DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

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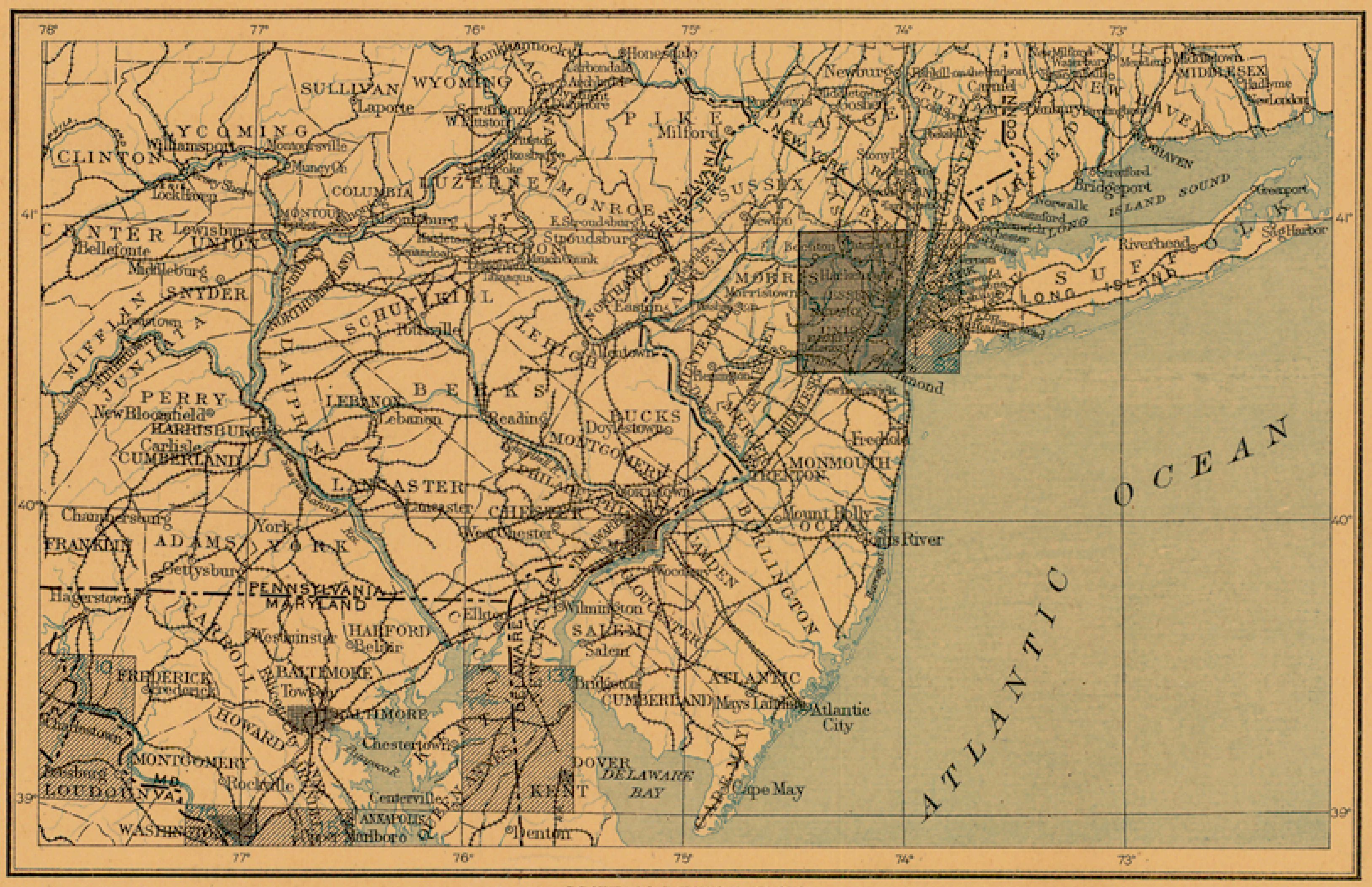
~~J. P. Springfield.~~

GEOLOGIC ATLAS
OF THE
UNITED STATES

PASSAIC FOLIO
NEW JERSEY-NEW YORK

INDEX MAP



SCALE: 40 MILES-1 INCH

▩ PASSAIC FOLIO

▨ OTHER PUBLISHED FOLIOS

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GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic map and geologic maps of a small area of country, together with explanatory and descriptive texts.

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 which are most important 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 altitudinal interval represented by the space between lines being the same throughout each map. These lines are called *contours*, and the uniform altitudinal space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map (fig. 1).

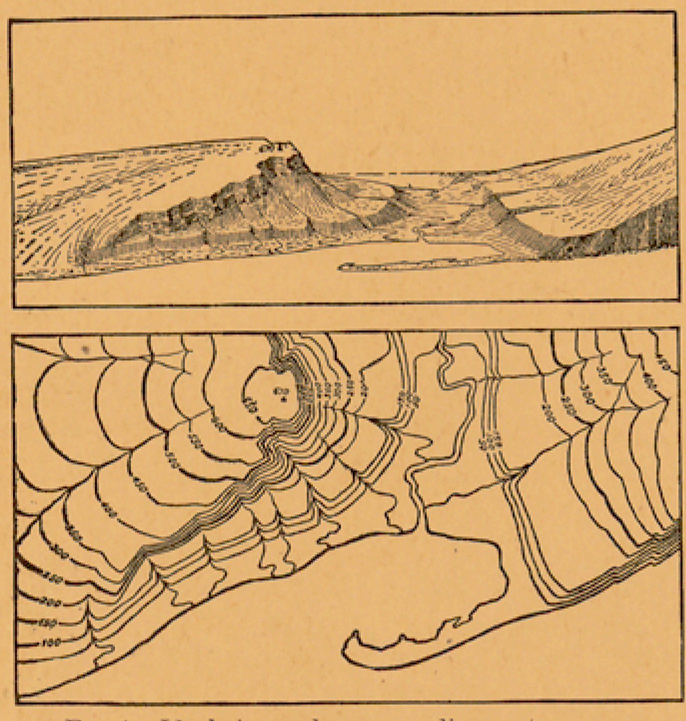

FIG. 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply, forming a precipice. Contrasted with this precipice is the gentle slope from its top toward the left. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours 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 sea; along the contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while 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 sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration all the contours are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contours, and then the accentuating and numbering of certain of them—say every fifth one—suffice, for the heights of others may be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. These relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The altitudinal space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise 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.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is serviceable for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. If a stream flows the entire year the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, are printed in black.

Scales.—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the *scale* of the map. In this case it is "1 mile to an inch." 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 an inch" is expressed by $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale $\frac{1}{125,000}$, about 4 square miles; and on the scale $\frac{1}{250,000}$, 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 in English inches, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map 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 $\frac{1}{250,000}$ contains one square degree—i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-fourth of a square degree; each sheet on the scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles.

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. 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 the names of adjacent sheets, if published, are printed.

Uses of the topographic map.—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

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 the structure sections show their underground relations, as 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.—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

Sedimentary rocks.—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

The chief agent of 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. In smaller portion the materials are carried in solution, and the deposits are then 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 deposits 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*. Rocks deposited in layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a *residual* layer. Water washes residual material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called *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 a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called *metamorphic*. In the process of metamorphism the substances of which a rock is composed may enter into new combinations, certain substances may be lost, or new substances may be added. There is often a complete gradation from the primary to the metamorphic form within a single rock mass. Such changes transform sandstone into quartzite, limestone into marble, and modify other rocks in various ways.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

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, a rapid alternation of shale and limestone. When the passage from one kind of rocks to another is gradual it is sometimes 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 is constituted of one or more bodies either containing the same kind of igneous rock or having the same mode of occurrence. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics.

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 the rocks were made is divided into several *periods*. Smaller time divisions are called *epochs*, and still smaller ones *stages*. The age of a rock is expressed by naming the time interval in which it was formed, when known.

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*.

(Continued on third page of cover.)

DESCRIPTION OF THE PASSAIC QUADRANGLE.

By N. H. Darton, W. S. Bayley, R. D. Salisbury, and H. B. Kümmel.

GEOGRAPHY.

By N. H. Darton.

LOCATION.

The Passaic quadrangle is bounded by parallels 40° 30′ and 41° north latitude and meridians 74° and 74° 30′ west longitude, covering one-fourth of a square degree. It is approximately 35 miles in length and 26 miles in width and has an area of about 905 square miles. The greater part of the district lies in New Jersey, but its southeastern corner includes Staten Island, the west end of Long Island, the south end of Manhattan Island, and several small islands also belonging to New York. In New Jersey it includes the counties of Union and Essex and portions of Hudson, Passaic, Bergen, Morris, Middlesex, and Somerset. The New York area is all in New York City, comprising the borough of Richmond and portions of the boroughs of Brooklyn and Manhattan. The region is thickly populated, and the greater part of the land is under cultivation or occupied by buildings. The quadrangle contains, besides a portion of New York City, the cities of Newark, Hoboken, Jersey City, Paterson, Elizabeth, Passaic, Plainfield, Rahway, and Perth Amboy, and numerous towns and villages in New Jersey.

TOPOGRAPHY.

This quadrangle exhibits a considerable variety of topography, representing several distinct geographic provinces. The northwestern corner lies in the Highlands, consisting mostly of gneiss, but the larger part of the area to the east extends across the Piedmont Plateau, underlain by the Newark sediments, and in the southeastern portion is a small area of the Coastal Plain, underlain by Cretaceous formations.

The Highlands area consists of numerous high, rocky ridges forming a portion of the system known as the Passaic Range. These ridges trend southwest and northeast and are approximately parallel. They rise very prominently along their southeastern edge, but on the west they are not so prominent and approach in character the more perfectly plateau-like ranges of the region farther west. If the valleys were filled, the surface of the Highlands would be a plateau sloping gently to the southeast. Southwest of Splitrock Pond the ridges are short and their crests have an east-west or southeast-northwest direction. This departure from the normal trend of the ridges is due to structural conditions—the most prominent structural features, schistosity and banding, in this neighborhood, trending east and west while elsewhere their strike is generally to the northeast.

The Highlands area has a general elevation of 850 feet or more. There are many narrow valleys whose bottoms are not much higher than the surface of the Piedmont Plateau, but these valleys in the aggregate occupy only a small area as compared with that of the hills and ridges between them. These hills and ridges, with their steep slopes, elongated axes, and almost uniform altitudes, constitute the characteristic features of the Highlands. They are the worn-down representatives of the Appalachian Mountains. On the east side of the area, within the limits of the quadrangle, the tops of the elevations are about 850 feet above sea level, though a few of them reach an altitude of 900 feet, and one, Watnong Mountain, rises to a height of 983 feet. Toward the west the heights increase to 1000 and 1100 feet and on Copperas Mountain, in the extreme northwest corner of the quadrangle, an altitude of 1220 feet is reached. The peak of this mountain is the highest point in the quadrangle. The range thus has a slope of 370 feet in a distance of 8 miles, or about 45 feet to the mile. The surfaces of its highest summits are regarded as portions of the old Schooley plain.

The eastern margin of the Highlands rises abruptly in rocky slopes that reach heights ranging from 500 to 800 feet. This escarpment extends in a nearly straight line from Pompton to Morris Plains, following a fault which lifts pre-Cambrian rocks high above the Newark rocks.

The Piedmont Plateau is very much lower and smoother than the Highlands. It consists largely of wide areas of gently undulating lands having an altitude of 200 to 400 feet along its western margin and sloping down below sea level on Hudson River, Newark Bay, and Staten Island. Most of its ridges and valleys trend northeast and southwest, with the strike of the rocks. From the wide plains rise a number of ridges of which the most prominent are First and Second Watchung mountains. The south end of the Palisade Ridge extends along the eastern side of the plateau, and west of the Watchung Mountains rises an interrupted ridge comprising Long Hill, Riker Hill, Hook Mountain, and Packanack Mountain. These ridges are caused by thick sheets of igneous rock inclosed in the sandstones and shales of the Newark group and their prominence is due to their great hardness as compared with the inclosing strata. Snake Hill (Hudson County) and the semicircular ridge near New Vernon are of similar nature. The Watchung Mountains average somewhat higher than 500 feet, and an altitude of 866 feet is attained in High Mountain, a peak on a portion of Second Watchung Mountain known as Preakness Mountain. The Watchung ridges rise from plains averaging about 200 feet in altitude and are characterized by rocky escarpments on the east and gentle slopes on the west. The Palisade Ridge is of similar form, but it rises from lands near or at sea level and declines from an altitude of 220 feet in Union Township to sea level on Bergen Point. The Watchung ridges have notably level crest lines, which, together with the higher portion of the Palisade Ridge and the high hills of Staten Island, are believed to define the eastward extension of the Schooley plain. The Watchung ridges are crossed by Passaic River through wide U-shaped gaps at Little Falls and Paterson, and by Rahway River through a similar gap at Milburn. Great Notch, south of Paterson, is a deep gap only partly occupied by watercourses.

The western margin of the Coastal Plain in the Passaic quadrangle is somewhat indefinite, but generally it may be considered to follow the Cretaceous boundary from a point south of Metuchen, through Woodbridge, and across Staten Island to Stapleton. On Long Island it begins near Gowanus Bay. The lands are low and everywhere margined by tide water, but the relief is considerably heightened by the presence of hills of glacial drift, notably in the prominent terminal moraine on Staten Island and Long Island. The glacial drift also gives rise to prominent ridges and hills in the Piedmont area, especially in the terminal moraine extending from Morristown to Short Hills and thence southward via Fanwood to Metuchen. This feature in many places has a rise of 100 feet, with steep slopes to the south or west.

DRAINAGE.

The greater part of the drainage of the Passaic quadrangle flows into Passaic River, which empties into Newark Bay. The south-central portion of the area is drained mainly by Elizabeth, Rahway, and Raritan rivers. Hudson River empties into the Upper Bay at the south end of Manhattan Island, but its channel continues southward through the Narrows and southeastward out into the Atlantic Ocean. This river, Upper and Lower bays, Kill van Kull, Newark Bay, and Arthur Kill are tidal estuaries or submerged valleys occupied by sea water. Staten Island is separated from the mainland of New Jersey by the two kills above mentioned. Most of its numerous small streams flow into these kills, but a few enter the Upper Bay, Narrows, and Lower Bay.

Passaic River is a large stream and drains the greater portion of northern New Jersey. It has a number of large tributaries which rise in the Highlands, of which the principal ones are Pompton and Rockaway rivers. The main stream enters the quadrangle northwest of Plainfield, flows northeastward and northward for 20 miles, then eastward for 12 miles, crossing the Watchung Mountains in wide depressions, and thence flows southward into Newark Bay, thus following a remarkably tortuous course. Hackensack River, which may be regarded as a branch of the Passaic, rises in the northeastern corner of New Jersey and drains a region of considerable extent lying along the west slopes of the Palisade Ridge. Below the town of Hackensack it occupies a valley 4 miles in width largely filled by tide-water marsh which continues to Newark Bay and along its western side. Above Little Falls, the Passaic has a very low declivity, falling only 40 feet in a distance of 25 miles. Owing to this low grade, its valley is very flat and contains a number of extensive fresh-water marshes or meadows, especially in the district north of the terminal moraine. Its branches in the Highlands are streams with rapid fall, flowing in part through flat-bottomed valleys of moderate width and at intervals crossing the ridges in narrow, rocky gorges. Raritan River flows across the southwestern corner of the quadrangle and receives a moderate amount of local drainage in the region west and south of the terminal moraine. Two of its smaller branches, Ambrose Brook and Bound Brook, flow to the west and northwest for some distance within this quadrangle. Rahway River is a small stream that rises in the valley between First and Second Watchung mountains west of Orange and flows through the wide gap near Milburn and thence southward across a drift-covered plain, emptying into Arthur Kill east of Rahway. Elizabeth River drains the slopes west of Newark and empties into Arthur Kill a short distance west of Newark Bay.

DESCRIPTIVE GEOLOGY.

GENERAL RELATIONS.

By N. H. Darton.

The Passaic quadrangle includes portions of several geologic provinces which present great diversity in rocks and structure. It extends entirely across the belt of rocks of the Newark group which reaches from Rockland County, N. Y., across New Jersey, Pennsylvania, and Maryland into Virginia. In the northwest corner of the quadrangle is a small portion of the Highlands area of pre-Cambrian gneisses and limestone. These rocks extend northward from the Reading Hills in Pennsylvania across northern New Jersey into Orange and Putnam counties, N. Y., and thence curve southward through Westchester County to Manhattan Island. To the east of the Newark area is a portion of the southern extension of the metamorphic Paleozoic rocks which appear prominently in the southeast corner of New York and adjacent portions of Connecticut and Massachusetts. To the southeast also there is an overlap of the Cretaceous formations of the Coastal Plain, which extend from Long Island across southern New Jersey, through Delaware, eastern Maryland and Virginia, and southward. The greater part of the quadrangle was covered by ice during the glacial invasion, and the ice sheet left a variety of drift deposits which constitute the predominant surface formations of the area.

The rocks of the Passaic quadrangle comprise an extensive series of ancient gneisses, metamorphic schists, slates, sandstones, shales, conglomerates, igneous diabase and basalt, clays, sands, and glacial drift. The Highlands are carved from pre-Cambrian gneiss. The wide central area is underlain by red shales and sandstones of the Newark group, of Triassic age, among which are interbedded lava flows and intrusive sheets and dikes of diabase. Jersey City, Hoboken, Manhattan Island, and the north-central portion of Staten Island exhibit metamorphic schists, of Ordovician age, and serpentine, and the southeastern part of the area is underlain by clays and sands of the Cretaceous. Over all but the southwestern corner of the quadrangle is spread a mantle of drift composed of sand, clay, and bowlder deposits brought by the ice of the continental glaciers. In many areas the underlying rocks are deeply covered by drift and appear only in isolated exposures. Glacial lake deposits cover portions of the upper Passaic Valley and alluvial deposits occur along the streams. Some of the valleys contain large fresh-water marshes, and along the tidal estuaries, notably Hackensack River, Newark Bay, Raritan River, and Arthur Kill, there are extensive salt marshes.

PRE-CAMBRIAN ROCKS.

By W. S. Bayley.

INTRODUCTORY STATEMENT.

GENERAL RELATIONS.

The Highlands of southeastern New York and New Jersey form a part of the Appalachian Province. They lie within an irregularly bounded and complexly interrupted area of rocks older than the Cambrian, which extends from Schuylkill River at Reading, Pa., northeastward across Hudson River into Putnam and southern Dutchess counties, N.Y.; eastward across Putnam County into the edge of Fairfield County, Conn.; and from Putnam County southward across Westchester County to Manhattan Island. This roughly hook-shaped area is bounded on the inside by the belt of Mesozoic rocks belonging to the Newark group, which extends from the Hudson Palisades southwestward across New Jersey and Pennsylvania. Around the periphery of the pre-Cambrian area on the northwest, north, and east, the rocks are Paleozoic. The boundary between the area of ancient crystalline rocks and the Newark belt is on the whole a simple one, but the line limiting the older rocks against those of Paleozoic age is sinuous in the extreme. The irregularity of this boundary and the occurrence of many strips of the Paleozoic formations within the general district occupied by the pre-Cambrian rocks result largely from the presence of many northeast-southwest corrugations of the sort characterizing the Appalachian region, to use that term in its broadest application.

The lower Cambrian formations may have been deposited over the whole region, but they now appear only in the areas where they were protected from erosion by having been infolded or downfaulted into the older rocks upon which they lie.

In Pennsylvania, New Jersey, and southeastern New York, from Reading on the Schuylkill to Hudson River, the Paleozoic rocks bordering on and included in the pre-Cambrian area are essentially unmetamorphosed. The Cambro-Ordovician limestone is nowhere changed to marble, and the overlying Ordovician shale, though exhibiting slaty cleavage in many places, has not been converted into schist. Throughout this zone the Paleozoic and pre-Cambrian rocks are invariably exhibited in sharp contrast, because the latter are so completely crystalline. Within the Paleozoic formations intrusive rocks other than diabase dikes of post-Triassic age occur in one place only, namely, at Beemerville, N. J.

East of Hudson River the aspect of the lower Paleozoic formations is very different. Immediately north of the pre-Cambrian area in Dutchess County, N. Y., the rocks of Hudson time are almost uniformly slaty, and the limestone which occurs between these slates and the pre-Cambrian rocks is crystallized to a considerable extent. In eastern Dutchess County and in northeastern Putnam County the Paleozoic rocks exhibit even greater alteration. The shale and limestone have been completely recrystallized, the former being converted into mica schist and the latter into marble. Still farther east, in Connecticut, intrusive rocks appear and are present generally beyond the eastern border of the Westchester County pre-Cambrian area. The Paleozoic rocks that lie within the general pre-Cambrian area in Putnam and Westchester counties, N. Y., are likewise highly metamorphosed, and locally they are also invaded by igneous intrusions. In certain parts of this district the pre-Cambrian rocks, including the Fordham gneiss described in the New York City folio, have suffered the same deformation as the Paleozoic formations associated with them, and it is often a matter of difficulty to distinguish these gneisses in their altered form from phases of the Hudson schist.

In Pennsylvania, New Jersey, and southeastern New York the basement rocks comprise mainly several varieties of gneiss or massive feldspar-bearing rocks of a granular texture and foliated habit, rocks of similar composition but almost or quite free from foliation, very coarse granite or pegmatite, and crystalline limestones. Nearly all these ancient rocks are laminated to a greater or less degree, and the different sorts are interlayered on both a large and a small scale in such a way that they usually appear at the surface as relatively narrow bands. These bands have a general northeast-southwest trend throughout the region, and as a rule the dips of the structural surfaces are inclined toward the southeast.

Locally the gneisses carry valuable deposits of iron ore in the form of magnetite, and the same mineral is in some places associated with the white crystalline limestone. This limestone is especially noteworthy, however, because it forms the matrix of the unique deposits of zinc ore occurring in Sussex County, N. J.

Taken together, the pre-Cambrian rocks of this region show a close resemblance to the crystalline complex of the Adirondack Mountains and to the pre-Cambrian of the Green Mountain region, which in turn are like the rocks of the Laurentian area in Canada. They are different in their general make-up from some of the ancient rocks of the Philadelphia district and from the apparent correlatives of these rocks occurring in Maryland and Virginia.

CHARACTER AND GROUPING OF THE ROCKS.

The limestones, being composed essentially of calcite, are readily distinguished from the gneisses made up of silicate minerals in different combinations, but there are so many varieties of gneiss and the different sorts are so intricately mingled that detailed representation of their distribution is quite impracticable. As observed in the field, the most noteworthy differences of appearance presented by the elements of the gneissic complex are those of color, and inasmuch as color distinctions have been found to correspond broadly with fairly definite lithologic differences, they may be used as a guide in classifying the gneisses for the purposes of description and mapping.

All the dark gneisses which owe their color to the hornblende, pyroxene, or biotite which they contain, are grouped together under the name Pochuck gneiss. A second group, the members of which show brown-gray, bronzy, pink, and ocherous tones, is called the Byram gneiss. Here are included a great variety of granitoid or granite-like rocks related to one another and distinguished from the other gneisses by the presence of potash feldspar as an essential ingredient. A third group, the Losee gneiss, includes light-colored granitoid rocks, many of them nearly white, which contain lime-soda feldspar as an essential and characteristic mineral component.

Rocks of intermediate composition do not in general constitute readily definable geologic masses, and as a rule it has not been found practicable to separate them from the other gneisses. However, several masses of coarse granite occurring in the northern part of Pochuck Mountain are so distinct in appearance from the surrounding rocks that their limits may be readily traced. This rock contains subequal amounts of potash and lime-soda feldspar and is like the granite of Mounts Adam and Eve in Orange County, N. Y., which invades the Franklin limestone.

All the rocks which have been mentioned are cut by irregular dikelike masses of pegmatite, but these rocks have not been mapped except within the general area of the white limestone.

The varieties of gneiss are seldom found in large masses, free from intermixture with other sorts, but the different facies or varieties occur in tabular masses which are interlayered both on a large and on a small scale. The mingling is so intimate and the proportions of the lithologic facies are so various that even after bringing the varieties together in groups it is impossible to give a really faithful representation of their distribution on a map of small scale. As a matter of necessity, therefore, the bands which are distinguished on the geologic map represent merely the presence of varieties of gneiss resembling the designated type as the most abundant rocks in the area covered by the appropriate color or symbol. Mapping of the crystalline complex on this principle leads to the result that the boundaries shown are to a considerable degree arbitrary. They are therefore not to be considered in the same light as the hard and fast lines which can be drawn between the well-defined formations usually represented on detailed geologic maps. Furthermore, the various boundaries are arbitrary in different degrees, some of them being quite as definite as the boundaries between different sorts of granular igneous rocks, where one of these is intrusive into another, and others being located by personal judgment as to the most fitting line to indicate a general difference in the rocks occurring in adjacent areas. In many portions of the field, with a large-scale map, it would be possible to represent the occurrence of the different sorts of rock in great detail, but however minute the subdivisions might be made it would still be inevitable that the areas distinguished should represent preponderance of varieties rather than the occurrence of invariable rock masses.

STRUCTURE OF THE PRE-CAMBRIAN.

The general structure of the Highlands pre-Cambrian complex rocks is monoclinal. The more or less well-defined layering between the various rock masses strikes on the average from southwest to northeast and dips usually toward the southeast, though rarely toward the northwest. Straight or gently curving structural features are the rule, but in many places individual layers or sets of layers, if followed along the strike or along the dip, exhibit at intervals sharp, troughlike corrugations. These corrugations range in size from mere wrinkles to folds of considerable span. Usually they are very minor features compared with the notably great extent of the nearly straight layering which they modify, but in a few places they are of importance in determining the areal distribution of the different varieties of gneiss. Also, in some of the mines of the region, particularly in the zinc mines at Franklin Furnace and Sterling Hill, a short distance west of the Passaic quadrangle, the ore bodies have the form of pitching troughs. Within the layers of gneiss, besides a commonly well-marked foliation due to the arrangement of the more or less flattened mineral constituents in parallel planes, there is in many places a distinct streaking or graining which runs diagonal to the strike and dip, in the same direction as the pitch of the corrugations referred to above. Locally the foliation may be observed to almost disappear and to give place to a pitching linear structure, produced by the grouping of mineral grains into pencils. The edges of some individual layers of gneiss exhibit a like pitch. The very general existence of obscure graining in this common direction, though usually not apparent to the eye, is brought out by a topographic feature observable throughout the glaciated portion of the Highlands. The longitudinal profiles of the gneiss ridges are in many places like unsymmetrical sawteeth, with gentle slopes toward the northeast and a more abrupt falling off on the southwest. In many of the magnetite mines the ore layers are divided by pinches and swells into long pod-shaped shoots, nearly all of which, like the corrugations described, dip toward the northeast or east; and, where ore bodies are entirely capped or bottomed by barren rock, the edges of the shoots likewise pitch in the same direction.

Long faults running nearly parallel with the general strike of the crystalline rocks are known to exist mainly from the fact that movements along them have produced the existing insets of Paleozoic formations. Near these breaks the minerals of the gneisses are considerably decomposed, but they are ordinarily not traceable beyond the areas of younger rocks, owing to the presence of glacial drift north of the terminal moraine and to the deep mantle of decomposed rock farther south.

Cross breaks have been found in some of the mines, but usually they are not important and few of them are discoverable on the surface.

ORIGIN AND RELATIONS OF THE ROCKS.

The gneisses of the New Jersey Highlands, with few exceptions, correspond accurately in their mineralogical and chemical composition with common types of coarse-grained igneous rocks like the granites and diorites. They differ from the usual igneous rocks in that they possess foliated or linear structures instead of evenly granular textures. The members of the gneissic complex which are present in the largest amounts are light-hued granitoid rocks, here included under the names Losee gneiss and Byram gneiss. There can be little doubt that these rocks have solidified in part out of silicate solutions or molten magmas, which moved while in a soft or plastic condition from the more or less distant regions in which they had originated into the positions now occupied by the resulting rocks. The fact that they comprise invading masses is shown locally by irregular crosscutting contacts, by the manner in which they inclose masses of older rocks, and in places by the development of metamorphic minerals along their borders. That large amounts of preexistingi rock material have been more or less completely dissolved and assimilated by the invading magmas is suspected but can not be affirmed.

In all the gneisses foliation is conditioned both by the interlayering of different varieties of rock and by the more or less elongated or flattened form of the component mineral grains and the arrangement of these grains in such a manner that their longer dimensions lie in sets of nearly parallel planes. Lamination of the first sort may be called structural foliation, and of the second sort textural foliation. Textural foliation may be developed during the first crystallization of a rock magma when consolidation takes place under the influence of some straining pressure, as, for instance, while the material is flowing, or it may be induced through processes of recrystallization accompanying complete deformation of the rock after it had once solidified. Elsewhere in the pre-Cambrian rocks, notably in northern New York and Canada, foliation exists in different stages of development, leaving in certain localities no doubt of the secondary manner in which it has been produced. Throughout New Jersey, however, evidence of crushing in the minerals of the gneisses is almost entirely wanting and appearances strongly favor the belief that the gneissic foliation is original in the invading rocks of the pre-Cambrian complex.

Less abundant than the granitoid rocks, but still of considerable importance in the field at large, is the dark Pochuck gneiss. The rocks embraced under this term have the composition of igneous diorites or gabbros, but whether they have been derived from igneous or sedimentary originals, or, as is thought, in part from both, their present characteristics have in most places been acquired by metamorphism, involving secondary crystallization. In these dark rocks foliation is everywhere present, and parallel to this structure the rocks are injected in all proportions by sheets of light-colored material similar in composition to phases of the Losee gneiss, with which group these sheets are undoubtedly to be classed. In addition to being definitely injected by thin bodies of the Losee rock, the dark gneisses are interlayered with both the Losee and the Byram gneisses on a broad scale, and the white crystalline limestones which occur here and there throughout the Highlands are similarly interlayered with the granitoid gneisses, so that these two sets of rocks—the dark gneisses and the limestones—together seem to constitute a matrix holding the intrusive granitoid rocks in the form of relatively thin but extended plates.

Apparently the dark rocks were already foliated before they were invaded, because the interlayering of the granitoid materials is so regular that the presence of some structural control would seem to have been a necessity. At the time of the injection, and perhaps as an effect of it, the dark rocks must have been reduced to a physical condition such that both in large masses and in thin plates their materials were able to adjust themselves to deforming pressure by solid flow instead of by rupture. During this deformation the early texture of the rock was broken down, important addition or subtraction of elements may have occurred, and a later crystallization ensued contemporaneous with the crystallization of the injected material. Both in the invading and in the invaded rock the process of crystallization went on subject to some widely operating control which, by allowing the mineral grains to grow more rapidly in certain directions than in others, gave them their flattened or elongated shapes and produced the observed foliated structure of the gneisses. The parallelism existing between the plates of rock and the foliation within them suggests as the most probable explanation that the forces causing flowage continued to operate after crystallization had begun, and practically until it was complete, so that the injection of the granitoid material, the pressing out and kneading of the masses of the matrix, and the development of textural foliation in both were phenomena connected in origin with a single cause.

The Franklin limestone locally retains traces of original stratification, showing its sedimentary origin, but the lamination observed within masses of this rock is regarded mainly as a sort of flow structure developed through the recrystallization of the limestone masses while they were being molded under the action of deforming stresses and at the same time traversed by mineral-charged waters derived from the invading Losee and Byram magmas.

Though it can not be claimed that determinable facts are sufficient to substantiate fully the relations and history outlined above, yet the occurrence of the different sorts of rock as interlayered masses with generally parallel contacts, the pitch of various structures in a common direction, the interlocking of mineral grains along contacts, and the conformation of the foliation within individual layers with the general lamination of the complex as a whole are believed to warrant the conclusion that the white limestones and the various gneisses with which they are associated, together with the ore deposits which they inclose, came into their present state of crystallinity and received their present forms as geologic masses during a single period of regional deformation.

Subsequent to the crystallization of the gneisses and limestones, though perhaps before the period of general deformation had closed, the rocks were invaded by the irregular dikelike masses of pegmatite which now occur in them.

HISTORICAL SKETCH.

In past years the weight of opinion has been in favor of a sedimentary origin for the typical gneisses of the Highlands region, though it has been rather generally admitted that many of the more massive rocks which are associated with the highly laminated members might prove to have been formed in a purely igneous way. This view of the origin through the metamorphism of sedimentary rocks was advanced in 1836 by Rogers, the first official geologist of New Jersey, and although it was consistently upheld by his successors, Kitchell, Cook, and Smock, the facts from which the conclusion was drawn now seem inadequate, and the conclusion itself appears not to have been based on strict deduction from observed facts. Investigation along this line of approach culminated in a report by Britton, published in 1886, in which the pre-Cambrian rocks of New Jersey (there designated Archean) were divided into three groups, separated primarily on the basis of differences in the perfection of gneissic structure, though for one group the presence of iron-ore deposits was taken as a distinguishing feature.

The first geologist to throw well-sustained doubt on the sedimentary theory was Nason, who pointed out (1889) that existing knowledge was inadequate for a decision whether the gneisses in the Highlands have been derived from sedimentary or igneous rocks, or even possibly from a mixture of the two. A special study of the rocks in the vicinity of the iron mines at Hibernia, N. J., by Wolff (1893) led him to the suggestion of a sedimentary origin for the rocks of this particular district, but the same geologist (1896) regards certain of the granitic rocks occupying extensive areas in the Franklin Furnace region as undeniably intrusive.

Two views have been held regarding the age of the white crystalline limestone of the Wallkill and Vernon valleys, with which the limestone outcropping on the east slope of Turkey Mountain, in the Passaic quadrangle, has been correlated. It has been regarded on one side as a metamorphosed form of the blue Paleozoic limestone which occurs in the same region, and on the other as a formation entirely distinct from this rock and of far greater antiquity. The latter view, which has been argued by Wolff and Brooks (1896), is here accepted without qualification.

LOCAL DISTRIBUTION OF THE FORMATIONS.

Pre-Cambrian crystalline rocks, constituting a basement or floor upon which the Paleozoic sedimentary formations were deposited, underlie the whole of the Passaic quadrangle, but they appear at the surface only in the Highlands of the northwest corner and on Manhattan and Staten islands. These rocks are characteristic of the Highlands district, and form all of its surface, but are locally covered by Paleozoic formations which appear at the surface in strips trending northeast and southwest, parallel with all the most noteworthy features of topographic and geologic structure throughout the general region.

The longest and widest inset of Paleozoic rocks within the Highlands contains formations of Silurian and Devonian age which are younger than any occurring elsewhere east of the Wallkill Valley. These rocks extend in a belt from one-half mile to 4 miles wide, from a point near Dover, N. J., along Green Pond, Bearfort, and Schunemunk mountains to Cornwall, N. Y., and occupy the extreme northwest corner of the Passaic quadrangle.

The various rocks, grouped and set apart in the manner outlined under a previous heading, are disposed upon the surface in relatively narrow northeast-southwest bands, which, like the inset strips of Paleozoic strata within the crystalline area, conform in direction with the principal features of the topography.

The rock groupings which have been represented on the map of the Passaic quadrangle, and which are described in the following pages, are as follows: Franklin limestone, Pochuck gneiss, Losee gneiss, Byram gneiss, granite, and pegmatite.

RELATIONS TO ADJOINING PRE-CAMBRIAN AREAS.

The Highlands area of the Passaic quadrangle is a portion of a narrow plateau composed mainly of pre-Cambrian crystalline rocks and extending from Hudson River between Stony Point and Cornwall-on-the-Hudson southwestward to Schuylkill River near Reading, Pa. The width of this plateau ranges from a few miles to over 20 miles. At its southwest end it narrows and finally disappears beneath Cambrian quartzites and limestones just east of Schuylkill River. (See fig. 1.) A small outlier of similar rocks occurs 10 miles farther west, but beyond this no more outcrops of pre-Cambrian rocks are known until South Mountain is reached. This mountain is about 55 miles distant, and constitutes the north end of the Blue Ridge uplift. Although the rocks of South Mountain are quite different from the predominant rocks of the Highlands belt, nevertheless the Highlands may be regarded geologically as the northeastward extension of the Blue Ridge, for the rocks in both areas are pre-Cambrian.

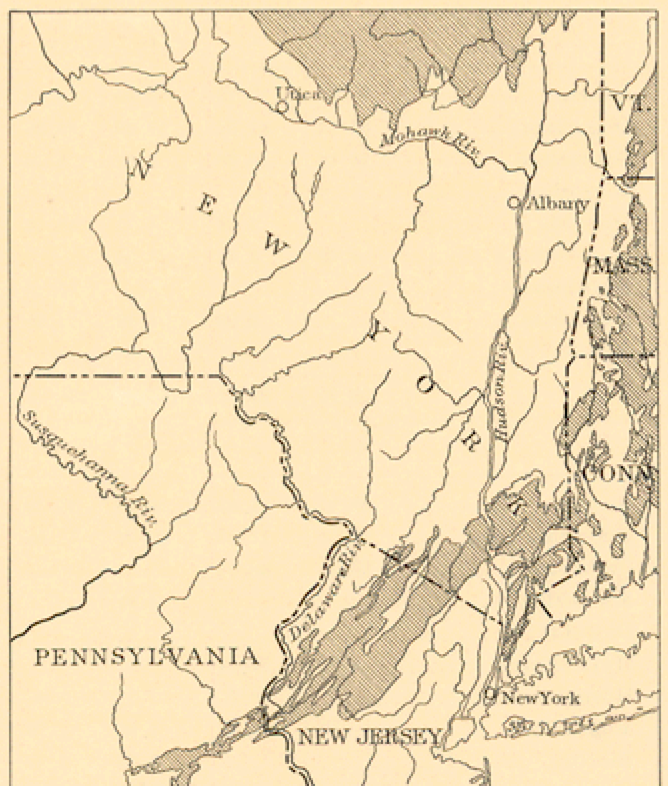

FIG. 1.—Sketch map showing areas of pre-Cambrian crystalline rocks in New Jersey and adjacent States.

At its northeast end the Highlands belt, after crossing Hudson River, expands to a width of 30 miles. On the south and southeast it merges into the uplands underlain by the Fordham gneiss and the Stockbridge dolomite of the New York quadrangle and loses its plateau-like character in these directions. To the northeast the pre-Cambrian rocks of the plateau continue about 15 miles beyond the river, to a point within about 5 miles of the Connecticut line, where they disappear under metamorphosed Hudson schist and metamorphosed limestone that is regarded as the equivalent of the Kittatinny limestone of New Jersey. Farther northeast the pre-Cambrian reappears in the western highlands of Connecticut in the complex composed of the Becket gneiss and the Stockbridge limestone.

The relations of the rocks of the New York and New Jersey Highlands to those of the New England plateau, of which the highlands of western Connecticut are a part, have not yet been worked out, but it is known that the rocks of the New Jersey area have their exact counterparts in the northwestern extension of the plateau in eastern Ontario and in the Adirondacks.

Parallel with the Highlands belt in its western part is a second belt of pre-Cambrian rocks, involved with rocks of later age, which begins at Trenton, passes north of Philadelphia and Baltimore, and extends thence southwestward as a part of the Piedmont Plateau. At Philadelphia this belt is separated from the Highlands belt by about 35 miles of Triassic and older sediments. The rocks as a whole appear to be much more highly metamorphosed than the Highlands rocks, in this respect being more closely allied to the gneisses and schists near New York City.

A third area of pre-Cambrian crystallines lies between the Highlands and Philadelphia belts, just south of Reading and west of Phoenixville, Pa. This is an isolated triangular area entirely surrounded by Paleozoic and Newark deposits. Its rocks are described as gneisses and are thought to be in large measure similar to the Highlands gneisses.

CHARACTER AND AGE.

Lithologically, the rocks of the Highlands in the Passaic quadrangle, like those of the Highlands elsewhere, are mainly granitoid gneisses and pegmatites with subordinate amounts of magnetite and of garnetiferous graphite schist. In one locality, on Turkey Mountain, north of Montville, there is a small exposure of white marble, which contains nodules of serpentine, and on Copperas Mountain are conglomerates and quartzites.

All the crystalline rocks in the Highlands area are pre-Cambrian, with the exception of a few narrow diabase dikes that are probably Triassic. The evidence of the pre-Cambrian age of the first-named rocks is not apparent in the Passaic quadrangle, but in the country to the north and west it is so strong that it can not be questioned. In the Franklin Furnace quadrangle, which lies immediately northwest of the Passaic, the oldest rocks are white crystalline limestone and associated quartzite. These are overlain unconformably by Cambrian conglomerate. Cambrian beds are not exposed anywhere in the Passaic quadrangle, but as the crystalline rocks here are identical in character with those of the Franklin Furnace quadrangle, and as they are continuous to the southwest into the Raritan quadrangle, where they are unconformable under Cambrian rocks in the neighborhood of Peapack and Gladstone and on the western slope of Mount Paul, there can be no question as to their pre-Cambrian age.

FRANKLIN LIMESTONE.

Name.—The white crystalline limestone associated with the gneisses in the Franklin Furnace quadrangle was called the Franklin limestone by Wolff and Brooks because of its extensive development at Franklin Furnace. The white limestone in the Passaic quadrangle is correlated with the Franklin limestone because of its lithologic similarity to the Franklin Furnace rock and because its relations with the surrounding gneisses are similar.

Distribution.—The only area of the white limestone in the Passaic quadrangle is on the east side of Turkey Mountain, about 2 miles north of Montville station on the Delaware, Lackawanna and Western Railroad. The limestone is exposed for a length of about 1000 feet and a breadth of 20 to 30 feet by a trench and some pits made for the purpose of procuring rock for burning into lime and for use as a flux at the old Boonton iron works. To the northeast and southwest the ledges run down into a valley in which there are no exposures, hence the relations of the limestones and the inclosing gneisses can not be made out with certainty.

At only one other place within the quadrangle is the limestone known to occur. This is in the Splitrock Pond mine, at the northeast end of the lake of the same name, where pieces of a well-characterized chondroditic limestone were found in the mine dump.

Lithologic character.—Where well exposed, the Franklin limestone is found to be a white crystalline marble varying greatly in texture and composition from place to place. It is generally coarsely granular. In some places, however, it is fine grained and in others is nearly amorphous. Usually it is milky white in color, but this kind passes locally into pink or yellow or gray varieties and at one place, about 1½ miles north of Danville, in the Hackettstown quadrangle, it is a mottled red and white rock speckled with black flakes of biotite and small green granules of pyroxene. At many places it is free from included minerals; it then ranges in composition from a nearly pure calcite, through magnesian varieties, into dolomite. In a few localities thin beds of sandstone have been found intercalated with pure limestone.

In most exposures the limestone contains a large number of minerals, among them being graphite, quartz, phlogopite, diopside, and other pale-colored pyroxenes, tremolite, and chondrodite. Magnetite, sphalerite, and garnet are noted here and there. Serpentine is abundant at many places as an alteration product of the pyroxene and chondrodite, and talc and muscovite have been observed in a few places where the rock has been sheared. The Turkey Mountain rock is notable for the large quantity of serpentine in it. This appears in large and small nodules scattered through the white limestone and as sheets coating slickensided surfaces. The production of the serpentine has been ascribed to the alteration of a gray and a white pyroxene (diopside), occurring in the limestone in the form of crystals or nodules. The derived serpentine is a highly hydrous variety, approaching retinalite in composition.

Structure.—Although stratification is not noticeable in the limestone at Turkey Mountain, at some points in the Franklin Furnace quadrangle it is plainly apparent. The relations of dip and strike indicate that at a few of these localities the limestone is folded. Usually, however, its dip is uniformly to the southeast, when it conforms to the dip of the contiguous gneisses. Where the limestone contains graphite and the silicates these minerals are usually arranged in layers producing a laminated structure, which, so far as observed, is everywhere parallel to the linear structure in the surrounding gneisses.

At Turkey Mountain slickensides are observed here and there in the body of the rock, and many of the slickensided surfaces are coated with serpentine. This was due apparently to the increase in bulk that resulted from the serpentinization of pyroxene. Pressure was thus produced which was sufficient to cause in the serpentine and surrounding limestone not only numerous slickensides but also in some places a distinct platy structure.

The laminated structure of the limestone and practically all of its component minerals except the distinctly secondary minerals and some of the quartz, are thought to be the result of metamorphism induced by the granitoid gneisses, which are of igneous origin.

Relations to surrounding rocks.—The limestone at Turkey Mountain is bounded on both sides by gneisses of the usual kinds. At one place the western contact of the rocks is seen. Here the limestone near the gneiss is bordered by a band of gray pyroxene, 1 to 1½ inches wide, resembling a contact band. At other places on this wall large crystals of muscovite are developed. On the east side of the exposure there seems to have been faulting between the limestone and the gneiss, for both show slickensides near the contact, and in some places a considerable development of biotite. The mode of occurrence of the limestone gives the impression that the rock is a comparatively thin plate interlaminated with the gneiss and dipping with it at a steep angle to the northwest.

This relation between plates of limestone and the banded gneisses, which is a common one throughout the Highlands, has led many geologists to regard the limestone and the gneisses as interstratified members of a series of sediments. In the Franklin Furnace district, where the limestone is well exposed in comparatively large areas, it is cut by pegmatite and in a few places by small dikes of black rock resembling some of the dark gneisses here described as Pochuck gneiss. At the Turkey Mountain locality, also, a small stringer of dark gneissoid rock cuts the limestone, and a coarse magnetitic pegmatite occurs along the northwest wall of the quarry. In other places, outside of the Passaic area, little tongues of the light-colored acidic gneisses intrude the limestone. From these facts it is inferred that the Franklin limestone is older than the siliceous gneisses and some forms of the dark gneisses and that these rocks are intrusive into it.

It is possible that the Turkey Mountain mass may be merely a large fragment that was torn off from the main body of the limestone and brought to its present position by the viscous magma which later yielded the gneisses by which the limestone is surrounded.

The relations of the limestone to the Hardyston quartzite in the Franklin Furnace area are those of unconformity, with the quartzite above the limestone.

Age.—From the relations of the white limestone to the gneisses and the Hardyston quartzite it is evident that the limestone is older than these rocks. It is therefore pre-Hardyston. Whether it should be regarded as Algonkian or pre-Algonkian remains yet to be determined.

For many years was the prevailing opinion among geologists who had personally investigated the white limestone that it is a metamorphosed phase of the Kittatinny (Cambro-Ordovician) limestone, but this view has recently been disproved.[1]

GNEISSES.

GENERAL CHARACTERS AND CRITERIA EMPLOYED IN MAPPING.

The prevalent gneisses of the Passaic quadrangle are similar in character to those found elsewhere in the New Jersey Highlands. In composition they correspond to rocks usually distinguished by the names granite, syenite, diorite, gabbro, etc., but they differ from these rocks in the possession of well-defined foliated or linear structure. Those rocks which exhibit only linear structure are evenly granular on surfaces at right angles to this structure. Although the gneisses grade into one another by a great number of intermediate forms, there are several distinct types which are present all over the Highland area and which are composed of very characteristic groups of minerals. In thin sections under the microscope these types are as a rule easily recognizable, but in the field it is not always possible to differentiate them with certainty.

The gneisses occur in tabular masses or very thin lenses which on the surface appear as a series of parallel belts, some of them continuing for long distances. The same arrangement is present also on a smaller scale. Belts which are on the whole composed of one kind of gneiss, when examined in detail are found to be made up of wide bands of one kind and narrow bands of a different kind, the former of course predominating. In some portions of the area the several kinds of gneiss are interleaved in approximately equal proportions, in layers of nearly equal thickness. The individual layers wedge out at their ends, and thus have on

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[1] Westgate, L. G., Am. Geologist, vol. 14, 1894, pp. 369-379; Wolff, J. E., and Brooks, A. H., Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 431-457.

the surface, like the broader belts, the shapes of sections of flat lenses.

The alternation of different gneisses is everywhere observable. In the Passaic quadrangle the intermingling of gneisses in the different belts is so intimate that it is impossible to represent their distribution with any degree of accuracy on the scale of the accompanying map. Moreover, as the rocks grade into one another, they are not separated by any distinct boundaries, and the mapping has consequently been based on the mineralogical composition of the predominant gneiss in the several belts. On this basis the boundaries delineated on the map are largely arbitrary. They represent merely convenient lines between areas in which the indicated rocks preponderate. It is to be understood that in all these areas, besides the kind represented by the color on the map, there are present also rocks of a different composition, but not in sufficient quantity to predominate. The rocks intermediate between those selected as types are included with that type with which they are most closely affiliated by composition.

Small masses of a garnetiferous graphite schist form narrow bands in the midst of the gneisses referred to above, and these also include numerous small and large masses of pegmatite. On a map of very large scale the positions of many of the pegmatites might be represented with considerable accuracy, for their boundaries are in many places fairly well defined. On the present map, however, no attempt is made to differentiate them from the gneisses with which they occur. Some of them are dikes cutting across the structure of the gneisses, but more commonly they occur as narrow bands following the gneissic structure. Over no considerable area do they constitute the prevailing rock, though in some areas they are much more abundant than in others.

TYPES OF GNEISSES.

The gneisses of the Passaic quadrangle have been grouped around three types, which in their most characteristic phases are readily distinguished from one another by their appearance in the field and in thin sections under the microscope, as they consist in part of different aggregations of minerals and in part of the same minerals in very different proportions. These three types are known as the Losee gneiss, the Byram gneiss, and the Pochuck gneiss. Rarely does one type alone occupy any large area, but each occurs variously mixed with others in long, narrow belts wedging out at their ends. Within these belts one type may preponderate, but at the same time both the other types are usually represented in smaller amounts. Not only is there in many places an interlamination of varieties within a belt, but not uncommonly one type may grade into another along the strike of the belts through intermediate phases.

In this quadrangle the occurrence of the different gneisses in well-defined belts is not so pronounced as it is in some other portions of the Highlands, the predominant rock—that is, the one covering the greater portion of the area—being the Losee gneiss, with the Byram and Pochuck gneisses occupying comparatively small areas within that occupied by the Losee.

POCHUCK GNEISS.

Name.—The Pochuck gneiss was so named because of its characteristic exposures in Pochuck Mountain, in the Franklin Furnace quadrangle, northwest of the Passaic area.

Distribution.—The Pochuck gneiss forms the principal mass of Bald Hill (Rockaway Township), where it is associated with the Losee gneiss, and constitutes a very narrow belt between belts of Byram and Losee gneisses in the northwest corner of the quadrangle. It is found also in thin plates interlaminated with the Losee and Byram gneisses in the neighborhood of Hibernia and with the Losee gneiss in other portions of the quadrangle. The result of these interlaminations in the ledge is a striped rock alternating white and black, or gray and black, with the light color usually predominating.

Pochuck gneiss is also generally associated with the ore bodies wherever they are found, but in such narrow bands that it is impracticable to map them. It constitutes one or both of the walls in many mines and often also the "vein rock" intermingled with the magnetite. Indeed, some of the ore is nothing more nor less than a magnetitic hornblende gneiss, as at the Beach Glen mine, where the rock recently raised contained about 41 per cent of iron.

Character and varieties.—The rocks included in the Pochuck gneiss are all dark colored, usually black, on account of the presence in them of large quantities of pyroxene, hornblende, and biotite. They have a wide range in mineralogical composition, and are, as a rule, more closely allied to the Losee than to the Byram gneiss. As found in the Passaic quadrangle, the Pochuck gneiss is composed of oligoclase, orthoclase, diopside, hornblende, hypersthene, biotite, magnetite, and quartz in varying proportions. In some specimens all these minerals are present, but usually two or more are absent. Magnetite is the most constant component, though oligoclase, hornblende, and green pyroxene are nearly always present. In other portions of the Highlands microcline or scapolite may occur in some varieties, but in the Passaic quadrangle these minerals have not been seen in any of the specimens studied.

For the most part the Pochuck gneiss may be regarded as a basic phase of the acidic type with which it is associated—that is, where associated with the Losee gneiss the principal feldspathic mineral of the Pochuck is oligoclase, and where associated with the Byram gneiss it is microperthite, with or without the addition of microcline. Moreover, in the former association the Pochuck gneiss usually contains a considerable quantity of diopside, but in the latter this mineral is rare and hornblende is the principal bisilicate present, almost to the exclusion of the pyroxene. The inclusions of Pochuck gneiss found in the Byram gneiss are, so far as has been determined, of the variety containing microperthite.

The gradation between the Losee and the Pochuck gneisses and the wide variation in the mineral composition of the latter are shown in the table below, in which column 2 represents a mass of Pochuck gneiss between masses of Losee gneiss, column 1. Columns 3 and 4 represent rather basic phases of the Losee gneiss, 5 to 7 phases of typical black Pochuck gneiss, and 8 is a biotitic phase of the Pochuck.

Mineral composition of Losee and Pochuck gneisses.

	1.	2.	3.	4.
Quartz	1.94	--------	16.71	--------
Orthoclase	15.18	15.91	--------	8.35
Oligoclase	70.12	28.35	64.47	72.50
Diopside	--------	20.93	--------	--------
Hypersthene	10.10	--------	--------	--------
Hornblende	--------	30.51	17.50	17.05
Biotite	--------	--------	--------	--------
Magnetite	2.66	4.32	1.32	1.69
Apatite	--------	--------	--------	.36
	100.00	100.02	100.00	99.95
	5	**6.**	**7.**	**8.**
Quartz	1.51	2.40	--------	--------
Orthoclase	9.02	14.30	--------	9.49
Oligoclase	27.31	27.50	--------	51.59
Diopside	24.43	33.01	38.47	19.01
Hypersthene	--------	--------	--------	--------
Hornblende	21.27	.51	39.06	--------
Biotite	--------	--------	--------	17.72
Magnetite	16.47	22.25	22.47	2.18
Apatite	--------	--------	--------	--------
	100.01	99.97	100.00	99.99

1. Normal Losee quarry rock, Montville quarries.
2. Pochuck band in quarry rock, Montville quarries.
3. Losee gneiss from north of Durham Pond.
4. Losee gneiss from side of Morris County R. R., just north of Passaic quadrangle.
5. Pochuck gneiss from Pikes Peak mine, Stickle Pond.
6. Pochuck gneiss from Rockaway Valley mine.
7, 8. Pochuck gneiss from Charlottesburg mine, north of Passaic quadrangle.

Chemical composition.—The chemical analysis of a specimen of a black schistose variety of the Pochuck gneiss associated with the ore at the Pardee mine, which is just beyond the northern boundary of the quadrangle in the extension of the belt crossing its northwest corner, is given in the table in the next column, together with the analysis of a norite forming the wall rock of the titaniferous ore at the Kent mine, near Lincoln Pond, Elizabethtown, Essex County, N. Y.[1] This rock consists of green augite, hypersthene, brown hornblende, plagioclase, magnetite, and a little microperthitic feldspar. The composition of the two rocks, calculated in terms of the standard rock-forming minerals (the norms) is very similar, except that the Pochuck gneiss contains a smaller amount of salic minerals than the norite by 3½ per cent and a corresponding greater quantity of femic minerals. The component molecules are practically the same.

Analyses of Pochuck gneiss and of norite.

[W. T. Schaller, analyst.]

	Gneiss.	Norite.
SiO_2	43.98	44.77
Al_2O_3	12.01	12.46
Fe_2O_3	6.60	4.63
FeO	12.20	12.99
MgO	5.46	5.34
CaO	11.99	10.20
Na_2O	2.93	2.47
K_2O	1.10	.95
H_2O-	.29	.12
H_2O+	1.04	.48
TiO_2	2.25	5.26
CO_2	.18	.37
S	--------	.26
P_2O_5	.28	.28
NiO	--------	Trace.
BaO	--------	Trace.
MnO	.05	.17
	100.36	100.75

Norm, or standard mineral composition, of Pochuck gneiss and of norite.

	Gneiss.		Norite.	
Orthoclase	6.67	43.38	5.6	46.8
Albite	15.20		20.9	
Anorthite	16.40		20.3	
Nepheline	5.11		-----	
Diopside	33.05	40.77	21.5	34.4
Hypersthene	------		11.2	
Olivine	7.72		1.7	
Magnetite	9.51	13.77	6.7	16.7
Ilmenite	4.26		10.0	
	97.92		97.9	

The Pochuck gneiss, as represented by the specimen analyzed, has thus the mineralogical composition of a basic igneous rock belonging in the gabbro family. According to the chemical classification of magmas recently proposed the rock is auvergnose—that is, an auvergnase of the order gallare.

Structure.—The structure of the Pochuck gneiss varies in different belts, ranging from almost massive to very gneissic, the gneissic structure increasing with an increase in the hornblende and biotite. The most gneissic phases are almost invariably very micaceous. Interlayering of different gneisses at many places is also noticeable, narrow threads and seams of light-colored feldspathic rock (Losee type) alternating with seams of the dark rock parallel to its foliation. These individual seams are rarely more than one-tenth inch thick, though many may be crowded together forming a group half an inch or more in thickness, in which the component parts are separated from one another by very thin plates of dark rock.

Relations to other rocks.—The relations of the Pochuck to the Losee and Byram gneisses have been described in part. It has already been stated that a dark rock allied to the Pochuck gneiss intrudes the Franklin limestone and is intruded by the Losee gneiss, but the relations between the limestones and the main mass of the Pochuck gneiss have not been determined. In the Passaic quadrangle a small dike of schistose black gneiss cuts obliquely across the area of the Franklin limestone at Turkey Mountain, but no intrusions of the Losee gneiss into the Pochuck have been observed.

Intrusive relations between the Losee gneiss and dark hornblendic gneisses are rather common in some portions of the Highlands, so that there would seem to be no doubt that some forms of the Pochuck gneiss are older than the Losee and Byram gneisses. Moreover, small wisps and streaks of the black gneisses are often observed embedded in the Byram gneiss and in some places small angular masses are found completely surrounded by the lighter gneiss. These are taken to be fragments, in which case the Pochuck that furnished them must have been solid when the inclosing Byram material was still plastic.

On the other hand, the dark pencils in the Byram gneiss are in some places found to coalesce, forming large, flat lenses whose composition is identical with that of some of the Pochuck bands interlaminated with the siliceous gneiss. In places these lenses are so large that they become definite belts. If the dark pencils are simple aggregates of the basic minerals of the Byram magma, as they appear to be, then there are certain belts of black gneiss that are contemporaneous with the main mass of the Byram gneiss with which they are associated. This black gneiss is indistinguishable in the field from other black gneisses that are not so closely associated with the Byram, and no attempt, therefore, has been made to discriminate between them on the map.

From the facts above recounted it must be inferred that some of the Pochuck gneiss existed as solid rock before the advent of the acidic Losee and Byram gneisses, and that another portion was contemporaneous with the Byram gneiss.

LOSEE GNEISS.

Name.—The Losee gneiss is so named because of its excellent development near Losee Pond, in the Franklin Furnace quadrangle. It was called the Losee Pond granite by Wolff and Brooks.

General character and varieties.—Although all gradations seem to exist between the Losee gneiss and the other gneisses, nevertheless the typical Losee rock is well characterized in the field and under the microscope. In the field it is distinguished by its white or light-green color in fresh exposures. On weathered surfaces, where decomposition is only superficial, the ledges are in many places snow white. When deeply weathered it takes on a bronzy luster, which becomes deeper as the quantity of light-colored pyroxenes increases. It is often impossible to distinguish such rock from the weathered Byram gneiss.

The light-colored phase of the Losee gneiss is not common in the Passaic quadrangle, though it is present at a few places in small layers associated with the black Pochuck gneiss. The prevailing phases are those tending toward gradations into the black gneisses—that is, into phases containing considerable quantities of pyroxenes, hornblende, or biotite. As the proportions of these components increase the rock loses its characteristic appearance and no longer has the white or light-green color of the more feldspathic phases. On the contrary, it ranges from a uniform gray rock showing no dark components to a yellowish or purple rock speckled uniformly with tiny black scales or irregular blotches. These phases resemble closely some varieties of the Byram gneiss, and it is only by recourse to the microscope that their relationship to the Losee type can be determined.

Mineral composition of various phases of the Losee gneiss.

	1.	2.	3.	4.
Quartz	16.07	13.75	19.59	0.43
Oligoclase	63.14	61.52	43.49	36.30
Orthoclase	16.16	16.66	4.62	8.70
Microcline	--------	--------	--------	--------
Diopside	--------	2.52	8.02	40.12
Hypersthene	4.62	2.44	22.53	--------
Hornblende	--------	--------	--------	3.10
Magnetite	--------	3.06	1.82	11.35
Biotite	--------	--------	--------	--------
	99.99	99.95	100.07	100.00
	5.	**6.**	**7.**	**8.**
Quartz	25.84	11.82	26.68	35.39
Oligoclase	38.07	17.05	66.07	57.90
Orthoclase	30.86	38.54	--------	--------
Microcline	--------	--------	1.91	--------
Diopside	--------	--------	--------	--------
Hypersthene	4.22	21.44	--------	--------
Hornblende	--------	9.70	--------	3.28
Magnetite	.97	1.45	1.92	1.73
Biotite	--------	--------	3.36	1.67
	99.96	100.00	99.94	99.97

1. Ledge of dark-gray variety on New York, Susquehanna and Western Railroad just east of Smith Mills, in Greenwood Lake quadrangle, about 1 mile north of 2.
2. Top, north end of Kakeout Mountain. Very similar to 1; contains bands of Pochuck gneiss.
3. Small ledge of bronzy rock, northwest of Durham Pond.
4. White variety of Losee type. Ledge few feet from old shaft of Wood mine, near Hibernia.
5. Light-gray variety. Top of hill one-half mile west of 4.
6. Dark-brown or bronze variety. South side of Sheep Hill, north of Boonton.
7, 8. Average rock of two belts of light gneiss in Franklin Furnace quadrangle.

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[1] Kemp, J. F., Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 407.

Mineral composition.—The Losee gneiss consists mainly of plagioclase (oligoclase) and quartz, with smaller amounts of bright-green pyroxene (diopside), hypersthene, biotite, apatite, magnetite, sphene, and locally zircon. Microcline, microperthite, and orthoclase occur in the typical rock in minor amounts only, though they are found in large quantity in many specimens that represent intermediate phases between the Losee and the Byram types. Of the dark components diopside is most abundant, followed by hornblende, hypersthene, and biotite in the order named. Magnetite is present in all specimens, but in many only in minute quantities.

The variation in the composition of the phases included in the Losee gneiss in the Passaic quadrangle is shown by columns 1 to 6 in the foregoing table, which indicates the relative percentages of their various components as determined by measurements in thin sections. Columns 7 and 8 show the mineral composition of the average rock of two distinct belts of a light-hued phase in the Franklin Furnace quadrangle.

Chemical composition.—An analysis of a specimen of the Losee gneiss obtained from a little knob about a mile northeast of Berkshire Valley, in the Lake Hopatcong quadrangle, corroborates the testimony of the microscope as to its composition. The specimen analyzed is a fine-grained, granular white rock representing the purest phase of the gneiss in which there are practically no dark minerals.

Analysis of Losee gneiss from knob near Berkshire Valley.

[W. T. Schaller, analyst.]

SiO_2	77.53
Al_2O_3	13.60
Fe_2O_3	.23
FeO	.16
MgO	Trace.
CaO	.73
Na_2O	6.65
K_2O	1.20
H_2O-	.15
H_2O+	.18
TiO_2	.16
CO_2	Trace.
P_2O_5	.03
MnO	Trace.
	100.62

Norm, or standard mineral composition, of Losee gneiss, calculated from chemical analysis.

Quartz	32.85
Orthoclase	7.23
Oligoclase (albite, 56.07; anorthite, 3.43)	59.50
Other components	1.22
	100.80

The chemical composition of the rock corresponds to that of the persodic liparase magma of the order britannare, a magma that is known as noyangose. In its mineralogical composition it corresponds to a very highly siliceous acidic granodiorite. The special feature of this phase of the rock is the practical absence of dark components. As these increase there is naturally an increase in the percentage of MgO, CaO, Fe_2O_3, and FeO, and the rock becomes more basic. These more basic phases are the most prominent in the Passaic quadrangle.

Structure.—Nearly all specimens of the Losee gneiss show more or less of a gneissoid structure. Many also exhibit foliation. In the light-colored varieties the gneissoid structure is obscured by the lack of contrast in the colors of the component minerals, but in the darker varieties it is easily discernible. In all cases it is due to the slightly lenticular shapes of the quartz grains and the arrangement of the dark minerals in lines or streaks, thus giving rise to "pencils." The strike of this linear structure is usually northeast, and its pitch from 15° to 40° in the same direction. Nowhere is schistosity observed except where the rock has been sheared.

Sheared phases.—All the crystalline rocks within a mile of the southeastern boundary of the Highlands area are more or less sheared, and at a few other places within the main gneiss area sheared phases are also found. Within the zones of shearing practically all the original components of the Losee gneiss, except the quartz, have disappeared and only their alteration products remain as evidence of their former existence. Kaolin, chlorite, epidote, secondary hornblende, and in some phases muscovite or biotite, all in thin plates, arranged in parallel position, make up the greater portion of the rock mass; through this are scattered sharp-edged fragments of quartz grains and a few particles of magnetite. Here and there garnets occur embedded in the schistose aggregate. In those phases where schistosity is highly developed the rock presents the appearance of a light-colored quartzose micaceous schist.

Relations to other gneisses.—The relations of the Losee gneiss to the other gneisses can not be determined in the area of the Passaic quadrangle, but farther northwest, in the Franklin Furnace quadrangle, there are contacts between white granitic gneiss and black dioritic gneisses of such a character as to indicate that the former are intrusive into the latter. In general, however, the contacts between the Losee and the other gneisses are such as to leave the relations indeterminate. In the Passaic quadrangle the Losee gneiss grades into the other gneisses.

BYRAM GNEISS.

Name.—The name applied to the Byram gneiss is taken from Byram Township, in Sussex County, where excellent exposures occur in the hills northeast of Roseville.

Distribution.—The rocks included under the name Byram gneiss seem to be more widely spread throughout the Highlands in general than either the Losee or the Pochuck gneiss. Within the Passaic quadrangle, however, they occupy a comparatively small portion of the surface in six detached areas, the boundaries of which are rather indefinite. In the extreme northwest corner of the quadrangle this gneiss forms the predominant rock in a belt a few hundred yards wide on the eastern slope of Copperas Mountain, extending from the western to the northern border of the quadrangle, and there wedging out. Two other areas lie west and southwest of Splitrock Pond. They are curved and are separated from each other by a body of the Losee gneiss which extends in between them from the great area of this rock on the east. The two ends of the smaller, southwestern area connect just west of the quadrangle inclosing a small area of the Losee gneiss. The three other areas are comparatively narrow belts trending northeast and southwest. The largest of these comprises a belt from one-half to 1 mile wide and 7 miles long, extending from a point southwest of Bald Hill through Dixon Pond and Rockaway Valley nearly to Splitrock Pond. The other two areas are near the border of the Highlands region and their long axes trend parallel to its boundary. The larger of these, just north of Boonton, is lenticular in shape, with an average width of three-fourths mile and a length of 4 miles. The smaller area west of Riverdale, is a narrow belt less than half a mile wide. A length of 2½ miles is included within the quadrangle, but how much farther northeast the belt extends is not yet known.

Character and varieties.—The several phases of the Byram gneiss vary greatly in appearance, but as seen in the ledge most of them resemble one another more than they do the Losee or the Pochuck type. Intermediate phases between the Byram and the other types have, of course, intermediate characteristics.

There are two principal phases of the Byram gneiss, as observed in other portions of the Highlands. One is a dark-gray rock moderately coarse grained and possessing a bronzy brown tone on freshly fractured surfaces. It is composed essentially of microperthite, microcline, orthoclase, hornblende, a little pyroxene, quartz, magnetite, and in some specimens biotite. The dark minerals are usually grouped into pencils arranged in lines parallel to the strike of the rock bands. This grouping produces a gneissoid appearance on all fracture surfaces except those that are transverse to the axes of the pencils, where the structure is evenly granular. This pencil arrangement is the linear structure which is characteristic of nearly all the gneisses in the district. Its pitch is usually northeastward, at angles between 15° and 40°.

The second variety of the rock is yellowish on outcrop surfaces, and pink, light gray, or nearly white on fresh fractures. It is usually finer grained than the dark-gray variety, from which it differs mineralogically mainly in the subordination of dark components. Because of this characteristic the rock lacks the pencils of the darker variety and consequently the distinct pitch structure. The rocks of this phase may possess a slight linear structure, but in many places this is so obscure that the texture is practically granitic.

In the Passaic quadrangle both phases of the Byram gneiss are present, but not in distinct areas. The lighter colored phase is probably more abundant than the darker one, but both are so intricately intermixed that it is not practicable to separate them on the map.

Mineral composition.—In mineralogical composition the Byram gneiss differs from the Losee gneiss in the prevalence of potash feldspars particularly in the form of microperthite, and from the Pochuck type in the smaller proportion of hornblendic and pyroxenic minerals. It grades into the Losee type by the introduction of oligoclase and into the Pochuck type by the increasing presence of oligoclase and bisilicates. The composition of some of the varieties in the Passaic area has been determined by weight as follows:

Mineral composition of various phases of the Byram gneiss.

	1.	2.	3.	4.	5.	6.
Quartz	24.27	27.12	28.06	30.89	35.54	35.29
Oligoclase	------	------	------	3.92	------	3.03
Orthoclase	31.75	12.07	.87	16.46	4.40	19.64
Microperthite	39.37	53.22	68.35	43.89	58.50	33.57
Hypersthene	------	------	------	------	------	3.03
Hornblende	2.31	------	.61	4.75	Trace.	------
Magnetite	2.35	------	1.98	------	1.57	5.37
Biotite	------	7.68	------	------	------	------
	100.05	100.09	99.87	99.91	100.01	99.93

1. Medium-grained bronzy variety, ledge on southwest spur of hill northeast of Powerville.
2. Medium-grained light-colored variety, ledge on New York, Susquehanna and Western Railroad, 1¼ miles west of Riverdale.
3. Band of fine-grained light-colored variety in Losee gneiss, side of road crossing east ridge of Stony Brook Mountains, one-half mile from Brook Valley.
4. Very light-colored fine-grained variety, top of southeast slope 1169-foot hill southwest of Durham Pond.
5. Light-yellow medium-grained variety, south end of knoll on east side of road between Boonton and Taylortown, 1 mile south of Taylortown.
6. Coarse-grained gray variety, top of 1038-foot ridge, 1 mile east of Splitrock Pond.

Chemical composition.—The chemical composition of a very light colored variety of the Byram gneiss, which contains almost no dark minerals, is represented by the following analysis:

Analysis of Byram gneiss from quarry 1 mile west of Hibernia.

[W. T. Schaller, analyst.]

SiO_2	77.07
Al_2O_3	12.61
Fe_2O_3	.71
FeO	.73
MgO	Trace.
CaO	.87
Na_2O	3.43
K_2O	4.06
H_2O-	.23
H_2O+	.62
TiO_2	.12
CO_2	Trace.
P_2O_5	Trace?
MnO	.09
	100.54

Norm, or standard mineral composition, of Byram gneiss, calculated from chemical analysis.

Quartz	39.13
Orthoclase	24.46
Plagioclase (albite, 28.82; anorthite, 4.37)	33.19
Other constituents	3.13
	99.91

The magma corresponding to the above analysis belongs in the subrang tehamose, which is a sodipotassic alsbachase, very near the border line with alaskose. The essential difference between the samples of the Byram and the Losee gneisses analyzed is in the relative proportions of the orthoclase and the albite molecules. The mineralogical composition of the Byram rock corresponds to that of a very acidic quartz monzonite.

Relations to other gneisses.—The genetic relations of the Byram gneiss to the Losee gneiss have not been discovered. No intrusions of one gneiss into the other have been seen. There are, however, in several places embedded in the Byram gneiss a few wisps and small, irregular-shaped, sharp-edged masses of a black gneissic rock that resembles Pochuck gneiss. Occurrences of this sort indicate that dark gneisses existed prior to the intrusion of the Byram gneiss.

The Byram gneiss, where it occurs in close association with the other gneisses, is interlayered with them as tabular masses. In most places the contacts are sharp, but here and there transitions occur and the gneisses pass over into one another by almost insensible gradations.

ORIGIN OF THE GNEISSES.

The gneisses in the Passaic quadrangle are identical with those in the other portions of the Highlands. In composition they correspond to well-recognized types of intrusive rocks. The reasons that actuated earlier students of the region in declaring them to be metamorphosed sediments were in large part their occurrence in layers and the supposed existence of more schistose phases on the flanks of ridges whose axes were thought to be composed of more massive phases. No such distribution of varieties could be made out in the area now under discussion. Nothing was seen in the field that proved the gneisses to be altered sediments, nor was any evidence of clastic grains detected in any of their sections.

On the other hand, in the Raritan and Franklin Furnace quadrangles some of the Losee gneiss occurs in masses that are intrusive into the other gneisses and into the Franklin limestone. Furthermore, the Byram gneiss contains inclusions of dark gneiss, and in the Raritan quadrangle it grades into pegmatites which are regarded as igneous rocks. For these reasons the Losee and Byram gneisses are considered to be original rocks resulting from the consolidation of igneous magmas, rather than secondary rocks derived by profound metamorphism of either sedimentary or igneous rocks. Their foliation and linear structure are regarded as mainly the consequence of the flowage of the magmas during the period of their solidification.

The linear structure is plainly not the result of granulation or the crushing of a rigid mass, as is the case with similar structures in some gneisses, for no granulation is observed in the rocks, except along certain narrow zones, which are regarded as fault zones, and within a belt that borders the gneisses at some places along their contact with the Paleozoic beds. Of course, it is possible that the rocks were once crushed, but if so, subsequent crystallization has entirely obliterated all traces of the crushing. There is, however, no evidence to show that this has been their history. Whatever the cause of the linear structure, the interlamination of the different gneisses is almost certainly the result of intrusions controlled perhaps by the arrangement of the rock beds into which they were forced.

Both the interbanding and the linear structure were produced before the deposition of the Hardyston quartzite, as fragments of the banded gneisses exhibiting a linear arrangement of particles are observed as pebbles in the conglomeratic beds of the quartzite. It is therefore a phenomenon that can not be correlated with the deformation of the Paleozoic rocks, but is vastly older.

The Pochuck gneiss has the same mineral components as those found in the Losee and Byram gneisses, except that quartz is rare and hornblende is more abundant than pyroxene. Moreover, it has the same constituents as those observed in many norites, with this difference, that the plagioclase of the Pochuck gneiss is mainly oligoclase, whereas that of the norites is more basic. In other words, the Pochuck gneiss, while closely allied to the siliceous gneisses of the district in the character of its mineral components, possesses at the same time the chemical composition of a distinct and well-defined igneous rock type belonging in the gabbro family. In texture the rock exhibits the features of one that has solidified from a magma, and in the field parts of it appear to be intrusive in the limestone. Its structure is more gneissic than that of the acidic gneisses, but there is no evidence in the rock that this structure is due to crushing. A portion of the gneiss is apparently older than the acidic gneisses with which it is associated, but another and smaller portion is contemporaneous with the Byram gneiss, being presumably a differentiate of the same magma that produced that rock. This rarer phase of the Pochuck is an igneous rock, whose structure, like that of the acidic gneiss, may be ascribed to fluxion, or to crystallization under unequal pressure.

The portions of the Pochuck that are older than the acidic gneisses either may be parts of an old igneous rock into which the later acidic gneisses were intruded, or they may possibly represent an old sedimentary rock that has been entirely crystallized through the influence of the Byram and

Losee magmas, which forced their way between its layers, stoped off slabs and fragments, partially dissolved them, and left the remnants of the smaller fragments as the inclusions now observed in the Byram gneiss. Whether the fragments were originally part of an igneous or of a sedimentary rock, the invading magma must have suffered changes in its composition through the absorption of their material, and on solidification the modified magma must have produced gradational phases between the Pochuck and the other gneisses such as have been described as being very common in all portions of the Highlands region.

No evidence has been discovered in the Passaic quadrangle that would lead to a decision as to the original condition of the older Pochuck gneiss, but from consideration of the phenomena observed in the Adirondacks and eastern Canada, where the geologic conditions appear to be nearly identical with those prevailing in the Highlands of New Jersey, and where rocks very closely resembling the Pochuck gneiss appear to be metamorphosed sediments without doubt, it is thought possible that some of the older rocks classified as Pochuck gneiss in New Jersey may have had this origin.

COMPARISON WITH ADIRONDACKS AND EASTERN ONTARIO.

A comparison of the gneisses in the Passaic quadrangle and in other portions of the New Jersey Highlands with the gneisses of the Adirondack Mountains and eastern Ontario shows that the Byram, Losee, and Pochuck gneisses have their equivalents in the northern districts.

The oldest rocks in the Adirondack region are crystalline limestones, quartzites, amphibolites, and micaceous schists all of which, except the amphibolites, are regarded as metamorphosed sediments. Beneath these and interlayered with them are gneisses composed of quartz, feldspars, emerald-green augite, brown hornblende, and biotite in various proportions. They may be mashed intrusive granitic rocks or they may be results of extreme metamorphism of arkose or acidic volcanic tuff. This complex is invaded by gabbros and by syenites composed of microperthite, augite, hornblende, biotite, and varying amounts of quartz. The syenite is almost identical in composition with the Byram gneiss of New Jersey, and no doubt of its intrusive origin is entertained by those who have studied it.

In the eastern Ontario region the rocks are similar to those of the Adirondacks and in addition there is a series of amphibolites which seem to have a threefold origin. Some of them are considered as representing limestones that have been altered by invading granites, others have been produced by the dynamic alteration of basic igneous intrusions, and still others have in all probability resulted from the recrystallization of basic fragmental volcanic material. From all three sources amphibolites are produced that can not be distinguished from one another either by appearance or by chemical composition. A gneissic granite intrudes the sedimentary rocks and contains fragments of the amphibolites.

The phenomena in the Adirondacks and eastern Ontario are therefore practically the same as in the New Jersey area, except that in the Highlands there are no great intrusions of gabbro and anorthosite.

In the Adirondacks and the Canadian region the limestones, the quartzites, and the schists supposed to be derived from sedimentary rocks are collectively called the Grenville series, and the granitic gneisses that are intrusive into the series, but which are structurally beneath it, are called the Laurentian gneiss.

GARNETIFEROUS GRAPHITE SCHIST.

General characters and distribution.—The rocks included under the term garnetiferous graphite schist are certain coarse- and fine-grained aggregates of quartz, feldspar, biotite or muscovite, garnet, magnetite, pyrite, and graphite, with a very schistose structure which is strongly emphasized when the proportion of mica is large. These rocks weather with a rusty-red color and become very friable.

Rocks of this class are very rare in the Passaic quadrangle. They occur in two narrow bands running for long distances in the direction of the prevailing gneisses. One of these bands is found at intervals from a point about a mile south of Rockaway Valley to a point west of Kakeout Mountain in the northern part of the quadrangle, a distance of about 6 miles. It has a width of about 20 feet in some places and at others is reduced to almost nothing. A second band begins at the eastern margin of the quadrangle, about a mile south of Hibernia, and runs northeastward nearly to the Cobb mine, east of Splitrock Pond. Small masses of the same rock occur scattered here and there through the gneisses, but not in sufficiently large areas to warrant mapping. They are particularly abundant in the region south and west of Splitrock Pond. These have been considered[1] as constituting an extension of the belt that apparently terminates at the Cobb mine.

Origin.—Similar rocks in the Adirondacks are generally regarded as representing metamorphosed sediments and this origin has been assigned to the occurrence at Hibernia by Wolff. The facts presented in support of this conclusion seem inadequate, and though it can not be proved that some of the graphite gneisses of the district are not altered sediments, others can be shown to have had a different origin.

In the Passaic quadrangle many of the pegmatite dikes that cut the gneisses contain graphite and some of them have been mined for that mineral. In places pegmatites of this sort are greatly crushed and in a few localities, with a continually increasing degree of crushing these rocks are observed to grade into coarse graphite gneisses containing garnet, mica, and pyrite, minerals that are not characteristic of the unbroken rock. Instances have been noted of coarse gneiss grading into finer grained varieties, so that there is no apparent reason why all these peculiar rocks may not have been formed in this way.

MAGNETITE.

Although occurring in small quantity and over restricted areas, magnetite nevertheless constitutes a rather common rock in parts of the Highlands. It is in many places associated with Pochuck gneiss or with pegmatite, forming long, narrow lenses or sheets in the Losee or Byram gneiss, with dips conformable with those of the neighboring gneisses. The rock consists mainly of the mineral magnetite, with hornblende, augite, feldspar, quartz, apatite, and in places biotite as accessories. Hornblende is the most abundant of the accessories and the most widely spread. Feldspar is also abundant in some specimens, but it is by no means as common as hornblende. With increase in feldspar there is usually also an accompanying increase in quartz, and the magnetite passes over into pegmatite. It grades into Pochuck gneiss by increase in the hornblende and augite, especially the former. Most of the bands of magnetite exposed on the surface are short, but in places, as at Hibernia, they measure several miles along the strike. Their widths, however, are rarely more than 20 feet, so that on a map of small scale they would not be represented, were it not for their commercial importance.

On the areal geology map the positions of the known bands are indicated, but their widths are greatly exaggerated. A fuller discussion of the magnetites is given in the section on economic geology.

PEGMATITE.

General character and distribution.—Pegmatite is found in large quantity associated with all the other rocks of the Highlands, and in some places it covers considerable areas unmixed with other rocks. Although commonly occurring in sheets or layers running parallel to the associated limestones and gneisses, nevertheless in some places the pegmatite forms veinlike bodies cutting across the structure of these rocks and penetrating them in such a way as to leave no doubt that it is distinctly younger. In several localities pegmatite masses that are intercalated between gneiss bands and run parallel with them for long distances send off branches which leave the main masses at approximately right angles and traverse the gneiss nearly perpendicular to its strike.

No attempt has been made to map the pegmatite dikes in the Passaic quadrangle, although they are present in all portions of the Highland area, as they are usually in bodies so small that they could not be represented on a map of this scale without undue exaggeration.

In some portions of the quadrangle, near Hibernia, for instance, the gneisses are so thickly injected by pegmatite that the two rocks are almost equal in quantity. In other portions there are areas of considerable size in which pegmatite is absent. As a rule, however, the gneisses are so uniformly cut by that rock that there is not a square mile that does not shown it to some extent.

Composition.—The principal minerals of the pegmatite are the same as those of the gneisses associated with it, viz, quartz, microcline, microperthite, oligoclase, hornblende, pyroxene, biotite, and in many places magnetite. The hornblende and pyroxene vary greatly in quantity, here and there comprising more than half of the rock mass. Hornblende is especially abundant in many dikes, and it occurs in large crystals many of which measure 12 or 15 inches in length. Garnet is a common constituent, more particularly where the rock has been sheared. Apatite, sphene, zircon, and graphite are also present, the latter locally in large quantity. In some of the pegmatite bodies the proportion of magnetite present is so great that the rock has been mined as lean iron ore.

Relations to associated gneisses.—The composition of the pegmatite bodies, which consist of the same minerals as those constituting the gneisses, seems to suggest that they are closely allied to these rocks genetically. Considerable force is added to the suggestion by the facts that their chief feldspar is, as a rule, like that of the associated gneisses; that in many places pegmatite and gneiss grade into one another without any sharp line of contact between them; and that in other places there are very coarse grained patches in the gneiss that are unquestionably identical in character with much of the pegmatite. The dikelike or veinlike pegmatite is similar to the patches in the gneiss. Hence it is assumed that this also is a phase of the same magmas that produced the gneisses. But, as some of the pegmatites cut across the structure of the gneisses, it is clear that they must be later in age than the gneisses which they traverse. In the Franklin Furnace quadrangle some of these pegmatites have a schistosity which is discordant with that of the inclosing gneiss but is parallel to the dike walls.

In order to bring these seemingly contradictory facts into accord, it is assumed that the pegmatites are intrusive portions of a deep-seated magma, the earlier invasions of which gave rise to the Losee and Byram gneisses. Here and there within the earlier intrusive masses the conditions were such that the magmas solidified as coarse grained patches. Elsewhere the earlier magma solidified in part and was intruded by the underlying partly crystallized liquid magma, which found easier access through the overlying rocks parallel to their foliation and formed intercalated layers. Where the intruded material was still liquid there was a gradation between the material of the pegmatite and that of the invaded mass. Where the latter rock had already solidified the invading material acted like a later intruding mass and made sharp contacts with the intruded gneisses. In a few places the pegmatitic material cut across the gneissic banding in irregular courses, but usually it insinuated itself between the layers and helped to emphasize this structure.

There is no evidence of any kind that the pegmatite dikes are the fillings of crevices by vein matter. Their constituents are identical with those of the accompanying gneisses, and they are not arranged in any definite order.

Reference has already been made to the fact that here and there the pegmatite has been crushed, and in consequence has assumed a gneissoid structure. At the same time considerable garnet and muscovite developed, the latter sometimes in large quantity. The resulting rock is a garnetiferous-micaceous gneiss which in many places contains a very considerable quantity of graphite.

DIABASE.

Cutting through all the other rocks of the Highlands are a few narrow dikes of diabase and allied rocks that are believed to be apophyses of the Triassic diabase, so common toward the south and east. In the Passaic quadrangle only two such dikes have been observed and these have been traced for only a few hundred feet and are not shown on the map. The larger of these dikes is composed of a dense, fine-grained black rock of the usual appearance of the Triassic diabase. It is only 20 feet wide, and occurs on the west flank of the 903-foot hill about 1½ miles east of Splitrock Pond. The other is alongside of and parallel with the road running along the west side of Rockaway River about midway between Powerville and Denville. This dike is about 25 or 30 feet wide and has been traced along its strike for a distance of about 100 yards. Its material is a diabase of medium grain, very slightly altered. Both dikes apparently strike and dip with the surrounding gneisses.

ORDOVICIAN SYSTEM.

By N. H. Darton.

HUDSON SCHIST.

Distribution.—Manhattan, Governors, Ellis, and Liberty islands and portions of Jersey City, Hoboken, Long Island, and Staten Island are underlain by mica schist or gneiss known as the Hudson schist. It presents no surface exposures now, but formerly was exposed at low tide in some low reefs in the eastern portion of Jersey City near the present shore of Hudson River. It is reached in many deep excavations for foundations of buildings in the lower portion of Manhattan Island and has been penetrated by wells in New York City, Jersey City, Brooklyn, Staten Island, and Ellis Island. It is known to underlie the Cretaceous rocks of Long Island, Staten Island, and the mainland to the south, having been penetrated by deep borings near Perth Amboy, Sayreville, Hoffmans Island, and Bay Ridge. How far west under the Newark sediments it may extend is not known, nor has it been possible to ascertain its precise limits under the surficial deposits in Jersey City and on Long Island. In the northern part of Staten Island it lies just east of the area of serpentine and it may also underlie the region to the west of that area under drift or rocks of the Newark group. In portions of the channels of Hudson and East rivers is a limestone known as the Stockbridge dolomite which underlies the Hudson schist and reaches the surface in the upper part of New York City and on the northwest corner of Long Island. Exposures of Hudson schist in Jersey City formerly appeared at low tide in a reef extending between Washington and Green streets and north of Harsimus street. It rose as a narrow crest about 100 feet in length with nearly vertical walls, out of mud which was 60 feet or more deep. There was a second reef of the same nature at the south end of Washington street, at the canal crossing, where the rock was a mica schist or gneiss. The Hudson schist was also penetrated to a depth of about 1000 feet in a boring at the Mattheison & Wiecher sugar refinery. Borings on Ellis Island, Liberty (Bedloe) Island, and Robins Reef show that the principal underlying rock is gneiss, apparently a prolongation of the reef which outcropped in Jersey City.

A small area of dark slate of supposed Hudson age appears in the valley of Pompton River at the edge of the Highland area. It outcrops in the river bank at the bridge east of Pompton station. Apparently it is a portion of the floor which underlies the Newark group, and it is separated from the old rocks of the Highlands by the great fault. This slate differs greatly from the Hudson schist of the Manhattan Island region in being much less metamorphosed.

Character.—The Hudson schist consists of quartz and biotite, with more or less orthoclase and several accessory minerals. Its schistosity is pronounced and as a rule is nearly parallel to the bedding. In the area east of the quadrangle are exposures in which it is seen to be penetrated by granite and basic intrusions, the latter altered to serpentine at various points. The material was originally clay deposited by water. Through pressure and lithification this clay became shale or slate and finally, under strong pressure and mineralization, was metamorphosed to mica schist.

SILURIAN SYSTEM.

By N. H. Darton.

GREEN POND CONGLOMERATE.

Copperas Mountain, in the extreme northwest corner of the Passaic quadrangle, contains a synclinal mass of Green Pond conglomerate. This

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[1] Wolff, J. E., Ann. Rept. Geol. Survey New Jersey for 1893, p. 365.

formation is extensively developed in Green Pond Mountain and other ranges in adjoining quadrangles. The rock consists mainly of quartz pebbles, mostly from one-fourth to 1 inch in diameter, in a gray to purple quartzitic matrix. Toward the base especially it includes pebbles of quartzite, gneiss, and rarely of dark intrusive rocks. The conglomerate is hard, massively bedded, and about 1300 feet thick. It lies directly upon gneiss which extends up the east side of the mountain to a point within about 250 feet of the crest. The conglomerate dips 55° NW. on the east side and the crest of the mountain and at a much lower angle in the same direction on the western slope. It is cut off by a fault at the extreme northwest corner of the quadrangle, by which the gneiss is brought to the surface in the adjoining areas. On lithologic grounds it is correlated with the Silurian Shawangunk conglomerate. As it lies on pre-Cambrian gneiss the Ordovician and Cambrian rocks are absent in this area. To the northeast it overlies Hudson shale and is itself overlain by fossiliferous limestones, shales, and sandstones of later Silurian to Devonian age.

POST-HUDSON IGNEOUS ROCKS.

By N. H. Darton.

SERPENTINE.

Distribution.—Two areas of serpentine appear in the Passaic quadrangle, one large mass constituting the high hills of Staten Island and a smaller one occurring at Castle Point, Hoboken. It is reported also that serpentine was found under the drift in a deep excavation at Broad street and Exchange place, New York City. The principal exposures on Staten Island are along the summit and steep eastern slope of the ridge extending from Tompkinsville to Richmond, especially at Pavilion Hill, Tompkinsville, New Brighton, near Garretsons, on Meissner avenue near Richmond, and near Egbertville. On the western slope of the ridge the rock is extensively and deeply covered by drift, but it has been found in wells and uncovered at the old iron mine at Castleton Corners. Its western boundary is not located within half a mile or more, but to the east the rock probably ends at or near the foot of the steep slope to which the Cretaceous rocks appear to extend. In the Castle Point area the serpentine appears in cliffs 10 to 30 feet high along the shore for several hundred yards, and formerly it was exposed in a somewhat wider area to the west. The boundaries of this area are not definitely located. It is reported that serpentine was reached at a depth of 179 feet at the end of Long Dock, Jersey City, and there are some reasons for supposing that the rock bored into at a brewery on Ninth street near Grove street, Jersey City, may be serpentine.

Character.—The serpentine of Hoboken and Staten Island is a soft rock, a hydrous silicate of magnesium ranging in color from light green to greenish gray and greenish brown. It is believed to have been originally an igneous rock, possibly in part of a hornblendic nature, intruded into the Hudson schist and now greatly altered. On Staten Island the serpentine contains remnants of hornblendic minerals, but much of it shows under the microscope a reticulate structure thought to be characteristic of serpentine derived from olivine, while the lattice structure characteristic of serpentine derived from hornblende is wanting. Some fresh rock found at one locality is irregularly veined with compact, semitranslucent serpentine of lighter green color and conchoidal fracture, but most of the material is porous and earthy in appearance. Some portions are asbestiform, with fibers as long as 2 feet in places. Various magnesian minerals occur in it, such as foliated talc in white masses, magnesite, massive and crystalline, veins of dolomite, and deweylite. Chromite and magnetite in small, scattered crystals are of common occurrence.

The serpentine is foliated and the following dips of the foliation have been reported: About Pavilion Hill, New Brighton, 70° to 85° NW.; in most exposures, west of Garretsons, 70° to 80° S. 30° E., with much crumpling; west of Grant City, 55° to 70° N. 30° W.; in the ravine near Egbertville, 85° S. 15° E.; near Richmond, 80° N. 10° W.; and in a brook a mile north of Egbertville, 40° to 50° NW.

Both on Staten Island and at Hoboken, the serpentine at some points is overlain by masses of hard, siliceous rock consisting mainly of quartz which is believed to be of secondary origin, for on Staten Island it is associated with the iron ores. At Brighton Point, St. George, an outcrop of tough, fibrous, nearly pure tremolite similar to that which was penetrated in the deep well at Bischoff's brewery in Stapleton was formerly visible, but it has since been covered. North of New Dorp the serpentine contains some soft schistose rock, apparently now chloritic, containing altered crystals of tourmaline.

On the serpentine hills of Staten Island limonite of good quality was formerly mined to a moderate extent. This ore of iron resulted from the decomposition of the basic rocks from which the serpentine was derived.

GRANITE.

A small area of granite rises about a foot above low-tide level on the shore at Tompkinsville, but it has been mostly covered by railroad embankments. The locality is about 100 yards west of the old steamboat landing and the original exposure was 80 feet long by 50 feet wide at low tide. Another outcrop of small size formerly appeared at a point 200 feet farther south. Probably this granite, like similar masses east of the Hudson, is an intrusion in the Hudson schist which is believed to underlie the Raritan formation on the east side of the serpentine on Staten Island, and consequently is of post-Ordovician age. It is included with the Hudson schist on the geologic map. It is a coarsely crystalline rock consisting of large orthoclase crystals, quartz ranging in color from dark brown to nearly white, and in places muscovite. Some oligoclase is also reported. In 1892 a reef removed from the mouth of Kill van Kull near St. George landing was found to be formed of this granite. Samples blasted out consisted of coarse-grained granite precisely similar to the rock at Tompkinsville.

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 lie in Nova Scotia, Connecticut, Massachusetts, 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. There are 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, in New Jersey and in the Connecticut Valley, are unmistakably lava flows. The structure of the strata 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 toward the west at angles of 10° to 15°, but 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 numerous longitudinal faults repeat the outcrops of the various formations.

The age of the Newark group is believed to be later Triassic and earlier 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 after Carboniferous time, and therefore must be of later date, and they are clearly older than the earliest Cretaceous formations, which overlap them unconformably in Maryland and farther south. They are thus separated from earlier and later deposits by intervals of upheaval and erosion of unknown duration, and their position in geologic history can not be determined more closely than by the general correlation of fossils above indicated.

Distribution and subdivisions in New Jersey.—The Newark group in the New Jersey area 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 low 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. Extensive faults traverse the group mostly along its strike and with downthrow on the east side. The abrupt margin on the northwest is for the most part defined by several faults in 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 the Hudson, but of this there is less definite indication. From the southern part of Staten Island southward there is unconformable overlap by the Raritan formation, of Cretaceous age, which for some miles lies across the lower beds of the Newark group.

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 may be classified in three formations—the Stockton, Lockatong, and Brunswick—the last named being the youngest. These subdivisions are distinct along Delaware River and northward to a point beyond Raritan River, but they are less easily traceable across the northeastern part of the State, for the surface is extensively covered by drift and the upper formation partly loses its distinctive character while the middle member can not be recognized at all.

The Stockton formation comprises arkose sandstone with some red-brown sandstones and red shale, occurring in no regular succession and presenting many local variations in stratigraphy. It rests upon 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 Palisade diabase. The sandstones are in many 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 close proximity to a shore of the ancient metamorphic rocks.

The Lockatong formation along Delaware River and for some distance to the northeast 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 overlies the Stockton some distance above Trenton and west of Princeton, and is brought up by faults along the southeastern side of Sourland Mountain and again above Stockton. In northeastern New Jersey the Lockatong can not be recognized, its place apparently being taken 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 shales with a few thin sandstone layers. To the north the sandstone increases in amount and coarseness. Ripple marks, mud cracks, raindrop impressions, and footprints of reptiles at various horizons indicate that the Brunswick beds were also deposited by shallow waters, with intervals in which there were bare mud flats.

NEWARK GROUP IN THE PASSAIC QUADRANGLE.

General relations.—The rocks of the Newark group occupy a belt about 23 miles wide extending diagonally across the Passaic quadrangle, from northeast to southwest.

The sedimentary rocks of the Newark group 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 their hardness causes high ridges, of which the Palisades and Watchung Mountains are the most conspicuous. These ridges rise several hundred feet above the plains or rolling lowlands of softer sedimentary beds, and present high cliffs to the east and gentler slopes to the west. Their course is mainly northeast and southwest. Section B–B on the structure-section sheet illustrates the general structural relations of the sedimentary and igneous rocks. It shows the general dip to the west and the order of succession and relations of the larger igneous masses, and it illustrates the origin of the more prominent topographic features. The Watchung rocks are lava flows which were poured out at three separate times during the accumulation of the sedimentary deposits.

On the east the Newark strata lie upon gneisses and other crystalline rocks of the series which constitute the surface on the east side of Hudson River and in the eastern portions of Hoboken, Jersey City, and Staten Island. At no point is the contact exposed, so but little is known in regard to the contact relations. It has been thought that there is a fault extending along the eastern border of the group at Hudson River, and some of the deep borings in Jersey City bear out this idea. In one well gneiss is reported to a depth of 1500 feet, and in another not far away red sandstone is reported to a depth of 1400 feet. On the other hand, overlap is indicated by the boring at the Central Stock Yards, which is stated to have penetrated red sandstone to a depth of 215 feet and then to have entered gneiss. Another boring at Eagleswood, in Perth Amboy, after passing through surficial deposits and Cretaceous sands and clays, penetrated the Newark red sandstone, here only 9 feet thick, and found the underlying gneiss at a depth of 70 feet below the surface.

On the west the Newark sediments extend to the steep mountain slopes of granites and gneisses of the Highlands, from which they are separated by a fault, probably of great throw, extending northeast and southwest. Near Pompton black shales of supposed Hudson age appear to lie east of this fault and immediately underlie Newark conglomerates and sandstones, and probably these shales, together with limestone, occur at no great depth along the western margin of the Newark area, as indicated by some of the materials in the marginal conglomerates. The Newark beds are unconformably overlapped to the southeast by the Raritan formation (Cretaceous), which appears to lie upon an irregular surface, one high point of it outcropping in the midst of the clay area northwest of the city of Perth Amboy. Quaternary deposits extensively mantle the Newark group, especially north of the terminal moraine which extends across it from Metuchen to Morristown.

SEDIMENTARY ROCKS.

General character.—In northeastern New Jersey the sedimentary rocks of the Newark group are sandstones, shales, conglomerates, and arkose. The predominant rocks in the exposures are sandstones with alternations of shales, but the local stratigraphic order is variable. Some of the shales are bright brownish red, and the sandstones are of paler tints of the same color. Adjoining the intrusive igneous rocks the shales are nearly everywhere greatly hardened and darkened in color, not uncommonly so much so as to resemble closely the finer grained varieties of the igneous rock in general aspect. The sandstones range from a soft rock, with disposition to weather into shale, to a compact, moderately hard, massive stone which is quarried to some extent for building material and is the well-known brownstone of New York City. Much of it occurs in thick beds, and usually there are shale partings of greater or less thickness. Conglomerates occur mainly at a horizon not far below the base of the first Watchung sheet north and south of Paterson, and along the western margin of the Newark group. Thin conglomerate lenses and pebbly sandstones are also rather common along the northern border of the quadrangle. Arkose sandstones occur at or near the base of the group along the shore of Hudson River at the foot of the Palisades. All these rocks are comprised in the Stockton, Lockatong, and Brunswick formations, but owing to the heavy drift cover and the apparent absence of the distinctive Lockatong black slates, the divisions are not separately mapped in this folio.

The basal sandstones and arkoses along the eastern margin of the Newark group belong to the Stockton formation. The hard, dark, fine-grained beds of the Lockatong formation of the Delaware and Raritan River region are here probably represented by an unknown thickness of light brownish-red sandstone and shales not distinct from the Brunswick formation, which becomes much more sandy to the north.

Lowest beds.—The lowest Newark beds seen in this district are exposed near the shore of the Hudson from Hoboken northward and consist largely of coarse arkose, containing angular fragments of quartz, feldspar, mica, and locally other minerals in small proportions. Many of the quartz fragments are half an inch in length. More or less rounded material, mainly quartz sand, is intermixed. Streaks of shaly matter occur, and here and there these beds give place to cross-bedded coarse sandstones with shale intercalations. The shales at Weehawken at some horizons contain remains of a fish and of a small crustacean known as *Estheria ovata*. The thickness of this series of basal deposits is not known, because there are no means for ascertaining the depth to the underlying crystalline rocks which outcrop on the opposite side of Hudson River.

Beds above Palisade diabase.—The sedimentary strata lying next above the Palisade diabase are mainly arkose and sandstones, with local included beds of shale. The most extensive exposures are in the deep cuts at the west end of the West Shore Railroad tunnel through Bergen Hill, where the rocks are coarse-grained, light-colored, massive sandstone, usually containing a large proportion of feldspar. Other exposures occur at Ridgefield, in the streams northeast of Granton, in the quarries in the Granton diabase, and at both entrances to the New York, Susquehanna and Western Railroad tunnel. It is reported that on Shooters Island red shale formerly outcropped. A well 200 feet deep on this island found rock at 55 feet which was hard and yellow with black layers, probably altered beds overlying the Palisade diabase. On Staten Island the only localities at which the red shales appear are on the shore near Mariners Harbor, at Erastina, and in the railroad cut beyond Arlington. Apparently this lower series of rocks representing the Stockton formation passes beneath the Raritan formation, reappearing near Princeton.

Beds in Hackensack Valley.—In the wide area lying between the Palisade Ridge and the Watchung Mountains there is a thick succession of alternating sandstones and shales, which are finer grained to the south but gradually increase in coarseness to the north, until finally, in the northern part of New Jersey, nearly the entire mass of sediments is coarse pebbly sandstone with local thin intercalations of shale. Owing to the scarcity of connected outcrops no definite stratigraphic succession has been determined in this area; doubtless it is traversed by longitudinal faults that repeat the surface outcrops of the beds.

For some distance west of the inner slope of the Palisade Ridge the rocks are for the most part deeply buried by drift to the north and by the Hackensack meadows to the south. At Snake Hill and along the Secaucus Ridge a small thickness of red shales and argillaceous sandstones is seen. North of Ridgefield Park, in the ridge east of Hackensack River, there are scattered exposures of shale with thin sandstone layers, showing increased coarseness to the north.

The Hackensack meadows appear to lie in a deep depression excavated mainly in shales, which have been reached by some of the wells. Extending from Harrison to Hackensack is a thick mass of reddish-brown, only moderately massive sandstone which gives rise to the long, low ridge separating the Hackensack meadows from the valley of Passaic River. This belt of sandstone probably extends farther north than Hackensack, but the ridge dies out and its place is taken by a wide area of lowlands with scattered drift hills. The sandstone lies upon the shales which underlie the meadows. A portion of these shales can be seen in the railroad cut in the eastern part of Rutherford, and there is a moderate thickness of overlying shale along the Passaic Valley. The sandstones of this series are well exposed in deep cuts of the Greenwood Lake branch of the Erie Railroad just west of Arlington station, where they are traversed by several faults.

Slopes east of Watchung Mountains.—West of the rocks just described appears another similar series of sandstones, but much harder and thicker bedded and of lighter color. It extends through Newark, Avondale, and the western part of Passaic, where the rock has been extensively quarried for building stone. Its upper beds merge into a thick mass of shale of red color, with interbedded sandstone, which extends westward nearly to the base of First Watchung Mountain. This shale underlies Orange, Bloomfield, and the eastern portion of Paterson, but it is largely hidden by heavy deposits of drift.

In Midland, Washington, and Saddle River townships outcrops are very rare owing to the thick drift cover. Nearly all the ridges rising out of the general drift plain have a core of sandstone or present alternations of sandstone and shale. Small outcrops of a very coarse, pebbly sandstone are found on the knoll southeast of Arcola. In the eastern slopes of First Watchung Mountain the material is almost entirely sandstone lying upon a conglomerate which is exposed at the eastern entrance of the Great Notch and along Goffle Brook west of Hawthorne and Vanwinkle. In the eastern part of Paterson a well was bored some time ago which penetrated 2400 feet of red sandstones and shales, lying east of the line of this conglomerate and doubtless representing the beds which underlie the drift-covered region for some distance farther east. Excellent exposures of sandstone can be seen in the gorge below the falls of Passaic River in Paterson, and others in the quarries along the face of Garret Rock. There are coarse- and fine-grained beds and layers of conglomerate containing pebbles and bowlders of quartz, quartzite, sandstone, and limestone, some of which near the falls are 6 inches in diameter. The beds underlying the first Watchung basalt are exposed at many places south of Paterson, notably in quarries near Montclair Heights, Montclair, Orange, and South Orange and in the notches west of Richfield, Scotch Plains, and Plainfield. Sandstones predominate and clearly indicate the manner in which the deposits increase in coarseness to the north. They include much shale toward the south, but are coarse from Orange northward, and from Great Notch northward some conglomerate is present.

Region south of Newark.—From Newark southward to the terminal moraine, outcrops are rare and there is a wide district lying between Plainfield, Metuchen, Rahway, and Springfield in which the drift cover is so heavy and continuous that the sedimentary rocks do not appear at the surface. In the western part of Elizabeth and about Irvington there are outcrops of red sandy shales and soft sandstones, and north of Plainfield there are a few small exposures. South and west of the moraine there is a sheet of superficial material which extends for some distance, especially in the valleys of Green Brook and Dismal Swamp. Farther south the sedimentary rocks gradually reappear and occupy the surface in the southwest corner of the quadrangle, outcropping extensively in the banks of Raritan River. In this district they present typical features of the Brunswick formation, consisting mainly of soft red shales, with some beds of soft red sandstones. The lowest rock exposed along Mill Brook northeast of New Brunswick is soft micaceous sandstone, and this rock underlies the Raritan beds in the Perth Amboy and Woodbridge regions.

Beds overlying first and second Watchung basalts.—The first Watchung basalt is overlain by sandstone, which is exposed at intervals from Franklin Lake to Warrenville. Its thickness is about 600 feet, except at the north, where it decreases to 550 feet. The best exposures are at the quarries near Haledon and Little Falls, and along the valley extending southwest from the terminal moraine. In their northern extension the rocks are not as coarse as the beds which underlie the basalt, but consist mostly of sandstones of moderately fine grain, which furnish excellent building stone at the Haledon and Little Falls quarries. West of Scotch Plains and Plainfield red shales and thin-bedded, fine-grained, moderately hard sandstones prevail, including for a few miles along Blue Brook some thin-bedded layers of gray impure limestone, one of which attains a thickness of nearly 2 feet northwest of Scotch Plains.

Disconnected outcrops of red shale occur along the valley on the top of Second Watchung Mountain, from Summit southwestward, but they are small and mostly covered by débris from the adjoining slopes. They are sufficient, however, to indicate the presence of a very narrow belt of shale between the double crests of the ridge. Their presence may be due to a fault, as represented on the map, or more likely, as suggested by J. Volney Lewis, to a local deposit of shale between two flows of the second Watchung basalt.

Lying between the second and third Watchung lava flows there are from 1350 to 1500 feet of sedimentary beds which owing to the covering of surface materials are rarely exposed. They appear southeast of Pompton Lake, along the east side of Hook Mountain, on the east side of Riker Hill, along Passaic River east and southeast of Chatham, and along the southeastern side of Long Hill. To the north fine-grained, thin-bedded sandstones, with intercalated soft red shales, prevail, and to the south red shales with a few thin greenish and black layers. These beds appear to be brought up again by the anticline west of Green Village, outcropping extensively inside of the ridge of the basalt east and northeast of New Vernon. In the region southeast of Pompton Lake the shales and thin sandstones contain several interbedded layers of conglomerate. They also carry fish and plant remains.

Beds overlying third Watchung basalt.—The sedimentary beds overlying the third Watchung lava flow are rarely exposed and but little is known of their stratigraphy. In the wide area east of Morristown they probably occupy a shallow syncline, but they are covered by superficial deposits in the Great Swamp, by the thick mass of the drift deposits of the terminal moraine extending from Morristown to Chatham, by Black and Troy meadows, and by the drift cover extending northward to Rockaway River. East of Boonton they are exposed in the river banks, exhibiting thin-bedded sandstones and red, gray, and black shales containing beds of conglomerate. Some of the shale layers here contain beautiful impressions of fossil fish, notably at the excavation for the reservoir dam below Old Boonton. In the Pompton Plains region they are also buried by drift, but appear at one or two points in the ridge lying east of the canal feeder, where they comprise a succession of thin-bedded red sandstones and shales.

Marginal conglomerates.—Owing to the heavy mantle of drift, there are only a few scattered outcrops of the Newark beds along the northwestern margin of the formation. They all exhibit conglomerates of various kinds, and probably the deposit extends all along the margin within this quadrangle, but only the known occurrences of conglomerate are shown on the map. At the west end of the basalt ridge south of Morristown, a few hundred yards east of the gneisses of the Highlands, there is a small exposure of coarse conglomerates consisting mainly of bowlders of sandstones and conglomerates of various colors, quartz, and quartzite. Similar rocks are exposed along Rockaway River below Boonton and at intervals for the next 6 miles; east of Boonton in the river bank they are intercalated in a red and black shale series.

About Montville there are conglomerate outcrops at the canal locks, in a road cut a short distance farther east, in the stream banks below the milldam, in the railroad cut northeast of the station, and at intervals for 2 miles to the north. The predominating material is a light-colored granite in bowlders up to a foot in diameter, mixed with varying amounts of quartzite, conglomerate, limestone, and (to the northeast) basalt pebbles, in a matrix of quartz sand and small pebbles. The materials appear to be of relatively local derivation—the granite and quartz from the Highlands just to the west, the sandstones and conglomerate from the Green Pond conglomerate, and the basalt probably from the third Watchung lava flow in Hook Mountain, on which the conglomerate overlaps in places. Near Pompton there is a mass of conglomerate lying beneath the third Watchung basalt. It is exposed in the slope at the south end of Pompton Lake, a few yards east of the igneous rock, and consists mainly of bowlders and pebbles of greenish-gray sandstone, gray limestone, black slate, quartz, and purple quartzite, but gneiss and granite seem to be absent. Some of the sandstone and quartzite bowlders are a foot in diameter. To the north beyond the quadrangle it grades into a limestone breccia, which has been burned for lime. The black slate is similar to that which is seen in the river bank just east of Pompton station, the limestone is of the kind found along the margin of the Newark group at several localities in New Jersey and New York, and the sandstone and quartzite are evidently derived from the Green Pond conglomerate. To the east the conglomerate is intercalated in red and dark shales, as along Rockaway River below Boonton, but, inasmuch as these beds lie beneath the third Watchung lava flow and the conglomerates of the Boonton-Montville belt above, it is here somewhat lower in the series. These conglomerates along the western margin of the group indicate proximity to a shore of later Newark age, and probably they here overlap directly on limestones and slates as in other portions of the area, the black slates exposed in Pompton River just east of Pompton station and at intervals to the north being part of this basement. This relation has nothing to do with the juxtaposition of the Newark sediments and the granite and gneiss of the Highlands farther west, for the great fault intervenes, west of which no overlap of Newark deposits has been found.

Fossils.—Remains of life are relatively rare in the Newark rocks of the Passaic quadrangle, but fossil fish, reptile tracks, crustacean shells, and plant remains occur at several localities. Fossil fish have been obtained in considerable quantities at several points along the banks of Rockaway River below Boonton, and recently a large supply was brought to light by excavations for the waterworks dam a short distance below Old Boonton. The light-gray shales southeast of Pompton Lake have yielded a few fish remains, and some have also been found at Weehawken and in the old copper mine near Warrenville. Fossil bones have been reported from the quarries at Belleville, but their occurrence is not authenticated. In the sandstone quarry a mile east of Glenview, under the basalt flow, numerous reptilian tracks have been obtained. The crustaceans are the form known as *Estheria ovata*, in shales at Weehawken and at the old copper mine near Warrenville. The limestone in the valley of Blue Brook, northwest of Scotch Plains, contains numerous small fossils supposed to be *Cypris*. Plant remains occur at many points in all the larger quarries and in the shales lying between the first and second Watchung basalts west of Plainfield and in the next valley to the north, near New Providence.

WATCHUNG BASALT.

Distribution.—In the western portion of the Newark area in northern New Jersey there are two prominent ridges known as the Watchung or Orange Mountains, west of which lies a line of lower disconnected ridges, made up of Packanack and Hook mountains and Riker and Long hills. These three lines of ridges are the edges of three thick and extensive sheets of lava which were outpoured successively during the deposition of the Triassic sediments, deeply buried under subsequent deposits, and uplifted and flexed in the post-Newark deformation. Erosion has since removed a great thickness of the sedimentary rocks, and the upturned edges of the lava sheets are now exposed. Although greatly decomposed, eroded, and glaciated, these sheets present all the usual evidence of being extrusions contemporaneous with the inclosing strata. At their bases the lava flows lie conformably upon unaltered or but very slightly altered strata and usually are vesicular; they all present evidence of successive flows, in part on tuff deposits; the upper portions of the flows are vesicular to a considerable depth; and they are overlain by unaltered strata, which in some localities rest upon an intervening breccia containing fragments of the igneous rock.

The precise stratigraphic position of these basalt sheets in the Newark group is not determined, but they are in its upper portion. The sheets themselves and the immediately associated strata constitute a series that appears to be relatively regular in order of succession and total thickness. These features are shown in the four columnar sections in fig. 2, the first near High Mountain, the second just south of Paterson, the third opposite Orange, and the fourth near Plainfield. These sections are based mainly on detailed measurements, with calculations from numerous dips, but also in part on the assumption that the bases of the three lava flows are practically parallel.

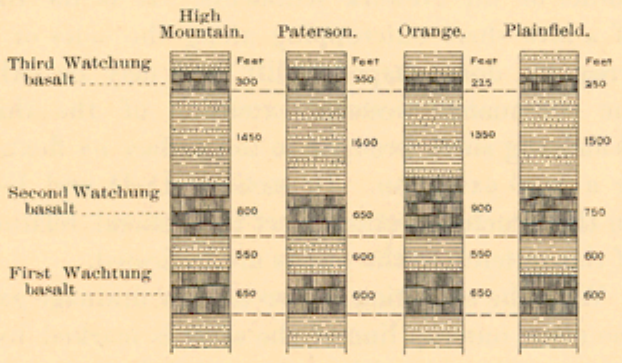

FIG. 2.—Sections illustrating the stratigraphy of the Watchung lava flows in the Passaic quadrangle.

It has been suggested that there is only one lava sheet, with its outcrops repeated by two long parallel faults, but it is extremely improbable that two such faults or even one fault would have such uniform throw and parallelism as to maintain the present regular succession for a distance of 60 miles. It is also significant that the sheets differ greatly in thickness, the third Watchung sheet especially being much thinner than the other two—a variation which would not be expected if there were faulting.

The First and Second Watchung mountains are two long, parallel, and, in places, double-crested ridges which trend north-northeast for many miles, but north of Paterson swing around to the northwest. They generally rise between 300 and 400 feet above the adjoining rolling country, but notches, depressions, and high summits break the continuity of their crest lines. This irregularity is notable at Paterson and at Little Falls, where Passaic River cuts across the two ridges through wide valleys. Owing to the hardness of the igneous rock and the westerly dip of the beds, the ridges present to the east high escarpments above slopes of the sandstone and shale upon which the lava sheets lie. The western sides of the ridges are gentle slopes in which the basalt extends down to the overlying strata in the valley or plain below. The width of the ridges averages about 2 miles. At Paterson the first Watchung basalt is crossed by Passaic River in a wide, low gap, the river falling over the edge of the lava sheet into a narrow inner gorge. (See fig. 28, illustration sheet.) The wide depression at Little Falls is similar topographically and is also traversed by the Passaic.

The relations, boundaries, and general structure of the Watchung basalt sheets are well marked for the greater part of their course, but at some localities the outcrops are obscure or lacking, so that the relations could not be ascertained. Along the northern portion of First Watchung Mountain the drift mantle is so heavy that the location of the boundaries between the sedimentary and igneous rocks could not be determined even approximately.

The outcropping edge of the third Watchung basalt constitutes a line of single-crested ridges known as Packanack Mountain, Hook Mountain, Riker Hill, and Long Hill, which rise a short distance west of the inner slopes of Second Watchung Mountain. These ridges are narrow, in few places exceeding half a mile in width, and, although topographically similar to the Watchung Mountains, are much less prominent and rugged. Through much of their course they present a steep eastern slope, but escarpments are few, low, and irregular, and the line of contact of the basalt and the underlying sandstone is generally not far below the crest. The inner slopes are rocky but gentle. The ridges ordinarily attain an elevation of about 200 feet above the surrounding plains, but here and there rise somewhat higher. Owing to the comparatively small thickness of the sheet, slight changes in its thickness, extent, or structure cause breaks in the continuity of its outcrops or considerable deflections in its course, such as are not found in the larger Watchung masses.

The most notable of these deflections is the bowing in the line of outcrop in Hook Mountain. The curved course of this ridge is apparently due to a very low anticline, or crumple, trending and gently declining northwestward and crossing the sheet in the angle formed by the change in trend. There is a gradual change of dip as this angle is approached from the south, and although in the east-west ridge the basalt extends down to the country level, and the regions north and south are drift and marsh covered, the evidence seems ample that its course is due to flexure. In the north-south ridge the sandstone extends up nearly to the crest, dipping about 10° NW. conformably under the basalt. The east-west ridge terminates at a low, wide marsh and drift-filled gap, through which Pompton River crosses the sheet. East of this gap the basalt rises in a curved ridge, which thence extends northward parallel to the strike of the sandstone and gradually sinks below the drift plain near Pompton. Toward the southern termination of Hook Mountain the sandstone outcrops cease and the basalt sheet passes beneath the surface in the gap toward Riker Hill, apparently crossing the southward extension of the anticline which causes the east-west ridge of Hook Mountain. The basalt in Riker Hill rises gradually from the meadows, either by slight flexure or by increase in thickness of the sheet, and forms a thin capping on gently westward-dipping shales, which extend nearly to its crest. Long Hill is similarly constituted, being a long ridge about 200 feet high, with a slightly curved course trending southwest and then west-southwest.

North of Glenview (now Towaco) there are, near the Highlands border, three outlying outcrops of scoriaceous basalt which are probably parts of the third Watchung sheet either separated by erosion or continuous under the drift-covered surface that lies between.

Relations of first Watchung sheet to underlying beds.—The relations of the first Watchung lava flow to the underlying sediments are exhibited at a number of localities in the Passaic quadrangle. At Paterson the best exposures are in the gorge immediately below the falls of Passaic River, where the basalt may be seen lying conformably upon the shale for several hundred yards, mainly on the south bank of the river. The sandstones are not baked, except perhaps slightly for the first 2 or 3 inches, and the basalt for a few inches above its smooth, undulating lower surface is somewhat vesicular. The relations are strikingly in contrast with those presented in basal contacts below the Palisade diabase, where the igneous rock in numerous places has cut across the sedimentary beds and baked them, locally for many feet. In old quarries and railroad cuts along the face of Garret Rock, just south of Paterson, many extensive exposures show the base of the lava sheet lying conformably upon the unaltered sandstones and slightly baked shales. Some features of the lower contact exhibited in a quarry near upper Montclair are shown in fig. 27 on the illustration sheet. The exposure of contact is more than 150 feet long and the conformity is perfect. At one point the base of the sheet descends into a slight hollow, such as a lava mass might be expected to make in soft mud as it flowed over a sea bottom. The lower part of the basalt is very vesicular and deeply decomposed for about 12 feet, but this phase grades up into hard rock. Some portions of the vesicular basalt yield large masses of beautiful zeolites. The sandstone is slightly hardened for an inch or two below the contact, but not darkened in color. In the large quarries northwest of Orange the contact shows perfect conformity, entire absence of alteration in the sandstone, and some vesicularity in the lower portion of the basalt.

From Orange southward to Wyoming the sedimentary rocks are seen at several points in close proximity to the overlying lava sheet, but the contact is hidden by drift or débris. About Millburn there is a low gap in the range, occupied partly by a heavy mantle of drift which covers the rocks. South of Springfield the sandstone and basalt reappear, but not in contact, and west of Locust Grove the moraine lies against the slope of the mountain. From Scotch Plains southward the igneous and sedimentary rocks are seen near together at many points, but the only contacts observed are in the gorges of Blue Brook and Stony Brook. At both these places quarrying operations have exposed the lava flow lying upon sandy shales with perfect conformity along a slightly undulating plane. The sedimentary beds are somewhat hardened and darkened in color for a few inches. The basalt is vesicular for a few inches from the contact and its lower surface is ropy.

Relations of first Watchung sheet to overlying beds.—The sedimentary rocks overlying the first Watchung lava flow are exposed at many places in the valley between the two ridges, but the contact relations are visible only in the region west and north of Plainfield. The most instructive exposure is in a small gorge just east of the abandoned village of Feltville, 2 miles north-northeast of Scotch Plains, where the contact can be seen for some distance. The general relations in this exposure are shown in fig. 3. Except at the middle of the exposure shown in the section the uneroded basalt surface consists of smooth, low bosses, 2 or 3 feet in diameter, sheathed by an inch or two of enamel-like, ropy-surfaced, light-colored, fine-grained, glassy basalt. This sheathing is generally filled with shotlike masses of calcite and grades downward into vesicular rock, much of it filled with elongated, radial vesicles, and more rarely into firm or columnar basalt. In places the bosses are separated by reticulating bands of chloritic decomposed basalt an inch or two in width and extending downward for several inches. Near the middle of the southern side of the gorge the basalt surface loses its bossy contour for some distance and becomes a mass of irregular, partly separated ragged fragments similar to the aa of the Hawaiian Islands lavas. Breccia occurs at intervals in this portion of the section, filling the interstices and capping the rough surface, as shown in a general way in the figure, and no traces of the rock were found at other points. This breccia consists of masses of more or less vesicular basalt of all sizes, from that of a bushel basket down, in a matrix of soft, bright-red shale and small fragments of decomposed basalt. The greatest development of the breccia is at the so-called "copper mine," where its thickness is 8 feet. Here it grades upward into the red shale which forms the upper two-thirds of the walls of the lower half of the ravine. This shale is exposed at many points in the vicinity lying upon the basalt surface without intervening breccia. Generally the shale is bright red in color, but at a point in the eastern portion of the exposure it is so intermixed and darkened with basalt sand that its contact with the underlying brownish-red, highly altered basalt is hardly recognizable.

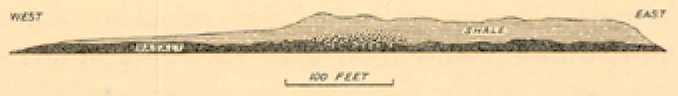

FIG. 3.—Section showing relations of surface of first Watchung basalt and its contact with overlying strata along south side of gorge northeast of Scotch Plains, N. J. Looking south.

At the foot of the ravine, and thence southward for many miles down the valley between First and Second Watchung mountains the vesicular basalt surface and unaltered shales are exposed at numerous places very near together, but not in contact. Northwest of Plainfield, near the Stony Brook gorge, the basalt surface outcrops in the roadside, and the alteration has at some points progressed until the deeply vesicular basalt is almost entirely converted into a bright emerald-green mixture of chlorite and serpentine. About 2½ miles farther southwest, at an old copper mine near the hamlet of Warrenville, a shaft sunk through the overlying shales penetrated the surface of the first Watchung basalt for some distance, but the openings are now filled with water, and nothing could be learned of the relations except from the heaps of excavated rock in the vicinity. The fragments of basalt found in these heaps are of an olive-green rock with abundant vesicles filled with shotlike masses of calcite, and apparently having an enamel-like surface composed of darker, fine-grained, more vesicular material. No traces of intervening breccia were found, and, although the overlying carbonaceous shales carry small amounts of chrysocolla, azurite, calcite, and coal, they are otherwise unaltered.

In the region of glacial drift, northwest of Locust Grove, the basalt is either eroded in the bottom of the valley or deeply covered with débris. The overlying strata are exposed very near the contact due west of Orange and 4 miles north of Paterson, and although they are unaltered and undisturbed the relations at the immediate junction could not be determined. There is a clear exposure of the vesicular upper surface of the first Watchung basalt in the excavations at the lower end of the Orange waterworks, where the vesicularity extends at least 10 feet below the somewhat eroded surface, and many vesicles filled with zeolites attain an inch or two in diameter.

In several exposures of the upper surface of the first Watchung sheet, in the southwestern portion of Paterson and east of Little Falls, the rock presents a slaglike or ropy appearance, in part of billowy form like the pahoehoe of the Hawaiian Islands. In some of the quarries the old surface is seen to be covered with a thick skin of glass. Much of the basalt here is deeply vesicular, a feature which appears at intervals for several miles north of the western part of Paterson. At the base of High Mountain there is an exposure in which the 80-foot red shale outcrops within 15 feet of the first Watchung basalt, or about 4 feet vertically above it.

Relations at base of second Watchung sheet.—The base of the second Watchung basalt is very instructively exposed at Little Falls, mainly in the quarries along the north bank of Passaic River a short distance below the falls. In these quarries neither the basalt nor the sandstone is noticeably altered in texture or color, and the contact is along a perfectly horizontal line. To the west, near the falls, and also farther east, the base of the sheet is a mass of vesicular rock, in many places exhibiting ropy flow structure. Where this feature is prominent the contact plane is slightly undulating, but the sedimentary layers are conformably flexed about the lower surface of the basaltic rolls. In places the vesicular, ropy variety is underlain by columnar basalt, but the latter is usually above. Half a mile below the falls, on the north side of the river, there is an exposure in which appear the relations shown in fig. 4

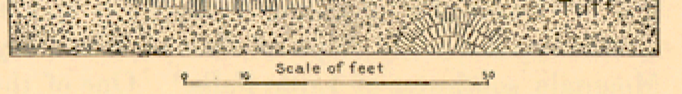

FIG. 4.—Diagram of cliff 1 mile below the falls of the Passaic at Little Falls, N. J., showing relations between supposed tuff deposits and columnar basalt. Looking west.

The fragmental deposit consists of a loose, heterogeneous mixture of vesicular masses of all sizes and fine-grained, decomposed, tuffaceous and ashy materials, all so much decomposed as to render specific identification difficult. The columnar basalt appears to grade into this bed at the contacts, but the features exposed strongly suggest that there is here a deposit of fragmental volcanic ejection products overflowed and penetrated by lava flows in the manner shown in the figure. North of this locality for many miles drift and talus are so thick along the foot of the ridge that there are no exposures of the base of the sheet and the underlying sandstones. The next appearance of the sandstone is in the old quarries 1½ miles north of Haledon, where a mass of highly altered, vesicular basalt lies with perfect conformity upon unaltered sandstone. In some portions of these exposures the greater part of the basalt is dense and columnar, but in others the rock has a ropy flow structure and is deeply vesicular. At one or two points the vesicular rock includes large masses of the dense rock. In much of the more deeply altered material there is a heterogeneous mixture of fragments cemented into a breccia by silica, zeolites, and calcites. South of Little Falls the sandstone is exposed here and there along the eastern slope of Second Watchung Mountain, but the contact is not exhibited, owing to the covering of drift and talus. In the gap west of Milburn the drift cover is so heavy that even the general location of the contact can only be approximately given. Borings 200 feet deep do not reach the rock. In the valley west of Scotch Plains and Plainfield the sedimentary rock is seen at many places a short distance below the base of the lava flow, its top averaging about 100 feet below the crest of the mountain.

Contact relations of third Watchung sheet.—Although the third Watchung basalt can be seen in contact with underlying strata only near its northern and southern terminations, and contacts with overlying strata are not exposed, there is ample evidence to prove that it is an extrusive sheet. The visible under contacts present precisely the same features as those of the other Watchung sheets, and at many other localities the strata seen very near the basalt are entirely unaltered and are conformably overlain by the sheet, the course of which is determined by their flexures. Beginning at the south the shales are exposed at many places near the basalt, and in the gorge at Millington, a few miles west of the quadrangle boundary, the contact is finely exhibited for about 20 yards. In this exposure the slightly vesicular, decomposed base of the sheet is perfectly conformable to the bedding of the shales, which are slightly bent, distorted, and indistinct for a short distance from the contact. The shales show slight local increases in hardness and are changed in color to a purplish gray about a foot below the contact. Northward from Millington the sandstone and shale extend along the eastern face of Long Hill and Riker Hill and the southern part of Hook Mountain, very near the basalt, but not exposed in contact. In the gorge of the Ramapo near Pompton, about a mile south of the northern edge of the ridge, there is a fine exposure in which the basalt is seen lying upon calcareous conglomerate dipping conformably to the southwest. The basalt is firm and dense and the calcareous rock entirely unaltered.

As already stated, no exposures of the contact with overlying strata are known, and in most places the nearest outcrops on the inner slopes are at a considerable distance from the basalt. A mile north of Millington, on the road to Basking Ridge, in the adjoining Raritan quadrangle, there are some very argillaceous shales, which at one point outcrop within 5 or 6 feet of the surface of the sheet and do not present the slightest sign of alteration.

Structure of flows.—The outcrop of the first and second Watchung basalt presents columnar structure, which is usually well developed, dividing the rock into columns that are mostly hexagonal. Some of the best examples of this feature are exhibited at Orange, Paterson, and Little Falls and in Green Brook on the slope of Second Watchung Mountain southwest of Little Falls.[1] One of the finest exposures of columns is in O'Rourke's quarry west of Orange, as shown in fig. 30 on the illustration sheet. Here there are large columns at the base merging rather abruptly into a great radiating mass of small columns above. At Paterson also the occurrence of larger columns below the smaller columns is a prominent feature. (See fig. 29, illustration sheet.) The difference in columnar structure does not necessarily indicate successive flows, and the larger columns probably are due to slower cooling.

The third Watchung basalt is a fine-grained rock, similar in every respect to that of the other Watchung ridges. Its structure is in few places columnar, and ordinarily it breaks down into wedge-shaped masses of small size. Although the upper surface of the sheet is deeply eroded at the south, and bears indications of severe glaciation at the north, some vesicular rock still remains. This is an especially noticeable feature northwest of Preakness, about Towaco station, on the west slope of Riker Hill, and southwest of Pleasant Plains.

In most places the Watchung basalt presents a bedded structure, which is usually very marked near the base. This is finely exhibited along West street in Paterson.

Succession of flows.—The Watchung basalt presents evidence of successive flows, indicated by vesicular surfaces overlain by compact basalt. Exposures of this relation occur at Little Falls, where at about 150 feet above the base of the sheet there is a vesicular surface apparently including some fragmentary materials, overlain by massive and columnar basalt supposed to represent a later flow. In a well bored on the western ridge of the second Watchung basalt, east of Livingston, 50 feet of sandstone was reported under 90 feet of basalt, which would indicate two flows, but unfortunately the identity of the sedimentary rock was not established and it may be merely a soft reddish phase of the igneous rock, which is sometimes observed in outcrops. The red shales lying between the two ridges of Second Watchung Mountain northwest of Plainfield probably indicate that there are two lava flows separated by a thin local body of sediments, and a succession of this character is indicated by a boring near East Livingston which is reported to have passed through 90 feet of basalt, 51 feet of brown sandstone, and then 381 feet of basalt.

J. Volney Lewis has discovered also that the other sheets of Watchung basalt probably consist of three flows. The basal flow is a rock of bluish-gray color, 50 feet or less in thickness, and distinctly marked from Paterson to Scotch Plains, except near Orange, where it appears to be either very thin or absent. In places its upper surface is vesicular or ropy. The middle division, which is the most important, is a dark-gray to black rock, usually showing well-developed columnar structure, with columns from 6 to 12 inches in diameter and locally arranged in clusters radiating downward. Its surface ranges from vesicular to ropy in many places. The uppermost division is exposed in quarries near Springfield with a thickness of 35 feet, and in the northern part of Paterson with a thickness of 10 feet, but the surface has been eroded to an unknown amount. The rock is fine grained and of a grayish color, and in thicker portions the upper part is highly vesicular. The third Watchung basalt exhibits evidence of three successive flows at Millington, and also in the gap on Ramapo River east of Pompton, where a body of soft decomposed rock at the top of one flow is overlain by hard basalt.

Petrography.—The igneous rocks of the Watchung sheets are relatively uniform in mineral constituents and are classed as basalt. They have recently been studied in detail by J. Volney Lewis. They consist mostly of augite and plagioclase with small amounts of magnetite, some olivine, and considerable glass. The structure is mostly ophitic, the plagioclase occurring in slender interlacing crystals with the interspaces filled with augite and more or less glass. Locally the rock is holocrystalline. Some magnetite is included, mostly in the augite. Some of the rock presents a porphyritic texture with scattered larger crystals of augite or plagioclase. The proportion of the glass varies, and near the top and bottom of the flows its amount is large and it is in part highly spherulitic. In the very glassy rock the augite disappears and plagioclase is the only mineral present besides fine dust of magnetite. Much rock of the latter type is altered to green serpentine. Orthoclase rarely occurs. Olivine crystals are present in places, but they are generally not abundant.

The basalt occurring in O'Rourke's quarry is described as follows:[1]

> The rock is dark bluish gray when freshly fractured, usually turning greenish upon exposure. It is compact and breaks with an even-grained texture. Megascopically it is finely crystalline to aphanitic, sometimes slightly porphyritic, with small phenocrysts. * * *
>
> In thin sections, under a microscope, the rock is seen to consist of abundant monoclinic pyroxene and much plagioclase feldspar, with magnetite and scattered patches of microlitic and globulitic glass base, and a variable amount of serpentine or chlorite. The pyroxene, which is in excess of the feldspar, is mostly malacolite, being pale green to colorless in thin sections, with high double refraction and poorly developed cleavage. It may easily be confounded with olivine. However, the occurrence of completely altered areas inclosed in perfectly fresh pyroxene indicates that the serpentine represents a much more easily altered mineral, such as olivine. The pyroxene of similar basalts and diabases occurring in Connecticut was analyzed by G. W. Hawes and shown to be an iron-lime-magnesia pyroxene, low in alumina, corresponding to the composition of malacolite. In the basalt of Orange Mountain it does not exhibit the basal parting, or twinning, or the idiomorphism that characterize salite. It is probable that olivine was present in the rock before decomposition set in. A few partly altered crystals of this mineral have been observed in some thin sections. In others there are brown serpentine pseudomorphs which are unquestionably decomposed olivines. It is possible that the scattered patches of serpentine, which have been deposited in irregularly shaped spaces have resulted from the alteration of olivine. But serpentine may also be derived from the decomposition of the malacolite.
>
> The plagioclase feldspar forms lath-shaped crystals with polysynthetic twinning, often with only three or four stripes. The high extinction angles and relatively strong double refraction show it to belong to the more calcic species, probably labradorite. Hawes has shown that two species of feldspar often occur together in these rocks, and has demonstrated the presence of labradorite and anorthite.
>
> The feldspar is in part altered to an almost colorless, brilliantly polarizing mineral, without definite crystallographic boundaries, probably prehnite.
>
> Remnants of a glass base are occasionally observed. They form angular patches, the glass being colorless, with globulites and microlites, mostly of augite with attached grains of magnetite. The magnetite is sometimes present in small aggregations. In places this residual base is holocrystalline, possibly through alteration. A study of the whole rock mass showed that glass was more abundant in the upper portion of the lava sheet.

Composition.—The composition of the Watchung basalt is relatively uniform and it does not differ much from that of the Palisade diabase. There are, however, certain differences in the proportions of the constituents in the different flows of each sheet and some local variations. The rocks of the third Watchung flow are more basic than those of the first Watchung flow, lower in alumina, magnesia, and lime but higher in sodium and titanium and much richer in iron. The following analyses, mostly from a forthcoming report by J. Volney Lewis, illustrate the principal features:

Analyses of Watchung basalt.[a]

	First Watchung sheet.						Third Watchung sheet.			Second Watchung sheet.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
SiO_2	50.19	51.09	51.77	51.82	51.84	51.36	49.68	49.17	49.71	50.81
Al_2O_3	14.65	14.23	14.59	14.18	15.11	16.25	14.02	13.80	13.66	13.25
Fe_2O_3	3.41	2.56	3.62	.57	1.78	2.14	4.97	4.90	5.49	14.66
FeO	6.96	7.74	6.90	9.07	8.31	8.24	9.52	10.61	9.51	
MgO	7.95	7.56	7.18	8.39	7.27	7.97	5.80	5.04	6.13	6.97
CaO	9.33	10.35	7.79	8.60	10.47	10.27	6.50	9.87	5.85	10.96
Na_2O	2.64	1.92	3.92	2.79	1.87	1.54	3.49	2.21	4.51	.76
K_2O	.75	.42	.64	1.26	.34	1.06	1.41	.54	.37	1.71
H_2O+	2.38	1.01	1.85	1.40	1.33	1.33	1.89	.73	2.66	.88
H_2O-	.66	1.66	.46	.30	.56	----------	.54	1.04	.48	
TiO_2	1.13	1.30	1.13	1.17	1.22	----------	1.39	1.50	1.53	----------
NiO	----------	----------	----------	----------	----------	.03	----------	----------	----------	----------
P_2O_5	.18	.16	.18	.17	.13	----------	.21	.24	.10	----------
MnO	.07	.25	.05	.13	.09	.09	.18	.07	.13	----------
SrO	----------	----------	----------	----------	----------	----------	Trace.	.03	----------	----------
	100.30	100.25	100.08	99.85	100.32	100.28	99.60	99.75	100.13	100.00
Specific gravity	2.92	2.936	2.91	2.95	2.93	----------	2.949	2.997	2.91	----------

[a] Analyses by R. B. Gage, except No. 6 by L. G. Eakins and No. 10 by W. C. Day.

1. Lower gray layer, Hartshorn's quarry, near Springfield.
2. Middle black layer, Hartshorn's quarry, near Springfield.
3. Upper gray layer, Hartshorn's quarry, near Springfield.
4. Lower gray layer, Hatfield & Weldon's quarry, Scotch Plains.
5. Middle black layer, Hatfield & Weldon's quarry, Scotch Plains.
6. Large columns near base, O'Rourke's quarry, Orange.
7. Lower gray layer, quarry at Millington.
8. Middle black layer, quarry at Millington.
9. Upper gray layer, quarry at Millington.
10. Francisco's quarry, Little Falls.

The basalt in large columns at O'Rourke's quarry (analysis No. 6) is thought to be the middle member, the lowest member, which is always thin and variable, is probably the thin platy layer at the contact, or perhaps it is absent.

Thickness.—The estimated thicknesses of the Watchung basalt sheets are given in fig. 2 (p. 9). These figures are calculated from the width of outcrop, altitudes of contacts, and dips of inclosing sedimentary rocks, with allowance for known faults in some cases. They can be regarded only as approximations, for dips are variable and numerous small faults of unknown amount occur. Direct evidence of the thickness of a portion of the second Watchung sheet is afforded by a well at Caldwell, which reached the eroded surface of the basalt under the drift at a depth of 100 feet and passed through 775 feet of igneous rock to the underlying shale. This figure does not represent much more than two-thirds of the original thickness of the sheet, which is at least 900 feet, as calculated from dips of the inclosing sedimentary beds.

The well bored at the Keane residence near East Livingston, on the inner crest of Second Watchung Mountain, is reported to have passed through soil, 5 feet; basalt, 90 feet; brown sandstone, 51 feet; basalt, 381 feet. There is some question as to the identity of the material reported as brown sandstone, but if it is sedimentary it indicates that there are two sheets of basalt at this locality.

The thickness of the third Watchung basalt is somewhat variable, and as its outcrops do not appear to be traversed by faults the amount may be satisfactorily estimated at a number of localities. The sheet gradually rises out of the glacial lake beds near Pompton, and in the deep gorge of Ramapo River, half a mile to the south, has a thickness of at least 215 feet. Five miles farther south the thickness is near 300 feet, and in Hook Mountain it is about 450 feet in the north-south ridge and at least as much in the cross ridge. In Riker Hill the basalt is between 200 and 250 feet thick, and in Long Hill the average is near 250 feet. In the gap at Mountain View and in the depressions at either end of Riker Hill the thickness appears to be locally diminished.

Basalt at New Vernon.—Three miles northwest of Long Hill, from which it is separated by the Great Swamp, there is a semicircular basalt outcrop which extends within a few rods of the western border of the Newark sediments. It is the edge of a lava sheet outcropping along the sides of an irregular, dome-shaped uplift, and may be either the attenuated western extension of the third Watchung sheet brought to the surface by flexure, or a local extrusion. In sections D–D and E–E on the structure-section sheet the general relations of this outcrop to the others are indicated.

With the exception of two narrow drainage gaps the main outcrop line of the sheet is marked by a ridge a mile wide, rising about 200 feet above the surrounding plain, its inner portion consisting of sedimentary rock. In contour the ridge is not so steep and rugged as the Watchung Mountains and its steeper inner slope is not marked by escarpments. The basalt of the New Vernon region is a fine-grained rock, very much decomposed superficially, but notably vesicular and slaglike in places on its surface, and very similar on the whole to the rocks of the Watchung ridges. The thickness of the sheet is usually between 150 and 250 feet, and becomes very slight in the northwesternmost outcrop. There is every evidence that the sheet is perfectly conformable to the sedimentary rocks. The underlying sandstones and shales flank the inner side of the ridge; and their strike is closely parallel to its trend. Outcrops of sedimentary rock near the basalt are few, but in those observed there were no traces of alteration. The only exposures of overlying beds are some distance farther south, along and near Passaic River. Southwest of these exposures, to the second and third Watchung basalts, the strikes vary so much from west to northwest that the relative stratigraphic position of the basalt near New Vernon could not be exactly determined; but it is probably connected either on the south with the third Watchung sheet by a syncline under the Great Swamp, as is most likely, or on the southwest with the second Watchung sheet, passing below the surface in the intervening gap.

A typical sample of the igneous rock obtained 2 miles northeast of New Vernon has been examined by F. L. Ransome, who has furnished the following description:

> A dark-gray, nearly aphanitic rock of basaltic appearance. The microscope shows this to be an ordinary basalt consisting of labradorite, augite, magnetite, apatite, and glass in the usual intersertal aggregate. The rock is rather decomposed and contains a yellow serpentine-like secondary mineral in fibrous spherulitic

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[1] For detailed description of this structure see Iddings, J. P., Am. Jour. Sci., 3d ser., vol 31. 1886, pp. 321-331.

[1] Iddings, J. P., Bull. U. S. Geol. Survey No. 150.

aggregates. The origin of this mineral is a little obscure, as it is apparently not an alteration product of olivine. It seems rather to have formed at the expense of the glassy groundmass of the rock.

ROCKS INTRUSIVE INTO THE NEWARK GROUP.

PALISADE DIABASE.

General relations.—The Palisade diabase is a great sheet of igneous rock intruded among the lower strata of the Newark group. It gives rise to the high ridge extending along the west bank of Hudson River opposite New York City and for many miles northward, and presenting to the east the great escarpment of high cliffs familiarly known as the Palisades, a name suggested by the vertical columns of the rock.

Extent.—The most southerly appearance of the diabase on the surface is on Staten Island, where it forms a low hill extending to Kill van Kull. On Bergen Point it again rises in a low ridge which gradually increases in elevation to the north and within a short distance presents a low escarpment to the east. In Jersey City, where the ridge is known as Bergen Hill, its altitude is 100 feet. The escarpment reaches Hudson River at Weehawken and thence continues northward with a bold front, its elevation increasing to about 200 feet in Union Township. In configuration Bergen Hill is generally a nearly flat-topped ridge with gentle slopes on the west, and an escarpment, in which diabase caps the underlying strata, on the east. The columnar front, which is so characteristic of the ridge, begins near Claremont and thence northward the columns are moderately prominent.

The southern termination of the Palisade diabase is not plainly defined. The southernmost outcrop on Staten Island is near Bulls Head, but the rock has been found in a well at Linoleumville. At Carteret, on the west side of Arthur Kill, a very hard rock, which almost surely is the diabase, was found at a depth of 60 feet in a well, and a well at Boynton Beach near by is reported to have entered "trap" at 78 feet. Wells at Maurer, 3 miles farther southwest, are reported to have been bored from 110 to 500 feet in hard rock, which may be the diabase, and another boring was stopped at 78 feet by rock stated to be extremely hard. Highly altered shale and sandstone were entered at a depth of 56 feet in a well at Valentine Brothers' works three-fourths mile east of Woodbridge. Near Keasley, on Raritan River 2 miles west of Perth Amboy, very hard rock was entered at 72 feet, which probably indicates the presence of the Palisade diabase underground.

Intrusive nature and attitude.—The Palisade diabase above the present surface is in greater part a thick sheet which was intruded between the strata. Probably it was fed by dikes, but apparently these are underground and no evidence of their relations is presented at the surface. The presence of such a dike is suggested by exposures at the west end of the West Shore Railroad tunnel through Bergen Hill at Weehawken.

The sheet lies in beds which dip gently westward, with the course of the diabase outcrop closely parallel to the strike. Local variations in direction and amount of dip are not unusual, but their influence is in most places confined to increasing or decreasing the elevation of the contact line in the face of the cliff, although here and there they cause slight deflections of the crest line. Several faults somewhat modify the uniformity of the course and contour of the diabase outcrop.

So far as known, the Palisade diabase sheet is the result of a single intrusion, continuous from beginning to end. It may be connected underground with the small intrusion at Granton and it is undoubtedly the source of the several small sheets which are intruded in the underlying strata near Weehawken. The intrusive nature of the Palisade diabase is clearly exhibited in its relations to the sedimentary beds with which it is associated. North of Hoboken the base of the sheet is exposed at many places, and though it is usually conformable to the bedding of the sedimentary rocks, it presents local irregularities of contact and position in which the diabase crosses the underlying strata laterally, up or down, in some places for a hundred feet.

Lower contacts.—There are many instructive exposures that illustrate the relations of the Palisade diabase to the underlying beds. The sedimentary rock at the contacts is generally the shale overlying the basal arkose, and as a rule it is greatly increased in hardness and darkened in color for many feet from the diabase. One of the most notable of these exposures is at Kings Point, as shown in fig. 5. Ordinarily the two rocks are welded together along the contact, but the line of junction usually is plainly exhibited, particularly where the surface is weathered. Descending plates and dikes of diabase are comparatively abundant, and irregularities in which the diabase breaks across the ragged edges of the strata are found in nearly every exposure.

The southernmost outcrop of underlying strata is just north of the head of Paterson street, in the western portion of Hoboken, where the contact line rises above tide level for a short distance and breaks irregularly across the arkose. Several masses of arkose are included in the lower part of the diabase at this locality. To the south and for the next mile north the diabase appears to extend below the level of the lowlands at the foot of the ridge.

In the northwestern portion of Hoboken, near the electric railroad grade, the contact rises steeply to a height of 25 feet above the meadows, and the baked sedimentary beds are well exposed, with increasing thickness, in cuts of the Connecting Railroad and the slopes above. The diabase cuts across the shale at intervals and sends into it a branch sheet, first 4 feet and then 10 feet thick, which extends for a short distance about 10 feet below the main contact. All the basal portion of the diabase is very fine grained, and at many points it includes small fragments of shale. The shale is baked to a high degree of hardness and darkened to black, purplish, and gray, but some beds are light gray and gray-buff. The dip is to the west at a low angle. The thickness exposed is 50 feet, including arkosic sandstones at the base. The contact finally rises to an altitude of 60 feet, and then, at the west end of Nineteenth street, in the southwest corner of Weehawken, the igneous rock descends across more than 100 feet of shales into the arkose to about tide level. The cross contact is exceedingly ragged, the diabase penetrating the shattered edges of the shales in various directions and for some distance including great fragments of them. Owing to the increased thickness of the hard rock, the escarpment advances eastward for several hundred feet, forming the bluff upon which the "observatory" was built. At the southeast corner of this bluff the underlying strata again emerge from below the surface. A short distance farther north, near the "One Hundred Steps," the diabase lies upon the arkose along an irregular contact plane, one of the most notable irregularities of which is exposed along the road below the "One Hundred Steps." In this vicinity is seen also a small descending sheet of diabase which extends into the arkose for some distance.

The new tunnel of the Pennsylvania Railroad which passes under Bergen Hill just south of Kings Point cuts the base of the Palisade diabase at a point beneath Gregory avenue. This is about 40 feet below sea level. The sedimentary rock is mainly arkose and the dip is to the west at an angle of 17°. The contact is conformable. As far east as the river shore the tunnel is in arkosic sandstones, including some beds of altered shale, while to the west the diabase extends to the portal at the margin of Hackensack Meadows. A short distance north of the line of the tunnel a ravine extends up into the ridge and, owing to a fault which will be described later, the line of escarpment offsets to the shore of Hudson River, forming the prominent headland of Kings Point. At the south end of this point the bluffs are diabase from bottom to top, but a few rods farther north the base of the sheet rises from sea level, below which it was carried by the fault, and crosses the strata as shown in fig. 5. This ascent of the diabase is lateral to the course of the main intrusion, and probably it extends into the ridge for some distance. The small diabase sheet shown in the figure is undoubtedly an offshoot from the main mass, and extends for about a quarter of a mile to the north, preserving throughout a nearly uniform horizon in the shale. Its thickness averages about 3 feet. Three-fourths mile farther north is another exposure, in which the diabase ascends 15 feet across the shales and sends a thin branching sheet northward for some distance. At the eastern entrance of the West Shore Railroad tunnel 2 miles north of Kings Point is exposed a fine cross section showing the relation of the diabase to the underlying baked shales.

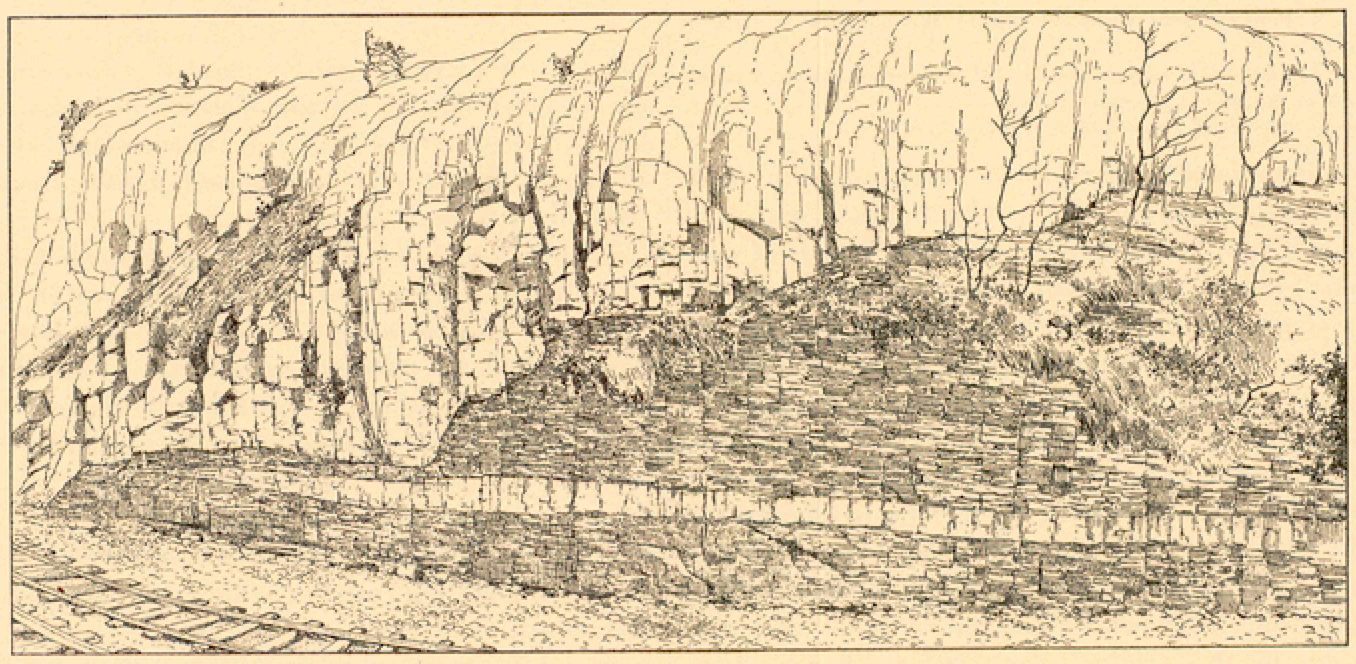

FIG. 5.—Base of Palisade diabase, showing lateral ascent across the strata of the Newark group, Kings Point, Weehawken, N. J. Looking west. (From photographs.)

North of the tunnel for some distance outcrops are few, but the line of contact appears to remain essentially unchanged in position to a point near Guttenberg, where there are some indications of either a slight fault or a change in horizon. In the road below the Guttenberg quarries there is a dike in the arkose underlying the main mass of diabase. This dike appears to be connected with the diabase above, but whether it is an ascending dike or a downward offshoot is not known. In the vicinity of Bulls Ferry, just beyond the quadrangle boundary, there are extensive exposures of baked shales underlying the diabase, and the contact, although rarely exposed, appears to preserve a nearly uniform horizon for some distance.

Upper contacts.—Owing to the extensive denudation of the Palisade diabase the overlying strata as a rule do not extend far up its inner slope; generally they are either removed down to the level of the adjoining plain or are hidden by heavy masses of drift. Scattered exposures, however, indicate the relations of the upper contact. In every exposure the diabase is seen to cut across some of the beds, and where the sedimentary rocks are argillaceous they are baked very hard and dark and are welded to the diabase. Along Bergen Point the western outcrops of Palisade diabase extend to the margin of Newark Bay. In the western portion of Jersey City the diabase is bared to the base of the ridge, as shown by local outcrops, but is usually more or less thickly covered by drift. At the West Bergen steel works, a short distance west of Marion, a well was bored to a depth of 410 feet, which appears to have entered the diabase 304 feet below the surface, after passing through alternations of sandstone and altered shale possibly penetrated by thin diabase sheets. The record, unfortunately, does not identify the beds very definitely. A short distance east of Marion, in the railroad cuts, a thin mass of sandstone is included in the diabase. In an old quarry near the roadside half a mile south of Schuetzen Park there is an exposure in which the diabase is seen to be overlain by a small mass of metamorphosed shale. The shale dips southwestward and is welded to the diabase along a nearly conformable contact line, with many local irregularities. At several points small dikes of diabase extend a few inches up into the shale. A short distance north of this locality the line of contact bears to the northeast across the strike of the sandstones, and thence northward the plane of intrusion is at a lower horizon in the formation. This change of horizon may be connected with the corresponding change in the position of the base of the sheet exposed at Kings Point, already described. The next upper contact is exposed at the western entrance to the tunnel of the West Shore Railroad, east of New Durham, N. J., presenting the relations shown in fig. 6. At this point the diabase cuts diagonally across the overlying beds along a north-northwest course, carrying the sheet to a higher horizon. The contact has a steep inclination, about 60°, and the strata dip 15° NW. The beds are coarse sandstones, baked slightly in the immediate vicinity of the contact. At some points the sandstone and diabase are welded together along a ragged contact, showing that the sharp break is not due to faulting. It is not known whether this feature exhibits a portion of a great dike or feeder or simply a change in horizon of the top of the igneous mass. In a depression a mile northeast of Granton there is an exposure of the strata immediately overlying the diabase, and although the contact is not visible, considerable unconformity exists in both dip and strike. The next exposure is a very fine one in the western portal of the tunnel of the New York, Susquehanna and Western Railroad. Sixty feet of baked shales are exhibited, dipping gently west-northwest, the diabase gradually ascending across the beds with the same strike, but having an inclination of 18°. In the north wall of the tunnel two small dikes extend from the main mass of diabase into the sandstone. They average about 6 inches in thickness, and after crossing 2 feet of the sandstone penetrate the beds for a short distance. North of this locality the boundary of the diabase trends down the slope into the hollow just east of Ridgefield. Here it is exposed at two points, one very near a small outcrop of baked shale dipping gently west-northwest. Higher up the hollow and in the slopes toward Leonia the contact is hidden by drift.

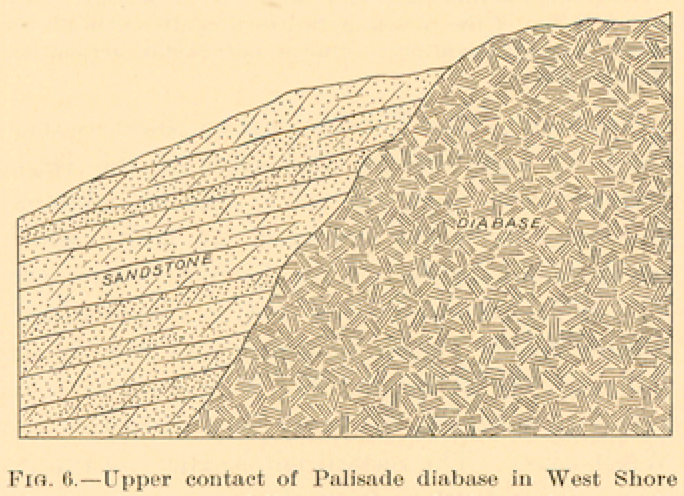

FIG. 6.—Upper contact of Palisade diabase in West Shore Railroad cut east of New Durham, N. J. Looking north. Shows dikelike attitude of west side of diabase cutting across Newark strata.

Inclusions.—The inclusion of fragments of metamorphosed shale in the diabase, particularly near its base, has been alluded to in connection with the description of the under contacts. Lewis, however, has recently called attention to inclusions of highly altered arkose sandstone well within the diabase mass. In the high cliffs overlooking the road that leads up from the West Shore Railroad ferry at Weekawken a bed of feldspathic sandstone or arkose about a foot thick extends vertically from the base of the cliff to the top. It has a well-developed diagonal lamination, apparently cross-bedding, which is distinct even in thin slivers of an inch or less that branch off into the surrounding diabase. Four hundred and twenty feet east of Marion station, Jersey City, thin sheets of arkosic sandstone ranging from 5 inches to 3 feet in thickness lie in an irregular undulating position in the diabase exposed in the Pennsylvania Railroad cut. Similar inclusions have been observed elsewhere along the Palisades, but beyond the limits of this quadrangle, and in the diabase at Granton, as shown in fig. 7 (p. 12). These inclusions have been described by Lewis as follows:

> The thinner portions of the sandstone inclusions are very hard and compact and look in all respects like fine-grained, light-colored granite with a slight sprinkling of dark constituents. From this facies every gradation is found to apparently normal feldspathic sandstone (arkose) in the thicker

> portions, showing little sign of alteration. This slightly metamorphosed facies is found abundantly, even in the thicker parts (3 feet) of the inclusion at Marion, and apparently constitutes most of the large mass at Granton. It is a relatively friable rock, crumbling under the blow of the hammer like the similar arkose that forms beds of considerable extent both above and below the diabase of the Palisades along the Hudson. In thin sections the thinner portions of the sandstone inclusions, up to about 2 feet thick, are found to be composed of quartz, both orthoclase and plagioclase feldspars (in very variable proportions), and augite in a granular aggregate much resembling granite. Plagioclase is sometimes very abundant and at others scarcely present at all. The pale-green augite sometimes appears to penetrate the quartz, as though formed at its expense. In smaller amounts occur irregular grains and clusters of titanite, small crystals and granular aggregates of apatite, occasional grains of magnetite, flakes of biotite, and more rarely calcite and pyrite. The feldspars, especially orthoclase, are usually more or less clouded by kaolinization. The augite is apparently identical with that of the inclosing diabase and often exhibits the same types of alteration to uralitic hornblende, serpentine, chlorite, etc.

Structure.—The Palisade diabase sheet is traversed by many cracks, and some of the larger vertical joints give rise to a massive columnar structure. It is also traversed by faults, which are described in the section devoted to structure. The columnar structure is not so conspicuous a feature in the Passaic quadrangle as it is in the Palisades farther north, but it appears to some extent in the cliffs in Jersey City, Hoboken, and Weehawken. The vertical joints extend in various directions and although in places a narrow zone of the rock is shattered along the cracks, many of the planes present surfaces polished by the slight movements which have caused the breaks. The more open cracks or those containing shattered rock are generally filled with rotted diabase, but many of them carry veins of calcite and various zeolites which have made Bergen Hill famous for its minerals. Incipient joint planes, rudely parallel to the inclosing sedimentary rocks, appear at many places in the lower and upper portions of the Palisade diabase.

Thickness.—The original thickness of the Palisade diabase sheet is difficult to estimate. All along its course it has been bared of overlying strata and more or less deeply eroded. The sheet is also traversed by numerous faults of small throw. A well recently bored on Jersey City Heights penetrated 364 feet of diabase and reached the sandstone below. The thickness increases toward the north, and in Union Township it is probably at least 500 feet. At Fort Lee, just beyond the limits of this quadrangle, a well penetrated 875 feet of diabase before reaching the indurated shale beneath.

Petrography and composition.—The Palisade diabase varies somewhat in constitution and texture but it is a diabase throughout. Near its contact with the inclosing sedimentary rocks it is usually fine grained, and has a bedded structure. The fine-grained portion near the base of the sheet is 40 to 50 feet thick and merges upward into coarser rock which for the first 10 to 20 feet shows a pronounced tendency to disintegration. This is the "rotten layer" which is especially noticeable in the northern portion of Hoboken and in Weehawken. Different portions of the sheet vary somewhat in texture, but the predominant phase is a moderately coarse grained, dark-gray rock, popularly called "trap" and sometimes "granite." Under the microscope the intrusive rock is seen to be completely crystallized and to consist of augite, plagioclase feldspar, magnetite, and a small amount of apatite. Quartz and orthoclase in micrographic intergrowth are generally present and locally constitute as much as one-half of the rock. Olivine is absent from the great mass of the diabase, but it occurs in small scattered crystals, mostly near the upper and lower contacts, and constitutes a notable proportion, up to 15 per cent, in the "rotten layer" above referred to. Biotite is present in small amount and a few grains of pyrite, chalcopyrite, and rutile occur.

The proportion of minerals varies greatly, the augite, which averages 50 per cent, ranging from 27 to over 60 per cent and the feldspars from 26 to 44 per cent. There is 7 per cent of quartz in the rock near Marion and 19 per cent in the upper portion of the sheet in the tunnel near Homestead. These portions would be classed as quartz diabase and gabbro. The "rotten layer," which lies about 50 feet above the base of the sheet in Hoboken and Weehawken and is from 10 to 20 feet thick, is an olivine diabase which contains, in places, 15 per cent of olivine. It lacks the graphic intergrowth of quartz and orthoclase that occurs so extensively in other portions of the sheet. The olivine in it is in small fresh crystals and grains, mostly included in the feldspars. Near the West Shore Railroad in Weehawken the rock includes a mass of quartz diabase which is prominent because of its greater hardness.

The texture is usually ophitic—that is the feldspars are in a network of lath-shaped crystals, and the augite fills the interstices. Where the augite predominates, the feldspars are embedded in it. Some coarser grained portions of the rock have a granitoid texture, with the two principal minerals in grains of approximately equal size, the rock thus becoming a gabbro. Some of the dense contact rock presents a porphyritic facies consisting of a fine-grained groundmass of feldspar rods and augite and magnetite grains, through which are scattered larger augites, feldspar, and a few olivine crystals. The feldspars range from orthoclase to albite and basic labradorite. Anorthosite appears to be present.

No portion of the Palisade diabase has a vitreous groundmass like the Watchung basalt, which consists of surface flows from the same or a similar magma. Some parts of the rock are very coarse grained, with crystals nearly an inch in length. The completely developed crystalline structure of the Palisade diabase is due to slow cooling when the sheet was inclosed between the sedimentary beds. The fine-grained character of the rock near the contact is due to more rapid cooling of that portion of the sheet, and the olivine-bearing portion is thought to be due to the settling of heavy minerals at the beginning of the crystallization.

A detailed description of the petrography of the Palisade diabase and associated rocks has been prepared by J. Volney Lewis for the report of the State Geological Survey of New Jersey for 1907. Most of the facts given above have been condensed from that description. The composition of the rock is indicated by the following analyses:

Analyses of Palisade diabase.

[By R. B. Gage.]

	1.	2.	3.	4.	5.
SiO_2	60.05	51.34	51.88	50.40	49.62
Al_2O_3	11.88	12.71	14.53	15.60	10.51
Fe_2O_3	3.22	2.65	1.35	3.65	.64
FeO	10.21	14.14	9.14	6.30	12.02
MgO	.85	3.66	7.78	6.08	15.98
CaO	4.76	7.44	9.98	10.41	7.86
Na_2O	4.04	2.43	2.06	2.57	1.40
K_2O	2.10	1.44	.93	.62	.55
H_2O+	.66	.69	.97	1.67	.49
H_2O-	.21	.18	.12	1.02	.38
TiO_2	1.74	3.47	1.35	1.35	1.01
P_2O_5	.52	.20	.14	.16	.16
MnO	.28	.36	.10	.06	.09
	100.52	100.71	100.33	99.89	100.71
Specific gravity	2.87	3.09	2.98	2.89	3.12

1. Pennsylvania Railroad tunnel, Homestead, 400 feet from western portal.
2. Pennsylvania Railroad cut near Marion station, Jersey City (coarse-grained rock).
3. Pennsylvania Railroad tunnel, Weehawken, at base of sheet.
4. New York, Susquehanna and Western Railroad tunnel, upper contact, in western portal.
5. Olivine diabase facies, Weehawken.

Metamorphic effects.—The alteration of the sedimentary rocks adjacent to the Palisade diabase is due largely to the development of minerals of various kinds. The arkosic sandstone, which usually presents but little appearance of alteration, is generally changed to a metamorphic rock resembling granite for a few inches from the contact. The shale, on the other hand, is altered for a thickness of 100 feet or more to hard, flinty, gray to brown and black hornfels showing the original lamination by banding. The hornfels varies considerably in mineral constituents, the character in many places changing from bed to bed, probably in close relation to the original composition of the shale. According to Lewis, the hornfels consists of various combinations of feldspar, biotite, quartz, augite, hornblende, magnetite, muscovite, cordierite, scapolite, vesuvianite, chlorite, calcite, analcite, titanite, tourmaline, and apatite. The altered arkosic sandstone consists of orthoclase, plagioclase, and quartz in varying proportions, with more or less augite and biotite, epidote, cordierite, chlorite, calcite, tourmaline, and apatite in smaller proportions. Much of the hornfels in the Passaic quadrangle is of the cordierite variety, consisting of a dense groundmass of feldspar, with biotite or chlorite (or both) abundantly sprinkled with cordierite in all stages of development. Some of the latter mineral also is altered.

In the northern portion of Hoboken and at the east portal of the West Shore tunnel augite-biotite hornfels occurs, showing under the microscope dense augite and feldspar aggregates with darker bands and splotches of augite, biotite, and feldspar. At the West Shore tunnel portal there is also a scapolite hornfels showing large irregular areas of scapolite in a dense groundmass of feldspar (chiefly orthoclase), biotite, hornblende, and augite. In the thick mass of hornfels overlying the diabase in the west portal of the New York, Susquehanna and Western Railroad tunnel metamorphic rocks occur in considerable variety. One is a dense augite-feldspar aggregate thickly sprinkled with granules of magnetite. Other portions consist of biotite flakes and minute grains of feldspar, the biotite being most abundant in the darker layers. Certain beds are a laminated feldspar-augite hornfels carrying irregular massive vesuvianite inclosing biotite, augite, and magnetite. Some arkosic layers bear epidote, chlorite, augite, calcite, and a few crystals of pyrite. The small mass of altered shale lying upon the diabase near Homestead consists largely of feldspars and augite, the augite predominating in the darker layers, with some biotite, magnetite, and minute crystals of apatite. The arkose included in the diabase a short distance east of Marion station contains so much augite in granular intermixture with the quartz and feldspar that it might be classed as an augite granite. It contains 75 per cent of silica.

Diabase at Granton.—The diabase at Granton constitutes a short ridge lying not far west of the slope of the Palisade Ridge just north of Granton station. It is an intruded sheet which appears to be closely similar to the Palisade sheet in structure. On the eastern, northern, and southern sides the sandstone separating this diabase from that of the Palisades dips northwestward under the edge of the sheet. The diabase outcrop terminates on the north, south, and east in escarpments, so that its original extent and relations are not evident. Presumably the sheet thins out like a lens where it passes underground at the northwest and southwest corners of the ridge. In the quarries at the south and north ends of the ridge the diabase-shale contact is extensively exhibited and the relations are clearly exposed. The sheet is about 50 feet thick. In the northern quarry the diabase sends a small branch into the underlying sandstone, and there is considerable local irregularity along the contact.

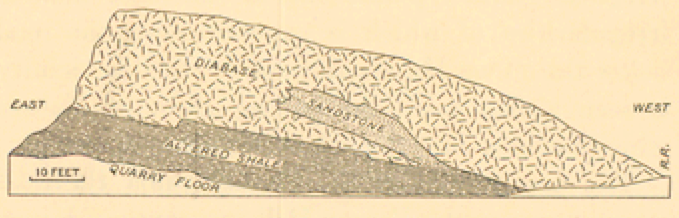

FIG. 7.—Section of diabase sheet in quarry at north end of ridge north of Granton, N. J.

Some features exposed at this place in June, 1907, are shown in fig. 7. In the West Shore Railroad cut on the western side of the ridge a small mass of highly altered shale is exposed crossed almost vertically by the diabase.

The diabase of the Granton ridge is moderately fine grained, very similar to much of that of the adjacent Palisades mass. It is dense and homogeneous, without trace of vesicularity. The adjacent shales are baked to great hardness and the igneous rock is fine grained near the contact, where it is welded to the sedimentary material. The thickness of the sheet now remaining is about 50 feet, but as the entire surface has been more or less deeply eroded the original thickness may have been considerably greater.

Snake Hill masses.—Snake Hill and Little Snake Hill are two knobs rising steeply from the tide marsh west of Hoboken. The smaller hill is all diabase. It occupies a few acres and rises to a maximum height of 76 feet, but nothing is known of its structural relations. The larger hill is half a mile farther west, on the eastern shore of Hackensack River, and occupies approximately a square half-mile. Its elevation ranges from 100 to 200 feet. It has steep slopes on all sides but the northern, which is drift covered and gradual. Its central mass of igneous rock is flanked by small remnants of sandstone and shale, but owing to drift and talus the structural relations are not clearly exhibited. Apparently it is a large triangular plug of diabase cutting across the strata for the greater part of its course. Sandstone and shale, exposed in an abandoned railroad cut at the south end of the hill, dip N. 30° W. at an angle of 14°. This dip carries the strata beneath the surface toward the west and the southwest corner of the hill is entirely diabase. In the western face of the hill there is a large quarry in the north end of which sandstone and indurated shale are exposed abutting against a nearly perpendicular face of diabase. Whether this relation is due to a fault or to a vertical plane of intrusion is not apparent. The contact trends nearly north and south. Along the northern slope of the hill there are scattered outcrops of sandstone and shale extending eastward from the penitentiary. The strata dip northwestward at low angles and may in part at least pass under the edge of the diabase, which rises in precipitous ledges above the shale slopes. On the east side of the hill a deep cut exposes the diabase cutting across the strata along a nearly vertical plane which extends to sea level. The strata are considerably disturbed and greatly altered and a branch sheet of diabase 8 inches thick has been intruded into them. To the east the plane of contact trends toward Little Snake Hill; to the west it extends into a quarry north of the old railroad cut, where a steep ragged contact is exposed. The diabase is undoubtedly intrusive, as shown by its contact relations and by the baking of all the shale near the contacts. Apparently the rock is precisely the same as the typical Palisade diabase and in both Snake Hill and Little Snake Hill is probably an offshoot of the Palisade intrusion. A sample from the quarry on the west slope of the hill was examined by F. L. Ransome, who has supplied the following description:

> The rock is fine grained and of even granular texture. It is somewhat weathered. The microscope shows that it was originally an ophitic aggregate of labradorite and augite with accessory magnetite and apatite. Owing to the alteration, the feldspar is partly decomposed to sericite, while much of the augite has been transformed into aggregates of chlorite, epidote, and an obscure fibrous mineral which is perhaps serpentine.

Arlington sheet.—Along the eastern slope of the sandstone ridge 3 miles west of Snake Hill there are several small diabase sheets. One exposed just north of the railroad is 6 feet thick. It lies conformably between beds of coarse sandstone which are not perceptibly altered. A few rods farther north the edge of this sheet was exposed in excavations for copper ore in an old quarry, as shown in fig. 8. Here it has forced its way eastward near the junction of shales and sandstones, lifting the latter and probably causing the fissures which contained a small amount of chalcocite. The diabase is a fine-grained, dense, bluish-gray rock 5 feet thick, with smooth surfaces, to which the strata are generally welded. The adjoining shales are intensely altered for a few feet from the diabase.

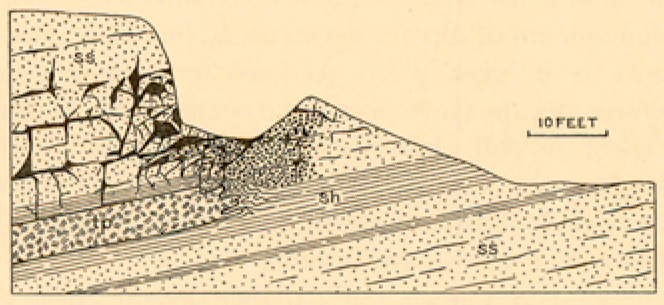

FIG. 8.—Sketch section in Westlake's quarry near Arlington, N. J., looking north. Shows crumpling of the shale at the front of the intrusive diabase sheet, and the impregnation of copper ore in the sandstone overlying the diabase.

ss, Sandstone; sh, shale; tp, diabase sheet; black masses and spots, copper ore.

Diabase appears again in the cemetery a quarter of a mile to the north, and it extends northward for about a mile, with a few exposures, to the old Schuyler mines. In the cemetery two smaller diabase masses are associated with the main sheet. They appear to be formed by a dike ascending along a fault line and sending off a small sheet eastward. The main sheet in this vicinity is conformably intercalated in the sandstones, with but little disturbance or alteration of the strata. North of the cemetery the edge of the sheet forms a low cliff along the turnpike, and its thickness increases to 20 feet. A short distance farther west is another small sheet in the overlying strata, crossing the turnpike on top of the ridge. In its northward extension beyond the turnpike the main sheet pitches beneath the surface and forms the floor of a portion of the old Schuyler mine, which consists of a network of galleries through the cupriferous sandstones near the contact. In this mine the surface of this sheet is smooth and conformable to the gently dipping sandstones, except at a few points where the strata are crossed for a few feet. The sheet also sends several offshoots up into the sandstone. It is stated that the diabase surface was followed westward for half a mile in the mining operations, and that it is traversed by a fault of considerable amount.

BOGOTA DIKE.

About a mile east of Hackensack, on the road to Leonia, there is a small exposure of basalt, the exact relations of which could not be definitely determined on account of the drift and débris. It lies on the crest of the first ridge east of Hackensack River, in westward-dipping red shales, which are somewhat hardened and darkened in its immediate vicinity. The exposure is about 10 feet in width, and could be traced for only a short distance along a north-by-east course. The exact line of its contact with the shales is not exposed, and it may constitute either an irregular sheet 3 or 4 feet thick or a dike. The rock is dark gray and compact. A specimen examined by F. L. Ransome is reported to have the following characters. Minute feldspar laths and augite grains show on the freshly fractured surfaces. In thin sections the component minerals are seen to be labradorite, augite, magnetite, and apatite, with glass in the interstices. The rock is a common basalt and is the only dike of that rock found in the area.

CRETACEOUS SYSTEM.

By Henry B. Kümmel.

The Coastal Plain or lowland bordering the Atlantic Ocean is underlain by a series of sands and clays of Cretaceous and later systems lying upon an eastward-sloping floor of the granites, gneiss, and other older rocks. In New Jersey and Virginia these sands and clays are known to overlap locally on the Newark rocks. The formations of Cretaceous age lie in a succession of widespread sheets dipping gently eastward, and the floor upon which they rest dips in the same direction.

RARITAN FORMATION.

GENERAL CHARACTER AND EXTENT.

The Cretaceous deposits occurring within this quadrangle belong to the Raritan, the lowest of the Cretaceous formations in New Jersey, but the uppermost member of the Potomac group of the Atlantic Coastal Plain. They extend across the southeast corner of the quadrangle, underlying the region east of Metuchen and south of Woodbridge in New Jersey, the southern and eastern portions of Staten Island, and the southwest end of Long Island. Their northern margin is for the most part obscured by heavy morainal deposits or by earlier Quaternary gravels, so that for only a short distance south of Metuchen and at the base of the high ridge of serpentine on Staten Island can it be located at all definitely. Elsewhere scanty data derived from scattered well borings, some of which penetrate 50 to 70 feet of glacial drift and reach underlying strata, are the only guide in determining the position of its boundary. The Raritan beds range from coarse sands or gravel containing pebbles an inch or more in diameter to dense, thick-bedded clays. The clays are white, blue, red mottled, or black; the sands are usually yellow from iron stains but are in places pure white. Masses of lignite and impressions of leaves are common at many horizons, but animal remains are very rare.

The sands and clays occur in many alternating layers, some of which are definite enough to be recognized in all the exposures of this area. Many individual beds exhibit marked variation in thickness, and evidence is at hand to show that certain clay layers after deposition were partially eroded by shifting currents before the succeeding sand beds were deposited. Cross-bedding is also common in some of the sand deposits.

The Raritan beds are exposed in portions of the New Jersey area, and on Staten Island at intervals from Kreischerville to Green Ridge, near Giffords, along the shore at Tottenville, at Princess Bay, half a mile south of Elmtree beacon, and near The Narrows. On the western portion of Long Island the formation is deeply buried beneath drift, but it has been penetrated by wells. In New Jersey the principal exposures are on the slopes rising out of the marshes on the north side of Raritan River and on the slopes adjoining Woodbridge Creek from Woodbridge to Perth Amboy. In these areas there are numerous quarries, some of great size, in which the formation is extensively exhibited.

THICKNESS.

Owing to the irregular configuration of its floor, the Raritan formation varies considerably in thickness. With the general downward slope of the floor to the southeast, the formation thickens in that direction. On Hoffman Island its base lies 450 feet below sea level and the floor is gneiss or some similar rock. Borings 147 feet deep at Princess Bay, 220 feet at Arbutus Lake, 246 feet near Annadale, and 200 feet at Kreischerville failed to reach its base. A well at Clifton is reported to have passed through 200 feet of glacial drift and 400 feet of Cretaceous sands and clay, reaching mica schists at a depth of 600 feet, but the record is probably erroneous. At Maurer a boring 78 feet deep passed through alternations of clays of various colors and found a hard rock supposed to be Palisade diabase; another well reached the hard rock at 110 feet. At Valentine Brothers' works, east of Woodbridge, "trap rock" is reported at a depth of 56 feet. At Perth Amboy there are several borings which may have reached the Newark rocks, one at a depth of 130 feet and another at 152 feet. The material is reported as "soft red clayey sand" and "blood-red tough clay," penetrated to 230 feet, but possibly these materials are in the lower part of the Raritan formation.

At the waterworks engine house just north of Eagleswood, in the western part of Perth Amboy, a boring was sunk through 55 feet of black clay, 6 feet of red and white clay, and 9 feet of red shale and sandstone to crystalline rock, at 70 feet. This rock was penetrated to a depth of 470 feet.

The Newark rocks continue to rise rapidly to the west and with very irregular surface contour, one high projection of the group outcropping on the summit of the ridge, a mile southwest of Maurer. At the foot of Poplar Hill, west of Fords, a red shale was found projecting through the Raritan beds but mostly overlain by Quaternary deposits.

Near Valentine station on the Lehigh Valley Railroad the red shale was entered at a depth of 78 feet. At Sayreville, on the south side of Raritan River, clay and red sandstones were bored through by a well which found gneiss at a depth of 70 feet and penetrated it to a depth of 893 feet.

FEATURES IN NEW JERSEY.

Although it is not possible to establish any subdivisions of the Raritan which are traceable over considerable areas, yet within the limits of this quadrangle in New Jersey certain well-defined beds can be recognized and traced from exposure to exposure. As these beds are only local, however, no attempt is here made to separate them in mapping, although it is well to describe them in the text for they afford a clearer conception of the formation. The lowest is discussed first.

Potter's and fire clay.—The term Raritan was applied to the lowest clay member many years ago, before it was used for the whole series of clays, but it is used here in the broader sense. Wherever the base of the Raritan formation is seen, there is found a red, plastic clay grading downward into undecomposed Newark shales and upward into beds of red mottled and white clays, some of which have a high degree of refractoriness. Inasmuch as the Newark shales dip 15° to 20° NW., and as the Cretaceous beds are nearly horizontal, dipping to the southeast only 35 to 60 feet per mile, and rest upon the beveled edges of the Newark rocks, the apparent transition from the unweathered shale into the clay indicates that the lowest clay layers were derived directly from the residuary products of the shale with practically no admixture of foreign material and with very little reworking. Excavations and borings indicate that this basal clay rests in hollows in the shale and is more or less discontinuous—a fact which adds to the difficulty of accurately mapping its inner margin. Its thickness ranges from a few inches up to 35 feet. It is exposed at a number of clay banks southeast of Bonhamton and south of Metuchen, as well as along Heard Brook at Woodbridge. Its elevation (top) near Metuchen is 120 feet, east of Bonhamton 50 to 60 feet, and at Woodbridge 40 feet.

Fire sand.—Above the potter's and fire clay is a bed of quartz sand, much of which is so angular in grain and so free from other minerals as to be used extensively for foundry and fire sand. Locally it carries thin beds of gravel and toward its base thin lenses of clay. Its thickness in the area under discussion ranges from 15 to 25 feet, but it thickens somewhat to the southwest. It is extensively exposed in the sandpits south of Bonhamton and farther east, to Sand Hills.

Woodbridge clay bed.—The most important and most widely worked clay bed of the Raritan formation is known as the Woodbridge clay, from its prominence near Woodbridge. In general it consists of two widely dissimilar portions, although at all clay banks much more minute subdivisions can be made. Adjoining sections, however, do not correspond in detail.

The basal portion is in general a light-blue or gray clay, rather sandy in its upper and lower parts and locally somewhat spotted with red. Where not too sandy this clay is hard and brittle and of a high degree of refractoriness—thus being a high-grade fire clay. Some portions of it contain considerable pyrite in the form of "sulphur" balls. The surface of the fire clay is in places sharply undulatory, showing differences of 5 to 15 feet within a few rods—an irregularity evidently due to interdepositional erosion where it is overlain by higher beds in the Cretaceous, and to preglacial erosion where it is overlain directly by glacial drift. As the base is also somewhat irregular, and the top and bottom irregularities do not correspond, the fire clay varies considerably in thickness, ranging from 6 to 40 feet, with an average of 15 to 20. The fire-clay bed is present in the bottom of nearly all the clay banks about Woodbridge, and also in the vicinity of Sand Hills. The elevation of its top decreases from 85 or 90 feet west of Woodbridge to 10 feet below sea level near Maurer, and from 55 feet just west of Sand Hills to about 10 to 20 feet below sea level near Florida Grove.

The upper portion of the Woodbridge clay bed is made up of a series of black lignitic clays and thin sand layers, so that it generally has a strongly laminated appearance. The clay seams range in thickness from a fraction of an inch to several feet, but the sand layers are on the average somewhat thinner. There is no order of arrangement of these beds, although on the whole the thicker clay layers lie near the bottom, near the fire clays, whereas at the top alternating sand and clay seams are very numerous and very thin. A well-marked leaf-bearing bed is not uncommonly found near the bottom of this subdivision, which may be called the "black laminated clays." Lignite and pyrite are irregularly disseminated through the entire mass, occurring in nearly every layer in at least small quantities and forming a large part of some beds. In some layers "ironstone" concretions are so numerous as to form almost continuous beds of stone. These clays are 50 to 60 feet in thickness, but only the lower portions are shown in the banks about Woodbridge and the upper portions in those near Maurer and north of Raritan River near Eagleswood and Florida Grove.

"Feldspar-kaolin" sand beds.—Above the Woodbridge clays comes an assemblage of beds, mostly sand, of varying texture and order of stratification. The so-called "feldspar" and "kaolin" occur here as irregular lenses at various horizons. The former is a very coarse quartz sand with large amounts of partly or completely decomposed feldspar, and the latter is not a kaolin at all but really a very fine quartz sand with a considerable amount of mica and a little clay. Here and there thin clay lenses also occur above the "feldspar" lenses. This member ranges from 30 to 40 feet in thickness and is best exposed in several "feldspar" banks about midway between Woodbridge and Perth Amboy. The "kaolin" appears on the shore of Princess Bay at the foot of the bluff between the grounds of the light-house department and the pier of the Catholic Children's Home.

Amboy fire clay.—Another bed of fire clay occurs above the "feldspar-kaolin" sands. It is in general a white, light-blue, or red-mottled clay, but locally some portions of it are rather dark colored and contain bits of lignite. Many bunches of pyrite several inches in diameter are irregularly disseminated in it, and small bits of amber occur at some localities in the dark-colored clays. This bed is best developed south of Raritan River beyond the limits of this quadrangle, but a small outlier occurs north of Florida Grove, where it is extensively dug. Here its thickness ranges from 15 to 25 feet and its base has an elevation of about 85 to 90 feet above sea level.

Total thickness.—The above-described beds are the only portions of the Raritan formation that occur within the Passaic quadrangle. Their aggregate thickness is about 175 feet, but the total for the Raritan in this part of New Jersey is 200 to 210 feet.

FEATURES ON STATEN ISLAND.[1]

On Staten Island the most extensive exposures of the Raritan beds are in quarries near Kreischerville, Rossville, and Green Ridge, where the fire clay and "kaolin" are worked. In the vicinity of Kreischerville considerable complexity is presented in the distribution of the Raritan beds, most of the clay occurring in isolated masses separated by sand and gravel of later age. Probably some portions have been moved by the glacial ice and to a considerable extent were deeply eroded by currents which deposited the Quaternary sands and gravels on an irregular surface. Near the village extensive excavations have been made at several points, yielding various kinds of clays. A boring at Kreischerville is reported to have passed through the following beds:

Record of boring at Kreischerville, N. Y.

	Feet.
Gravel	0– 4
Sand	4– 40
White clay	40– 61
White sand	61– 90
Blue clay	90–101
Fine white sand	101–191
Black sandstone	191–194
Quicksand	194–196

A mile and a quarter northeast of the fire-brick factory at Kreischerville micaceous "kaolin" is worked in a pit which exposes 15 feet of the bed. A quarter of a mile farther north is another pit in the same bed, but the thickness is less and the "kaolin" is seen to be underlain by bluish sandy clay with lignite fragments. At the Anderson Brick Company's clay pit near Green Ridge, the lower black clay shows signs of disturbance; the upper beds are blue and gray and at one place there is a thick seam of lignite. The clay is not sufficiently refractory for fire brick.

A well at the dental works at Princess Bay, begun at 4 feet above sea level, affords an important though imperfect section of the Cretaceous beds, including the typical "kaolin" at the bottom. The following record is reported:

Record of well at Princess Bay, N. Y.

	Feet.
Sand	0– 16
Coarse sand and gravel	16– 31
"Mud"	31– 56
Coarse sand and gravel	56– 70
"Mud"	70–120
Fine sand	120–121
"Hard pan" and gravel	121–124
Fine white sand (kaolin)	124–147

In a boring at Arbutus Lake, 220 feet deep, much "kaolin" was found. At Bachman's brewery, Annadale, a well 246 feet deep found yellow gravel extending from 200 to 236 feet, underlain by a bed of white and blue clay said to be a fine pottery clay. An outcrop of Cretaceous clay has been reported on the bay shore southeast of Eltingville. Cretaceous beds have been exposed by road grading at a number of points near Arrochar. The principal exposures are on Fingerboard road, where there are sandy, micaceous clays, or "kaolin," with characteristic ferruginous concretions, containing plants, overlain by yellow sand and gravel with concretions. The beds are greatly disturbed and may possibly be included in the drift.

In the deep railroad cuts across the terminal moraine at Arrochar more than 50 feet of drift is exposed, apparently without revealing the under-

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[1] These statements regarding the Cretaceous on Staten Island are compiled from numerous papers by Hollick, Britton, Ries, and others.

lying Cretaceous. In this vicinity the drift carries masses of hardened clay marl containing marine Cretaceous fossils which indicate the former presence of the Matawan formation in this region.

Some of the concretions near Arrochar have yielded *Cardium dumosum*, also *Moriconia cyclotoxon*, a characteristic plant of the Amboy clays.

FOSSILS.

Fossil plants of Raritan age occur in some of the beds at Kreischerville and Green Ridge. At Tottenville sandstone and conglomerate fragments, with numerous well-preserved plant remains and a few mollusks of Cretaceous age, have been found along the beach. They occur at the foot of a cliff of glacial drift and probably they are not far out of place. Some of them weigh over a hundred pounds. They belong in the regular series of Raritan deposits, for they appear in New Jersey in the clay cliffs on Raritan River above Perth Amboy. Similar masses of plant- and shell-bearing sandstones have been reported in the drift south of Clifton and near Pleasant Plains station. In the bluff at Princess Bay the Raritan "kaolin" bed appears underlying drift or possibly it is in masses included in the drift. In a ravine near by there are small outcrops of clay and of a gravel bed believed to be of Cretaceous age. Some of the pebbles in this gravel contain Paleozoic fossils in considerable variety.

QUATERNARY SYSTEM.[1]

By Rollin D. Salisbury.

To the Quaternary division of geologic time are referred most of the unconsolidated materials lying upon the bed rock described in the preceding pages. The Quaternary formations in this area are (1) partly of preglacial age (at least antedating the last glacial invasion), (2) partly of late glacial age and origin, and (3) partly of postglacial age. Of these several classes, the glacial drift is the most widespread. All of the area of this quadrangle, except a very small tract about New Dorp, Staten Island, and a more considerable one in the southwestern part of the quadrangle, was overspread by the ice of the last glacial epoch, and is now covered with the drift which the ice left.

BRIDGETON OR BEACON HILL GRAVEL.

There is a little gravel, chiefly of quartz and chert, in the driftless area north of New Dorp, Staten Island, at an elevation of about 200 feet above sea level. This remnant of gravel is so small and so isolated that its relations and age can not be definitely fixed. It is certainly older than the glacial formations of the region, but how much older is not determinable. It may be early Quaternary or late Tertiary, and accordingly is mapped under the name Bridgeton or Beacon Hill gravel.

PENSAUKEN FORMATION.

The Pensauken formation occurs in the western part of Staten Island and on the mainland to the west. On Staten Island it is well exposed in several of the clay pits about Kreischerville, where it overlies Cretaceous sand and clay and underlies the glacial drift. Its thickness here is usually 8 to 10 feet. This slight thickness represents the basal part of the original formation, most of which has been removed by erosion. After fresh cutting by the waves, gravel which is probably Pensauken is exposed in the cliff at Princess Bay light-house. When the railway cut at Arrochar was fresh, gravel of the same sort was exposed. In spite of their meager exposure, the Pensauken sand and gravel are perhaps somewhat widely distributed in the western part of the island, though now concealed by younger formations. Although not of glacial origin, the Pensauken formation was probably contemporaneous with one of the early glacial formations, not represented or not differentiated in this region.

Within this quadrangle the chief development of the Pensauken formation in New Jersey is in the area south of the moraine and southeast of a line drawn from Metuchen to New Brunswick. At its northwestern edge the formation lies upon the Triassic shale, but to the southeast upon Cretaceous beds. Within this area the Pensauken is best exposed about Bonhamton, where there is an extensive gravel pit, but it is also shown at numerous clay pits farther east. Where it is deepest, its bottom reaches down nearly to sea level. Its upper surface attains an elevation of 120 feet and this limit is in general well defined. Considerable areas at about this level have been little affected by erosion. This formation, which is one of the several "yellow gravel" formations of the Coastal Plain, is not chiefly, and perhaps not in any part, of glacial origin, but is regarded as the aqueous equivalent of a sheet of drift older than the terminal moraine and the drift north of it. Glaciated stones have been found in the Pensauken, though very rarely.

Thin beds of gravel, which are to be correlated, probably, with the Pensauken formation, occur at two points near New Durham, west of Metuchen, N. J., and at two points just north of Plainfield. They cap the tops of more or less isolated elevations which exceed 130 feet in height. Similar beds of gravel in similar situations occur at several points west and southwest of the area shown on this map. In constitution these remnants of gravel are similar to the Pensauken formation.

GLACIAL DEPOSITS.

The drift of this region is but a small part of a great sheet of drift covering about half of North America. It owes its name to the obsolete idea that its materials were drifted by water from their original sources to their present position. It is now known, however that the drift is primarily a deposit made by an extensive sheet of ice, a glacier of continental dimensions, which once occupied the drift-covered area.

GENERAL DESCRIPTION OF GLACIAL PHENOMENA.

Drift-covered Area.

The accompanying map (fig. 9) shows approximately the area of North America formerly covered by ice, and now covered by drift. It also shows that northern New Jersey lies near the southern margin of the great drift sheet.

Fig. 9.—Map of North America, showing the area covered by the Pleistocene ice sheet at its maximum extension, the three centers of ice accumulation, and the approximate southern limit of glaciation.

The condition of the northern part of the continent when the ice sheet was at its maximum was comparable to that of Greenland today. The larger part of the 500,000 square miles which that island is estimated to contain is covered by a vast sheet of snow and ice, hundreds and probably thousands of feet in thickness. In this field there is constant movement, the ice creeping slowing out toward the borders of the island, tending always to advance until its edge reaches a position where it is wasted by melting and evaporating as rapidly as it advances. The total area of the North American ice sheet at the time of its maximum development has been estimated at about 4,000,000 square miles, or about ten times the estimated area of the present ice field of Greenland.

Growth of the Ice Sheet.

The ice sheet which covered this great area was of slow growth. Its beginnings are believed to have been snow fields on the east and west sides of Hudson Bay. With increasing rigor of climate, the cause of which is not certainly known, these snow fields became larger, just as mountain snow fields become larger during periods of low temperature or of heavy precipitation of snow. As they increased in size, all the snow except that at the surface was converted into ice, so that the great fields, like all great perennial snow fields of the present time, were really great ice fields, but thinly covered with snow. As soon as the ice attained sufficient thickness, movement was inaugurated. This movement was glacial movement and the ice in motion was glacier ice.

From the separate centers the ice and snow fields extended themselves in all directions, partly as the result of movement and partly as the result of the marginal accumulation of snow. The ice sheets spreading from these centers ultimately became confluent, and invaded the territory of the United States as a single sheet which, at the time of its greatest development, had the area shown in fig. 9.

The map also shows that the edge of the drift-covered area is somewhat lobate. The lobation is, indeed, more pronounced than this small map shows.

Recurrent Glaciations.

In the preceding paragraphs the ice sheet has been referred to as if it developed once, and then melted from the face of the land. But a great mass of evidence is now in hand showing that the history of glaciation was not so simple. One ice sheet developed and then melted wholly or partly, only to be succeeded by another, which in turn was wholly or partly dissipated before a renewal of glacial conditions caused a third advance of the ice. Within the United States the number of pronounced advances of the ice was not less than five, though the ice did not reach the same limit in successive advances, and probably did not retreat to the same position during the epochs of deglaciation. There is reason to believe that the region with which we are here concerned was covered by ice at least twice, though nearly all of the accessible drift was deposited by the last ice sheet and the waters associated with it.

Work of an Ice Sheet.

The work effected by an ice sheet is twofold. In the first place, it erodes the surface over which it advances, widening and deepening valleys which are parallel to its direction of movement, cutting off hilltops, and smoothing down roughnesses of all sorts. In the second place, it sooner or later deposits the débris which it gathers in its movement and carries forward in its basal parts. Glaciation therefore tends, first to cut the surface down by erosion, and then to build it up by deposition; but the two processes rarely affect the same spot in an equal degree. The result is that the configuration of much of the surface is considerably altered by the passage of glacier ice over it. If the drift is thick it may level up an uneven surface of rock, or it may be so disposed as to increase the relief instead of diminishing it. If the drift is thin its effect on the topography is less pronounced. Where the relief of the rock surface beneath the drift is great, the drift has relatively little influence on the topography.

The deposits occasioned by glaciers fall into two distinct classes, those made by the ice itself and those made by the waters derived from the ice. The ice deposits are unstratified and unassorted; the water deposits are stratified and assorted. The unstratified drift constitutes moraines.

Characteristics of Glacial Drift in General.

From the method by which it was gathered, it is evident that the drift of any locality may contain fragments of rock of every variety occurring along the route followed by the ice which reached that locality. The variety of materials in the drift may therefore be great.

Another characteristic of the drift is its physical heterogeneity. As first gathered by the ice, some of the materials of the drift were fine and some coarse. The ice tended everywhere to grind and crush the débris it carried, reducing it constantly to a finer and finer state. Much of the softer material, such as shale, was crushed or ground to powder, forming what is popularly known as clay; other sorts of rock, such as soft sandstone, were reduced to sand; and masses of more resistant rock escaped comminution and remained as bowlders. From clay and sand on the one hand to bowlders on the other, all grades of coarseness are represented in the glacial drift.

Still another characteristic of glacial drift, and one which clearly distinguishes it from all other formations, pertains to the shapes and markings of the stones it carries. Many of them have planed and striated faces.

Types of Drift.

Ground moraine.—The ground moraine constitutes the great body of the glacial drift. Bowlder clay, a term descriptive of its constitution in some places, and till are other terms commonly applied to the ground moraine. It consists of all the unstratified drift which lodged beneath the ice during its advance, all that was deposited back from its edge while its margin was farthest south, and most of that deposited while the ice was retreating. From this statement it is seen that the ground moraine of an ice sheet should be essentially as widespread as the ice itself. Locally, however, it failed of deposition, and many areas of bare rock, mostly small, occur within the great tract which the ice covered. As it constitutes the larger part of the drift, the characteristics already enumerated as belonging to drift in general are the characteristics of the till. The character of the till in any locality depends on the sorts of rock over which the ice passed in reaching that locality. Where it passed over much sandstone the till is likely to be sandy, and where it passed over much shale the till is apt to be clayey. If the formations passed over were resistant and so situated that the ice could erode them effectively, the resulting till is likely to be rich in bowlders; if the formations passed over were soft, bowlders are few.

In general the till of any locality is made up predominantly of materials derived from formations close at hand. Within the area of this quadrangle, for example, probably less than 10 per cent of the material came from areas north of the New Jersey boundary. This leads to the conclusion that deposition must have gone on beneath the ice during its movement, even back from its margin.

Terminal moraines.—The marginal portion of the ice sheet was more heavily loaded in proportion to its thickness than any other. Here the thinned and thinning ice was constantly losing its transporting power, and at its edge this power was gone. As the ice was continually bringing débris to its edge and leaving it, the average rate of drift accumulation must have been greater beneath and at the edge of the ice than elsewhere.

Whenever, at any stage of its history, the edge of the ice remained essentially constant in position for a long period of time, the corresponding submarginal accumulation of drift was great, and when the ice melted, the former site of the stationary edge was marked by a belt of drift thicker than that adjacent. Such thickened belts of drift are terminal moraines. It will be seen that a terminal moraine does not necessarily mark the terminus of the ice at the time of its greatest advance, but rather its terminus at any time when its edge was stationary, or nearly so, for a considerable period of time.

In composition, terminal moraines are very similar to the adjacent ground moraines, though large bowlders and stratified drift are rather more abundant in the former than in the latter. The most distinct feature of a terminal moraine is its topography. This, more than any other one feature, distinguishes it from the ground moraine.

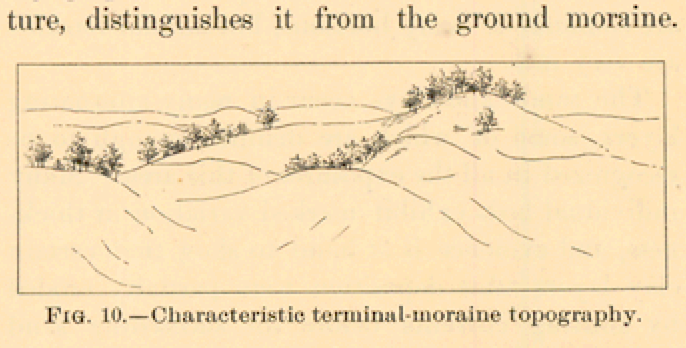

Fig. 10.—Characteristic terminal-moraine topography.

Although the topography varies from point to point, its most distinctive phase is marked by hillocks and hollows, or interrupted ridges and troughs, following one another in rapid succession, as illustrated in the sketch, fig. 10. The relief is in places scores of feet within short distances.

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[1] The field work on the Quaternary deposits in the New Jersey portion of this quadrangle was done at the expense of the New Jersey Geological Survey.

The depressions inclosed by the elevations are the sites of marshes, ponds, and lakelets, wherever the material constituting their bottoms is sufficiently impervious to retain the water falling and draining into them.

The manner in which the topography of terminal moraines was developed is worthy of note. In the first place, the various parts of the ice margin carried unequal amounts of débris. This alone would have caused the moraine of any region to be of unequal height and width at different points. In the second place, the margin of the ice, though maintaining the same general position during the making of a moraine, was yet subject to many minor oscillations. Some of these oscillations were seasonal and some covered longer periods of time. If the ice retreated and advanced repeatedly during a considerable period of time, always within narrow limits, and if during this oscillation the details of its margin were frequently changing, the result would be a complex or "tangle" of minor morainic ridges of various heights and widths. Between and among them there would be depressions of various sizes and shapes. Thus, it is conceived, many of the peculiar hillocks and hollows which characterize terminal moraines may have arisen. Some of the depressions probably resulted from the melting of ice blocks left behind when the ice retreated.

Stratified drift.—A large part of the drift is stratified, showing that it was deposited by water. This is not strange when it is remembered that the total amount of water which operated on the drift was scarcely less than the total amount of ice, for the larger part of the ice was ultimately converted into water, and to this was added the rain which fell on the marginal part of the ice.

Stratified drift may be formed in various ways. It may be deposited by water alone, or by water in cooperation with the ice. The water may be running or standing. When the ice cooperated with the water, it was generally a passive partner.

The most extensive deposits made by water arising from glacier ice are laid down either as the water issues from beneath the ice, or as it flows away. At the immediate edge of the ice sheet, therefore, certain deposits were made. The margin of the ice was probably irregular, as the ends of glaciers now are, and as the waters issued from beneath it they left some of their débris against its irregular front and in its reentrants and marginal crevasses. When the ice melted, these marginal accumulations of gravel and sand assumed the form of hillocks. Such hillocks of gravel and sand are *kames.* The streams emanating from the ice carried some gravel, sand, and silt beyond the edge of the ice, and deposited them in the valleys through which the drainage passed, just as other overloaded streams deposit such material under like conditions. These deposits are *valley trains.* Where the water was not confined in valleys, but spread more or less widely over a plain surface, it developed plains of gravel and sand, often called *outwash plains.* If the water issuing from the ice flowed into lakes or the sea, as sometimes happened, *deltas* were developed from the material it carried. Most of these types of stratified drift are illustrated in this quadrangle.

All the deposits made by water issuing from the ice at the time of its maximum advance were likely to remain after the ice melted. Likewise all similar deposits made while the ice was retreating were likely to be preserved. On the other hand, all deposits made by water at the edge of the ice or beyond it during its advance were likely to be overridden and buried or destroyed by the farther advance of the ice. Thus a part only of the stratified drift actually deposited is finally preserved. When it is remembered that there were several ice epochs, and that in each the edge of the ice was subject to considerable oscillations, it is evident that the relation between the stratified and the unstratified drift may be very complicated.

GLACIAL PHENOMENA IN THE PASSAIC QUADRANGLE.

All the principal types of glacial drift are shown at one point or another in the area of this quadrangle. During the last glacial stage the edge of the ice made a protracted halt at its position of maximum advance, as shown by the terminal moraine which it left. Most of the drift south of the moraine is stratified; that lying north of it is partly stratified and partly unstratified.

DIRECTION OF ICE MOVEMENT.

The general direction of ice movement within the area of this quadrangle and in the area adjacent to it on the east, as well as the limit of ice of the last glacial stage, are shown on the map (fig. 11). The general direction of movement is known both by the course of the striæ, which the passage of the ice left on the bed rock, and by the distribution of the materials of the drift. In general the movement was approximately at right angles to the course of the terminal moraine. In the southeastern part of the area the movement was east of south, the easting being locally (on some parts of the Palisade Ridge) as much as 45° to 50°; elsewhere the movement was west of south.

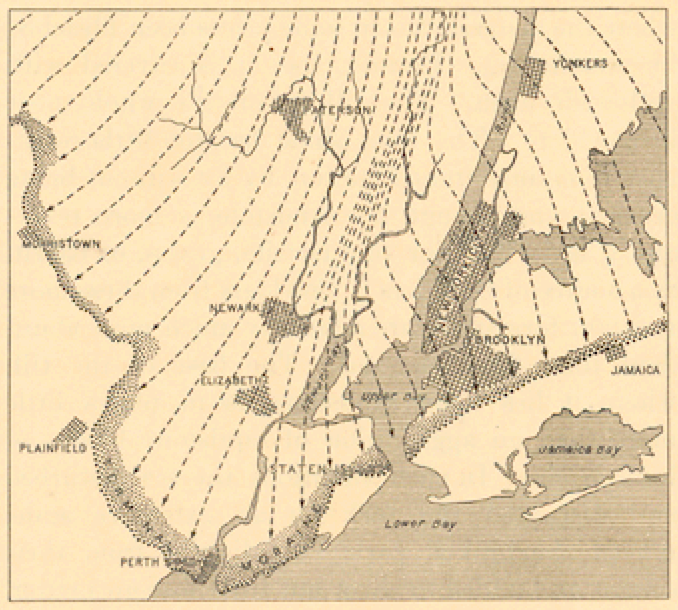

FIG. 11.—Sketch map showing the terminal moraine and the direction of ice movement in the Passaic quadrangle and on western Long Island.

THE TERMINAL MORAINE.

Position.—The terminal moraine of this quadrangle is a part of a large moraine loop extending from Denville (north of Morristown) on the northwest, to Jamaica, Long Island, on the northeast (fig. 11), the most southern or forward part of the loop being at Perth Amboy and Tottenville. The width of the moraine varies from about half a mile a little north of Morristown to 2 miles or more in the vicinity of Woods of Arden, Staten Island.

Topographic relations.—The vertical range of the moraine is from about 500 feet near Denville to sea level on either side of Arthur Kill, between the mainland and Staten Island, and on either side of The Narrows, between Staten Island and Long Island. The southernmost point of the moraine loop corresponds with the lowest surface which the moraine occupies, and is in line with low land in the direction whence the ice came. Though the general course of the moraine between Brooklyn and Tottenville is northeast and southwest, it bends distinctly northward about the high land near the east end of Staten Island. Similarly, though the general course of the moraine from Perth Amboy to Denville is northwest and southeast, there is a notable deflection in its course between Plainfield and Madison. In both localities the moraine bends northward around rock elevations, showing that the advancing ice was retarded by the high ground which it encountered, and that it advanced less where the surface was high than where it was low.

The moraine as a topographic feature.—As a topographic feature the moraine is in some places conspicuous and in others not. Its vertical range is not primarily the result of the height of the base upon which it rests. It is to be remembered that the moraine is simply a belt of drift somewhat thicker and more irregularly disposed than that to the north of it. It is not a well-defined ridge of equal dimensions at all points, but a composite ridge of unequal width and height, made up of numerous subordinate hillocks and ridges associated with depressions of similar outline. In many places the terminal moraine is not notably higher than the ground moraine adjacent to it. In the eastern part of Staten Island, for example, it adds so little to the height of the high land that it can hardly be said to be important topographically. In general, it is more conspicuous when viewed from the south than from the north. Near the east end of Staten Island its outer face is 60 to 100 feet above the adjacent plain. Similar relations exist most of the way between Perth Amboy and Scotch Plains, where the rise is locally more than 100 feet; and also between Chatham and Morristown. Elsewhere the moraine can hardly be said to be a conspicuous topographic feature. Stated in other terms, the moraine is generally conspicuous where its surroundings are relatively flat, and inconspicuous where their relief is great. From the inside, the moraine is less well marked topographically, the transition from ground moraine being generally gradual. These relations are shown by fig. 12.

Topography of the moraine.—Although the moraine as a whole is but a belt of drift somewhat thicker than that to the north, and therefore in many places inconspicuous as a topographic feature, its own topography is distinctive. The characteristics of moraine topography have been mentioned. This topography is well developed between Fort Tompkins and Giffords on Staten Island, the tract between Arrochar and Grassmere affording as good a view of the characteristic topography as the island affords. Here the billows of earth rise and fall in graceful curves of notable magnitude, and some of the depressions are occupied by ponds and lakelets. Similar topography is strongly marked northwest of Fords, N. J., and also southeast of Plainfield (fig. 12), where it is especially well defined near the outer border of the moraine. Here hillocks 20, 30, and even 40 feet high are associated with abrupt depressions of circular or elongated form, some of which are 20 or 30 feet below their surroundings, though more of them are but 5 to 15 feet deep. Numerous little ponds and marshes occupy the depressions. Topography of the same kind is also well defined a mile and more east of Morristown, on the road to Florham Park, where advantage has been taken of its unique topography for the location of summer residences. The rolling topography at this point, though much less decided than at some others, illustrates the surface features which characterize the moraine throughout most of its course. Notable depressions occur in the outer part of the moraine just north of Convent. The most conspicuous is about 60 feet deep and probably represents the site of an ice block about which drift was deposited. The melting of the ice left the depression.

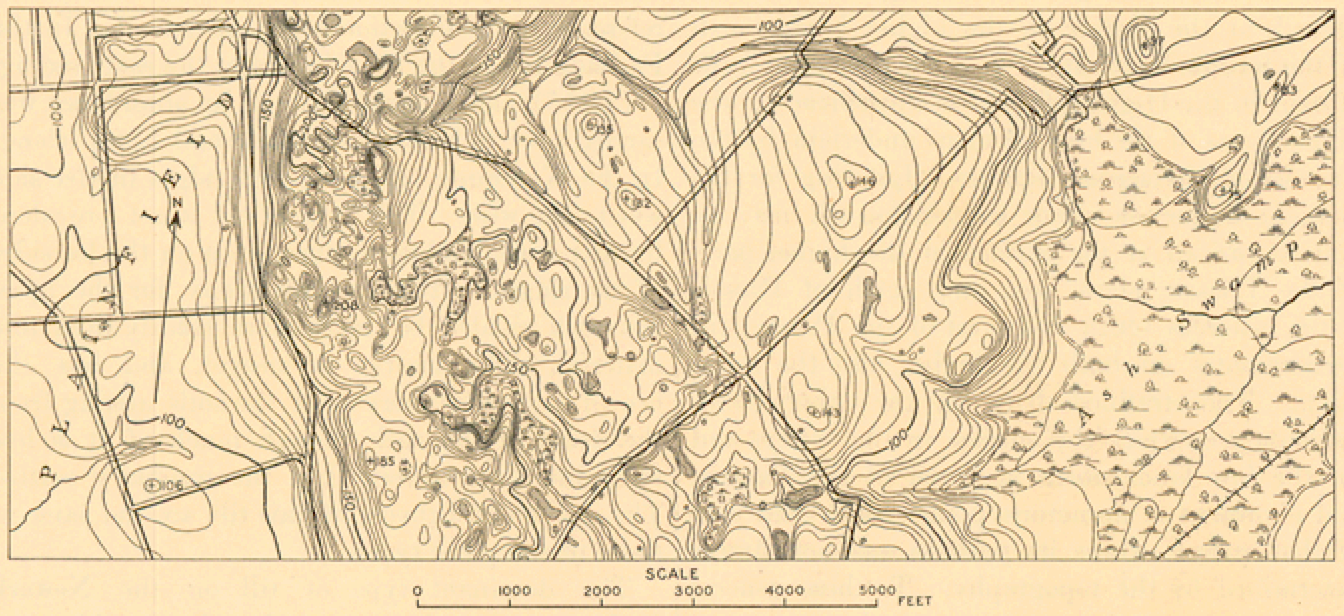

FIG. 12.—Map showing a portion of the terminal moraine southeast of Plainfield. Contour interval, 5 feet. The moraine is the belt of numerous hillocks and depressions in the west-central part of the area. A portion of the outwash plain is shown to the west and the ground moraine to the east.

It is not to be understood that the characteristic morainic topography affects all parts of the belt mapped as morainic; rather does this belt include the areas where this sort of topography occurs, together with some connecting areas where it is but feebly developed. The mapping of the inner border of the moraine is somewhat arbitrary, and the student of the drift must not expect to find a notable change in the surface at the line which stands for that border. The crest of the moraine is not everywhere along the central line between its inner and outer borders, but is more commonly near the outer border. Moreover, in many places the moraine has two or more crests instead of one.

Composition of the moraine.—Between Brooklyn on the east and Scotch Plains on the west the moraine is made up primarily of clayey till with less stratified drift than is common in terminal moraines. The till has usually a reddish color, due to the large amount of material derived from the red Triassic shale and sandstone over which the ice which made this part of the moraine had come. Surface bowlders are not now everywhere abundant. The numerous stone walls in place of fences, especially in the thickly settled districts, show that surface bowlders were once more plentiful than now. The bowlders of this part of the moraine are chiefly of Triassic sandstone and igneous rock. There are also bowlders of gneiss and schist, and some of white and purple quartzite, apparently from the Oneida formation of New York. Other sorts of rock also enter into the composition of the moraine, though not in the form of bowlders. Here belong white quartz pebbles, like those on the driftless area north of New Dorp, and bits of shale and limestone from the middle course of the Hudson. Were these various sorts of bowlders ground up to the consistency of clay and sand, the product would be somewhat like the finer constituents of the moraine. Such, indeed, was the origin of the matrix in which the bowlders are set. Where the moraine crosses First and Second Watchung mountains at Milburn and Short Hills, it is composed largely of basalt.

From Passaic River to Tabor gravelly material predominates over till. This is especially true of that part of the moraine between the Passaic and Convent, and also about Morristown. From Madison to Littleton and beyond, the inner face of the moraine below an altitude of 360 feet carries a good deal of gravel, for which the extinct Lake Passaic, which occupied the basin to the north, seems to have been partly responsible.

In the vicinity of Morristown bowlders from the Green Pond conglomerate are abundant. At about this point, too, gneiss becomes the dominant element of the drift, though material derived from the red shale and sandstone is common, and locally abundant, as far north as Denville.

The constitution of the moraine is exposed in numerous cuts along the railways, in cliffs along the shore, and in shallow road cuts. The best exposures along railways are those about Fanwood and Metuchen, between Giffords and Fort Tompkins, and on the coast at Princess Bay, Staten Island.

Thickness of the moraine.—The thickness of the drift in the moraine varies greatly from point to point. The greatest thickness known on Staten Island is 75 feet, and the average for the island is probably less than half this amount. In New Jersey the drift of the moraine is reported to exceed 200 feet in thickness at various points about Madison. The average thickness within the area shown on the map may be as much as 75 to 100 feet.

There are some belts of the nature of recessional moraines. They are composed largely of kames, and will be mentioned in connection with kame belts.

Stratified drift on outer face of the moraine.—Many terminal moraines are bordered on the outside by plains or valley trains of stratified drift carried out beyond the ice by the water arising from its melting. The relations of the stratified drift to the moraine are shown in section in fig. 13, the profile being taken from the area southeast of Plainfield. Between Scotch Plains and Fords, and also between Great Kills and Fort Tompkins, the stratified drift outside the moraine is disposed in the form of plains. Along the moraine between Long Hill and Morristown, too, there is stratified drift disposed as a plain, but here it has the slope

FIG. 13 —Cross section showing the relation of outwash (stratified drift) to the terminal moraine, similar to that which exists southeast of Plainfield.

characteristic of a delta or of a subaqueous outwash plain. In all these situations the stratified drift was contemporaneous in origin with the terminal moraine, the materials of which it is composed having been washed out from the edge of the ice when the moraine was being made. At their moraine edges, these bordering plains are made up of coarse gravel; but with increasing distance from the moraine the material becomes finer, grading off into sand. The sand and gravel are in many places covered with clay loam, so that the coarser materials below are shown only in excavations. The depth of the stratified drift is known to exceed 40 feet at many points on Staten Island, its base in many places being below sea level. It has a similar depth at various points about Metuchen and Plainfield, and a considerably greater depth, probably as much as 150 feet, at some points southwest of the moraine between Long Hill and Morristown.

The Ground Moraine.

Distribution.—In general, till or ground moraine prevails at the surface on the higher lands north of the terminal moraine. It is the dominant type of drift in the Highlands, and is widespread on the higher parts of the broader areas underlain by the Triassic or Cretaceous terranes. Ignoring for the moment numerous minor exceptions, till may be said to prevail at the surface in the higher parts of the Triassic plain, east and north of Passaic River, whereas south and west of the Passaic till predominates on both the higher and the lower lands. The stratified drift, on the other hand, commonly occupies the surface in the valleys and on the low lands north and east of the Passaic, and is present at numerous points south and west of that stream, where its position was not always determined by the topography. To these general statements there are numerous exceptions.

Till of the Highlands.—The till of the Highlands belongs to the gneissic type; that is, it is composed chiefly of material derived from the underlying gneisses and schists. This type of till consists primarily of a gritty matrix composed of the comminuted products of gneiss and schist, in which are embedded fragments and masses of the same sort of rock, ranging in size from that of sand grains to bowlders several or even many feet in diameter. The stony constituents are generally abundant, in many places constituting a considerable portion of the body of the till. Till of this type is rarely gravelly, and nowhere so clayey as much of the till derived from the shale. Much of it is disposed to be sandy, the sand being coarse and angular. Gneissic materials predominate, but materials from other formations are also present. The second most abundant constituent is that derived from the belt of Green Pond conglomerate, either in New Jersey or New York. Bowlders of this conglomerate are distributed eastward to the limit of the Highlands, and even beyond. Sandstone and slate are rarely important constituents. The best exposures of this type of till are in the vicinity of Boonton.

Rock outcrops are of common occurrence in the Highlands region, being most numerous on the steep slopes and sharp summits of the mountains; however, outcrops are not rare on low-lying surfaces. The average thickness of the drift in this region is probably less than 20 feet, and may not exceed half that amount.

Till of the Triassic plain.—The till of the Triassic plain is of three principal types. These are made up chiefly of material derived (1) from the Highlands, (2) from the Triassic igneous rocks, and (3) from the Newark shales and sandstones. Between these types there are all gradations, yet most of the till is referable to one or another. A minor type of till, found only at Castle Point, Hoboken (fig. 32, illustration sheet), and near the east end of Staten Island, contains a large proportion of serpentine; and another minor type occurs on either side of Arthur Kill, where the drift contains much material from the underlying Cretaceous beds.

The gneissic type of till is present on the Triassic plain only along the north border of the area shown on the map, and along the southeastern face of the Highlands. Its southern and eastern limits are not well defined, but in the upper part of the till at many places between Hohokus and Franklin Lake gneiss is a dominant constituent. About Hohokus, Midland Park, and Wortendyke sections have been seen which show that much of the deeper part of the till is distinctly red, even where the surface part shows little or no material derived from the Newark sediments. That material from the Highlands to the north should predominate in the upper part of the till, rather than in the lower part, is to be expected, for in coming over the rough Highlands the ice acquired some débris which was carried well above its bottom. When the ice descended to the lower Triassic terrane, with its lesser relief, the material which it gathered there remained relatively near its bottom. When the ice melted, the gneissic material above its bottom was left on the surface of the Triassic material, which was lower in the ice mass. There is nothing in the area to warrant the inference that the gneissic material in the upper part of the till became superglacial before deposition.

The basaltic and diabasic till is practically confined to the ridges of igneous rock, or "trap," and their immediate surroundings on the lee side, with reference to the direction of ice movement. In the Palisade Ridge the lee side was to the east (see fig. 11, p. 15), and igneous material in abundance was carried over to Manhattan Island and Long Island. In the Watchung and associated ridges the lee side was to the west. This type of till is not prevalent for any considerable distance, even on the lee sides of the ridges. It is generally stony, for the igneous rock yielded bowlders more readily than fine material. The matrix is meager, and has the brown color characteristic of the soils arising from the decay of the rock, though much of it is less ferruginous or ochery than the residuary earths. The minor constituents of this till are the same as those of the other types.

The dominant type of till on the Newark Plain occupies the stoss side of the ridges of igneous rock, especially near their bases, and even the crest of the Palisade Ridge, so far as shown on this map. Its most conspicuous characteristic is its redness. It is in places clayey, where shale furnished most of the material, and in places sandy, where sandstone was the chief contributor. The more clayey portions are to the south and west; the more sandy to the north and east. Much of it is poor in bowlders, especially where it is derived principally from shale. If it contains abundant bowlders, as it does in some places where it is derived principally from the sandstone, many of them are but little worn.

To the till derived chiefly from the Newark rocks minor contributions were made by other terranes, such as the gneiss of the Highlands and the quartzite and sandstone of the Green Pond Mountain belt or its northern continuation (Schunemunk Mountain). These formations are more generously represented among the bowlders than in the finer material. Even in the terminal moraine many of the surface bowlders are of rock foreign to the region. So far as sections afford a basis for generalization, the bowlders of gneiss, quartzite, sandstone, etc., are more common at and near the surface than in the body of the till below. At numerous points up to altitudes of more than 200 feet, pebbles and cobbles of quartz believed to have been derived from the former northern extension of one of the extra-glacial gravel formations (Beacon Hill or Bridgeton) are found in the till. Where the red type of till prevails, the drift is, on the average, much thicker than where the basaltic and diabasic type occurs.

Till between Palisade Ridge and First Watchung Mountain.—The axis of the ice lobe which affected this area lay near its eastern edge. (See fig. 11.) Along the axis, and between it and First Watchung Mountain, the ice worked on the sedimentary part of the Newark group only, so far as New Jersey is concerned, and the material of other origin in the drift of this area came from outside the State, except (1) the small amount of basalt and diabase which was derived from the small bosses and dikes in the area, or which have been brought down to the low land from the Palisade Ridge on the one hand, or from First Watchung Mountain on the other, in preglacial time; and (2) the pebbles from such remnants of the Tertiary or early Pleistocene (Beacon Hill, Bridgeton, Pensauken) formations as remained in the region when the ice came in. To the above general statement an exception must be made of the small area south of Woodbridge, where the ice overrode the Cretaceous beds and where remnants of the Pensauken formation were considerable.

As a consequence of the uniformity of the rock on which the ice of this area worked, the till is somewhat constant in character. Most of it has the red color characteristic of the Newark sediments, from which is was chiefly derived, though this color is not always obvious at the surface, where the material has in some places been bleached by weathering. Locally, too, it is covered with yellowish loam. The till is, on the whole, poor in bowlders. The local shale has too little resistance to endure transportation by ice without being crushed, and though the sandstone is more resistant, it is far inferior to quartzite, gneiss, or basalt, as a source of bowlders. Bowlders from these more resistant formations are relatively much more abundant than finer material. The base of the till, where it lies upon sandstone, is in places little more than an aggregation of sandstone blocks of local origin. In such situations the ice disturbed and disrupted the rock on an extensive scale, moved the broken parts but slightly from their source, and added to them but little foreign matter. There is at some localities so complete a gradation from the till made up of the local rock, through the slightly disturbed beds, to the rock in place, that it is difficult to say precisely where the till leaves off and the rock begins. There may be also a very complete gradation from the till made up of slightly worn blocks of rock of strictly local origin below to that made up of materials which have suffered much more wear and more extensive transportation above. On the whole, bowlders of types foreign to the area decrease in number and in size toward the south, with increasing distance from the formations which yielded them. The largest bowlder (gneiss) in the Triassic area, and one of the largest in the State, lies west of Glen Rock, just west of the railway. Its exposed portion is 42 by 25 by 11 feet. The average thickness of till for this area, aside from that which underlies stratified drift, is probably not far from 25 feet.

Drumlins.—The till is locally and rarely aggregated into drumlins. The best examples of drumlins are in the vicinity of the Oranges, but one hill which is perhaps a drumlin lies south of Avondale, and two others near Franklin, west of Caldwell. There is some difficulty in determining whether some of these are drumlins or only ridges of rock heavily coated with till, but the data at hand seem to warrant the former interpretation for most of them.

Till between the Highlands and the Watchung Mountains.—Between the Watchung Mountains and the Highlands the till is relatively thick and presents greater variations than farther east. On the lowlands it is primarily of the red sandstone type, and among the bowlders those from the Highlands predominate. Those from the Green Pond conglomerate and from the basalt ridges are present in subordinate but notable quantity. Near the Highlands the till is primarily of the gneissic type. For some distince east of the zone where that type prevails, gneissic débris is most abundant in the surface portions of the drift, Newark material being more abundant below. Thus east of Morristown the surface material is mostly gneissic, but at a depth of 2 or 3 feet the redness due to the admixture of Newark material becomes noticeable in many places, and at depths of 10 to 20 feet it predominates. The explanation to this relationship has already been given. At a distance of 2 to 4 miles from the Highlands the redness becomes distinct even in the surface part of the till. In the northeastern part of the area the underlying Newark sediments are largely conglomeratic, and in many places but poorly cemented. The till over the conglomerate consists largely of material derived from it, and has a gravelly character, giving much of the surface the false appearance of stratified drift. Because of the variations in the constitution of the conglomerate and because of its more subdued color, the till derived from it is less red than that east of First Watchung Mountain.

Over the area about the Troy Meadows, and between Whippany and Parsippany, the drift was modified somewhat by the waters of Lake Passaic. The effect of the lake was to make the surface more clayey, as fine mud settled from the water over the surface of the drift previously deposited, and also to obscure the relations of the stratified drift and the till. Nearly all the more prominent hills of drift in the region show stratified drift either at their tops or on their slopes, as if really kames partly buried by till.

There is a very considerable belt inside the moraine where a slight thickness of drift, not distinctly or not at all stratified, overlies a large body of stratified drift. This, in turn, overlies till. This relationship prevails to such an extent as to lead to the belief that the edge of the ice fluctuated in position, drawing back from the main moraine and allowing stratified drift to be deposited between its edge and the moraine, and advancing again at a later time, burying the stratified drift with a new deposit of till.

The till of the low-lying part of the Passaic basin north of the moraine is thick, ranging up to 70 feet at least, where its thickness is known. It is probable that the average thickness of the drift between the moraine and the Highlands, on the one hand, and Rockaway and Passaic rivers, on the other, is not less than 30 to 50 feet, though much of it is not till. Within this area few striæ have been recorded. East-northeast of Montville their direction is S. 62° W.

Till on the Palisades and Watchung mountains.—The drift on the diabase and basalt ridges is chiefly till, thicker, as a rule, where the slopes are gentle, and thinner or even wanting where they are steep. Steep slopes and narrow summits are common, and rock outcrops are therefore abundant.

As the ice which covered the Palisade Ridge moved southeastward, it carried up abundant débris from the sandstone and shale below. The till of the ridges is therefore composed primarily of material from the sandstone and shale to the west, of diabase débris derived from the ridge itself, and very subordinately of material from sources farther north. Within the area represented on this map, red till occupies not only the west slope of the ridge, but much of the crest as well. Rarely does the till contain much diabase, though that rock becomes an increasingly important constituent toward the east side of the ridge. Bowlders of gneiss are not rare, but those of quartzite are uncommon and those of limestone very few. Pebbles which are believed to have come from former remnants of the Beacon Hill or Bridgeton gravel are found at various points, but remnants of the formation from which they might have come are nowhere exposed on the ridge. A notable bowlder of gneiss, 12 by 20 by 6 feet, occurs a few hundred yards east of Tyler Park, and a bowlder 8 by 8 by 3 feet at Castle Point. The distribution of the red till on the diabase ridge, and even beyond in New York, shows that the ice transferred material from lower to higher levels along much of the ridge.

The till of First and Second Watchung mountains was deposited chiefly by ice which moved nearly parallel to them, but which had a tendency to crowd over obliquely from the east side to the west. This direction of movement, together with the fact that the eastern slopes of the ridges, in places nearly to the summits, are made up of sandstone, or shale insured the existence of much red Newark débris in the drift of these ridges. With this material there is more or less basaltic débris, which locally makes up nearly the whole body of the drift. In many places at the extreme north the till consists largely of gneissic material.

The same rules govern the distribution of till here as elsewhere. The steep slopes and narrow crests of the ridges have little drift, but the gentler slopes are more generally covered. As a rule there are thick aggregations of till at the east bases of the ridges north of the Passaic, as if lodged where the ice crowded against the ridges from the east. Locally it is bunched in the manner characteristic of terminal moraines. This is the case, for example, southwest of Haledon and here and there west of that place. Drift is also thick (25 to 70 feet) on the lower part of the west slope of Second Watchung Mountain in the same region.

In the gap in First Watchung Mountain at Paterson a large part of the drift is stratified, though till is locally associated with the sand and gravel. South of the Passaic the upper part of the east slope and the crest of First Watchung Mountain are so thinly covered with drift that outcrops of rock are common, and for considerable areas almost continuous. Drift is more abundant on the west slope, and on both slopes increases in thickness to the south.

At many places for some distance south of the Passaic the crest of the Second Watchung Mountain is double. Where narrow, the crests have little drift, and thought its amount increases toward the south, rock outcrops continue to be common along the crests. The slopes of Second Watchung Mountain south of the Passaic are generally well covered with till, thicknesses of 50 feet being known. This is especially true of the west slope, where the topography is in places notably undulatory, as between Caldwell and Livingston. Two drumloidal aggregations of till occur on the west slope of Second Watchung Mountain, one the 265-foot hill a little south of Westville, and the other the 240-foot hill at Franklin. The trends of these hills are S. 15° W. and S. 25° to 30° W. respectively.

South of the Passaic, as north of it, the till of Second Watchung Mountain is predominantly of the basaltic type, though red or reddish till occurs at numerous points. The till of First Watchung Mountain has more material from the sedimentary beds of the Newark group.

The drift of Third Watchung Mountain (Long Hill–Riker Hill–Hook Mountain–Packanack Mountain) is characterized chiefly by its thickness and by the number of basalt bowlders on the surface. The summit of Packanack Mountain is nearly bare, though the slopes below are well covered, the till being chiefly of basalt. The south and east slopes of Hook Mountain are steeper than the north and west slopes, and have correspondingly less drift. The till of Riker Hill is similar in kind and disposition to that of Hook Mountain, and Long Hill lies outside the moraine.

The valley between First and Second Watchung mountains has a bed of drift sufficient to conceal the rock very generally. As this valley both north and south of the Passaic was a line of glacial drainage, some of its drift is stratified. The drift of the valley is much more stony than that of the shale areas east of the mountains, the greater proportion of the stones being of basalt.

The distance between Second Watchung Mountain and the range forming Third Watchung Mountain is greater than that between Second and First Watchung mountains, and the drift has the general character of drift derived chiefly from the Newark sediments, but associated with such material is a generous admixture of basaltic débris. The drift of this region is largely stratified, and much of it was deposited in the extinct Lake Passaic, which covered this area up to an altitude of nearly 400 feet.

Striæ.—As the rock is exposed at many places in the basalt and diabase ridges, and as it received striæ readily and retains them well, such scorings are abundant on all these ridges. On the Palisade Ridge they range in trend from S. 3° E. to about S. 45° E., with an average of about S. 30° to 35° E. The frequent excavations on this ridge have made the number of recorded striæ great.[1] On First Watchung Mountain the striæ range from S. 15° W. to S. 75° W., the average direction being about S. 40° W. On Second Watchung Mountain the recorded striæ are also numerous and range from S. 27° W. to S. 68° W. The recorded striæ on Third Watchung Mountain trend from S. 7° W. to S. 62° W.

The ground moraine of Staten Island.—Ground moraine covers most of Staten Island north of the terminal moraine. In composition it consists in general of a red, clayey, compact matrix, with a small proportion of stony matter in the southwestern part of the island, and a larger proportion in the northeastern part. In general the material of the drift of the western part of the island was derived chiefly from the Newark shales and sandstones lying west of the Palisade Ridge in New Jersey. Some of the till rests upon Cretaceous clay, and locally it is made up of material derived largely from that formation. This is especially true where the till is thin. In the western part of the island the constitution of the ground moraine is best seen at the numerous clay pits about Kreischerville and between Rossville and Fresh Kills. At some of them the till is very thin; at others it has a thickness of 15 feet. It is readily recognized by its red color, which is in sharp contrast with the color of the formations beneath. In the northeastern part of the island the exposures are chiefly along roads, railways, and quarries.

In the lower, western part of the island the average thickness of the till is probably not more than 10 feet; in the higher, eastern part it is twice or thrice this amount, with a known maximum of 84 feet. The bed rock appears at the surface at many places about Graniteville, and also between New Brighton and Tompkinsville.

Mixed drift.—In many places within this area the drift is not readily separable into stratified and unstratified. Good exposures would doubtless show its constitution to be one thing or the other, but in the absence of exposures there is much confusion. In many places, too, the boundary between the stratified and unstratified drift is very indefinite. The two kinds alternate in vertical section at many localities, and in such cases only the uppermost kind of drift can be mapped.

Stratified Drift Inside the Moraine.

General outline.—East of Passaic River stratified drift occupies more than half of the surface underlain by sandstone and shale. In general, it covers the lowlands rather than the highlands, but is not confined to any particular level. It commonly lies at lower levels along the lower courses of the streams, and at higher levels along the upper courses; yet to this general rule there are many exceptions, and the disposition of the stratified drift is so irregular as to make it evident that conditions other than those of normal drainage controlled its distribution. Not only this, but the stratified drift has at various points, peculiarities of arrangement. Much of it does not lie in valleys. There are plains of stratified drift of such configuration as to show that free drainage did not exist when they were developed. At several points east of First Watchung Mountain these plains simulate deltas. At few of these points is the delta form unequivocal, and nowhere is it so well developed as in some of the deltas in the basin of the ancient Lake Passaic west of Second Watchung Mountain. The evidence is not so conclusive but that there may be serious question concerning the delta origin of some of the deltoid plains, but that some of them are deltas admits of little doubt. At other places the stratified drift assumes the form of kames, some of which occur singly and some in groups. Considerable areas are marked by topography of a less pronounced kame type, without the development of pronounced kame hillocks. Kames are on the whole abundant, and not a few of them are conspicuous. Terraces of stratified drift which have kamelike slopes toward the valleys and in places kamelike tops occur along some of the valleys, especially between the basalt ridges in the central part of the area. Such terraces are known as *kame terraces*. Here and there the stratified drift is disposed in the form of narrow ridges known as *eskers*. A large area west of the Palisade Ridge is underlain by laminated clay similar to that of the Hudson and Connecticut river valleys. Brief mention will be made of these several types of stratified drift.

Plains of the stratified drift.—Much of the gravel and sand occupying the low land has the disposition which should have been assumed under normal conditions of drainage as the ice retreated. This phase of the drift does not call for special consideration. The plains of gravel and sand which seem not to have been deposited by freely flowing waters and which do not have the configuration normally developed by surface drainage are several. Such, for example, is the plain of gravel and sand south of Paramus (northeast of Paterson) which declines toward the south as might be expected if the material was deposited by running water; but the slopes of the plain to the east and west are in many places abrupt, and they still remain much as they were when the sand and gravel were deposited. They are not slopes which would have been developed in the deposition of gravel and sand by running water if the flow was unimpeded, and they are not slopes developed by subsequent erosion. At many points, as on the Paramus plain and in the vicinity of Delawanna and Lyons Farms, the surface of these plains of gravel and sand is marked by extraordinary sinks. This feature of topography is not unusual or unexpected at the head of a plain of gravel developed just outside the ice, but is hardly to be looked for at any considerable distance from the head. In the Paramus and Delawanna plains these features are almost as prevalent at a considerable distance from the heads of the plains as near them. Similar features are present south of Vanwinkle and Glen Rock.

Masses of stagnant ice, left behind as the ice front retreated, might well have been one of the causes of the irregularities in the disposition of the stratified drift. Small blocks of ice might have been separated and perhaps buried by the drift deposited by water after the retreat of the main ice front. The melting of the buried ice blocks then gave origin to the depressions. If stratified drift were deposited against but not completely around large masses of ice, the melting of the ice would leave the gravel and sand with steep and irregular slopes. However, even if such isolated masses of ice are credited with the fullest influence which it seems reasonable to ascribe to them, they still fail to explain some of the peculiarities of the disposition of the stratified drift of this region.

The deltoid plains of gravel and sand are widely distributed, not only east of Passaic River, but elsewhere at corresponding levels. The more striking deltoid bodies of gravel are some of those on the north side of the west branch of Elizabeth River, east of Union, in Union County, where the elevation of the delta fronts, if such they are, is about 100 feet; and at Athenia and Clifton, in Passaic County, where the elevation of the suspected delta front is about 120 feet. Other deposits of gravel which resemble deltas occur 3 miles west-northwest of Oradell, at an elevation of about 90 to 100 feet; at several localities in the vicinity of Westwood, at 70 to 80 feet; and at Englewood and Hackensack, at 40 to 50 feet. It is to be noted that these levels are discordant, though most of them are between 80 and 100 feet. A certain amount of discordance might be explained on the basis of surface deformation since deposition, but this can hardly account for the differences which exist. So far as the history of postglacial deformation has been worked out, the rise of the land relative to the sea has been greater to the north than to the south, and the heights of these plains do not increase progressively to the north. The meaning of these deposits will be referred to again.

About Franklin Lake, 5 or 6 miles northwest of Paterson, there is a delta belonging to a different class. It was deposited in a temporary lake formed between Second Watchung Mountain on the southwest and the ice on the northeast, at a stage in the retreat of the ice. The small lake basin was largely filled with gravel and sand, the lake itself representing the unfilled part of the basin.

Kames.—The kames of this area occur both singly and in groups, the groups being small or large. The groups of kames belong to two types which, at their extremes, are distinct. These are (1) the *kame moraine type* and (2) what may be called the *undulatory plain type*.

Many groups of the first type are associated with till areas of morainic topography, and are poorly differentiated from them. In structure, there are all gradations from the hillocks made up of distinctly stratified gravel and sand, through those showing imperfect or partial stratification, to hills which have the kame form but lack the kame composition and structure. Many kame groups of this type are in the form of elongate belts, and some are bordered on the south by plains of gravel and sand. They have the topography of terminal moraines, and their surfaces are in many places strewn with bowlders. They include the most conspicuous kames of the region. Among the better examples of kames of this sort are those 2 miles north of Cranford, about Livingston, at Caldwell, west of Haledon, northeast of Bloomfield, north of Franklin Lake, and 3 miles west-northwest of Oradell. Of these groups or belts, that north of Cranford has so great an extent as to merit special mention. It is in effect a recessional moraine, extending, with some interruption, from Waverly Park on the east to Springfield on the west. Although kames form the conspicuous part of the moraine, considerable till is associated with the stratified drift. Apart from the very conspicuous kames of this belt, such as those near New Orange, the highest of which rises 100 feet above its surroundings, the most notable feature consists of the depressions which occur in it. To the east the depressions reach sea level. To the west they are even deeper below their surroundings, though their bottoms are not so low in elevation. The great depression through which the west branch of Elizabeth River flows southwest of Union is the most notable, but the smaller depression to the south of it, known as the "Ship Hole," is perhaps more striking. The apparent deltas on the north side of the west branch of Elizabeth River, east of Connecticut Farms or Union, occur in connection with this belt. The delta fronts fall off to the depression through which this stream flows. Some other kame groups, notably that northwest of Oradell, are adjoined by deltoid bodies of ground on the south. The belt of kames, with some associated till, between Woodside and Bloomfield, is perhaps also an ill-defined terminal moraine. If the morainic patches of this belt are contemporaneous, the front of the ice had a northwest-southeast position.

The kame groups of the second type are less well defined. Normally, they are areas of undulatory topography where the individual hillocks may be regarded as small kames. With the hillocks there are depressions comparable in dimensions to the knolls. In form kames of this type may be likened to those of the first type, somewhat flattened out. They are usually of finer material or, at least, they are likely to be essentially free from bowlders. They are, on the whole, rather more homogeneous in composition and more evidently made up of stratified material. By diminution of relief they may grade off toward pitted plains, in which there are all gradations from the plains with few sinks, through the plains that have many sinks with gravel ridges and knolls between, to those where the depressed areas predominate and the gravel knolls and ridges are isolated. The kame areas of this type may represent the deposition of sand and gravel among and about ice blocks. They differ from pitted plains primarily in the greater proportion of surface covered by depressions, and in the less constant level of the intervening knolls and ridges. Among the kame areas of this type may be mentioned those in the Rockaway basin northeast of Troy Meadows and south of Great Piece Meadows; some parts of the Waverly Park–Springfield kame belt, especially west of Waverly Park; and the area southeast of Ridgewood in the valley of Hohokus Creek. Some parts of the Paramus plain also approach this type.

Isolated kames, or kames in small groups, occur at Cherry Hill (north of Hackensack), at various point about the Oranges, at Garfield, in Paterson, and at numerous other points. In Paterson some of the kames that were most prominent have been obliterated by the grading of streets.

Kame terraces.—The most pronounced kame terraces occur in the valley between First and Second Watchung mountains, especially above Cedar Grove. The gravel of these terraces was probably deposited while considerable remnants of ice still lay in the bottom of the valley, but after the ridges themselves were free from ice. The drainage passed down between the ice and Second Watchung Mountain to the west, leaving its burden of gravel and sand. Stratified drift of similar type, though much less well developed, occurs in that part of the same valley drained by Rahway River.

Eskers.—Within this quadrangle there are several places where the stratified drift is aggregated into ridges having the form of eskers. Eskers are much less common than kames, and most of them are small. The exact number can not be stated other than arbitrarily, for there is some difference of opinion as to whether certain disconnected ridges should be regarded as separate eskers or as parts of one; moreover, some ridges may be considered either elongate kames or eskers. The largest esker is in the basin of the extinct Lake Passaic between Florham Park and Hanover (north of Madison). It is nearly 4 miles in length but not altogether continuous. Another esker nearly parallel with this one, 2 miles to the east, runs through Cheap-

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[1] See Rept State Geologist New Jersey, 1893; Glacial geology of New Jersey, 1903, pp. 560, 566, 571.

side and near West Livingston. Some short eskers of the same type, though less well developed, occur between First and Second Watchung mountains north of Milburn, and others between the pronounced kames near Springfield and those at New Orange. Another lies on the right bank of the valley of Saddle River between Rochelle Park and Lodi. It has a length of somewhat more than a mile, and a height of several feet (rarely more than 10 or 15). A very short esker (or esker-like kame) occurs 3 or 4 miles farther northwest.

Eskers are ridges of stratified gravel and sand, believed to have been deposited in the channels of subglacial streams. The streams are supposed to have built up their beds and to have flowed on the top of the deposits in a sort of tunnel, the sides and top of which were ice. When the ice melted, the filling of the old channel constituted a ridge. From their mode of formation it is clear that only eskers made during the maximum stage of the ice and during its decadence would be likely to be preserved. Those made during the advance would be likely to be destroyed. It is probable that relatively few subglacial streams were so well organized and so closely confined by the ice as to have developed eskers, and of those once developed perhaps but few remain.

In general the eskers occupy lowlands or valleys. A favorite position may be said to be the lower slope of a valley. In places they descend from higher to lower levels, lying obliquely on the slope.

Laminated clay.—Laminated clay underlies the Newark Meadows and some of their surroundings. It is best shown west of Hackensack River, south of Hackensack, where it is extensively used for the manufacture of brick. It is also exposed north of Hackensack at New Milford, and even farther north. South of Hackensack the clays are known to occur wherever borings have revealed the material beneath the meadows. Similar clay, probably of the same origin and probably continuous laterally with that of the Hackensack Meadows, has been seen below Passaic Bridge in the valley of the Passaic, and has been reported, though not seen by the writer, at other points in the same valley. These clays have sometimes been referred to the "Champlain," a term which means the closing phase of the last glacial stage. In the vicinity of Hackensack the surface of the clays is now but little above sea level. To the north it is a little higher, and at the State boundary its surface is about 30 feet above sea level.

The composition and structure of the clay show that it was deposited in standing water. At Hackensack, as well as at several other points, it overlies till of the last glacial stage. The clay contains a few striated stones or bowlders, suggesting that floating ice sometimes found its way into the body of water where the clay was being deposited.

Numerous borings about Hackensack and Newark and at some other points give information concerning the depth of the clay. At Merhof's lower brickyard, south of Hackensack, the clay is about 85 feet thick. As several feet of sand overlies the clay, the surface of the rock at this point is about 100 feet below sea level. Other borings about Little Ferry show a similar thickness. The borings about Newark which are relevant in this connection are mostly in the meadows (marsh) in the southern and eastern parts of the city, or in regions which were meadow before they were reclaimed. In most of these borings the drift, much of which is laminated clay, has a thickness of more than 100 feet, and in some it is more than 200 feet thick. One boring, indeed, starting from the level of tide marsh, did not reach rock at a depth of 250 feet. In many places it is not known how much of the drift is laminated clay, but thicknesses of clay exceeding those at Hackensack are reported.

These data are sufficient to show that standing water occupied a large tract in northeastern New Jersey after the retreat of the ice, and that in this standing water, up to elevations somewhat above sea level, laminated calcareous clays were deposited. The surface of the water may have been considerably above the surface of the clay, but the clay itself does not indicate how much.

Stratified drift in the upper Passaic basin.—There is a large amount of stratified drift in the upper Passaic basin, much of which is connected in origin with the lake which formerly occupied this basin. The stratified drift deposited about the shores of the extinct Lake Passaic, largely in the form of deltas, has its most extensive development inside the moraine north and northwest of Morristown, east of Boonton, about Caldwell, and above Preakness, though distinct deltas are found at some other points, as northeast of Montville. The delta or subaqueous outwash plain bordering the outer face of the moraine between Chatham and Morristown has already been referred to. Some of the deltas north of the moraine are remarkably well developed. The largest is that at Upper Preakness, northwest of Paterson. When the delta was built, the level of the lake was about 340 feet above present sea level. Another distinct though small delta lies just north of Montville (fig. 14). The old shore of the lake at this point when this delta was made is nearly 400 feet above the present sea level. Southwest of Horse Hill (north of Morristown) there is a well-defined spit, which was built into the lake, and similar spits occur at a few other points. At numerous other places there are greater or less deposits of gravel about the old shore lines, even where deltas and other distinct shore features are wanting.

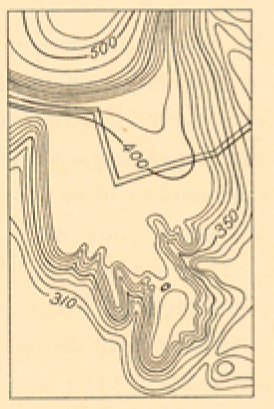

Fig. 14.—Contour sketch of the delta formed in Lake Passaic, near Montville.

Many of the deltas were built at the edge of the ice by heavily laden glacial streams. Under these conditions the supply of material was great and the growth of the deltas rapid, resulting in the production of very considerable plains in a comparatively brief time. At least one delta was built out into water 70 to 80 feet deep, and many into depths of 40 to 50 feet. The northern margins of the Montville and Upper Preakness deltas have the irregular form and the hummocky surfaces characteristic of gravel which was built against the ice and which has since slipped and fallen down as the ice melted, though retaining in part the irregularities of the ice mold in which it was cast. Several of the other delta plains pass into kame areas which are believed to have been formed beneath and at the irregular edge of the ice, contemporaneously with the deltas. The surface of many of these kame belts is strewn with bowlders, in marked contrast with the surface of the associated plain. In a number of places, but especially in the Caldwell area, kames of an older generation have been partly buried by the advancing front of the growing deltas.

The only delta in which the structure is well exposed is that north of Montville, where the railroad has cut across the end of one of the lobes. Here the outward-dipping fore-set beds are clearly shown, underlain by horizontal deposits of fine sand and clay. At the bottom of the exposure, near one end, there is an irregularly stratified body of coarse gravel and sand, which may represent the upper part of a buried kame.

In addition to the highest shore line indicated by the tops of all the glacial deltas except the Upper Preakness plain, two indistinct lower levels can be made out in several places. One of these is about 20 feet and the other between 65 and 75 feet below the highest.

Besides these glacial deltas there are a few small spits connected with what appear to be wave-cut terraces, and a few kames whose summits seem to have been somewhat truncated by the waves; but the wave-built forms are not conspicuous or decisive. The constructional shore features of the extinct Lake Passaic are much better developed than those fashioned by the destructive action of the waves.

Stratified drift in the Highlands.—There is some stratified drift in most of the valleys of the Highlands which lie within this quadrangle. In many places it has no distinctive form and no peculiarities which call for special mention. Some of it was deposited by drainage which flowed freely through the valleys after the ice front had retreated. Locally ice was left in the valleys after it had melted from the hills, and the gravel and sand deposited about it have now the irregular form of deposits made under such conditions. Northwest of Denville, in the valley of the Rockaway, the gravel has the form of a pitted plain interrupted by kames.

Stratified Drift Outside of the Moraine.

Reference has already been made to the stratified drift lying immediately outside of the moraine. In addition to the drift in this position, there are scattered bowlders about the borders of Great Swamp, south of Morristown, which are believed to have been carried to their present position by ice blocks which floated out into Lake Passaic. They are found up to the level of the old Passaic shore line. There is also some drift, mostly stratified, between Long Hill and Second Watchung Mountain. Between First and Second Watchung mountains, quite outside of the moraine, there is some till that was probably deposited by the ice during a temporary advance beyond the moraine.

Southwest of the deltas adjacent to the moraine in the upper Passaic basin, and extending several miles beyond the moraine, there is a great series of kames about the borders of Great Swamp. The exact mode of origin of these kames is uncertain. It seems very possible that the ice at some time pushed beyond the moraine into the extramorainic part of the basin, and that kames were then developed. They are all low and composed of material which is coarser near the moraine and finer at greater distances from it. Smaller kames of the same sort occur between Long Hill and Second Watchung Mountain. Toward the southwest the gravel and sand of the kames grade into silt and clay, and beyond the kames Great Swamp is underlain by laminated clay. Similarly clay underlies the kame tracts near the moraine. Laminated clay also occurs southwest of Morristown outside of Great Swamp. These laminated clays were deposited in Lake Passaic, the material being furnished by the glacial waters. The clay of the old lake basin is highly calcareous, and much of it contains abundant concretions—the "clay dogs" of the clay pits. The depth of the clay and other loose material above the rock under Great Swamp is considerable, and is an index of the depth to which the surface had been lowered before the ice came in. It has already been pointed out that the gap across First and Second Watchung mountains at Short Hills would be deep if the drift were removed. Unfortunately borings have never shown how deep, though they have shown that the bottom of the drift is locally lower than Passaic River above the falls at Little Falls. This in itself is proof that in preglacial time some outlet lower than that at Little Falls was available for the drainage of this region.

There are meager deposits of gravel at a number of points about the hills south of Morristown, about Long Hill, and on the slope of Second Watchung Mountain. These gravels all occur at about the same level and were accumulated along the shores of Lake Passaic. Against the Highlands southwest of Morristown the gravel is composed of gneissic material; about the basalt ridges immediately south of Morristown, on Long Hill, and on Second Watchung Mountain the gravel is composed of basalt. The summits of Long Hill were islands in the lake (see surficial geology map), and the gravel is best exposed on this ridge.

In the area southeast of First Watchung Mountain and south of the moraine there is a considerable body of stratified drift in the form of an outwash plain well developed about Plainfield, Dunellen, South Plainfield, and Metuchen. The drainage from the ice passed down Green Brook and Bound Brook, and carried the gravel and sand off to the southwest, where it entered the Raritan Valley. The stratified drift seems not to have been spread south of the valley of Bound Brook for any considerable distance. At a few points south of this brook there are, however, small accumulations of very fine gravel and sand, too meager to be represented on the map, which are certainly of glacial derivation. They occur in such situations as to make it impossible to suppose that the drainage followed the same course when they were deposited as it does now. Its present position shows that the gravel must have been carried not only down the slope from the moraine to Bound Brook, but up the slope south of Bound Brook. This is one of the many minor lines of evidence which have led to the conjecture that the region may have been temporarily submerged either at the closing stages of the ice invasion or since. The gravels referred to are in a position whither they might have been carried by waves, though not by streams. Furthermore, although the amount of dune sand south of Bound Brook is relatively small, there is a little of it, and evidence exists that there has been a great deal, for the cobblestones which strew the surface are very generally worn and faceted by wind-driven sand.

The area lying between Metuchen and New Brunswick on the southeast and Bound Brook on the north has very little surface material other than that which has arisen from the decay of the underlying shale.

Glacial Changes in Topography.

The changes in topography effected by the ice resulted partly from glacial erosion and partly from the deposition of the drift. It would seem, on the whole, that the changes resulting from deposition were of more consequence than those resulting from erosion, for though the ice deposited only the material which it had previously eroded, some of the drift in this area was derived from areas farther north. This is true both of the material which the ice itself deposited, and of that which the water deposited while the ice was retreating.

Changes from erosion.—The extent of glacial erosion can best be judged by the amount of drift. The average depth of the drift in that part of the Newark plain where till lies at the surface is probably not more than 30 feet. The average depth of the drift where the stratified type prevails is perhaps twice or possibly thrice as great. After making allowance for that part of the drift which was brought in from the north, these figures warrant the inference that although the modification of the topography by erosion was considerable, it was not such as to alter it profoundly. North of Newark the relations of divides and valleys were not greatly changed. South of that point and east of First Watchung Mountain, where the relief was slight, erosion and deposition together, but chiefly deposition, changed the preglacial topography materially. The valleys which were parallel to the ice movement were probably deepened by glacial erosion before drift was deposited in them. Glacial erosion also smoothed down the roughnesses of surface, both in the sandstone areas and on the basalt ridges. Being of resistant rock, the basalt ridges were probably not lowered much, whereas the sandstone ridges, which were less resistant and covered by a greater depth of ice, were probably reduced to a greater extent. The aggregate effect of ice erosion on topography was probably to smooth down the rugosities of the surface, without profoundly altering its relief. On the whole, the relief was probably increased, for the valleys were probably deepened more than the hills were lowered.

Changes from deposition.—From what has been said concerning the depth of the stratified drift, it is clear that the topography of the rock floor in the Triassic area is very different from that of the present surface. If the drift were removed, an extensive and somewhat deep bay would extend northward from Newark Bay nearly or quite to the State line, by way of the Hackensack Valley. Another arm of the bay would extend northward at the west base of the Palisade Ridge to Highwood, a few miles east of Hackensack, and would, perhaps, connect northward with the more westerly arm at Neuvy, north of the Passaic quadrangle. The bay would, at the maximum, be more than 200 feet deep. Still another arm of the bay would extend up the valley of the Passaic as far as Dundee Dam. The depth of the water in this arm of the bay would be at least 40 to 60 feet. Still another arm of the bay would extend westward from some point south of Newark to Springfield, for at the latter place the surface of the rock is known to be about 20 feet below sea level at one point, and there is no reason to suppose that this is the lowest point.

It is not now possible to say how far these deep, valley-like bays were excavated by preglacial erosion (preceding the last glacial stage) and how far they were excavated by the ice itself. The amount of glacial drift to the south does not, however, warrant the supposition that glacial erosion was sufficient to account for them. The presumption is therefore in favor of their excavation by stream erosion before the last advance of the ice. This is the more probable because the preglacial valley at Springfield, about 10 miles from Newark Bay and below the present sea level, is in a position where glacial erosion is not likely to have deepened it to any considerable extent.

If these deep valleys were preglacial or largely so, the land when they were excavated must have stood much higher than now. The valleys tributary to the main valleys must have been correspondingly deep, and it is probable that the rock surface in their lower courses was also below sea level. It is therefore probable that a very considerable part of the surface (probably not less than one-fourth) of the Newark plain between the Palisade Ridge on the east and First Watchung Mountain, as far north as Paterson on the west, would be submerged if the drift were removed.

From the foregoing facts it is clear that the surface has been greatly evened up by the deposition of the drift, and that, if the drift were removed, the relief would be much greater than now. In many places the filling has gone so far as to completely obliterate even great valleys. Thus the position of the eastward continuation of the deep preglacial valley which passed through Springfield is not definitely known, though it doubtless lay somewhere between Elizabeth and Newark.

Apart from the great change in the surface brought about by the filling of the valleys, the deposition of the drift has not greatly modified the larger topographic features of the region. On the ridges and higher lands the drift is too thin to affect, in any very important way, these larger features. The most considerable elevations for which the drift is responsible are the moraine ridges between Chatham and Morristown, and between Fords and Scotch Plains. The former ridge, standing 100 to 200 feet above its surroundings, divides the basin west of Second Watchung Mountain into two parts. Elsewhere there are minor ridges of drift of consequence, and many of the kame groups already mentioned are conspicuous topographic features of local extent.

The minor topographic features of the drift are more numerous. Many of the kames are notable knolls, and some of the recessional moraines (kame belts) are also conspicuous. Many of the notable flats and plains, such as those about Franklin Lake, Paramus, and Westwood, are due to the disposition of the stratified drift, as are the striking depressions, such as those near Convent station, those on the Delawanna plain, and those between Union and Waverly Park.

Glacial Changes in Drainage.

Changes in the upper Passaic basin.—The changes in drainage effected by glaciation in this area were considerable. Some of them were brought about when the ice was here, and some appeared after its dissolution. The former were due to the ice itself, and the latter to the peculiar deposition of the drift.

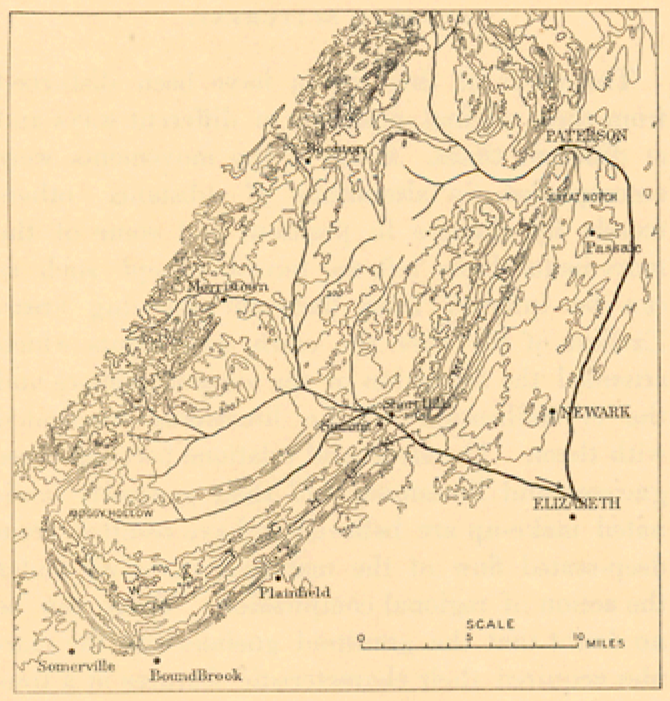

FIG. 15.—Diagram showing the supposed course of the drainage in the Passaic basin previous to the last glacial invasion.

There is a thick bed of drift in the gap through First and Second Watchung mountains at Milburn and Short Hills. Were this removed, the bottom of the gap would be lower than the gap across Second Watchung Mountain at Little Falls, where the Passaic now flows. It is concluded that all the drainage of that part of the Passaic basin which lies southwest of the moraine, and probably of a considerable part which lies between the moraine and Little Falls, flowed to the sea through the Short Hills outlet before the ice filled it with drift. It is altogether possible that the Rockaway flowed southward from Pine Brook and joined the waters which flowed through the Short Hills pass. The size of the gorge through the mountain at Little Falls makes it probable that the Pompton followed its present course before the last glacial invasion. Fig. 15 indicates some such system of drainage as is believed to have existed before the disturbing influence of the ice was felt.

Lake Passaic.—When the ice in its readvance reached and closed the gap at Little Falls and Paterson, the drainage which would otherwise have escaped to the sea by this route accumulated in front of the ice as a lake. Any lake which formed here at this time must have been small and shallow (see fig. 16), for it would soon have overflowed the low divide separating the drainage basin which had its outlet at Little Falls from that which had its outlet through the Short Hills gap. As the ice advanced, it encroached upon this early lake, displacing its water, diminishing its size, and finally obliterating it altogether (fig. 17).

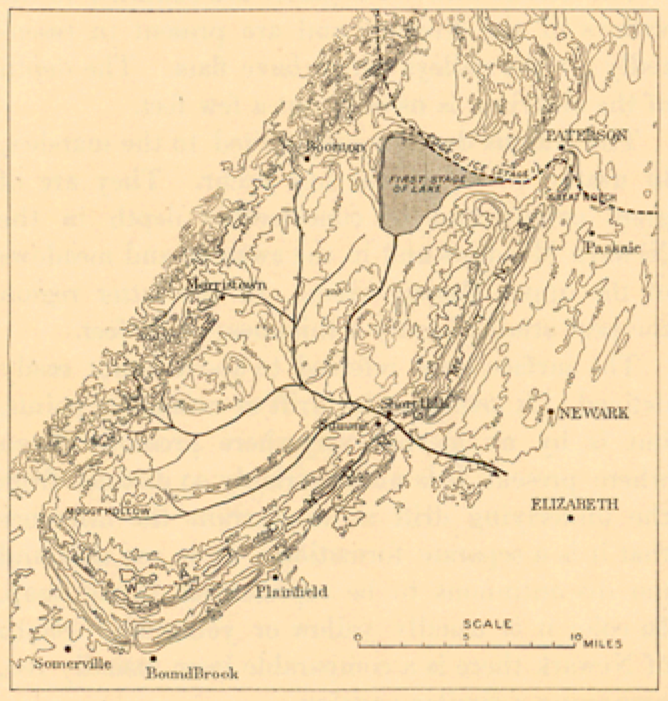

FIG. 16.—An early stage of the glacier during its last invasion, and the initial stage of Lake Passaic.

The edge of the ice blocked the Paterson pass across the basalt ridges, and a small lake developed in the basin to the south, which is represented as having an outlet by way of the Short Hills gap across First and Second Watchung mountains.

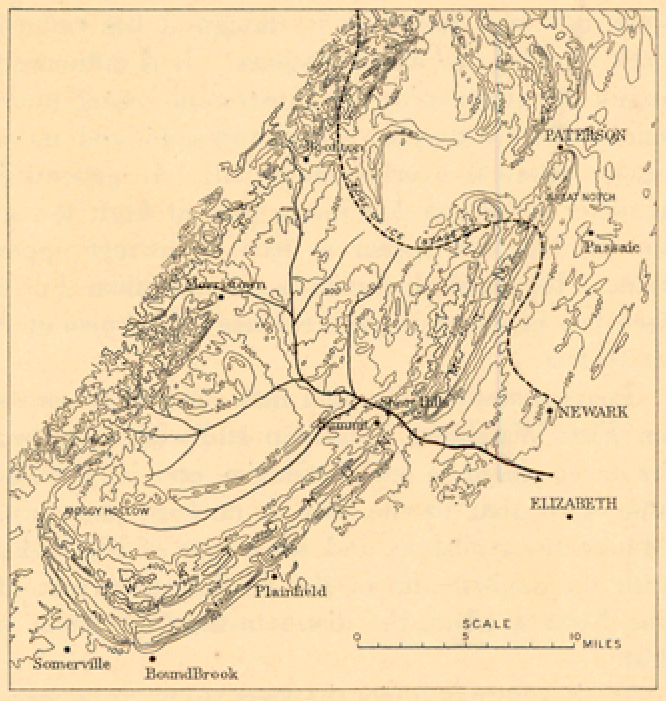

FIG. 17.—A later stage of the glacier.

The advance of the ice obliterated the lake shown in fig. 16.

No lake could have formed in the drainage area of the river system which flowed through the Short Hills gap (unless in the upper courses of such tributaries as were obstructed at their lower ends) until after the ice reached that gap and filled it. Then, and not until then, could a lake have existed in the basin southwest of the moraine. Once formed, the level of the lake rose until it found an outlet. This was at Moggy Hollow, near Liberty Corner, about 12 miles southwest of Morristown, beyond the boundary of this quadrangle. (See fig. 18.) As the ice made little advance after occupying the passes in Second Watchung Mountain, near Short Hills, neither the area nor the level of the lake was subject to much variation, and the edge of the ice stood where the moraine is now. During this time distinct shore features were developed about the lake. They are pronounced along the moraine between Summit and Morristown, and feeble, though distinct, at other points along Second Watchung Mountain and about the summits of Long Hill, which stood as islands above the lake.

FIG. 18.—Stage of maximum advance of the glacier.

The edge of the ice was at the position of the terminal moraine, and the glacier filled the Short Hills gap. The upper basin of Lake Passaic was shut in and occupied by a lake with its outlet to the west at Moggy Hollow.

As the ice melted back from the moraine, the preglacial outlet of the upper Passaic basin via Short Hills was closed by the drift which the ice had deposited, and the Moggy Hollow pass remained the outlet of the lake. The lake therefore increased in area as the ice withdrew, by filling that part of the basin from which the glacier retreated. During this period the lake was more or less completely divided into two parts by the moraine, which, for part of its course across the basin (southeast of Morristown), rises above the highest level that the water reached. (See fig. 19.) This moraine barrier probably prevented icebergs from reaching the extra-morainic part of the basin, limiting the time in which berg deposits could have been made there to the period of ice advance.

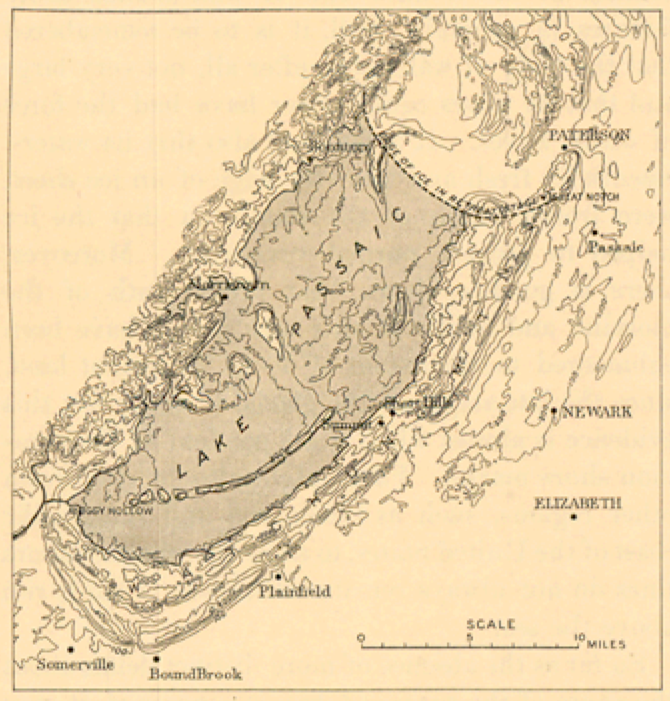

FIG. 19.—Expanded stage of Lake Passaic.

The retreat of the ice had left the Short Hills gap filled with drift.

It is easy to conceive of a very simple subsequent history for the lake. Its northern border might have followed the retreating southern border of the ice until the latter had passed Great Notch. The lake should then have discharged through this outlet, its level falling to 303 feet, the elevation of Great Notch, and the outflow via Moggy Hollow ceasing. Though there is no positive evidence of outflow through Great Notch, it must have taken place, unless an outlet under the ice was opened along the course of the present Passaic River. A little later, as the ice retreated farther, the Little Falls and Paterson gaps in Second and First Watchung mountains were opened, and the lake must then have discharged its waters through the Passaic. Once this outlet was opened, the lake would soon have been mostly drained.

The actual history of the lake seems to have been a little less simple. At a number of places more or less well defined shore features are found at altitudes 65 to 75 feet lower than the highest line of the lake. At a time still later than that at which these features were formed, the waters of the lake seem to have risen again to a level corresponding with the Moggy Hollow outlet. These facts have been interpreted to mean that the level of the lake fluctuated to some considerable extent during its history.[1] It is probable that these changes of level were connected with oscillations of the edge of the ice, which alternately opened and shut some outlets, possibly Great Notch or a subglacial outlet along the course of the present Passaic. A mile northwest of Little Falls till overlies lacustrine clay, showing that the ice subsequently advanced over an area from which it had retreated and over which the lake had spread. It is possible that the outlet via Little Falls was opened and closed again by the oscillation of the ice, though of this there is no positive evidence.

FIG. 20.—Maximum stage of Lake Passaic.

All outlets except that at Moggy Hollow were either blocked by ice or filled with drift.

Whatever were the effects of the oscillation of its edge near Little Falls, the ice finally melted back beyond the present course of the Passaic, and when this happened, the intramorainic part of the lake was drained to the level of the outlet at Little Falls—about 185 feet. If drift overlay the rock in the valley at this point, the outlet was a little higher than 185 feet at the outset, but the great volume of the outflow must shortly have swept away whatever drift there was in the valley at this point. The drainage of the intramorainic part of the lake must have been rapid, for on none of the many hills within the basin, rising to heights of 200 to 300 feet, are there shore lines, though many of these hills are made up of loose sand and gravel, in which terraces could have been easily and quickly cut.

The remaining stages in the history of the draining of the basin of Lake Passaic belong not to the time when the ice was in the basin but to the time after it had withdrawn. To make the story complete, however, they may be outlined here. When the intramorainic part of the lake was in large part drained by the opening of the Little Falls outlet, shallow bodies of water occupied the lowest lands along the Passaic between Little Falls and the moraine (fig. 21). When the outlet was at 185 feet, the water over Great Piece Meadows and Hatfield Swamp was 15 to 20 feet deep. As the outlet was lowered this shallow body of water was drawn down. Inasmuch as the outlet is over resistant

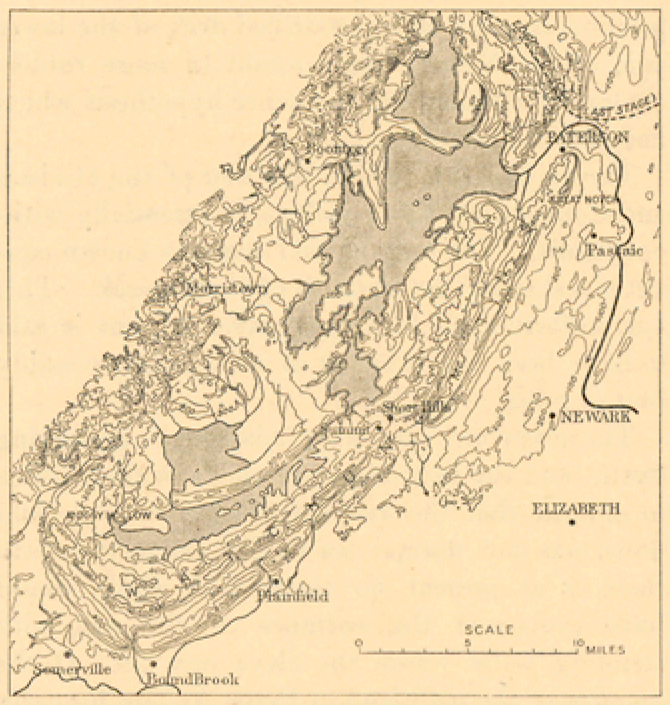

FIG. 21.—Late stage of the lake, when the retreat of the ice had freed the Little Falls-Paterson outlet.

Shallow bodies of water still occupied the lower portions of the basin.

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[1] Rept. State Geologist New Jersey, 1893.

rock, it was probably lowered slowly, and the shallow lake may have endured for a considerable time. A small lake more or less independent of that which covered Great Piece Meadows remained over the low belt between Second Watchung Mountain and Long Hill and southwest of the moraine along the courses of the present Passaic River and Black Brook. At the outset its level was at about 230 feet, where it was held by the moraine dam at Stanley, west of Summit. The greatest depth of this lake, which has been called Dead Lake, was not much more than 20 feet. The outflow soon cut down the dam, lowering the lake and finally draining it altogether.

Changes in the lower Passaic basin.—The changes in drainage in the lower part of the Passaic basin were not less considerable than those in the upper part. After escaping from Second and First Watchung mountains, the lower course of the preglacial stream (fig. 15) was eastward to the sea, probably somewhere south of Newark; but so completely is its valley effaced that it can not be accurately located. To it all the minor streams of the southern part of Essex County and of most of Union County were tributary. Their valleys were largely effaced by the drift, and the drainage of the area east of First Watchung Mountain and south of Newark, within the terminal moraine, probably has little resemblance to that of preglacial time. The other changes in drainage were probably inconsiderable.

Lakes.—There are relatively few lakes in this area, and most of them owe their existence to the obstruction of preglacial valleys by drift. Franklin Lake occupies a depression in the drift itself. Even this lake, however, lies in the course of a preglacial valley.

SUBMERGENCE OF THE LOWER PART OF THE NEWARK PLAIN SINCE THE LAST GLACIAL STAGE.

Taken all in all, the phenomena of the lower part of the Newark plain of New Jersey seem to point to the existence of standing water over the area after the ice departed, up to levels now more than 100 feet above the sea. Conclusive evidence of submergence, though not to this extent, is found in the laminated clays of the Newark Meadows and their surroundings. Inference as to the height of the water relative to the land is based on the deltas already referred to. A little further evidence of submergence, though of rather uncertain import, is found in the character of the surface of the drift about Rahway and Elizabeth. The absence of a distinct upper limit to the phenomena of this region which suggest submergence, serves to throw doubt on their validity. If the water stood 100 feet or so higher than now, relative to the land, when the ice withdrew, this stand may have been temporary. Its level may have become notably less before the ice had receded to the northern border of the State. If there were such a body of water, and if, in addition, considerable masses of ice were left behind in the shallow water as the edge of the main body of ice retreated, the disposition of some of the stratified drift of the lower part of the Newark plain would be more readily accounted for than on any other hypothesis which has been suggested.

The clay of this region, like that of the Hudson and Connecticut River valleys, is essentially without fossils. The only animal remains known consist of a skeleton found south of Hackensack. This has, unfortunately, not been preserved, but is said to have been the skeleton of a carnivore, possibly that of a fox.

The clays are admirably adapted to preserving fossils, and the lack of marine shells in them seems to indicate that the water in which they were laid down was not normal sea water; yet to the south there is at present no obstruction which would have prevented the entrance of the sea, with standing water where the clays now lie. If the moraine of the mainland at Perth Amboy formerly extended with less interruption than now to Staten Island, it would have helped to exclude the sea from Hackensack Bay. The topography of the west end of Staten Island and of the mainland opposite is not inconsistent with the hypothesis that the moraine once extended across Arthur Kill at a level about 25 feet above the present sea level. If a similar moraine dam existed between Staten Island and Long Island, it would have further helped to exclude the sea. Kill van Kull is not so wide nor so deep as to make it unreasonable to suppose that it is of postglacial development, and perhaps the same may be said of The Narrows and East River.

In view of the limitations which seem to be imposed on the height of possible moraine dams south of the Hackensack Meadows, it seems that the water which stood over the Hackensack region in late glacial time was probably not a lake completely shut off from the sea. Over any dams which may have existed the water from the north, constantly fed by the melting ice, must have found an outlet. Such drift dams might account for standing water where the clays are now, but they could hardly have lasted long enough to allow the deposition of such a thickness of clay as exists. Furthermore, a body of water held in by such dams would not account for the doubtful deltas at higher levels. It therefore seems that the water over the area was connected with the sea, and that its presence was due primarily to the fact that the land was then lower than now relative to sea level. If the water which stood over the Hackensack Meadows and their surroundings had only a shallow and narrow connection with the sea, as seems probable, the heavy discharge from the melting ice to the north would have made the passageway between this nearly inclosed body of water and the sea an outlet, rather than an inlet, and so the bay may have been kept fresh, or its salinity so much below the normal that marine life did not flourish in it. It can hardly be supposed that its temperature was so low as to prevent the entrance of sea animals, for marine life of certain types abounds about the coast of Greenland at the present time, even close to the edge of the ice.

It must be admitted, however, that the evidence of submergence up to the level of the deltas is not so convincing as could be wished, owing to the absence of beach lines and of well-defined shore features in general. Still, it is to be remembered that the body of water was, after all, not very large and that its waves could never have had the force of ocean waves. It is believed also that its waters, essentially fresh and near the edge of an ice sheet, were frozen much of the time, and that the ice helped to prevent normal wave work. Moreover, there is good evidence that areas south of the moraine and south of this quadrangle have been submerged to the extent of 40 to 50 feet, at least, since the late stages of the glacial history; yet this evidence is almost wholly independent of the common shore marks. Facts might also be cited from other regions, such as Greenland and the Pacific coast of the United States, to show that distinct shore lines do not always remain when coastal lands rise above the sea.

So far as the absence of more distinct deltas about the shore of the supposed bay is concerned, it may be said that no streams of consequence entered it from the east, south, or west. Almost all the water which discharged into the bay came from the north, and if the edge of the ice was continually shifting its position, deltas more distinct than those now found might have failed of development.

NONGLACIAL DEPOSITS CONTEMPORANEOUS WITH THE DRIFT.

Two formations which occupy small areas in the southwestern part of the quadrangle consist of nonglacial deposits approximately contemporaneous with the drift. These are (1) the older alluvial deposits along Raritan River and Ambrose Brook, and (2) the Cape May formation which occurs on the southern border of the quadrangle in New Jersey.

OLDER ALLUVIUM.

Most of the river drift along the Raritan was probably contemporaneous with the last glacial stage, and some of its materials are from the glacial formations. Some remnants of it, on the other hand, antedate the last glacial stage. The deposits similarly mapped in the valley of Ambrose Brook are of local origin. If the depression at the close of glaciation referred to above, actually occurred, these deposits may have dated from the time of the depression. They betoken sluggish drainage.

CAPE MAY FORMATION.

The Cape May formation is very meagerly developed in this quadrangle. It is a coating of gravel and sand, so thin that it but imperfectly conceals the Cretaceous rocks beneath. So far as this area is concerned, the formation might almost be passed without mention, but elsewhere it has a greater thickness. These materials were deposited chiefly since the retreat of the ice.

POSTGLACIAL CHANGES.

DEPOSITS.

Some reference to postglacial deposits has already been made in connection with the discussion of stratified drift. Aside from the laminated clays which belong to the closing stages of the glacial history, there are postglacial deposits of three classes—eolian sand, alluvium, and humus. To these should perhaps be added the surface loam which is present in some areas and which is of undetermined origin.

The eolian sands are of importance at only a few points, notably east of the head of Newark Bay, about West Bergen, and at a few points about Hackensack. Other minor accumulation are found at several points along the streams, and wind-blown dust, not always differentiated, is of wide distribution.

The recent alluvial deposits are confined to the valleys of the streams, and are present in essentially all the valleys which have flats. The depth of the alluvium is usually but a few feet.

The humus deposits are limited to the marshes, in nearly all of which they occur. They are of great extent, and of considerable depth in the Newark Meadows and in the swamps and meadows of the upper Passaic basin. In the latter region the peat attains locally a thickness of 27 feet.

The surface loam referred to above is not easily defined. It overlies the drift at numerous points, but is by no means everywhere present. Even where present, it is not invariably so distinct from the underlying drift as to warrant the inference that it is a separate formation. It is too thin and too discontinuous to be represented on the map. In color it is usually yellow or yellowish. South of Newark there is a comparable loam, usually red, occupying a similar position.

In New Jersey the loam has its best development south of the latitude of Passaic and west of lower Passaic River. It is particularly well developed about Newark, Avondale, and Nutley, where it may be seen in numerous exposures, though by no means in all. It is most conspicuous where the underlying till is red. It covers indiscriminately till of the ground moraine and terminal moraine, and stratified drift of all sorts. In places, where till is absent, it covers the rock. Striated stones have not been found in it, though it has yielded both rounded and angular stones. It is influenced in its constitution by its substratum, being more sandy where it overlies gravel and sand, and more clayey where it overlies clayey till. In general it is better defined at low levels than at high levels, but it does not appear to have a distinct upper limit. Its usual thickness is no more than 2 or 3 feet, but here and there it reaches a thickness of 8 or 10 feet.

Loam somewhat like that here referred to occurs on First Watchung Mountain and west of it, but its development is less distinctive and its correlation with that to the east is at best uncertain. Where the sandstone and shale type of till grades into the gneissic till, in the northwestern part of the Newark plain, the distinctness of the loam is lost.

Within certain limits the loam seems to be independent of altitude. East of Great Notch it has an altitude of more than 200 feet. Surface loam on First Watchung Mountain, which may not be the equivalent of that at lower levels, is found at still greater heights. In general it is thicker on gentle slopes than on those that are steep and is absent on narrow summits, though it has a tendency to accumulate in depressions on summits, as well as on slopes.

Indistinct as the loam is at any point, the observer can not examine its numerous occurrences throughout the length and breadth of the area without raising a question, and a very persistent one, whether it is not really, as in many places it seems to be, thoroughly distinct in origin from the drift. It is not possible, however, to affirm that its origin was distinct from that of the drift, or that all of it was contemporaneous or had the same origin. It was formerly thought to represent dust accumulated on the ice by the wind and let down on the drift when the ice melted; but the similarity of the loam to that on the surface south of the area of glaciation raises the question of their community of origin, and the hypothesis just mentioned is not applicable to the loam lying outside the drift-covered area. Any of the processes by which loam may originate may have been operative here.

EROSION.

Postglacial erosion has been, on the whole, slight, but notably more at some points than at others. Its great variation is the result of the inequality of the filling which the valleys suffered by the deposition of drift. The erosion has been chiefly in drift, but below the falls at Little Falls the channel of Passaic River may have been lowered as much as 40 feet in basalt. Midway between Little Falls and Paterson, where the river makes a sharp turn from a southeast to a northeast course, it passes between a great kame on the west and the basalt of First Watchung Mountain on the east. The kame formerly extended east of its present position toward the mountain, and, though it never completely filled the valley at this point, it probably did fill its bottom to some considerable height above the present channel. The amount of postglacial cutting here is not less than 50 feet and may be as much as 90 feet. This probably represents the greatest vertical postglacial cutting to be found along the streams in the Newark area of this quadrangle. The point of next greatest erosion is between the north end of the Delawanna plain and Lyndhurst, where the postglacial cutting may have been 40 to 60 feet. At most other points the Passaic has lowered its bed less than 20 feet, and in some places not at all. Above Little Falls, for example, there has been practically no erosion except where the river crosses the moraine. Over most of this area, indeed, there has been aggradation by alluviation, or by the accumulation of humus. Where the Passaic crosses the moraine at Chatham, it has lowered its channel 25 to 30 feet.

Postglacial erosion in the other valleys has been less. In the valley of Saddle River it may have been locally (along the Paramus plain) as much as 30 to 40 feet, but more commonly not more than 10 to 20 feet. In the valley of the Hackensack the erosion has been trifling. In the valley of the Rockaway, in the Highlands, the erosion has been as much as 100 feet at Boonton, but slight or nothing on the Newark plain below.

Human modification of the surface has been great. Many marshes have been drained and others filled; in many places the streams have been walled in; much of the original topography has been made smooth or its configuration otherwise notably changed. Between Paterson on the north and Newark on the south, and between First Watchung Mountain on the west and the Newark Meadows on the east there is relatively little of the surface which remains unmodified. The modification has also been great between Woodbridge and Perth Amboy.

GEOLOGIC STRUCTURE.

GENERAL STATEMENT.

The rocks of this region have been disturbed from their original positions in different ways and at different times. Some of the movements were accompanied by alterations of substance, others merely by changes in position, and some of the movements have left no record, except such as can be inferred from facts in adjoining areas. Earliest of all were the earth movements which attended the formation of the ancient gneisses and the crystallization of the limestones associated with them. The structural relations between these gneisses and limestones and their generally laminated make-up are believed to have resulted from deep-seated flow of the materials involved under the action of regional compression. There can be no doubt that the granitoid gneisses and the marbles acquired their characteristic features at a time when they were deeply buried, and their appearance at the surface of the earth prior to the deposition of the oldest Paleozoic formations is considered to be due to a long pre-Cambrian period of erosion.

Throughout the region comprising and adjacent to the present Appalachian Mountains, within what may be called the Appalachian province, important earth movements closed the Paleozoic era. Evidence of this great deformation, which is often called the Appalachian revolution, is preserved in the folded formations occurring west of the New York and New Jersey Highlands and in other parts of the general region occupied by the pre-Cambrian rocks, and in the highly metamorphosed representatives of the same formations occurring east of the Highlands in West Chester County, N. Y., and on Manhattan Island. In this eastern district folding also occurred at the close of Ordovician time.

From the presence of the well-defined, long and straight folds, in places broken by faults, which are so characteristic of the Appalachian structure both east and west of the Highlands, and to a less extent within that area, it must be inferred that the whole region has suffered a general compression transverse to the northeast-southwest trend of the folds. Though it is plain that the pre-Cambrian rocks must have been deformed by the forces which caused the folding of the younger formations within the Highlands, the effects of deformation in the gneisses are so obscure that they have not been detected. A locality in which it is apparent that the gneisses must have been involved with the folded strata lying on them is a short distance northwest of the Passaic quadrangle, beyond Green Pond. On Manhattan Island evidences of movement within the gneisses are observed, though it is not possible to separate the effects of the post-Ordovician and post-Paleozoic deformations. In the Highlands the principal effect of the Appalachian movements on the sedimentary Paleozoic rocks was to change their former attitudes, but farther east metamorphism was added to folding and the folds themselves are closely appressed.

Copperas Mountain forms a small part of one of the larger Appalachian folds in the Highlands. This fold here consists of an open syncline with steep dips on the southeast and light dips on the northwest. Its details are shown in part in section B–B. The greater portion of this syncline passes just outside of this quadrangle and is there complicated by three faults. In this fold there was no development of metamorphism or schistosity. Other Appalachian folds are to be seen on Manhattan Island. The beds are there much more closely compressed, and most of the folds are overturned toward the northwest, in the common Appalachian fashion. In the same place there is considerable metamorphism and development of secondary quartz and mica, which has transformed the original shales into mica schists. An intermediate stage between shale and schist is seen just west of Pompton along the eastern foot of the Highlands, where the Hudson black slate shows only a moderate degree of metamorphism.

The next period of strong earth movements of which there is record in this region was that which followed Newark sedimentation. As in other and similar districts, these movements consisted of a general dissection of the earth's crust by faults and a westward tilting of the blocks so formed. The faults run, for the most part, northeast and southwest, the trend of the Appalachian structure. The northwestern portion of each block is relatively depressed, and the amount of tilting ranges from 10° to 20° NW. The precise attitude of the fault planes has not been determined, but it is not far from the vertical, and the faults cut abruptly across the various formations. A minor feature of this deformation is a series of shallow cross folds. The axes of these folds run northwest and southeast, and their dips are usually less than 10°. They consist of shallow basins and low dunes, so that the successive beds have curving outcrops. This feature is prominently shown in the courses of the Watchung basalt sheets. The deformation which they express is much less important than the general tilting and faulting.

These faults have been determined in many places in the Newark area, as is shown on the geologic map. Doubtless there are numerous others which can not be detected because the different Newark beds resemble each other so closely that displacement is not shown. In the Highlands similar faults are known only along the borders of the depressed areas of Paleozoic rocks. The features presented, however, are the same as in the Newark area. It is probable that there are still other faults which cut the gneisses but which can not be seen owing to the uniformity of the rocks involved. The inset areas of Paleozoic rocks owe their preservation largely to their depression on these post-Newark faults. If they had remained in the attitudes which they acquired during Appalachian folding they would have stood much higher and perhaps been entirely removed by erosion. The post-Newark faults in general parallel the main Appalachian folds, yet have no definite relation to them. There is no constant association of the faults with anticlines, as in Appalachian structural features, but any portion of an original Appalachian fold may be found dissected and depressed. The abundance of the old synclines in the downthrown areas is explainable by the fact that they were lower originally and thus were the last to be removed by erosion.

In addition to those movements which have obviously deformed the rocks, there have been numerous other movements of uplift and depression. The majority of these are necessarily unknown. One of long duration preceded the Cambrian and permitted the surface to be worn down until the deep-seated rocks were at the surface. Cambrian deposition was initiated by another widespread movement of depression. Uplift again took place in the early part of the Ordovician and was followed in Silurian time by widespread depression. Another uplift terminated the Paleozoic, and extended the land areas until the surface was again lowered in Triassic time and sediments were deposited. Similar uplift and depression preceded the Cretaceous, Tertiary, and Pleistocene depositions. With these there is good evidence of tilting of the land toward the southeast.

STRUCTURE OF THE HIGHLANDS AREA.

By W. S. Bayley.

In the Highlands area in general broad belts of pre-Cambrian crystalline rocks are separated from one another by comparatively narrow belts of Paleozoic sediments. The latter usually contain much limestone and form valleys, but one of the Paleozoic formations constitutes the crests and the greater portions of the mountain ridges that extend from Mount Arlington, on the Delaware, Lackawanna and Western Railroad, northeastward to Greenwood Lake.

In the Passaic quadrangle the rocks are all crystalline, except over an area of about one-half square mile in its northwest corner, where the Green Pond conglomerate is present in Copperas Mountain.

Gneissic structure.—The different sorts of pre-Cambrian rocks occur in belts that have a general northeasterly strike except in the region southeast of Splitrock Pond, where the belts are curved. These belts consist of alternating strips or bands of gneisses, some of which are rich in potash feldspars, others rich in soda feldspars, and still others rich in magnesia and iron minerals. All show a more or less distinct linear structure in the arrangement of their components, and this structure usually strikes and pitches at moderate angles to the northeast. At one place in the Passaic quadrangle there is a small mass of crystalline limestone which may be an inclusion in the gneiss.

The banding of the gneisses is parallel to the strike of the belts, being to the northeast where the belts run in this direction and curved where the belts are curved. South of Splitrock Pond, however, where the belts of rock sweep in large uniform curves, the banding within the belts forms a series of smaller curves, which are the outcrops of minor corrugations pitching to the northeast. The dip of the layers is usually to the southeast at high angles, but at a few places it is vertical or steeply to the northwest. In the curved belts it is naturally directed toward various points of the compass, but always has a northerly inclination.

Origin of structure in gneisses.—It has already been explained that the banding and linear structure of the Losee and Byram gneisses are regarded as original features due to pressure during fluxion, though it is recognized that it may possibly be due to recrystallization under static pressure. In either event it is believed that the magmatic invasion that gave rise to these gneisses affected a series of pre-Cambrian sediments of which the Franklin limestone and the associated quartzites and conglomerates and probably some of the Pochuck gneisses and garnetiferous graphite schist are the only remaining representatives. In most places the invasions were along structural planes running northeast and southwest, resulting in the regular banding which is so conspicuous a feature of the district. In certain places the first intrusions were along curved lines. Later intrusions followed these lines and thus the curved belts seen south of Splitrock Pond were formed. Still later there may have been much added to this gneiss complex by the intrusion of fluid or thinly plastic material into the practically consolidated gneisses. This intruded material was forced between the tabular masses or flat lenses of the almost completely solidified rocks and spread out as plates between them. These plates constitute the numerous pegmatitic masses that are so constant and uniform a feature of the gneiss areas and that usually follow the trend of the gneissic structure but in places cross it transversely. Subsequently the rocks were faulted and were injected by dikes of diabase which are probably apophyses from the Triassic masses toward the southeast.

Major faulting.—After the Newark sediments that occur south of the Highlands area were laid down and consolidated, great faults were produced, one of which bounds the southeastern side of the gneiss area in the Passaic quadrangle. In the vicinity of the faults movement was distributed through the gneisses and these were sheared. Thus that portion of the Highlands area which lies in this quadrangle may be regarded as a part of a great block that during the period of faulting was raised bodily a considerable but unknown distance above its original position with respect to the Newark beds. From observations made elsewhere in the Highlands it is known that similar fault blocks were not only uplifted but tilted as well, and in most all cases known the tilting was toward the west. The mountains of the Highlands are groups of ridges eroded from such blocks, with faults limiting them on their southeast sides and Paleozoic strata on their northwest borders. The portion of the Highlands in the Passaic quadrangle is part of the "Passaic block," the western side of which is beyond the limits of the area mapped. The amount of throw of its limiting fault is unknown, but it was in excess of 1200 feet, the downthrown side, of course, being on the southeast.

Minor faulting.—In addition to the faulting between the pre-Cambrian crystalline rocks and the Newark sediments, there was also faulting within the crystalline blocks. The faults within the blocks are of two classes—(1) those striking with the structure of the gneiss, which for convenience may be called longitudinal faults, and (2) those cutting across this structure, called cross faults.

Those of the first class are not easily recognized. Faults discovered in the sedimentary beds surrounding the crystalline rocks have in some places been traced to the sedimentary-crystalline contact, but attempts to trace them into the crystalline rocks have failed because of the impossibility of identifying individual rock layers. On the prolongations of the fault lines, however, shear zones have in some places been observed, which may possibly indicate that the faults cross the contact line into the gneisses.

In a few other places similar shear zones have been detected which are not on the prolongations of the visible faults in the sedimentary rocks. It may be that this shearing also indicates the presence of faults, but if so the faults are not otherwise revealed. The shear zones of both kinds die out within short distances, so that the faulting, if it exists, is not of great magnitude.

Many of the cross faults are more easily recognized. The movement on the sides of those which intersect well-banded gneisses is readily detected, where exposures are abundant, by the displacement of the bands on the surface. As a rule the downthrow is on the southwest side of the fault. The fault planes usually dip almost vertically and strike about N. 30° W. These faults are important only as they affect the ore bodies, for though the displacement caused by them is in general comparatively slight, it nevertheless in some faults amounts to scores of feet and is of considerable importance from the mining point of view. As might be expected, the available knowledge of them depends principally on their development in the underground workings of the mines.

In the Raritan quadrangle, to the west, where mining operations are more numerous than in the Passaic quadrangle, a large number of small faults have been discovered, but in the Passaic area only one is known. This lies between the Montauk mine and the south end of the Hibernia lead, displacing the ore body about 22 feet.

STRUCTURE OF THE NEWARK AREA.

By N. H. Darton and H. B. Kümmel.

The Newark rocks usually exhibit a monoclinal structure, with the strata dipping gently to the west-northwest. A few local flexures occur in some areas, but faults are numerous and some of them are the result of great vertical displacement.

Flexures.—In nearly all the exposures of the sedimentary rocks in the Passaic quadrangle the beds dip to the northwest or west-northwest and the structure in general is monoclinal. The angle of dip is from 8° to 10° in greater part. Here and there it is somewhat more but as a rule it presents no marked variations. The ridges of basalt closely follow the strike and dip of the sediments. The only conspicuous flexure is west of Second Watchung Mountain and Long Hill, where the strata are gently folded, but the evidence of this fold is exhibited mainly by the distribution of outcrops of the third Watchung basalt. It is a region in which the outcrops of sedimentary rocks are rare and dip mainly to the west or northwest. West of Long Hill there is almost certainly a shallow syncline under the Great Swamp which brings to the surface the third Watchung lava sheet in the New Vernon ridge. The sandstones lying within the crescent of this ridge dip to the south and southwest near New Vernon and to the east and northeast on either side of the lava sheet in the ridge extending northward from Green Village, presenting an irregular, dome-shaped flexure. The syncline of the Great Swamp area probably extends northward under the moraine and down Passaic River, crossing the third Watchung basalt south of the village of Pine Brook and again in the vicinity of Mountain View, but there are no outcrops of sedimentary rocks in this interval to define its relations. To the west there is an anticline whose axis probably passes near Whippany and Troy Hills, crossing Hook Mountain near its south end and again near Lincoln Park, where it passes out under Pompton Plains. Apparently it is a very low arch, but its presence is plainly perceptible southwest of Lincoln Park in the strata underlying the basalt of Hook Mountain.

Along the western margin of the Newark group, from old Boonton beyond Montville, the dips are from 10° to 15° NW., and near Pompton S. 75° W. at angles of 10° to 20°. North of Paterson the strike curves from northeast to west of north but at a point beyond High Mountain it changes to northwest, causing the curvature to First and Second Watchung mountains in the vicinity of High Mountain. This curvature probably is augmented by faults between High Mountain and Franklin Lake. At the head of this lake the sandstones and shales are seen dipping west-southwestward, whereas the general trend of Second Watchung Mountain is west-northwest. At Pompton Lake the beds dip slightly south of west at an angle of 10°. Along the east side of First Watchung Mountain northward from Milburn the beds dip at an average angle of about 10° W. The angle increases slightly south of Springfield. In the vicinity of Plainfield there is a noticeable change in the strike to nearly due northeast and southwest, and west of Berkeley Heights the change of strike toward the west is still more marked in the basalt ridge of Long Hill. Along Raritan River, at New Brunswick and for several miles above, the dips are 10° NW.

Faults.—In the Passaic quadrangle the Newark group exhibits few faults, but this is probably due to the extensive drift cover and the lack of distinctive stratigraphic succession by which the breaks can be established. To judge from the great width of the monocline and the existence of numerous dislocations in other portions of the area, it is probable that the Newark rocks are faulted at more places than has been supposed. In the ridges of igneous rocks, where the outcrops are prominent and continuous for long distances, a number of faults of moderate amount are clearly exhibited, and it is almost certain that there is a great fault along the northwestern margin of the Newark area in the Passaic quadrangle. The faults trend between north-south and northeast-southwest and range in length from a few yards to many miles. They appear not to be related to flexures.

One of the clearest exposures of a fault is in the cut of the Greenwood Lake branch of the Erie Railroad, west of Arlington, of which some of the relations are shown in fig. 31 on the illustration sheet. The amount of the dislocation is not known, but it is thought not to exceed 22 feet, with the downthrow on the east side. The fault is marked by a breccia zone occupied by sandstone in angular fragments, most of which are slickensided. It dips westward at an angle of 60°. Farther east, in the cut, some other faults are exhibited, but they are of small amount. A fault apparently having considerable throw is exposed in the railroad cut in the western part of Hackensack. It brings gray sandstone on the west against shale on the east, with more or less crumpling in the shale near the fault plane. The dip of the fault plane is nearly vertical. Numerous small breaks appear at other localities. One is in the quarries at Avondale, the throw being about 5 feet, with uplift on the east side and a dip of 25° W., and one of small amount is exposed in the railroad cut a mile south of Newmarket. In a road cut on the ridge between Hackensack and Tea Neck there is a fault showing considerable overthrust from the west, which is a most exceptional feature.

The Palisade diabase is traversed by a number of small faults with downthrow on the east side. These trend mostly parallel to the north-northeast course of the ridge, but some extend diagonally into it on a north-by-east course. They usually cause longitudinal depressions or breaks in the crest line of greater or less prominence. There are also innumerable minor faults, marked by offsets on horizontal joint planes.

A fault apparently extends along the center of Bergen Point and Bergen Hill to and through Jersey City Heights. The first indications of this fault are in Bayonne, where a narrow strip of sandstone extends along the center of the diabase outcrop and is apparently protected from erosion by a fault scarp on the west side. The sandstone is clearly exposed on Forty-fourth street near the canal. Southward from this exposure a strip of red soil extends for several miles, and within a short distance to the north there is a depression which appears in the canal cut as a break in the continuity of the diabase. In the cut of the Central Railroad of New Jersey across Bergen Hill the fault is indicated by a wide, deep break in the diabase. In the cut of the Pennsylvania Railroad just east of Marion the depression between diabase outcrops is 700 feet wide and was found to be underlain by thin-bedded sandstone dipping toward the diabase wall on the west side. The relations in this vicinity are shown at the left of the section in fig. 22. In the two tunnels half a mile farther north the fault is marked by a narrow belt of greatly disturbed and decomposed diabase, and a short distance north of these tunnels sandstone was found near the surface in excavating for a reservoir. Thence northward for several miles there are indications of the continuance of a débris-filled depression, but the termination of the fault could not be located. The amount of the dislocation is not known. The absence of sandstones in the tunnel sections is ample proof that the diabase is not in two sheets separated by a layer of sandstone, and also that the amount of the fault is not sufficient to bring up the underlying strata.

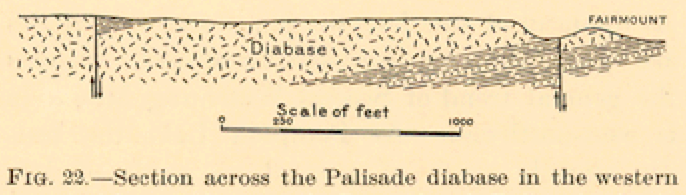

FIG. 22.—Section across the Palisade diabase in the western part of Jersey City near the Pennsylvania Railroad. Looking north. The Bergen Hill fault is at the left and the smaller fault at Fairmount at the right.

At the right of the section forming fig. 22 are also shown the supposed relations of a small diabase outlier in Jersey City, formerly known as Fairmount but now nearly leveled for a roundhouse. This was a small knoll separated from the main ridge by a marsh. It may be a small branch from the Palisade diabase, but it is probably due to a small fault, as shown in the figure. North of Hoboken the escarpment of the Palisade diabase is offset to the shore of Hudson River, giving rise to the prominent feature known as Kings Point. Behind this point is a deep ravine which extends northward to a point near Guttenberg, where it heads in a marsh-filled depression. It holds a small creek which empties into the Hudson just below Kings Point, and marks the line of a fault which extends to the north for several miles. Baked shales are exposed in the ravine, and they were also found in the West Shore Railroad tunnel 2 miles farther north, dipping westward under the diabase. They are cut off to the east by the fault which drops the diabase some distance. A well sunk in the ravine behind Kings Point, just west of the fault plane, penetrated 125 feet of baked shale without meeting any diabase. The extremities of this fault have not been located. To the north there is no evidence of it beyond Guttenberg and to the south it extends into the low ground toward Hoboken. It is crossed by the new tunnel of the Pennsylvania Railroad a short distance south of Kings Point, near the west side of the large working shaft, but as this shaft is walled with concrete the relations are hidden. The shaft is said to have been in sandstone and this material extends westward to the main diabase contact and eastward to the river except where it includes some beds of indurated shale.

Several faults are exhibited in the northern portion of the first Watchung basalt. The clearest exposures are in the slopes and railroad cuts in the northern face of Garret Rock, in the southern part of Paterson. The principal dislocation, which has a downthrow of about 70 feet on the east side, is plainly discernible in the basalt and underlying sandstone. To the north it is lost under the drift in Paterson; to the south its line is marked by a rocky-sided depression separating the mountain into two ridges as far south as Montclair Heights, where it passes southeastward out into the sandstone plain. In crossing Great Notch, the fault is deflected somewhat toward the west, and in this vicinity its amount is about 150 feet, apparently not quite sufficient to bring up the sandstone on the north side of the Notch, although the valley to the south appears to be underlain by sedimentary rocks. Three other small faults are exhibited in Garret Rock west of the main one. The first has a downthrow of about 12 feet on the east side and the second and third each drop a small block a short distance. From Great Notch southward there is apparently another fault west of those above described and indicated by a double crest line extending to and beyond Verona. It finally deflects toward the east and passes out of the mountain at Eagle Rock, where it causes a material offset in the cliff line and has a downthrow of about 50 feet on the east side.

The second Watchung basalt presents some evidences of faulting but the relations are not clearly exhibited. Just south of Haledon there is a break and offset similar to the one at Eagle Rock, and the deep hollows and offset of the mountain front between High Mountain and Franklin Lake are undoubtedly due to two or three faults, for the deflection of the range to the northwest in that vicinity is not due to change in strike of the sedimentary rocks. In the region west and northwest of Plainfield the Second Watchung Mountain consists of a double line of ridges separated by a depression in which red shale is exposed at intervals for 10 miles. This feature has been supposed to be due to a fault and is so represented on the map and section, but J. Volney Lewis has recently presented evidence that the shale is probably a local deposit between two flows of lava.

The existence of a great fault along the western margin of the Newark group is indicated by very satisfactory evidence. It is suggested in the first place by the abrupt rise of the Highlands front along a line that is very nearly straight and up to which the sedimentary rocks exhibit a westward dip. Along this line also various formations of the Newark group abut against the older rocks, which would not be the case with overlap. This relation is notable both north and south of the Passaic quadrangle, where the first and second Watchung basalts are cut off as their curving strike carries them westward. Near Bernardsville the basalt exhibits an actual fault breccia along its contact with the granite. Other evidence is afforded by the remarkably small amount of granite and gneiss found in the marginal conglomerates, for a large amount of these materials would be included if there were overlap along a shore line.

GEOLOGIC HISTORY.

By N. H. Darton.

PRE-CAMBRIAN EVENTS.

The oldest rocks in the Passaic quadrangle are those of the Highlands and, as has been shown, these are of pre-Cambrian age. They consist entirely of igneous or metamorphic materials, which have been subjected to many earth movements, so that now they are extensively folded, fractured, and modified in character. The oldest rocks are limestones and other products of sedimentation of which the original extent and source are not known. Into these sediments large bodies of igneous rocks were intruded. Later came extensive metamorphism of the pre-Cambrian rocks in general, which, however, was less prominent in this than in adjoining regions. In the long period prior to Cambrian deposition the rocks were greatly eroded. Thus the deeply buried plutonic rocks in time came to form the surface of the earth in this region. Probably this land persisted here during the early part of Cambrian time.

PALEOZOIC CONDITIONS.

As Cambrian rocks occur in the adjoining areas, it is possible that they underlie a portion of the quadrangle, under the Newark group. It is believed that during early Cambrian time a narrow sea extended through eastern New York and southward in a zone now occupied by the Appalachian Mountains. On the floor of this sea were deposited sand and other sediments. The sea widened greatly with the passage of Cambrian time, and received extensive sheets of sand, clay, and finally carbonate of lime, which now appears as crystalline limestone on Manhattan Island and blue and gray massive limestone farther west in New Jersey. Marine conditions continued during Ordovician time and extended the limestone deposition for a long period. In the later portion of the Ordovician there was a very general change in conditions, probably including a shallowing of the waters that resulted in widespread clay deposition, forming the great mass of sediments known as the Hudson. This formation, subsequently altered by metamorphism, is now the Hudson schist of southeastern New York and the Hoosac schist of western New England. In the region a short distance north and west of the Passaic quadrangle, where the shale is not metamorphosed, it overlaps in places and rests upon the older crystalline rocks, indicating the position of at least a portion of the shore line in later Ordovician time.

In this region west and north of the quadrangle the shale of Hudson age is overlain and overlapped by the Green Pond conglomerate, believed to be of Salina age. This rock consists of coarse, pebbly sands and some conglomerate, the product of strong currents and local sources of supply along the margin of the Ordovician shale. The Green Pond beds were followed by attenuated representatives of the later Silurian and Devonian, indicating that there was extensive submergence which farther north and west was general and resulted in the great mass of Silurian and Devonian sediments which cover a large portion of western New Jersey, eastern Pennsylvania, and New York. In the vicinity of New York City and in western New England there are no deposits to represent the long interval between Ordovician and Triassic time and but little evidence as to the geographic conditions. It is believed that there was a wide land mass in this region, including the Highlands, for the overlap relations indicate the presence of a shore during a long period. The Devonian sediments in eastern New York also show very plainly in their character the approach to a shore on the east. This is well illustrated in the Catskill Mountains, where nearly all the middle and upper Devonian rocks, which are fine grained and filled with many fossils in western New York, gradually change into coarse-grained sandstones. Additional evidence is also afforded by the difference between the Devonian faunas in New York and eastern New England, a difference which would not be expected if there was open water between the two regions. The Silurian sandstones also indicate the presence of a land mass to the southeast, rising above water level along the Hudson Valley for many miles north from the Highlands. This land mass probably remained far into Carboniferous time, gradually wasting by long erosion. Doubtless it was a country of diversified topography, with hills, valleys, and rivers, and bearing life of various kinds. The relations of land and water during this long period varied, and no doubt the position of shore lines changed greatly from time to time. The land sloped to the west into a sea which extended many miles. How far east the later deposits extended is not known.

POST-CARBONIFEROUS UPLIFT AND METAMORPHISM.

After the Carboniferous, in the southeastern New York region, there were extensive intrusions of igneous rock of various kinds and profound compression and alteration of the sedimentary deposits. These agencies in part metamorphosed the Cambrian and Ordovician shales and limestones into mica schists and marbles, which appear prominently in New York City and adjoining regions. The date of the intrusions and alteration is not known, but, as similar agencies are known to have affected Carboniferous rocks in portions of New England, it is believed that they were about contemporaneous with the general Appalachian uplift at the end of Carboniferous time. Probably some of the intrusions were earlier than the metamorphism, for some of the igneous rocks have been compressed, sheared, and more or less altered.

TRIASSIC CONDITIONS.

During and following the great Appalachian uplift, there was an extensive degradation of the uplifted Paleozoic sediments and of the remainder of the land area of later Paleozoic time. This process continued through Triassic and early Jurassic time and in its later stages the land waste was deposited to form the great mass of sediments now constituting the Newark group. Apparently the region now known as the Highlands was a part of the western margin of the basin or coastal plain in which these sediments were laid down, and the eastern margin was out on the present Atlantic Coastal Plain. This basin probably extended northward into New England and perhaps continuously to a similar basin in Nova Scotia. To the south it extended across New Jersey and Pennsylvania and into the Carolinas, possibly with local interruptions. There were at this time, wide flood plains of rivers and long estuaries, mainly of fresh or brackish water. These estuaries were not deep, for the deposits at all horizons show ripple marking, raindrop impressions, footprints, and other evidences of shallow water. In some areas, especially in Virginia and North Carolina, there were extensive marshes in which were formed vegetal deposits now represented by coal beds. A vast amount of reddish-brown sand and clay was laid down in this epoch, with gradual subsidence, until a thickness of 15,000 feet or more had accumulated. Probably there were during most of the epoch wide alluvial flats and low shores bearing luxuriant vegetation, while from the adjoining hills large amounts of sediment were washed.

During the later portion of the epoch, in the northern New Jersey region, there were three, or perhaps four, successive volcanic eruptions, resulting in the outspreading of thick and extensive lava sheets among the sediments, and several igneous masses which failed to reach the surface were intruded as extensive sheets between the shales and sandstones. These igneous rocks now appear most extensively in the Watchung mountains and Palisade Ridge.

POST-NEWARK UPLIFT.

At some time following the accumulation of the Newark sediments and the eruption of the associated igneous rocks the sandstones and shales were dislocated by movements of the earth's crust, normal faults were developed with a general northeast-southwest trend, and the blocks into which they divided the formations slipped past one another in such a manner as gradually to cause displacements, some of them amounting to several thousand feet. The effect must have been to develop ridges of greater or less height, which erosion immediately attacked and wore down to hills of moderate altitude. In the development of this particular generation of hills, the hard igneous rocks must have maintained their altitude above the areas of soft sandstones and shales, as they do now; and inasmuch as their distribution was in a measure similar to that which they now have, some of the heights of the landscape may have resembled those of the present day. These hills did not survive, however, but were reduced to very low relief in succeeding epochs.

CRETACEOUS CONDITIONS.

During later Jurassic and early Cretaceous time the eastern Atlantic slope consisted of an upland with low hills, merging eastward into a low coastal plain somewhat similar to the present one but largely submerged. The Appalachian Mountains, including the Highlands of New Jersey and New York, were not developed then as prominently as now.

The relations of land and sea were maintained with slight changes of level during the greater part of the Cretaceous period, and such high ground as had survived into the beginning of that period was consequently worn down by erosion to still more monotonous lowlands. The present Coastal Plain area of New Jersey was bordered by estuaries and lagoons in which first were laid down brackish-water deposits represented by the Raritan clays. These clays form the upper member of a succession of sand and clay deposits known as the Potomac series, of which the lowest member is probably of Jurassic age. The Potomac series generally lies upon gneiss or granite, and the marginal deposits consist largely of feldspathic materials of local origin. These components indicate that the shore was part of a land surface which had been so long exposed to weathering that the granites were deeply decayed, much as they now are in the same region. This weathering may have been the last phase of a cycle of erosion which occupied Triassic time. The surface upon which the Potomac series rests is even and now slopes up toward the northwest. Extending in that direction from existing Potomac strata are flat hilltops, from which the Potomac deposits have been eroded and which were therefore part of the submerged plain. Beyond the probable limits of the former extent of the Potomac deposits there are hilltops with flat surfaces that accord in slope with the floor of those deposits farther east and so are believed to be representatives of the same plain. These remnants rise toward the west and become smaller, less numerous, and more widely separated by valleys. Nevertheless, if the valleys are pictured as filled to the hilltops with the material which streams have carried away, the former plain may be restored. Thus the basal Potomac plain is traced far beyond the extent of the Potomac sediments, over the Appalachian Mountains, and so it is recognized that the land in early Cretaceous time was nearly flat throughout the province. This surface which lies beneath the Potomac strata to the east and rises beyond them over the hilltops to the west is known as the Schooley plain, from the fact that it is well represented in the flat surface of Schooley Mountain, New Jersey. In general the recognition of this plain as a feature which once existed is based on the long, even mountain summits of the Highlands, Schooley Mountain, the Watchung mountains, and the Palisades.

In the vicinity of this quadrangle the Schooley plain lies at sea level on Long Island and in the Perth Amboy region and rises over the Palisade Ridge west of Hudson River. From the Palisades it may be extended above the wide valley to the even-topped Watchung mountains and beyond them to the summits of the Highlands. The valleys which are excavated below the once continuous surface of the Schooley plain have resulted from stream erosion after the uplift of the land. This uplift was greatest toward the northwest, and the old plain is highest and thus most deeply eroded in that direction.

The coast in early Cretaceous time was probably like that which exists to-day in New Jersey—a shore with long barrier beaches partly inclosing estuaries and lagoons. Near its present western margin, at least, sedimentation did not begin until late Potomac time, when there was deposited the Raritan formation, consisting of white or colored sands and light or dark clays, here and there containing leaves.

During later Cretaceous the Atlantic Coastal Plain was submerged to a greater or less extent. The materials deposited were largely clays and sands derived from the shore, but they also contain much marl, which was produced by chemical changes through the agency of marine organisms (Foraminifera) from finely divided sediments. Foraminifera live in relatively clear seas, but they cause the formation of glauconite, the characteristic mineral of marl, only where they obtain some sediment from the land. Thus the marl beds indicate clearness of the water beneath which they accumulated, and from the small amount of sediment present we may further infer that the near-by lands were undergoing but slight erosion and consequently still had a low and very nearly smooth surface.

TERTIARY CONDITIONS.

There is no definite evidence that conditions along the Atlantic Coastal Plain changed markedly during early Eocene time, when the Shark River formation of eastern New Jersey was laid down conformably upon the highest Cretaceous beds, which it resembles in character. Next followed an interval, extending through the later Eocene, regarding which the record is not clear. Then came the beginning of the movements which have raised the wide plain of that time to the level of now existing mountain tops and which, with many fluctuations, have placed the land in its present relation to sea level.

Early in the Tertiary period there was an extensive uplift of the Piedmont zone and regions farther west and the excavation of the valleys was in active progress. Doubtless the uplift was intermittent and its rate was not uniform areally, for the old Schooley plain was somewhat deformed. The position of the coast line is not known, but most of southern New Jersey was submerged and a great volume of sediments was laid down upon the Cretaceous deposits. Unconformity between the Eocene and Miocene indicates one important epoch of uplift, but its extent is not determined. The Miocene sediments are mostly sands, the products of more rapid wasting of the land than had occurred during the epochs just preceding. They indicate not only that the land surface yielding the sediment became higher, but also, as they spread landward beyond the Eocene sediments, that there was a broader submergence. From their development it is inferred that uplift had begun in the region west of the shore line, probably in the district of the Highlands, and was accompanied by downward tilting of the Coastal Plain along its seaward margin. This movement closed the cycle during which the present Coastal Plain had developed and initiated the present cycle, which has thus far been one mainly of uplift.

The development of the Schooley plain, which stood near sea level but which might now be restored over the summits of hills and mountains, has been described. It is a striking fact in the physical history of the eastern United States that from late Jurassic time on through the Cretaceous period there was no considerable uplift of the land. Whether the sediments or the topography be studied, the conclusion is the same. A plain of very great extent had been developed by erosion before the Cretaceous period began, and it was reduced to even flatter, more monotonous aspects as time passed. The character and distribution of the sediments derived from its rocks show that the plain suffered gentle uplifts and depressions, and at last the lowland was elevated and assumed the broad dome shape which the Schooley plain would now have if it were still continuous.

The Schooley plain is not only the oldest topographic stage recognized in the Highlands, but it is also the highest, and below it are other plains which are successively younger according to their positions one below another.

The rivers, which flowed seaward across the general slope of the Schooley plain, cut valleys into the hard and soft rocks lying across their paths, and became superimposed upon the underlying ribs of rock. Later, through the processes of adjustment by which streams seek valleys along lines of soft rocks, the courses were changed, and the river systems of the present were to some extent developed. During a pause in the uplift of the surface of the province, valleys were widely excavated, and a broad lowland was eroded in the soft shales and sandstones of the Newark group in New Jersey. As this surface is well represented in the vicinity of Somerville, the name Somerville stage has been given to it.

The process of adjustment and erosion had proceeded so far as to outline the present heights and valleys in their broader features, when the uplift was renewed, resulting in mountains of the altitude of the Highlands. The streams developed their deeper and inner valleys. The broad dome which the Schooley plain would have formed, if valleys had not developed in its surface, sloped southeastward from the axis of uplift in the Highlands and passed beneath sea level near the southeast corner of the Passaic quadrangle. The destruction of the Schooley plain proceeded intermittently and resulted in more than one set of features, each younger set being carved into the next older, as for example a narrow, later gorge within a wide valley. When sufficiently lowered, valley bottoms became covered by alluvium, forming flood plains; and being raised in a later movement, these deposits were cut away, except remnants which now form terraces on slopes. At times the upward movement of the land surface with reference to sea level has been not only checked, but even reversed, and the sea has submerged plains and valleys more or less extensively, adding estuarine sediments to the alluvial deposits. The complex sequence of movements which is recorded in these details of land sculpture and construction has been interpreted for this district chiefly by Davis[1] and Salisbury.[2]

The development of river systems and of relief had reached approximately the present degree of maturity when the erosional agencies were modified by the influence of the cold epochs that resulted in general glaciation of northern North America.

QUATERNARY CONDITIONS.

The great ice sheets which covered northern North America were the dominant features of early Quaternary time. There were several stages of glacial advance, with intervening times of milder climate. In the latest advance and perhaps also in one or more of the earlier ones the ice sheet extended southward nearly through the Passaic quadrangle. In its advance from the north the glacier ground off the rock surface in some places and buried it beneath gravel, sand, and clay in others. The worn rock surfaces are scratched and grooved and the deposits have characters peculiar to materials carried by ice and laid down by it or by waters flowing from it.

Before the ice advanced the larger rivers had adjusted themselves to their present valleys. When the ice disappeared the streams resumed their courses with such changes as the glacial deposits required, and they now flow in the channels thus determined. The features due to glaciation are described on previous pages.

At an epoch not yet well determined the land stood several hundred feet higher than now in reference to sea level, and the streams in consequence sunk their channels deep. The waters of East River and the Hudson joined below a bold hill, where the Battery is now, and, flowing out through the Narrows, crossed a wide plain to the ocean. The old channel is traceable by soundings. When the land sank to its present level the valleys were submerged, and the harbor of New York resulted. The submergence established a new shore, which waves and currents are modifying. Their work is seen in such features as the beaches of Sandy Hook and Coney Island. Beneath the waters of the ocean, bays, and rivers, deposits of sediment of various kinds are accumulating. The bar and its channels are produced by the deposit and scour of shore currents and tides. On the land the vegetation, the atmosphere, the rains and frosts, and the streams are remodeling the surface, and man is doing much to change the topographic features.

ECONOMIC GEOLOGY.

By W. S. Bayley, N. H. Darton, and H. B. Kümmel.[1]

IRON ORE.

OUTLINE OF DEVELOPMENT.

The iron ore of the Highlands is all magnetite. It has been found in a great number of places within the Passaic quadrangle, but at only a few has it been mined in any considerable quantity. This may be due partly to the cost of transportation to market.

Among the most prominent mines that have been active in the past may be mentioned the Hibernia group, the Beach Glen mine, and the Montauk mine, near Hibernia; the Rockaway Valley mines, near Taylortown; the Pikes Peak or Stony Brook mine, near Stickle Pond; the Cobb and Splitrock Pond mines, near Splitrock Pond; the Kahart mine, north of Montville; and the De Bow mine, near Riverdale. Some of these mines were opened in colonial days in the eighteenth century, and all of them were worked to supply local forges until their abandonment as a consequence of the concentration of the iron and steel industry at points within the coal fields. In recent years only the Beach Glen and the Hibernia group have yielded ore. At present the Hibernia only is producing, the ore being utilized entirely at the Wharton furnace at Wharton, N. J.

CHARACTER AND COMPOSITION.

The ore of all the mines is practically of the same character, though it differs in degree of purity. It consists of an intimate mixture of magnetite, hornblende, pyroxene, quartz, feldspars, biotite, apatite, sphene, and pyrite, in varying proportions. Hornblende, pyroxene, and apatite are the most persistent of the components aside from magnetite, and quartz is common. Apatite is present as small green, gray, or brown granules, at some places in large quantity and at others only in minute traces. Pyrite is almost universally present, but in much of the ore only sparingly. Some of it is in the form of veinlets which were formed after the magnetite. Calcite is also locally present as a late introduction. Where it occurs it is in thin layers along fractures. Manganese has been found by almost all analyses in specimens in which it has been sought, but in the ores of the Passaic quadrangle it is apparently present in only very small quantity.

The variations existing in the sulphur and phosphorus contents of the ore may be learned from the following figures, which represent material actually shipped.

Commercial analyses of iron ore from mines in the Passaic quadrangle.

	Mine.	Sulphur.	Phosphorus.	Iron.
1	Ryerson's De Bow	3.36	0.028	61.47
2	Kahart	1.23	.17	52.34
3	Jackson	.06	.226	52.96
4	Splitrock Pond, east vein	.068	.0109	63.399
5	Beach Glen	----------	.025	48.63
6	Hibernia	.07	.332	59.72

1. Ann. Rept. New Jersey Geol. Survey, 1878, p. 98.
2. Ann. Rept. New Jersey Geol. Survey, 1873, p. 26.
3. Ann. Rept. New Jersey Geol. Survey, 1873, p. 27.
4. Ann. Rept. New Jersey Geol. Survey, 1879, p. 58.
5. Tenth Census Rept., p. 172.
6. Calculated from complete analysis.

A complete analysis of the Hibernia ore after passing through one of the magnetic separators installed at the mine—that is, as prepared for shipment in 1906—is given below.

Chemical composition of ore as shipped from the Hibernia mine, 1906.

[Analysis by W. T. Schaller.]

SiO_2	9.25	P_2O_5	0.86
Al_2O_3	1.98	S	.07
Fe_2O_3	55.71	Cr_2O_3	.01
FeO	26.64	NiO	.02
MgO	1.11	MnO	.05
CaO	1.89	BaO	.00
Na_2O	.57	SrO	.00
K_2O	.12	Li_2O	.00
H_2O-	.43	CuO	.00
H_2O+	.56	CoO	.00
TiO_2	.54	ZnO	.00
ZrO	.00	V_2O_3	.14
CO_2	.35		100.30

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[1] Davis, W. M., Rivers of New Jersey: Proc. Boston Soc. Nat. Hist., vol. 35, 1888–89.

[2] Salisbury, R. D., Physical geography of New Jersey: Rept. State Geologist of New Jersey, vol. 4, 1895.

[1] Of the materials of economic value that occur in the Passaic quadrangle, iron ore and graphite are described by W. S. Bayley; copper ore, building stone, lime, flux, and underground water by N. H. Darton; and clay, sand, gravel, and peat by H. B. Kümmel.

This corresponds to a mixture of minerals in approximately the following proportions:

Approximate mineral composition of ore as shipped from Hibernia mine, 1906.

Magnetite	79.60
Ilmenite	1.03
Hornblende and pyroxene	6.25
Oligoclase	6.40
Orthoclase	.72
Quartz	2.39
Apatite	2.01
Pyrite	.01
Calcite	1.59
	100.00

The ore as it is taken from the mine contains a much larger proportion of hornblende and pyroxene and of the feldspars and quartz.

Inasmuch as it is probable that the Hibernia ore is a normal type of the magnetites associated with the gneisses in New Jersey, the analysis may be regarded as fairly representing this class of ore, which is by far the most important class in the State and the only one represented in the Passaic area.

In other portions of the Highlands magnetite is also associated with the Franklin limestone. The ore of this class will no doubt be found to vary slightly in composition from the Hibernia ore as recorded here. It is known that much of it is characterized by a comparatively large percentage of manganese.

RELATIONS TO SURROUNDING GNEISS.

The minerals associated with the magnetite in the ore are the same as those in the surrounding gneisses. Where these minerals increase the ore becomes lean, and vice versa. There is usually no sharp line of demarcation between ore and rock, the former passing into the latter by the gradual diminution in the quantity of magnetite present. In some places, however, the line separating the two is plainly marked and the rock beyond the line is almost entirely free from magnetite. Many seams and masses of rock are inclosed in the ore and in places are entirely surrounded by it. Such inclosed masses are either bunches of Pochuck gneiss or of pegmatite, or masses of the same composition as the neighboring gneiss where this is not of the Pochuck type.

SHAPE AND OCCURRENCE OF ORE BODIES.

Practically all the rich ore bodies are distinctly pod-shaped lenses, with the longitudinal planes of the pods parallel to the dip of the foliation in the neighboring gneisses and their longer axes conforming with the pitch of the rock structure (figs. 23 and 24). Usually a number of these lenses lie one above another in the same plane, all pitching and dipping in the same direction (fig. 25). The pods are known as shoots and the comparatively barren rock between them as pinches. The rock overlying the shoots—that is, that under which the ore pitches—is called the cap rock and that under the shoot the bottom rock. The hanging wall is that under which the shoots dip and the foot wall that over which they lie. The succession of shoots and pinches in their horizontal direction is known as the vein or lead. Where the limits of the vein coincide with the planes of junction between layers of gneiss, its bounding walls are sharply marked; where the boundaries of the vein and the junctions between gneiss layers are not coincident, the walls are not distinct, but there is a gradation between ore and rock.

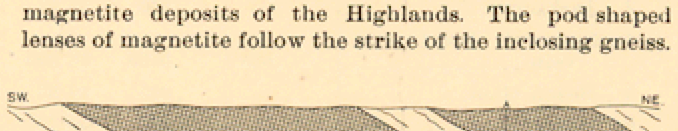

FIG. 23.—Diagrammatic plan of ore shoots characteristic of the magnetite deposits of the Highlands. The pod shaped lenses of magnetite follow the strike of the inclosing gneiss.

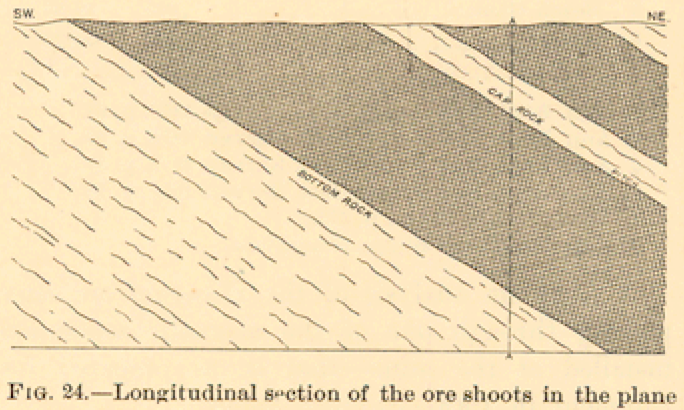

FIG. 24.—Longitudinal section of the ore shoots in the plane of the dip, along the line B-B, fig. 23.

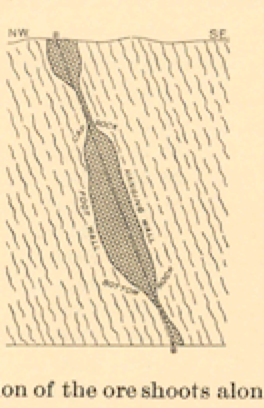

FIG. 25.—Cross section of the ore shoots along line A-A, fig. 23.

The pinches, though poor in ore, are not entirely barren. In some veins the walls close in, reducing the width of the ore bodies to a few feet or even a few inches. More commonly, however, the space between the shoots is occupied by rock, which in some places is a pegmatite full of magnetite, in others is country rock (gneiss) traversed by a few or many very narrow stringers of magnetite, connecting the shoots with one another, and in still others is a mass of coarse hornblende crystals cut by tiny veinlets of ore running parallel with the general direction of the gneiss.

Cap and bottom rocks are supposed to terminate the horizontal extension of the vein in the two directions, so that beyond them in its strike no continuation of the shoots is to be expected. As a matter of fact, however, no true cap or bottom rocks have been proved to exist in the developed mines of the Passaic quadrangle, although they are probably present in some of the minor explorations. It was supposed that they had been encountered locally in the more important mines, but close observation showed the presence of tiny streaks of magnetite in them and subsequent exploration has developed beyond them new and unexpected ore bodies. Wherever the ore bodies have appeared to terminate suddenly, this has been due to cross faults which have displaced the vein to such a distance that persistent search has failed to discover its continuation. Outside the Passaic quadrangle faults that are known to traverse the ore bodies are very numerous. Within the quadrangle, however, the development of the ore bodies has been so slight that only one such fault or offset has been disclosed. This is at the south end of the Hibernia property, separating the old Lower Wood shoot from that of the Montauk mine to the southwest. The displacement is 22 feet.

The developed portions of the veins vary greatly in length. Some, judged by their outcrop, are extremely short, perhaps being limited to the length of a single ore shoot. Others are 300 or 400 feet long and may contain a succession of several shoots. The Hibernia vein has been developed for at least a mile in length on the Hibernia property and, if the veins at the Montauk and Beach to the southwest are on its continuation, its entire length is over 1½ miles. In the Hibernia portion of the vein there are reported to be ten or twelve shoots and a corresponding number of pinches.

All the veins of ore in the Passaic quadrangle, as well as those in the other portions of the Highlands, so far as known, strike and dip with the inclosing gneisses—that is, as a rule they strike northeastward and dip to the southeast at high angles. In the few places where the dip and strike of the gneisses depart from these directions the corresponding features of the ore veins vary with them. At the Taylor mine, for instance, the strike of the vein is reported to be east and west. At the Beach Glen mine the strike curves but is in a general northeasterly direction, and the dip which is prevailingly southeast, varies to a vertical and in some places, where a roll has been developed in the rock series, to a steep northwesterly dip. At the Hibernia mines the prevailing dip is to the southeast at angles varying between 62° and 86°. At the Wharton mine, however, the dip near the surface is vertical and, for short distances, steep to the northwest.

The pitch also, like that of the surrounding gneiss, is usually to the northeast at low angles. At the Hibernia property the pitch at the Lower Wood mine is 27° NE. and the supposed cap rock north of the Wharton mine pitches 21° in the same direction. At a few of the mines in the Lake Hopatcong and Hackettstown quadrangles the pitch is to the southwest, but the northeasterly pitch is almost universal.

HIBERNIA MINES.

The group of mines situated at Hibernia is the most important iron-ore producing center in the State. It comprises a number of openings that were originally worked as independent mines under the names of Andover, or Lower Wood, Glendon, Scott, Decamp, Upper Wood, and Willis. (See fig. 26.) In 1901 these were all consolidated under a single management and since that time they have been operated to supply ore to the Wharton furnace, which is also under the same control. The yield of the consolidated mines in 1905 was 226,598 tons and the total aggregate yield of the group to the end of this year is estimated to be a little over 5,250,000 tons.

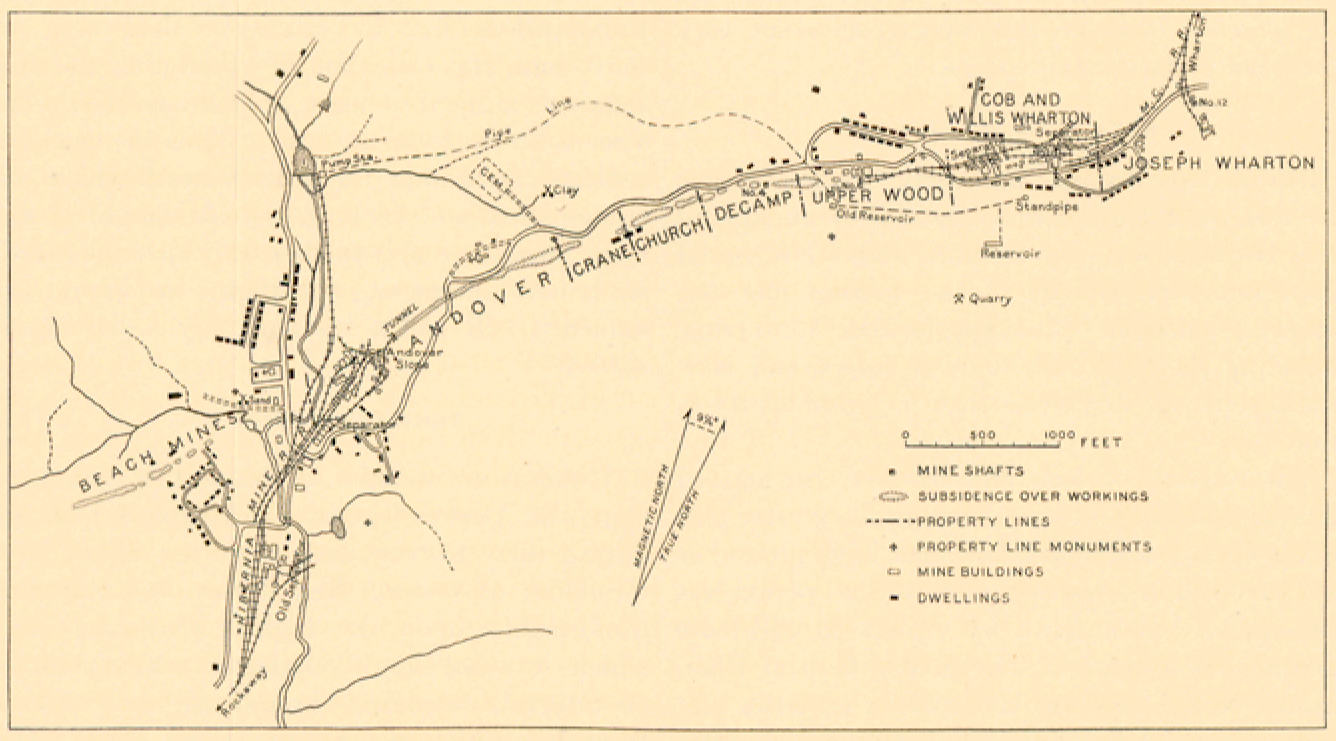

FIG. 26.—Map of magnetite mines at Hibernia, N. J.

Prior to 1896 the ore was used as mined or after hand cobbing. In that year the first mechanical separator was built and this was followed later by several others, so that much of the material which before 1896 went to the dump is now being utilized as ore. This is crushed and so successfully concentrated that material originally containing from 22 to 30 per cent of iron leaves the machine with its metallic content between 58 and 62 per cent.

Several commercial analyses of the hand-cobbed ore produced in 1880 were made by the chemists of the Tenth Census. These are reproduced below, as they furnish a good idea of the quality of the product of the mine at that time. For comparison the composition of the ore that had been passed through the concentrators and prepared for shipment in 1906 is given in column 6.

Commercial analyses of hand-cobbed ore from Hibernia mines in 1880 and concentrated ore in 1906.

	1.	2.	3.	4.	5.	6.
Metallic iron	58.22	57.27	53.75	56.00	49 82	57.72
Phosphorus	.407	.139	.364	.223	.343	.332

1. Sample taken across northwest branch of vein at Scott mine.
2. Sample taken across southeast branch of vein at Scott mine.
3. Sample taken from shipment of 24 carloads from Glendon and Lower Wood mines.
4. Sample taken from shipment of 14 carloads from Lower Wood mine.
5. Sample taken from canal-boat load from Willis mine.
6. Sample of concentrated ore, 1906.

ORIGIN OF THE ORE.

From the brief description of the ore bodies given above it is evident that they do not differ materially in character from the bands of Pochuck gneiss or from some of the magnetiferous pegmatite associated with the acidic gneisses. They strike and dip with the surrounding gneisses, possess the same pitch, and end like the Pochuck bands.

In many places the ore is nothing but gneiss containing a large percentage of magnetite. This mineral may be disseminated uniformly or it may occur in tiny veinlets running approximately parallel to the structure of the gneisses. Where it occurs in such veinlets much of the rock traversed by them is also more magnetiferous than the country rock in general.

Where the ore is rich—that is, where it is in definite shoots—more or less of the minerals recognized as characteristic components of the gneisses, viz, hornblende, pyroxene, quartz, plagioclase, and apatite, are always associated with it. The calcite and pyrite where they have been seen are later introductions in the form of veins cutting through the ore, but this is not the invariable mode of occurrence in other parts of the Highlands.

Furthermore, the rock most closely associated with the ore bodies is either a mass of hornblende crystals or a hornblendic rock of the Pochuck type. When the ore-bearing rock is not of the Pochuck type it is usually a pegmatite. Indeed, pegmatite is so common in the dumps of nearly all the mines that it seems that it must be almost universally present in or near the ore bodies.

In a few places the magnetite has been observed in irregular masses within the Losee gneiss and having such relations to the surrounding rock as to suggest that it is a basic secretion analogous to the secretions of titaniferous magnetite in certain gabbros.

From a consideration of the above facts it is concluded that the ores associated with the gneisses are divisible into three groups—(1) those that are very magnetiferous pegmatites, (2) those that are essentially very magnetiferous phases of the Pochuck gneiss, and (3) magnetite segregations in the granitoid gneisses. The last, however, are of no importance commercially as they are too small to work. The first group is also unimportant. In a few places a very rich pegmatite has been worked and the material has found a market at times when the price of iron was high. As this ore is merely a very rich magnetitic pegmatite, its origin is the same as that of the pegmatite in general. It is in the main an intrusive rock. There may have been a little subsequent enrichment, for in some specimens of the pegmatite seen a portion of the magnetite occurs in the spaces between the other components as if it were the latest material to solidify. The greater part, however, is inclosed within feldspar or hornblende, and thus appears to be one of the oldest of the rock's constituents.

The ores associated with the Pochuck gneiss have probably had the same origin as the gneiss. The small veinlets of ore are evidently younger than the hornblendic rock, but the greater portion of it is apparently of the same age. The magnetite and hornblende seem to be intimately intercrystallized, with the magnetite in some places inclosed within the hornblende and pyroxene crystals, and in others filling the spaces between adjacent crystals. The ore and the dark silicates in these aggregates constitute a rock mass, which becomes an ore when the magnetite predominates. If any of the ores associated with portions of the Pochuck gneiss are derived by differentiation from the magma that produced the other gneisses, such ores would have a similar origin as the "pencils" of hornblende and pyroxene in the Byram gneiss. If the Pochuck is metamorphosed sedimentary material the masses of ore must also be a metamorphic product. It does not necessarily follow, however, that the iron must have been present in the original sediment. The analogies of the ores with occurrences of magnetite in other regions where the inclosing rock is sedimentary suggest that the iron here may have been introduced by hot circulating solutions under conditions of igneous metamorphism. Whatever the origin of the ore, it appears to have been in such a condition that subsequent to its formation it was able to move as a mass and to a moderate extent invade the surrounding rocks in the form of small dikes or veins.

A vein origin for the ores of the district does not seem probable. It is true that the series of ore bodies follows the banding of the gneiss, as they probably would if they were infiltrations, but it is also true that they would tend to follow this direction whatever their origin. There are no gangue minerals associated with the ores other than those of the gneiss, nor is there an interbanding of magnetite and hornblende.

FUTURE DEVELOPMENT.

There is no means now known by which the position of ore beneath the surface in the Highlands may be predicted from the geologic features observed above ground. It is known that the best and most continuous veins are associated with narrow bands of black gneiss, but where the ore is rich the proportion of black silicates present is so small that the gneiss has not its usual aspect, and moreover it is in many places observable only as very narrow selvages on the sides of the ore bodies.

Fortunately ths ore is magnetic, so that by tracing lines of magnetic attraction on the surface the positions of ore-bearing rocks beneath the surface may be outlined. It is to be remembered, however, that much of the pegmatite of the Highlands contains magnetite and that the Pochuck gneiss always carries large quantities of the mineral, which may attract the magnetic needle even where it does not form definite ore bodies. Hence the discovery of a line or band of attraction is not always proof of the existence of a deposit of workable ore. Where the magnetic band is continuous and its breadth is comparatively great, the chances for the discovery of good ore are greater than where it constitutes a line, even though the strength of the attraction may be comparatively slight. In any event the ground must be tested by pits or explored by a diamond drill before an opinion as to the importance of the deposit is of any value.

GRAPHITE.

It has been known for a long time that graphite is a rather abundant mineral in the crystalline rocks of the New Jersey Highlands. It has been found in the Franklin limestone, in some of the gneisses, and in the pegmatites. It is especially common in the pegmatites that contain mica, and more particularly where they appear to have been sheared. Reference has already been made to the graphitic garnet-biotite gneiss at Hibernia, which is regarded in part as a pegmatite. Graphite has also been observed in a decomposed gneiss, possibly also a pegmatite, on both sides of the road between Rockaway Valley and Denville. A third location is in a narrow belt extending in a northeasterly direction from Dixon Pond to a hill about 1 mile southwest of Kakeout Mountain. Here also it is in a garnet-graphite gneiss. The fourth and most important occurrence is at the Bloomingdale graphite mine, situated between two knolls of gneiss, about one-fourth mile south of the New York, Susquehanna and Western Railroad and 1½ miles west of Pompton.

The belt in which the Bloomingdale mine has been opened is known to extend southwestward as far as Bald Hill, but it has not been traced farther. The mine was in operation about forty years ago. It was later closed down and remained idle until 1883, when it was reopened and again worked for a short period. It is now abandoned. The graphite at this place occurs in large flakes as a component of a very coarse pegmatite and in the form of small scales disseminated through a gneiss at its contact. Here there has been considerable slipping and shearing. Biotite has been developed in the gneiss adjacent to the pegmatite and the sheared portions have been impregnated with graphite. A little pyrite also occurs as veins in the adjoining gneiss. The mineralized zone is reported to be 16 feet wide and to dip at the same angle as the inclosing gneisses, viz, 50° to 70° SSW. An analysis of the ore on the dump is said to have yielded 11.2 per cent of carbon.[1] The ore was crushed and washed in separating works situated at the mine, the capacity of which was 1000 pounds per day. A ready market was found for all the material produced.

COPPER ORE.

At many places the Newark sandstone contains copper minerals of various kinds, and at certain localities the amounts have been sufficient in quantity to encourage mining operations. The principal workings in this area are at the old Schuyler mine a mile north of Arlington, which is said to have been discovered in the year 1719 by Arent Schuyler. Most of the operations there were carried on over a century and a half ago and it is claimed that many tons of ore were produced and shipped. There are extensive galleries extending westward from the edge of the meadows, and a deep shaft from the top of the ridge. The ore occurs in sandstone, in greater part adjacent to diabase dikes and intrusive sheets, and the principal ores were chalcocite and chrysocolla, with some cuprite and malachite. The mines are at present not worked, although an effort was made in 1900 to reopen them and considerable money was spent in clearing them out and in the erection of a reducing plant. Some years ago a small body of rich ore was found in a quarry northeast of Arlington station, and taken out with moderate profit. Its relations are shown in the section forming fig. 8 (p. 12). Small amounts of chrysocolla and other copper minerals appear at many points in the sandstones, both adjacent to the igneous rocks and at places where there is no evidence of igneous action. In New Brunswick there are many stains of copper minerals in the shales and thin layers of metallic copper have been found in the shale at several points under the city.

BUILDING STONE.

Both the Byram and the Losee gneisses furnish excellent stone for rough building purposes and for all uses to which crushed rock is put. Almost any ledge where the rock bands are wide and where the rock is not sheared or badly weathered will furnish suitable stone for all these purposes. The location of quarries therefore depends more on the ease of quarrying and the facilities for transportation than on variations in the quality of the rock. Only three quarries are at present being worked in the Highlands part of the Passaic quadrangle, and these are producing crushed stone from the Losee gneiss. The largest quarry is in a ravine on the southwestern side of Turkey Mountain, about a mile north of Montville station, where a large portion of the hill has been removed; another is on Pequanac River, about a mile west of Pompton; and the third beside the road between Morristown and Mendham, about 1½ miles west of the Morristown railroad station.

At a number of other points quarries have been opened to furnish building stone for local use, but these are worked intermittently, mainly to supply material for foundations, bridge piers, and other purposes for which rough rock is suitable. Stone suitable for dressing is abundant and at many points it might be worked profitably were it not for the lack of transportation facilities. Dimension and monumental stone is produced at quarries just outside the Passaic area from rocks identical with those occurring in it. With an improvement in the means of transportation there is no reason why equally valuable openings should not be made in this quadrangle.

There are extensive beds of sandstone in the Newark group which have been worked at several localities and yield much of the brownstone for the New York City market as well as for local use. The largest production has been from the quarries at Newark, Avondale, Paterson, and Little Falls, which have been in operation for many years. The extensive Newark quarries have been abandoned and lately they were filled for city lots. The Little Falls quarries have yielded large supplies of excellent brownstone. There are two old quarries east of the Avondale depot and another quarry a mile north by west. The stone is rather light colored, fine grained, and massive, and occurs in a succession of thick beds. At Paterson there are old quarries along the northeastern slope of Garret Rock, now abandoned, and active quarries in the gorge along Passaic River. Here the rock is rather coarse and suited mainly for rough work. A mile and a quarter north of Haledon sandstone of a pleasing red-brown color, fine grained and massive, was formerly obtained under the edge of the second Watchung basalt sheet, but the removing of the heavy capping of igneous rock under which the stone dips adds greatly to the difficulty of quarrying. In the eastern portion of Arlington, on the slope just west of the meadows, there are two quarries in gray and light-brown sandstone, some of which is suitable for superstructures. In the western portion of Passaic there is a quarry which produces a fine-grained, massive stone very similar to the material obtained from the Avondale quarries.

Considerable sandstone is obtained from quarries just below the igneous rock west of Orange and at Pleasantdale, Washingtonville, and Warrenville.

ROAD METAL.

The igneous rocks of the Newark group furnish vast supplies of the best of road metal. Paving blocks have been quarried to some extent, mainly along the Palisades, but the principal material now produced is crushed rock for macadamizing. At several points by the river, along the Palisades front, diabase has been blasted out, crushed, and loaded directly on scows for shipment to points about New York. Quarrying has recently been stopped by the Palisades Park Commission.

The diabase at Granton and Snake Hill is worked to some extent for road metal, and there are several quarries on the Watchung Mountains, notably about Paterson, Great Notch, Upper Montclair, Milburn, Springfield, West Summit, Murray Hill, Scotch Plains, and Plainfield, and on the west slope of Second Watchung Mountain east and northeast of Preakness. At Graniteville, on Staten Island, the diabase is extensively quarried and crushed for use in constructing the fine roads of Richmond borough.

LIME AND FLUX.

The white limestone occurring 2 miles north of Montville was at one time worked extensively for flux for use in the Boonton iron works and also for burning into lime. The following analysis, from the Geology of New Jersey, 1868, indicates that the rock is a dolomite.

Analysis of limestone 2 miles north of Montville, N. J.

Lime	30.41
Magnesia	19.29
Oxide of iron and alumina	.80
Carbonic acid	42.60
Insoluble (in acid)	4.80
Water	.90

At one time the thin bed of limestone in the Newark group, 2 miles north of Scotch Plains was burned for lime and a fairly satisfactory product obtained for local use. The rock contains 65 per cent of carbonate of lime, 4 per cent of carbonate of magnesia, and 31 per cent of other components, mostly insoluble.

CLAY.

Large amounts of clay are annually mined from the small area of Raritan clay in the Passaic quadrangle and sent to many States. In addition a much larger amount is manufactured into various kinds of clay products within the limits of the district. So extensive have been the operations for many years that hundreds of acres have been dug over and many large excavations made, which are now partly filled with refuse heaps of inferior clay and stripping.

The importance of this district as a clay-mining center is due to the great variety, superior quality, and extent of the clay deposits; the hilly character of the district, whereby the clay is exposed at a large number of places; the excellent transportation facilities, both by rail and water; and the situation of the district with respect to the great trade centers of the country.

The kinds of clay here dug are numerous, many of the pits yielding five or six grades, which are carefully sorted in digging and sold for different purposes. The principal grades are described below, although the local names provide for several times as many varieties.

The No. 1 fire clays, the fusion point of which ranges from Seger cone 30 to 35 (3146° to 3326° F.), are white or light blue clays, brittle and not very sandy. They are commonly used for the best grades of fire brick, but some are sold for saggers. The most highly refractory clays are from the Woodbridge fire-clay bed in the banks near Woodbridge, these being superior in refractoriness to the best fire clays from the same bed elsewhere and from the Amboy and Raritan fire-clay beds.

Ball clay is produced to a small extent. In point of refractoriness it is equal to the best fire clays, but is used in the manufacture of floor tile and with other clays in making lead crucibles. Analyses of samples of some of the best fire clays, a ball clay, and "kaolin" are as follows:

Analyses of clays from Passaic quadrangle.

	Ball clay.	No. 1 fire clay.	Fire clay.	"Kaolin."
Silica	45.76	50.6	64.28	82.51
Alumina	39.05	34.35	24.67	11.57
Ferric oxide	Trace.	.78	.83	.63
Titanium oxide		1.62		
Lime	.95	Trace.	.73	.29
Magnesia	.04	Trace.	Trace.	.78
Alkalies	Trace.		2.35	2.66
Loss on ignition	14.46	12.90		
	100.26	100.25		

The No. 2 fire clays are usually red or red mottled and fuse between cones 27 and 33 (3038° and 3254° F.). Some No. 2 fire clays from the banks at Woodbridge are more highly refractory than the No. 1 fire clays of other localities. They are used for No. 2 fire brick, and also in hollow brick, saggers, bath tubs, terra cotta, buff brick, fire mortar, etc.

Stoneware clays are in point of refractoriness good No. 2 fire clays, but burn denser and are used for stoneware.

All of the above-described clays burn white or buff; none of them red.

Fireproofing and conduit clays come almost entirely from the black laminated clays above the Woodbridge fire clay, and are dug extensively at Woodbridge, Maurer, and Florida Grove. They burn red at comparatively low temperatures, are of moderate tensile strength, but are not refractory. They are used largely for hollow brick, fire proofing, and conduits.

In addition to the clays, the so-called "feldspar" is dug at several places for use in fire-brick mixtures. The following analyses of samples from different localities indicate its composition:

Analyses of "feldspar" from Passaic quadrangle.

Free silica	58.89	57.41
Combined silica	16.99	16.59
Alumina	18.95	17.55
Ferric oxide	.49	.54
Potash	.15	.12
Soda	.21	.21
Titanium oxide (with SiO_2)	-----	.90
Water	4.90	6.30
	102.58	99.62

Owing to the large quantity of sand present, this material is not highly refractory, although the amount of fluxes is low.

In addition to the Cretaceous clays so extensively worked near Woodbridge and Perth Amboy, brick clays of Pleistocene age are dug at several points. At Little Ferry and Hackensack there are extensive openings along Hackensack River, some pits being 60 feet deep. The clays burn red and become "steel hard" at a comparatively low temperature. Ten firms here manufacture many millions of brick annually, all by the soft-mud process. The yards are all situated along tide water, so that shipping facilities are good. Below are given the chemical analyses of two of these clays:

Analyses of common brick clays from Passaic quadrangle.

	Little Ferry.	Hackensack.
Silica (SiO_2)	66.67	59.69
Alumina (Al_2O_3)	18.27	24.05
Iron oxide (Fe_2O_3)	3.11	
Titanium oxide (TiO_2)	.85	.44
Lime (CaO)	1.18	1.63
Magnesia (MgO)	1.09	2.03
Potash (K_2O)	2.92	.54
Soda (Na_2O)	1.30	2.39
Water (H_2O)	4.03	4.85
Moisture		.80
Total	99.42	96.42
Total fluxes	9.60	

At Singac and Mountain View dark-colored glacial-lake clays are dug extensively for common red brick. In some pits the laminated clays are overlain by clayey till, which is also used, the bowlders being rejected in digging, the larger stones separated

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[1] Ann. Rept. Geol. Survey New Jersey, 1879, p. 154.

by a rotary sieve, and many of those under an inch in diameter finding their way into brick. The railroad and canal afford good shipping facilities. Clayey till or glacial-lake clays are also dug for common red brick at Morristown, Whippany, Elizabethport, Linden, Berkeley Heights, and North Plainfield. A postglacial flood-plain clay is utilized in a small way at Dunellen. At Linden the glacial till, composed chiefly of the ground-up Triassic shales, is so plastic that it is used for earthenware pottery in neighboring towns, and at Kingsland excellent bricks are made from the Triassic shales themselves.

SAND AND GRAVEL.

Pits have been opened in many of the kames, morainal knolls, and deltas of the stratified drift deposits, and various grades of sand and gravel are dug for road metal, ballast, building sand, and like purposes. It is hardly possible or necessary to enumerate all the localities at which these materials have been dug. One of the largest openings is near Montville, on the edge of a glacial delta associated with Lake Passaic, and another is south of Morris Plains station along the railroad. Small amounts of molding sands have been dug in a few localities, but not extensively.

The best of the fire sands underlying the Woodbridge fire clay carry from 92.5 to 98 per cent of silica, and 1.45 to 6.55 per cent of alumina and iron oxide. They are used to some extent in fire-brick manufacture, in foundries, and for building sand.

PEAT.

Beds of peat occur in many of the swamps, but at only one point has there been any recent attempt to utilize it. During 1904 and 1905 the American Peat Coal Company operated a plant on the Bog and Vly Meadows near Lincoln Park. The peat was dug, broken, thoroughly kneaded, and then forced through a die, issuing from the machine in two bars each 4½ inches in diameter. These were cut into small sections and air dried on shelves for several days, until they became hard and brittle. The market was local and the product sold for $3 per ton.

The following analyses of peats found within the area of this quadrangle were made by the New Jersey State Survey:

Analyses of peat from Passaic quadrangle.

Locality.	Moisture at 105° C.	Ash, air-dried sample.	Fixed carbon.	Volatile matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Pequanac	18.09	10.91	27.20	61.77
Do	19.84	12.69	26.46	60.85
Hackensack	14.20	20.74	26.01	53.25
Chatham	15.21	33.07		
Do	14.82	53.87		
Black Meadows	17.80	12.43	26.38	61.19
Great Meadows	17.81	10.84	26.61	62.55
Great Swamp	7.58	66.40		
Do	9.59	50.48		
Do	11.80	45.92		
Do	16.19	13.86	26.23	59.91
Troy Meadows	13.27	39.02		
Do	13.94	32.61		
Do	17.54	10.60	27.20	62.20
Do	17.86	13.44	25.52	61.04
Hatfield Swamp	13.15	39.89		
Bog and Vly Meadows	15.26	25.19		
Do	17.25	7.28	29.80	62.92

Locality.	Calorific value.		Nitrogen.	Coke.
	Calories.	B. t. u.		
			Per cent.	*Per cent.*
Pequanac	4,966	8,938	2.18	38.23
Do	4,789	8,620	1.61	39.15
Hackensack	4,312	7,761	1.87	46.75
Chatham			1.50	
Do			.98	
Black Meadows	4,791	8,624	2.05	38.81
Great Meadows	4,885	8,794	1.88	37.45
Great Swamp			.74	
Do			1.26	
Do			1.34	
Do	4,947	8,905	2.07	40.09
Troy Meadows			1.36	
Do			1.65	
Do	5,272	9,490	1.46	37.80
Do	4,901	8,820	1.98	38.96
Hatfield Swamp			1.40	
Bog and Vly Meadows			1.58	
Do	5,378	9,680	2.16	37.08

UNDERGROUND WATER.

NEW JERSEY.

In most of the New Jersey portion of the Passaic quadrangle abundant local water supplies are obtained from shallow wells. The largest number of these wells are sunk in the glacial drift or other Quaternary deposits, to depths mostly from 10 to 50 feet. Many shallow wells also obtain water in the red shales or sandstones of the Newark group. These rocks, however, vary greatly in the amount of water which they yield and no definite water horizons are known. In some of the coarser sandstones, as in the region about Newark and Passaic, there appears to be a considerable volume of water in the rock, but in the finer-grained materials the water exists mostly in the small fissures along the joint planes. Large volumes of water are obtained in numerous wells in red sandstone about Newark and Passaic, the depths at Newark ranging from 120 to 800 feet, and at Passaic from 90 to 400 feet. Deeper borings at Passaic and a boring 2100 feet deep at Paterson were unsuccessful. In the deep well at Paterson water was found at a depth of 900 feet only.

The following is a list of deep borings reported in the New Jersey portion of the Passaic quadrangle:

Deep borings in New Jersey portion of Passaic quadrangle.

Locality.	Depth.	Remarks.
	Feet.	
Arlington	270	In red sandstone; yields 375 gallons a minute.
Bayonne	600	Small yield.
Belleville	150	Yields 150 gallons a minute from red shale.
Bonhamton	208	Gravel to 65 feet, then red shale with water at 208 feet; good water supply.
Caldwell	875	Through basalt into sandstone.
East Rutherford	189	In red sandstone, 48 to 189 feet; good water supply.
Elizabeth	216–300	Several wells; good water supply in red shale.
Ellis Island	1400	Brackish water; 35 to 1400 feet in gneiss.
Franklin	355	Yields 125 gallons a minute.
Harrison	400	Yields 100 gallons a minute from red shale.
Hoboken, near south end of Grand street.	400	Bored in 1828; rock at 40 feet: mostly serpentine from 40 to 400 feet; no water.
Hohokus	200	Good supply.
Jersey City:		
Pavonia (Erie) Ferry.	179	To "serpentine."
Limbeck's brewery.	846¼	Yields 33 gallons a minute. In red sandstone, 70 to 846¼ feet; water in gravelly bed at 826 feet.
Malone & Co	500	Yields 50 gallons a minute.
Central stock yards.	455	Red sandrock 70 to 215 feet, then in mica schist; brackish water.
Communipaw	500	Salt water.
Sugar refinery	1000	Yielded 50 gallons a minute, mostly from 720 feet, but water too brackish for use. "In gneiss."
Cox's brewery	400	Small supply of very hard water; dark and brown sandstone, 70 to 400 feet.
Dixon Co	1205	Yields 22 gallons a minute.
Colgate & Co	1500	Yields 15 gallons a minute; in gneiss.
Canal Co.	650	Small supply.
Traction Co.	2200	No water; red sandstone, 1400 feet and more.
Mehl & Co.	1007	Yields 150 gallons a minute; on the Heights.
Coal dock.	450	Brackish water.
Hudson street, between Morris and Essex.	250	In gneiss 150 feet.
Montgomery and Henderson streets.	215	In red sandstone 15 to 200 feet; mineral water.
Kearney	600	Yields 50 gallons a minute from sandstone.
Linden	146–200	Red shale; two wells yield 750 gallons a minute.
Marion	410	In altered shale and diabase.
Maurer	500	"Granite" below 110 feet.
Milburn	800	Through "trap" 30 to 235 feet; yields 100 gallons a minute
Montclair, Mount Prospect.	510	Yields 45 gallons a minute; soft water.
Morristown, 2 miles west.	438	Small supply within 60 feet of surface.
Newark:		
Ballentine's brewery.	529	Yields 150 gallons a minute from red shale.
Celluloid Co.	827	Yields 200 gallons a minute.
Citizens' Gas Co.	600	Yields 50 gallons a minute.
	615	Yields 550 gallons a minute.
Smelter	500	Yields 500 gallons a minute; water slightly hard.
Lister Bros	615	Yields 500 gallons a minute; water too impure for steam or drinking.
New Brunswick	175–303	Several flowing wells; hard water.
New Orange	106	Gravel 45 feet, reddish shale 161 feet; yields 60 gallons a minute; water rises within 14 feet of surface.
Passaic:		
Parchment Paper Co.	1000	Small supply.
Worsted Co	558	Yields 112 gallons a minute; water at 400 feet in sandstone.
Do	402	Yields 240 gallons a minute; water rises within 28 feet of surface.
Do	200–250	Yields 200 gallons a minute from red sandstone under 86 feet of drift.
Paterson:		
Rolling mill	2100	No good water below 900 feet; yields 100 gallons a minute from that depth.
Do	900	Good supply of excellent water.
Burton brewery	204	Yields 30 gallons a minute.
Perth Amboy	230	Water-bearing sand at 105 to 152 feet; nearly flows.
Perth Amboy (Eagleswood).	470	No water; 70 to 470 feet in crystalline rock.
Plainfield:		
Eastern city line.	205	Drift 149 feet; good supply of water in red shale, 149 to 205 feet.
	400	Yields 300 gallons a minute from red shale.
Pompton	200	Blue rock; but little water.
Rahway	150–200	Water at 26 to 30 feet in drift; but little water in red shales below.
Rutherford	202	Flowing well; sandstone from 35 to 202 feet.
Sand Hills	202	Red shales below 100 feet; moderate water supply.
Secaucus	600	Water from 200 to 250 feet; yields 8 gallons a minute.
Sewaren	250	Yields 20 gallons a minute.
Soho	120	Red sandstone; good supply of water.
South Plainfield	200–250	Good supply of water from red shales.
Springfield	275	Red shales 68 to 275 feet; yields 20 gallons a minute.
Summit, ice company.	325	Yields 100 gallons a minute from red sandstone near the basalt.
Union	500	Ten flowing wells.
Waverly Park	450	Small supply of water from sandstone.
Do	280	Fair supply of water from sandstone.
West Orange	384	Yields 100 gallons a minute; red shale and sandstone.

Most of these borings are in the red sandstone or red shales of the Newark group. Some of those in the eastern part of Jersey City are in the underlying crystalline rocks, but these have not been successful. The igneous rocks of the Newark group yield water supplies in many wells of various depths, but the water is entirely in fissures and its amount varies from place to place. A deep boring at Caldwell passed entirely through the basalt sheet of Second Watchung Mountain and obtains water from the underlying sandstones. On the Palisade Ridge wells have penetrated the diabase, and one of them in Jersey City yields 150 gallons a minute. In the Highlands springs and running water of good quality are abundant, and shallow wells in the valleys obtain plenty of water from the Quaternary deposits.

Flowing wells are obtainable on the inner side of the terminal moraine, in a small area about Chatham. A number of borings in this locality, 90 feet in depth, have flows of considerable volume, which rise several feet above the surface, and they have continued to flow for several years. One 5-inch well is reported to flow 100 gallons a minute. The water-bearing stratum is a bed of gravel and coarse sand overlain by clay and fine sand. Similar conditions prevail at Madison, where, at depths of 83 to 148 feet, flows of large volume are obtained. One well 83 feet deep had a flow of 400 gallons a minute at a point 2 feet above the ground.

Artesian flows have likewise been found along the west slope of Second Watchung Mountain, at the East Orange waterworks, and there are also flowing wells along the valley of Canoe Brook. This region is a basin filled with a great mass of glacial drift sloping up on the adjoining higher lands from which the head of the water is derived.

An excellent artesian well has been obtained at Rutherford at a depth of 202 feet. Its water supply is derived from dark sandstone in the Newark group.

About Woodbridge several wells obtain water from coarse sands in the lower beds of the Raritan formation. These beds lie upon a floor of Newark rocks, which appears to be very uneven in contour, and the water-bearing sands are of slight extent.

At Perth Amboy several attempts to obtain deep-seated waters have been unsuccessful. One boring in the western part of the city (Eagleswood) penetrated 61 feet of Raritan clay, 9 feet of red shale, and 400 feet of granite or gneiss without obtaining water.

At Maurer a large amount of water is obtained from several wells 53 to 146 feet deep. One boring at this place penetrated "granite" from 110 to 500 feet and found it to contain no water.

STATEN ISLAND.

There is considerable diversity in the underground water conditions on Staten Island and although a large amount of water appears to be available in shallow wells, satisfactory supplies are not obtainable at all localities. The coarse deposits of the drift which cover nearly all of the island are the principal sources of supply. Most wells are less than 50 feet in depth and they obtain sufficient water for domestic use. A number of deep wells have been bored, as a rule without obtaining a large volume of water. The Raritan formation, which underlies the eastern and southern portions of the island, contains sand beds that yield water to a number of wells, but in most localities little or no water has been found in them. They lie upon a floor of gneiss or mica schist, sloping eastward and probably at least 400 feet below the surface along the bay shore, their depth being 450 feet at Hoffman Island. The best prospects are in the lowest beds, which apparently have not been tested in the southeastern and southern portions of the island. At Clifton a well 900 feet deep penetrated 200 feet of drift, 400 feet of Raritan sand and clay, and then was bored 300 feet into the mica schist, obtaining a moderate supply of water. At Princess Bay a well 147 feet deep is reported in Raritan beds which yielded no water. At Arbutus Lake, near Huguenot, there is a boring which failed to obtain water at a depth of 220 feet, but, at the time of the report, it was to be bored deeper. At Kreischerville a boring 200 feet deep ended in quicksand and was a failure, but a well in the hills at Annadale, 246 feet deep, obtained a satisfactory supply which rises within 120 feet of the surface. This well found yellow gravel extending from 200 to 236 feet, underlain by a bed of white and blue clay said to be a fine pottery clay. Apparently none of these wells in the southern portion of the island is sufficiently deep to test the water resources of the lower coarser beds of the Raritan formation. Several wells have been sunk in the serpentine; one on Ocean Terrace at an altitude of 260 feet is 150 feet deep and yields 15 gallons a minute. Another west of New Dorp is 600 feet deep in serpentine and yields no water. A well at Dongan Hills is 265 feet deep in serpentine and obtained but little water until it was dynamited, when it developed a supply of 250 to 300 gallons a minute. At Castleton Corners a boring 150 feet deep is stated to have entered serpentine at 64 feet and obtained water which rises within 63 feet of the surface and pumps 8 gallons a minute.

No deep wells are reported in the Newark sediments except one on Shooters Island which was sunk to a depth of about 200 feet without success.

LONG ISLAND.

The west end of Long Island is underlain by sands, gravels, and clays lying upon a floor of crystalline schist. This floor is not far below the surface opposite the south end of Manhattan Island, but it sinks gradually toward the south, to a depth of 450 feet on Hoffman Island and probably to about 500 feet on the west end of Coney Island. The surface material is glacial drift, underlain to the south by Cretaceous sands of which the northern margin is probably not far south of Gowanus Bay. Water occurs in large amount in the drift at depths 10 to 180 feet and usually is of good quality, except along the immediate bay shore, where much of it is brackish. The Cretaceous sands probably contain water for deep wells south of Bay Ridge, but they have not been tested on the west end of the island. The only deep well reported is one sunk for the Rapid Transit Company at the foot of Thirty-ninth street, Brooklyn. It is an 8-inch boring and reached a depth of 1503 feet, obtaining considerable water that was too salty to be of use. The following is the record:

Record of deep well at foot of Thirty-ninth street, Brooklyn.

	Feet.
Sand	0– 73
Clay	73– 95
Fine sand	95– 101
Clay	101– 139
"Hardpan"	139– 169
Coarse sand	169– 189
"Hardpan"	189– 212
Rock (gneiss)	212–1503

Passaic.

It is supposed that the basal sedimentary beds below 189 feet may possibly represent the edge of the Cretaceous sediments, but there is no definite evidence on this point.

HOFFMAN ISLAND.

The well on Hoffman Island is 1000 feet deep and 8 inches in diameter and yields 33 gallons a minute. The boring passed through 450 feet of sand, clay, and gravel of Pleistocene and Cretaceous age, containing salty water. Rock, probably gneiss, was entered at a depth of 450 feet and penetrated to 1000 feet. Some water found in its upper portion was brackish, but below 750 feet the quality improved and a supply of fresh water was finally obtained.

GOVERNORS ISLAND.

There is a remarkable well on Governors Island, which yields a flow from the crystalline rocks at a depth of 1715 feet. The flow is 18 gallons a minute, but unfortunately the water is too salty for use. The rock penetrated was reported to be gneiss and it was entered at a depth of 75 feet, under glacial drift.

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March, 1908.

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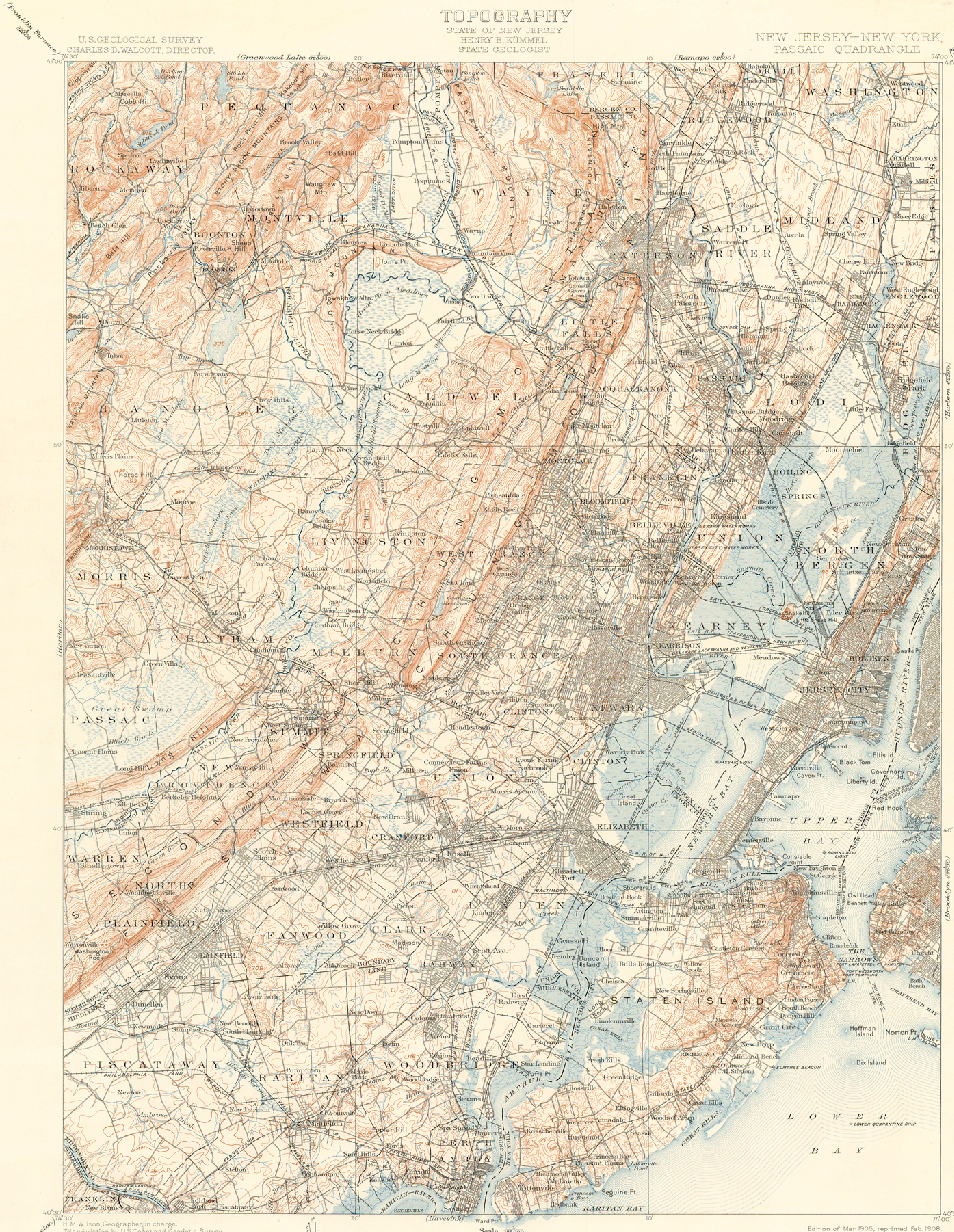
TOPOGRAPHY

STATE OF NEW JERSEY
HENRY B. KÜMMEL
STATE GEOLOGIST

NEW JERSEY–NEW YORK
PASSAIC QUADRANGLE



H.M.Wilson, Geographer in charge.
Triangulation by U.S.Coast and Geodetic Survey.
Topography by the U.S.Coast and Geodetic Survey, the Geological Survey of New Jersey, S.H.Bodfish, Frank Sutton, R.D.Cummin, E.B.Clark, J.H.Wheat, J.W.Thom, and W.E.Horton.
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N.Y. AREA SURVEYED IN COOPERATION WITH THE STATE OF NEW YORK.

APPROXIMATE MEAN DECLINATION 1902.

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. 1905, reprinted Feb. 1908.

LEGEND

RELIEF
printed in brown

493 Figures *showing heights above mean sea level instrumentally determined*

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

Depression contours

DRAINAGE
printed in blue

Streams

Canals and ditches

Aqueducts

Lakes and ponds

Salt marshes

Fresh marshes

CULTURE
printed in black

Roads

Private and secondary roads

Railroads

Bridges

Drawbridges

Dams

State lines

County lines

Township lines

City, village and borough lines

△ Triangulation stations

☼ LH Lighthouses

AREAL GEOLOGY

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NEW JERSEY—NEW YORK
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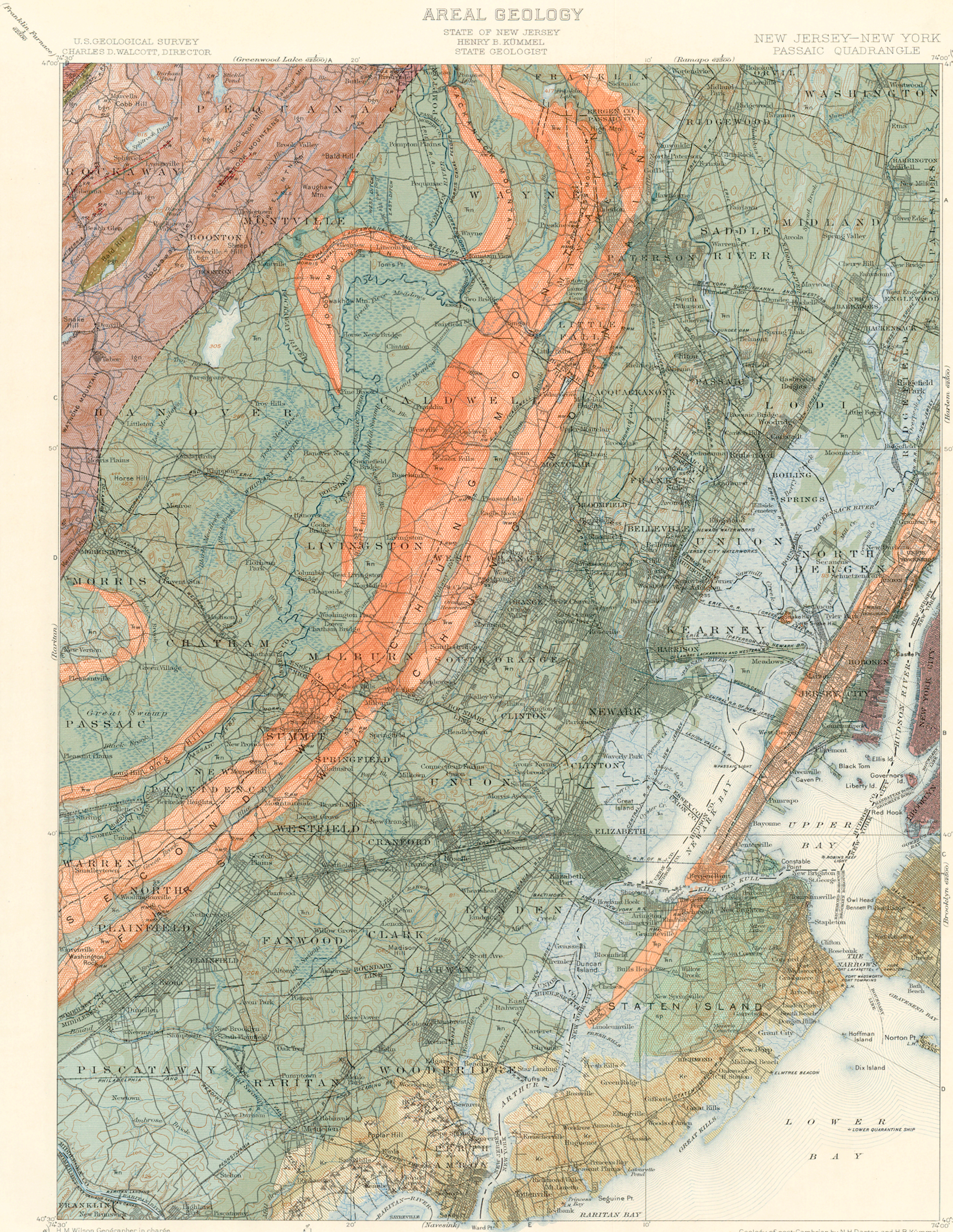

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LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, metamorphism is indicated by hachures combined with the line patterns)

CRETACEOUS

Kr — **Raritan formation** *(coarse sand and dense, variegated clays)*

UNCONFORMITY

TRIASSIC

Tkn, Tkc — **Newark formation** * *(red sandstone and shale with occasional outcrops of conglomerate, Tkc)*

UNCONFORMITY

SILURIAN

Sgp — **Green Pond conglomerate** *(coarse white quartz conglomerate)*

UNCONFORMITY

Metamorphic

ORDOVICIAN

Oh — **Hudson schist** *(gneiss and mica schist, with granite dikes in eastern portion, black slate in northern portion)*

UNCONFORMITY

PRE-CAMBRIAN

fl — **Franklin limestone** *(white marble containing pyroxene and much serpentine)*

IGNEOUS ROCKS

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

TRIASSIC

Tkp — **Palisade diabase** *(intrusive sheet forming the Palisades of the Hudson, and small dikes, one of basalt, Tkb)*

Tkw — **Watchung basalt** *(three successive lava flows interbedded in the Newark formation)*

ORDOVICIAN OR LATER

sp — **Serpentine** *(altered igneous rock)*

PRE-CAMBRIAN

bgn — **Byram gneiss** *(gray granitoid gneiss composed of microcline, microperthite, quartz, and hornblende, with a little pyroxene and biotite)*

lgn — **Losee gneiss** *(white granitoid gneiss composed of quartz, oligoclase, pyroxene, and in places some hornblende and biotite)*

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

(Areas of metamorphic rocks of unknown origin are shown by hachures)

PRE-CAMBRIAN

pgn — **Pochuck gneiss** *(dark gneiss composed of pyroxene, hornblende, oligoclase, and magnetite)*

Garnetiferous graphite schist *(schistose rocks of quartz, mica, garnet, and graphite; weather red)*

Note: *In areas deeply covered by drift the patterns are subdued by an overprinted color and the boundaries are dotted. The Quaternary deposits are represented on the surficial geology map.*

Faults

Known mineral deposits

Belts of magnetite deposits

⚒ *Mines and quarries*

R	*Iron, active within 25 years*
GP	*Graphite*
RM	*Road material*
SS	*Sandstone*
LS	*Limestone*
G	*Granite*

X R *Abandoned iron mines*
X C *Abandoned copper mines*
⚒ *Clay and sand pits in Raritan formation*

* *Sedimentary rocks of the Newark group should be substituted for Newark formation.*

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SURFICIAL GEOLOGY

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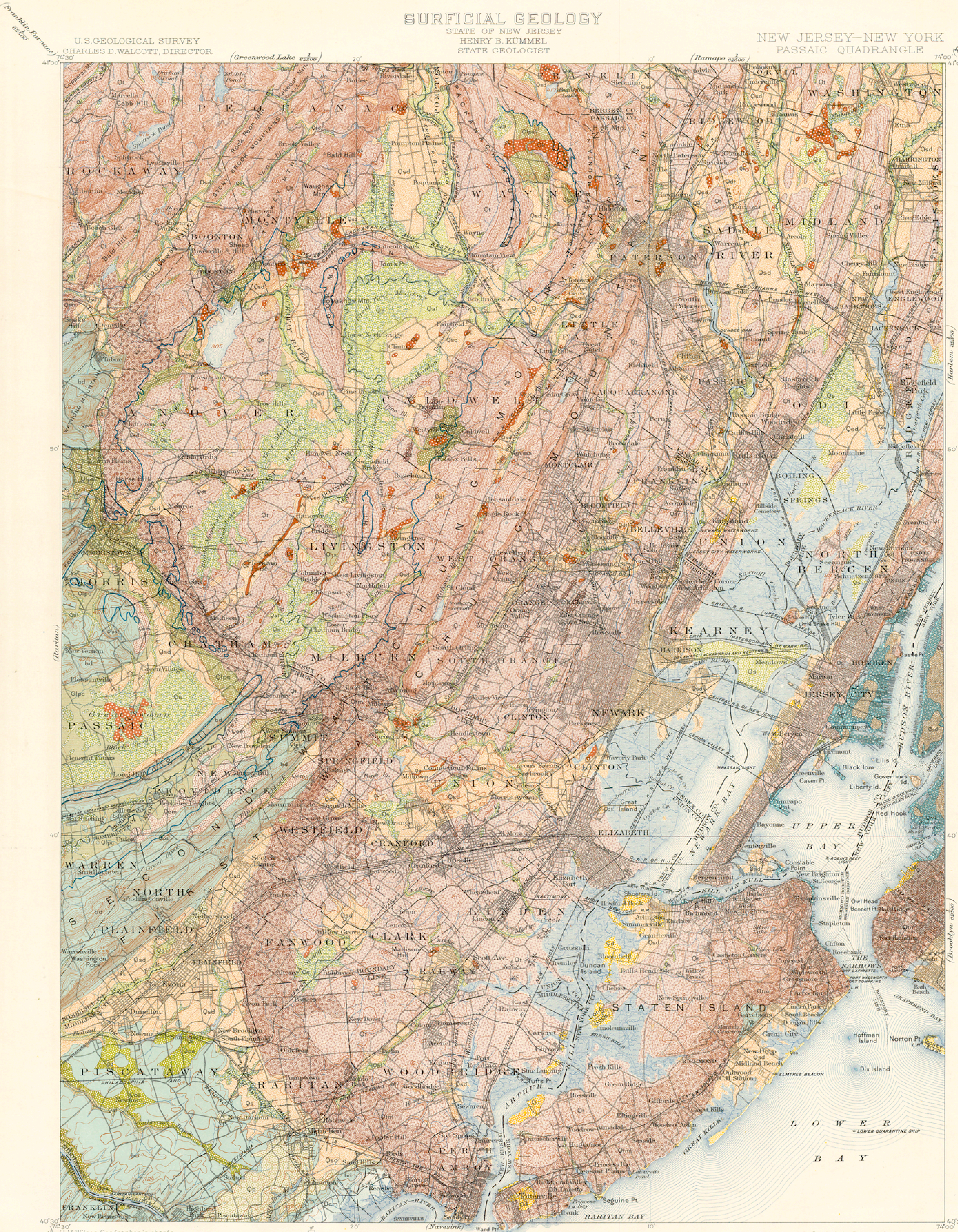

LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY

Recent

- Qml — Made land
- Qal — Recent alluvium *(in stream bottoms)*
- Qs — Swamp muck *(tidal flats not included)*
- Qbs — Recent beach sand and gravel
- Qd — Dunes and dune sand

Pleistocene

- Qcm — Cape May formation *(gravel and sand of marine shallow-water origin)*
- Qoa — Older alluvium
- Qlpc — Loam and clay deposits of Lake Passaic
- Qlps — Shore deposits of Lake Passaic *(stratified sand and gravel of beaches and deltas)*
- Shore line of Lake Passaic *(broken line indicates approximate location)*
- Qe — Eskers *(ridges of stratified drift)*
- Qk — Kames, kame terraces, and stratified drift of kame habit *(irregular deposits of stratified drift)*
- Qsd — Stratified drift
- Qdt — Stratified drift and till *(undifferentiated)*
- Qem — Extra-morainic drift *(of late glacial age)*
- Qdr — Drumlins and drumloids *(elongate elliptical hills of till)*
- Qt — Till *(includes areas where there is very little drift and rock exposures are numerous)*
- Qtm — Terminal moraine *(belt of thick drift with very irregular topography)*
- Qp — Pensauken formation *(sand and gravel thinly covered with till)*
- Qb — Bridgeton or Beacon Hill gravel

PRE-QUATERNARY

- bd — Bed rock *(outside of the glacial moraine, bedrock inside the moraine included with till)*

% *Sand and gravel pits*
%c *Clay pits, in surficial deposits*

H.M.Wilson, Geographer in charge.
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Topography by the U.S.Coast and Geodetic Survey, the Geological Survey of New Jersey, S.H.Bodfish, Frank Sutton, R.D.Cummin, E.B.Clark, J.H.Wheat, J.W.Thom, and W.E.Horton.
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Edition of Mar. 1908.

Geology by Rollin D. Salisbury, Charles E. Peet, and Henry B. Kümmel.
Surveyed in 1894–1896.

SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY.

STRUCTURE SECTIONS

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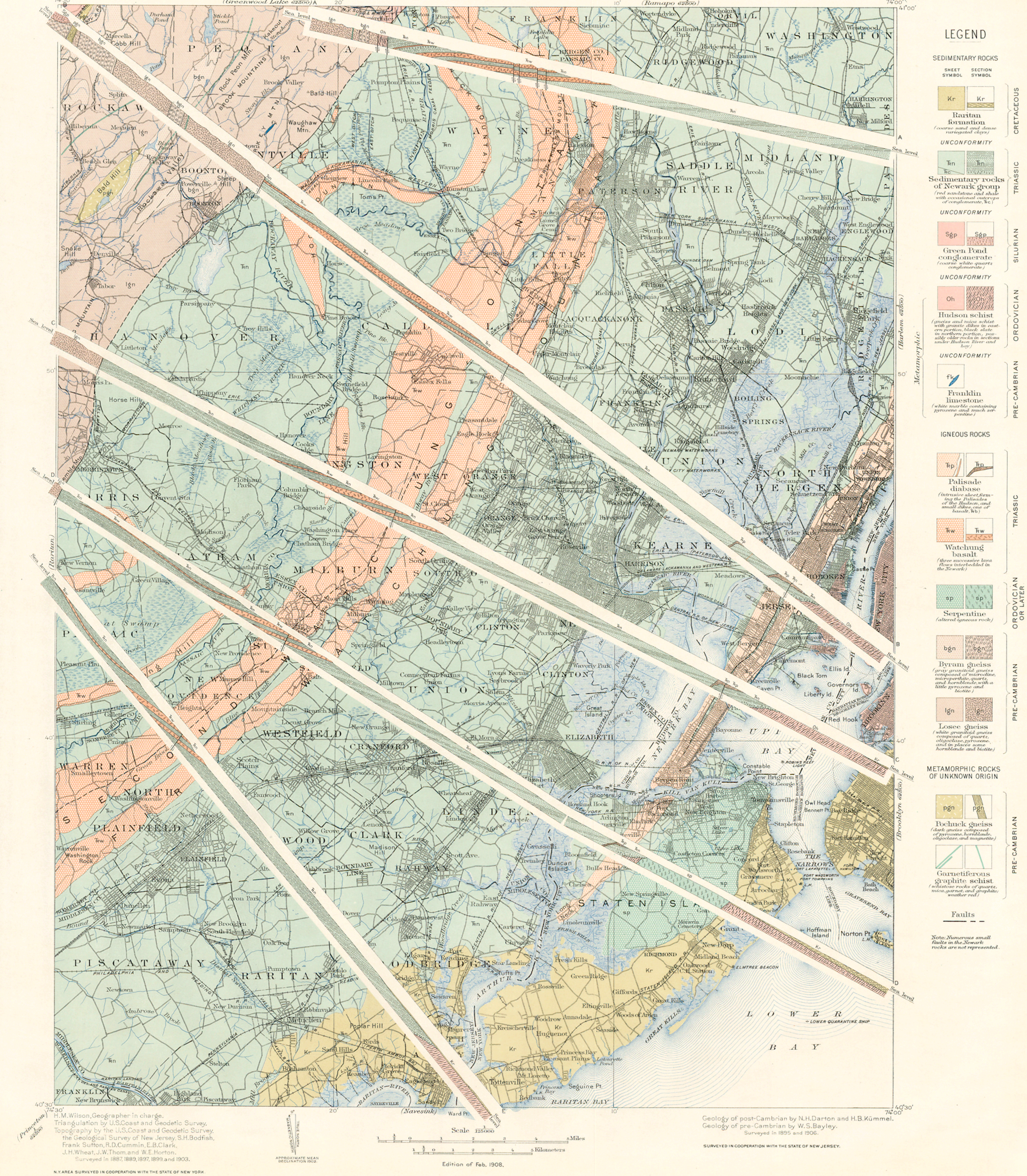

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ILLUSTRATIONS

Fig. 27.—QUARRY NEAR UPPER MONTCLAIR, N. J., LOOKING NORTHWEST.

Watchung basalt lying conformably on Newark sandstone. The sandstone is both bedded and jointed; the basalt is irregularly jointed and columnar.

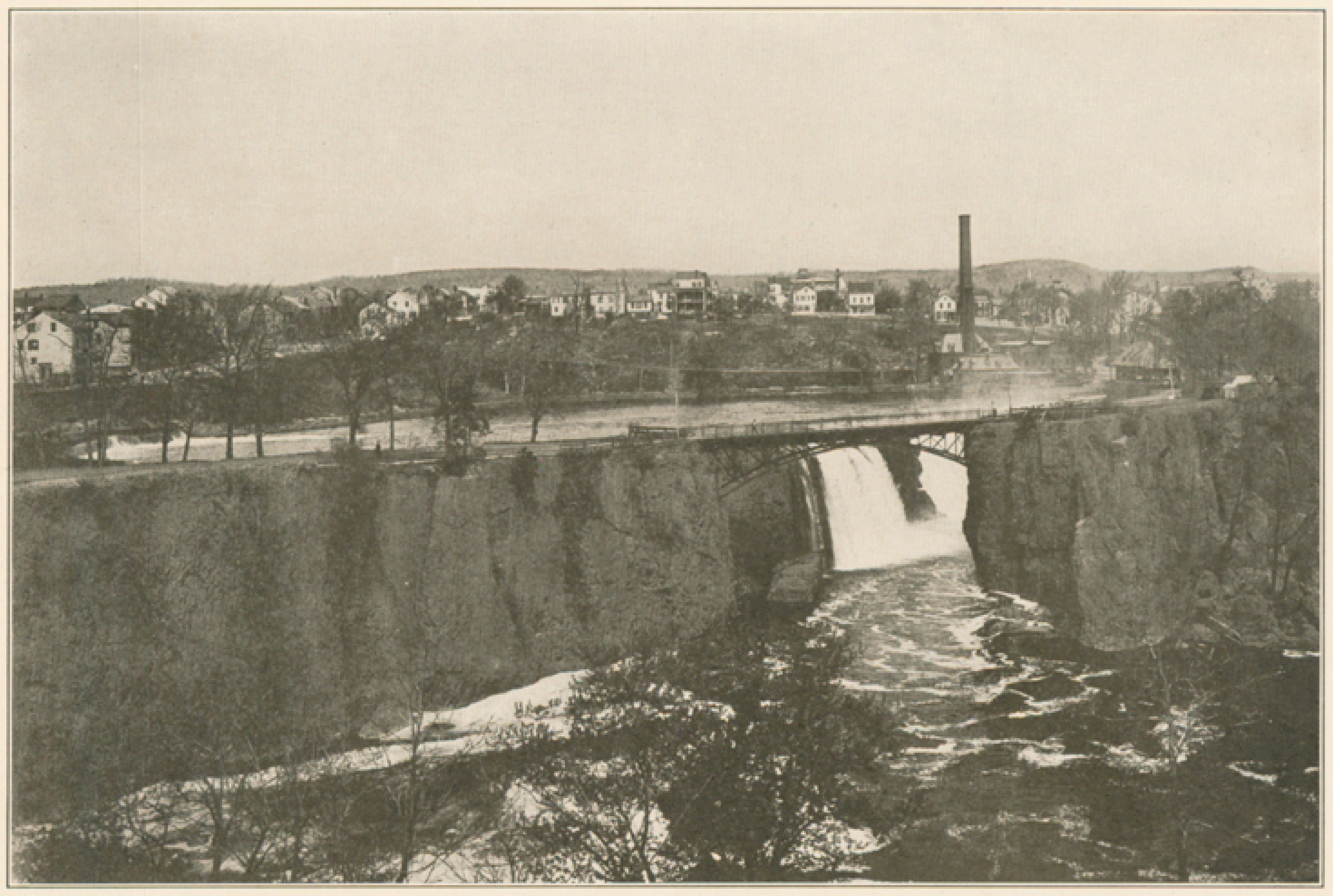


Fig. 28.—GREAT FALLS OF PASSAIC RIVER, PATERSON, N. J.

The gorge is cut in Watchung basalt, and the narrow cleft into which the falls have retreated is along the major joint system.

Fig. 29.—CONFORMABLE CONTACT OF BASALT OF THE FIRST WATCHUNG SHEET ON NEWARK SANDSTONE, BELOW FALLS OF THE PASSAIC, PATERSON, N. J.

The sandstone forms the base of the section immediately above the retaining wall and is overlain by massive-bedded basalt capped by finely columnar basalt.

Fig. 30.—BASALT COLUMNS OF FIRST WATCHUNG SHEET, O'ROURKE'S QUARRY, WEST OF ORANGE, N. J.

The lower portion of the basalt, which rests on sandstone, presents large vertical columns; the upper portion consists of small radial columns.

Fig. 31.—FAULT IN SANDSTONE OF NEWARK GROUP, IN RAILROAD CUT WEST OF ARLINGTON, N. J., LOOKING NORTH.

Shows broad zone of breccia along the fault plane.

Fig. 32.—SECTION OF GLACIAL TILL ON SERPENTINE, CASTLE POINT, HOBOKEN, N. J.

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be determined by observing their positions. This relationship holds except in regions of intense disturbance; in such regions sometimes the beds have been reversed, and it is often difficult to determine their relative ages from their positions; then *fossils*, or the remains and imprints of plants and animals, indicate which of two or more formations is the oldest.

Stratified rocks often contain the remains or imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, 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. When 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 found 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 often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes 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 is sometimes 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 of their metamorphism.

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.

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	Saratogan Acadian Georgian	Є	Brick-red.
	Algonkian		A	Brownish-red.
	Archean		AR	Gray-brown.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. 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 by which formations are labeled 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 recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

Hills and 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; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 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, and these are, in origin, independent of the associated material. 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 afterwards 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. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is called a *peneplain*. If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored 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 given formation, its name should be sought in the legend and its color and pattern noted, when 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 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.—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which 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 the 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 of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

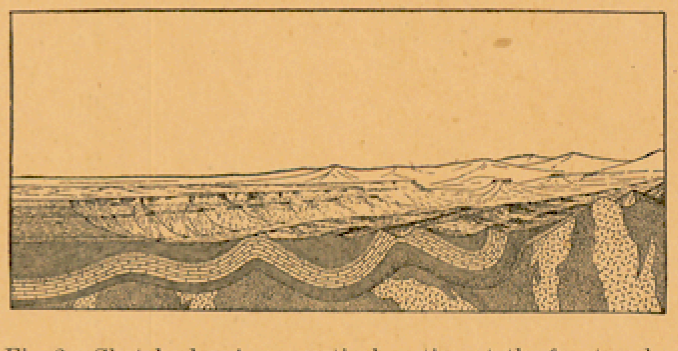
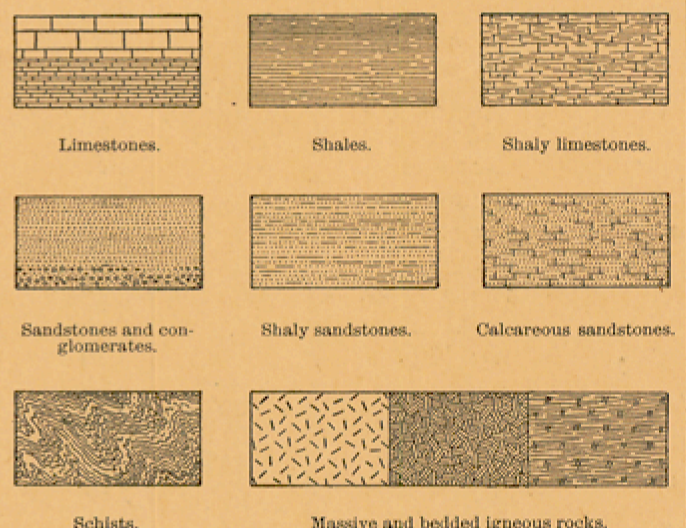


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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 symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:



Limestones. Shales. Shaly limestones.

Sandstones and conglomerates. Shaly sandstones. Calcareous sandstones.

Schists. Massive and bedded igneous rocks.

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

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section. 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 that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; 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 fig. 4.

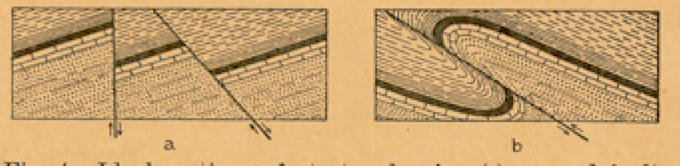


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. 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 well-founded inference.

The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a set of sandstones and shales, which lie in a horizontal position. These sedimentary strata 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 raised from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. 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 at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their 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 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 suffered metamorphism; they were the scene of 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 fig. 2 are ideal, but they illustrate relations which actually occur. 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 which appears in the section may be measured by using the scale of the map.

Columnar section sheet.—This sheet contains a concise description of the sedimentary formations which 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 which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

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

CHARLES D. WALCOTT,
Director.

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