangle is a region of low relief. The highest altitudes reached are 230 feet at Arney Mount, on the southern border of the quadrangle, 234 feet at Stony Hill, and 248 feet near Imlaystown, on the eastern border of the quadrangle. These heights represent isolated eminences rising abruptly above the general level of a plain which does not exceed 100 feet in altitude.

The surface inclination of the Coastal Plain of the Trenton district is toward Delaware River, into which the drainage of the plain empties in the southern half of the district, and toward Millstone River and Lawrence Brook in the northern half. In the southern half the plain rises from 10 feet at the Delaware to 150 and 160 feet in the extreme east. To the north it rises from 80 to 90 feet at the fall line to a little over 100 feet in the east.

Bordering the Delaware below Trenton there is in general a terrace rising from the river to a maximum height of 60 feet. Between Kinkora and Bordentown the river has so encroached upon this terrace as to produce a steep bluff rising from the water's edge. Above Bordentown this bluff recedes a mile from the river and is bordered by a lower terrace—the modern flood plain. The inner margin of the 60-foot terrace is in general marked by a gentle and obscure escarpment, beyond which a gently undulating plain with elevations ranging from 80 to 120 feet stretches eastward for several miles. It is terminated by a second escarpment, irregular in outline but more distinctly marked than the first.

This second escarpment forms an irregular ridge or series of hills ranging from 190 to 248 feet in elevation and extending northeastward from Fountain Green to Imlaystown. It was formerly continuous with the higher land still farther east, beyond this quadrangle, which forms the divide between the Atlantic and the Delaware drainage. In the southeast corner of the quadrangle it has been dissected and reduced to a rolling plain by the headwater erosion of the tributaries of Crosswicks Creek. Mount Holly, Arney Mount, Juliustown Mount, and a hill 2 miles north of Juliustown are island-like outliers of this higher land that rise sharply above the level of the 100 to 120 foot plain.

Undercutting is going on locally on the margin of the first terrace; the underlying beds, containing little if any of the iron stone conglomerate of the overlying gravels, are more readily worn away, and this terrace is therefore being slowly cut back.

A characteristic feature of the dissection of the Coastal Plain is the relatively greater steepness of the slopes on the southern banks of the streams compared with that of the northern banks. This feature may be seen wherever erosion has been deep enough to produce well-defined valleys, as on Doctors Creek, Crosswicks Creek, Blacks Creek, and Bacons Run. An explanation of this phenomenon is not to be found in the dip of the underlying formations, for this is not transverse to the streams; nor in deflection due to rotation of the earth, for deflection from this cause would, by turning the stream against the right bank, tend to steepen the southwest slopes. The conditions may be due to the fact that weathering is stimulated on the southwest slopes, which are more exposed to the action of the sun than are the northeast slopes. The rapid melting of frost and snow and the consequent alternate freezing and thawing which take place wear down the easily eroded Cretaceous material more rapidly on the northern bank with its southern exposure than on the southern bank, where the materials may remain continuously frozen during the greater part of the winter season. This differential weathering would be effective in producing observable results only in such easily transported materials as the unconsolidated sands and marls of the Cretaceous, and would not be operative to anything like the same degree in the crystalline formations of the Piedmont Plateau; the valley slopes of the plateau, consequently, show no similar disparity.

DRAINAGE.

Delaware and Raritan rivers receive all the drainage of the Trenton quadrangle. Neshanic and Millstone rivers, draining the northeastern portion of the quadrangle, are tributary to the Raritan, which lies north of the district and empties into Raritan Bay at Perth. Neshanic River with its tributary Back Brook drains about 55 square miles of the Trenton quadrangle. This area lies between Sourland Mountain and the highlands in the northern portion of the quadrangle, and possesses a distinctly basin-like character with low, flat divides; less than 6 per cent of it is forested.

East of the Neshanic basin is the drainage area of Millstone River. This river, which drains the northeastern third of the quadrangle, gathering tributaries from both Coastal Plain and Piedmont Plateau, is one of the important tributaries of the Raritan. Its basin embraces 285.7 square miles, of which only 9 per cent is forested. The main stream is 35 miles long, and the sources of the east and west tributaries are 30 miles apart. Its fall from the junction of Stony Brook to its mouth, 17 miles, is only a little more than 20 feet. It carries therefore only fine sediment, which it spreads upon a narrow flood plain.

The tributaries of the Millstone from the Coastal Plain exhibit shallow, open valleys of low gradient, partly filled with marsh land utilized for the culture of cranberries, and low, flat divides, both of which are the characteristic features of Coastal Plain streams. Stony Brook, the chief tributary from the Piedmont Plateau, with a drainage area of 64.8 square miles, is of a very different character. From its source near Buttonwood Corners in Sourland Mountain to its junction with the Millstone, a distance of approximately 22 miles, it has a fall of 445 feet. Through a large portion of this distance it flows in a gorge 100 to 160 feet in depth, and the divides between it and Beden Brook, a similar tributary to the Millstone, possess altitudes of 400, 450, and 500 feet. For the greater part of its course it pursues a southerly direction, just opposite to that taken by the Millstone, but 4 miles south of the Millstone it makes an abrupt turn and flows northeastward into that stream. This peculiar course is due to stream piracy. At one time Stony Brook, as a tributary to Assanpink Creek, emptied into the Delaware. The old valley once occupied by Stony Brook now forms a low divide between Stony Brook and Shipetaukin Creek. A tributary to Millstone River working southeast to Port Mercer captured Stony Brook at that point and turned its waters into the Millstone. This tributary must owe its ability to cut below the level of Stony Brook at Port Mercer to the fact that its channel lies in consolidated material which it is able to corrade, keeping a clear channel and carrying tools for corrasion supplied to it by the bed rock. The Assanpink, on the other hand, flowing over unconsolidated materials, is choked by sand and unable to corrade, as its shallow, flat channel testifies. Only 8 per cent of the Stony Brook basin is forested. (New Jersey Geol. Survey, vol. 3, pp. 51–58.)

Delaware River, which receives two-thirds of the drainage of the district, has a total length of 410 miles, of which only about 44 miles is included in the Trenton district. It is navigable by ocean steamers to Philadelphia, and by other craft to Trenton, where it has a mean low-water depth of 5 feet; it is tidal to this point, 130 miles above the Delaware capes. The area drained by the Delaware and its tributaries is 12,012 square miles; it is estimated by the New Jersey Survey that 45 per cent of the whole State is contained in the Delaware basin. As a source of water supply and water power the Delaware is therefore of great importance to New Jersey.

On the Piedmont Plateau the Delaware pursues the usual southwesterly course consequent upon the slope of the plateau and independent of the character of the underlying formations. On the Coastal Plain it makes a bend remarkable for its abruptness and flows at a right angle to its former course, parallel to the strike of the Coastal Plain formations and in a former estuarine basin.

The tributaries of the Delaware in the Trenton district on the New Jersey side are Wickecheoke, Alexauken, Moore, Fiddler, Jacobs, Assanpink, Crosswicks, Blacks, Assiscunk, and Rancocas creeks. Of these the more important are the Wickecheoke, Assanpink, Crosswicks, Assiscunk, and Rancocas.

Wickecheoke Creek, in the northwest corner of the quadrangle, has a drainage area of 269 square miles, with headwaters draining a comparatively wooded district. It has a fall of 560 feet from source to mouth, and has cut gorgelike valleys in the hard sandstone of the Lockatong formation. Its high, flat, and badly drained divides, locally known as "the swamp," form the plateauland of Hunterdon County.

Assanpink Creek, rising 17 miles to the east in Monmouth County and emptying into the Delaware at Trenton, has a drainage area of 89.6 square miles, distributed between the Coastal Plain (62.6), where the stream and its tributaries flow over unconsolidated materials, and the Piedmont Plateau (27), where its tributaries flow over sandstones. The 70 per cent contained in the Coastal Plain is low and is characterized by considerable marsh areas, while the valleys are open and shallow and the streams muddy.

The headwaters of Crosswicks Creek are not more than 10 miles southeast of its mouth at Bordentown, but the stream first flows to the south and east away from the Delaware, draining a large area (139.2 square miles), which is entirely included in the Coastal Plain. The headwaters of its tributaries are in flat, marshy country, but for the last 12 miles of its course the Crosswicks flows in a valley 40 to 60 feet deep and in places not more than one-fourth mile wide. It is navigable to Groveville and might be made a valuable source of water supply and water power.

Assiscunk Creek, which empties into the Delaware at Burlington, drains a much smaller area. Its basin, which is almost entirely included within the marl region, is low, flat, and badly drained; its waters are muddy, as the name signifies; and it is not valuable as a source of water supply, though it possesses much undeveloped water power.

Rancocas Creek is the chief tributary to the Delaware in this district, but of its total drainage area, 301.4 miles, only a small fraction is embraced in the quadrangle. It is tidal to Mount Holly on the North Branch and to Lumberton on the South Branch, about 10½ miles from its mouth, and is navigable to Centerton, where the North and South branches unite, 6½ miles from the Delaware. Its headwaters drain cedar swamps, which impart to them a brown tint and an aromatic flavor. Its lower courses are bordered by tide-water marshes, from which considerable areas have been reclaimed and cultivated.

The tributaries to the Delaware in the Trenton district on the Pennsylvania or west side are Pidcock, Brock, Common, Mill, Neshaminy, and Poquessing creeks. Of these the Neshaminy is the chief, possessing a drainage area of a little more than 139.3 square miles, a length of 27 miles, and a fall of 600 feet from source to mouth. This gradient gives the stream good corrasive power and it has cut a valley in the hard rocks of the plateau 160 feet deep, with a width of not more than three-eighths of a mile.

Because of the reduction of ground storage consequent on the sacrifice of forests to agricultural interests, the Neshaminy is subject to seasonal freshets, when its volume and velocity may be increased many times. Woods now exist in the drainage areas of the Neshaminy and other creeks only on steep slopes and bottom lands bordering the streams. The proportion of woodland and cultivated land on the Neshaminy has been estimated by John E. Codman to be as follows: Woodland, 6 per cent; cultivated land, 92 per cent; roads, 2 per cent; flats, one-half of 1 per cent. Under such conditions spring rainfall is not retained by ground storage. The run-off is relatively large, carrying a great amount of surface soil with it, and the main stream becomes torrential and transports a heavy load of fine sediment. The yellow color of the water after heavy rains, due to the large amount of finely divided material in suspension, is a characteristic feature of streams of this area.

The conditions which diminish ground storage also accelerate evaporation during the summer months and thus in another way augment seasonal fluctuation in stream flow. The soil exposed to the sun is parched and cracked by evaporation, and the level of ground water falls below the surface springs and the upper courses of the tributaries. The springs dry up and the streams are reduced.

For these reasons and because of plant absorption in the summer months, stream flow on the Neshaminy and other streams in this area most nearly equals the rainfall on its basin from December to May, and is lowest in proportion to rainfall from June to October.

DESCRIPTIVE GEOLOGY.

PIEDMONT PLATEAU AREA.

PRE-TRIASSIC METAMORPHIC ROCKS.

By F. Bascom.

GENERAL STATEMENT.

The crystalline formations of the Piedmont Plateau throughout most of the Trenton quadrangle are concealed beneath a cover on the southeast of Cretaceous, Tertiary, and Quaternary clays, marls, sands, and gravels, and on the northwest of Triassic sandstone and shale. They are uncovered in a belt ranging from 4 miles to 1 mile in width and extending from the southwestern edge of the quadrangle northeast to Trenton. On the northeastern outskirts of this city the crystallines disappear beneath the Triassic and Quaternary formations, and are not again exposed within the Trenton quadrangle, except at a point 2 miles northwest of New Hope on Delaware River, where a fault movement has brought them up and erosion of the Triassic rocks has left them exposed in a triangular area.

The crystallines of the Trenton quadrangle are a continuation of the Philadelphia belt of crystallines that extends southwest into Maryland, the District of Columbia, and Virginia. The formations of this belt may be correlated with those which have been described in New England and New York, although not stratigraphically continuous at the surface with these formations.

In southwestern New England the sedimentary series has been determined as follows:

Ordovician	Berkshire schist.
Cambro-Ordovician	Stockbridge limestone.
Cambrian	Cheshire quartzite.
Pre-Cambrian	Stamford, Becket, and other gneisses.

The New York belt furnishes the following succession:

Ordovician	Hudson schist.
Cambro-Ordovician	Stockbridge limestone.
Cambrian	Poughquag quartzite.
Pre-Cambrian	Fordham gneiss.

In Pennsylvania the sedimentary succession has been described as follows:

Ordovician	Octoraro schist.
Cambro-Ordovician	Shenandoah limestone.
Cambrian	Chickies quartzite.
Pre-Cambrian	Wissahickon mica gneiss.
	Baltimore gneiss.

In Maryland the following series has been provisionally determined:

Ordovician	Peach Bottom slate.
	Cardiff quartz conglomerate.
	Mica schist or phyllite.
Cambro-Ordovician	Cockeysville marble.
Cambrian	Setters quartzite.
Pre-Cambrian	Baltimore gneiss.

In the District of Columbia the limestone and quartzite do not appear. The pre-Cambrian mica schist and mica gneiss have been combined under the term Carolina gneiss.

The metamorphic sedimentary formations of the Trenton district are as follows:

Cambro-Ordovician	Shenandoah limestone.
Cambrian	Chickies quartzite.
Pre-Cambrian	Franklin limestone.
	Wissahickon mica gneiss.
	Baltimore gneiss.

Into the pre-Cambrian members of this series have been injected great masses, sheets, and smaller bodies of igneous material—granite, gabbro, pyroxenite, and peridotite.

The trend of both sedimentary and igneous formations is northeast and southwest.

SEDIMENTARY ROCKS.

PRE-CAMBRIAN ROCKS.

BALTIMORE GNEISS.

Distribution.—The Baltimore gneiss appears in a belt extending from the western border of the quadrangle to Trenton and lying northwest of the Wissahickon mica gneiss, from which it is separated by a narrow belt of quartzite. Possessing in the southwest a width of 2 miles, the gneiss narrows at Trenton to less than half that width. It is injected by an intrusive gabbro and passes to the northwest under a Triassic cover, and to the northeast is partly concealed by Quaternary deposits.

Character and stratigraphic relations.—The Baltimore gneiss is a medium-grained, thoroughly crystalline aggregate of quartz, feldspar, and biotite, and may be either quite massive or characterized by pronounced banding. Within the Trenton quadrangle the gneissic type is relatively more important. The finely gneissic character of the rock is due to the alternation of layers of biotite with quartz or quartz feldspar. Biotite occurs in minute plates, but is nowhere developed in such dimensions or in such excess as to render the formation schistose. Associated with the biotitic layers are hornblende, epidote, titanite, garnet, and rounded apatite and zircon crystals. The feldspar is microcline, orthoclase, and acidic plagioclase of about the composition of oligoclase and more or less completely altered to zoisite. Much graphite occurs, disseminated in pegmatitic material and in beds parallel to the gneissic structure, and has been mined in several localities in the Trenton quadrangle. One abandoned graphite mine exists at Trevose, and another lies three-fourths mile east of Langhorne on property belonging to Mr. Gross, where three generations ago an attempt was made to mine graphite. One-half mile north of Langhorne, where the Pennsylvania Railroad tracks cut through the gneiss, graphite occurs disseminated in minute plates. In Chester County, southeast of Phoenixville, graphite in this formation has been mined to a considerable extent.

The more granitic facies is only sporadically exposed. Where the Trenton branch of the Pennsylvania Railroad cuts through the rock formation, 3 miles west of Langhorne, this type is shown in contact with gabbro which is intrusive in it. It is medium grained and granular in texture. Quartz and feldspar are present in about equal proportions, with biotite, apatite, and zircon as accessory constituents, and zoisite and epidote as secondary products. The feldspar is chiefly orthoclase, clouded by zoisitization. Other occurrences of a similar granitic character are on the west bank of Delaware River, one-third mile north, and 1 mile north of Calhoun Street Bridge. The rock of these localities contains considerable hornblende as well as biotite. On the river south of Calhoun Street Bridge occurs a micaceous granitic rock containing no hornblende; and 3¼ miles southwest of Clarksville on the Brunswick road, a garnetiferous, rather coarse grained, granitic, pegmatitic rock is exposed.

The Baltimore gneiss is not well exposed in the Trenton quadrangle and no conclusions can be drawn relative to its origin from the exposures within this area. Extended areas of the formation in northwestern Chester County exhibit a genuinely granitic aspect indicating that much of the formation outside the Trenton quadrangle is of igneous origin. This is borne out by the following chemical analyses:

Chemical analyses of Baltimore gneiss.

	1.	2.	3.
SiO_2	70.21	72.99	63.93
Al_2O_3	13.95	10.90	12.02
Fe_2O_3	1.05	.55	2.40
FeO	3.08	2.50	2.95
MgO	1.26	1.07	2.44
CaO	3.10	1.88	4.00
Na_2O	3.27	3.34	3.15
K_2O	2.69	1.20	.84
H_2O+	.48	1.47	1.30
H_2O-	.19		
CO_2	.11	C 1.13	CO_2 .51
TiO_2	.52	.84	1.04
ZrO_2	Trace.		
P_2O_5	.10	.18	Not det.
Cl	Not est.		
F	Not est.	FeS_2 1.61	Fe_7S_8 4.04
S	.09		
NiO	Faint trace		Trace.
CuO			Trace.
MnO	.11		Trace.
BaO	.09		
SrO	Trace.		
Li_2O	None.		
	100.30	99.66	98.62

Analysis 1 was made by W. F. Hillebrand, of the United States Geological Survey, from a composite sample representing six localities.

Analyses 2 and 3 were made by F. A. Genth, jr., vol. C 6, Second Geol. Survey Pennsylvania, pp. 116, 105. Material of 2 was from Johnson's farm, 1 mile east of Feasterville and north of road to Somerton. Material of 3 was from the west side of Neshaminy Creek, on the property of Phineas Paxon.

The norm may be calculated as follows from analysis 1:

Quartz	30.06
Orthoclase	16.68
Albite	27.77
Anorthite	15.01
Diopside	.22
Hypersthene	6.99
Magnetite	1.39
Ilmenite	.91
Pyrite	.18
Apatite	.34
H_2O	.67
CO_2	.11
	100.33

Under the quantitative system of classification the rock falls into Class I, order 4, rang 3, and subrang 4, a persalane, quardofelic, alkalicalcic, dosodic yellowstonose, which means that the rock is extremely rich in salic constituents, that is, quartz and feldspars; that of these minerals the feldspars are dominant; that of the feldspars the orthoclase and albite molecules do not greatly exceed the anorthite molecules; and finally that of the alkaline feldspars albite is more abundant than orthoclase.

The structure of the rock is hypautomorphic; biotite and hornblende are abnormative minerals. Recognizing these facts, it is classed as a biotitic hornblende granoyellowstonose, the name showing the present chemical relations of the rock. There is no reason to assume that they have been materially modified by metamorphism.

The other two analyses also show a dosodic, granofelic rock.

Thickness, correlation, and name.—There is no means of estimating the thickness of this formation—the floor upon which the other members of the sedimentary series were laid down. This gneiss underlies material known to be of Cambrian age and presumably Georgian. It is therefore pre-Cambrian and is correlated with the pre-Cambrian Stamford and Becket gneisses of western New England, with the Fordham gneiss of New York State, with the Baltimore gneiss of Maryland, and with the Carolina gneiss of the District of Columbia and Virginia. While the pre-Cambrian gneiss of Pennsylvania is not stratigraphically continuous with the Baltimore gneiss of Maryland, similar stratigraphic relations, like lithologic character, and proximity of the two formations have found recognition in a common name. The pre-Cambrian gneiss of Maryland has been called the Baltimore gneiss because of a fine exposure of it in Jones Falls Creek in the city of Baltimore. The Baltimore gneiss includes H. D. Rogers's Primal Lower slate and a part of his northern or Third gneiss belt. The major part of the Third gneiss belt is gabbro. Both the Baltimore gneiss and the gabbro are included by the Second Geological Survey of Pennsylvania under the term Laurentian gneiss.

WISSAHICKON MICA GNEISS.

Distribution.—The Wissahickon mica gneiss extends from the western border of the Trenton quadrangle northeast to Morrisville. With a width of 6 miles the gneiss is exposed along the tributaries of the Delaware nearly to that river, but is concealed on the divides by Pleistocene gravels. It is injected by igneous material which outcrops irregularly within this area.

Character.—While showing considerable variation, the Wissahickon is typically a medium to coarse grained gneiss characterized by an excess of mica. The chief constituents are quartz, feldspar (both orthoclase and plagioclase), green or brown biotite, and muscovite. Magnetite, apatite, zircon, tourmaline, garnet, andalusite, sillimanite, and zoisite are accessory constituents. The more gneissic beds contain abundant orthoclase and plagioclase which is usually an acidic variety between oligoclase and andesine (Ab_3An_1), but is locally as basic as labradorite (Ab_1An_1). The rock is perfectly crystalline, and the constituents are relatively fresh with sharply defined boundaries. The freshness of the crystallization and the absence of pressure effects on the constituents indicate a recrystallized sediment.

The rock possesses a chemical composition which, while it resembles that of a shale and bears out the field and petrographic determination of the formation as of sedimentary origin, is still not conclusive. The high alumina and low alkali percentages and the preponderance of magnesia over lime shown by the following analyses are all characteristic of siliceous argillites; in all feldspar-bearing rocks of igneous origin, on the other hand, lime dominates the magnesia.

Analyses of Wissahickon mica gneiss.

	1.	2.	3.
SiO_2	56.40	66.13	73.68
Al_2O_3	19.76	15.11	12.49
Fe_2O_3	4.35	2.52	2.10
FeO	4.40	3.19	2.22
MgO	3.11	2.42	2.04
CaO	.09	1.87	.56
Na_2O	5.82	2.71	2.97
K_2O	1.27	2.86	2.91
H_2O+	3.37	1.55	1.34
H_2O-		.24	
CO_2		None	
TiO_2	1.05	.82	.81
ZrO_2		Not est.	
P_2O_5	.37	.22	.12
Cl		Not est.	
F		Not est.	
S		.03	
Cr_2O_3		None.	
NiO	Trace.	Trace.	
MnO		.20	.18
BaO		Trace.	
SrO		Trace.	
Li_2O	Trace.	None	
	99.99	99.87	101.42

1. Mica gneiss, Neshaminy Creek.
2. Mica gneiss; analysis made from composite sample representing four localities.
3. Mica gneiss, Neshaminy Creek, below 2.

Analyses 1 and 3 made by F. A. Genth, jr., volume C 6, Second Geol. Survey of Pennsylvania, pp. 108, 109.

Analysis 2 made by W. F. Hillebrand, U. S. Geological Survey.

The beds show minute crumpling and both gentle and steep folding. In the latter case cleavage, fissility, and bedding are parallel structures and are inclined 60° to 70° SE. The strike is N. 60° to 80° E., with a pitch of 5° to 25° NE.

Thickness.—It is not possible to determine with exactness the thickness of the mica gneiss. The isoclinal folding and constant variation in beds give a false idea of its thickness, which is probably between 1000 and 2000 feet.

Stratigraphic relations.—The determination of the age of the mica gneiss rests wholly on the stratigraphic relations which the formation sustains with fossil-bearing sediments. The mica gneiss contains within itself no clue to its age.

In northern Delaware and in the southwestern part of Chester County, Pa., the formation is found in association with crystalline limestone and quartzite. While most of the limestone lies southeast of the main mass of Shenandoah limestone, the rock perfectly resembles that formation and one series of exposures is continuous with its strike. The quartzite associated with the limestone resembles the thin-bedded sandy material of the Chickies quartzite, and like it contains broken tourmaline crystals. No fossils have been found in either formation, but because of their lithologic resemblance to recognized Paleozoic rocks and their similar stratigraphic relations, they are presumptively considered to represent Cambrian and Cambro-Ordovician sediments.

In the exposures where the limestone and mica gneiss are seen in contact, the latter formation overlies the former. The gneiss is here and there separated from the limestone by thin beds of quartzite, but is in places in immediate contact with the limestone. If this superposition of the gneiss represents its stratigraphic position, the Wissahickon mica gneiss is of Ordovician age. There is some evidence, however, which furnishes a presumption in favor of an inverted sequence:

(1) West of the Philadelphia district the Wissahickon mica gneiss and recognized Ordovician mica schists are adjacent for long distances. Although in proximity to the boundary between the two formations the mica gneiss shows a close resemblance to the mica schist, making it a difficult and sometimes an arbitrary matter to separate the two formations, yet a separation can be made and is made on the basis of the greater metamorphism of the mica gneiss as exhibited in a more coarsely crystalline texture. It is true that crystallinity increases eastward in all the formations, but this change in grain of crystallization seems sufficiently abrupt to indicate a different and older or pre-Ordovician formation.

(2) The structure of the limestone exposures permits the interpretation that they are overturned and in some cases fan-shaped synclines, in the troughs of which limestone is left by erosion. This structure puts the gneiss below the limestone.

(3) The presence of tourmaline-bearing quartzite between the limestone and mica gneiss also suggests an inverted series.

(4) Lenses of quartzite which occur in the mica gneiss have a similar significance.

(5) A garnetiferous mica gneiss interbedded with recognized Cambrian material is seen in a section through Cambrian sediments made by the Pennsylvania Railroad near Atglen, Pa. Here a mica gneiss is exposed between the quartzite and limestone and is also interbedded with the quartzite.

(6) No formation resembling the Wissahickon mica gneiss has been found associated with the Paleozoic series northwest of the Baltimore gneiss axis.

(7) Intrusive igneous material occurs abundantly in the Wissahickon mica gneiss and in the Baltimore gneiss, but with exceptions to be mentioned it is significantly absent from recognized Paleozoics. The exceptions are a single occurrence of serpentine in the Ordovician mica schist, and the indiscriminate passage of pegmatites from the Wissahickon mica gneiss to later Paleozoics. It may be stated, however, that in the first case the serpentine exposure shows no contact relations with the mica schist and the serpentine may be older than the latter formation; and that in the second case pegmatization does not represent vigorous igneous activity, but is rather the result of expiring igneous force. The igneous activity, whose vigorous action resulted in the basic intrusions which are seemingly confined to pre-Cambrian time, may have its expiring force in pegmatization, which continued through Cambrian and Ordovician time. It is also conceivable that pegmatization occurred in connection with the intrusion of the Devonian and Carboniferous granites found in the Appalachian Mountains.

These stratigraphic relations and igneous associations seem to indicate that the Wissahickon mica gneiss is in part at least older than the Chickies quartzite, and that to the southeast it often supplants the latter. That there was some micaceous-argillaceous sedimentation during Cambrian time is plainly shown in the Atglen section, in the gradation of mica gneiss into quartzite elsewhere, and in the passage of quartzite into mica gneiss parallel to the strike in still other localities. Yet both north and south of Pennsylvania sedimentation in earlier Cambrian time was dominantly arenaceous. In consideration of this fact, the Wissahickon mica gneiss, probably representing originally many thousand feet of scantily arenaceous sediments, is assigned to pre-Cambrian time. Subaerial erosion of the mica gneiss subsequent to the deposit of sand in an encroaching sea will explain the apparent gradation of the mica gneiss into the quartzite, while the thin and lenticular character of lower Cambrian sedimentation toward the east will explain the apparent passage of quartzite into gneiss along the strike.

The absence of the Wissahickon mica gneiss in the northwest, where the Paleozoic series immediately overlies the Baltimore gneiss, compels one of two assumptions. Either there was land during Wissahickon time in the west while the Wissahickon accumulated in an eastern sea, or there was a subsequent abruptly defined uplift in the west which permitted pre-Cambrian erosion to cut deeply into the mica gneiss, removing it completely on the northwest, so that Cambrian sand was laid down at first directly upon the Baltimore gneiss and later, as the sea encroached upon the land, upon superficially decayed Wissahickon mica gneiss. This deposition took place in bays or estuaries; later the Cambro-Ordovician limestone accumulated in enlarging bays or estuaries. This material, both pre-Cambrian and later sediments, was subsequently folded, metamorphosed, faulted, and thrust upon the western Paleozoics. In the Trenton quadrangle the Cambro-Ordovician material overlying the Wissahickon mica gneiss has been completely removed by erosion. The folded, metamorphosed, and faulted Wissahickon mica gneiss alone remains.

In the Philadelphia district the Wissahickon mica gneiss is found at a single locality, lying directly against the Baltimore gneiss and between it and the Chickies quartzite. The Baltimore gneiss is therefore considered the older formation.

Name and correlation.—Wissahickon Creek in the neighborhood of Philadelphia affords an excellent section across the strike of the formation. Because the mica gneiss is so finely exposed in the gorge of this stream it is called the Wissahickon mica gneiss. The mica gneiss, together with intrusive granite gneiss, comprises H. D. Rogers's First and Second gneiss belts and the "Chestnut Hill," "Manayunk," and "Philadelphia" mica schists and gneisses, considered by the Second Geological Survey of Pennsylvania to be pre-Cambrian in age. It is to be correlated with the Carolina gneiss of Virginia.

FRANKLIN LIMESTONE.

Distribution.—One mile southeast of Holland and three-fourths mile west of Neshaminy River there is a very small area of limestone, which, because of its character and associations, is assigned to a pre-Cambrian horizon.

The limestone is exposed only in the walls of an abandoned quarry, known as the Vanartsdalen quarry, which was opened about fifty years ago and was operated for thirty years. Sink holes in line with the strike of the limestone indicate that the rock underlies about 10 acres. Limestone is reported in the bed of the Neshaminy, where the new bridge for the Pennsylvania Railroad crosses that creek; this location is continuous with the strike of the quarry rock.

The quarry rock is a coarsely crystalline marble, white when pure but usually darkened by the presence of graphite and silicate minerals. Thirty mineral species have been attributed to this locality. The most abundant of the silicates are the feldspars (orthoclase, oligoclase, and bytownite), scapolite, titanite, and phlogopite; apatite and siderite are also common. The marble is surrounded by and thoroughly injected with gabbro. To this association the rock probably owes its high degree of crystallinity. Along the contact zone augite and hornblende are abundantly developed in the calcareous rock, while calcite veins and inclusions characterize the igneous rock.

Stratigraphic relations.—The limestone of the Vanartsdalen quarry sustains no stratigraphic relations with any formation, and it is therefore impossible to determine with precision the horizon to which it belongs. That it is presumably pre-Cambrian is indicated by the intrusion in it of igneous material which elsewhere is confined to pre-Cambrian formations.

In color, perfection of crystallization, and the presence of graphite and silicate minerals, the rock resembles the pre-Cambrian Franklin limestone which outcrops 70 miles to the northeast in New Jersey, and it not improbably represents a remnant of that formation left by erosion.

In the northwestern part of Chester County occur other isolated areas of white crystalline limestone in which graphite is richly developed and which is associated only with pre-Cambrian formations.

CAMBRIAN SYSTEM.

The Cambrian system is represented in the Trenton quadrangle by arenaceous and calcareous sediments which are thoroughly metamorphosed and now appear as quartzite and a crystalline limestone. These formations are devoid of igneous intrusions and represent continuous deposition during early, middle, and late Cambrian time. They extend for many miles toward the southwest.

CHICKIES QUARTZITE.

Distribution.—The hard, resistant Chickies quartzite constitutes a belt three-eighths mile wide, striking northeast across the quadrangle from Trevose on the western edge to Trenton, where it passes under a cover of later material. From Langhorne to a point 2 miles northeast of Edge Hill it forms part of the second escarpment, and its presence is always marked by high land.

Character.—Outside the Trenton quadrangle the quartzite shows a conglomeratic lower member, largely composed of elongated pebbles of the blue quartz which characterizes the Baltimore gneiss, but in the Trenton quadrangle it is typically a pale-green schistose quartzite, in which the color and schistosity are due to the presence of sericite.

Chemical analyses of Chickies quartzite.

	1.	2.[a]
SiO_2	87.87	84.59
Al_2O_3	6.61	
Fe_2O_3	2.39	
MgO	Trace.	
CaO	.24	
Na_2O	.19	.19
K_2O	1.73	2.79
Ignition	1.20	1.66
TiO_2	.38	
P_2O_5	.06	
MnO	.13	
Li_2O		Faint trace.
	100.80	

[a]Partial analysis.

1. "Itacolumite" 1½ miles southeast of Vanartsdalen's near Neshaminy Creek.

2. "Itacolumite," east bank of Neshaminy Creek.

Analyses by F. A. Genth, jr., volume C 6, Second Geol. Survey Pennsylvania, pp. 107, 116, 117.

The sericitic quartz schist is exposed in quarries at Trevose, at Neshaminy Falls on the east side of the creek, at Edge Hill, and on Delaware River. It is a thin-bedded formation with bedding and cleavage usually coinciding and dipping steeply southeast. The quartz schist is in places light buff to white in color and always contains feldspar. The feldspar is for the most part orthoclase, more rarely microcline, and is usually more or less kaolinized. Tourmaline, apatite, zircon, magnetite, and staurolite are accessory constituents. "Stretched" or broken tourmalines are very characteristic of the formation elsewhere. The schist readily cleaves into slabs and, by means of fissility developed in shear planes, into flattened rhombohedrons. A chemical analysis shows the rock to be highly siliceous, with sufficient alumina and potassa for sericite and feldspar.

Stratigraphic relations.—Southwest of the Trenton quadrangle the Chickies quartzite lies in an overturned syncline on the northwest flank of the Baltimore gneiss anticline. It immediately overlies the Baltimore gneiss, with a conglomerate at the base. The belt of quartzite exposed in the Trenton quadrangle is the southeast limb of the same anticline of which the northwest limb is concealed beneath the Triassic cover.

Thickness.—The thickness of the formation does not exceed and may be less than 1300 feet, although isoclinal folding gives the appearance of much greater thickness. Overturned folds with stratification and cleavage dips to the southeast are the prevailing structures. The average strike is N. 60° to 75° E. and the dips 75° to 85° SE.

Correlation and name.—The name of the formation is taken from the locality of its finest exposure and greatest thickness on Susquehanna River north of Columbia. At this locality *Scolithus linearis* has been found, as also in the North Valley Hills, and the quartzite underlies quartzite in which *Olenellus* fragments have been found by Mr. Walcott, thus fixing its age as Georgian (Lower Cambrian).

The quartzite of the Trenton quadrangle was deposited farther to the east than this typical exposure of Georgian quartzite on Susquehanna River, and may have been laid down in an encroaching sea, thus representing a slightly later horizon in the Cambrian than the Georgian. No forms of life save *Scolithus linearis* have been found in it, hence it can not be positively stated to be of Georgian age. It can be safely affirmed to be Cambrian and is to be correlated with the Cheshire quartzite of New England and the Poughquag quartzite of New York. It is the Primal sandstone of H. D. Rogers, and Formation No. 1, the Chicques or Potsdam sandstone of the Second Geological Survey of Pennsylvania.

SHENANDOAH LIMESTONE.

Distribution.—North and west of New Hope there is a triangular area of limestone extending from the western border of the quadrangle, where it has a width of 2 miles, to the west bank of the Delaware opposite Brookville.

Character.—The rock is a pale-blue, finely crystalline limestone, in many places argillaceous or siliceous, interbedded with compact dark-blue noncrystalline limestone and slate, and locally overlain by a few feet of banded red slate which has stained the underlying limestone. Ripple marks are preserved in the more argillaceous limestone beds. This formation is well exposed in quarries 2¼ miles north of New Hope at Limeport and in scattered quarries southwest of Limeport. An analysis of the rock from a locality 15 miles west follows.

Analysis of Shenandoah limestone.

$CaCO_3$	40.27
$MgCO_3$	31.24
SiO_2	24.23
Al_2O_3	1.12
Fe_2O_3	.11
CaO	.55
Alkalies	1.42
	100.00

Analysis by F. A. Genth, jr., vol. C 6, Second Geol. Survey Pennsylvania, pp. 126, 127. Material from limestone on Schuylkill River, between Mogee and Conshohocken.

This analysis shows that the limestone is both siliceous and magnesian, though the percentage of the magnesian carbonate is scarcely enough to warrant calling the rock a dolomite.

Stratigraphic relations.—The limestone is overlain by Triassic formations. While it shows no other stratigraphic relations within the Trenton quadrangle, in the adjacent Doylestown quadrangle on the west it overlies a quartzite similar in lithologic character to the Chickies quartzite, of Cambrian age. The two formations possess the character and the strike of the Cambrian quartzite and the Cambro-Ordovician limestone respectively, which are exposed north and south of the Triassic cover and which presumably underlie the Triassic formations throughout this portion of the plateau.

These underlying Paleozoic formations have clearly been brought to the surface by a normal fault either vertical or hading steeply southeast (fig. 2). The Stockton formation immediately overlies the limestone on the north. Adjacent to the limestone on the south are the Lockatong hard blue metamorphosed argillites and red shales. The argillites are indurated and excessively jointed with slickensided surfaces, evidently affected by proximity to a fault. Because of their hardness they form high land wherever they occur.

Thickness.—The thickness of the formation has been estimated from its structural relations in Chester Valley to be approximately 1500 feet.

Correlation and name.—Fossils of Chazy, Beekmantown, and Trenton ages have been found west of Chester Valley in limestone stratigraphically continuous with the Shenandoah limestone of that valley. Fossils have also been found in Chester Valley in somewhat ambiguous material. This material is geodiferous drusy quartzite, which is found in place south of Bridgeport, near the Trenton branch of the Pennsylvania Railroad. It is interpreted as a replacement of the uppermost calcareous beds of the Shenandoah limestone.

At Henderson station loose material of the same character lies on top of the limestone, and in this material have been found gasteropod and cephalopod fossils, from which the following determinations were made by E. O. Ulrich: *Raphistoma* (two species), *Maclurea*, *Lituites*, and *Cyrtoceras*. These are Ordovician forms and indicate a horizon in its lower portion. In one of the abandoned quarries at Limeport, near Delaware River and southeast of Brookville, and in another 1½ miles southwest of Limeport trilobite and brachiopod fossils have been found, and have been determined by E. O. Ulrich as *Solenopleura jerseyensis* (Weller) and *Lingulepis acuminata* (Conrad), respectively. These forms, so far as known, are confined to the Saratogan (Upper Cambrian) and are considered to be older than Walcott's Saratogan fauna but younger than the latest Acadian, and hence are early Saratogan. This corresponds in time to some part of the Conococheague formation of the Chambersburg quadrangle, Pennsylvania.

These fossils and the stratigraphic relations which the limestone bears to Georgian quartzite show it to be Cambro-Ordovician in age. It is therefore correlated with the Stockbridge limestone of New England and New York, and with the Shenandoah limestone of Pennsylvania and Virginia.

It is part of the Auroral limestone of H. D. Rogers, and of Formation No. 2 of the Second Geological Survey of Pennsylvania. To the Cambro-Ordovician limestone of Pennsylvania the name Shenandoah has been given because the greatest exposure of limestone of this age is in the Shenandoah Valley of Maryland and Virginia.

IGNEOUS ROCKS.

Associated with the pre-Cambrian crystalline sedimentary formations of the Trenton quadrangle are igneous bodies, intrusive in geologic occurrence and granitic and gabbroitic in lithologic character. This igneous material with varying petrographic facies invades the Atlantic belt of crystallines from Virginia to New York. It constitutes important formations in North Carolina, Virginia, Maryland, Delaware, and southeastern Pennsylvania. In the Trenton quadrangle the exposures are not extensive; they are confined here as elsewhere in the Plateau to pre-Cambrian rocks, which in this quadrangle are the Baltimore gneiss, the Wissahickon mica gneiss, and the Franklin limestone; the intrusives are therefore assigned a pre-Cambrian age.

GABBRO.

Distribution.—The maximum development of this igneous type in the Pennsylvania Piedmont is in the southwest.

From Susquehanna River and from the region about Wilmington, Del., a great body of gabbro extends northeast, forming the main mass of Buck Ridge, west of the Trenton quadrangle, and continues northeast into the Trenton quadrangle, in which it shows itself in exceedingly irregular areas. It thoroughly injects the Baltimore gneiss and Wissahickon mica gneiss and because of the intimate commingling of igneous and sedimentary rocks and the absence of exposures the boundaries can not always be drawn with accuracy.

Character.—The gabbro is a medium-grained massive rock, possessing either a bronzy-gray or a greenish-gray color, depending upon the character and freshnsss of the ferromagnesian constituents. It weathers in dark-colored bowlders with rusty exteriors which strew the fields and afford almost the only indication of the character of the underlying rock. These bowlders are exceedingly tough unless the rock has been rendered somewhat schistose through the development of hornblende or mica.

Typically, the gabbro is a hypersthene-augite-plagioclase rock, with accessory quartz, biotite, hornblende, magnetite, apatite, titanite, pyrite, pyrrhotite, garnet, and orthoclase. Exclusively decomposition minerals are actinolite, chlorite, and serpentine. Quartz is variable in amount, ranging where present from a trace to 30 per cent. The pyroxenic constituent may be exclusively hypersthene, chiefly hypersthene, or less frequently chiefly augite, or exclusively augite, or diallage; it constitutes from 10 to 40 per cent of the rock. The feldspathic constituent is labradorite or labradorite-bytownite, and varies from 5 to 60 per cent of the rock. Between the pyroxene, whether hypersthene or augite, and the labradorite there occur reactionary peripheral zones of garnets. Associated with the garnet there may be hornblende. These garnet rims form the most striking petrographic feature of the gabbro.

Wherever the gabbro has been subjected to pressure, as along the periphery of the intrusive mass, pyroxene is replaced chiefly by green hornblende and subordinately by biotite. A more or less schistose structure was produced by the development of these two minerals. Most of the gabbro of the Trenton quadrangle is hornblendic and schistose in character.

An analysis of the gabbro made by W. F. Hillebrand from a composite specimen representing three localities gives the following oxide percentages:

Analysis of gabbro from the neighborhood of Radnor and of Bryn Mawr.

SiO_2	54.03
Al_2O_3	16.71
Fe_2O_3	1.37
FeO	7.70
MgO	5.66
CaO	8.84
Na_2O	2.99
K_2O	.67
H_2O+	.53
H_2O-	.14
TiO_2	.84
ZrO	Not estimated.
CO_2	.40
P_2O_5	.13
Cl	Not estimated.
F	Not estimated.
S	.09
Cr_2O_3	Trace.
NiO	Trace.
MnO	.13
BaO	Trace (?)
Li_2O	Faint trace.
	100.23

The norm according to the quantitative classification would be:

Quartz	4.56
Orthoclase	3.89
Albite	25.68
Anorthite	30.30
Hypersthene	20.67
Diopside	10.52
Apatite	.34
Ilmenite	1.52
Magnetite	2.09
Pyrite	.24
H_2O	.67
CO_2	.40
	100.88

The rock therefore falls into Class II, order 5, rang 4, subrang 3, and is a hessose.

This means that the salic constituents, or quartz and feldspar, are dominant, and the femic or ferromagnesian constituents subordinate. Of the salic constituents, feldspar predominates to an extreme degree, and lime-soda feldspar with dominant lime is the prevailing feldspar. Augite is the only abnormative mineral among the essential constituents of the rock, and it usually plays the rôle of a critical mineral. The texture of the rock is hypautomorphic granular. It may therefore be designated an augitic granohessose.

Age.—The youngest material into which the gabbro intrudes, disregarding the Franklin limestone, so far as our present knowledge justifies a statement, is the pre-Cambrian Wissahickon mica gneiss. The gabbro is therefore, presumably, pre-Cambrian in age. By the previous surveys it was not separated from the Baltimore ("Laurentian") gneiss.

METAPYROXENITE AND METAPERIDOTITE.

Throughout the Atlantic belt gabbro is associated with, or through decrease in feldspar grades into, pyroxenites, or with the addition of olivine into peridotites. These pyroxenites and peridotites are usually altered by hydration and carbonation to serpentines and related rocks. Serpentines of such origin are found in the Piedmont belt of North Carolina, Virginia, Maryland, Delaware, Pennsylvania, and New York.

While to the southwest there are extensive areas of serpentine in the Pennsylvania Piedmont, the serpentine of the Trenton quadrangle is confined to two exposures. Two miles south of Hulmeville, at Ford, a dike of such material occurs in the Wissahickon mica gneiss and is exposed for about one-fourth mile. The rock is mottled green and gray and is now composed of tremolite, serpentine, and steatite. Calcite and magnetite are accessory constituents and by-products in the alteration of the original constituents to serpentine and talc. Serpentine is the chief constituent and is plainly secondary to the tremolite, though it is impossible to say whether all of the serpentine is of this origin. Steatite seems to be secondary both to the tremolite and to the serpentine. Tremolite has the appearance of a primary constituent, but is probably secondary to diopside or olivine. Of these constituents, however, no trace remains.

A dike of somewhat similar constitution comes to the surface for a short distance on the west side of the Neshaminy one-half mile southwest of Parkland. The rock consists chiefly of radiating crystals of yellowish-brown anthophyllite. In addition to this mineral occur calcite and steatite.

HORNBLENDE GNEISS.

Distribution.—In the Wissahickon mica gneiss there are isolated outcrops of a coarsely crystalline hornblende gneiss. The rock is exposed on Poquessing Creek at the crossing of the Pennsylvania Railroad near Torresdale, in the southwest corner of the quadrangle. A considerable area of it occurs 1 mile northwest of Cold Spring, also 1½ miles northwest and 2½ miles north of the same place.

The chief constituents of the gneiss are hornblende, quartz, and feldspar, composing about 45, 30, and 25 per cent respectively of the rock. Augite is scantily associated with the hornblende, and apatite is an accessory constituent. The feldspar is orthoclase and an acidic plagioclase, the former species predominating.

In the lack of a chemical analysis of the rock, its petrographic position can not be determined with accuracy. It is considered an altered basic granite.

TRIASSIC SYSTEM.

By N. H. Darton and H. B. Kümmel.

NEWARK GROUP IN GENERAL.

Extent, constitution, and structure.—The Triassic area described in this folio is a representative portion of an occurrence of the Newark group which extends from Hudson River southward through New Jersey, Pennsylvania, and Maryland into Virginia. Other detached areas are found in Nova Scotia, Massachusetts, Connecticut, Virginia, and North Carolina. The belt of occurrences is thus over 1000 miles long, but the areas are now widely separated and may never have been directly connected.

The Newark rocks in general are remarkably uniform in character. They comprise great thicknesses of alternating sandstones and shales, in larger part of reddish-brown color, with intercalated sheets and dikes of igneous rocks. Many of these sheets are intrusive, but others are unmistakably outflows of lava upon the sediments. The structure is monoclinal over wide areas, with faults having the downthrow mainly on the side from which the strata dip. From New Jersey southward this monocline in greater part slopes west at angles of 10° to 15°, while in New England and Nova Scotia, and at some of the easternmost outcrops in Virginia and North Carolina, the inclination is in the opposite direction. The thickness of the sediments is great but as yet has been determined only approximately and only in portions of the belt. The great width of territory in which there are monoclinal dips would indicate a vast succession of sediments, but this is only apparent, since many longitudinal faults repeat the outcrops of the series.

The age of the Newark group is believed to be late Triassic and perhaps also early Jurassic, but its precise equivalence is not established. Fossil plants, crustaceans, and vertebrates have been collected and compared with similar forms from European deposits of those ages, and they correspond within general limits, but correlation of exact horizons is not practicable. The Newark strata did not share in the folding which occurred at the close of Carboniferous time, and therefore must be of later date, and they are clearly older than the lowest Cretaceous formations, which overlap them unconformably. They are thus separated from earlier and later deposits by intervals of upheaval and erosion of unknown duration, but their position in geologic history can not be determined more closely than by the general correlation of fossils above indicated.

The Newark group in the New Jersey region occupies a broad belt extending across the north-central portion of the State from Delaware River to Hudson River. It is 32 miles wide on the Delaware, and about half this width on the New York state line. To the northwest rise the Highlands, consisting of old granites and gneisses; to the northeast are Hudson River and the serpentine hills of Staten Island, and to the southeast are low plains composed of formations of the Cretaceous and Tertiary periods. Over wide areas the dips of the strata are to the west and northwest, but in the central-western portion, about the Watchung Mountains, there is a low syncline with various minor flexures. There are extensive faults traversing the rocks, mostly along their strike, with downthrow on the east side. The abrupt margin on the northwest is defined by a fault on which the generally westward-dipping strata abut against the old crystalline rocks, which usually rise in high slopes. The northeastern boundary may also be defined by a fault passing along Hudson River, but of this there is less definite indication. From the southern part of Staten Island southward to Trenton there is unconformable overlap by the Raritan formation, of Cretaceous age, which for some miles lies across the lower beds of the Newark group.

Subdivisions.—In the rocks of the Newark group of the New Jersey region the typical red-brown sandstone and shale predominate. The igneous rocks occur in extrusive flows and intrusive sheets and dikes. It has been found that the sedimentary rocks can be classified in three formations—the Stockton, Lockatong, and Brunswick—the last-named being the youngest. These subdivision are distinct along Delaware River and northward beyond Raritan River, but they are less easily traceable across the northeastern part of the State, for the surface is extensively covered by glacial drift and the two upper formations lose their distinctive characters.

The Stockton formation comprises arkosic sandstone with some red-brown sandstone and red shale, in no regular succession and presenting many local variations in stratigraphy. It lies on gneiss at Trenton, and is brought up again by faults in zones passing west of Hopewell and about Stockton. To the north it lies along both sides of the diabase of the Palisades. The sandstones are in places cross-bedded, and the finer-grained rocks exhibit ripple marks, mud cracks, and raindrop impressions, which indicate shallow-water conditions during deposition. The arkose, a sandstone containing more or less feldspar or kaolin derived from granite or gneiss, indicates proximity to a shore of the ancient metamorphic rocks.

The Lockatong formation along Delaware River and for some distance north consists mostly of dark-colored, fine-grained rocks of argillaceous nature but hard and compact. Some beds are massive and others are flaggy. They show mud cracks and other evidences of shallow-water deposition, but all their materials are clay and very fine sand. The Lockatong formation succeeds the Stockton formation some distance above Trenton and west of Princeton, and is brought up by faults along the southeast side of Sourland Mountain and above Stockton. In northeastern New Jersey the Lockatong appears to be thinner and is less characteristic, apparently being represented by a red shale belt extending along the valley west of the Palisade ridge.

In its typical development the Brunswick formation consists mainly of a great thickness of soft red shale with local thin sandstone layers. To the north the sandstone increases in amount and coarseness.

NEWARK GROUP IN THE TRENTON QUADRANGLE.

GENERAL RELATIONS.

In the Trenton quadrangle the rocks of the Newark group underlie most of the area north of a line from Trenton to Monmouth Junction. They are best exhibited in the section exposed along Delaware River from Trenton northward.

The sedimentary rocks in this region are comparatively soft sandstones and shales which are worn to a low level, forming valleys. The igneous rocks occur mainly in thick sheets, and owing to their hardness they give rise to high ridges, of which Sourland, Baldpate, Jericho, Solebury, and Pennington mountains and Rocky Hill are the most conspicuous. These are elevated several hundred feet above the plains or rolling lowlands of softer sedimentary beds, and in places present high cliffs to the east and gentler slopes to the west, the course of most of the ridges being northeast and southwest. The sections on the structure-section sheet illustrate the general structural relations of the sedimentary and igneous rocks. These sections show the general dip to the west and the order of succession and relations of the larger igneous masses and illustrate the origin of the more prominent topographic features. Most of the igneous rocks crossed by the section are intruded sheets of diabase which were forced between the layers of sandstone and shale. On Sand Creek, however, there is lava similar to that of the Watchung Mountains, which was poured out during the accumulation of the sedimentary deposits.

The Newark strata lie on gneisses and other crystalline rocks of the series which rises to the surface on the east side of Hudson River and in the eastern portions of Hoboken, Jersey City, on Staten Island, and from Trenton southward. In the region southwest of Lambertville they lie on Cambrian limestone brought up by the great fault in the middle of the Newark area.

SEDIMENTARY ROCKS.

STOCKTON FORMATION.

Character.—The rocks of the Stockton formation consist of coarse, more or less disintegrated arkosic conglomerate, yellow micaceous feldspathic sandstone, brown-red sandstone or freestone, and soft red argillaceous shale. These are interbedded in no regular order and are many times repeated, a fact that indicates rapidly changing and recurrent conditions of sedimentation. Although there are many layers of red shale in the formation the characteristic rocks are the arkosic conglomerate and sandstone, the latter of which affords valuable building stone.

In addition to the cross-bedded structure which prevails in much of the sandstone, ripple marks, mud cracks, and impressions of raindrops occur. The rapid alternation from conglomerates to shales and vice versa, the changes in composition in individual beds, and the cross-bedding and ripple marks all indicate very clearly that these beds were deposited in shallow water in close proximity to the shore. The bulk of the material of which they are composed was derived from the crystalline rocks on the south and southwest.

Arkosic conglomerate and yellow sandstone prevail near the bottom of the Stockton formation and brown-red sandstones near the top; but the lower beds are not all coarse grained, for at some localities red shale and fine sandstones are interbedded with the conglomerate. Layers of soft, argillaceous red shale are also found separating the brownstone beds near the top of the formation. Here and there thin layers of green, purple, and black shale occur at various horizons but they are inconspicuous. The conglomerate consists chiefly of quartz pebbles up to 3 or 4 inches in diameter and fragments of feldspar crystals, some of which measure an inch or more across. The cleavage faces of the latter generally show but little effect of weathering. Some mica is present and a few pebbles of sandstone and slate tially the same materials as the conglomerate but are finer and occur. The yellow and gray sandstones are composed of essen- contain some mica in addition to the quartz and feldspar that are the chief constituents. Minute rust-colored specks usually appear in the sandstone, probably due to some disintegrated ferromagnesian mineral, and it is not uncommon to find pebbles of various kinds sparsely scattered through it. These last are mostly quartz, but include fragments of red shale, somewhat irregular in shape, which seem more like masses of clay deposited with the sand and afterward hardened than water-worn pebbles of shale. Cross-bedding in the sandstone is very common. The shale is composed of fine red mud, containing more or less minute flakes of mica. In some places it occurs in thick beds, which, when seen in a freshly exposed wall in a quarry, appear firm and massive. However, it splits readily on exposure to the weather. Rarely, a thin bed of green or black shale occurs with the red.

Thickness.—The thickness of the Stockton formation is estimated to range from 2300 to 3100 feet, allowance being made for repetition of beds by faulting, but owing to the monotonous character of the beds and the possibility of undiscovered faults there is much uncertainty as to the precise amount.

Distribution.—Owing to tilting and faulting, the Stockton beds outcrop in several belts within this quadrangle. These are (*a*) the Trenton area, which extends northeastward to Princeton, beyond which the formation is mostly buried by Cretaceous and Quaternary deposits; (*b*) the Hopewell area, along the southeastern slope of the Sourland plateau, where the upper part of the formation has been brought to the surface by a fault; (*c*) the Stockton area, where the beds are exposed in numerous quarries near the village of Stockton.

The first belt begins in the western part of Trenton and extends along the Delaware to a point about three-fourths mile above Wilburtha station. At Trenton the formation rests on the old crystalline rocks, which have contributed largely to the arkose beds, but the contact is not exposed. The basal beds outcrop for only a short distance, because a few miles northeast of Trenton they are overlapped by Cretaceous clays. The upper limit of the formation extends from Delaware River above Wilburtha, through Ewingville, Lawrenceville, and Princeton. At the latter place it crosses the college campus, and excavations made for the foundations of the college library revealed the upper beds. Along Millstone River the line of separation between the Stockton formation and the overlying Lockatong formation is plainly exposed in the line of quarries along the canal, the southern quarries being in the Stockton. East of Millstone River the boundary has not been determined, owing to thick Quaternary deposits which mantle the surface. Northwest of Trenton this belt has a width of about 3 miles, but to the northeast it rapidly narrows, owing to the overlap of Cretaceous and later formations.

The second area in which the Stockton formation outcrops is near Hopewell, where it constitutes the southeastern face of the Sourland plateau in a belt three-fourths mile wide extending from Harbourton nearly to Skillman, a distance of about 10 miles. Its upper limit lies a little west of the crest of the east side of the plateau. The beds exposed in this zone are the upper part of the formation brought to the surface by a great fault located along the foot of the escarpment.

A second great fault 7 miles farther northwest brings the Stockton formation to the surface in a zone which crosses the Delaware from Brookville to a point a little beyond Raven Rock, with a maximum width of about 3 miles. Its northwestern margin extends along the crest of the eastern edge of the Hunterdon plateau, the steep slope being formed by the upper beds of the formation, here predominantly red shale with a few sandy layers. The southeastern margin of this area is determined by the fault, and as this crosses the strike obliquely the outcrop becomes narrower to the northeast and finally ends near the northern margin of the quadrangle.

Local features.—The most extensive exposures of the Stockton formation are in the quarries near Wilburtha, 5 miles above Trenton, and in the quarries near Stockton. It is from the latter place that the formation was named. In all these quarries the rapid alternation from shale to freestone and to arkosic conglomerate is shown. Not uncommonly a well-marked bed thins out rapidly within the limits of a quarry, or even disappears entirely, its place being taken by a layer of different character. In other places a bed, although retaining its identity as a distinct layer, changes so in texture or color that it would not be recognized as the same bed were the outcrop not continuous. The individual beds are in thin lenses which overlap at their edges where they thin out.

In the ravine at the western edge of Cadwalader Park, Trenton, there are heavy beds of arkosic conglomerate, with pebbles of quartz several inches in diameter and good-sized feldspar crystals. The rock here is firm and might be used for rough masonry. Near the canal bridge, a quarter of a mile southeast of the Asylum station, the rock is so completely decomposed that it is spaded out and used for road material and sand. In addition to the constituents derived from the underlying gneissic rocks, there are pebbles of quartzite and sandstone, probably derived from the southwest in Pennsylvania, where the formation lies on Cambrian sandstones.

In the Hopewell area the rocks of the Stockton formation are generally harder than near Trenton and Wilburtha. They are mainly varicolored sandstones, red-brown, gray, and steel-blue predominating, although the weathered fragments are mostly yellowish. The sandstones are quartzose and feldspathic, and, in general, not so free-splitting as those in the Wilburtha quarries. Some beds of heavy arkosic conglomerate occur, the most marked locality being half a mile west of Marshalls Corner. A drilled well 106 feet deep, on the Edgerly place, Hopewell, passed through alternating beds of red shale, hard gray quartzitic sandstone, brownstone, and arkose sandstone. When the rapid changes noticed in individual beds in the Wilburtha and Stockton quarries are considered it is not surprising that the beds in them are somewhat different from those in other localities. There can, however, be no reasonable doubt that these sandstones belong to the Stockton formation. There are no quarries along this belt, and the principal exposures are along the small streams which cross the outcrop zone. At other places the surface is sandy and generally strewn with angular weathered slabs of the harder layers.

In the northern area the quarries near Stockton afford excellent opportunity for studying the composition, texture, and succession of the beds. The rocks here are chiefly free-splitting sandstones of various tints of gray, yellow, and red-brown, very similar to those at Wilburtha. Beds of red shale and also conglomerate are interbedded with the sandstones. In the bluff between Stockton and Brookville thick beds of very coarse conglomerate occur, the lower beds in this locality being much more consolidated than those near Trenton. Except for exposures in the quarries and a few unimportant outcrops along the streams, the rocks are rarely seen. The soil, however, is clearly indicative of the formation beneath, being rather loose, sandy, and locally pebbly and having abundant scattered slabs of sandstone and conglomerate. Owing to the gray color and sandy texture the soil is in marked contrast with that of the adjoining regions, which is a red or yellow clay. The topography in the area north of Stockton presents some peculiarities. There are three broad, low ridges, trending northeast and southwest parallel to the strike and due to the harder and coarser conglomerates. These ridges are separated by wide, shallow valleys on the outcrop of bodies of softer sandstones and shales. The ridges rise 150 to 200 feet higher than in the red-shale region on the southeast side of the fault. Each ridge is cut off to the northeast as the great fault crosses the strike obliquely in its extension to the north.

LOCKATONG FORMATION.

General character.—Above the Stockton formation is the succession of hard dark-colored shales and flagstones constituting the Lockatong formation. They consist of dark, gray to black shales, which split readily along the bedding planes into thin layers, but have no slaty cleavage; hard, massive, black and bluish-purple argillite; dark-gray and green flagstone; dark-red shale resembling flagstone; and some thin layers of highly calcareous shale. There are all gradations between these types, so that the varieties of individual beds are almost countless. Some of the argillites are specked with minute crystals of calcite and many faces of joint planes and cavities are covered with deposits of the same mineral. Minute crystals of iron pyrites occur abundantly in some layers, but besides these and the calcite there are no secondary minerals. It was formerly supposed that the dark Lockatong beds owed their hardness and dark color to baking by the igneous rocks. The transition between the Stockton and Lockatong beds is through a series of intermediate beds a few hundred feet in thickness which might be classed with either formation.

Both ripple marks and mud cracks occur at all horizons in the Lockatong beds, showing that shallow-water conditions prevailed throughout the time of their deposition. On the other hand, the absence of strong currents is indicated by the extreme fineness of the material.

Distribution and local features.—Owing to faulting, the Lockatong beds occur in several areas. The first belt, commencing three-fourths mile above Wilburtha, has a width of about 1¾ miles along the Delaware. The lower beds are exposed at Savage's quarry along the canal, and upper layers are shown at Ayres's quarry, Somerset, and near the mouth of Jacobs Creek. Small exposures occur along the canal between these points, but there are extensive exposures in the high banks and quarries on the Pennsylvania side of the river. The southeastern margin extends northeastward through Scudders Falls, Ewingville, Lawrenceville, and Princeton. The upper limit is approximately parallel to the lower, the average width of the belt as far east as Rosedale and west to Neshaminy Creek being about 2 miles. North of Princeton the beds which can be referred without any doubt to the Lockatong form a belt less than a mile in width. As this narrowing is not due to diminution of dip it appears to indicate less thickness than in other districts. Between the upper limit of distinctive Lockatong beds in this area and the diabase of the Rocky Hill ridge, three-fourths of a mile distant, there are some green and black shales, which might well be assigned to the formation if it were not that most of the intervening beds are soft, crumbly red shale of characteristic Brunswick aspect, and no such thickness of this material has been found in the Lockatong formation in other areas. Near the diabase there are pale blue-gray and purplish-red shales, containing amygdules with secondary minerals, the result of metamorphism by the igneous rock. Unfortunately, exposures are lacking at many critical points, so that it was not possible to determine (*a*) whether the Lockatong beds rapidly diminish in thickness east of Rosedale and north of Princeton owing to less material having been deposited; (*b*) whether the beds change lithologically along the strike, so that the red shales between Princeton and the diabase ridge are at the same horizon as the upper beds of this formation farther west; or (*c*) whether the upper part of the Lockatong has been cut out by faulting. A few cases of crushed and contorted beds and slickensides are in favor of the last supposition.

There are good exposures of the heavy-bedded black and dark-green argillites at several points along Stony Brook below Rosedale, and at the quarries of J. K. Brown and Stephen A. Margerum, Princeton. Quarries along Millstone River south of Kingston also show various horizons. East of the Millstone the limits of the Lockatong formation can not be determined with accuracy, owing to the more recent deposits which conceal all outcrops save along a few streams. Hard black shale, interbedded with red flagstones, is exposed in a small quarry along the railroad 1½ miles due east of Kingston. Along Lawrence Brook below Davidson's mills, 2 miles east of Deans, there are also a number of exposures of the dense black argillite. An outcrop of argillite on the Brunswick turnpike southeast of Franklin Park is probably near the upper limits of the Lockatong beds in this vicinity, as the region to the north is underlain by soft red shale.

The Lockatong formation outcrops along the southeastern side of the Sourland plateau, resting upon the narrow strip of Stockton sandstone from Harbourton nearly to Skillman. The outcrop zone is about 1¾ miles wide, the dip being from 15° to 20° NW. It is bordered on the northwest by the wide outcrop of diabase which constitutes the backbone of the plateau, except from Delaware River to Snydertown, where an interval is occupied by the softer red shale of the Brunswick formation. The latter shale is somewhat metamorphosed near the igneous rock, so that in places it resembles the Lockatong beds. Near Snydertown the diabase cuts down nearly at right angles across the Brunswick and upper Lockatong beds, so that in the region to the northeast the plane of intrusion is about 1760 feet below the upper limit of the Lockatong formation. Northeast from Snydertown, therefore, the upper limit of the Lockatong formation is found on the northwestern side of the diabase sheet and about three-fourths mile from it.

Numerous exposures of the various beds of the formation occur along all of the brooks which flow from the southeast side of Sourland Mountain. No continuous sections are found, but the outcrops are so numerous that the succession of beds can be ascertained by combining the observations on several streams. As in the case of the Stockton formation the individual beds change somewhat along the strike, both in color and texture. Sections through Woodsville and southwest of that place show a considerable thickness of hard red shale approaching flagstone, interbedded with layers of black and green shale. These red strata grade into black and green shale and argillite to the northeast along the strike, so that in a section near Amwell the beds are almost entirely of the latter character and red layers are very few. Still farther northeast hard red-brown shale appears again, but not so extensively as in the region to the southwest.

A small area of Lockatong formation lies between Delaware River and Dilts Corner, bounded by two faults which have brought it to the surface. As the area contains several igneous masses, it seemed possible that these rocks were metamorphosed Brunswick shale, but they are unlike the altered beds near igneous rock in other localities and their extent is in a measure independent of the diabase. They also grade downward into the arkose sandstones of the Stockton formation.

The Lockatong formation outcrops extensively on the Hunterdon plateau, in the region known as the "Swamp." The conditions which gave rise to this name are due largely to the close texture of the rock and the heavy clay soil resulting from its decomposition. Rapids and falls, which abound along Lockatong and Wickecheoke creeks, have deeply incised the margin of this plateau. Hard dark-red flags are interbedded with the black argillite and some of the more prominent beds can be easily traced for several miles along the strike. This has been done in so many cases at different horizons as to render it almost certain that this belt is not traversed by oblique faults of any magnitude.

Thickness.—The thickness of the Lockatong formation may be as great as 3600 feet in the Sourland Mountain and Hunterdon plateau areas, if that region is not traversed by faults. The formation near Ewingville and Princeton is apparently only 1800 feet thick if the beds of predominantly dark material are alone included.

Soil.—The Lockatong beds give rise to a rather heavy, wet clay soil. The surface is thickly strewn with slabs of argillite and flagstone, and is generally rocky on slopes. Except in places favorable to the accumulation of wash the depth of the soil is generally less than 5 or 6 feet.

BRUNSWICK SHALE.

Character.—The Brunswick consists of soft shales with local sandstone layers. The rocks are predominantly red in color, although a few purple, green, yellow, and black layers occur. In general there is presented a monotonous succession of soft argillaceous red shales which crumble readily to minute fragments, or split into thin flakes and give rise to a red clayey soil of varying sandiness. Much of the shale is porous, many of the minute, irregular-shaped cavities being partly filled with a calcareous powder. Calcite veins and crystals are common in some layers. Lenticular masses of green shale occur locally, ranging in size up to a foot or two in diameter and varying in shape from nearly spherical bodies to thin layers. Much of the shale is micaceous and where mica is present in notable amount the layers separate evenly along bedding planes. More commonly, however, the rock breaks up into small, more or less rectangular fragments. Although the greater part of this formation is soft red shale, there are some hard layers, chiefly near the base, consisting of beds of fine-grained sandstone and flagstones.

Abundant ripple marks, mud cracks, and raindrop impressions at many horizons indicate that the materials were deposited in shallow water or are subaerial accumulations. In some quarries imprints of leaves and of tree stems, or the stems themselves are frequently found. The numerous reptile tracks which have made the Newark group famous occur chiefly in this formation.

As compared with the adjoining formations the Brunswick shale is soft and easily eroded, so that the region which it underlies is distinctly lower and more nearly level than that of the other formations.

Distribution.—Within the Trenton quadrangle the Brunswick shale occupies two broad belts, one crossing the Delaware near Lambertville and the other near Washington Crossing. Both extend northeastward with increasing width and at the northern end of Sourland Mountain, just at the northern edge of the quadrangle, they unite to form the broad undulating plain drained by Raritan River.

On the Delaware the exposures of the formation begin a short distance above the mouth of Jacobs Creek and extend almost continuously along the canal to Washington Crossing, $1\frac{1}{4}$ miles above. Beds to the thickness of 1700 feet are shown in this section, including some harder red shales with black layers just above the Lockatong formation. They extend along the river nearly to Moore, where they are interrupted by the diabase of Baldpate Mountain. Their northwestern limit is the fault which brings up first the Lockatong and then the Stockton beds, forming the southeastern part of the Sourland plateau. The width of outcrop near the Delaware and for some distance north is about 4 miles, but the area widens north of Rocky Hill and occupies the extensive rolling country from Hopewell to New Brunswick and beyond.

A second belt begins on the Delaware just below Lambertville, where the shale next the diabase has been much altered and indurated. Its northwestern limit is at the south end of the small diabase hill, Mount Gilboa, above Lambertville. It extends north by east through central Hunterdon County, following the fault which has brought up the Stockton and Lockatong beds of the Hunterdon plateau. The lower or southern limit of this belt follows the Sourland plateau, the lower beds forming the northwest slope of that highland.

Thickness.—The thickness of the Brunswick shale is very uncertain. Only a portion of the formation occurs in this quadrangle, for in each belt the upper portion is cut out by a great fault. Some evidence as to the thickness is afforded by the narrow diabase dike which extends continuously from Sourland Mountain, near Rocktown, to Copper Hill, a distance of 5 miles. The dike crosses the strike at an angle of 45° and the thickness of the shale thus traversed is between 6000 and 7000 feet. As the dike was intruded before the tilting and faulting its continuity is proof that the shale traversed by it is not cut by faults along the strike. These beds are only a part of the whole formation, and it is probable that the entire thickness of the Brunswick beds is near 12,000 feet.

IGNEOUS ROCKS.

CHARACTER AND DISTRIBUTION.

GENERAL RELATIONS.

The igneous rocks included in the Newark group comprise intrusive sheets and dikes of diabase and extrusive sheets of basalt. A few dikes of diabase and other rocks also occur. The principal igneous masses are in extensive sheets. The basalt sheets are conformable to the inclosing strata, but the diabase intrusives, though approximately conformable for greater or less distances, cut across the strata locally. The sheets vary in thickness from a few inches to over a thousand feet. The dikes are of various widths and most of them appear to be connected with the intrusive sheets.

The extrusive basalts are contemporaneous in age with strata in which they are inclosed. The intrusive rocks are younger than the beds which they penetrate, but they may have been intruded deep underground at the same time that the basalts were ejected on the surface. As the intrusive rocks are overlapped by the Raritan formation they are pre-Cretaceous in age, and the inclosing strata were deeply eroded before the time of Raritan deposition.

DIABASE.

General features.—The several large irregular sheets of diabase as well as the dikes of the same rock in the Trenton quadrangle appear to be parts of one general intrusion into the sedimentary rocks and continuous with that of the Palisades. In the northeastern portion of the area the horizon of intrusion is low in the Newark group, but at intervals to the south and west it rises and finally reaches the medial portion of the Brunswick shale. Owing to the faults and the failure of the diabase to reach the surface in the intervals between outcrops it is not possible fully to ascertain the structural relations of the various diabase masses. Doubtless they were fed by great dikes, but no signs of such feeders appear at the surface. Except when changing horizon locally the larger masses have a general trend parallel to the strike of the sedimentary rocks, but their intrusion appears to be entirely independent of lines of fracture or zones of flexure.

The strata adjoining the large diabase intrusions are extensively altered, especially where they consist of shales, as they generally do in this region.

Rocky Hill.—The sheet of diabase which has usually been known by the name of "Rocky Hill trap" extends from the vicinity of Hopewell eastward to Lawrence Brook, crossing Millstone River at Rocky Hill. For the greater part of its course it gives rise to a prominent ridge rising from 100 to 200 feet above the adjacent plains of red shale and presenting a steep face toward the south. At Rocky Hill and for several miles west it has an average width of a mile, but from Mount Rose to its western termination it is very much narrower. It ends about a mile southwest of Hopewell, at the fault a short distance west of the Philadelphia and Reading Railroad. East of Rocky Hill it bifurcates; one branch extending northeastward to the vicinity of Franklin Park dwindles into a dike and disappears, and the other, passing under the southern side of the Sand Hills, crosses the Pennsylvania Railroad at Deans, east of which it soon passes under Quaternary and doubtless also Cretaceous deposits. Borings indicate beyond much question that it is continuous underground with the diabase of the Palisades.

The diabase, a thick sheet intruded between the sedimentary rocks, repeatedly crosses the beds, so that while at its western end it is at a horizon high in the Brunswick shale, at Rocky Hill it is near the base, and on Lawrence Brook it is in the Stockton beds. For some distance, in the region north of Princeton, it appears to be nearly conformable to the inclosing beds, which dip gently to the northwest. The thickness of the diabase in this vicinity and to and beyond Millstone River is about 1000 feet, which is the maximum amount.

The sedimentary rocks adjacent to the igneous mass are everywhere extensively altered, the alteration consisting of the hardening and darkening of the beds and the development of various secondary minerals. No exposures of contact were observed, but the altered sedimentary rocks appear at many points in the immediate vicinity of the diabase, notably at Rocky Hill, in the railroad cuts southwest of Hopewell, and in the old copper mine south of Griggstown. At the last place the excavated material consists largely of altered shales containing chlorite nodules (probably pseudomorphs after cordierite) feldspar, tourmaline, hematite, and small amounts of various copper minerals. Some of the tourmaline and feldspar occur in small veins in the altered shales.

At Rocky Hill village there are excellent exposures of the altered shales which overlie the diabase sheet. They are best seen along the canal, north from the tollhouse. Just east of the railroad station the fine-grained, dense upper surface of the diabase is exposed, dipping 18° N., conformably to the shale and sandstone in this vicinity. About a foot above the contact is a fine-grained sandstone which has not been so much altered as the overlying shale. The next exposures are some distance higher, where some layers are drab or green in color, are not very hard, and contain numerous small black nodules—perhaps tourmaline. Beds still farther from the diabase are an extremely hard black argillite, characterized by more or less distinct nodules of an oily-appearing green mineral, which in places is so abundant as to form thin sheets, the rock appearing to be made up of black and green laminæ. Still higher in the series occur green shaly sandstones and black, blue-gray, and dark-red shales, some very hard, containing black nodules of radiate structure, and others containing green nodules of epidote.

On the supposition that here the diabase sheet conforms in dip with the overlying shale, the latter has been greatly changed through a thickness of 600 feet and traces of alteration are found for over 200 feet higher. There is good opportunity for studying the altered shale along the road from Rocky Hill to Hopewell. Traced westward the thickness of altered shale above the igneous rock decreases at about the same rate that the thickness of the diabase sheet diminishes. North of Cedar Grove the highly altered beds are about 400 feet thick, and the change in color can be detected for about 200 feet farther. South of Hopewell their thickness is probably not more than 200 feet at most. The shales beneath the diabase have also been altered in much the same way as those above, but the altered beds are not so well exposed and apparently are not so thick.

Pennington Mountain.—Pennington Mountain is a rocky ridge which rises about 250 feet above the plains, 2 miles northwest of Pennington. It consists of an irregular sheet of diabase about 400 feet thick and $1\frac{1}{2}$ miles long, intruded in the Brunswick shale. It cuts across the strata for at least a portion of its course and is terminated on the west by the great fault which brings up the sandstone of the Stockton formation. No contacts of the sedimentary and igneous rocks are exposed, but the former appear at various points in proximity to the contact, showing extensive alteration.

Baldpate.—Baldpate Mountain is a high ridge which rises on the banks of Delaware River, at Moore, and extends for 3 miles to the east. Its top and north slope consist of igneous rock which lies on Brunswick shale at approximately the same horizon as the diabase of Pennington Mountain. It is possible that the two masses are connected underground, but at the surface they are separated by outcrops of unaltered red shale. On the north side of Baldpate Mountain the diabase passes beneath Brunswick shale which is in large part altered to a hard, dark-colored rock. The contact is not exposed but it is a very irregular one, crossing the bedding repeatedly, so that in the northern portion of the area a thick mass of the igneous rock extends nearly to Moore Creek. Here it is cut off by a fault, which probably also cuts off the diabase at its western extremity. The exposures are, however, too indistinct for the latter to be ascertained.

Jericho Mountain.—Jericho Mountain is a ridge rising from 200 to 300 feet above the red-shale area south and west of Buckmanville, Pa. Its crest and north slope consist of a sheet of diabase intruded in the medial portion of the Brunswick shale. This sheet may cross the strata for some distance locally, but in the main it is conformable and its curved course west of Brownsburg is due mainly to the flexed structure of the inclosing shales. At its north end it appears to be cut off by the fault passing just south of Bowman Hill. The diabase sheet is probably thickest west of Brownsburg, where it is not far from 200 feet thick. On the road southwest of Buckmanville it is only a few yards thick, and, although thicker on the ridge next west, it soon terminates in the shale slopes $1\frac{1}{2}$ miles southwest of Buckmanville, apparently by thinning out. It is probable that this sheet is the extension of the diabase of Baldpate Mountain, the break in outcrop being due mainly to the fault.

The contact relations with the sedimentary rocks are not exposed, but shale outcropping in the vicinity of the igneous rock is greatly altered.

Bowman Hill–Belle Mountain.—Belle Mountain in New Jersey and Bowman Hill in Pennsylvania are two isolated ridges due to the outcrop of a sheet of diabase which crosses Delaware River above Moore. The plane of intrusion is in the upper portion of the Lockatong formation in New Jersey, but to the west it rises a short distance into the Brunswick shale. The east end of the igneous rock is not well exposed, but to the west it thins out rapidly at about 1 mile northeast of Buckmanville. The maximum thickness may be 250 feet, but owing to the lack of decisive exposures no accurate measurement could be made. The adjoining strata are much altered for a short distance on both sides of the thicker portion of the sheet, a feature particularly well exposed along Pidcock Creek, near its mouth. On the east side of Belle Mountain dark shale is exposed, but apparently it belongs in the Lockatong formation, and but little of its color is due to alteration except in the immediate vicinity of the diabase. In the quarry in Belle Mountain a long fragment of gray sandstone is included in the diabase. It has an average thickness of about a foot and evidently has been torn from the beds adjoining the intrusive rock.

Sourland Mountain.—The prominent flat-topped ridge known as Sourland Mountain consists of a thick sheet of diabase and flanking masses of altered strata. The diabase crosses Delaware River a mile below Lambertville, and in Pennsylvania gives rise to Solebury Mountain, which extends to the great fault a short distance west of the Trenton quadrangle. Throughout its course the ridge rises steeply about 200 feet above the adjacent plains, and in Sourland Mountain it widens into a plateau averaging nearly 4 miles across, with both slopes approximately the same. The diabase outcrop occupies the center of this plateau with an average width of slightly more than a mile. West of the Delaware the ridge is considerably narrower and the igneous rock constitutes the summit. The diabase is a sheet, probably 800 to 900 feet thick in its maximum development, which has been intruded in the shale and sandstone. Adjoining Delaware River and for some distance eastward it is in the lower portion of the Brunswick shale, but near Rocktown it rises to a slightly higher horizon and then, curving around to the north and east, descends several hundred feet into the Lockatong formation, a total change in horizon of about 800 feet. With the exception of this curious crescentic offset near Rocktown, it preserves relatively uniform conformity to the inclosing sedimentary beds, although doubtless it crosses them to some extent locally. At its north end it appears to terminate by rapidly thinning.

The strata inclosing the sheet dip to the northeast at angles generally between 12° and 18°. The principal variations are near the northeast end of the ridge, where the dip is only about 5°, causing considerable widening of the outcrop, and along the Delaware, where the amount is about 22°. A notable feature in the structure of part of the Sourland igneous sheet is a comparatively greater inclination of the strata on its northwestern flanks than that of the underlying beds and of those in the plains to the north. This structure is most apparent between the deflection near Rocktown and the northern termination of the mountain. East of Ringoes the dips are at first 10° to 12°, but southeastward up the slope of the ridge they progressively increase to 25°. On the eastern side of the ridge the dip is about 12° throughout. It seems probable that the increase in dip indicates a wedge-shaped intrusion, as shown in structure section A–A, but it is possible that it is due to a longitudinal flexure.

The thickness of the Sourland Mountain diabase appears to be generally near 700 to 800 feet, but along the Delaware the amount is nearly 1500 feet if the sheet is not traversed by faults. Its northern termination near Neshanic is due to thinning out, but the means by which it increases in thickness southward is not known; the increase may be due either to wider separation of the inclosing beds or to rise of the plane of intrusion across the overlying strata.

Contacts of the diabase with the inclosing strata were not found owing to talus and wash on the slopes. The great increase in hardness and darkening in color of the shales form one of the most characteristic features of the ridge, and it is owing to their hardness that the altered beds constitute so considerable a portion of its flanks. This alteration extends at least 200 feet vertically above and 30 to 40 feet below the diabase, and generally prevails in both directions for 500 to 600 feet. At Lambertville and on the opposite side of the river, as described by Rogers, and near Rocktown, southeast of Ringoes, nodular alteration products are conspicuous in considerable variety. The exposures at Lambertville are representative. The strata in contact with the diabase are sandstones, dark gray in color and moderately coarse grained, specked with numerous well-developed tourmalines, some of which are one-half inch in diameter. A few hundred feet higher are shales which are compact and of dull purplish-gray color. They contain large numbers of black to blue spherical nodules varying in size from minute grains to those one-half inch in diameter and consisting of some imperfectly formed material, apparently tourmaline, in a semicrystalline state, locally surrounded by a crust of nearly white material. These strata merge upward into red sandy shale and sandstone slightly darker than normal and containing numerous large spheroidal nodules of green epidote up to an inch in diameter. They occur irregularly, but appear to lie rudely parallel to the stratification.

Branches from Sourland Mountain sheet.—Three dikes rise from the upper surface of the diabase sheet of Sourland Mountain and extend for several miles through the overlying shale. The first starts 1½ miles from Delaware River, ascends about 250 feet, and then extends parallel to the main sheet. It can be traced by a line of low ridges and weathered fragments. For much of the distance its width is not more than 20 feet, but it is wider near the junction with the main diabase sheet to the southwest. It unites again with the main sheet at the horseshoe curve, over 3 miles from the starting point. The intervening shales outcrop at a number of places. The second offshoot starts at the bend of the diabase southwest of Rocktown and extends continuously for 2 miles to Mount Airy. It appears plainly in the road just south of that village. At the point where it crosses the creek half a mile east of Mount Airy it is hardly more than 18 feet in width and apparently vertical, although the contact with the shale is not shown. The adjoining shale is very hard and is ashy gray or pale green in color; some layers are marked by segregations of epidote. Other beds are thickly specked with crystals of iron pyrites. Nearer the main sheet the dike increases in width, and to judge by the amount and distribution of the débris, its width apparently is between 50 and 60 feet. For much of the distance its course is marked by a line of trees or bushes and uncultivated ground. The third and longest dike starts from the main sheet three-fourths mile northeast of Rocktown and can be traced continuously to a point nearly a mile north of Copper Hill, a distance in a straight line of 5 miles. The slightly sinuous course of the dike increases its length about half a mile. North of Copper Hill station it is interrupted and offset a quarter of a mile to the west, probably by a fault. Thence it continues, more or less interruptedly, to Flemington, 2 miles distant. The copper deposits found years ago near Flemington and Copper Hill occurred in the shale along this dike, and the explorations then made indicate that the dike, even where interrupted on the surface, is probably continuous below. Its width varies considerably, but for the greater part of the distance it is probably between 50 and 90 feet. Near the village of Union it widens suddenly, and from this wider portion another narrow dike extends a short distance toward Union. The dike can be readily traced by a slight rise of ground, a zone of disintegrated material, scattered large bowlders, and a line of trees which have grown where the bowlders are thickest.

Dilts Corner.—A wide dike of fine-grained diabase extends from Dilts Corner northward for nearly half a mile. It forms a slight elevation and the ground is strewn with residuary fragments in a zone which indicates that the maximum width of the dike is about 200 feet. A small detached area of diabase occurs a few rods west of Dilts Corner and a narrow dike is exposed in the bed of a stream one-third mile east of that place. West and southwest of Dilts Corner a line of narrow dikes lies parallel to the main Mount Gilboa mass but several hundred feet east.

Lambertville.—On the top of the hill overlooking the ball park at Lambertville there is a zone of weathered masses of diabase about 80 yards wide and nearly one-half mile in length, and a mile to the northeast there is a similar zone which has a length of one-third mile and a width of about 100 yards. Both are of coarse-grained diabase similar to that of Sourland Mountain, and possibly are underground offshoots from it. The surrounding shale is so much contorted, altered, and apparently faulted that the precise structural relations could not be ascertained.

Glenmoore.—Near the barite mines, half a mile north of Glenmoore, residuary soil of igneous rock occurs over a considerable area and obscure exposures of disintegrated diabase occur along the highways at several points. Whether there is here a complex of dikes or a boss of igneous rock is difficult to determine. The barite occurs in veins traversing the decomposed and fractured diabase and some of the fragments of it from the dump piles resemble friction breccias. This diabase is near the great Hopewell fault, a branch of which may have caused the shattered condition of the rock and its consequent deep decomposition.

Franklin Park.—A mile northeast of Franklin Park the presence of a narrow dike is indicated by the surface débris and by a slight ridge 1½ miles long. It is twice interrupted, and each time slightly offset as if faulted, but no other evidence of a fault could be found. Near its northeastern end, where it crosses the road leading northwest from Franklin Park station, its width is less than 20 feet. Three-fourths mile west by south of that place it crosses a small stream, and is exposed in ledges of fine-grained dense and hard blue-black diabase. Farther west, in the timber, the ridge is especially distinct and the width of the dike is nearly 150 feet. Nearer Franklin Park its limits are indefinite. Its position suggests that it is an eastward continuation of the prong of the Rocky Hill sheet, which curves north and then east past Griggstown, almost to Franklin Park.

Griggstown.—Three-fourths mile south of Griggstown there are three somewhat widely separated intrusive masses which are probably underground offshoots of the Rocky Hill sheet. Indurated shale is found near the largest. A fourth mass occurs in a small grove 1½ miles east of Griggstown. The rock is medium grained and has altered the adjoining shales slightly.

New Hope.—Two dikes occur in Pennsylvania on the west side of the fault south of Brookville. One, appearing in the road in the limestone 1½ miles south of the village, is short and deeply disintegrated. Another larger dike intersects the arkose and underlying limestone 3 miles northwest of New Hope, beginning at or near the great fault.

Buckmanville.—In the old baryta pit southwest of Buckmanville a breccia occurs, consisting of fragments of decomposed diabase in a matrix of quartz and baryta similar to the breccia north of Glenmoore. No structural relations are exposed, but apparently the locality is on the line of the Hopewell fault.

Yardley.—The fault plane exposed in the railroad cut west of Yardley station is occupied by a nearly vertical dike 5½ feet wide. The rock is completely decomposed in a yellowish residual earth and could not be traced along the surface.

GABBRO.

Mount Gilboa consists of an intrusion of gabbro which extends from the bank of the Delaware, 2 miles above Lambertville, to the great fault north of Brookville. It is inclosed in the Lockatong formation as an irregular sheet 500 feet or more in thickness which probably cuts across the strata to a considerable extent. Along its eastern side there are several offshooting masses and a dike which lies at a short distance from the main mass. Although the shales which adjoin the intrusion are the dark-colored Lockatong beds, they are considerably altered, as is shown by increased hardness and by the development of secondary minerals in the vicinity of the contact. The precise contact was not observed, except in some indistinct exposures on the road three-fourths mile northeast of Brookville.

SYENITE.

Occurrence.—In the midst of the gabbro of Mount Gilboa occur several small masses of dissimilar rocks which Mr. Ransome has found to be nepheline, hornblende, and mica syenites. The nepheline syenite appears on the northwest edge of the main igneous body, just below the forks of a little brook which flows into the Delaware about one-fourth mile south of Brookville. The exposure is not more than a few square yards in extent and the contact with the ordinary fine-grained gabbro which surrounds the nepheline syenite on at least three sides was nowhere seen. Closely associated with the nepheline syenite is a micaceous syenite, exposed in the bed of the little brook above mentioned, just at the forks. Like the nepheline syenite, this rock is apparently limited in its occurrence to a small mass, the exact relations of which to the adjacent rocks were not discoverable in the field. Near the south end of the Mount Gilboa igneous area, nearly one-half mile south of the locality above described, there is a quarry in which a small mass of hornblendic syenite and hornblende granite is inclosed in the gabbro.

Relations.—No evidence was detected, either in the field or through microscopic investigation, which in any way supports the hypothesis that syenites are variations of, or immediately derived from, the magma which cooled as gabbro. The syenites are distinctly different from the gabbro which surrounds them, and transitional facies appear to be wholly lacking. The gabbro as a whole shows rather striking uniformity, and none of the specimens afford suggestion of such extreme differentiation as would be necessary for the production of rocks so rich in alkali as nepheline syenite, mica syenite, or hornblende granite. The syenitic masses, therefore, are either small dikelike intrusions in the gabbro, or else they are inclusions in that rock, brought up bodily by the gabbro from some unknown terrane below. The exposures were not sufficiently good to determine which of these hypotheses is the true one, but on the whole it seems most likely that the masses are included fragments, brought up in the gabbro magma at the time of its intrusion.

BASALT.

Flows.—Near the western margin of the Brunswick shale area, southwest of Sand Brook village, there are several masses of igneous rock which are the remains of surface flows contemporaneous with the inclosing shales. There is a horseshoe-shaped area of basalt and an outlying area, the form of outcrop being due to a syncline which pitches northwest. The northwest part of the horseshoe is cut off by the great fault which extends north of Brookville. The dips of the surrounding beds vary from 10° to 40°. The basalt sheet in the curved ridge has a thickness of about 450 feet, but the configuration of its upper surface is somewhat uneven and it appears to thin out near its southwestern end. The outlying knob of basalt probably represents a second lava flow, although its structural relations are not well exposed.

There is ample evidence that the basalt is extrusive, for it is conformable to the strata and its upper surface is everywhere extremely vesicular. The lower portion is dense and fine grained. At two places the overlying shale was found less than 3 feet and 1 foot above the basalt, presenting absolutely no indication of induration, change of color, or development of new minerals such as appear in strata adjoining the intrusive sheets. One of these localities is along the road which crosses the end of the southern extremity of the curved ridge and the other is near the road crossing the northern extremity. At both places red shale fills cavities in vesicular basalt, and at the latter place the shale is underlain by a thin layer of mixed finely comminuted basalt, volcanic glass, and red mud. The shale underlying the basalt is exposed at a few points near the contact and presents no signs of alteration. The basalt, where not vesicular and scoriaceous, is dark colored, dense, and fine grained in texture, unlike the diabase of the intrusive sheets.

Dikes.—A long but narrow dike of basalt extends on an easterly and northeasterly course from a point south of Hillsboro to a point 2 miles southeast of East Millstone, a distance of about 4 miles. It crosses Millstone River half a mile north of Blackwells Mills, where it is finely exposed in the east bank of the stream. Its width here is from 10 to 12 feet, and it breaks across the shale at a steep angle. The contacts are sharp, the one on the south side being nearly smooth and the one on the north side somewhat irregular. The igneous rock is fine grained and is traversed by cleavage planes rudely parallel to the contacts. The shale is altered for several feet on either side, the alteration consisting mainly of darkening to black, gray, and dark red, in part in irregular blotches. A mass of altered shale 5 feet long and from 1 to 2 feet thick is included in the igneous rock. The dike gives rise to a faint ridge with yellowish soil and numerous rounded masses of basalt, features by which it is traceable to its terminations. At its east end it bifurcates for a short distance.

Another long, narrow dike of basalt extends for 3 miles along the red-shale slopes northwest of Sourland Mountain. It has a northeast-southwest course parallel to that ridge and passes a short distance west of Wertsville. On the road just south of Wertsville schoolhouse its thickness is about 2½ feet. Here it is conformable to the shale for a few feet, but it also cuts across the bedding. The dike is traceable by scattered fragments and red soil for some distance to the north and south, but may not be continuous throughout the course shown on the map. South and west of Wertsville the dike is thicker and gives rise to a slight ridge. It appears plainly in the bank of the brook a mile southwest of Vanlieu Corners, where its width is 35 feet. A short distance farther southwest it appears in another brook, where it is well exposed with a width of 18 feet. It here cuts the shales vertically and has caused their alteration to a slight extent for 1 to 3 feet on either side of the dike. North of Wertsville the igneous rock thins to about 1 foot, and it disappears one-half mile west of the Somerset-Hunterdon county line.

PETROGRAPHY.

The igneous rocks of the Newark group in the Trenton quadrangle are similar to those elsewhere characteristic of the group, the intrusive sheets consisting mainly of diabase (dolerite) with gabbroitic facies and the effusive sheets of basalt. Dikes are mostly diabase, but a few are basalt and there are some syenitic masses. The subjoined petrographic descriptions have been furnished by F. L. Ransome.

DIABASE.

The diabase of the larger intrusive masses is in greater part a moderately coarse-grained rock of light-gray color. Near the contacts with the inclosing sedimentary beds, however, the texture becomes nearly aphanitic and the dikes are entirely fine grained. The texture as seen under the microscope is generally ophitic. The principal constituent materials are labradorite and augite, with accessory biotite, magnetite, apatite, in some cases quartz, orthoclase, and olivine. The last occurs sparingly near the top and bottom contacts of the sheets. The rocks are in many places somewhat decomposed, the augite being altered to uralite and chlorite and the plagioclase to calcite.

A representative specimen of diabase from a quarry at Rocky Hill shows a typical ophitic aggregate of labradorite and pinkish augite with a little biotite, rather abundant magnetite, and some apatite. A specimen from the quarry south of Hopewell is similar in character but considerably decomposed. It appears to have contained some original quartz. A detailed description of the petrography of the diabase near Rocky Hill is given by Prof. A. H. Phillips (Am. Jour. Sci., 4th ser., vol. 8, 1899, pp. 267-285). According to him, the biotite in this rock is entirely secondary.

The following analyses are quoted from Dr. Phillips's paper. No. 1 represents rock about 420 feet from the upper contact, No. 2 is from rock near the middle of the mass, and No. 3 is of a specimen from the lower contact band.

Analyses of diabase from Rocky Hill, N. J.

[A. H. Phillips, analyst.]

	1. Quarry No. 3.	2. Quarry No. 2.	3. Contact band.
SiO_2	56.78	50.34	51.46
TiO_2	1.44	1.56	1.06
Al_2O_3	14.33	15.23	13.98
Fe_2O_3	5.76	2.82	2.66
FeO	9.27	11.17	8.92
MnO	.25	.14	
CaO	5.26	9.60	10.49
MgO	1.58	5.81	7.59
Na_2O	3.43	2.93	4.75
K_2O	1.75	1.02	
P_2O_5	.36	.20	.17
H_2O above 110° C	.10	.07	Dried at 150°
H_2O below 110° C	.33	.19	
	100.64	101.09	101.08

In the Pennington Mountain and Jericho Mountain rocks the quartz, like the augite, occupies the angular spaces between the partly idiomorphic labradorite, in places poikilitically inclosing crystals of the latter mineral. Slender prisms of apatite pass through both quartz and feldspar, and the quartz is undoubtedly a primary mineral. Accordingly these rocks should be classed as quartz-bearing diabase. There is considerable decomposition in places, with development of sericite, amphibole, and chlorite as secondary minerals.

In the rock of Baldpate and Belle mountains the quartz and orthoclase occur intergrown as micropegmatite in little angular spaces between the feldspars, as in the well-known quartz diabase of Rawdon, Quebec. The augite is partly changed to uralite and chlorite, and the feldspars contain some sericite.

A sample of rock from Goat Hill, representative of the Sourland Mountain mass, contains considerable hypersthene and accessory biotite, magnetite, and apatite. A sample of nearly aphanitic rock obtained near the basal contact at Rocktown on Sourland Mountain is holocrystalline and between intersertal and ophitic in texture. It is composed of labradorite, augite, and olivine with a little biotite and magnetite. The olivine is partly changed to serpentine. This rock is an olivine diabase very near an olivine basalt. An analysis of the rock from Goat Hill given in the Geology of New Jersey, 1868, is as follows:

Analysis of diabase from Goat Hill, near Lambertville, N. J.

Silica	51.4
Iron (FeO)	12.2
Alumina	18.3
Magnesia	5.3
Lime	8.0
Soda	1.1
Potash	.9
Water	1.9
	99.2

Specific gravity 2.95.

The dike near Mount Airy is a dark greenish-black aphanitic rock. The microscope shows that it is obscurely ophitic in texture and consists of approximately equal quantities of augite and plagioclase with much less magnetite. The dike near Union is typically ophitic; the labradorite is slightly in excess of the augite and the proportion of magnetite is small.

The dike in the basal arkose and limestone 3 miles northwest of New Hope is a bluish-black aphanitic diabase showing only scattered dark crystals in a fine groundmass. The minerals are augite, plagioclase, and magnetite. The texture is ophitic, but the augite instead of being optically continuous occurs in granular aggregates which fill the interstices between the plagioclase laths. The augite and plagioclase are about equal in quantity and there is very much less magnetite.

The dikes west and southwest of Dilts Corner consist of a dark greenish-black aphanitic diabase composed of augite, plagioclase, and magnetite. The augite is slightly greater in amount than the labradorite, and the magnetite is in small proportion. The texture is typically ophitic.

GABBRO.

The rock of Mount Gilboa is commonly dark gray in color, of fine to medium grain, and of granular structure. A typical specimen collected near the center of the area shows under the microscope a hypidiomorphic-granular structure and is a fairly fresh aggregate of labradorite, augite, hypersthene, quartz, biotite, and iron ore. It is a fine-grained gabbro in which a brown diallagic augite is intergrown with smaller quantities of hypersthene and biotite. The quartz was the last mineral to crystallize, and is very subordinate in amount. It is in places micropegmatitically intergrown with a small amount of a dusty alkali feldspar, probably orthoclase. The hypersthene is not always present, and its place is locally taken by hornblende. As the texture on the whole is granular rather than ophitic, the name gabbro is an appropriate designation for the rock. It differs from the diabase of the neighboring igneous masses only in its granular structure.

NEPHELINE SYENITE.

The nepheline syenite in the small area southeast of Brookville is a light-gray granular rock of medium grain. Under the microscope it exhibits a hypidiomorphic granular structure and consists of alkali feldspar, nepheline (including its alteration products), amphibole, biotite, cancrinite, soda-lime feldspar, muscovite, ægirine-augite, apatite, titanite, and fluorite. A few grains of magnetite are included in the amphiboles. Analcite, usually filling triangular spaces between the feldspars, is rather abundant in some sections. It is probably wholly secondary. Sericite is present as a decomposition product of the feldspars and calcite occurs rather irregularly, usually associated with the analcite. The latter is also accompanied by a small quantity of a fibrous mineral which is probably natrolite.

All the feldspars show a gray turbidity similar to that which is so common a feature of syenitic rocks. The nepheline originally occupied areas between the feldspars, in part of triangular form, but it is almost wholly decomposed and replaced by fine aggregates of secondary products or by transparent areas of analcite. The amphibole, which is black in the hand specimens, agrees in its optical character with the hornblende common in many nepheline syenites. Much of it is intergrown with biotite, the latter commonly forming an outer fringe or border to the amphibole. More rarely it is intergrown with a pyroxene which is apparently an ægirine-augite; but the latter mineral is nowhere abundant and is wholly lacking in some thin sections. The biotite possesses no features of special interest beyond a tendency toward poikilitic structure and numerous intergrowths with amphibole. Cancrinite, which is a rather conspicuous constituent in some thin sections, is clear and colorless, and it occurs in irregular areas or in forms partly idiomorphic in the prism zone. Muscovite (including sericite), for the most part plainly secondary, forms a considerable part of the fine-grained aggregates which now represent the nepheline. Apatite is a moderately abundant accessory in slender prisms up to a millimeter in length. Titanite occurs in small crystals and grains but is not abundant. Fluorite occurs sporadically in nests with calcite and analcite and is without much doubt secondary. A chemical analysis of the nepheline syenite follows:

Analysis of nepheline syenite from Brookville, N. J.

[George Steiger, analyst.]

SiO_2	54.68
Al_2O_3	21.63
Fe_2O_3	2.22
FeO	2.00
MgO	1.25
CaO	2.86
Na_2O	7.03
K_2O	4.58
Water above 100° C	1.88
Water at 100° C	.27
TiO_2	.79
CO_2	None.
P_2O_5	.28
Cl	None.
MnO	Trace.
BaO	.05
F	.22
SO_3	.07
	99.81
Less O	.09
	99.72

MICA SYENITE.

The mica syenite from the small area southeast of Brookville is a gray medium-granular rock which in hand specimens shows abundant biotite, apparently some amphibole or pyroxene, and both white and pinkish feldspars. The pinkish feldspar is unevenly distributed and shows a tendency to gather in small, ill-defined, veinlike segregations or streaks.

Under the microscope the rock exhibits a hypidiomorphic-granular structure and is seen to consist of alkali feldspar, biotite, pale-green diopside-like pyroxene, with accessory apatite and iron ore, and considerable secondary chlorite, calcite, and sericite. The feldspars are generally turbid and partly decomposed to sericitic aggregates. The biotite is in the main fairly fresh, but some of it is partly chloritized. The pyroxene is largely altered to calcite and chlorite. In some specimens no pyroxene is recognizable; in others there is a green amphibole which may be more abundant than the pyroxene.

HORNBLENDE SYENITE.

The hornblende syenite occurring in the gabbro mass of Mount Gilboa is a coarse-grained and slightly microlitic aggregate of flesh-colored feldspars and rather bleached-looking fibrous green amphibole. The feldspar and amphibole both show a tendency toward prismatic development, and some cleavage faces of the former are seen under the lens to be finely striated.

The microscope reveals a hypidiomorphic-granular aggregate of alkali feldspar, amphibole, and a little quartz. The alkali feldspar is turbid with the usual brown dustlike particles, and is besides usually full of wisps of secondary sericite. Some acidic soda-lime feldspar (oligoclase) may possibly be present, but the bulk of the feldspar is probably an alkali feldspar identical with or closely related to anorthoclase. The amphibole is pale yellowish green and xenomorphic. Some of it is compact, but as a rule it is fibrous. Quartz is subordinate as irregular clear grains between the feldspars. Apatite in stout colorless prisms is a fairly abundant accessory constituent. Titanite occurs generally as rounded or irregular grains and there is a little magnetite, associated with the amphibole.

HORNBLENDE GRANITE.

The small mass of hornblende granite included in the gabbro of Mount Gilboa is a medium-granular dark-gray rock, in which the feldspars are brownish in color and show a tendency toward prismatic development. The dark constituent, apparently dark-green hornblende, is fairly abundant in rather irregular prisms. A little dark mica is also visible in the hand specimen.

Under the microscope partly idiomorphic sections of decomposed feldspar and irregular plates of amphibole are seen to lie in a sort of groundmass composed of quartz and feldspar micropegmatitically intergrown. The idiomorphic feldspar appears to be in part at least an acidic oligoclase, while that in the groundmass is doubtless an alkali feldspar closely related to soda orthoclase or to anorthoclase, although it may be in part ordinary orthoclase. The quartz is all more or less intergrown with feldspar but shows some homogeneous patches of considerable size.

BASALT.

The basalt of the flow southeast of Sand Brook is gray and compact, showing minute feldspar laths and augite grains on freshly fractured surfaces. In thin sections the component minerals are seen to be labradorite, augite, magnetite, apatite, and glass. The texture is almost typically intersertal and the rock is a common basalt. Much of it is vesicular and near the surface is deeply decomposed.

The rock of the Blackwells Mills dike is compact, dark gray, and nearly aphanitic. Specimens from three localities showed under the microscope an intersertal aggregate of labradorite, augite, magnetite, apatite, and glass. The magnetite forms delicate skeleton crystals in the glassy base. The rock originally contained small phenocrysts of olivine which are now altered to a yellow serpentine. It may therefore be called an olivine basalt, although the olivine is not abundant. An analysis of this rock given in the Geology of New Jersey, 1868, is as follows:

Analysis of basalt from dike at Blackwells Mills.

Silica	50.4
Iron oxide (FeO)	12.5
Alumina	15.8
Magnesia	6.0
Lime	11.2
Soda	1.1
Potash	.7
Water	2.7
	100.4

Specific gravity 2.96.

The Westville dike consists of a nearly black aphanitic rock, which under the microscope is found to be a basalt. It contains no olivine and its only noteworthy feature is the rather curious way in which the plagioclase laths are intergrown with prisms of augite.

COASTAL PLAIN AREA.

By Wm. Bullock Clark, H. B. Kümmel, and B. L. Miller.

GENERAL STATEMENT.

The geologic formations of the Coastal Plain area represent a nearly complete sequence from Cretaceous to Recent. They form a series of thin sheets which are inclined slightly toward the southeast, so that successively later formations are generally met in crossing the district from the inland border of the region to the coast. Variations in the angle and direction of tilting, as well as later denudation, have occasioned in some places marked divergences from these normal conditions. These variations, however, are most pronounced along the western margin of the belt, where, as the result of transgression, it is not uncommon to find one or more formations lacking in a given district. As the result of denudation, detached outcrops likewise appear along the western margin of the several formations, at times far removed from the main body of the deposits. These various factors must of course be worked out for each individual district and their relations in the Trenton region will be discussed later.

CRETACEOUS SYSTEM.

GENERAL STATEMENT.

The Cretaceous deposits of the Trenton region represent portions of both the Lower and Upper Cretaceous. Beyond this district still older Cretaceous deposits have been recognized southward in Maryland and Virginia. In general the Upper Cretaceous formations are best developed in New Jersey and the Lower Cretaceous in Maryland and Virginia.

The Lower Cretaceous deposits of estuarine origin were described by McGee as the Potomac formation, but they are now known to represent several stratigraphic units. As the type of deposition was much the same through the entire succession of deposits, the name Potomac group is retained to designate them as a whole. Of the four formations into which the Potomac group is divided only one, the Raritan formation, is known with certainty to occur within the confines of the Trenton quadrangle. Overlying the Raritan formation are transitional beds that from their fossil remains at more northern localities have been referred to the base of the Upper Cretaceous. The deposits themselves contain materials that ally them in part with the overlying and in part with the underlying formations. They were evidently marine in the vicinity of Raritan Bay, but no marine fossils have been observed south of Burlington County and it is evident that they were estuarine from that region southward into Maryland. They have been designated the Magothy formation.

The Upper Cretaceous deposits of strictly marine origin were referred to by the older writers as the Clay marls and the Greensand marls, the mineral glauconite occurring in greater or less amounts in all of the formations. The lithologic features of each formation are in general sufficiently distinctive and persistent to render the determination of the several horizons, even in the absence of fossils, a relatively easy task. Four major subdivisions, the Matawan, Monmouth, and Rancocas groups and the Manasquan formation, are recognized in the Trenton quadrangle.

LOWER CRETACEOUS SERIES.

POTOMAC GROUP.

The Potomac group of the Coastal Plain consists of highly colored gravels, sands, and clays which outcrop along a sinuous line extending from New York to Richmond and passing near the cities of Philadelphia, Wilmington, Baltimore, and Washington. In Maryland, where the Potomac deposits are best developed, four formations have been differentiated, viz, from below upward the Patuxent, Arundel, Patapsco, and Raritan. The two older formations, of questionable Jurassic affinities, and the Patapsco are not known to occur in the Trenton area.

RARITAN FORMATION.

Areal distribution.—South of Trenton the Raritan formation occupies a belt along the valley of Delaware River, but for the most part it underlies the river or is covered by Pleistocene deposits on the New Jersey side of that stream. Northeast of Trenton it extends toward New Brunswick in a belt bordering the Triassic rocks, but it is almost entirely covered by the Pleistocene sand and gravel. North of Monmouth Junction two outliers rest upon the Triassic shale and diabase at elevations ranging from 160 to 300 feet. The best exposures are those at the base of the bluff at Florence on Delaware River, in the clay pits southeast of Trenton, and in the road cuts crossing the Sand Hills outlier.

The Raritan formation continues beyond the limits of the quadrangle northeastward to Woodbridge and Perth Amboy, on the shores of Raritan Bay and beyond. Southwestward it extends along Delaware River, across Delaware to the headwaters of Chesapeake Bay in Maryland, and thence southward to the Potomac River valley, where it finally disappears beneath the cover of later deposits.

The outcrops of the formation are more extensive in New Jersey than toward the south, where the late Cretaceous and Eocene deposits gradually transgress the upper beds until they come to rest directly upon the Patapsco formation in southern Maryland and Virginia.

Lithologic character.—The Raritan formation is somewhat variable in character, consisting chiefly of light-colored sands and clays, the former in places highly ferruginous and locally forming a firm ironstone. In general the deposits are not so highly colored or variegated as those of the Patapsco formation, though they not uncommonly contain beds of red-mottled clay. In composition, they are extremely variable, the sandy layers being in many localities replaced within short distances by beds of clay. Cross-bedding is common in the sands and no section can be considered as typical except within very narrow limits. In the vicinity of Raritan River, where the most complete section of the beds has been found, there is an evident preponderance of clay in the lower half and of sand in the upper half of the series. In the Sand Hills white and mottled clays occur at the base, overlain by 80 feet or more of coarse, highly colored quartz sand not uncommonly cemented to a firm ironstone. At Haedrick's pits, near Florence, 40 to 45 feet of bluish and reddish clay (Raritan) are exposed beneath white and yellow sands and laminated black and brown clays (Magothy).

Paleontologic character.—The fossils of the Raritan formation consist largely of plant remains which have been recognized in many different localities in New Jersey. The known flora of the formation includes about 170 species, including one thallophyte, ten ferns, six cycads, eighteen conifers, and one monocotyledon, the remainder being dicotyledons distributed among many genera, some of which still exist. No fossil plants of Raritan age are known within the area of the Trenton quadrangle. The known fauna is very scanty, consisting of a few mollusks, some of which are brackish-water types and two of which are typically marine, a plesiosaurian bone, and possibly an insect.

Thickness.—The thickness of the deposits is somewhat variable, owing to the irregular surface upon which they are laid down. At the outcrop the formation is evidently from 200 to 250 feet thick, but it thickens toward the southeast beneath the later formations and in places has been penetrated in well borings to a depth of more than 500 feet, although part of the latter may represent the Patapsco and possibly even the Patuxent formation. Owing to the cover of Pleistocene materials only a small part of the Raritan is represented by outcropping strata in the Trenton area.

Name and correlation.—The Raritan formation was so called by Clark from the typical development of the deposits in the valley of Raritan River. The flora of the Raritan is highly characteristic, with its large proportion of dicotyledonous forms, and affords the basis for a correlation of the deposits on paleontologic grounds. Ward considers that the Raritan flora represents for the most part the late Lower Cretaceous and is therefore approximately equivalent to the Gault of England. Berry, on the other hand, suggests the probability of the flora being Cenomanian and thus Upper Cretaceous.

Stratigraphic relations.—Within the area of the quadrangle the Raritan rests unconformably upon the floor of ancient crystalline rocks which outcrop along Delaware River as far as Trenton and thence at intervals northeast to Princeton Junction; upon the later rocks of the Triassic from Princeton northeastward; and perhaps to the southeast (down the dip) at undetermined points upon Patapsco deposits. That the formation once extended farther to the northwest and considerably overlapped the Triassic is shown by the outliers north of Monmouth Junction.

The Raritan formation is unconformably overlain by the Magothy formation and, where outcrops at the contact are found, the line is for the most part sharply defined, although an exception to this occurs where dark-colored carbonaceous beds are present at the top of the Raritan.

The deposits strike from northeast to southwest. They dip to the southeast at an average rate of 40 to 50 feet per mile, the inclination of the basal beds being steeper than that of the upper.

UPPER CRETACEOUS SERIES.

MAGOTHY FORMATION.

Areal distribution.—The Magothy formation occurs as a narrow belt east of the Raritan formation but appears at the surface only in small detached outcrops where the Quaternary cover has been removed. The best exposure is found at Florence, where a thickness of 25 feet is shown between the Raritan clay below and a thin cap of Merchantville strata above. It is also well exposed at the brickyards between Kinkora and Bordentown, and at various points in the bluffs along Delaware River and Crosswicks Creek.

Beyond the limits of the quadrangle it has been identified from the shores of Raritan Bay to the District of Columbia, where it finally disappears beneath the cover of later deposits.

Lithologic character.—The Magothy deposits are very variable, consisting of alternating beds of dark clay and light sand, the latter locally reddish or brownish. The clays are for the most part strongly laminated and commonly lignitic; near Raritan Bay, where they carry a large marine fauna, they are in places slightly glauconitic. The carbonaceous clays are locally filled with minute particles of lignite that give them a somewhat spotted appearance. They are in places micaceous and are then not unlike some of the overlying Matawan beds, but are usually readily distinguished from the higher beds by thin seams of white sand which separate the clay layers.

Segregation of the ferruginous matter, usually somewhat evenly distributed through the sand, has occurred in several places, producing irregular iron crusts in many fantastic shapes.

Paleontologic character.—In this quadrangle the only organic remains thus far recognized in the Magothy are leaf impressions in the thin laminæ of drab clays that alternate with layers of sand. The impressions are mostly fragmentary, but at Kinkora Berry collected the following species just below the Matawan contact (Geol. Survey New Jersey for 1905, p. 139): *Carex clarkii*, *Gleichenia saundersii*, the cones of *Sequoia gracillima*, and *Heterofilicites anceps*. All of these are forms which occur at other localities within this formation in New Jersey. At Cliffwood Point, on the south side of Raritan Bay, New Jersey, beds of this formation have yielded a considerable flora and a marine fauna. The animal remains described by Weller (Geol. Survey New Jersey, Paleontology, vol. 4, pp. 33–42) were found mainly in smooth concretionary nodules in a clay bed or lying loose on the beach, where they were left by the erosion of the clay beds that originally contained them. The fauna is characterized by the presence of great numbers of crustacean remains. Some portion of a crab seems to have been the nucleus about which almost all the nodules were formed. Pelecypods, gasteropods, and cephalopods also occur. The most abundant forms are the following: Among the pelecypods, *Trigonarca triquetra*, *Leda cliffwoodensis*, *Pteria petrosa*, *Nucula percrassa*, *Yoldia cliffwoodensis*, *Isocardia cliffwoodensis*, *Cymbophora lintea*, and *Corbula bisulcata*; among the Crustacea, *Tetracarcinus subquadratus*. These are of considerable importance, since they are the earliest marine fossils found in the deposits of the Atlantic Coastal Plain, if the marine forms from the Raritan be excepted. Weller states that the assemblage of forms constitutes a distinct faunule of 43 species, of which 14 do not occur in other formations in New Jersey. Of the remaining 29 forms which have a wider range, a larger number occur in the Woodbury and Wenonah formations than in the Merchantville, which immediately overlies the Magothy.

The flora of the Magothy formation (formerly known as the "Cliffwood clay") studied by Berry at Cliffwood Point[a] is notably varied, over 100 species having been described. Many of the species occur also in the Raritan formation, but most of them are new or are characteristic of later formations elsewhere. The most common fossil plants of that locality are the imperfectly petrified cones of *Sequoia gracillima*. Other common species are *Cunninghamites squamosus*, *Dammara cliffwoodensis*, and *Sequoia reichenbachi*. Berry and Hollick state that the flora of these beds show Cenomanian characteristics, while Weller has pointed out that the fauna is more like the Senonian.

Thickness.—The thickness of the Magothy formation in this region is about 30 feet, but it increases to the north, where it reaches about 150 to 175 feet on the shores of Raritan Bay. In southern Maryland it is not more than 20 to 30 feet.

Name and correlation.—The Magothy formation, so named by Darton from the typical development of the deposits in the valley of Magothy River, Maryland, can be traced almost continuously except for the cover of Pleistocene materials, from the valley of Raritan River southward to the western shore of Chesapeake Bay. It changes somewhat in character southward, and the marine fossils of the north have not thus far been observed to the south of Burlington County, N. J., although the alternating clays and sands with their lignitic beds persist. A more or less constant characteristic of the clays is the presence of iron nodules, many of which are fossiliferous. Most of the beds here classed as Magothy were formerly included in the Raritan.

[a] Bull. New York Bot. Garden, vol. 3, No. 9, pp. 45–103; Bull. Torrey Bot. Club, vol. 31, pp. 67–82; vol. 32, pp. 43–48.

The flora of the Magothy presents a much more recent aspect than that of the Raritan. Only 37 per cent of Raritan forms have been described from the Magothy formation and these not of the oldest and most characteristic types. Many later forms appear, and the flora as a whole is regarded by paleobotanists who have examined and described the specimens as showing Cenomanian affinities.

The fauna consists mainly of marine molluscan shells, crab claws, and shark teeth. It is the lowest appearance of a fauna which recurs in the Woodbury, Wenonah, and Redbank formations. Weller considers that it possesses close affinities to that of the Ripley beds of the south, and that it is thus allied to the Senonian of Europe.

MATAWAN GROUP.

SUBDIVISIONS.

The strata included in the Matawan group were regarded by Clark as constituting a single formation (composed of two members—the "Crosswicks clays" and the "Hazlet sands") to which he applied the name Matawan because of its typical development along Matawan Creek in Monmouth County, N. J. The geologists of the New Jersey State Survey, however, have subdivided it into five members, which are regarded as distinct formations for this area. The fifth formation, the Wenonah, while paleontologically distinct from the overlying Mount Laurel, is not sharply so lithologically, and it is, therefore, combined with that formation in the Trenton region for mapping purposes and will be discussed in connection with the Monmouth group. To the south these divisions gradually disappear and the Matawan strata in Maryland constitute a single unit of very constant lithologic character.

The five formations in New Jersey that are believed to be the correlative of the single Matawan formation of Maryland are the Merchantville and Woodbury clays, the Englishtown sand, the Marshalltown formation, and the Wenonah sand. All of them outcrop in the Trenton quadrangle, the first four being separately represented on the maps.

MERCHANTVILLE CLAY.

Areal distribution.—Outcrops of the Merchantville clay occur in a northeast-southwest belt from one-half mile to 2 miles in width. In the vicinity of Bordentown this belt lies close to Delaware River, but above and below that place it lies some distance away because of the changed course of the river. Exposures are most commonly found along the steep slopes of the tributary streams. The formation is well exposed, in whole or in part, at the brickyards at Kinkora, at Fieldsboro (only the basal layers), at Bordentown, and in the banks of Blacks Creek, Crosswicks Creek, Doctors Creek, and Assanpink Creek. On the south bank of Blacks Creek and three-fourths mile east of Fieldsboro the entire formation is shown with both basal and upper contacts exposed. Its contact with the Magothy is also seen at the Kinkora and Fieldsboro brickyards and in the bluff at Florence.

Lithologic character.—The Merchantville clay, the lowest member of the Matawan group, is a black, glauconitic and micaceous clay, which is usually greasy in appearance and commonly massive in structure, particularly in the lower portion; the upper part is more sandy and is in places distinctly laminated. The upper and the basal portions of this bed are commonly much more glauconitic than the middle part, and have at times been dug for marl, although their use for this purpose has not been extensive. The glauconite is unevenly distributed, occurring commonly in patches rather than as disseminated grains. It is entirely absent at some horizons. Locally small pebbles occur very sparingly in the basal portion.

The weathered portions of this formation are very characteristic. Where marly, they form an indurated cinnamon-brown earth, in which the small black unweathered grains of marl are conspicuous. Where more sandy, the weathered portion has a peculiar "pepper and salt" aspect. The weathered part of the nonmarly portion is less characteristic and is in some places a light chocolate-colored clay, resembling the weathered part of the next higher formation.

The base of the Merchantville clay is a sharply marked stratigraphic line, readily recognized wherever exposed and easily traceable throughout the area in which it outcrops. The underlying Magothy strata consist mainly of loose coarse lignite-bearing sand or finely interlaminated sand and clay, with the upper sandy layers not uncommonly cemented to form an ironstone. The contrast between these materials and the overlying Merchantville black marly clay or its weathered equivalent is a striking one. The upper contact of the Merchantville formation is much less distinct, but the transition to the overlying Woodbury clay is generally accomplished within 1 to 3 feet, and where exposures are fresh there is rarely any question as to where the division between the two formations should be made.

Paleontologic character.—The Merchantville fauna is a large and varied one (102 species), and is characterized by the abundance of *Axinea subaustralis, Cucullæa antrosa, Cardium tenuistriatum, Turritella merchantvillensis,* and *Panopea decisa,* species which are conspicuous for their absence or great rarity both in the underlying beds of the Magothy and in the superjacent formation, but which recur more or less commonly in the Marshalltown and Navesink formations above.

Thickness.—The greatest observed thickness of the Merchantville clay is about 60 feet, the entire bed being exposed three-fourths mile east of Fieldsboro, along the road crossing Blacks Creek.

Name and correlation.—The formation receives its name from the town of Merchantville, in Camden County, N. J., which is underlain by beds of this age. It represents the lower part of the "Crosswicks clays," the lower of the two members of the Matawan as described by Clark in the reports of the New Jersey Geological Survey, and forms the base of the Clay-marl series of Cook.

Stratigraphic relations.—The Merchantville clay rests upon the Magothy formation and is overlain by the Woodbury clay, with which it is conformable. The contact of the Merchantville and Magothy formations is exposed on the south bank of Blacks Creek due south of the center of Bordentown, in the brickyards at Kinkora, and at Haedrick's pit, Florence.

In the region of outcrop the Merchantville is throughout much of the area unconformably overlain by deposits of Pleistocene age.

WOODBURY CLAY.

Areal distribution.—The Woodbury clay outcrops in a narrow belt lying just southeast of the Merchantville line of outcrop. There are good exposures near Three Tuns, along Blacks Creek above Dunns Mills, along Crosswicks Creek and its tributaries above Crosswicks and at Braislin's brickyard, and along Rocky Brook near Hightstown. Northwest of Rancocas an extensive area of the Woodbury clay is slightly covered by wash from later deposits. At an abandoned brickyard a mile west of Rancocas the clay contains large masses of limonite, which traverse it in all directions. Beyond the Trenton area the Woodbury clay has been differentiated entirely across New Jersey with no striking change in lithologic character, fauna, or thickness.

Lithologic character.—The Woodbury formation is composed primarily of a thick bed of clay. It is somewhat micaceous, black in color, not sandy in the lower portion but slightly so in the upper part, where it is distinctly laminated. It does not contain glauconite except perhaps at the very base and locally to a slight amount in the extreme upper portion, and, in this respect, it is to be distinguished from the Merchantville clay. It weathers to a light-chocolate color, and when dry breaks into innumerable blocks, large and small, frequently with a conchoidal fracture. In its lower portion it is penetrated by numerous joints, which, in some localities, are smoothed and polished. Many of the joints are filled with crusts of limonite, which locally form large honeycombed masses many feet in diameter and tons in weight. In fact, all gradations can be found between these large masses and films of limonite coating joint faces.

Lithologically the Woodbury is readily differentiated from the Merchantville by its light-brown color where weathered, its usual lack of glauconite, and its numerous joints. The transition to the overlying Englishtown sand is comparatively abrupt, through beds rarely more than 2 or 3 feet thick.

Paleontologic character.—The Woodbury clay contains an abundant fauna, 95 species having been recognized by Weller. *Lingula subspatulata, Yoldia longifrons, Lucina cretacea,* and *Cyprimeria cretacea* are the most characteristic forms. The facts that not one of these forms has been seen in the Merchantville formation and that the several abundant forms of the Merchantville are exceedingly rare in the Woodbury show a faunal as well as a lithologic difference between these formations. The Woodbury fauna has more in common with that of the Magothy and Wenonah than it has with the Merchantville fauna below or the Marshalltown above.

Thickness.—The thickness of the Woodbury clay is about 50 feet.

Name and correlation.—The formation receives its name from the town of Woodbury in Gloucester County, N. J. It was so designated because of the good sections formerly exposed in the railroad cut at that place. It represents the upper part of the Crosswicks clays of Clark, described in the reports of the New Jersey Geological Survey, and forms part of the Clay-marl series of Cook.

Stratigraphic relations.—The Woodbury formation rests upon the Merchantville and is overlain by the Englishtown, with both of which it is conformable. Similar to the other Cretaceous formations of the region, the Woodbury in the region of its outcrop is in many places unconformably overlain by Pleistocene deposits.

ENGLISHTOWN SAND.

Areal distribution.—Within the Trenton quadrangle the Englishtown sand appears as a series of outcrops from Rancocas to Allens. In its wider distribution it has been recognized from Atlantic Highlands to Salem County. Owing to the generally loose, incoherent character of the materials composing the formation, fresh exposures are speedily washed down and obscured. It covers considerable areas near Mansfield, Columbus, and southwestward, but deep exposures are not common. Steep stream banks and fresh-cut gullies usually afford the best chances for observation, but these often change from year to year. Good opportunities for studying the formation can usually be found along Crosswicks Creek and its tributaries near Extonville and on Assanpink Creek near New Sharon.

Lithologic character.—This Cretaceous formation is a conspicuous bed of white or yellow quartz sand, slightly micaceous and with minute amounts of glauconite. It is in some places marked by delicate lines of red, giving it a highly variegated appearance, while locally the percentage of iron present is much greater and the sand has been cemented to form rather massive beds of sandstone. Although for the most part the formation is composed of loose quartz sand, in places closely resembling the sand of the present beaches, yet not uncommonly it contains thin laminæ of fine brittle clay which stand in sharp contrast to the adjoining sand, without any gradation between them. Toward the upper portion of the formation there is a horizon at which a bed of clay, a few feet thick, occurs locally. It is apparently not continuous though it has been seen at a number of widely separated points.

Paleontologic character.—So far as known the Englishtown sand contains no fossils.

Thickness.—The thickness of the Englishtown sand ranges from 20 feet near Swedesboro to nearly 50 feet on Crosswicks Creek and to about 100 feet still farther north in Monmouth County.

Name and correlation.—The formation receives its name from Englishtown, Monmouth County, where it is well developed. It represents the lower part of the "Hazlet sands," the upper formation of the Matawan as described in several articles by Clark, and forms a part of Cook's Clay-marl series. It is the formation formerly called Columbus sand in reports of the New Jersey State Survey.

Stratigraphic relations.—The formation is conformable with both the underlying Woodbury and the overlying Marshalltown formations. Throughout considerable areas the Englishtown sand is covered by unconformable Pleistocene strata.

MARSHALLTOWN FORMATION.

Areal distribution.—The outcrops of the Marshalltown formation border those of the Englishtown sand on the southeast and form a belt extending diagonally across the region in a southwest-northeast direction from Mount Holly to Walnford and beyond. The formation is exposed at few places except along stream valleys, although some larger interstream areas are so thinly covered with the later formations that shallow excavations show its weathered phases. The formation can be best seen below the millpond 1 mile southeast of Chesterfield, in a ravine one-half mile north of Ellisdale, and along Crosswicks Creek near Walnford.

Lithologic character.—The formation ranges from a black sandy clay to an argillaceous marl. Within the area under discussion both phases occur, but farther northeast it is chiefly a black laminated micaceous clay with thin seams of sand and only scattered marl beds, while to the southwest the marly phase predominates. Locally, the glauconite forms so large a constituent of the mass that the bed has been exploited as a "marl bed" and, indeed, by several earlier geologists it was correlated with the "Lower marl" (Navesink) of Monmouth County.

Paleontologic character.—The Marshalltown formation, in its southern extent, is abundantly fossiliferous (43 species). Near Swedesboro, Salem County, in particular, a considerable distance south of the Trenton quadrangle, the fossils occur in a remarkably perfect state of preservation and in great numbers. *Cucullæa tippana, Neithea quinquecostata,* and *Carolium tenuistriatum* are prominent species which are recurrent from the Merchantville, but the most conspicuous element appears for the first time and persists in the recurrent fauna of the late Mount Laurel and Navesink formations. "This element is represented most conspicuously by the ponderous species of *Exogyra* and *Gryphæa,* by the little oyster *O. falcata,* which is of the type of *O. larva,* and by *Gryphæostrea vomer.* Besides these oyster-like forms which so strongly characterize the Marshalltown and the Navesink, some other species should probably be included in the same faunal element, among which are the following species, which are as yet known only from these two faunas: *Plagiostoma erecta, Unicardium umbonatum,* and *Odontofusus medians.*"[a]

Thickness.—Along its outcrop the thickness of the Marshalltown formation is about 30 to 35 feet, but this increases to the southeast to at least 50 feet, as shown by a well boring at Grenloch, Camden County.

Name and correlation.—Marshalltown, Salem County, N. J., near which strata belonging to this division were once extensively worked for marl, has furnished the name for the formation. In Monmouth County these beds are a part of the "Laminated sands," which formed the upper portion of the

Clay-marl series of Cook, but in their extension southwest of Burlington County they were correlated with the "Lower marl" (Navesink) and so mapped by him. They were included in the Hazlet (upper Matawan) sands of Clark.

Stratigraphic relations. — No unconformities have been observed between the Marshalltown formation and the underlying Englishtown sand nor between the Marshalltown and the overlying Wenonah strata. Locally the Marshalltown formation is overlain unconformably by Pleistocene deposits.

WENONAH SAND.

The Wenonah sand, although included in the group of formations known as Matawan, has not been mapped separately from the Mount Laurel in this region and is therefore discussed below in connection with that formation.

MONMOUTH GROUP.

SUBDIVISIONS.

The Monmouth group, named by Clark from Monmouth County, N. J., where the deposits are typically developed, was divided by him into the Mount Laurel sand, the Navesink marl, and the Redbank sand. All three of these formations are present in the eastern part of the Trenton quadrangle, but in the vicinity of Sykesville the Redbank thins out and disappears, while in Maryland no differentiation of the beds into formations has been found possible. The disappearance of the Redbank sand southward brings the Navesink marl into immediate contact with the overlying Hornerstown marl of the Rancocas group, from which it can not be readily distinguished lithologically, although a more or less arbitrary line has been drawn on the map to mark the supposed boundary. Paleontologically, the two formations are readily separable, but as fossils are in many places absent, the differentiation may become a matter of considerable difficulty.

WENONAH AND MOUNT LAUREL SANDS.

There has been some difference of opinion regarding the classification and nomenclature of the Wenonah and Mount Laurel sands, the terms Mount Laurel and Wenonah having both been used for them in part. There are somewhat definite lithologic differences between them, although not always to the same degree, thus rendering it difficult to separate them in many places. Paleontologically they are, however, distinct, the fauna of the lower portion (Wenonah) containing many species recurrent from the Woodbury and a much less number common either to the Marshalltown immediately below or to the Mount Laurel and Navesink above; this fauna is furthermore closely allied to that of the Redbank. The fauna of the upper portion (Mount Laurel), on the contrary, is identical with that of the Navesink marl and is closely allied with that of the Marshalltown on the one hand and that of the Tinton sand, or uppermost member of the Redbank, on the other. It therefore seems best to recognize both subdivisions in the stratigraphic column, restricting the term Wenonah to the lower and Mount Laurel to the upper subdivision. For representation on the map of the Trenton region, where the Mount Laurel sand is for the most part thin and with difficulty separated from the underlying Wenonah, it seems best to combine them as a single unit.

Areal distribution.—These formations outcrop along a belt from $1\frac{1}{2}$ to 3 miles wide, extending from Mount Holly to Wrightsville. In the railroad cut near the fair grounds at Mount Holly 15 feet of fine micaceous sand (Wenonah) is shown, while on the side of the hill back of the town the Mount Laurel sand outcrops under the marl bed. Both types of sand are shown along the east-west road $2\frac{1}{2}$ miles northeast of Jobstown, while the Mount Laurel type outcrops just south of Georgetown. The contact of the Wenonah and the underlying Marshalltown is shown in a roadside gully 1 mile southeast of Chesterfield. Good exposures of both the Wenonah and the Mount Laurel sands are found along a tributary of Crosswicks Creek $1\frac{1}{2}$ miles east of Walnford, and also along similar tributaries for several miles upstream from that place. Both types of sand are also exposed one-third mile west of Cream Ridge station, while at Imlaystown the Wenonah sand is exposed about 15 feet below the base of the marl bed, the interval being referable in part at least to the Mount Laurel.

Lithologic character.—In Monmouth County the deposits of this horizon consist mainly of a fine varicolored quartz sand with considerable mica and some clay laminæ (Wenonah), overlain by coarse quartz sand containing considerable glauconite, many of the grains of quartz being one-eighth to one-quarter inch in diameter (Mount Laurel). Southwestward the lower sands are less micaceous, and in Salem County the deposits consist essentially of coarse reddish quartz sand, glauconitic through its entire thickness and strongly impregnated with iron which forms crusts of all imaginable shapes and which locally has cemented the sand into firm beds of sandstone. In the absence of fossils it is impossible to determine how much belongs to the Wenonah and how much to the Mount Laurel. Within the Trenton quadrangle both types have been recognized, but the lithologic differences are not so marked as farther to the northeast, in which direction a gradual increase in coarseness in the lower member takes place.

Paleontologic character.—Weller has shown that while the Wenonah fauna (80 species) contains an equal number of Merchantville and Woodbury species, yet characteristic forms of the Merchantville are absent or very rare, while its affiliations with the Woodbury fauna are close. The ponderous *Gryphæa* and *Exogyra* of the Marshalltown fauna are absent in the Wenonah, but *Ostrea plumosa* is very numerous in places. The fauna of the Mount Laurel sand, on the other hand, is marked by the introduction of species entirely foreign to the earlier faunas of the region, the most characteristic being the cephalopod *Belemnitella americana* and the brachiopod *Terebratella plicata*, both of which are also especially abundant in and characteristic of the overlying Navesink marl. The paleontologic data indicate that the line between the Mount Laurel and Wenonah sands marked by the introduction of the *Belemnitella* fauna is of greater significance than the relatively slight difference in the character of the sediments would imply.

Thickness.—The combined thickness of the Wenonah and Mount Laurel strata in the Trenton area ranges from 40 to 60 feet, of which 15 to 20 feet belongs to the Mount Laurel.

Name and correlation.—The town of Wenonah, in Gloucester County, N. J., and the hill known as Mount Laurel, in Camden County, furnish the names to these formations. As already stated, the Wenonah constitutes the uppermost formation of the Matawan group and the Mount Laurel is the basal formation of the Monmouth group.

Stratigraphic relations.—Beneath the Wenonah is the Marshalltown formation, with no stratigraphic unconformity separating them, and the same condition exists between the Mount Laurel sand and the overlying Navesink marl.

NAVESINK MARL.

Areal distribution.—The Navesink marl outcrops in an almost continuous line of exposures from the vicinity of Imlaystown southwestward nearly to Arney Mount, and a small outlier is found on the hill north of Mount Holly. For two-thirds of its outcrop in this quadrangle and northeastward to Atlantic Highlands it is separated from the overlying Hornerstown marl by the Redbank sand, but owing to the abrupt disappearance of the latter near Sykesville the two marl beds coalesce to the southwest and although they have been separately mapped to the southern margin of this area, the separation is more or less arbitrary. Owing to the extensive use, in former days, of the greensand as a fertilizer, the outcrop is marked by numerous pits which, where not too long abandoned, give good exposures. These are most numerous along Crosswicks Creek above Walnford.

Lithologic character.—The Navesink marl consists of greensand (glauconite) mixed with varying amounts of quartz sand and fine earth, the latter containing much carbonate of lime in a powdery state. The following table (Cook, Ann. Rept. State Geologist New Jersey, 1886, p. 184) shows the composition of four samples of the Navesink marl:

Analyses of Navesink marl.

	1.	2.	3.	4.
Greensand	58.4	75.0	65.0	52.5
Clay, etc	33.6	25.0	32.5	28.8
Quartz sand	6.6		2.5	18.7
Iron crusts	.7			
Shells in pieces	.7			
	100	100	100	100

Where purest, the marl has a dark-green or bluish-black color. In its upper part the blue marl passes gradually into a layer 10 to 11 feet thick, which contains progressively less greensand and more and more mica and sandy clays. Not uncommonly the marl has a very astringent taste due to the presence of sulphate of iron. Within the Trenton quadrangle the base of the Navesink is almost everywhere marked by a shell bed several feet thick, which is best seen in the bed of the brook $2\frac{1}{2}$ miles south of Walnford and 1 mile northeast of Arneytown. To the northeast this shell bed occurs not at the base but within the marl, indicating that conditions favoring the deposition of the marl began earlier in the northeast than they did farther south.

Paleontologic character.—The Navesink marl (with the Mount Laurel sand) has yielded a large fauna of 121 species (Weller), of which *Belemnitella americana* and *Terebratella plicata* are the most characteristic, neither occurring in any other formation in New Jersey. A second conspicuous element is the *Exogyra* and *Gryphæa* group of forms, which were first present in the Marshalltown, although *E. ponderosa* has been succeeded by *E. costata*. A third conspicuous element, distinct from the European *Belemnitella* element and from the southern *Exogyra* element, is the *Cucullæa* fauna recurrent from the Merchantville and Marshalltown, of which *Axinea subaustralis* and *Cucullæa antrosa* are examples. The characteristic members of the *Lucina cretacea* fauna of the Woodbury clay are entirely absent.

Thickness.—In Monmouth County the Navesink marl has a maximum thickness of nearly 40 feet, which decreases southwestward to 25 feet or less. Probably the average thickness within this quadrangle is about 30 feet.

Name and correlation.—The Navesink Hills near Sandy Hook, where it is well exposed in the bluffs from Atlantic Highlands eastward, give the name to this formation. It corresponds to Cook's Lower marl, except that his Sand marl is now regarded as Mount Laurel, and locally some of the black sandy clay which he included in the "Lower marl" is in the later classification regarded as Redbank.

Stratigraphic relations.—The Navesink marl rests conformably upon the Mount Laurel sand, with which it is shown by identity of faunas to be very closely related. It grades upward into the Redbank sand, the line of separation not being lithologically a sharp one. Southwest of Sykesville and Georgetown the Redbank is absent and the Navesink is overlain by the Hornerstown marl.

REDBANK SAND.

Areal distribution.—The Redbank sand extends from the vicinity of Sykesville northeastward. Beyond this quadrangle it forms a conspicuous bed in Monmouth County, but does not occur anywhere in the State southwest of this quadrangle. It forms the surface over a wide area of high land north of Arneytown and appears on the slopes of the hills northeast of Cream Ridge. Good exposures are common in road cuts on the steeper slopes, particularly 1 mile south of Ellisdale, near Arneytown, and south of Imlaystown.

Lithologic character.—The Redbank sand is, for the most part, a fairly coarse ferruginous quartz sand, with the characteristic yellow and reddish-brown color due to iron staining. Locally the beds have been cemented to a firm stone by the infiltration of iron; and iron crusts and concretions are a characteristic feature of many exposures. The lower portion of the formation (10 to 20 feet) is very commonly a black, somewhat micaceous and clayey sand which at first sight seems referable to another formation. Locally, however, the black sand occurs at other horizons from base to top, so that is impracticable to subdivide the formation on this basis. According to Cook, the coloring matter in the black sands is protoxide of iron and that in the red-brown sands is the peroxide, so that the color depends merely on the degree of oxidation of the iron. While this is true, differences in texture as aiding or retarding these changes have been of importance in this connection, the black sands being somewhat more clayey than those which are most highly oxidized.

Paleontologic character.—The fauna of the Redbank is known chiefly from fossils in the lower, more clayey layers of the formation, those from the upper and more sandy beds being poorly preserved and few in number. The fauna observed in this area constitutes an assemblage of forms quite different in character from the Mount Laurel and Navesink fauna, being in its essential features a recurrence of the *Lucina cretacea* fauna of the Magothy, Woodbury, and Wenonah formations, with a smaller element holding over from the Navesink marl. None of the characteristic species of the foreign element of the Navesink, such as *Belemnitella americana* and *Terebratella plicata*, are present. *Lucina cretacea, Pteria navicula, Cardium dumosum*, and *Veronnæoderma georgiana* are members of the fauna which have not been observed elsewhere except in the Woodbury (Weller). Farther to the northeast the Tinton sand member, which is poorly developed in this area, contains a fauna possessing many points in common with the Mount Laurel and Navesink fauna.

Thickness.—The Redbank sand has a maximum thickness of about 100 feet in Monmouth County and gradually thins until it disappears near Sykesville. At Stony Hill, south of Ellisdale, its thickness is about 50 feet.

Name and correlation.—The formation derives its name from the city of Redbank in Monmouth County, N. J., near which it is extensively developed. It is the Red sand of Cook and earlier writers, but does not include the sand which in the southern portion of the State Cook correlated with the "Red sand" of Monmouth County. The latter is in reality older and is now classed as the Wenonah and Mount Laurel sands. The Redbank sand farther north is made to include a bed of green indurated clayey and marly sand (Cook's indurated green earth), which has a thickness varying from 10 to 25 feet and is known as the Tinton sand member.

Stratigraphic relations. — The Redbank rests conformably upon the Navesink marl, grading into the highly glauconitic beds of the latter through black clayey sands which become increasingly marly. It is conformably overlain in the Trenton quadrangle by the Hornerstown marl, from which it is sharply distinct. Farther northeast there is an intervening bed of indurated greenish earth, regarded by the United States Geological Survey as a part of the Redbank but by recent workers of the State Survey as a separate formation, the Tinton, both on lithologic and paleontologic grounds. Along its line of outcrop the Redbank is in places overlain unconformably by Pleistocene sand and gravel.

[a] Weller, Paleontology of New Jersey, vol. 4, 1907, pp. 88-89.

Correlation of beds from Magothy to Redbank, including the Tinton.—The assemblages of fossils making up the faunas of the beds from the Magothy to the Tinton inclusive constitute a larger faunal unit much more sharply separated from the faunas above and below than are any of its constituent faunules from one another. Weller has shown that this larger faunal unit is made up of two or more distinct facies, one of which, the *Cucullæa* fauna, is characteristic of the more glauconitic beds, the Merchantville, Marshalltown, Navesink, and Tinton; the second, characterized by *Lucina cretacea* or its associates, occurs in the clays or clayey sands of the Magothy, Woodbury, Wenonah, and Redbank formations. The two facies of the fauna existed contemporaneously and migrated backward and forward across the present outcrop of the Cretaceous beds in New Jersey as deeper or shallower water conditions prevailed.

The introduction of *Belemnitella americana*, *Terebratella plicata*, and other forms in the Mount Laurel sand at the base of the Monmouth marks a faunal change that has been recognized throughout the Atlantic Coastal area and apparently in the eastern Gulf region. In New Jersey these forms range through the Mount Laurel sand and Navesink marl, but do not occur in the Redbank sand, the fauna of which is essentially a recurrence of the *Lucina cretacea* fauna of the Woodbury clay, or in the Tinton member. Farther south, however, the introduction of *Belemnitella americana* and associated forms at the base of the Monmouth apparently marks a permanent faunal change, no return to the earlier faunules having been observed. This older fauna occurs in the Matawan formation in Maryland and in the Bladen formation in North Carolina, while the Eutaw and certain beds regarded as lower Ripley in the eastern Gulf region are evidently synchronous deposits. The upper or *Belemnitella* fauna, on the other hand, occurs in the Monmouth formation in Maryland and has been traced from North Carolina to the Gulf, where it is found in unquestioned Ripley strata.

The larger faunal unit characteristic of the beds in New Jersey from Magothy to Tinton is represented by the Ripley and associated formations in Alabama, Mississippi, and Texas. The community of species between this southern region and New Jersey is so marked that the essential time equivalence of the formations and faunas seems beyond question. Clark has correlated the beds of the Matawan and Monmouth groups (Merchantville to Redbank inclusive) with the Senonian of Europe, and, although recognizing its close faunal association, has regarded the Magothy, primarily on floral evidence, as Cenomanian. Weller's later studies of the faunas lead him to believe that the Magothy faunule is also a part of a larger Ripley fauna, which seems to be most closely allied to that of the Aachen beds. He therefore regards all the deposits from the Magothy to the Redbank as Senonian.

RANCOCAS GROUP.

SUBDIVISIONS.

The formations composing the Rancocas group are two in number and were earlier described by Clark as the Sewell marl and the Vincentown lime sand. Later the name Hornerstown was substituted for Sewell, the latter name having been elsewhere employed. The formations of the group were first classed as members of a single formation, to which the name Rancocas was applied because of its typical development in the valley of Rancocas Creek, Burlington County, N. J. More recent studies by members of the New Jersey State Survey indicate that there are good paleontologic reasons for uniting the Hornerstown, Vincentown, and Manasquan in a single group, although their lithologic likeness to each other is no greater than to the subjacent formations of the Upper Cretaceous.

Greater faunal changes occurred between the Redbank (including the Tinton) and the Hornerstown than between any previous formations, and on paleontologic grounds the most important division of the Upper Cretaceous of New Jersey occurs at the base of the Hornerstown marl.

HORNERSTOWN MARL.

Areal distribution.—The Hornerstown marl outcrops as a distinct and separate marl bed from Atlantic Highlands southwestward to Sykesville. Farther southwest it is with difficulty separated from the Navesink marl, owing to the disappearance of the Redbank. Within the Trenton quadrangle the line of outcrop extends from Hornerstown to Arney Mount, with small outliers at Stony Hill, Arneytown, and Imlaystown. The best exposures are at the marl pits near Hornerstown and along Crosswicks Creek north of New Egypt.

Lithologic character.—The Hornerstown marl is a bed of glauconite with clay and sand not differing materially in appearance from the Navesink, although in color, where unweathered, it may have a slightly greener tinge. Chemical analyses by Cook show that it contains on the average less calcium carbonate than does the Navesink, and a series of mechanical analyses by him shows that the percentage of glauconite is higher, ranging in the samples tested from 71 to 91 per cent. The upper 4 to 7 feet of the formation is commonly a mass of shells in a matrix of sand and marl, constituting a shell bed which rivals in extent and prominence the shell bed in the Navesink marl, but the species are not the same.

Paleontologic character.—The fauna of the Hornerstown marl is small and, apart from the shell bed at the top of the formation, has not yielded many fossils, but it is totally different in its essential characteristics from the faunas of all the underlying formations. *Terebratula harlani*, *Cucullæa vulgaris*, and *Gryphæa dissimilaris* are characteristic forms. The shell bed at the top of the marl contains a fauna so closely allied to that of the Vincentown sand that it is a question whether it ought not to be regarded as the base of that formation, rather than the top of the marl.

Thickness.—The Hornerstown marl probably nowhere exceeds 30 feet in thickness and commonly it is a little less. Where it is in contact with the Navesink its thickness can not be definitely fixed. Well borings show that the marl bed increases in thickness to the southeast, as do most of the other formations.

Name and correlation.—The name is taken from the village of Hornerstown, near which there were extensive marl pits. The formation is the lower half of the Middle marl of Cook.

Stratigraphic relations.—In Monmouth County the formation rests to all appearances conformably upon the Redbank sand and upon the Tinton sand member, where that is present. Southwest of Sykesville the Hornerstown merges downward into the Navesink marl. It is overlain conformably by the Vincentown sand, its top being marked by a thick and persistent shell bed. Locally the Vincentown and higher Cretaceous beds are overlapped by the Miocene formations, which then rest unconformably upon the Hornerstown, as at Arney Mount, Stony Hill, Arneytown, and near Imlaystown. It is also in places covered unconformably by Pleistocene beds.

VINCENTOWN SAND.

Areal distribution.—The Vincentown sand outcrops along a belt from Long Branch, in Monmouth County, N. J., to Salem, near Delaware Bay. Even if the comparatively recent Pleistocene cover of gravel and sand be disregarded, the Vincentown does not outcrop continuously, owing to the repeated but irregular overlap of the Miocene formations. Within the Trenton quadrangle it occurs at intervals from Hornerstown to Juliustown, the largest area being near New Egypt. Good exposures are found along Crosswicks Creek and tributaries at various points near Cookstown and New Egypt, particularly at a quarry 1 mile north of the latter place and along the county road crossing the creek.

Lithologic character.—The Vincentown sand presents, both lithologically and paleontologically, two somewhat distinct phases, a lime-sand and a quartz-sand phase. Both phases are well developed within the Trenton quadrangle. Beds of indurated lime sand occur along Crosswicks Creek north of New Egypt and along a little run north of Cookstown, while the quartz-sand phase is best seen near the bridge over Crosswicks Creek 1¼ miles north of New Egypt.

Where most typically developed, particularly in the southern counties of New Jersey, the lime sand consists of a mass of broken bryozoan, echinoid, coral, and other calcareous remains, with some quartz sand and glauconite. These more calcareous layers form numerous beds of limestone intercalated with softer layers which are locally a lime sand but more commonly a glauconitic quartz sand. The alternating hard and soft layers range from 4 inches to 2 feet in thickness, the indurated beds being, on an average, only about one-half as thick as the incoherent layers, so that even where the calcareous phase is best developed a large part of the formation is a quartz sand. Traced northeastward the lime-sand phase becomes less marked, particularly in the upper portion, until in Monmouth County the whole formation is essentially a yellow quartz sand carrying varying amounts of glauconite with some broken shells; it was described by Cook as the Yellow sand.

Paleontologic character.—The calcareous phase of the Vincentown is almost entirely made up of the remains of bryozoans, while foraminifers and echinoids are very abundant, forming a fauna quite different in these respects from that occurring in the Hornerstown marl. But where the yellow-sand phase is developed *Terebratula harlani*, a *Gryphæa*, and other pelecypods belonging to the same genera as the forms occurring in the Hornerstown shell bed are found in association with forms characteristic of the calcareous phase of the formation, thus furnishing a sufficient reason for placing the Hornerstown and Vincentown in one paleontologic group in which might also be included the overlying Manasquan.

Thickness.—The thickness of the Vincentown sand in the vicinity of New Egypt is probably not more than 60 to 70 feet. Farther southwest its thickness is rarely more than 25 feet along the line of outcrop, although in some places it has been been penetrated in wells to a depth of more than 100 feet at points not far down the dip.

Name and correlation.—The Vincentown sand received its name from Vincentown, N. J., near which the calcareous phase is typically developed. It was included by Cook as a part of his Middle marl.

Stratigraphic relations.—The Vincentown sand rests conformably upon the shell bed at the top of the Hornerstown marl, and where the Cretaceous beds are all present in outcrop it is overlain conformably by the Manasquan formation. The Miocene beds, however, in many places overlap the Eocene and the higher Cretaceous formations and rest unconformably upon the Vincentown, or even overlap it also. It is also covered in places by the Pleistocene formations.

MANASQUAN FORMATION.

Areal distribution.—The Manasquan formation occurs along the south branch of Crosswicks Creek and tributaries 2 miles south of New Egypt, where a number of abandoned marl pits afford somewhat meager opportunity for its examination. Beyond the limits of the Trenton quadrangle it has been observed near Long Branch, Farmingdale, Pemberton to Vincentown, Medford, Clementon, and farthest southwest along Swedes Run in Mannington Township, Salem County. These widely separated outcrops indicate its continuous extent across New Jersey beneath the overlapping Miocene beds.

Lithologic character.—In its lower part (13 to 17 feet) the formation is, like the Navesink and Hornerstown marls, composed chiefly of glauconite, dark green in color and mixed with more or less clay and sand. Its upper portion (8 to 12 feet), however, is made up of very fine sand mixed with greenish-white clay, flaky in structure and containing little or no glauconite. Piles of this marl look much like heaps of ashes, hence the local name ash marl.

Paleontologic character.—The fossils of the Manasquan are not abundant, and are in places poorly preserved. Small, simple horn corals are conspicuous elements in the fauna, the commonest of which, *Flabellum mortoni*, is also present in the Hornerstown. *Terebratulina atlantica* and *Caryatis veta* are two other forms which recur from the Hornerstown, while the latter is also present in the Vincentown, according to Weller.

Thickness.—The thickness of the Manasquan formation was given by Cook as 13 to 17 feet for the lower green marl and 8 to 12 feet for the ash marl, and these figures are undoubtedly correct, as his observations were made when the bed was exposed at many pits. Present exposures do not permit accurate measurement of its thickness.

Name and correlation.—The formation, first separated by Clark, derives its name from Manasquan River in Monmouth County, N. J., along which it was formerly extensively dug. It corresponds to the green and ash marls of Cook's Upper marl and is the youngest of the Cretaceous formations exposed in New Jersey.

Stratigraphic relations.—The Manasquan formation probably rests conformably upon the Vincentown, although this relationship can nowhere now be seen. At some pits it was seen to be overlain without apparent unconformity by a bluish marl of Eocene age, but at most exposures it is unconformably succeeded by Miocene or Pleistocene deposits.

Correlation of the Hornerstown, Vincentown, and Manasquan.—The faunas of the Hornerstown, Vincentown, and Manasquan are closely related in their important elements, although a large foraminiferal and bryozoan element is limited to the lime-sand phase of the Vincentown; and they form a larger fauna sharply separated from the fauna of the other Cretaceous beds beneath. This fauna appears to have its typical development in New Jersey and has not been recognized south of Maryland. As was pointed out earlier by Clark, it shows certain affinities with the lower or Maestricht division of the Danian series of western Europe. In particular, the bryozoan fauna of the Vincentown shows a remarkably close relationship to the bryozoan faunas of typical Maestricht beds.

TERTIARY SYSTEM.

The Miocene is the only division of the Tertiary certainly known to be represented by deposits within the Trenton quadrangle. The Eocene, which is shown at a few points to the northeast, does not occur in the quadrangle and beds referable without question to the Pliocene are also absent. In the southeastern part, however, there are outliers of a widespread formation, the Cohansey, which in the absence of fossils can not be referred positively to either the Miocene or the Pliocene.

SUBDIVISIONS.

The known Miocene deposits of the quadrangle comprise a part only of the extensive series of beds so characteristically developed along Chesapeake Bay and its tributaries and known as the Chesapeake group. In that region they are divided into three formations, which are, from below upward, the Calvert formation, the Choptank formation, and the St. Marys formation. Within the area of the Trenton quadrangle two divisions have been made of the Tertiary beds, the Kirkwood and the Cohansey, the former certainly of Miocene age, corresponding in part at least to the Calvert formation of Maryland and Virginia.

The Cohansey is unconformable with the Kirkwood and may represent a horizon higher than the St. Marys, as beds of similar lithologic character are found to the southeast in New Jersey above strata carrying fossils recognized only in beds of St. Marys age farther south. On the other hand, in Maryland the Choptank formation presents lithologic characters not unlike those of the Cohansey and rests unconformably on the Calvert. In the absence of fossils, however, it is not possible to determine positively between these two possible assignments.

KIRKWOOD FORMATION.

Areal distribution.—In the Trenton quadrangle the Kirkwood formation occurs in a number of isolated outliers on the crests of upper slopes of hills, as a narrow band along the flank of the high ridge from Lewistown to Sykesville and Jacobstown, and along streams. Arney Mount, the hill near Juliustown, and that southeast of Imlaystown are the most important outliers. In adjoining quadrangles the Kirkwood extends in a belt of variable width from Asbury Park and the head of Barnegat Bay at the northeast to the shores of Delaware Bay.

Lithologic character.—The Kirkwood of the Trenton quadrangle is principally a fine quartz sand usually somewhat micaceous and in places delicately banded in shades of salmon pink and yellow. Black lignitic clays are abundant at or near the base, and some yellow clayey layers occur at other horizons. Locally, thin beds of coarse sand or even fine gravel occur immediately at the base. In the region southwest of this quadrangle the lower sand has in some places been converted to nodular masses of quartzite by the infiltration of silica. The bull's head bowlders of quartzite which occur on the surface from which the Kirkwood has been eroded are believed to have been derived from this formation.

Farther southwest, in Salem County, N. J., the Kirkwood changes considerably in character. A fine, loose, somewhat glauconitic sand occurs near the base, above which there are several feet of very soft micaceous sand and clay, with a soapy talclike feeling; it is snow white where pure, but is not uncommonly stained with iron. Above this sand there is an 80 to 90 foot bed of clay, chocolate to drab and locally black in color. It is cut by many joint planes into small cubes, many of the joint faces being covered with thin crusts of iron oxide. Borings show logs of lignite, leaf beds, and considerable lenses of sand occuring within the clay, although no sand layers are recognized within its area of outcrop. Locally it is fossiliferous, but fossils are not common. Above the clay there is a bed of brown clay and fine, clayey gray sand containing great numbers of shells. The latter is known only from openings along the headwaters of Stowe Creek and its tributaries, and has been often described by earlier writers as the Shiloh marl. It forms the upper member of the Kirkwood formation in the region in which it occurs.

Paleontologic character.—The Kirkwood formation is not markedly fossiliferous, except that part known as the Shiloh marl member, from which a large fauna of over one hundred species has been described (Whitfield, Mon. U. S. Geol. Survey, vol. 24). It contains the characteristic fauna of the Calvert formation of Maryland and Virginia.

Thickness.—The thickness of the formation within this area varies from a few feet up to 100 feet or more. To the southwest the thick clay bed about Woodstown and Alloway is at least 80 feet thick, while locally the Shiloh marl member has been penetrated for 30 feet and the talclike sand reaches 10 feet.

Name and correlation.—The name Kirkwood is taken from the small village of Kirkwood, Camden County. The formation is probably to be correlated with the Calvert formation of Maryland, the fauna of the Shiloh marl being closely related to that of the Plum Point marl of Maryland and the lower fine micaceous sand probably corresponding closely to the Fairhaven diatomaceous earth of that region, although no diatoms have yet been found in it.

Stratigraphic relations.—The Kirkwood formation rests unconformably upon the various Cretaceous beds, chiefly the Vincentown and Hornerstown, but in some outliers it covers even lower members, while farther northeast the Eocene appears beneath it.

No evidence of unconformity between the Cohansey sand and the Kirkwood formation can be detected in exposures where both are shown, and in many respects they appear to grade into each other, but, when their larger relations are considered, the Kirkwood appears to be overlapped by the Cohansey. Similar relations exist in Maryland between the Calvert and the Choptank.

COHANSEY SAND.

Areal distribution.—The Cohansey sand appears in the southeastern part of the Trenton quadrangle as a series of outliers capping several isolated hills and a long curving ridge near Sykesville. Southeastward it outcrops in a broad belt and, except for discontinuous areas of Pleistocene gravels, forms the surface over a wide area of the Coastal Plain.

Lithologic character.—The Cohansey is primarily a sand formation, but it contains some gravel and locally considerable beds of clay, none of the latter, however, occurring within the

Trenton area. The sand is predominantly coarser than that of the Kirkwood, and the grains are in places so coated with clay that when moist it readily compacts; other beds are so clean that they are extensively utilized as glass sand. The fine, micaceous, mealy sand with delicate pink and buff mottlings common in the Kirkwood is rarely or never found in the Cohansey. The gravel of the Cohansey consists of pebbles of quartz, chert, and quartzose sandstone ranging from one-fourth inch to 1½ inches in diameter, with angular to subangular forms.

Paleontologic character.—No fossils have been found in the Cohansey in the Trenton quadrangle, but Hollick (New Jersey Geol. Survey, vol. 6, pp. 138–139) reports 50 species of plant remains in collections obtained near Bridgeton, representing a flora comparable with that of certain European upper Miocene localities; and he regards the sand as either late Miocene or Pliocene. Obscure casts of molluscan shells have been found in it near Millville.

Thickness.—In the outliers within this area the formation probably does not exceed 40 to 50 feet in thickness, but this is only a fraction of its original thickness, which was certainly more than 200 feet.

Name and correlation.—The formation takes its name from Cohansey Creek, Cumberland County, N. J., along which it is well developed. It corresponds to the sand member of the Beacon Hill formation, as formerly described in the New Jersey reports. Data regarding its age are indefinite and in a measure contradictory. Paleobotanic evidence favors its reference to the late Miocene or Pliocene, while the scanty paleozoologic data are indecisive. At its outcrop it rests on the Kirkwood without apparent unconformity, but farther southeast beds of similar lithologic character overlie strata bearing a St. Marys fauna, and it is, therefore, apparently unconformable with the Kirkwood.

Stratigraphic relations.—The Cohansey is overlain unconformably by the Quaternary formations, while its relations to the Kirkwood are slightly in doubt, although it is apparently unconformable. Its dip is to the southeast, its base declining from 100 feet above sea level at Grenloch, southwest of this quadrangle, to about 390 feet below sea level at Atlantic City—a descent of 490 feet in 45 miles, or 11 feet per mile.

The strike of the beds conforms in a general way to that of the underlying Cretaceous formations, northeast to southwest, although northeastward across New Jersey higher members of the Cretaceous and finally Eocene beds appear from beneath the Kirkwood, showing that the strike of the Tertiary formations is a little more to the east than that of the Cretaceous beds.

QUATERNARY SYSTEM.

By Rollin D. Salisbury.

GENERAL STATEMENT.

The Quaternary system of the Trenton region contains the record of two dominant processes—namely, erosion and deposition. While these two processes were probably contemporaneous in the region at all stages of the period, there were times when erosion predominated and sedimentation was subordinate, and times when deposition predominated and erosion was subordinate. The stages when deposition was dominant are at least three in number, and they were separated and each was followed by stages when erosion exceeded sedimentation.

This alternation was the result of two general conditions—namely, variations in climate and variations in the altitude and attitude of the surface here and in adjacent regions. The variations in climate were connected with the development and dissolution of the several ice sheets which affected the northern part of the continent, for though these ice sheets did not reach the Trenton area they approached its northern border closely at more than one stage of the glacial epoch, and the melting of the ice increased the amount of water which flowed through the region. Furthermore, the cold of the glacial epochs doubtless reduced greatly the amount of vegetation for some distance from the border of the ice, so that the run-off was more than usually effective in eroding the surface of the land which was above grade. Under these conditions the slopes and the uplands, as well as the ice to the north, furnished the streams with abundant débris, which they brought down through valleys of low gradient, leaving much of it and developing wide alluvial plains comparable to those now being formed along the low-gradient courses of many streams which carry the waters of melting glaciers or abundant sediment from other sources.

It is probable that there were slight changes in the altitude of the land as the period progressed. These changes seem to have been such as to decrease the gradients of the streams as they approached the sea, and perhaps such as to stimulate erosion in their upper courses at the same time. It is probable that at one time and another during the Quaternary period portions of the larger valleys were drowned, and that the sea crept up on the low borders of the land to a slight extent; but within the area of the existing land marine deposits seem to have been subordinate to those of terrestrial formation, so far as present evidence shows.

Three formations are recognized in this area, representing the three stages when deposition predominated. The oldest of the three, the Bridgeton formation, is represented by remnants so meager that their correlation would not be clear if this area were considered by itself. The second, the Pensauken formation, is more widespread, having suffered less erosion. The youngest, the Cape May formation, is of late (Wisconsin) glacial age.

It is to be distinctly borne in mind that in the erosion interval between the Bridgeton and the Pensauken there was more or less deposition, and that the valley and slope accumulations of this time are not readily separated from the main body of the Pensauken. Under the heading of unclassified deposits on the maps is included surficial material that can not be assigned to any one of the above formations, having been in part worked over by water or wind. It is usually thin and discontinuous. Similarly, there was more or less deposition during the post-Pensauken stage, when erosion was the dominant process of the region; and the valley fillings and basal slope accumulations of this stage are not readily separated, in all cases, from the Cape May formation on the one hand or from the Pensauken on the other.

BRIDGETON FORMATION.

Deposition.—The meager remnants of the Bridgeton formation in this portion of New Jersey appear chiefly in the southeastern part of the area under discussion. They are thought to be all that remains of a stratum of gravel and sand which once overspread most of the quadrangle east of Delaware River. Besides these remnants a hill 2 miles northeast of Lawrenceville, which has an elevation of 201 feet, is capped with gravel that is probably a remnant of the same formation, though its constitution would seem to ally it with the Lafayette formation, rather than with the Bridgeton, if the two are not the same. As the remnant is very meager and the exposures poor, it is impossible to make certain correlation.

In constitution the Bridgeton formation is essentially like the Pensauken, and as the latter is much better developed, this point will be discussed in connection with that formation. In spite of its likeness to the Pensauken, the topographic position and relations of the Bridgeton formation indicate that a long period of erosion followed its deposition before the Pensauken formation was laid down. Its separation from the Pensauken is therefore primarily topographic.

Quartzite bowlders, even 3 or 4 feet in diameter, occur on the surface at various points south of Pennington, up to elevations of 200 feet or so. These bowlders are not unlike those in the base of the Pensauken and Bridgeton formations, and it is probable that they belonged to the latter and that they are the only parts not removed by erosion. Near the northern border of the quadrangle, in the valley of the Delaware, between Raven Rock and Byram, bowlders of similar character and in similar topographic positions have been found, bearing glacial striæ. This fact, together with the size of some of the bowlders in the Bridgeton formation far to the south, has led to the belief that floating ice derived from glaciers affected the region when the Bridgeton formation was deposited. If this conclusion is correct, the ice was probably the earliest of the several Pleistocene ice sheets of which there is record.

Erosion.—After the deposition of the Bridgeton formation either the area where it had been laid down stood somewhat higher than before or the streams carried less load, or both, and an interval of erosion ensued. This interval was long, for east of the Delaware within this quadrangle the Bridgeton formation was mostly removed and broad, shallow valleys were developed in the Cretaceous formations beneath. It is true that both the Bridgeton formation and the Cretaceous beneath were relatively weak and that valleys may have developed in them rapidly, but even so the time necessary for the results accomplished was long.

An epoch followed when the streams flowing through these wide valleys carried heavy loads of débris, much of which was deposited, and the materials then laid down constitute the Pensauken formation.

PENSAUKEN FORMATION.

The widespread Pensauken formation consists, for the most part, of unconsolidated gravel and sand, most of which in this region is below tne level of 130 feet, though here and there it rises to 150 feet or even a little more. It probably once covered almost the whole of the area south of the outcrop of the Newark group, and it overlapped the southeastern border of that group up to the present altitude of 130 feet or more. The dissevered condition of the formation is the result of erosion, which has removed it from a large part of the area that it once covered.

Constitution.—Sand predominates over material of larger size in the Pensauken, but gravel is common and bowlders can hardly be said to be rare, especially at the base. At the top the material is in places loamy, the loam being due partly to the original constitution of the uppermost part of the formation, partly to weathering, and partly to subsequent deposition.

The Pensauken formation has two somewhat distinct phases with intermediate gradations. At the northwest it is somewhat arkose and contains some material derived from the pre-

Paleozoic and Paleozoic rocks to the north and some from the Newark group, closer at hand. With these materials whose place of origin is determinable there is much finer sediment of unknown origin and some which comes from the Cretaceous system. To the southeast the materials of northern origin diminish and finally disappear and materials derived from the Cretaceous and Tertiary deposits are the only ones which can be identified. The line which separates the two phases of the formation runs from a point about 2 miles southeast of Hightstown through Extonville, Mansfield, and Jacksonville to Centertown (1 mile south of Rancocas). The material of the formation may therefore be said to have come from two principal sources: (1) From the north, from the Newark group and from formations still farther north, and (2) from the south and east, from the Cretaceous and Tertiary formations.

Coarse material is more common in the arkose than in the nonarkose phase of the formation and is confined essentially to its base. The coarse material from points north of the Coastal Plain is in many places confined to the lowermost foot of the formation. In general, it is probably safe to say that nine-tenths of such material is in the lowermost 5 feet. Shale and sandstone from the Newark group are so widespread as to be characteristic. In general, material from this source is more abundant near the outcrops of the Newark group, though this rule is not without exception. Thus near Allentown, about 9 miles from the nearest outcrop of the Brunswick shale, there is as much of this material in the gravel as at Clarksville, where the formation lies directly on the Newark.

In general, all the materials of the formation are decomposed so far as is possible under the influence of atmosphere and water. Soluble constituents, such as carbonates, are lacking, and all ingredients appear to be oxidized and hydrated to the fullest extent. The original feldspar of the sand and gravel of the arkose phase has, as a rule, been completely kaolinized Pebbles and bowlders of crystalline rock (schist, gneiss, granite), unless of large size or largely of quartz, are almost always decayed to the core. The same is true for small masses of diabase ("trap") from the Newark group.

Another characteristic constituent of the gravel in some places, especially toward the east and southeast, is ferruginous sandstone derived from the cemented layers of the Cretaceous or later formations of the Coastal Plain. Chert is another common constituent of the gravel, and it is generally soft. Vein quartz abounds and generally retains its hardness. Pebbles, cobbles, and even bowlders of quartzite are found throughout the area and are the hardest and most resistant of the coarse materials entering into the formation. Owing to the decayed condition of many of the pebbles and stones of the coarser parts of the formation, it makes good road material, and numerous gravel pits occur at short intervals throughout its area, especially northwest of the line separating its two phases.

Base of the formation.—The formation, so far as this area is concerned, appears to have been laid down on a broad plain of erosion, most of which now stands at an altitude of 80 to 100 feet. The surface, however, was not without relief. It declined toward the Delaware, and it also declined toward an axis running northeastward from Trenton through Baker Basin to Port Mercer and beyond.

To judge from the configuration of the base of the formation, the Delaware seems to have been the master stream in pre-Pensauken time, as now. The surface was within 20 feet or so of present sea level at Trenton when the Pensauken formation was deposited, and the valley northeast from Trenton to and beyond Baker Basin was nearly as deep. Its axis was a little to the southeast of the contact of the Newark and Cretaceous deposits. Its old bottom is now less than 50 feet, and perhaps as low as 30 feet, above sea as far northeast as Port Mercer. This seems to make it clear that a large stream followed this course in pre-Pensauken time.

The tributaries of the Delaware and those of the northeast-southwest valley above Trenton followed, in a general way, the directions of the present streams; that is, they flowed from southeast to northwest. The tributary valleys were less deep than the main ones, as was appropriate. The plain of erosion on which the Pensauken deposits were laid down and from which the Bridgeton formation had been removed had a relief of 60 to 80 feet.

The southeastern border of the well-defined body of the formation was a former low scarp which extended from Swedesboro, southwest of this quadrangle, through Jacksonville and Allentown and beyond; but deposition took place to some extent in the valleys leading down from the higher lands to the southeast.

Isolated remnants.—A remarkable remnant of the Pensauken formation is found at Kingston, just south of the narrows, where Millstone River cuts through a diabase ridge, flowing north. The material of the Pensauken formation at this place is very much coarser than at any other point within the area, It consists of coarse gravel, in which there are bowlders up to 1½ feet in diameter. The gravel is remarkable for its compactness and coherence, vertical faces 40 feet high having stood for years with but little accumulation of talus at their bases. The proportion of crystalline-rock material is larger than elsewhere and nearly all the cobbles are decomposed to the core, so that the vertical face of the formation shows the broken faces of hundreds of cobbles and small bowlders. It is, indeed, rather uncommon to find a piece of crystalline rock which does not crumble readily under the hammer, or even in the hand.

This material came from the north and was apparently deposited by a stream flowing south. Escaping the narrow valley through Rocky Hill, this stream left its load of gravel, etc., where it entered its broader valley with lower gradient, south of the hard ridge. The precise course of the stream south of Kingston is not certainly known. It may have been southward to Princeton Junction and thence over to Fort Mercer, or, less probably, up the course of the present Stony Brook to Port Mercer.

A few remnants of the formation exist in the Delaware Valley above Trenton, as at Washington Crossing, Titusville, and Raven Rock. In these localities the remnants constitute or cap rude terraces well above the more modern deposits to be noted later. At several other points traces of the formation are found in similar situations, suggesting that it was once somewhat generally present along the Delaware Valley.

There are various isolated patches of the Pensauken formation east of the Delaware Valley, on the Brunswick shale, several miles north of Kingston. The correlation of most of these remnants is not beyond question, and it is possible that some of them may be older than Pensauken. The same may be said of some of the small areas mapped as Pensauken at high levels in the southeastern part of the quadrangle. They are higher than the main body of the formation, and they may be of Bridgeton age or, more probably, they may represent local accumulations of débris in the post-Bridgeton erosion interval. It would be expected, however, that the streams descending from the higher lands to the southeast in Pensauken time would, if making deposits at all, leave gravel and sands at levels considerably higher than those where similar deposits were made in the main valleys.

Thickness.—The present thickness of the formation varies from about 50 feet in the area between Allentown and Newtown, to practically nothing, and the original variation was probably about the same. The slight thicknesses are due in some places to subsequent erosion and in others to unequal deposition, especially where the formation buried the low hills which rose above the general level of its base. When the deposition of the formation was completed, most of the surface which it covered appears to have been built up to planeness, or nearly so, and this plain, had it not been degraded, would now have lain between the present levels of 130 and 150 feet. The formation extended up the valleys to somewhat greater heights.

Origin.—The Pensauken formation is believed to be in large part of subaerial (fluvial and pluvial) origin. So far as this area is concerned, the Delaware and its tributaries may be said to have been the principal agents of deposition, and the tributary from the north by way of Kingston was perhaps but little less important than the Delaware itself. The sources of this stream were probably in the upper drainage basin of the Raritan. Both the Delaware and the drainage from the Raritan basin came from the area affected by glacier ice, and the coarse material of the formation leads to the conclusion that floating ice and swollen streams were concerned in its transportation.

While this material was being brought down from the north and deposited in the valleys of the larger streams, the drainage from the southeast was bringing in sand, gravel, etc., from the Cretaceous and Tertiary sands and marls. The aggradation of the main valleys obstructed the tributaries and stimulated aggradation in them. It is possible, perhaps probable, that the area where the Pensauken sediments accumulated was a little lower than now, relative to sea level, when the deposition took place. It is even possible, so far as now known, that the lower parts of the region may have been partly submerged at some time during the accumulation of the formation; but in the absence of distinct paleontologic evidence this conclusion is uncertain, and there are other reasons for thinking that the main part of the deposit, at least, is of fluviatile origin. Not many miles below the southern border of this area fresh-water fossils are found in the Pensauken down nearly to sea level.

Erosion.—After the deposition of the Pensauken formation conditions so changed as to bring about an epoch of erosion. It is not known how far this was the result of change of altitude of the land and how far the result of decreased load of the streams, incident to climatic changes and the disappearance of the ice. Whatever the cause, the erosion continued long enough to allow the streams to deepen their valleys somewhat below their present levels and to widen the valleys of the larger streams. The Pensauken material deposited in the pre-Pensauken valleys, was not, however, all removed. Some of it still remained in the Delaware Valley and in the lower parts of some of its tributaries at the close of this erosion interval.

After this very considerable erosion had taken place, another period of sedimentation ensued, and the deposits made constitute the Cape May formation.

CAPE MAY FORMATION.

Distribution.—The Cape May formation is confined largely to the valleys of the present streams. During its deposition the valleys were aggraded, the larger ones as much as 30 to 40 feet. Aggradation was greatest where erosion had been greatest—namely, in the valleys of the larger streams, such as the Delaware.

This period of aggradation was in part at least contemporaneous with the ice of the last glacial epoch. The Delaware was bringing down quantities of gravel and sand from the moraine at Belvidere, and much of it reached the latitude of Trenton. Here, where the valley of the Delaware was wide, the heavier part of the load of the stream was spread widely over the low plain at the junction of the Delaware with the valley from the northeast. The result was that a wide area was overspread with gravels of late glacial age brought down from the edge of the ice. Little glacial gravel was carried far below Trenton, though traces of it are found to the southern limit of the quadrangle and even beyond. This gravel has long been known as the "Trenton gravel." When its deposition was completed glacial gravel filled the valley of the Delaware up to a level now 120 feet above the sea at the northern border of the quadrangle. From this maximum height the gravel now slopes to 100 feet at Lambertville, 60 feet at Trenton, and about 30 feet at Burlington. This slope if continued would reach sea level at about the southwest corner of the quadrangle and the Cape May formation would occupy the position of a delta.

One of the remarkable features of the distribution of this gravel is that it was spread widely and abundantly east and northeast of Trenton to Baker Basin and beyond. The conditions of drainage which made this distribution possible are not altogether clear. It seems probable that at some time during this stage of deposition drainage came down from the north, up the present valley of the Millstone, bringing with it a little gravel of late glacial age, for traces of such gravel are found along this valley at several points between the junction of the Raritan and the Millstone, 3 miles north of this quadrangle, and Penns Neck, near Princeton. This suggests that some of the gravel of the Baker Basin region came in by this route; but the meager traces of gravel along this valley are hardly consistent with this hypothesis. The traces of late glacial gravel along this valley are, however, of interest as indicating a former course of drainage. It is not thought that this old course, apparently followed by a stream in Pensauken time, was followed by a river continuously up to the close of the Cape May epoch, but rather that the drainage from the upper basin of the Raritan was toward Raritan Bay in post-Pensauken time and was temporarily turned back to its older course in late glacial time, after deposits from the ice had aggraded the valley of the Raritan in the vicinity of Bound Brook.

About Trenton and at some other points in the lower courses of the tributaries below Trenton the Cape May deposits rest on remnants of the Pensauken formation which had not been entirely removed from the valleys when the deposition of the Cape May began. The superposition of this gravel on the Pensauken formation has been seen at Trenton, for example, in several temporary excavations, where the relations were unequivocal. The same relations have been seen in the Delaware Valley farther south, on both sides of the stream. These sections show the impossibility of defining this formation by topography alone.

While the valley of the Delaware was being filled with glacial gravel from the north, the aggradation tended to obstruct the tributary valleys. At the same time it is assumed that the climatic conditions favored ready erosion, especially by effecting a reduction in the amount of the vegetation. The result appears to have been that the tributary streams gathered sediment readily in their upper courses, but found themselves unable to carry it through their lower courses. Aggradation of the side valleys was the result, and this aggradation appears to have kept pace, essentially, with the upbuilding of the bottom of the main valley. The sediments of the side valleys were, however, unlike those of the main valley. The latter were derived partly from the north, from the Newark and older rocks, while the former were contributed by streams flowing through the Cretaceous and Tertiary sands, marls, and clays and the Bridgeton and Pensauken sands and gravels.

In the Cape May formation, therefore, we have a twofold subdivision, comparable to that of the Pensauken. In this case, however, the phase derived from the north was much more narrowly restricted than the corresponding phase of the Pensauken formation. Furthermore, the deposition of the Cape May formation is so recent that the perishable constituents have not yet decayed to any great extent, and the two formations are in sharp contrast, so far as their physical condition is concerned.

The Cape May sediments in the side valleys are very like the Pensauken sediments of the same region. They have, however, a fresher look, have been less ferruginated, are less commonly cemented by iron oxide, and contain more fragments of ferruginous sandstone from cemented layers of the Cretaceous, Tertiary, or early Quaternary deposits of the region.

The Cape May deposits in the tributary valleys rise upstream, like the deposits of Pensauken age, previously outlined, and all other stream deposits. In the upper courses of the tributaries they may rise to an elevation equal to that of the Pensauken. In such places the separation of the two may be difficult, especially in the absence of good exposures, but as a rule the topographic relations make the correlations clear.

It seems possible that the surface may have been a little lower than now at some stages of the Cape May epoch. If so, this checked the streams in their lower courses and favored deposition there. Decisive marine fossils have not been found at any point in this area, but they have been found farther south in New Jersey, up to elevations of 10 feet or so above the sea, showing that the sea water stood a little higher than now during some part of the epoch, at least in the southern part of the State. Topographic features at various points about the shore of New Jersey suggest that the land may have been depressed as much as 30 or possibly 40 feet during this epoch.

A few miles south of this quadrangle fossil marine diatoms have been found in the loam overlying or constituting the top of the Cape May formation, up to elevations of about 60 feet. They are, however, not regarded as decisive of submergence, for they are easily blown about and might be carried far inland and well above the sea by the wind.

Erosion.—After the deposition of the Cape May formation renewed activity of the streams resulted in the partial removal of the newly deposited gravels and sands. The remnants of the old plains of aggradation now remain as terraces, locally ill defined. Terraces below the original Cape May level have been developed in some places, especially in the Delaware above Trenton, and lie above the present flood plains. Above Trenton little of the original plain of deposition remains, but in the vicinity of Trenton the wide plain of the Cape May formation is near the level at which it was laid down.

UNCLASSIFIED GRAVELS AND SANDS.

Considerable areas of the quadrangle are shown on the geologic maps as having a covering of surface sediment, the classification of which is not evident. The material so marked on the map is sand and gravel, not notably unlike that of the other formations, or in some localities not very unlike the weathered part of the underlying terrane. Much of this unclassified gravel and sand is thin, and in many places it does not wholly conceal the Cretaceous or Miocene beds beneath. It is of various ages. Some of it probably represents local accumulations during the post-Bridgeton erosion interval and some of it is to be referred probably to the post-Pensauken epoch, while in other places remnants of Bridgeton, Pensauken, or Cape May, whose relations are not clear, may be included.

Included in this division is some peculiar sand south of Doctors Creek between Imlaystown and Allentown, east of Crosswicks Creek between New Egypt and Walnford, south of the same creek for about 3 miles west of Walnford, and along Blacks Creek between Jacobstown and Chesterfield. It has somewhat the disposition of dune sand, and its surface has been much modified by the wind, but Mr. G. N. Knapp thinks it is not primarily of eolian origin.

EOLIAN SAND.

In recent times the wind has blown sand and loam about to some appreciable extent. Dunes are nowhere conspicuous, but there is some wind-blown sand at many points, as north of Bordentown, in the vicinity of Stevens, about Burlington, Sykesville, and elsewhere.

In many places there is a little eolian sand and loam on the bluffs bordering the Delaware. Such deposits occur at various points about Trenton. They are rarely more than 2 to 4 feet deep, but are in places sufficient to make a little ridge or swell along the edge of the bluff, high enough to be readily detected in this region of slight relief.

In other places eolian sand and loam are found on slopes, as at various points above Trenton. In most such situations the eolian material has a disposition comparable to that of the loess in the valleys of the interior. The material is, however, not loesslike. Most of it appears to have been blown up from the modern flood plains, or from the edges of the Cape May terraces, in the course of the degradation which gave rise to them.

SURFACE LOAM.

At numerous points in the area there is a loam which constitutes the latest phase of deposition. It lies on the Cape May terraces and on the Pensauken at various levels and is distinct and conspicuous at some points on the Brunswick shale, especially along the Delaware and between Trenton Junction and Pennington. Locally, as near Pennington, it is used for brick clay. The origin of the loam is not clear. It is not altogether the product of decay of the underlying formation. It is possibly wind blown, but locally it has a structure which seems to preclude this as the complete explanation. The view has been entertained that it might represent a temporary submergence of the region subsequent to the Cape May epoch or at its close, but the evidence supporting this view is not convincing. So far as now known, the loam may have originated in various ways and at various times, in spite of its appearance of unity.

STRUCTURAL GEOLOGY.

PIEDMONT PLATEAU AREA.

STRUCTURE IN THE PRE-TRIASSIC ROCKS.

By F. Bascom.

GENERAL STATEMENT.

The prevailing structural features of the Piedmont Plateau are major folding of the Appalachian type, forming anticlinoria and synclinoria which extend for long distances northeast and southwest and are roughly parallel; gentle minor folding at right angles to the major folds; normal and thrust faulting of varying magnitude; and a very complete metamorphism of the formations, associated with the production of cleavage and fissility.

A small portion of the Plateau is covered with Triassic sediments and with outliers of the Coastal Plain deposits, whose freedom from metamorphism and structural simplicity are in striking contrast to the complexity of the crystalline floor upon which they rest.

The structures of the crystalline formations are due to compressive force acting in a northwest-southeast direction normal to the strike of the major folds; and the gentle transverse folding is due to a minor force acting at right angles to this major force.

While much remains to be accomplished in the mapping of these major anticlines and synclines in their extension throughout the Piedmont Plateau, some well-defined folds have been recognized. One anticline extends from the neighborhood of Cabin John, on the west of the Washington quadrangle, where it has been traced by Keith, northeastward through Maryland, where it has been mapped by Mathews, into Pennsylvania, where it shows itself in the Buck Ridge anticline. East of this anticline two synclines and an anticline have been partly traced in Maryland and the District of Columbia; they are not well defined in the Trenton district. West of the Cabin John–Buck Ridge anticline is a synclinal basin which is clearly marked in Pennsylvania and Maryland. In Pennsylvania it is the Chester Valley syncline. It passes through Maryland in the neighborhood of Cardiff and was recognized by Keith in the Washington area just west of Great Falls.

The Cambro-Ordovician sediments of the whole width of the Piedmont Plateau, the Triassic formations which conceal a broad central area being ignored, apparently form an anticlinorium, which has brought to the surface pre-Cambrian gneiss along a central axis flanked by Cambrian quartzite, Cambro-Ordovician limestone, and Ordovician mica schist. The surface outcrop of these formations is interrupted parallel to the strike and is controlled in width by the minor folding which, alternately bending the axis of the anticlinorium in a low trough or raising it in a low arch, brings successively younger or successively older formations to the surface. There is, then, an anticlinorium compounded of anticlines and synclines of the first order, which are in turn composed of secondary and tertiary anticlines and synclines.

The secondary folds in the limestone and quartzite of the eastern portion of the Plateau are isoclinal in character and are uniformly overturned to the northwest, while in the gneisses and schists they are more varied, ranging from open and nearly symmetrical to inclined, overturned, or isoclinal folds. The folds are for the most part overturned to the northwest.

Normal and thrust faults are both found in the Piedmont district. The Triassic sediments, which were raised without folding or with slight folding and with a very gentle northwest tilt, for the most part show normal faults so numerous that they may be seen in every extensive exposure of the Triassic. It is impossible to ascertain their total number or the amount of displacement, which is locally very slight. They were developed in connection with the crustal movement which resulted in the uplift of the Triassic sediments and presumably are not confined to the present Triassic, but occur also in the adjacent crystallines. It is very difficult to trace such faults in the latter rocks, however, in the absence of well-defined beds.

Thrust faulting is the rule in the Appalachian structure and many important faults of the Piedmont Plateau are of this nature. Those that have been traced in the southern Piedmont area lie nearly parallel to the plane of schistosity of the formations; that is, they dip at a high angle. Adjustment by means of innumerable microscopic dislocations has also taken place along planes of schistosity, which are thus converted into planes of fissility.

STRUCTURE IN THE TRENTON QUADRANGLE.

The structure of the formations of the Trenton area is shown in three structure sections which are given on the structure-section sheet. The vertical and horizontal scales are the same, and the actual dips of the strata as they appear at the surface are incorporated in the sections. Of course, on the scale of the map the more detailed structures can not be shown, and all tertiary folds are omitted from the sections. Faults are represented on the map by heavy solid lines and in the sections by a solid line whose inclination shows the probable dip of the fault. The relative direction of the movement of the strata on either side of the fault plane is indicated by arrows.

The Baltimore gneiss and Chickies quartzite of the Trenton quadrangle are part of the Cabin John–Buck Ridge anticline of the first order on the southeast flank of the great anticlinorium of the Plateau. Of this primary anticline the quartzite is the southeast limb and is itself folded in a compressed secondary syncline. (See section C–C.) The northwest limb of the primary anticline is concealed beneath the Triassic cover. Upon the southeast flank of this anticline the Wissahickon mica gneiss has been thrust with a steep dip to the southeast. The evidence for the existence of such a fault consists in the absence on the southeast limb of the anticline of the sequence of sediments found on the northwest limb where that is exposed. Both the Cambro-Ordovician limestone and the Ordovician schist are missing, and the Wissahickon mica gneiss can only overlie the Chickies quartzite by means of a thrust fault. The mica gneiss is folded into crumpled and overturned anticlines and synclines which are parts of a primary anticline.

In the Trenton quadrangle the igneous material has intruded itself in irregular masses or chonoliths parallel to the strike of the axis of the major folds and is confined to the gneisses and the Franklin limestone. Minor folding transverse to the major folds is not apparent. In the Wissahickon mica gneiss there is usually a well-defined cleavage dipping steeply southeast, while the bedding planes may dip either southeast or northwest or may remain nearly horizontal. In the quartzite cleavage and bedding planes both dip steeply southeast. The average dip is 85° and the strike N. 75° E. The dip of the structure planes of the Baltimore gneiss adjacent to the quartzite is also steeply southeast, and the average strike is like that of the quartzite.

The Shenandoah limestone north of New Hope has been brought to the surface by normal faulting, as illustrated in section E of figure 2.

STRUCTURE IN THE TRIASSIC ROCKS.

By N. H. Darton and H. B. Kümmel.

GENERAL STATEMENT.

The Newark rocks in New Jersey present an extensive monoclinal structure with low dips to the northwest. The monocline gives place to local flexures in some portions of the region, especially in the Passaic Valley west of the Watchung Mountains and farther south in the vicinity of the western margin of the group. The monocline is also traversed by faults with throw of several thousand feet and many minor dislocations. The intrusion of the diabase has caused many local disturbances of the strata, partly by flexures and partly by dislocation, especially where the igneous rock increases in thickness or changes from one horizon to another. In the Trenton quadrangle the monoclinal structure is general over a wide area in which the strike is N. 30° E. and the dips mostly from 12° to 15°.

The beds of the Stockton and Lockatong formations are most constant in dip and strike, so that the monoclinal structure is most marked in their areas. The Brunswick shale region is traversed by shallow folds, some covering an area of several square miles. One of these occupies an area of moderate size south, east, and northeast of the Sand Brook sheet of basalt, where there is a shallow syncline prominently marked by the curved outcrop of the basalt. Several examples of sharp folds occur near Glenmoore and southwest of Hopewell, not far from the end of the Rocky Hill ridge.

Two great faults traverse the monocline; one of them west of New Hope is of such throw that it brings to the surface the Paleozoic floor. In places along the faults there is considerable local flexing of the strata.

STRUCTURE OF TRIASSIC ROCKS IN THE TRENTON QUADRANGLE.

DIPS AND FLEXURES.

Along the Delaware, between Trenton and Titusville, the shales and sandstones have an average dip of 12°, but the direction varies from N. 35° W. to N. 5° W. Near the diabase of Baldpate Mountain, north of Titusville, the dip increases to 20°. East from the river, toward Pennington and Lawrenceville, the dip varies from 10° to 22°, with an average of 15° or 16°, and has a general direction of N. 35° W., with many local variations. South of Rosedale the dip is as high as 40°, and thence eastward to Millstone River averages about 20°, with direction varying from N. 10° W. to due north.

Along Stony Brook, above and below the Lawrenceville pike, and along the pike itself there are great and abrupt changes of dip and strike within narrow limits, but good exposures are not sufficiently numerous to throw light on the structure. The strikes range from N. 30° W. to N. 70° E. and the dips from 10° to 50°.

North of Baldpate Mountain the dip of the shale varies both in amount and direction. In some places the strike is parallel to the outline of the igneous sheet, in others at right angles to it. In some exposures the beds dip toward the diabase and in others away from it.

In the brook just west of the south end of Pennington Mountain the shale is seen at intervals for half a mile dipping southward at an angle of about 20°. The dip then changes to northward, with an average amount of 10°. At one point along the stream the metamorphosed and crushed shale near the diabase forms a small indistinct anticline.

Between Pennington and Glenmoore the outcropping edges of the shale make a sharp S curve. A mile north of Pennington the strike is east and west and the dip 16° N.; half a mile south of Marshalls Corner the strike is N. 40° W. and the dip 37° SW; just north of Marshalls Corner the strike is N. 25° E. and the dip 30° NW.; at Glenmoore the strike is N. 65° W., changing gradually to N. 35° W., and the dip 30° NE.; northeast of Glenmoore the strike gradually shifts again to N. 35° E., with a dip of 12° NW.

Another small fold in the shale occurs 1½ miles southeast of Glenmoore, forming a shallow syncline, with axis inclined northward. The diabase of Rocky Hill, 1 mile north, cuts squarely across the strike of the beds in this fold.

FAULTS.

General features.—The Newark group in the Trenton area is traversed by two great faults with throws of several thousand feet and by numerous minor dislocations. These faults are not connected with flexures and are later than the igneous intrusions or flows. They trend northeast and southwest, partly parallel with the strike of the strata, but the larger ones cross the strike at small angles for part of their course. Except in a few minor faults the downthrow is on the southeast side. The direction and amount of hade are not known except for one small fault near Harbourton. In general the dislocations appear to be along a single plane, but locally there is a narrow zone of shattered rock. In places the strata are crumpled and upturned along the fault. Exposures of the faults are exceedingly rare, especially any which show the details of the dislocation.

Brookville-Flemington fault.—The great dislocation known as the Brookville-Flemington fault traverses the center of the Newark group along a general northeast-southwest course. Its principal features are shown in figure 2. A short distance west of Lambertville it brings to the surface the Paleozoic limestone floor in contact with beds high in the Brunswick shale. Here its maximum throw is probably not less than 11,000 feet, for it cuts off the entire thickness (6000 feet) of the Stockton and Lockatong formations and 5000 feet or more of the Brunswick shale. The limestone extends to Delaware River, where it passes beneath the basal conglomerate of the Stockton, and the fault, after crossing the river a few hundred yards south of Brookville, separates beds high in the Lockatong from basal Stockton beds. The fault branches a short distance west of the river and the branch dislocation passes southeast of Mount Gilboa, joining the main fault again a short distance south of Headquarters. By this means a long oval block is cut off, consisting on the surface mostly of Lockatong beds; it includes the Mount Gilboa intrusive mass and north of Dilts Corners overlies a small wedge-shaped mass of upper Stockton beds. Near Headquarters and Sand Brook the fault is single and has a displacement of about 8500 feet, bringing about 2600 feet of Brunswick shale into contact with lower Stockton beds. It cuts off the basalt of Sand Brook east of Sand Brook post-office. A short distance farther north the fault again branches and brings up an area of Lockatong shale, as shown in the upper section of figure 2. The strata in the middle block are considerably disturbed. For much of its course, the Brookville-Flemington fault extends along the foot of the Hunterdon Plateau escarpment. It is not clearly exposed at any point, but in its immediate vicinity the sandstone and shale are crushed, slickensided, and locally contorted.

In the north bank of Delaware River the fault is indicated by a slight notch in the bluff a few hundred yards south of Brookville. A few yards north is a ledge of coarse arkose; and 50 yards south a small quarry in crushed and crumpled black shale shows many slickensided surfaces and in part resembles a fault breccia. To the north the exposures of beds near the fault are poor and scattered, but on the west side rises a ridge of hard sandstone and conglomerate of the Stockton formation, which is cut off by the fault south of Headquarters. A second low ridge of harder sandstone is cut off by the fault east of Sergeantsville and a third one is terminated in the same manner northeast of Sand Brook. Northeast of Sand Brook, where the fault has brought the Lockatong argillites against the softer Brunswick shale, there is more marked contrast in topography than where the Stockton sandstone abuts against the shale.

East of Sand Brook the fault cuts off the west side of the shallow syncline of the Brunswick formation, probably causing the northwestern termination of the small sheet of extrusive basalt included in the shale in this flexure. Local disturbances in strata near the fault are exhibited at various points in this vicinity, notably in a ledge of red shale below the mill pond at Sand Brook, where the dip is to the south at an angle of 45°, probably indicating downward drag toward the fault, which is supposed to pass a short distance south of the exposure. A mile northeast of this locality, in the bed of a brook near Thomas Dalrymple's, there is a ledge of crushed and bent black argillite traversed by many joints with slickensided surfaces. The fault is believed to pass near by.

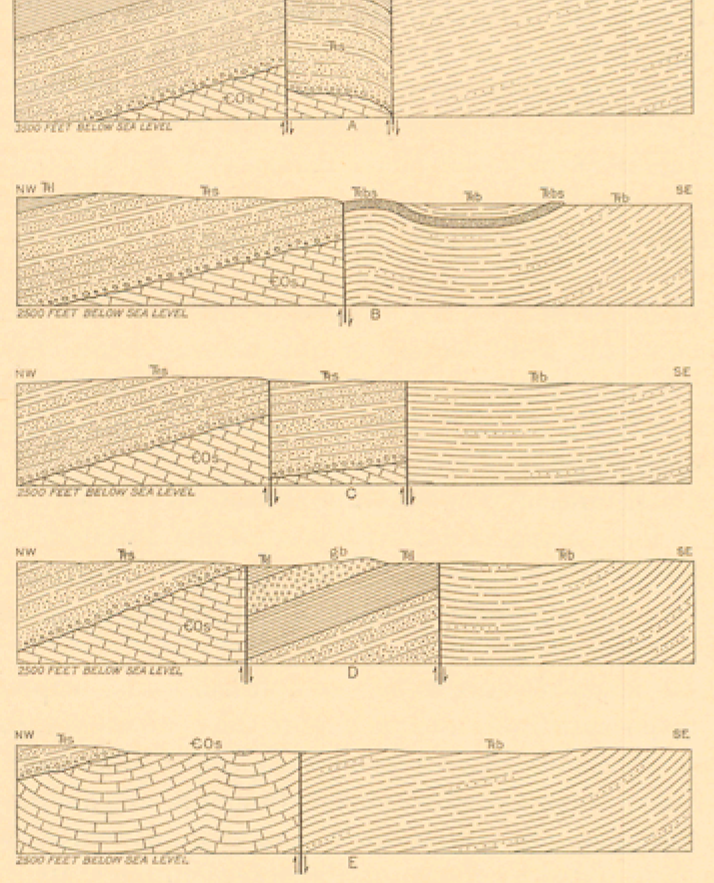

FIGURE 2.—Sections across the Brookville-Flemington fault: A, Northwest of Copper Hill; B, on Sand Brook; C, north of Dilts Corners; D, along north side of Delaware River; E, 2 miles southwest of Delaware River. Scale, approximately 1 inch = 2 miles.

COs, Shenandoah limestone; TRs, Stockton formation; TRl, Lockatong formation; TRb, Brunswick shale; TRbs, basalt flow. Hade of faults not determined, but probably steep.

Hopewell fault.—The Hopewell fault extends in a sinuous course from Buckingham Township, Pennsylvania, beyond the north end of Sourland Mountain. It crosses the Delaware near Moore and extends through Harbourton, west of Hopewell, and thence along the foot of the east slope of the Sourland plateau. In New Jersey the fault traverses the strata obliquely, and from Harbourton to Skillman the upper sandstones of the Stockton formation abut against the middle portion of the Brunswick shale with a maximum displacement of not less than 6000 feet in the vicinity of Hopewell and Glenmoore. The height and prominence of the Sourland plateau north of Skillman is due to the contrast in hardness between the Lockatong and Brunswick beds brought together by the dislocation, and quickly disappears as the fault crosses the strike and with diminishing throw passes out into Brunswick shale to the north. In Pennsylvania, where the fault is in Brunswick shale and of diminished amount, it is difficult to trace. It is believed to cut off the diabase in Jericho Mountain and to pass through the old baryta mine. The fault plane is nowhere exposed and in many places its location can not be determined within 50 feet. In the beds of streams evidences of the fractures are usually found in the crushed and slickensided condition of the rocks, and in a few localities the strata are steeply bent. Such features appear along the stream 1¼ miles west of Harbourton, near the end of the diabase ridge. In the bed of the first brook east of Hopewell, about 400 yards north of the railroad, a ledge of crushed and slickensided shale and sandstone is exposed, which dips 15° S. Twenty yards farther upstream the Stockton beds in the up-thrown block show the normal northwesterly dip, and downstream the Brunswick shale has a strike of N. 15° E. and a dip of 20° W. The fault passes a few yards south of the crushed beds. Similar phenomena occur in the bed of the next brook east, near the foot of the escarpment, not far from the house of David Labaw. Here the Stockton formation in the uplifted block has been dragged down at the fault line so that it dips 72° S. Along the Sourland Mountain road 2 miles southwest of Plainville, where the soft red Brunswick shale has been brought down against the hard dark-green Lockatong beds, there is striking contrast in color of the surface in the neighboring fields. Near the fault both rocks have been so completely crushed and afterward disintegrated that nearly all traces of the bedding planes are destroyed. Outcrops in the bed of Roaring Brook, southwest of Plainville, show the same kind of disturbance. East of the fault line in this vicinity the normal strike of the red shales is N. 55° W. and the dip 15° NE., while west of the fault the strike of the Lockatong beds is N. 75° E. and the dip 15° NW. Five-eighths of a mile west of the Plainville-Skillman road the black shale dips southeast at an angle of 45° and is considerably crushed. For 200 yards up the brook exposures of contorted beds, with slickensided surfaces parallel to the great fault, show that the beds have been much disturbed. The diabase in the quarries at the end of the Rocky Hill ridge south of Hopewell is traversed by many joints, which are in general parallel to the fault that passes just to the west.

In many localities the different layers terminate abruptly where the fault crosses their strike, a feature which is prominent in some of the ridges formed by hard beds. An instance of this occurs just east of Harbourton, where a ridge of hard sandstone begins in the upthrown block and extends northeast, the fault here trending more to the east than the strike of the strata. Another instance is southwest of Hopewell, where the diabase of Rocky Hill is terminated by the fault in the gap through which the railroad passes. West of Skillman the fault trends more nearly north than the strike of the strata and, crossing the sandstones of the Stockton obliquely, soon passes into the argillites of the Lockatong.

North from Skillman the fault is oblique to the course of the argillite, which, with the diabase, forms the Sourland plateau, and, as a consequence, the highland soon comes to an abrupt termination. It was at first supposed that the diabase sheet would be found to be cut off in turn by the fault, but this does not seem to be the case. It thins out and terminates shortly before reaching the fault.

South of Plainville the strike of the red-shale beds trends at right angles to the fault line, and for some distance the strata abut squarely against it. Owing, however, to their uniform softness they do not form ridges and the evidence from topography is lacking; the diverse structure on either side of the fault is, however, strongly marked.

Minor faults.—It is extremely difficult to detect faults which are entirely in the sedimentary rocks, unless they are of sufficient magnitude to repeat some of the formations, or unless the fault plane itself is exposed. This is due to the absence of individuality in the beds of each formation. Even when faults are detected it is difficult to estimate the amount of dislocation. Some of the faults described below are well exhibited, but the presence of some others is only inferred. In nearly all the amount of dislocation is probably small, but in a few it may be very much greater than has been supposed.

Several very slight faults occur in the Trenton Brownstone Company's quarries in the sandstones of the Stockton formation at Wilburtha. Faulting in a nearly horizontal direction is exhibited in the quarry of Dennis Roe at the same place.

A fault was found in the bed of the creek almost directly south of the southwest termination of the diabase mass 2 miles northwest of Pennington. The fault plane trends N. 22° E., nearly parallel to the strike of the adjoining shale, and it dips 27° NW. Continued northward, it passes along the western margin of the diabase, the termination of which may be due to the fault. Hard green argillaceous sandstone outcrops on the west side of the fault and red-brown shale on the east side, both belonging to the Brunswick formation. No fault breccia is present. To judge by the slickensided surfaces, the uplift has been on the westward or dip side, forming a reverse fault. The amount of dislocation can not be determined at this exposure. This fault was also observed in the bed of a brook one-half mile farther south, but no traces of it could be found beyond that point.

In the bed of a brook 1⅛ miles west of Harbourton, near the Hopewell fault, a fault is exposed along which heavy argillite abuts against red flagstones of the Lockatong formation. The fault plane strikes N. 65° W. and its dip is 40° SW. The slickensided surfaces indicate that the motion was nearly horizontal and the vertical component was small, but the amount is indeterminable.

In the bed of a small ravine midway between Moore and Lambertville a vertical slickensided face of dark-red shale of the Lockatong indicates a horizontal motion in a direction N. 40° E. The amount of dislocation is unknown. The adjoining rocks are considerably crushed.

North of Lambertville a fault is shown in the bed of the second tributary to Alexauken Creek, where green-black shale abuts against red shale and both rocks are somewhat shattered. The fault plane trends N. 12° E. but could not be traced beyond this exposure.

An obscure fault along which the rocks are much crushed is exposed in a ravine one-half mile west of Mount Airy. All along this ravine the dips are irregular and the rock shows repeated indications of dislocation and shearing. These beds are not far from one of the smaller diabase masses and their disturbed condition may be due in part to its intrusion.

A fault is seen in a high ledge of shale exposed along the bank of a brook 1⅛ miles south of Bowne, on the Flemington branch of the Pennsylvania Railroad. The throw is only 3 feet, but the fault is of interest because it is one of the very few where the downthrow is on the west or dip side.

A fault of unknown throw is exposed in the cut of the Philadelphia and Reading Railroad a few hundred yards west of Yardley station. The best exposure is on the north side. The fault trends northwest and southeast and is in strata dipping gently to the north-northwest. On the east side are conglomerratic beds and on the opposite side red shale. The fault plane is occupied by a dike $5\frac{1}{2}$ feet wide, standing nearly vertical. A portion of the shale is somewhat upturned along the contact. From this it is believed that the downthrow is on the west side, but its amount could not be ascertained.

COASTAL PLAIN AREA.

By W. B. Clark.

The Coastal Plain has not the simple structure which was earlier assigned to it. From the beginning of Cretaceous time onward the angle and direction of tilting constantly changed, and although the angle of dip is to-day slight and its direction is prevailingly easterly or southeasterly, it differs in nearly all the formations. As a result of uplifts and depressions the landward margins of the formations particularly show much complexity, with a marked change in the sequence of deposits from point to point. At times transgression has buried the landward outcrop over wide areas, though the formation may be found in sections farther east. These differential movements have in parts of the Coastal Plain even brought about the total disappearance above sea level of entire groups of formations, although they may be found far from the region of surface outcrops in some deep-well borings. The sequence and general eastward inclination of the strata are shown in figure 3.

The older formations of the Potomac group exposed in Delaware and Maryland have been in this way gradually transgressed toward the north in New Jersey and Pennsylvania by the Raritan, while toward the south the Raritan is itself gradually transgressed by Upper Cretaceous formations until it finally disappears in southern Maryland, the Matawan deposits resting directly on the Patapsco.

The Upper Cretaceous formations from the Magothy to the Manasquan, as well as the Eocene Shark River beds, are similarly transgressed from New Jersey southward by the Aquia formation, of late Eocene age, although the probable northward extension of the Aquia is again buried by transgressions of Miocene strata, with the result that the Shark River and Aquia formations nowhere come into actual contact so far as known. Although the lowest beds of the Matawan still outcrop as far south as southern Maryland, they disappear in Virginia below the Aquia formation, being represented in that State only in deep-well borings near the seaward edge of the Coastal Plain. Transgression likewise occurs within the series of Miocene formations, the Choptank formation of Maryland and it possible equivalent in New Jersey, the Cohansey sand, gradually overlapping the older beds.

The marked changes in the sequence of strata from one part of the Coastal Plain to another produced by these transgressions are reflected in the angle and direction of dip of the beds. In general the dip is slight, ranging from 40 to 50 feet to the mile in the earlier Cretaceous formations to 10 to 15 feet to the mile in the later Tertiary deposits. The direction of the dip, although in general easterly, is somewhat more northerly in the Lower Cretaceous formations than in the Upper Cretaceous and Eocene formations, where it becomes progressively more southerly. In the Miocene beds, however, the direction of dip swings gradually back toward the north and reaches its climax in this direction again in the upper Miocene. From the gradual disappearance northward of the marine Pliocene beds of the Carolinas, the direction of dip evidently changes again to the south before the end of the Tertiary is reached.

The mantle of Pleistocene formations everywhere slopes gradually seaward and locally toward the channels of the various estuaries. These formations occur as a veneer over the older deposits.

In the region of the Trenton quadrangle, as elsewhere in the Coastal Plain, the Lower Cretaceous formations dip eastward at greater angles than any other of the Coastal Plain formations, about 40 to 50 feet to the mile, while the unconformably overlying Upper Cretaceous formations have a slightly smaller dip, about 35 feet to the mile, but in a more southerly direction. The Miocene formations, which unconformably overlie the Upper Cretaceous deposits in this area, the Eocene being absent, dip at a still less angle, about 15 feet to the mile, but in a more northerly direction, which becomes progressively more marked in the higher beds, this being shown by the general overlap of the lower Miocene beds by the higher, toward the north. The overlying mantle of Pleistocene formations has in general the same characteristics as in adjacent areas, as already described for the whole Coastal Plain district.

Numerous unconformities appear in the series of Coastal Plain formations. Exclusive of the formations not represented in this district, the first appears between the Raritan and Magothy formations, and another between the Magothy and the Matawan. The later Upper Cretaceous formations are evidently conformable to the Matawan, but a pronounced unconformity occurs between them and the overlying Miocene Kirkwood formation. The latter is overlain unconformably by the Cohansey sand, of later Miocene age, and the Pleistocene formations rest everywhere unconformably upon the underlying deposits.

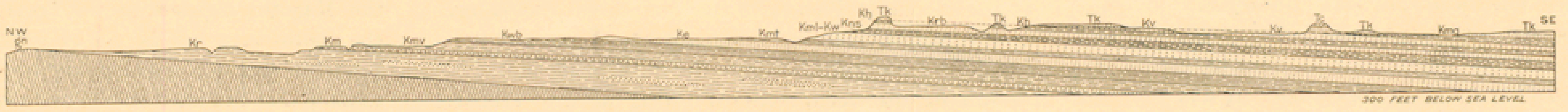

Figure 3.—Generalized cross section of the Cretaceous and Tertiary deposits southeast of Trenton Horizontal scale, same as map; vertical scale, 10 times the horizontal.

gn, Pre-Triassic crystalline rocks; Kr, Raritan formation, probably underlain by older Cretaceous deposits in the deeper part of the section; Km, Magothy formation; Kmv, Merchantville clay; Kwb, Woodbury clay; Ke, Englishtown sand; Kmt, Marshalltown formation; Kml-Kw, Mount Laurel and Wenonah sands; Kns, Navesink marl; Krb, Redbank sand; Kh, Hornerstown marl; Kv, Vincentown sand; Kmq, Manasquan formation; Tk, Kirkwood formation; Tc, Cohansey sand.

An epitome of the oscillations of the Coastal Plain in this area is as follows:

Subsidence and deposition of the Patapsco formation.
Uplift and erosion.
Subsidence and deposition of the Raritan formation with northerly tilting.
Uplift and erosion.
Subsidence and deposition of the Magothy formation with southerly tilting.
Uplift and erosion.
Subsidence and deposition of the conformable sequence of Matawan, Monmouth, and Rancocas groups and Manasquan formation with southerly tilting.
Uplift and erosion.
Subsidence and deposition of the Kirkwood formation with northerly tilting accompanied by extensive transgression over the latest Cretaceous and Eocene formations.
Uplift and erosion.
Subsidence and deposition of the Cohansey sand with northerly tilting.
Uplift and erosion producing main drainage lines.
Subsidence and deposition of the Pleistocene formations at different levels during the successive oscillations.

HISTORICAL GEOLOGY.

PIEDMONT PLATEAU AREA.

By F. Bascom.

SEDIMENTARY AND IGNEOUS RECORD.

While the Atlantic basin and the North American continental plateau are very ancient, the North American continent in its present form is much younger.

At the time when geologic history began in the Trenton quadrangle the present continent had not come into existence, and only isolated and limited portions of the continental plateau were above the sea. Along the Atlantic border there existed a comparatively small land mass, which has been called Appalachia. Appalachia extended east of the present shore line, but probably not beyond the present continental plateau. West of it was the Appalachian sea, in which sediments were accumulating. The western border of Appalachia, which would include the Trenton district, was submerged during the early history of this region. During this submergence, which began in pre-Cambrian time and continued with a considerable interruption through Cambrian and Ordovician time, there was deposited in the Trenton district a littoral belt of micaceous feldspathic sand, grading seaward into arkosic sand. These sediments accumulated upon an uneven gneiss floor and in an encroaching sea which permitted the argillaceous material to collect to the east of the earlier arkosic deposits. In this way the arkosic sand was overlain by argillaceous mud or—on the east—was altogether supplanted by it. This mechanical sedimentation was succeeded, in the north at least, by an organic and chemical deposit of calcareous material.

The sediments grew to a thickness undetermined and in a period not definitely known, but presumably long enough before Cambrian time to permit not alone their accumulation, but also their consolidation, metamorphism, and uplift to a land surface. This uplift was accompanied by the intrusion of great igneous masses, represented in the Trenton quadrangle by gabbro and serpentine.

When the sea again encroached upon the land it probably did not reach the eastern edge of the Trenton area. In this sea a pebbly beach deposit was formed, derived from the newly elevated sediments. This deposit was thin and was succeeded immediately by a clean beach sand. The land mass to the east did not, even at first, stand at a sufficiently high level to give its streams the velocity necessary for the transportation of coarse material, and soon, with the lowering of the land by denudation, only the finest material was brought down by the streams. With a slight deepening and consequent clearing of the sea, calcareous sediment accumulated. This continued into Ordovician time, when the sea shoaled again and received from the land a sandy clay deposit.

The Trenton quadrangle shows no record of further sedimentation during Paleozoic time. It is not probable, however, that the subsequent movements of uplift followed immediately on the deposition of the sandy clay and that sedimentation in this region ceased. The amount of material deposited in Paleozoic time which has disappeared through subsequent erosion is not known but was presumably considerable. On the New Jersey Piedmont Plateau a partial record is left of overlapping sedimentation during Silurian and Devonian time, succeeded by an uplift which was characterized by open folding, faulting, and little or no metamorphism.

Beginning perhaps at the close of Devonian time and continuing until the close of Paleozoic time there were earth movements along the Atlantic border which resulted in the uplifting, folding, and recrystallization of these sediments. The eroded pre-Cambrian crystallines were further deformed and faulted. The beach deposits of Cambrian time were altered to quartz conglomerate, quartzite, and quartz schist. The calcareous sediments were metamorphosed into calcareous schist and crystalline limestone. The sandy-clay deposits were consolidated and crystallized into a schist.

The uplifting of these sediments above the sea was probably not continuous but intermittent, and while erosion did not keep pace with the upward movement, Paleozoic topography undoubtedly never exhibited perfect constructional forms; that is, the arches and troughs of the folded crystallines never existed unmodified by erosion, and before the beginning of the next period of sedimentation of which there is record, they had been eroded to a relatively even surface.

This period, known as the Triassic, is separated by a long interval of time from Ordovician sedimentation. There was time enough in this interval for the formation by uplift and removal by erosion of mountain ranges, and finally for the development of great tidal estuaries or inland basins embracing all the areas now covered by Triassic formations.

These basins were long, narrow troughs roughly parallel to the coast and extending from Hudson River through New Jersey and Pennsylvania into Virginia and North Carolina. They were probably due not to erosion, but to warping or faulting, and early in their history possessed shores steep enough, on the west at least, to supply to the basins calcareous cliff débris and quartzose gravel. A limestone breccia, which has considerable local development on the western border, and a quartzite conglomerate are evidence of this configuration. The character of some of the other formations, consisting of cross-bedded and ripple-marked sandstones, or of sun-dried and cracked sandy shales, or of shales rich in carbon, shows that the basin or basins in which they accumulated were shallow, were bordered by low shores, and were associated with mud flats, or, occasionally, with marshes in which vegetation thrived and decayed. Huge reptiles, now extinct, and other vertebrate animals wandered over these mud flats, and their tracks, impressed on the soft mud, are now preserved in the indurated mudstone or shale.

Before the close of this period of Triassic sedimentation igneous material was intruded between the beds or traversed them in the form of dikes or flowed out at the surface. Following the consolidation and accompanying the uplifting and gentle tilting of these sediments, titanic crustal movements occurred, dislocating the sandstones and shales and associated igneous rocks, and rupturing and displacing the formations along planes of fracture.

There is little if any record in the Trenton quadrangle of the events of the following period, the Jurassic. Erosion rather than sedimentation marks this period. Toward the close of Jurassic time, however, and at the opening of the succeeding Cretaceous period estuarine conditions prevailed.

The most inland estuarine basin was located on the eastern borders of the former Triassic estuary and included in its floor the adjacent crystallines on the east, where, alone, remnants of the estuarine deposits have escaped erosion. Another estuarine basin exists to the east in the Delaware basin, embracing considerable areas in the Coastal Plain. Deposits of both these estuaries appear in the Trenton quadrangle. Those of the inland one occur in scattered outlying areas on the plateau, while those of the Delaware are represented by more or less continuous remains in the basin of that stream and on the adjacent Coastal Plain.

About the middle of Cretaceous time the barrier between the Delaware estuary and sea disappeared, and the Paleozoic crystallines with their cover of early Cretaceous deposits were submerged beneath the Atlantic. This submergence, which scarcely reached west of the Delaware, was gradual, and was accompanied by seaward tilting and landward uplift. Erosion on the plateau was renewed and supplied materials for thick beds of sand and clay.

While, on the whole, during later Cretaceous time depressions of the sea floor increased at the same time that erosion, lowering the surface of the land, decreased the activity of the streams, which consequently supplied a diminished amount of mechanical sediments, there must also have been oscillation of the level of sea floor and land surface, accompanied by variations in the angle and direction of tilting. The interbedding of sand, gravel, and clay, which characterizes the deposits of this period, indicates temporary changes in the activity of the streams, while the differences in direction and amount of dip of these formations indicate warping of the sea floor.

The deposits of Upper Cretaceous time have suffered little if any alteration since their deposition.

The periods following the Cretaceous—the Tertiary and Quaternary—were marked by a changing shore line, by renewed uplift of the Appalachian Province entailing the doming of the Piedmont Plateau, and by the glaciation of northern North America. The accelerated rivers, supplied from the ice sheet and the Plateau, furnished abundant sand and gravel for the thick deposits of these periods. These deposits, while in the main spread upon the Coastal Plain, also accumulated in estuarine waters bordering the Piedmont Plateau, and are now represented by gravels covering the eastern margin of the Trenton plateau region.

At the close of Pleistocene time elevation caused the disappearance of the estuary, the coast line assumed its present position, and the physical geography of the district approached that of to-day.

PHYSIOGRAPHIC RECORD.

It was stated under "Introduction" that the present form of the plateau is not a constructional form; that the rock structure is discordant with the surface configuration. If the comparatively slight depressions made by the present streams were filled in, a perfectly even plain sloping seaward would result. If, on the other hand, the arches and troughs of the original anticlines and synclines of the underlying rock were restored, a region of lofty mountains and deep valleys would be developed. These two strikingly unlike topographies are separated by a long and more or less complex erosional history. While the prompt action of erosive forces makes it impossible for the perfect constructional form to have ever existed, yet a much greater height of land than the present must have characterized this region during some portion of Paleozoic time. This height of land was so far reduced at the opening of Triassic time that it was upon a comparatively level and deeply eroded floor that the materials of the Triassic were laid down.

The later sediments of the Paleozoic series of the Appalachian region must, in a large measure, represent material removed from this belt of high land when, as is indicated by independent proof, the main drainage basins discharged into the western sea.

During Triassic time the portion of the Plateau east of the Triassic estuary drained northwestward into this estuary and furnished materials to the sediments accumulating there. The reduction of the surface of the present plateau must have continued during Jurassic and early Cretaceous time. It was during this time that a nearly featureless plain sloping seaward was formed. Such a plain, carved by subaerial erosion, the work of the atmosphere and of running water, is called a peneplain. Only peneplanation can explain the even sky lines of the hills and ridges and the discordance between surface configuration and underground structure.

The time of the peneplanation is established by the age of the deposits borne upon its surface. A peneplain of so vast a scope as that of which the Trenton quadrangle is an insignificant part is necessarily not of the same age throughout its extent. Peneplanation, begun along the main drainage lines, spreads with incredible slowness away from these lines. Thus the eastern border of the Piedmont region may have been reduced to a peneplain and even submerged while peneplanation was still progressing on the western margin.

The oldest deposits upon this peneplain are the Patapsco and the Raritan formations, indisputably laid down in Lower Cretaceous time. The peneplain also carries deposits of Upper Cretaceous, Tertiary, and Quaternary time. The presence of these deposits and their character indicate that submergence terminated Jurassic peneplanation, and that this submergence was not due to a single crustal movement but to an interrupted and complex series of movements.

First, there was subsidence with tilting, which produced estuaries bordering the sea and extending inland roughly parallel to the present sea border. In these estuaries were deposited the clays and gravels of the Patapsco formation. Uplift followed, bringing the Piedmont district above the sea, and erosion removed the Patapsco deposits except from the deepest portion of the inland estuary.

Following the erosion interval came a second subsidence and the renewal of estuaries in which Raritan deposits were laid down. The uplift that followed was more marked than the preceding, and the region remained above water for a long period, during which extensive erosion took place. The third subsidence, which followed this erosion interval, lasted during all of Upper Cretaceous time, was more extended than any of the preceding, and was oscillatory in character. The adjoining land must have been low, for the streams furnished only fine sand deposits. Cretaceous time was followed by an uplift and an erosion interval of long duration. During this period portions of the Coastal Plain were intermittently beneath and above water, but the present plateau region remained above water continuously until Lafayette time, when all the Coastal Plain and part of the Piedmont Plateau were brought beneath the sea by tilting which raised the northern half of the district. Stream velocity was accelerated so that the streams were able to carry to the sea coarse as well as fine gravel. This was true for the first time since early in the Cretaceous. The uplift which followed this tilting and which brought the continental shelf as well as the Coastal Plain above water produced a drainage system that could not have been very unlike the present. The lower courses of the Schuylkill and the Delaware became established along the present lines and the development of the present topography began. It was during this erosion interval that the master streams cut their gorges on the continental shelf.

After this uplift and erosional activity the eastern margin of the Piedmont district subsided. The highest terrace and escarpment so well developed along the eastern margin of the Piedmont Plateau and the corresponding less well defined terrace on the Coastal Plain have been interpreted by some geologists as marking the shore of a great estuary. According to this interpretation the successively lower terraces mark the stationary positions of the shore line of a contracting estuary. Other geologists have regarded these features as due in part to lateral corrasion and in part to aggradation by a meandering stream. In this view these terraces represent successive stages in the degradation of the region by the ancient Delaware. These views are not wholly exclusive of each other, for river terraces of the normal type may merge into estuarine terraces primarily of wave-cut origin, and it may not always be possible to differentiate the two types after their characteristic features have been obscured by subsequent erosion and warping.

The close of Pleistocene time was marked by the assumption by Delaware River of its present course below Trenton in the former estuarine depression. The Jurassic peneplain was elevated to its present height, which is sufficient for the establishment of a drainage actively eroding its surface.

The cover of Cretaceous, Tertiary, and Quaternary formations has been removed in the stream valleys and in the northwest from the interstream areas, and the Triassic and Paleozoic formations are not only exposed but have been eroded. The peneplain thus through elevation became a plateau, and now by the renewal of erosion it is losing its distinctively plateau character and is becoming a dissected upland.

Post-Jurassic peneplanation is recorded on the western margin of the Piedmont Plateau in traces of three peneplains, which on the eastern margin, embracing the Trenton quadrangle, can not be discriminated from the older peneplain.

As a result of the northwestward tilting of the Triassic sediments, it is assumed that the master streams of the Piedmont Plateau had northwest courses. These would seem to have been reversed in early Cretaceous time by the tilting which depressed the seaward margin of the Jurassic peneplain. With the final elevation of this region their lower courses became too well established in directions determined by the general slope of the uplifted peneplain or of the Cretaceous sediments on its seaward margin to permit subsequent adjustment to the underlying crystalline formations. For this reason they now pursue courses independent of the variations in the underlying rock. The secondary streams of the Trenton quadrangle, on the other hand, because subsequent to the establishment of the greater drainage basins, have not been controlled in their courses by the general slope of the plateau and show a nice adjustment to the underlying formations.

COASTAL PLAIN AREA.

By W. B. Clark.

GENERAL STATEMENT.

The later geologic formations along the Atlantic border form a low plain of varying width extending from the New England coast to the Gulf. The deposits consist of a succession of gravels, sands, clays, and marls, with a gentle dip toward the southeast. Representatives of nearly every epoch from the Upper Jurassic or the Lower Cretaceous to the Recent are recognized, the oldest formations in general being found along the west side of the Coastal Plain and the younger formations successively farther east.

A detailed study of the character and distribution of the several formations shows that the angle and direction of the tilting were not constant from Cretaceous time onward. The oscillations resulted in transgressions of the waters with their accompanying sediments, so that at several periods they locally entirely overlapped the earlier formations, burying from view their landward exposures and bringing about in places the deposition of some of the later formations far to the west of any outcrops of the earlier deposits.

Denudation at various periods down to the present has left remnants of all formations scattered as outliers along the western margin of the main bodies of the deposits. With the exception of the Pliocene and Pleistocene formations, however, the chief outcrops of the several formations in the Trenton district are successively encountered in crossing the Coastal Plain from northwest to southeast. Farther south the normal succession of most of these formations also is shown, although the relations of the Pleistocene deposits to the other members of the series are complicated because of the extensive erosion that took place at the close of the Tertiary period and the consequent submergence of the valleys throughout the coastal area.

POTOMAC HISTORY.

A great variety of conditions characterize the deposition of the Coastal Plain sediments. During the earlier periods of this history estuarine conditions prevailed throughout the region. A great estuary, the extent of which can no longer be determined, occupied a depression in the Piedmont surface and followed in general the main structure lines of the Appalachian uplift. Just when this later estuary was formed can not be definitely determined, but the dinosaur remains which have been found in one of the lower formations have led some eminent vertebrate paleontologists to regard the age as late Jurassic. The plant forms found in these earlier beds likewise show certain Jurassic affinities, but primitive dicotyledonous types also occur, which on the whole have led paleobotanists to regard even the oldest beds as early Cretaceous.

The estuarine deposits, during whose formation uplifts and depressions took place, are collectively known as the Potomac group, and have been divided in Maryland, where the most complete sequence occurs, into the Patuxent, the Arundel, the Patapsco, and the Raritan formations. Of these, the two lower have been doubtfully referred to the Jurassic because of the vertebrate remains, as above mentioned, in the Arundel beds. As far as known, neither the Patuxent, the Arundel, nor the Patapsco formation appears at the surface in the Trenton quadrangle, the only Potomac beds therein being referable to the Raritan, of whose Cretaceous affinities there can be no doubt. The Raritan deposits are coarser than those of the preceding Patapsco, and it would seem that considerable deformation of the shores of the ancient estuary must have been in progress, later culminating in the breaking down of the eastern barrier and the entrance of the open waters of the Atlantic.

MAGOTHY HISTORY.

The date of the change just mentioned was evidently not earlier than the close of the Lower Cretaceous. At first the marine faunas, which apparently entered the basin of deposition in the Raritan Bay region, did not extend far southward, for the Magothy deposits in the Trenton quadrangle and toward the south have not as yet afforded marine fossils. It seems probable that the encroaching sea merged into an extensive estuary that extended southward along the old line of Potomac sedimentation across Delaware to the western shore of Chesapeake Bay. The same is probably true in a measure to the north, although the exact limits of the so-called "Island series," on which this generalization must be based, are not fully comprehended. The flora of the Magothy strata suggests that this change was not consummated until late Cenomanian time, and the fauna points even to the Senonian. Magothy time apparently represents a transitional period between the estuarine conditions of Potomac time and the distinctly marine conditions that characterize the remainder of the Cretaceous.

MATAWAN HISTORY.

The materials composing the marine sediments are mainly sand and clay, which from the base of the group upward contain greater or less amounts of glauconite, showing that during much of the time land-derived materials must have reached the area of deposition in small amounts. It is probable that the region was not far removed from the shore line of the period, and that the land had been gradually reduced until a great peneplain had been developed, extending westward at least into the Appalachian district. The evidence for this is found not only in the glauconitic character of the sediments throughout late Cretaceous and early Tertiary time but also in the even-topped ridges throughout the Atlantic border district as far back as the Allegheny Plateau. A marked similarity in composition characterizes these late Cretaceous sediments, from the Matawan to the Manasquan, as a whole, although they vary sufficiently over considerable areas to make it possible to separate them on lithologic grounds into several formations. Glauconite in greater or less amounts appears, as above stated, at nearly all horizons, in places constituting the main body of the deposits, while in other places it is sparsely distributed and may be limited to definite beds or may occur as small lenses or patches inclosed in other material. In general the beds become gradually more glauconitic in passing upward in the series, the highest beds consisting in places almost entirely of glauconite.

The opening period of this later division of the Cretaceous, known as the Matawan, was marked at the outset by extensive deposits of clays and sands. The sea encroached over a more or less even floor, producing sediments that had their origin in the still unconsolidated materials of the earlier Cretaceous as well as in the older rocks to the west. Marine life was abundant and varied, an extensive fauna of cephalopods, gasteropods, and pelecypods characterizing the period. The conditions of sedimentation changed during this time, especially in the north, where a clearly defined differentiation in the materials occurs. Southward this feature is less pronounced and the deposits gradually become more homogeneous, the distinctions being entirely lost in Maryland.

MONMOUTH HISTORY.

The advent of Monmouth time was not marked by any pronounced change, sedimentation having continued without interruption. As the period advanced, however, thick-bedded glauconitic deposits were laid down, and the greensand of the Monmouth is very unlike anything which had preceded it. The middle formation of the Monmouth, known as the Navesink marl, is a characteristic greensand marl, and in its numerous fossils shows the extensive marine fauna that existed at this period. Many of the species are different from those of earlier time, although many fossils are found common to one of the zones of the earlier Matawan and to the later Redbank. The red sands found both above and below the greensand marl are quite unknown at later horizons, except in the northern phase of the later Rancocas. Locally the beds are highly calcareous on account of the great number of molluscan remains entombed in the deposits.

RANCOCAS HISTORY.

With the close of Monmouth sedimentation came a time of pronounced glauconitic accumulation. The greensands of the Hornerstown constitute the most significant beds of glauconitic materials in the entire Cretaceous system. They represent quiet seas, in which the accumulation of materials must have been extremely slow. The land area to the west by this time had become reduced to a featureless peneplain, while the sea floor itself may have been still further depressed, carrying the area of sedimentation farther landward. Conditions must in any event have remained uniform through a considerable period, for the thick deposits of nearly homogeneous greensand extend throughout the district from Raritan River southward to the point of their final disappearance near the Maryland border. The Rancocas closed with an extensive accumulation of quartz deposits, known as the Vincentown sand, which are in places largely made up of the remains of Bryozoa and Foraminifera, forming a lime sand, and are in other places decidedly glauconitic. These deposits where calcareous are among the most striking in the entire Cretaceous system of the north Atlantic Coastal Plain, and indicate a great profusion of life in the seas of the time.

LATE CRETACEOUS AND EOCENE HISTORY.

After the deposition of the Manasquan formation, which closed Cretaceous sedimentation, a long period of time passed before the next younger sediments of the Trenton quadrangle were deposited. The record of these times is represented in the Shark River marl, of early Eocene age, developed mainly toward the north, and in the Aquia and Nanjemoy formations, of middle Eocene age, developed mainly toward the south in Delaware and Maryland.

MIOCENE HISTORY.

So far as can be judged from the deposits farther south, conditions along the Atlantic border were little changed until Miocene time. The deposits of the earliest epoch are for the most part clays and fine sands, although in the extreme southern part of New Jersey occur marl beds which by their numerous fossils show the existence of an extensive molluscan fauna. To the south, however, extensive diatomaceous beds give evidence of the existence of vast numbers of diatoms in the seas of early Miocene time.

Unlike the early Miocene sediments of this district, the later Cohansey deposits consist of coarser sands and fine gravels, which show that the land areas toward the west had become extensively elevated as the Tertiary period advanced, causing the streams to transport large amounts of coarser material down their courses to the sea. A great thickness of highly characteristic sandy deposits was laid down, which farther off shore or in regions remote from the mouths of streams became finer, with beds of clay bearing an extensive molluscan fauna. Toward the south in Maryland, where these deposits are most characteristically developed, a great number of species have been recognized.

The latest portion of Miocene time is represented east of the Trenton quadrangle by deposits of sand and clay which are now buried beneath a cover of Pleistocene materials. In the deeper well borings along the coast and toward the south in Maryland these deposits afford sands and clays that lithologically are not unlike those of the earliest epochs in many respects, although generally finer, indicating in all probability the lessening volume of sedimentation.

PLIOCENE HISTORY.

The close of the Tertiary along the Atlantic and Gulf borders is marked by the deposition of a cover of gravels and sands. That this was brought about by landward uplift accompanied by a depression of the shore line is shown by the fact that the deposits of the Lafayette formation, which has been thought to represent the Pliocene, are distributed widely above the Miocene strata as well as above those of earlier time, reaching the crystalline rocks of the Piedmont area. The Lafayette is not known to occur in the Trenton quadrangle. The period of time represented by the Lafayette must have been short and was terminated by extensive uplift of the sea floor, during which the present drainage lines of the Coastal Plain were largely developed.

PLEISTOCENE HISTORY.

In the ancient channels described and on adjoining lowlands the deposits of the Pleistocene epoch were laid down. The materials consist of gravels, sands, and clays derived to a considerable extent from the earlier Coastal Plain strata, although streams flowing from the Piedmont Plateau added their quota. The life of the Pleistocene approached more nearly that of the Recent, although relatively few localities are known in the north Atlantic coastal region in which any considerable assemblage of Pleistocene species occurs.

The blocking of the minor post-Lafayette channels in later Pleistocene time produced ponded areas in which were laid down the thick deposits of black clay so typically developed at numerous points in southern New Jersey, Delaware, and Maryland.

ECONOMIC GEOLOGY.

MINERAL RESOURCES.

PIEDMONT PLATEAU AREA.

By F. Bascom.

In that portion of the Piedmont Plateau contained in the Trenton quadrangle the chief mineral products of economic importance are building stone and road metal. Minor products are graphite, copper, and barytes.

BUILDING STONE.

The supply of building stone in the Trenton quadrangle is inconsiderable and is furnished chiefly by the Triassic formations. The Baltimore gneiss does not furnish it in large amount nor in superior quality. Jesse Darrah's quarry near Langhorne and Charles T. Eastburn's quarry on the Neshaminy near Neshaminy Falls have produced stone for building purposes, though the output of these quarries has been utilized chiefly for railroad ballast and road metal.

The Chickies quartzite has been used only locally for building; schoolhouses and a few dwelling houses near Langhorne have been built of this material. The stone is quarried in thin slabs cut parallel to steeply dipping cleavage and bedding planes.

Considerable quarries were at one time operated in the Shenandoah limestone at Limeport. The stone was burnt chiefly for lime, which was used as a fertilizer. The quarries have been inactive for many years.

The Stockton formation yields gray and brown sandstones, suitable both for rough work such as foundations, bridge abutments, and culverts, and for finer work such as brownstone fronts. The largest quarries are located at Wilburtha and Stockton, where the canal and railroad afford good shipping facilities. Flagstones and foundation stones are also obtained from the Lockatong formation, in which there are several small quarries at Princeton. The Brunswick shale within this quadrangle is in general so soft that attempts to use it for building have been unsuccessful.

ROAD METAL.

Ample and excellent material for road building is furnished within the Trenton quadrangle by the rocks of the Plateau, both pre-Triassic and Triassic. The physical qualities requisite for such use are toughness, or capacity to resist fracture or impact; hardness, or resistance to abrasion; and cementing power, or capacity of the rock powder to recement larger fragments of the rock.

In toughness and hardness the Baltimore gneiss, the Wissahickon mica gneiss, the Chickies quartzite, the gabbro, and the diabase excel. In binding power the quartzite is deficient, but the gabbro has fair binding power, though less than that possessed by limestone. The gneisses are slightly superior to gabbro in this quality but do not wear so well. Diabase is superior to all the other formations in toughness, hardness, and binding power.

The Baltimore gneiss is quarried mainly for road metal. Joseph Finney's quarry at Holland, Darrah's quarry in Langhorne, and Eastburn's quarry at Neshaminy Falls are the more important openings for this purpose.

The Wissahickon mica gneiss, while not quarried within the Trenton quadrangle for building stone except in a very small way for local use, is extensively worked for road metal, of which it furnishes an excellent quality. Appleton's quarry, 1 mile north of Byberry, Wood's quarry, worked by McMenomy 1¼ miles northwest of Ford, and Folkcold's quarry, 1 mile south of Byberry, are actively engaged in supplying macadam material.

The Chickies quartzite has recently been utilized considerably for macadam. Quarries in this formation at Neshaminy Falls (Eastburn's), one-half mile northeast of Janney (McMenomy's), and between Glenlake and Oxford Valley (Thompson's) furnish road metal.

The pre-Cambrian gabbro, though capable of furnishing a superior quality of road metal, has not been quarried for that purpose.

The Triassic diabase or "trap rock" is extensively crushed for road metal and concrete, the largest and most active quarries being at Lambertville, Moore, and Rocky Hill. This rock is also quarried near Brookville, Marshalls Corner, and Mount Rose.

Physical properties of road-building stones.

	Per cent of wear.	Toughness.	Hardness.	Cementing value.	Specific gravity.
Biotite gneiss	3.2	19	17.5	41	2.76
Granite gneiss	3.8	12	17.7	26	2.68
Quartzite	2.9	19	18.4	17	2.70
Gabbro	2.8	16	17.9	29	3.00
Diabase (fresh)	2.0	30	18.2	49	3.00
Diabase (altered)	2.5	24	17.5	156	2.95

Large numbers of Belgian blocks have been made from the trap rock, but this style of pavement is decreasing in popularity and the industry has greatly fallen off. The blocks are made chiefly from huge trap bowlders and the industry is not localized at a few quarries but is distributed along Sourland Mountain and to a less extent along Rocky Hill.

GRAPHITE.

Graphite occurs sparingly in the Baltimore gneiss. It was once mined at Trevose and a mine was opened and early abandoned on the Gross estate east of Langhorne, near Glenlake. In the Trenton quadrangle graphite does not occur in such abundance as to pay the expense of separating it from the associated constituents of the gneiss.

COPPER.

Copper not uncommonly occurs in the shale in close proximity to the trap, but not ordinarily in commercial quantities. Somewhat extensive openings have been made, however, near Griggstown, Copper Hill, and Flemington (just north of the quadrangle) and a generation or more ago these mines were actively worked. The ore was chiefly in the form of carbonates.

BARYTES.

Barytes, or heavy spar, was at one time dug a mile north of Glenmoore, where deposits of this material occur in disintegrated diabase, but the mines have long been abandoned. Another deposit was also worked to some extent several years ago one-half mile west of Buckmanville in Pennsylvania. It is in a quartzose breccia of barytes and decomposed diabase, possibly connected with an igneous intrusion which lies beneath the surface.

SOILS.

The soils of the southern Piedmont Plateau are the residual products of the weathering of the rocks immediately underlying them, except where covered by soils of the Coastal Plain deposits. Long-continued decay has supplied a mantle of productive soils comparatively free from stones and possessing considerable depth. The soil derived from the disintegration of the Wissahickon mica gneiss is a brownish-buff micaceous clay loam. The clay derived from the decay of the feldspar is filled with small fragments of mica and stained by the hydroxide of iron. Larger fragments of vein quartz and of the mica gneiss also characterize the soil. It is a mellow, fertile soil, grading imperceptibly into solid unweathered rock through a considerable depth of decayed rock. It corresponds to soil which in adjacent regions has been designated the Cecil mica loam by the Bureau of Soils of the Department of Agriculture.

Toward the Delaware this mica loam is overlain on the interstream areas, and completely covered in the immediate vicinity of the river, by the Coastal Plain soils, called by the Bureau of Soils the Norfolk sand and the Meadow soil.

The Chickies quartzite disintegrates into a sandy soil which contains a little clay and minute scales of sericite. This soil is thin and immediately overlies hard rock. It corresponds to the Edgemont stony loam of areas to the west, shown on the maps of the Bureau of Soils.

The Baltimore gneiss decays into a sandy clay soil characterized by a yellow color and freedom from mica, and studded with flat fragments of the gneiss.

The gabbro, which occupies nearly as large an area as the Baltimore gneiss, gives rise to a red clay soil set with tough bowlders of gabbro. The soil is not so deep as that of the gneiss and gives place somewhat abruptly to solid rock. It has been called the Cecil clay by the Bureau of Soils.

The soil derived from the disintegration of the Triassic shales and sandstones covers a larger area than any other single type in the Trenton quadrangle. It is a sandy clay loam characterized by an Indian red or brownish-red color. Confined to gently rolling country and comparatively free from stones, it is tillable and productive. This soil is the Penn loam of the Bureau of Soils.

The diabase contributes to the Triassic areas a soil similar to that supplied by the gabbro.

The soils of the Piedmont of this quadrangle are not so dissimilar in character as to be characterized by a peculiar flora. They are alike productive and, along the Delaware and its tributaries, support a great variety of forest trees and shrubs. Among these are several varieties of the maple (the swamp, the sugar, and the silver maple), linden, ash, hickory, walnut, butternut, red birch, white oak, ironwood, poplar, willow, hemlock, spruce, tamarack, sumach, laurel, and azalea.

COASTAL PLAIN AREA.

By H. B. Kümmel.

The mineral resources of the Coastal Plain portion of this area consist chiefly of clay, sand, gravel, and marl.

CLAY.

Clays of varying economic importance and of widely different geologic age occur within the Trenton quadrangle and are more or less extensively worked. The Raritan, Magothy, Merchantville, Woodbury, and Pleistocene formations all afford excellent deposits of different grades.

Raritan clays.—Raritan clays are dug at Bridgeboro, Florence, Trenton, and Sand Hills for foundry uses, terra-cotta, and sagger manufacture. These clays, while they do not possess the refractoriness of the best fire clay, resist temperatures in some cases of 3100° F. (cones 28–29) before fusing and can be used in connection with more refractory clay for fire brick. Considerable quantities are used in the potteries of Trenton for saggers, but, contrary to popular belief, the extensive pottery industry at Trenton is not dependent on local clay; in fact, except for saggers, etc., little or no local clay is used in this industry.

At Bridgeboro a series of pits has been opened along the south bank of Rancocas Creek, where a red-mottled semi-refractory clay is found under 8 or 10 feet of pebbly sand of Cape May age. It is reported to be 14 feet thick and to be underlain by a white water-bearing sand. The character of the clay varies in different pits, some of it being of a white or light-blue color, burning buff, while other beds burn red. In the easterly pits a 6-inch layer of lignite occurs in the upper portion of the clay, which gradually passes horizontally into a lignitic sand. The creek is navigable at this point and the clay is shipped to Philadelphia, mostly for foundry and terra-cotta purposes. The red-mottled clay, which represents the run of the bank, is fairly plastic, although it contains some coarse grit. It has the following physical properties: Water for tempering, 22 per cent; air shrinkage, 5.3 per cent; average tensile strength, 104 pounds per square inch. When burned to Seger cone 3 (2174° F.) it has a fire shrinkage of 4.7 per cent, and an absorption of 9.88 per cent, is of light-red color, and is steel hard. The whitish sandy clay is less coherent and slakes rapidly. It requires more water for tempering (30.8 per cent), but its air shrinkage is less, being but 4.3 per cent. The tensile strength is 119 pounds per square inch. It has a low fire shrinkage, at cone 10 (2426° F.) only 2.7 per cent and at cone 15 only 3 per cent. It burns to a gray color with brown specks. Owing to its low shrinkage it can be used to advantage in mixtures with other clays which have too high a shrinkage.

At Florence the river is bordered for 2 miles or more by a bluff, in the steep slopes of which red and blue clay occurs at several points and has been extensively utilized. The following analysis of clay from pits of J. Eayre was published by Cook:

Analysis of clay from Eayre's pit, Florence.

Sand	40.50
Silica (SiO_2)	26.57
Alumina (Al_2O_3) } Titanic acid (TiO_2) }	21.06
Ferric oxide (Fe_2O_3)	1.98
Lime (CaO)	-----
Magnesia (MgO)	.60
Potash (K_2O)	2.47
Soda (Na_2O)	.21
Water (H_2O)	5.80
Moisture	.80
	99.99

Semirefractory blue and red mottled clay is now dug in the lower half of Haedrick's pits at Florence and sold chiefly for foundry purposes. As the pits are located along the Delaware the clay can be directly and cheaply loaded onto vessels.

Two miles east of Trenton a clay of Raritan age is dug in a number of pits along Pond Run. The overlying material, chiefly Pensauken gravel, varies from 5 to 15 feet in thickness. The clay is commonly red or red spotted, grading into a blue at the bottom of the pits. In some places the upper layer is white clay, and locally a black lignitic clay occurs beneath the blue clay. Elsewhere a bed of sand underlies the clay. These beds vary from 10 to 32 feet in thickness. The general section at one of the largest pits is as follows:

Section at pits of J. J. Moon, near Trenton.

	Feet.
Stripping, chiefly gravel	5–12
White clay (where stripping is thin)	2– 3
Red clay, grading down into a red-spotted and thence into a blue clay	14–28
Sand	3– 4
Hard tough blue clay, called "hardpan"	3– 4
Loose white sand, more than	8

The clay is used chiefly for saggers and wad and is hauled by wagon to the Trenton potteries. The following series of tests, made by Ries, fairly represent the properties of these Raritan clays in the vicinity of Trenton:

Physical tests of Raritan clays near Trenton.

	1.	2.
Water required (per cent)	18	28.5
Air shrinkage (per cent)	5.3	4.6
Average tensile strength, lbs. per sq. in.	85	90
Cone 05:		
Fire shrinkage (per cent)		1.4
Absorption (per cent)		19.82
Color		Pinkish red.
Condition		Not steel hard.
Cone 03:		
Fire shrinkage (per cent)		3
Absorption (per cent)		20
Color		Pinkish red.
Cone 3:		
Fire shrinkage (per cent)	7.3	6
Absorption (per cent)	13	13.63
Color	Creamy white.	Pinkish red.
Condition	Steel hard.	Not steel hard.
Cone 5:		
Fire shrinkage (per cent)		7.4
Absorption (per cent)		8.26
Color		Light red.
Condition		Steel hard.
Cone 8:		
Fire shrinkage (per cent)	8.7	9.4
Absorption (per cent)	8.64	
Color	Cream white.	

	3.	4.
Water required (per cent)	38.5	
Air shrinkage (per cent)	6	7
Average tensile strength, lbs. per sq. in.	72	
Cone 1:		
Fire shrinkage (per cent)	8	7
Absorption (per cent)	15.39	15.08
Color	Gray.	
Condition	Steel hard.	
Cone 3:		
Fire shrinkage (per cent)	9.3	
Absorption (per cent)	11.73	
Color	Gray.	
Condition		
Cone 5:		
Fire shrinkage (per cent)	10	
Absorption (per cent)	11.33	
Color	Gray.	
Condition		
Cone 8:		
Fire shrinkage (per cent)	11.6	
Absorption (per cent)	3.71	
Color	Gray.	

1. No. 1 blue clay, whitish color, with some fine grit, from J. J. Moon's pits. It slaked moderately fast and had tiny limonite specks.
2. No. 1 sagger clay. J. J. Moon.
3. Tough red wad clay with very little grit. J. J. Moon.
4. No. 2 sagger clay.

At cone 15 No. 1 had a fire shrinkage of 11.7 per cent; absorption, 1.21 per cent; it vitrified at cone 27. No. 2 vitrified at cone 10; No. 3 was viscous at cone 30.

At numerous points in the Sand Hills north of Monmouth Junction white and red mottled clay has been dug in small pits, many of which are now filled with débris or water. The clay was apparently similar in general appearance and character to that found near Trenton. It has been largely carted to Rocky Hill a few miles distant for use in the terra-cotta factory at that point.

Magothy clays.—The Magothy clays so far as mined are all red burning and are used only for common brick. At the brickyard 1 mile south of Fieldsboro the upper portion of the Magothy is dug to a depth of 16 feet. The clay is black, slightly micaceous and strongly laminated, the layers ranging from one-half to 1 inch in thickness and being parted by films of fine white sand, along which they readily separate. In the higher part of the bank occur the lower layers of the Merchantville clay, which are mixed with the Magothy clay for use. Pyrite concretions are very abundant. Owing to the large amount of carbonaceous matter, care has to be exercised in the early stages of burning not to push the firing too rapidly, lest the bricks swell and crack. In manufacture, a certain amount of surface loam of Pleistocene age is added to the clay. The addition of the loam improves its color-burning properties and renders it more porous.

The black clay, according to Ries, has the following physical characteristics:

Physical tests of Magothy clays.

	Cone—		
	03.	1.	3.
Fire shrinkage (per cent)	5	5.6	5.6
Absorption (per cent)	11.89	7.12	
Color	Pale red.	Pale red.	Pale red.
Condition	Steel hard.		

Water needed for tempering, 27.8 per cent; air shrinkage, 7 per cent; average tensile strength, 168 pounds per square inch.

The material burns to a red brick of moderate absorption but is too coarse grained to make a smooth pressed brick of the best grade.

At the Kinkora brickyard a similar laminated black clay is dug, but the bulk of the material used belongs to the Merchantville formation. According to Cook, the chemical composition of this clay is as follows:

Analysis of Magothy clay from Kinkora.

Sand	31.80
Combined silica (SiO_2)	25.50
Alumina (Al_2O_3)	17.70
Ferric oxide (Fe_2O_3)	6.40
Lime (CaO)	.16
Magnesia (MgO)	.65
Potash (K_2O)	1.54
Soda (Na_2O)	-----
Titanic oxide (TiO_2)	.90
Water (H_2O)	11.80
Moisture	3.50
	99.95

Merchantville clays.—The Merchantville clays are utilized for the manufacture of common brick at Bordentown, Fieldsboro, Kinkora, and Hightstown. At Bordentown the clay bed utilized is 8 to 10 feet thick; it rests on white sand (Magothy) and is overlain by 6 to 9 feet of Pensauken gravel and loam. In color it is black to greenish black, the green color being due to the presence of considerable glauconite. The upper portion for a foot or two is weathered yellow. The black clay has a high shrinkage and can not be used alone, hence a clay loam is added to it. It takes 23.4 per cent water to temper it, and it shrinks 8.8 per cent in drying, which is somewhat high. Its average tensile strength is 251 pounds per square inch. When burned, it gives the following results:

Burning tests of Merchantville clay, Bordentown Brick Company.

	Cone—			
	05.	01.	1.	3.
Fire shrinkage (per cent)	8.3	11.8	11.8	11.8
Absorption (per cent)	10.74	5.83	4.01	
Color	Deep red.			
Condition	Not steel hard.	Softened somewhat.		Beyond vitrification.

On account of the low cone number at which the clay softens care has to be used in burning, so that the bricks do not crush out of shape. This clay shows a very high fire shrinkage and therefore can not be used alone but is mixed with considerable surface loam. The latter burns to a porous body of low shrinkage, and thus counteracts the undesirable properties of the clay. Bricks manufactured from this clay have given good results when subjected to crushing and breaking tests.

At Kinkora similar clay, 12 to 14 feet thick in the bank, is used for brick in connection with some clay from the Magothy below and a Pleistocene loam above; and at Fieldsboro, as already stated, a thin layer of greenish-black clay of Merchantville age occurs at the top of the bank and is mined with the laminated Magothy clay below. At Hightstown small amounts of marly clay are dug and mixed with other clays in the manufacture of common red brick. The mixed clay molds well on a stiff-mud machine and is used also to some extent for making drain tile.

The physical properties of a sample from this locality taken at the contact of the Merchantville and Woodbury clays are given by Ries as follows: Clay, tough and fairly plastic, working up with 34 per cent of water; air shrinkage, 6.6 per cent. The fire tests were as follows:

Burning tests of Reed & Brother's black clay, Hightstown.

	Cone—			
	03.	1.	3.	5.
Fire shrinkage (per cent)	3.4	5.4	5.4	6.4
Absorption (per cent)	16.66	10.59		
Color	Pale red.	Red.	Red.	
Condition	Not steel hard.	Steel hard.		Few small fused specks.

A dry-press tile made from this clay and burned at cone 5 had a fire shrinkage of 5.2 per cent and was slightly mottled in color.

Woodbury clay.—The Woodbury, although well developed in this region, is utilized only at Crosswicks and at Hightstown. At the former place 25 feet of black jointed clay is exposed in the bank, overlain by 6 to 12 feet of Pensauken gravel. Where the overburden is thinnest the clay is more or less weathered to a brownish color in its upper portion. It is red burning at a comparatively low temperature, is probably of low fusibility, and is used for making hollow bricks and drain tile. In the bottom of the pit the upper beds of the Merchantville clay occur, but are not utilized. At Hightstown, as noted above, the lower beds of the Woodbury are used for common brick in connection with clays from the Merchantville and a surface loam.

The Woodbury clay was formerly utilized three-fourths mile southwest of Rancocas. An extensive plant was erected without a previous thorough examination of the clay, which was afterward found to be of little value owing to the formation in it of a network of iron-oxide crusts, and the plant was abandoned.

South of Bordentown along Blacks Creek there are numerous points where good banks of the Woodbury clay could be opened. Half a mile west of Columbus a black micaceous clay is exposed to a depth of 6 feet, its weathered portion, however, being yellowish in color. A sample burned at cone 05 had an air and fire shrinkage of 6.6 per cent and an absorption of 30.47 per cent, showing that the brick was very porous. A mile farther west a smooth, plastic, chocolate-colored clay is exposed along the road to a depth of 4 feet; no tests have been made upon this deposit.

Pleistocene clays.—The most extensive utilization of the Pleistocene clays has been in the neighborhood of Trenton, where for many years a clayey loam which mantles the Pensauken gravel on the flat-topped hills north of the city has been used in the manufacture of red brick, both common and pressed. The deposit is very shallow and consequently large areas have been worked over. In fact, the available supply near the yards has been nearly exhausted, and clay is now brought in from points near Trenton Junction and Ewing. These loamy clays around Trenton are rarely more than 5 or 6 feet thick and, moreover, may be pockety or basin shaped in their character. On account of the large number of stones which they contain, many of them have to be screened before use or put through rolls to crush the pebbles. When burned they produce a brick of excellent red color.

In the earlier years of the brick industry around Trenton, most of the brick were made by the hand process, and those which were sold for front brick were re-pressed in hand-power machines. At present, though hand molding is still used for brick that are to be re-pressed, common brick are often molded in steam-power stiff-mud machines.

A thick black clay on the flood plain of Delaware River near the mouth of Crosswicks Creek is also utilized for brick making. As there is but little stripping and the clay is dug with a steam shovel to a depth of 12 or 15 feet, the expense of mining is very slight.

Near Roebling a soft, black, sticky, sandy clay in the Cape May terrace, overlain by several feet of wind-blown sand, is utilized for brick. It is slightly micaceous and contains much carbonaceous matter in the shape of rootlets. It is apparently only a local deposit and probably represents a swamp clay of Cape May age. When used it is mixed with other clays, chiefly a surface loam and a light-colored Raritan clay that is dug close by at a lower level. This produces a mixture whose air shrinkage is 4.3 per cent and fire shrinkage 4.4 per cent. The clays burn to a red brick with the exception of the light sandy Raritan material, which burns whitish and shows as spots in the brick.

North of Rancocas a surface clay loam has been used for the manufacture of brick and drain tile. The deposit is dug to a depth of 3 or 4 feet only, but is reported to be much deeper.

At Edgewater Park a bluish-black clay covered by 1 to 3 feet of loam, which in turn is overlain by 2 to 6 feet of wind-blown sand, has been utilized. The clay is 8 feet in thickness, contains much organic matter, and is rather sandy. In working, about one-third loam was mixed with the clay. It is a red-burning clay, becoming steel hard at cone 1, with a fire shrinkage of 2½ per cent and an absorption of 11.97 per cent. The brickyard has recently been abandoned.

SAND.

The Cretaceous, Miocene, and Pleistocene beds afford valuable deposits of sand for molding, filtration beds, and building purposes of all kinds. Those which have heretofore been most extensively utilized have been confined to the Magothy, Pensauken, and Cape May formations, although locally small amounts have been dug from other horizons.

In the Raritan sands of the Sand Hills there are thick deposits of a coarse quartz sand, which, however, are but little utilized owing to their remoteness from transportation.

The Magothy formation furnishes clean quartz sand, both fine and coarse, some grades of which are in high demand for use in steel molding and foundry use. It is mined extensively near Florence, where the location of the pits in the face of a high bluff overlooking Delaware River gives exceptional shipping facilities.

The Englishtown, Wenonah, and Mount Laurel sands are for the most part seldom utilized. Many seams of clay occur in the Englishtown, destroying in a measure its availability, while the Wenonah and Mount Laurel either do not in general outcrop in localities close to transportation facilities or favorable to the development of large pits, or they are too impure for use.

The Kirkwood and Cohansey sands are used in some portions of the State, the latter particularly furnishing good glass sands, but they are not mined to any extent in this region.

Coarse arkosic sand of Pensauken age is dug in numerous small pits and most of it hauled by wagon to the pipe foundries at Burlington, Hainesport, and Florence, where it is used in making the cores for cast-iron pipe.

Certain loamy surface sands, chiefly Cape May in age, are widespread and are dug at numerous points for molding sand. They occur extensively along Rancocas Creek and its branches, particularly on the southern side. While the chief workings are near Mount Holly and Lumberton, just south of the limits of this quadrangle, the sands are also dug at Tullytown, Pa., on Burlington Island, near Florence, N. J., and perhaps at other points.

The cleanly washed Cape May sands, particularly those along Rancocas Creek near Borton Landing, and farther upstream at Hainesport and Birmingham, just beyond the limits of this quadrangle, are extensively used in filter and construction work and the excavations cover many acres.

GRAVEL.

In the Trenton quadrangle the Pensauken is the most important source of gravel; there is hardly a hilltop or divide capped by this formation which has not been pitted to obtain it. The chief use of the gravel has been for road material. The Delaware River phase of the Pensauken is best for this purpose, because its decomposed arkosic content acts as a binder when used on the roads. Miles of improved roads have been constructed wholly or in part of it. It has been dug for this purpose southeast of Burlington, at Deacons, Jacksonville, Bustleton, Mansfield, Mansfield Square, Kingston, and other places too numerous to mention.

The finer Pensauken gravel or coarse sand is used extensively at the pipe foundries at Burlington, Florence, and elsewhere as core sand. It compacts readily, but nevertheless is sufficiently permeable to permit the ready escape of steam and other gases in casting. The Bridgeton formation also furnishes good road gravel, but its importance in this area is much less owing to its lack of development. The Cape May formation contains much gravel and is used somewhat upon the roads, but with less happy results owing to its lack of a suitable binder.

GLAUCONITE MARL.

Glauconite is widely disseminated in the Cretaceous beds, and at some horizons forms so large a percentage of the whole that the material has long been known as greensand marl or simply marl. In times past these beds have been largely used as fertilizer, their value for this purpose lying in their content of phosphoric acid and carbonate of lime. The Merchantville, Marshalltown, Navesink, Hornerstown, and Manasquan formations have each been utilized to a greater or less extent in this way, although the Navesink and Hornerstown have been the most important and in this quadrangle are the only sources. The occurrence of the marl at these different horizons, outcropping more or less continuously across the State, made it readily accessible, and where these formations are near the surface there is hardly a farm which did not have its marl pit, while large quantities were hauled miles by wagons to less favored localities, or shipped from large pits located along the railroads. In 1881 the production of these larger pits was about 74,000 tons, but these figures did not include the numerous small pits and were far short of representing the total amount dug. In this quadrangle the chief pits were located at Hornerstown and along Crosswicks Creek north of New Egypt.

Samples of commercial marl analyzed by Cook contained from 50 to 90 per cent of glauconite and 33 to 7 per cent of clay. An average specimen from the marl bed at Hornerstown showed the following chemical composition.

Chemical composition of a marl from Hornerstown (Cook).

Phosphoric acid	1.33
Sulphuric acid	.00
Silicic acid and sand	46.03
Potash	5.67
Lime	2.01
Magnesia	3.47
Alumina	7.86
Oxide of iron	25.23
Water	8.40
	100.00

With the introduction of manufactured fertilizers the use of these marls has almost ceased. Here and there farmers with easily accessible deposits dig a little for their own use. Only at Sewell, in Gloucester County, are they still dug in New Jersey in commercial quantities.

SOILS.

The soils of the Coastal Plain portion are for the most part directly dependent on the various Pleistocene formations which over most of the region conceal the Cretaceous and Tertiary beds. Even over those areas from which clearly defined Pleistocene deposits have been removed by erosion, much of the soil is due to their remnants or to wash from higher slopes, although under these circumstances the underlying formations have strongly influenced them. The region has for so long a time been subjected to alternating stages of degradation and aggradation and there has been so much mixing and shifting of materials upon the surface by streams, rain, wind, and gravity that the various geologic formations are not always marked by definite soil types. The following notes regarding the soils may be summarized from the published results of the work of Salisbury and Knapp (Ann. Rept. State Geologist New Jersey, 1898).

Near Trenton the broad Cape May plain is in general covered with a fertile loam, but along its eastern margin, 1½ to 3 miles back from the Delaware, the soil is more sandy and in places so loose as to be readily blown by the wind. The subsoil is here generally brown loam, retentive of moisture, while the loose gravel and sand beneath insure ready drainage. Along Crosswicks and Doctors creeks the low sandy Cape May terraces are covered with 1 to 3 feet of loam which in the lower part of the valleys, where the terraces are nearly as high as the interstream areas, spreads over the low divides, mantling other formations. Locally, as at Kinkora, Fieldsboro, and elsewhere, this loam becomes so clayey as to be used for brick. For many miles south of Florence the clayey loam which originally formed the soil has been covered with a coarser, looser, wind-blown sand that extends up the slopes above the terrace and mantles the Cretaceous formations or even the Pensauken gravel which caps the hills.

The soils of the Pensauken formation are gravelly to clayey loams. In many localities a bed of silt from 1 to 3 feet thick covers the typical gravel and sand of this formation. This loam has a greater development in Mercer and Middlesex counties and in the northwestern corner of Burlington County near Bordentown than elsewhere. Its presence generally results in a better soil.

The Bridgeton soils are for the most part like the Pensauken, but are not of great importance in this area.

The soil of the Cohansey sand usually consists of a coarse, loose white sand which seems extremely unfavorable to any growth. At a slight distance below the surface, however, the whiteness disappears and the loam increases. The soils of the lower part of the formation are on the whole better than those at higher horizons, but nowhere do they approach the fertility of the other soils of the Coastal Plain, and the greater part of the region underlain by them is better suited for forest than for ordinary forms of agriculture.

The Kirkwood tends to give rise to a fine sandy or loamy soil, but in this region it is for the most part mantled with a sandy soil derived in large part from adjacent and topographically higher formations and not particularly characteristic of the formation itself. This soil becomes decidedly clayey with corresponding variations in the Kirkwood. Much of the Kirkwood is under cultivation and in this respect stands in strong contrast to the Cohansey.

The various formations of the Cretaceous do not, on the whole, give rise to sharply marked soil types over broad areas. The soils of the Vincentown, Redbank (in part), Mount Laurel, Wenonah, Englishtown, and Magothy are naturally loose and sandy and are typically developed chiefly on slopes. Some of them contain more or less glauconite and iron crusts. The Hornerstown and Navesink marls, where not covered by soils derived in large part from the Pleistocene cover, give rise to a black glauconitic loam, which, when properly tilled, is one of the most productive in the State, although liable to bake or "burn out." Much of the soil on the marl belts is a mixture of marl and sand washed from higher slopes, and in some respects these soils are better than those derived from the marl alone. The Woodbury and Merchantville clays give rise to a light-colored stiff clay soil and a brown ferruginous loam respectively. For the most part, however, these formations are mantled, in many places very thinly, with a soil of displaced material; under these circumstances the adaptability of the soil is markedly affected by the impervious subsoil of clay.

Truck farming and the raising of fruit—berries, pears, and apples—are carried on extensively on the loose sandy soils in the southern part of the area. Farther north such standard crops as corn, oats, and potatoes are raised abundantly, and in the southeast there are extensive and productive cranberry bogs. Comparatively little of the region is still in forest, what there is being chiefly southeast of New Egypt, which is at the edge of the great pine barrens.

WATER RESOURCES.

By F. Bascom.

SURFICIAL WATER.

Delaware River and its tributaries furnish most of the water power of the Trenton quadrangle. The only remaining streams of the quadrangle, the Neshanic and the Millstone, which drain northeastward into the Raritan, are relatively unimportant.

RARITAN DRAINAGE.

At Clover Hill, on the Neshanic, a fall of 9 feet furnishes a grist mill with 90 horsepower (gross).

The water power of Millstone River is considerable and remains to be fully developed. The upper Millstone, or that portion which is above the junction of Stony Brook and drains the Coastal Plain sands, possesses fair ground storage. C. C. Vermeule, consulting engineer of the New Jersey Survey, who furnished the estimates of water supply and water power quoted here for the New Jersey streams of the Trenton quadrangle (vol. 3, New Jersey Survey), estimates that with 4.91 inches storage the upper Millstone will furnish 34,400,000 gallons daily, or 53 cubic feet per second; and that, together with Stony Brook (with 7.25 inches storage), it would supply 144 cubic feet per second. The least monthly flow of the Millstone above Millstone village is estimated at 29,600,000 gallons daily. While because of the presence of mechanical detritus the water of the river could not be used without settlement or filtration, an analysis of it published by the State Survey shows it to be fair potable water.

DELAWARE DRAINAGE.

Of the tributaries of the Delaware, which with the Delaware drain the remaining and larger portion of the quadrangle, the following only are of importance.

Neshaminy Creek possesses an average daily flow, as estimated by John E. Codmon, of 157,600,000 gallons. The maximum flow has been 3,700,000,000 gallons per day and the minimum flow 2,800,000 gallons per day. As a source of water power and water supply it remains largely to be developed.

Wickecheoke Creek, the most northerly within the Trenton quadrangle of the tributaries to the Delaware on the New Jersey side, has an available horsepower of 0.75 per foot fall at its mouth.

On Alexauken Creek at Mount Airy a grist mill utilizes 30 horsepower (gross) with a fall of 11 feet.

Assanpink Creek, though draining a considerable area, is not desirable as a source of water supply because of its muddiness nor important as a water power because of its low gradient. Its available power has been estimated at its mouth as 6.75 horsepower per foot fall.

Crosswicks Creek possesses considerable importance as a source of water supply. The capacity of the stream without storage has been estimated at 23,600,000 gallons daily at its mouth; or with storage at 51,000,000 gallons daily. The stream is capable of furnishing considerable storage. It is navigable by canal boats to Groveville. At this locality the water power is estimated at 8.1 horsepower per foot fall, which is about the amount being utilized at present.

Blacks Creek is not suitable for water supply. At the lowest mill the water power has been estimated at 1.6 horsepower per foot fall. This may be doubled by pondage.

Assiscunk Creek, like Blacks Creek, is unfit as a water-supply source. At present, above Burlington, 3 horsepower per foot fall is available for nine months; with improvement of a 20-foot fall, 60 horsepower could be secured.

Rancocas Creek is one of the two largest tributaries to the Delaware from the State of New Jersey. The headwaters of the Rancocas drain wooded uncultivated land and the water which reaches the streams is filtered through sand. The supplying capacity of North Branch at Mount Holly without storage is estimated to be 22,900,000 gallons daily. South Branch above Vincentown will supply 9,000,000 gallons daily without storage.

Above tide water at Mount Holly the water power of North Branch is estimated at 10.20 horsepower per foot fall for nine months of the year. At Vincentown South Branch has an available water power of 4 horsepower per foot fall.

The value of Delaware River as a source of water supply and water power is very great. This river already supplies 150,000 inhabitants of New Jersey with water. At Trenton the supply is estimated at 601,600,000 gallons daily without storage. The natural flow of the river at Trenton amounts to 880,000,000 gallons daily.

As a source of water power the Delaware has been little utilized. There is no doubt that a much larger amount of water power could be profitably developed. At Trenton 447 horsepower per foot fall is available during nine months of the year in addition to the amount now in use.

The Trenton quadrangle, lying south of the line of glacial deposits, is without natural ponds.

UNDERGROUND WATER.

SPRINGS.

The formations of the Trenton quadrangle, stratified and gently dipping, furnish conditions favorable for springs, which are both abundant and copious and which supply the rural districts with water.

WELLS.

PIEDMONT PLATEAU.

The crystalline formations exposed through a very small portion of the Plateau district are penetrated abundantly and deeply by joint planes which afford passage for underground water. For this reason water may be obtained by boring, and artesian wells have been successfully drilled elsewhere in the same formations. No artesian wells are known to have been drilled within the Trenton quadrangle.

The Piedmont Plateau of the Trenton quadrangle is in Pennsylvania largely and in New Jersey exclusively an area of Triassic formations. Of these formations the sandstone, arkose, and conglomerate of the Stockton furnish the series most permeable to water. The flagstones and shales of the Lockatong are relatively impervious. The Brunswick formation, consisting chiefly of shale but including many beds of sandstone, while more permeable than the Lockatong, is less permeable than the Stockton.

The faulting which has displaced the Triassic formations affects the water horizon both advantageously and disadvantageously. While the Stockton formation is in some places made more available than it otherwise would be, in other localities it may be abruptly cut off, together with its water supply. Water may always be obtained when the Stockton can be reached. Water reaches the permeable beds of the Stockton not alone along outcropping strata, but by means of vertical or nearly vertical joint planes which thoroughly intersect and deeply penetrate the Triassic formations.

In general within the Piedmont area of the Trenton quadrangle water is found in rocks which may be drilled with comparative ease, and the chances of obtaining a supply can be foretold with considerable accuracy.

COASTAL PLAIN.

Of the Coastal Plain formations the Raritan, at the base, contains important water-carrying beds.

The Matawan may be divided into five formations, the lower two of which are impervious marl and clay and serve as a cover to the water-bearing sands at the top of the Raritan. The third formation from the bottom of the Matawan is, in the Trenton quadrangle, an important water-bearing stratum, a sand bed about 100 feet thick. This is covered by impervious marl and clay above which is another sand bed 100 feet in thickness, constituting a second important water carrier.

The red sand which separates the Rancocas marl beds from the underlying Monmouth marl beds contains water and is in the northeast about 100 feet thick. The yellow sand which separates the Manasquan from the Rancocas is also an important water bearer. The Manasquan forms an impervious cover to this bed.

The Tertiary formations of the Coastal Plain are important water bearers along the shore, but do not lie at sufficient depths in this quadrangle to serve as sources of water supply.

Summary of wells on the Coastal Plain within the Trenton quadrangle.[a]

Locality.	Range in depth.	Range in capacity.	Formation.
	Feet.	*Gallons.*	
Bordentown	119–195	Many.	Raritan; basal Raritan.
Burlington	135–253	0–25	Raritan.
Hightstown	201–500	12–70	Matawan; Raritan; basal Raritan.
Millville	150–160	Satisfactory.	
Mount Holly	675		Raritan.
Trenton		Large supply.	Raritan.

[a] Darton, N. H., Artesian-well prospects in the Atlantic Coastal Plain: Bull. U. S. Geol. Survey No. 138, 1896, pp. 42–48.

PUBLIC WATER SUPPLIES.

The towns of the Trenton area are inconsiderable in size. Springs are numerous throughout the Piedmont district and dug and driven wells in both the Piedmont and Coastal Plain districts furnish an abundant supply of water. For these reasons the number of water-supply companies is unusually small. Public water supplies are obtained chiefly from Delaware River and are furnished to the following towns in Pennsylvania and New Jersey.

PENNSYLVANIA.

Morrisville.—Morrisville is supplied with water by the Borough Waterworks, owned by the borough of Morrisville. The corporation obtains its water from Delaware River by pumps possessing a capacity of 1,000,000 gallons per 24 hours, and distributes it to the borough without filtration.

Bristol.—The Bristol Water Company, established in 1874, supplies the town of Bristol with water. The water is obtained from Delaware River by means of a plant with a capacity of 300,000 gallons daily and is distributed unfiltered to the town.

Langhorne.—An excellent quality of water is obtained by the Langhorne Spring Water Company from copious springs in the Chickies quartzite. The water flows into a 3,000,000-gallon reservoir, whence it is pumped to a 40,000-gallon tank placed on a stone tower 35 feet above the level of the town. The pumps have a capacity of 800,000 gallons in 24 hours. Private wells are also in use in Langhorne.

Newtown.—The Newtown Artesian Water Company supplies a populated area of about 800 acres from four artesian wells, pumping about 100,000 gallons daily into a reservoir from which the water is distributed without filtration.

Other places.—These are the only water companies supplying water to towns in the Pennsylvania portion of the Trenton quadrangle. The supply of the smaller villages is derived chiefly from private wells or springs, and occasionally is collected in cisterns. The wells are from 15 to 25 feet deep and the water is described as hard.

NEW JERSEY.

Trenton.—The city of Trenton, including Milham and Chambersburg, is supplied by the Trenton Waterworks, under municipal ownership. The source of the water is Delaware River, from which water is pumped to a storage reservoir with a capacity of 112,000,000 gallons. The daily consumption of water is 11,000,000 gallons.

Bordentown.—Bordentown was formerly supplied by a private company, the Bordentown Reservoir and Water Company, from Crosswicks Creek, the water being subjected to natural filter pressure and coagulated with alum. In 1906 a new supply under municipal ownership was obtained from springs at the foot of the bluff along Crosswicks Creek, near White Horse, the water being collected in a series of horizontal galleries and led to a large collecting well. The average daily consumption is about 300,000 gallons, and the population of the city is about 4200.

Fieldsboro.—Fieldsboro is supplied with water chiefly from private wells and cisterns. The only public supply is that furnished to a few families by courtesy of the Union Steam Forge, which obtains the water from the Delaware.

Burlington.—The city of Burlington is supplied with water by waterworks owned and operated by the city. The water is obtained from Delaware River and delivered direct without filtration, and the plant has a capacity of 2,000,000 gallons in 24 hours. Owing to the unsatisfactory nature of the water a new supply is being sought.

Beverly.—The Delaware River Water Company, obtaining its water from Delaware River and from wells, supplies an area which embraces the city of Beverly, South Beverly, Edgewater Park, Delanco, and Riverside. The plant has a capacity of 1,500,000 gallons in 24 hours. Delanco, Edgewater Park, and South Beverly are also supplied from private wells.

Mount Holly.—Mount Holly, a town of over 5000 inhabitants, is supplied with water by the Mount Holly Water Company, incorporated in 1845. The water is taken from North Branch of Rancocas Creek and first flows into a supply well, where a solution of aluminum sulphate is added. Thence it is pumped to sedimentation tanks, whence it flows by gravity to the filter tanks, which have a capacity of 1,500,000 gallons per 24 hours and are of the New York Continental Jewell type. From the filter tanks the water descends to the filtered-water reservoir and is pumped thence to a 1,500,000-gallon reservoir on Mount Holly 100 feet above the pumping station and 180 feet above sea level. The pumping capacity of the plant is 60,000 gallons an hour, with a duplicate plant for emergencies. The average consumption of water is 450,000 gallons per day. An analysis shows it to be good drinking water.

Wrightstown.—The Wrightstown Water, Electric Light, and Sewer Company supplies Wrightstown, a village of 200 inhabitants, with water from an artesian well having a capacity of 10,000 gallons per 24 hours. The water is not filtered.

New Egypt.—New Egypt is supplied by the New Egypt Water Company from an artesian well with a capacity of 10,000 gallons per 24 hours. The water is not filtered.

Hightstown.—The Hightstown Waterworks, owned and operated by the borough, furnishes Hightstown with water. The borough owns four artesian wells, of which the three in use possess a capacity of 150,000 gallons per 24 hours. The water is broken up by means of air pumps and a small stream of lime water is introduced. The water is then filtered through sand.

Lambertville.—Lambertville is supplied by water obtained from springs having a capacity of 38,000,000 gallons. The water is passed through sand filters and is handled by the Lambertville Water Company.

Hopewell.—Hopewell, a town of about 1200 inhabitants, is supplied with water by the Hopewell Water Company, which obtains the water from springs and an artesian well. The water is not filtered.

Other towns.—All other towns on the Coastal Plain are supplied from private wells, chiefly dug wells. All other towns on the Piedmont Plateau are supplied with water from dug wells, cisterns, or springs, and a few from driven wells. East Millstone is largely supplied by means of driven wells.

April, 1908.

TOPOGRAPHY

STATE OF NEW JERSEY
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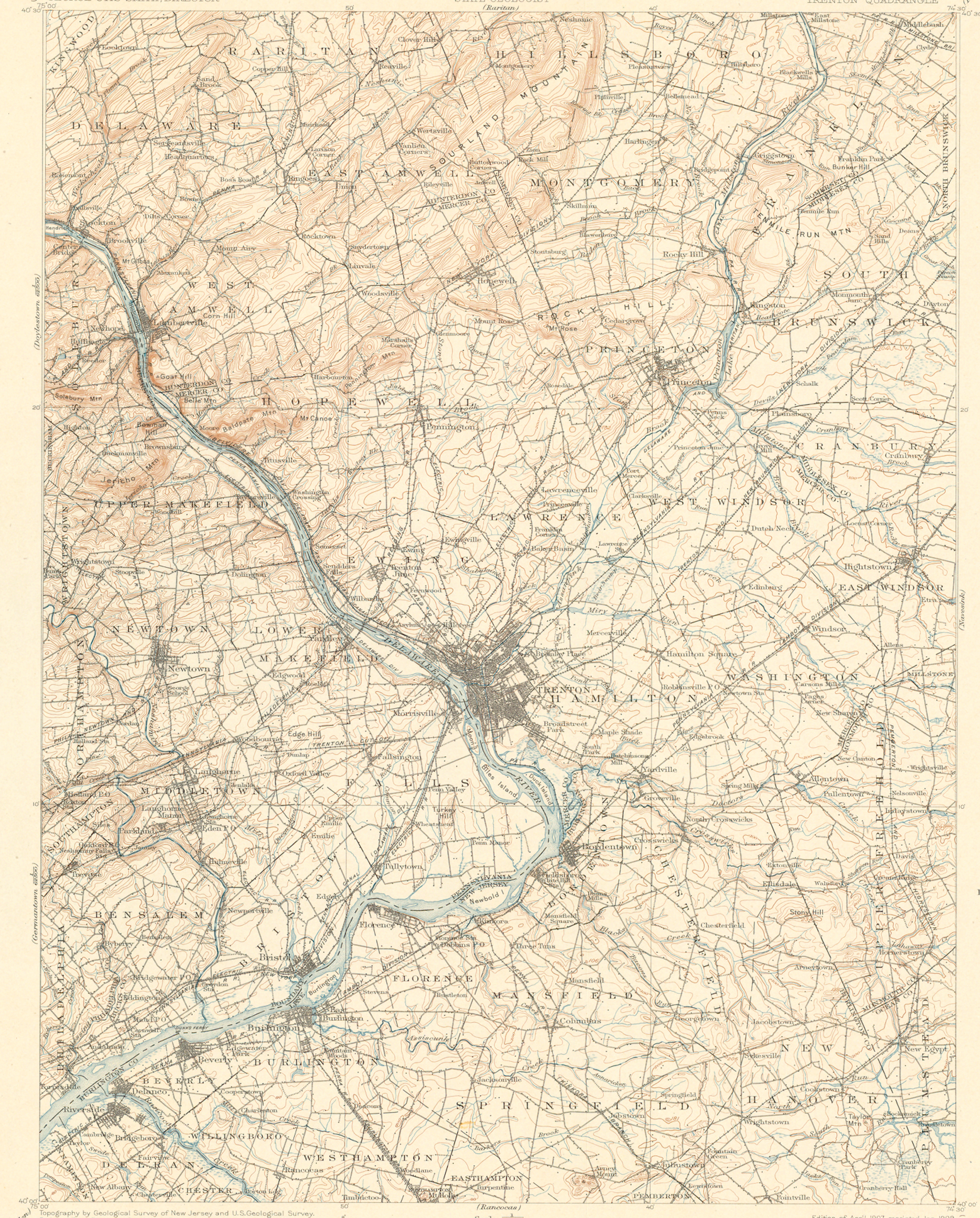
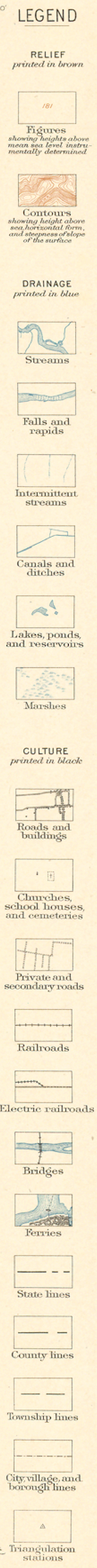
U. S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

NEW JERSEY – PENNSYLVANIA
TRENTON QUADRANGLE





Topography by Geological Survey of New Jersey and U.S. Geological Survey.
Reduced from Princeton, Burlington, Bordentown, and Lambertville sheets.
Surveyed in 1885-86.
Revised in 1904-05.

SURVEYED IN COOPERATION WITH THE STATES OF NEW JERSEY AND PENNSYLVANIA.

APPROXIMATE MEAN DECLINATION 1904.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of April 1907, reprinted Jan. 1909.

AREAL GEOLOGY

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF NEW JERSEY
HENRY B. KÜMMEL
STATE GEOLOGIST

NEW JERSEY – PENNSYLVANIA
TRENTON QUADRANGLE

LEGEND

SEDIMENTARY ROCKS
(continued)

CAMBRIAN

- €Os — **Shenandoah limestone** *(blue, crystalline, siliceous, magnesian limestone)*
- €c — **Chickies quartzite** *(quartz conglomerate and quartz schist)*

UNCONFORMITY

PRE-CAMBRIAN

- fl — **Franklin limestone** *(crystalline white limestone)*
- wg — **Wissahickon mica gneiss** *(banded quartz-feldspar-biotite rock)*
- bgn — **Baltimore gneiss** *(banded quartz-feldspar rock containing hornblende or biotite)*

Includes material of igneous origin

IGNEOUS ROCKS
(Areas of igneous rocks are shown by patterns of triangles and rhombs)

TRIASSIC

- Ŧbs — **Basalt flows in Newark group** *(includes some dikes)*
- Ŧdb — **Diabase** *(includes small bodies of syenite)*

EARLY CAMBRIAN OR OLDER

- gb — **Gabbro** *(gabbro, hypersthene gabbro, and norite)*
- sp — **Metapyroxenite and metaperidotite** *(serpentine, steatite, anthrophylite, and associated alteration products)*
- hgn — **Hornblende gneiss** *(hornblende-orthoclase rock)*

Faults

Concealed faults *(covered by later deposits)*

Strike and dip of stratified rocks

Economic data

Quarries, building stone, road material, and lime

COPPER *Abandoned copper mine*

BARITE *Barite prospect*

Pits in surficial deposits
c, clay; s, sand; g, gravel

Note: *Building stone can be obtained from* bgn, wg, €Os, Ŧs, *and* Tc; *road material from* bgn, wg, hgn, gb, €c, €Os, Ŧdb, Ŧbs, Qb, Qps, Quc, *and* Qcm; *limestone for lime from* €Os; *sand for building and molding from* €c, Kr, Km, Ke, Kw, Kml, Krb, Kv, Tk, Tc, Qb, Qps, *and* Qcm; *brick clay from* Kr, Km, Kmv, Kwb, *and* Qcm; *refractory clay from* Kr; *gravel from* Qb, Qps, *and* Qcm; *marl for fertilizer from* Kmv, Kmt, Kns, Kh, *and* Kmq.

LEGEND

SEDIMENTARY ROCKS
(Areas of subaqueous deposits are shown by patterns of parallel lines; subaerial deposits by patterns of dots and circles)

QUATERNARY

- Quc — **Unclassified deposits** *(gravel, sand, and loam of various ages; frequently wind blown and usually thin and discontinuous)*

UNCONFORMITY

Pleistocene — Wisconsin Stage

- Qcm — **Cape May formation** *(gravel, sand, and clay forming low terraces; includes some recent alluvium and swamp muck)*

UNCONFORMITY

- Qps — **Pensauken formation** *(gravel and sand on higher terraces and capping hills and divides)*

UNCONFORMITY

- Qb — **Bridgeton formation** *(gravel and sand, capping higher hills and divides)*

UNCONFORMITY

TERTIARY — Miocene

- Tc — **Cohansey sand** *(coarse sand with clay lenses)*

UNCONFORMITY

- Tk — **Kirkwood formation** *(fine, mealy, micaceous sand, and, locally, beds of clay)*

UNCONFORMITY

CRETACEOUS — Upper Cretaceous

- Kmq — **Manasquan formation** *(dark green and gray glauconitic marl)*

Rancocas group

- Kv — **Vincentown sand** *(quartz and lime sands, the latter mostly indurated)*
- Kh — **Hornerstown marl** *(dark-green glauconitic marl)*

Monmouth group

- Krb — **Redbank sand** *(highly colored and black ferruginous sand with many concretions)*
- Kns — **Navesink marl** *(dark-green glauconite marl)*

Matawan group

- Kml / Kw — **Mount Laurel and Wenonah sands** *(varicolored quartz sand, upper portion marly and coarse, lower portion finer and contains a different fauna, but not separated on map)*
- Kmt — **Marshalltown formation** *(black sandy clay and sandy marl)*
- Ke — **Englishtown sand** *(varicolored sand, somewhat lignitic, with occasional thin clay lenses)*
- Kwb — **Woodbury clay** *(black to dove-colored clay, usually nonglauconitic)*
- Kmv — **Merchantville clay** *(black sandy clay, usually glauconitic)*
- Km — **Magothy formation** *(lignitic sand and clay, the latter laminated and often black)*

UNCONFORMITY

Lower Cretaceous

- Kr — **Raritan formation** *(varicolored clay, some highly refractory, some lignitic, with coarse, cross-bedded sand and some gravel lenses)*

UNCONFORMITY

TRIASSIC — Newark group

- Ŧb — **Brunswick shale** *(soft red shale with few sandstone beds)*
- Ŧl — **Lockatong formation** *(dark argillite and fine-grained slabby sandstone)*
- Ŧs — **Stockton formation** *(gray sandstone, arkose, and red shale)*

UNCONFORMITY

Legend is continued on the left margin.

Topography by Geological Survey of New Jersey and U.S. Geological Survey.
Reduced from Princeton, Burlington, Bordentown, and Lambertville sheets.
Surveyed in 1885–88.
Revised in 1904–05.

SURVEYED IN COOPERATION WITH THE STATES OF NEW JERSEY AND PENNSYLVANIA.

TRUE NORTH — MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1904.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Mar. 1909.

Geology of pre-Triassic rocks by F. Bascom;
Triassic by N.H. Darton and H.B. Kümmel;
Cretaceous and Tertiary by W.B. Clark, G.N. Knapp, B.L. Miller, H.B. Kümmel, A. Bibbins, E.W. Berry;
Quaternary of New Jersey by G.N. Knapp.
Surveyed in 1893 to 1907.

SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY.

STRUCTURE SECTIONS

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF NEW JERSEY
HENRY B. KÜMMEL
STATE GEOLOGIST

NEW JERSEY – PENNSYLVANIA
TRENTON QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL	SECTION SYMBOL		
	QTK	Quaternary, Tertiary, and Cretaceous formations *(undifferentiated on sections)*	
Quc		Unclassified deposits *(gravel, sand, and loam of various ages; frequently wind blown and usually thin and discontinuous)*	QUATERNARY
		UNCONFORMITY	
Qcm		Cape May formation *(gravel, sand, and clay forming low terraces; includes some recent alluvium and swamp muck)* — Pleistocene, Wisconsin stage	QUATERNARY
		UNCONFORMITY	
Qps		Pensauken formation *(gravel and sand on higher terraces and capping hills and divides)* — Pleistocene	QUATERNARY
		UNCONFORMITY	
Qb		Bridgeton formation *(gravel and sand, capping higher hills and divides)* — Pleistocene	QUATERNARY
		UNCONFORMITY	
Tc		Cohansey sand *(coarse sand with clay lenses)* — Miocene	TERTIARY
		UNCONFORMITY	
Tk		Kirkwood formation *(fine, mealy, micaceous sand and, locally, beds of clay)* — Miocene	TERTIARY
		UNCONFORMITY	
Kmq		Manasquan formation *(dark green and gray glauconitic marl)* — Upper Cretaceous	CRETACEOUS
Kv		Vincentown sand *(quartz and lime sands, the latter mostly indurated)* — Upper Cretaceous, Rancocas group	CRETACEOUS
Kh		Hornerstown marl *(dark-green glauconitic marl)* — Upper Cretaceous, Rancocas group	CRETACEOUS
Krb		Redbank sand *(highly colored and black ferruginous sand with many concretions)* — Upper Cretaceous, Monmouth group	CRETACEOUS
Kns		Navesink marl *(dark-green glauconite marl)* — Upper Cretaceous, Monmouth group	CRETACEOUS
Kml / Kw		Mount Laurel and Wenonah sands *(varicolored quartz sand, upper portion marly and coarse, lower portion finer and contains a different fauna, but not separated on map)* — Upper Cretaceous	CRETACEOUS
Kmt		Marshalltown formation *(black sandy clay and sandy marl)* — Upper Cretaceous, Matawan group	CRETACEOUS
Ke		Englishtown sand *(varicolored sand, somewhat lignitic, with occasional thin clay lenses)* — Upper Cretaceous, Matawan group	CRETACEOUS
Kwb		Woodbury clay *(black to dove colored clay, usually nonglauconitic)* — Upper Cretaceous, Matawan group	CRETACEOUS
Kmv		Merchantville clay *(black sandy clay, usually glauconitic)* — Upper Cretaceous, Matawan group	CRETACEOUS
Km		Magothy formation *(lignitic sand and clay, the latter laminated and often black)* — Upper Cretaceous	CRETACEOUS
		UNCONFORMITY	
Kr		Raritan formation *(varicolored clay, some highly refractory, some lignitic, with coarse, cross bedded sand and some gravel lenses)* — Lower Cretaceous	CRETACEOUS
		UNCONFORMITY	
Trb	Trb	Brunswick shale *(soft red shale with few sandstone beds)* — Newark group	TRIASSIC
Trl	Trl	Lockatong formation *(dark argillite and fine-grained slabby sandstone)* — Newark group	TRIASSIC
Trs	Trs	Stockton formation *(gray sandstone, arkose, and red shale)* — Newark group	TRIASSIC
		UNCONFORMITY	

Legend is continued on the left margin.

LEGEND

SEDIMENTARY ROCKS *(continued)*

SHEET SYMBOL	SECTION SYMBOL		
COs	COs	Shenandoah limestone *(blue crystalline, siliceous, magnesian limestone)*	CAMBRIAN
Cc	Cc	Chickies quartzite *(quartz conglomerate and quartz schist)*	CAMBRIAN
		UNCONFORMITY	
fl		Franklin limestone *(crystalline white limestone)*	PRE-CAMBRIAN
wg	wg	Wissahickon mica gneiss *(banded quartz-feldspar-biotite rock)*	PRE-CAMBRIAN
bgn	bgn	Baltimore gneiss *(banded quartz-feldspar rock containing hornblende or biotite)* — Includes material of igneous origin	PRE-CAMBRIAN

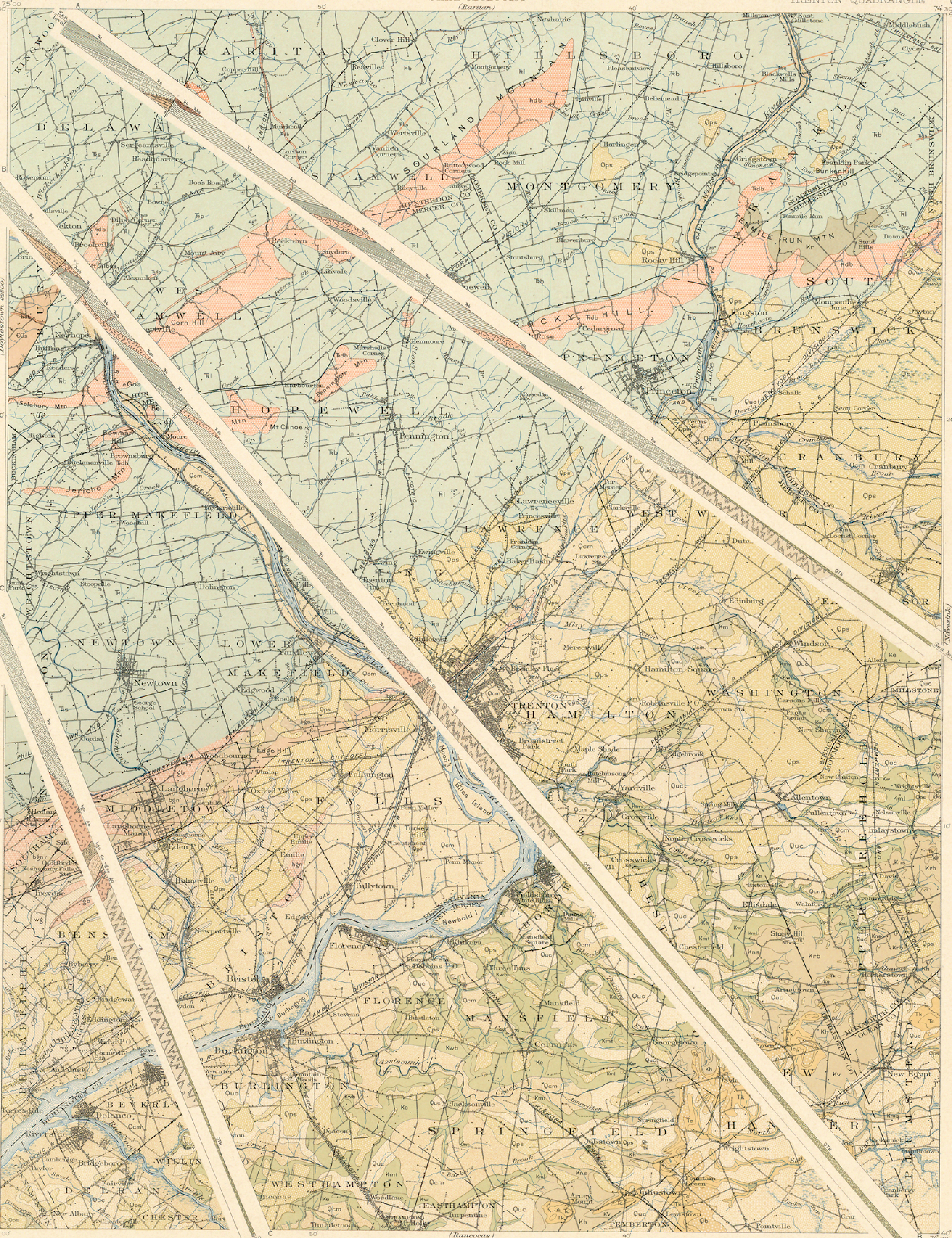
IGNEOUS ROCKS

SHEET SYMBOL	SECTION SYMBOL		
Trbs	Trbs	Basalt flows in Newark group *(includes some dikes)*	TRIASSIC
Trdb	Trdb	Diabase *(includes small bodies of syenite sy)*	TRIASSIC
gb	gb	Gabbro *(gabbro, hypersthene gabbro, and norite)*	EARLY CAMBRIAN OR OLDER
sp	sp	Metapyroxenite and metaperidotite *(serpentine, steatite, anthrophylite and associated alteration products)*	EARLY CAMBRIAN OR OLDER
hgn		Hornblende gneiss *(hornblende-orthoclase rock)*	EARLY CAMBRIAN OR OLDER

Faults

Concealed faults *(covered by later deposits)*

Strike and dip of stratified rocks



Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

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TRUE NORTH / MAGNETIC NORTH — APPROXIMATE MEAN DECLINATION 1904.

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SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY.

COLUMNAR SECTIONS

GENERALIZED SECTION OF THE PRE-CRETACEOUS ROCKS OF THE TRENTON DISTRICT.

SCALE: 1 INCH=1000 FEET.

System.	Formation.	Symbol.	Section.	Thickness in feet.	Character of Rocks.	Character of Topography and Soil.
	Quaternary, Tertiary, and Cretaceous rocks.				Described in columnar section of post-Triassic rocks.	Described in columnar section of post-Triassic rocks.
	UNCONFORMITY					
TRIASSIC (Newark group)	Brunswick shale.	Ŧb		6000+	Soft red shale, with local beds of red sandstone.	Wide rolling valleys with red sandy clay-loam soil.
	Lockatong formation.	Ŧl		1800-3600	Dark-colored argillite and fine-grained slabby sandstone.	Ridges and plateaus rising steeply above adjacent plains. Sandy clay-loam soil.
	Stockton formation.	Ŧs		2300-3100	Gray, yellowish, and reddish-brown sandstone mostly massive and moderately hard. Basal beds arkosic and locally conglomeratic. Red shale intercalations at various horizons.	Low ridges. Sandy clay-loam soil.
	UNCONFORMITY					
ORDOVICIAN / CAMBRIAN	Shenandoah limestone.	€Os		1500±	Crystalline, siliceous, magnesian blue limestone.	Open lowlands. Reddish clay soil.
CAMBRIAN	Chickies quartzite.	€c		1300±	Quartz conglomerate and quartz schist.	Well-defined ridges. Sandy soil.
	UNCONFORMITY					
PRE-CAMBRIAN	(Franklin limestone.)	(fl)				
	Wissahickon mica gneiss.	wg		2000±	Banded quartz-feldspar rock with an excess of biotite. Small isolated area of crystalline white limestone, probably Franklin limestone.	Relatively low rolling country. Yellow micaceous clay-loam soil.
					Granite and gabbro intrusive in pre-Cambrian gneisses.	
	Baltimore gneiss.	bgn			Banded quartz-feldspar rock.	

GENERALIZED SECTION OF THE POST-TRIASSIC ROCKS OF THE TRENTON DISTRICT.

SCALE: 1 INCH=200 FEET.

System.	Series.	Formation.	Symbol.	Section.	Depth in feet.	Character of Rocks.	Character of Topography and Soil.
QUATERNARY	PLEISTOCENE	Cape May formation.	Qcm	Occur on terraces on older formations.	0-40	Loam, sand, and gravel, with a few ice-borne bowlders.	Low terraces along the Delaware and tributaries. Loam, clayey, sandy, black soil.
		UNCONFORMITY					
		Pensauken formation.	Qps		0-30	Loam, sand, and gravel, with decomposed pebbles and some ice-borne bowlders.	Caps low hills and divides. Loam to a loamy gravel soil.
		UNCONFORMITY					
		Bridgeton formation.	Qb		0-30	Loam, sand, and gravel, with decomposed pebbles.	Caps higher hills and gently rolling uplands. Loamy to gravelly soils.
		UNCONFORMITY					
TERTIARY	MIOCENE	Cohansey sand.	Tc		50	Coarse sand with clay lenses.	Valley sides near headwaters. Loose sandy soils.
		UNCONFORMITY					
		Kirkwood formation.	Tk		90	Fine, mealy, micaceous sand, in places buff and pink mottled.	Usually rolling uplands, and some isolated hill tops. Fine sandy to clayey soil.
		UNCONFORMITY					
CRETACEOUS	UPPER CRETACEOUS	Manasquan formation.	Kmq		25	Glauconite, fine sand, and whitish clay.	Valleys. Mostly covered.
	Rancocas group	Vincentown sand.	Kv		25	Glauconitic quartz and lime sand.	Steep valley slopes. Sandy soil.
		Hornerstown marl.	Kh		25-30	Largely glauconite with sand and clay.	Hilltops and slopes. Rich clayey soil.
	Monmouth group	Redbank sand.	Krb		0-50	Black clayey red sand, with iron crusts.	Hills and steep slopes. Soil, reddish sand.
		Navesink marl.	Kns		30	Glauconite, quartz sand, calcareous clay.	Narrow bands. Rich dark loamy soil.
		Mount Laurel and Wenonah sands.	Kml Kw		40-60	Ferruginous sand, glauconitic near top, finer and micaceous near base.	Uplands, slopes, and valley bottoms. Reddish-brown sandy, loamy soils.
	Matawan group	Marshalltown formation.	Kmt		30	Glauconitic sandy clay, locally a greensand marl.	Valley slopes. Soil usually covered by wash.
		Englishtown sand.	Ke		30-50	Ferruginous varicolored sand with laminæ of clay.	Gentle valley slopes and low interstream areas. White to brown sandy soil.
		Woodbury clay.	Kwb		50	Black to dove-colored plastic clays, mostly nonglauconitic.	Steep stream banks and gentle interstream areas. Light-colored stiff clay soil.
		Merchantville clay.	Kmv		40-60	Black clay, somewhat sandy and laminated, usually glauconitic.	Valley slopes; some gently rolling surfaces. Brown ferruginous loam.
		Magothy formation.	Km		30-40	Cross-bedded sand and dark lignitic clay.	Rolling lowlands. Sandy to clayey soil.
		UNCONFORMITY					
	LOWER CRETACEOUS	Raritan formation.	Kr		150-200	White to red refractory clay with cross-bedded sand and gravel lenses.	Mostly covered.
		Pre-Cretaceous rocks.				Described in columnar section of pre-Cretaceous rocks.	Described in columnar section of pre-Cretaceous rocks.

NAMES OF FORMATIONS.

NAMES APPLIED BY VARIOUS AUTHORS TO THE FORMATIONS OF THE TRENTON DISTRICT OR THEIR APPROXIMATE EQUIVALENTS IN ADJOINING REGIONS.

System.	Names Used in Folio.		Symbol.	Geological Survey of Maryland.	Geological Survey of New Jersey. (1868-1897)	Second Geological Survey of Pennsylvania.	N. H. Darton, Washington Folio. U. S. Geological Survey.
QUATERNARY	Cape May formation.		Qcm		Cape May formation.	Trenton gravel. Philadelphia brick clay.	Later Columbia formation.
	Pensauken formation.		Qps		Pensauken formation.	Red gravel. Philadelphia brick clay.	Earlier Columbia formation.
	Bridgeton formation.		Qb		Bridgeton formation.	Yellow gravel.	Chesapeake formation (in part).
TERTIARY	Cohansey sand.		Tc				
	Kirkwood formation.		Tk				
CRETACEOUS	Manasquan formation.		Kmq		Upper marl.		
	Vincentown sand.	Rancocas group.	Kv	Rancocas formation.	Lime sand.		
	Hornerstown marl.		Kh		Middle marl.		
	Redbank sand.	Monmouth group.	Krb	Monmouth formation.	Red sand.		Monmouth formation.
	Navesink marl.		Kns		Lower marl.		
	Mount Laurel sand.		Kml		Sand marl.		
	Wenonah sand.	Matawan group.	Kw	Matawan formation.	Clay marl		Matawan formation.
	Marshalltown formation.		Kmt				
	Englishtown sand.		Ke				
	Woodbury clay.		Kwb				
	Merchantville clay.		Kmv				
	Magothy formation.		Km	Magothy formation.	Plastic clays.		Potomac formation (in part).
	Raritan formation.		Kr	Raritan formation.			
				H. D. Rogers, First Geological Survey of Pennsylvania, 1858.			T. D. Rand, Proc. Acad. Nat. Sci. Philadelphia, 1900.
TRIASSIC	Brunswick shale.		Ŧb	Mesozoic red sandstone.		Landsdale shales (approximately).	
	Lockatong formation.		Ŧl			Gwynedd shales (approximately).	
	Stockton formation.		Ŧs			Norristown shales (approximately).	
ORDOVICIAN / CAMBRIAN	Shenandoah limestone.		€Os	Auroral limestone.		Limestone No. II.	Limestone No. II.
CAMBRIAN	Chickies quartzite.		€c	Primal white limestone.		Chiques sandstone, formation No. I.	Cambrian sandstone.
PRE-CAMBRIAN	Wissahickon mica gneiss.		wg	First and second gneissic belts and mica slate.		Chestnut Hill, Manayunk, and Philadelphia mica schists and gneisses (in part).	Chestnut Hill, Manayunk, and Fairmount schists and gneisses (in part).
	Baltimore gneiss.		bgn	Primal lower slate. Northern or Third gneissic belt (in part).		Laurentian or Azoic gneiss (in part).	Ancient gneiss (in part).

and still smaller ones *stages*. The age of a rock is expressed by the name of the time interval in which it was formed.

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

Inasmuch as sedimentary deposits accumulate successively the younger rest on those that are older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or superposed by faulting, so that it may be difficult to determine their relative ages from their present positions; under such conditions fossils, if present, may indicate which of two or more formations is the oldest.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. Where two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

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

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

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

The symbols consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters.

The names of the systems and of series that have been given distinctive names, in order from youngest to oldest, with the color and symbol assigned to each system, are given in the subjoined table.

Symbols and colors assigned to the rock systems.

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

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—The map showing the areas occupied by the various formations is called an *areal geology map*. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any particular formation, its name should be sought in the legend and its color and pattern noted; then the areas on the map corresponding in color and pattern may be traced out. The legend is also a partial statement of the geologic history. In it the names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

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

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

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

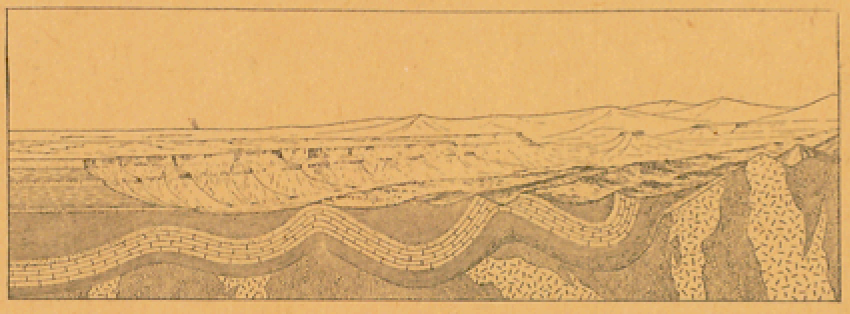

FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

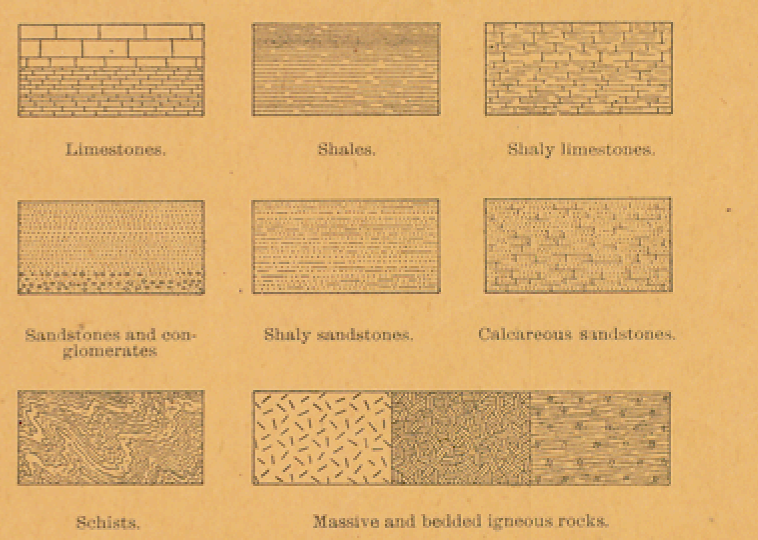

FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

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

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction of the intersection of a bed with a horizontal plane is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

In many regions the strata are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets, the fact that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

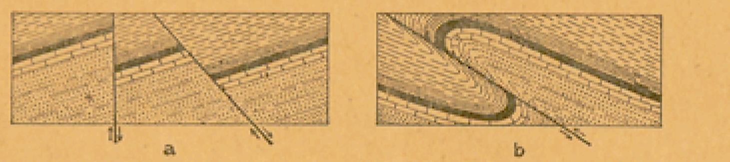

FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or by well-founded inference.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of sandstones and shales, which lie in a horizontal position. These strata were laid down under water but are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been uplifted. The strata of this set are parallel, a relation which is called *conformable*.

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

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set shown at the left of the section. The overlying deposits are, from their position, evidently younger than the underlying deposits, and the bending and eroding of the older beds must have occurred between their deposition and the accumulation of the younger beds. The younger rocks are *unconformable* to the older, and the surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists were metamorphosed, they were disturbed by eruptive activity, and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

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

Columnar section.—The geologic maps are usually accompanied by a *columnar section*, which contains a concise description of the sedimentary formations that occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures that state the least and greatest measurements, and the average thickness of each formation is shown in the column, which is drawn to scale. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest being at the bottom, the youngest at the top.

The intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

GEORGE OTIS SMITH,
Director.

May, 1909.

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