YORK CITY FOLIO
NO. 83

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STATES GEOLOGICA RVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

OF THE

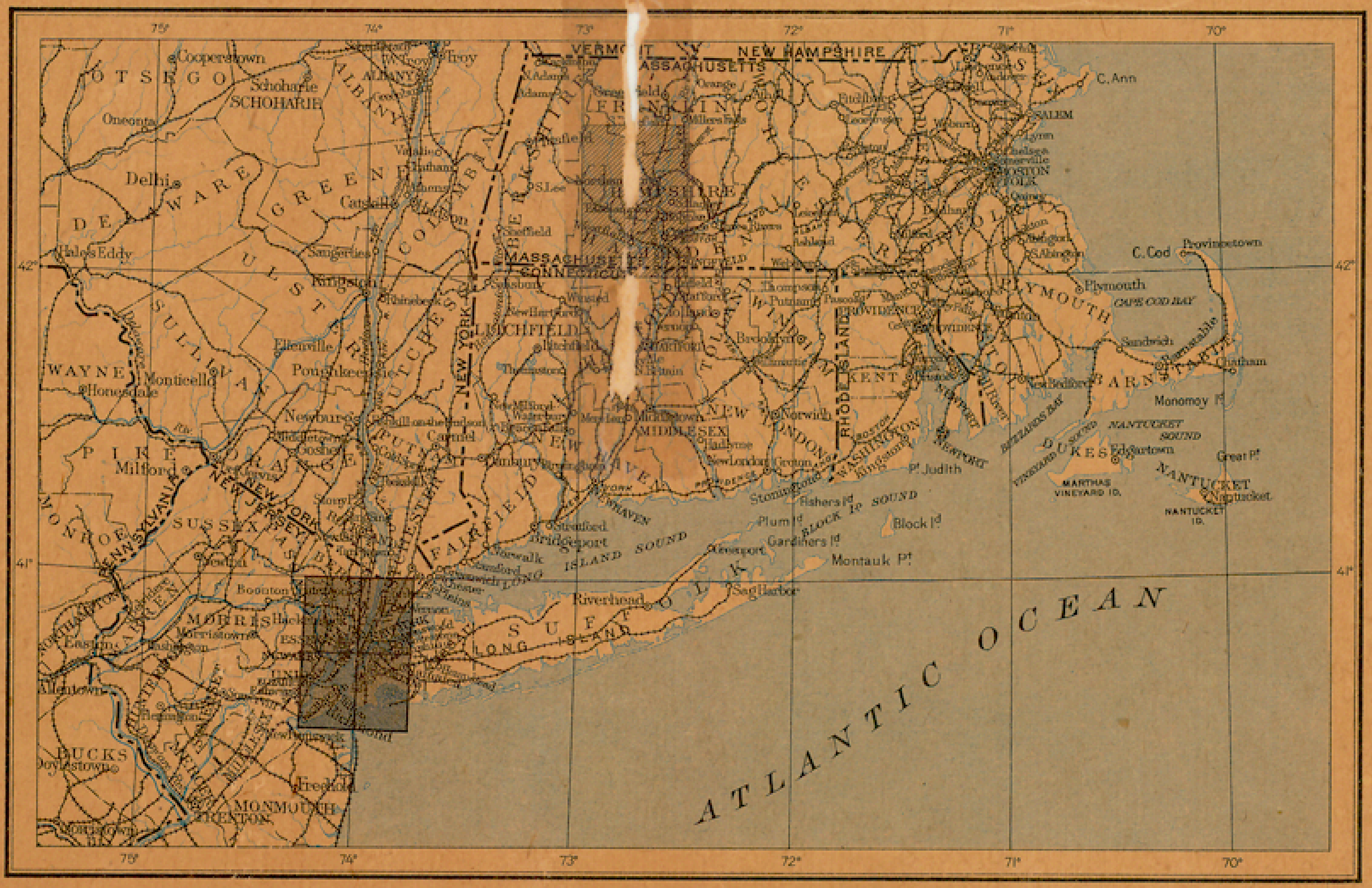
UNITED STATES

NEW YORK CITY FOLIO

PATERSON, HARLEM, STATEN ISLAND, AND BROOKLYN QUADRANGLES

NEW YORK–NEW JERSEY

INDEX MAP



SCALE 40 MILES=1 INCH

AREA OF THE NEW YORK CITY FOLIO

AREA OF OTHER PUBLISHED FOLIOS

DESCRIPTIVE
TOPOGRAPHIC
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SURFICIAL GEOLOGY MAPS
STRUCTURAL GEOLOGY MAP
ILLUSTRATION SHEETS

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NEW YORK CITY FOLIO
NO. 83

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ENGRA D BY T U. S. GEOLOGICAL

GEORGE W. STO. S J. KUBEL, CHIEF ENGRAVER

EXPLANATION.

The Geological Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map. The two are being issued together in the form of an atlas, the parts of which are called folios. Each folio consists of a topographic base 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 horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical 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:

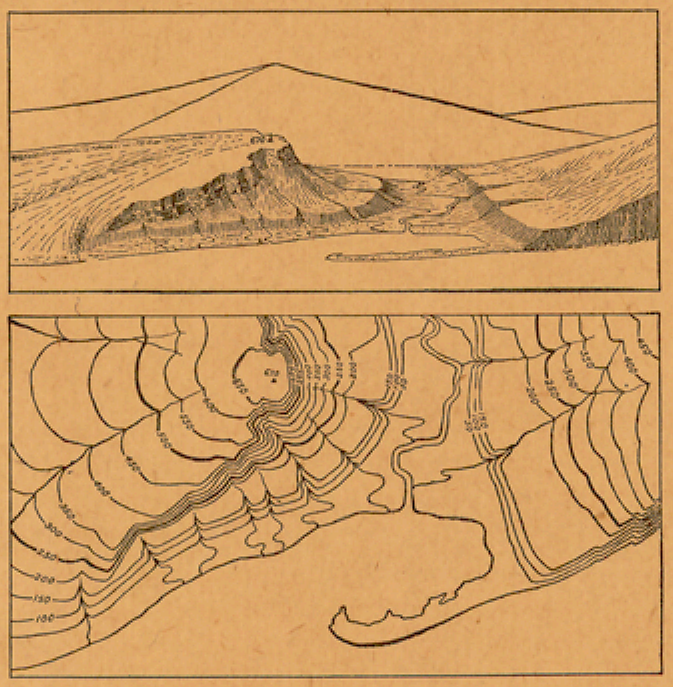


Fig. 1.—Ideal sketch and corresponding contour map.

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 in a precipice. Contrasted with this precipice is the gentle descent of the slope at 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 approximately a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, 200 feet, and so on, above sea level. Along the contour at 250 feet lie all points of the surface 250 feet above sea; and similarly with any other contour. In the space between any two contours are found all 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 nearly all the contours are numbered. Where this is not possible, certain contours—say every fifth one—are accentuated and numbered; the heights of others may then be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. The 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 vertical 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 used 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.—Water courses are indicated by blue lines. If the streams flow the year round 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, and artificial details, are printed in black.

Scales.—The area of the United States (excluding Alaska) is about 3,025,000 square miles. On a map with the scale of 1 mile to the inch this would cover 3,025,000 square inches, and to accommodate it the paper dimensions would need to be 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 of "1 mile to an inch" is expressed by $\frac{1}{63,360}$. Both of these methods are used on the maps of the Geological Survey.

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 and corresponds nearly to 1 square mile; on the scale $\frac{1}{125,500}$, to about 4 square miles; and on the scale $\frac{1}{250,000}$, to about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three different ways, one being a graduated line representing miles and parts of miles in English inches, another indicating distance in the metric system, and a third giving the fractional scale.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which are bounded by parallels and meridians. The corresponding four-cornered portions of territory 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-quarter of a square degree; each sheet on a 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, respectively.

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or 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 sheet.—Within the limits of scale the topographic sheet is an accurate and characteristic delineation of the relief, drainage, and culture of the district represented. Viewing the landscape, map in hand, every characteristic feature of sufficient magnitude should be recognizable. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property to be bought or sold; save the engineer preliminary surveys in locating roads, railways, and irrigation ditches; provide educational material for schools and homes; and serve many of the purposes of a map for local reference.

THE GEOLOGIC MAP.

The maps representing areal geology show by colors and conventional signs, on the topographic base map, the distribution of rock formations on the surface of the earth, and the structure-section map shows their underground relations, as far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. The original crust of the earth was probably composed of *igneous rocks*, and all other rocks have been derived from them in one way or another.

Atmospheric agencies gradually break up igneous rocks, forming superficial, or *surficial*, deposits of clay, sand, and gravel. Deposits of this class have been formed on land surfaces since the earliest geologic time. Through the transporting agencies of streams the surficial materials of all ages and origins are carried to the sea, where, along with material derived from the land by the action of the waves on the coast, they form *sedimentary rocks*. These are usually hardened into conglomerate, sandstone, shale, and limestone, but they may remain unconsolidated and still be called "rocks" by the geologist, though popularly known as gravel, sand, and clay.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried, consolidated, and raised again above the surface of the water. In these processes, through the agencies of pressure, movement, and chemical action, they are often greatly altered, and in this condition they are called *metamorphic rocks*.

Igneous rocks.—These are rocks which have cooled and consolidated from a liquid state. As has been explained, sedimentary rocks were deposited on the original igneous rocks. Through the igneous and sedimentary rocks of all ages molten material has from time to time been forced upward to or near the surface, and there consolidated. When the channels or vents into which this molten material is forced do not reach the surface, it may consolidate in cracks or fissures crossing the bedding planes, thus forming dikes, or spread out between the strata in large bodies, called sheets or laccoliths, or form large irregular cross-cutting masses, called stocks. Such rocks are called *intrusive*. Within their rock inclosures they cool slowly, and hence are generally of crystalline texture. When the channels reach the surface the lavas often flow out and build up volcanoes. These lavas cool rapidly in the air, acquiring a glassy or, more often, a partially crystalline condition. They are usually more or less porous. The igneous rocks thus formed upon the surface are called *extrusive*. Explosive action often accompanies volcanic eruptions, causing ejections of dust or ash and larger fragments. These materials when consolidated constitute breccias, agglomerates, and tuffs. The ash when carried into lakes or seas may become stratified, so as to have the structure of sedimentary rocks.

The age of an igneous rock is often difficult or impossible to determine. When it cuts across a sedimentary rock it is younger than that rock, and when a sedimentary rock is deposited over it the igneous rock is the older.

Under the influence of dynamic and chemical forces an igneous rock may be metamorphosed. The alteration may involve only a rearrangement of its minute particles or it may be accompanied by a change in chemical and mineralogic composition. Further, the structure of the rock may be changed by the development of planes of division, so that it splits in one direction more easily than in others. Thus a granite may pass into a gneiss, and from that into a mica-schist.

Sedimentary rocks.—These comprise all rocks which have been deposited under water, whether in sea, lake, or stream. They form a very large part of the dry land.

When the materials of which sedimentary rocks are composed are carried as solid particles by water and deposited as gravel, sand, or mud, the deposit is called a mechanical sediment. These may become hardened into conglomerate, sandstone, or shale. When the material is carried in solution by the water and is deposited without the aid of life, it is called a chemical sediment; if deposited with the aid of life, it is called an organic sediment. The more important rocks formed from chemical and organic deposits are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the above sedimentary deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in successive 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 over wide expanses, and as it rises or subsides the shore lines of the ocean are changed: areas of deposition may rise above the water and become land areas, and land areas may sink below the water and become areas of deposition. If North America were gradually to sink a thousand feet the sea would flow over the Atlantic coast and the Mississippi and Ohio valleys from the Gulf of Mexico to the Great Lakes; the Appalachian Mountains would become an archipelago, and the ocean's shore would traverse Wisconsin, Iowa, and Kansas, and extend thence to Texas. More extensive changes than this have repeatedly occurred in the past.

The character of the original sediments may be changed by chemical and dynamic action so as to produce metamorphic rocks. In the metamorphism of a sedimentary rock, just as in the metamorphism of an igneous rock, the substances of which it is composed may enter into new combinations, or new substances may be added. When these processes are complete the sedimentary rock becomes crystalline. Such changes transform sandstone to quartzite, limestone to marble, and modify other rocks according to their composition. A system of parallel division planes is often produced, which may cross the original beds or strata at any angle. Rocks divided by such planes are called slates or schists.

Rocks of any period of the earth's history may be more or less altered, but the younger formations have generally escaped marked metamorphism, and the oldest sediments known, though generally the most altered, in some localities remain essentially unchanged.

Surficial rocks.—These embrace the soils, clays, sands, gravels, and bowlders that cover the surface, whether derived from the breaking up or disintegration of the underlying rocks by atmospheric agencies or from glacial action. Surficial rocks that are due to disintegration are produced chiefly by the action of air, water, frost, animals, and plants. They consist mainly of the least soluble parts of the rocks, which remain after the more soluble parts have been leached out, and hence are known as residual products. Soils and subsoils are the most important. Residual accumulations are often washed or blown into valleys or other depressions, where they lodge and form deposits that grade into the sedimentary class. Surficial rocks that are due to glacial action are formed of the products of disintegration, together with bowlders and fragments of rock rubbed from the surface and ground together. These are spread irregularly over the territory occupied by the ice, and form a mixture of clay, pebbles, and bowlders which is known as till. It may occur as a sheet or be bunched into hills and ridges, forming moraines, drumlins, and other special forms. Much of this mixed material was washed away from the ice, assorted by water, and

DESCRIPTION OF THE NEW YORK CITY DISTRICT.

By F. J. H. Merrill, N. H. Darton, Arthur Hollick, R. D. Salisbury,
R. E. Dodge, Bailey Willis, and H. A. Pressey.

GENERAL GEOGRAPHY OF THE DISTRICT.

By Richard E. Dodge and Bailey Willis.

Position.—The district described in this folio is bounded by the meridians of 73° 45′ and 74° 15′ west longitude from Greenwich and the parallels of 40° 30′ and 41° north latitude. It covers one-quarter of a square degree, equivalent, in this latitude, to 905.27 square miles. The map is divided into four atlas sheets, called the Paterson, Harlem, Brooklyn, and Staten Island sheets, each measuring fifteen minutes of latitude and fifteen minutes of longitude. The district lies in two States, New Jersey and New York, comprising parts of the counties of Passaic, Bergen, Essex, Hudson, and Union in New Jersey, and Westchester, New York, Kings, Queens, and Richmond in New York. Within it lie many towns and boroughs, as well as the cities of Paterson, Newark, Jersey City, Hoboken, Yonkers, Mount Vernon, New Rochelle, and all of New York City except a small portion on Long Island east of Little Neck Bay and Far Rockaway. According to the census of 1900, 4,560,800 persons reside within its limits.

Drainage.—Drainage is a word here used to designate all streams, ponds, tidal ways, and bays of the district. The central axis, about which the features of New York and vicinity are grouped, is the channel of the Hudson River, which, extending southward beyond the city, expands into the Upper Bay, is restricted at the Narrows, again widens out in the Lower Bay, and passes into the Atlantic between the points of Rockaway Beach and Sandy Hook.

Eastward and northeastward from the main channel the East River extends to Long Island Sound, and connects again with the Hudson River by the tidal ways of Harlem River and Spuyten Duyvil Creek, thus completing the water circuit about the Borough of Manhattan of New York City. Northeast of the Borough of Manhattan the peninsula between Long Island Sound and the Hudson is drained by the parallel channels of Tibbit Brook, Bronx River and its tributary Sprain Brook, Hutchinson Brook, and Sheldrake River. The western end of Long Island is without running streams of notable size, the surface waters being gathered largely in small ponds, whose irregular disposition is in contrast to the parallelism of the channels northeast of the Harlem. The shores of Long Island, Manhattan Island, and the mainland are deeply indented by bays and estuaries. Some of the latter are locally called creeks or rivers, such as Newtown, Flushing, Harlem, Westchester, East Chester, Pelham, and Little Neck.

West of the Hudson channel, Arthur Kill and Kill van Kull isolate Staten Island from the mainland of New Jersey, and are outlets of Newark Bay, which is the estuary of the Hackensack and Passaic rivers. The Hackensack drains a small valley closely parallel to the Hudson, in Bergen County, N. J., and Rockland County, N. Y. The Passaic watershed is much more extensive, comprising the streams of a wide area in northern New Jersey, west to the divide of the Highlands, beyond which the waters flow to the Delaware. The Morris Canal, connecting Jersey City and Phillipsburg, on the Delaware, follows the Passaic Valley to the border of this district.

The depth of water in these waterways affects their relation to commerce and determines in large degree the value of adjacent lands. The Lower Bay is shallow between Sandy Hook and Coney Island, where the water over Romer Shoal, East Bank, and other banks is from $1\frac{1}{2}$ to 3 fathoms deep. These shoals constitute the bar, which is crossed by the Fourteen-foot, Ambrose, Swash, Gedney, and Main channels. Ambrose and Swash channels have a least depth of $3\frac{1}{2}$ fathoms, while Gedney and Main channels are nowhere less than 5 fathoms deep. Within the bar the Lower Bay is from 4 to 12 fathoms deep well out from shore, but toward the New Jersey and Staten Island shores the water shoals to 3 fathoms or less over extensive areas. In the Narrows the depth is as much as 20 fathoms, and the channel of the Hudson carries from 5 to 12 fathoms far up the river. This channel, though broad, is well defined through the Upper Bay by banks on the east and west over which there are but 3 fathoms or less of water. One small shoal lies in the lee of Governors Island, and another off Gowanus Bay, but the most extensive shallows occupy the western part of the bay.

East River, like the Hudson, has generally a depth of less than 10 fathoms, but it is locally very deep, there being depths of 25 fathoms among the narrow rocky channels of Hell Gate, which are swept by swift tidal currents. In Harlem River and Spuyten Duyvil Creek the water is but 2 to $3\frac{1}{2}$ fathoms deep.

Newark Bay is an extensive water body, but it is not available for sea-going commerce, as the depth is but 2 fathoms or less, except in a little channel near the outlet connecting with the Kill van Kull. This channel and the Kull carry 5 fathoms, while the Arthur Kill is generally shallow.

Relief.—Relief is the term used to designate the unevenness of the surface of the land A mathematical plane exhibits no relief; any land surface exhibits more or less as it departs more or less from a plane.

The Atlantic slope of the United States south of New York City is divided, according to relief of the surface, into two physiographic provinces, the lower and eastern of which is known as the Coastal Plain, the higher and western as the Piedmont Plateau. The latter extends back to the Appalachian Mountains and forms their eastern foot. The features which characterize the Coastal Plain in general are low peninsulas separated by estuaries, in which the tide ebbs and flows. These peninsulas are composed of beds of clay, sand, and gravel, or mixtures of these materials constituting loam, and are extensively developed in Maryland, Delaware, and New Jersey. The width of the Coastal Plain decreases from 110 miles southeast of Baltimore to 12 miles southeast of New York City.

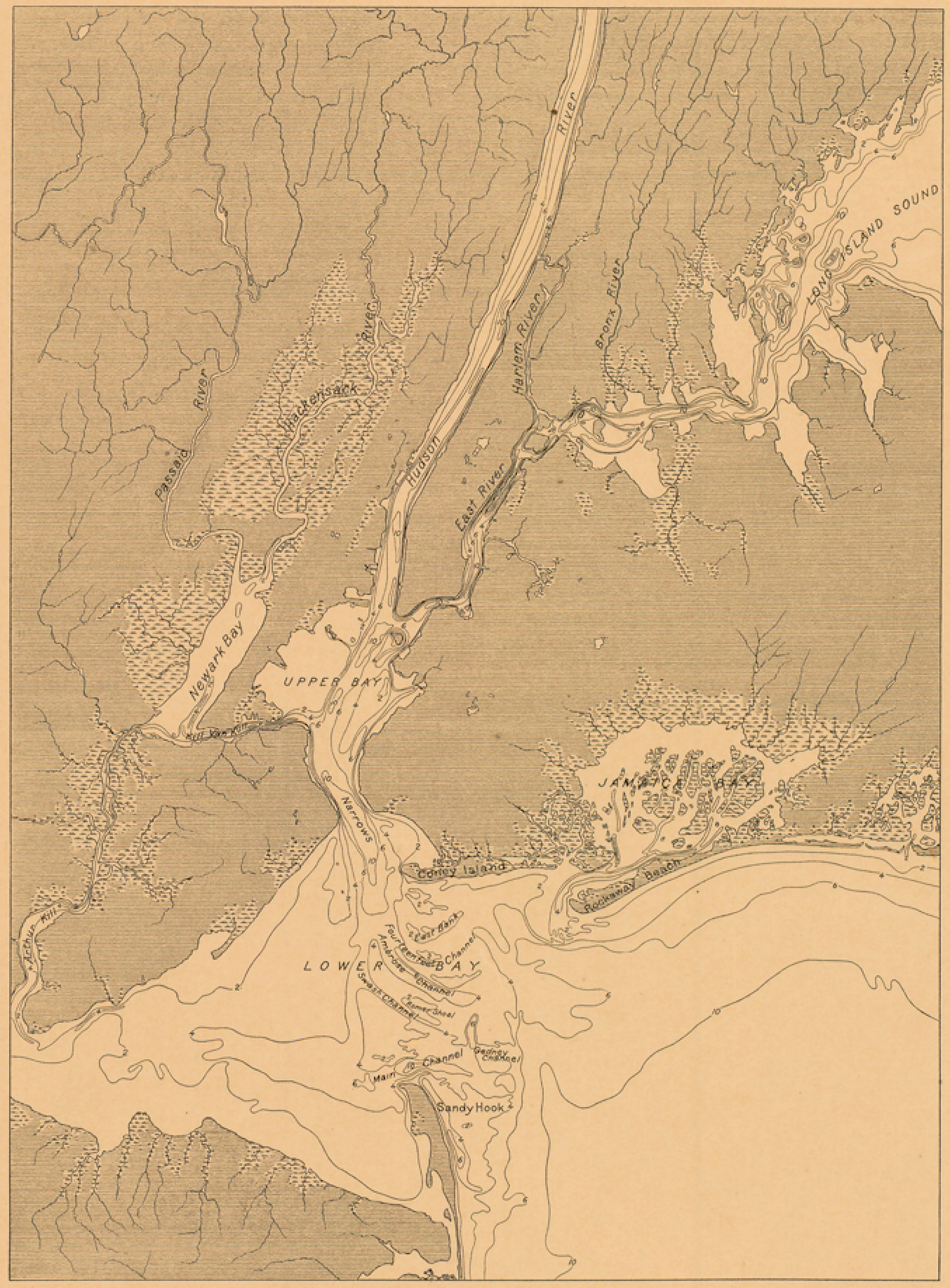


Fig. 1.—Map showing drainage lines in the vicinity of New York City and channels in the bays.
Depth of water shown by contour lines to depth of 10 fathoms.

The Coastal Plain is not clearly apparent in the vicinity of New York City. The rocks that to the south constitute this plain are here buried by later deposits. These surface deposits are mostly of glacial origin, and occur in two distinct phases. One is found in the high and irregular ridge of Long and Staten islands; the other in the frontal plain lying south and southeast of the ridge, and varying in width from less than a mile on Staten Island to about 9 miles in the eastern part of the district. The Coastal Plain exists in this section, as a plain, only beneath the sea, forming what is known as the continental shelf, which extends off shore for nearly 100 miles. This submerged portion is now receiving the deposits of land waste brought down by rivers and tidal currents, while the emerged portion has been so modified in form during its later history that it is only structurally a coastal plain.

The Piedmont Plateau is generally an upland, which is extensive in Virginia and Maryland, but is comparatively limited in the vicinity of New York. Occasionally its eastern margin sinks almost to tide water, as at the heads of the great estuaries, Potomac, Chesapeake, and Delaware, and at New York Bay. Its western margin is defined by the mountains known in Virginia as the Blue Ridge, in Pennsylvania as South Mountain, and farther north as the Highlands of New Jersey and New York. Within the district described in this folio the Piedmont Plateau is confined to the region west of the Palisades and the crest of Staten Island, and may be roughly described as a rolling lowland above which certain elevations, particularly the Watchung Mountains, rise abruptly. The Piedmont area west and northwest of the Paterson quadrangle is bounded definitely by the Appalachian Highlands, here known as the Ramapo Mountains.

That part of the New York district which lies east of the Hudson and north of the East River is not strictly a part of the Coastal Plain or the Piedmont Plateau, though the distribution of relief is in some ways parallel; it is rather the southern and southwestern extension of an upland which was continuous throughout the larger part of New England and which is connected with the Appalachian Highlands of New Jersey. This slightly rolling and yet accordant upland, as viewed from any of the higher points of the surface, may be seen to rise gently from sea level northward, until it reaches a maximum elevation within this district of over 300 feet. Below it narrow valleys have been cut, such as those of the Bronx and Sawmill rivers. Were they filled to the level of the stronger ridges a broad, rolling plain would be restored. There is strong evidence that such a plain did once exist, as will be described later. West of the Hudson this plain is represented in the longitudinal profile of the Palisades and of the First Watchung Mountain.

At sea level the slope of the plain and the slope of the present drainage coincide, but the plain rises inland until at the northern border of the Harlem quadrangle there is a difference in altitude of approximately 200 feet.

The highest point within the district is High Mountain, with an altitude of 879 feet, in the northwestern part of the Paterson quadrangle. Extending southwest from the vicinity of High Mountain are two ridges, more or less parallel and continuous, which form parts of First and Second Watchung Mountains. First Watchung Mountain faces the eastern lowland in a bold escarpment nearly 300 feet high, and is a striking feature of the view presented to all who leave New York by any of the railways terminating in Jersey City and Hoboken. In the lowland east of the Watchung Mountains are many short ridges following a general northeast-southwest direction, and locally of strong relief.

Probably the most striking single surface feature within the district is the ridge of the Palisades, which faces the Hudson River in a bold escarpment that reaches a height of 500 feet at the northern boundary of the Harlem quadrangle. The escarpment front forms one of the most majestic river banks in the eastern part of America, and gives to the Hudson a reputation for scenic beauty that is worldwide.

In the Borough of Manhattan the most extensive heights extend from Riverside Park to Tubby Hook. This ridge faces the densely populated plain to the east in a bold but irregular escarpment, and reaches a maximum height of 200 feet. In Westchester County and in New York City north of the Harlem River the country is rolling, and is marked by many hills rising to 300 or more feet, no one of which, however, is conspicuous among its fellows.

On Long Island the moraine ridge faces the southeast in an abrupt slope which reaches nearly 200 feet in height. In the center of Staten Island there are many points that reach a height of 300 feet.

Besides the ridges that have been mentioned because of their scenic beauty, there are certain river valleys and selected bits of relief also worthy of note. On the ridge of Long Island the several cemeteries and Prospect Park exhibit a variety of relief within a limited area that is very striking and picturesque. In the Borough of Manhattan the end of the ridge just north of Grant's Tomb, overlooking the cross depression at Manhattanville, furnishes one of the best vantage points for a view up the Hudson River. A similar extensive and striking view is to be obtained from the end of the ridge north of Fort George. The valley of the Bronx River in the northern portion of Bronx Park is a beautiful example of a narrow gorge.

In New Jersey the many spurs of the Palisades furnish excellent views of the Hudson River and the upland to the east, one of the best of which may be secured from an easily accessible point just northeast of Fort Lee. The top of the mountain at Upper Montclair, Garret Rock in Paterson, and High Mountain, all give extensive views of the adjoining country. Other features of special note and beauty are the falls of the Passaic at Little Falls and at Paterson, and the Great Notch, which is a good-sized valley, once the seat of a large river, now occupied in part by a very small brook.

Culture.—As has already been stated, more than four million people resided in this district in 1900. The greater portion of the inhabitants are grouped in the cities bordering the great waterways of the Hudson and East rivers. New York City alone had in 1900 a population of 3,437,262. The population of Newark was 246,070. The smaller cities not situated on the waterways but within easy rail communication with New York are largely residential towns, of which Rutherford and Montclair are good examples. Paterson, at the Great Falls of the Passaic, is the only large interior city in the district. It had a population in 1900 of 105,171, and its chief industry is silk manufacturing. The low-lying sections of the Paterson, Staten Island, and Brooklyn quadrangles are largely devoted to agriculture, especially to the growing of garden products for the cities.

New York City and its sister cities bordering the waterways form the greatest commercial center in the United States. In 1900 the port of New York had 45.73 per cent of the import and export trade of the country, the record for the year being 8,629,273 tons entered and 8,118,427 tons cleared. Besides this oceanic commerce, which is largely with the United Kingdom, Germany, France, the Netherlands, Belgium, Italy, Brazil, and Argentina, the port of New York has a great inland water and rail trade.

The cities bordering the Lower Hudson are connected to the north, west, and south by many trunk lines, of which the largest number terminate in the cities on the New Jersey side of the Hudson. The principal railways are the New York, New Haven and Hartford, the New York Central and Hudson River, the Pennsylvania, the Baltimore and Ohio, the Erie, the Delaware, Lackawanna and Western, and the Lehigh Valley. The two last-named roads are especially important as coal-carrying roads between the anthracite regions of Pennsylvania and the seaboard.

The Hudson River, with its tide-water connection to Albany and Troy, and thence via the Erie Canal to the West, is also an important trade route.

The chief industries of the district are agriculture and manufacturing. Agriculture is largely confined to the raising of vegetables and small fruits, and is so scattered that statistics can not be quoted for the different localities. New York City, Paterson, Bayonne, Jersey City, Hoboken, and Newark are the leading centers of manufacturing. New York is a very large manufacturing city, and the range of products is extremely varied, the leading articles, with their value in 1900, being: bread and bakery products, $32,239,307; clothing, $228,008,835; foundry products, $41,089,475; malt liquors, $39,105,837; masonry products, $43,353,473; books and periodicals, $77,882,237; refined sugar, $88,598,113; and manufactured tobacco, $37,998,261. Paterson is the leading silk-manufacturing city in the United States, the value of the product in 1900 being $26,006,156. Bayonne has in recent years grown to be a great center of petroleum refining, the value of the product in 1900 being $28,861,111. Newark has a large output of jewelry and leather goods, amounting in 1900 to $7,364,247 and $10,857,192, respectively.

The grouping of cities has been conditioned by the natural features which have been indicated, and these are the result of processes and events which began far back in the history of the earth. Some of the various aspects which the New York district has presented, sometimes beneath seas that have shifted, sometimes as hills or plains that are gone, are traced from a remote age to the present in the following outline of geologic history, and more detailed accounts of the geologic facts are subsequently presented in the order in which they occurred, from earliest to latest.

GEOLOGY OF THE DISTRICT.

By Bailey Willis, F. J. H. Merrill, N. H. Darton, Arthur Hollick, and R. D. Salisbury.

OUTLINE OF GEOLOGIC HISTORY.

By Bailey Willis.

Pre-Cambrian rocks.—The Cambrian system is the most ancient of the rock systems which in the New York district can be identified with certainty, but there are rocks still older, which are properly, though indefinitely, classed as pre-Cambrian. They may be of Algonkian age or may belong to the oldest system, the Archean, but they are so changed in structure and constitution from their original condition that distinguishing characters have been obliterated, and it is not known whether originally they were deposited as sediments or were igneous. The rocks of pre-Cambrian age of the New York district are described as the Fordham gneiss.

Events of the Cambrian period.—During the ancient Cambrian time the geography of North American was unlike the present even in the broadest features. Although the continental plateau and Atlantic Ocean basin existed at that time, the continent perhaps had greater extent eastward, where now is the ocean, so that a low land area, possibly of moderate but of unknown width, lay east of our Atlantic border. A salt-water sea reached from the St. Lawrence embayment far southwestward, passing west of New York City, during an early stage (see fig. 2); but in consequence of a change of relative level of land and waters, the sea was extended till it became a mediterranean body whose northern shore crossed Wisconsin. Spreading also over the region about New York City, this sea laid down, partly on areas of Fordham gneiss, the beach which has become the rock now called the Poughquag quartzite. (See page 4.) The position reached by its southeastern shore can not be known, as it probably lay east of the present Atlantic coast. While the sea was wide, though probably not very deep, there accumulated over much of its bottom a calcareous mud, part of which is now the Stockbridge dolomite. (See page 4).

Events of the Silurian period.—The wide-spreading interior sea continued during earlier Silurian time, and an upper part of the Stockbridge dolomite represents the sediments which gathered while the adjacent lands were reduced to very low plains. As a result of a reverse change of level of land and sea, the eastern land rose somewhat higher above the sea than it had stood, and its margin was extended westward, so that the shore lay probably not far southeast of New York City. The clayey-sandy waste then washed from the land was large in amount, and it formed the thick deposit which became consolidated, crushed, and crystallized into the rock described as the Hudson schist. (See page 4.)

Events of the later Paleozoic periods.—In the vicinity of New York City, Triassic sandstones constitute the series next younger than the Silurian deposits. The interval of time between the epoch of the Hudson schist and that during which the Triassic beds were laid down was very long, and in other regions important successions of events in the earth's history are recorded; but whatever the history of the New York region may have been during that time, the changes which have since taken place in the character of the rocks, and the amount of material removed by erosion, are so great that the record is very incomplete. However, it is clear that the region was part of the eastern continent, between the Atlantic and the interior sea, which, until the close of the Carboniferous, prevailed over western New York, Pennsylvania, Ohio, and westward. In Devonian time a mountain range rose and wasted away in New England, New York, and New Jersey, and similar though less obvious events probably occurred from time to time, while again the land area was reduced to a monotonous lowland.

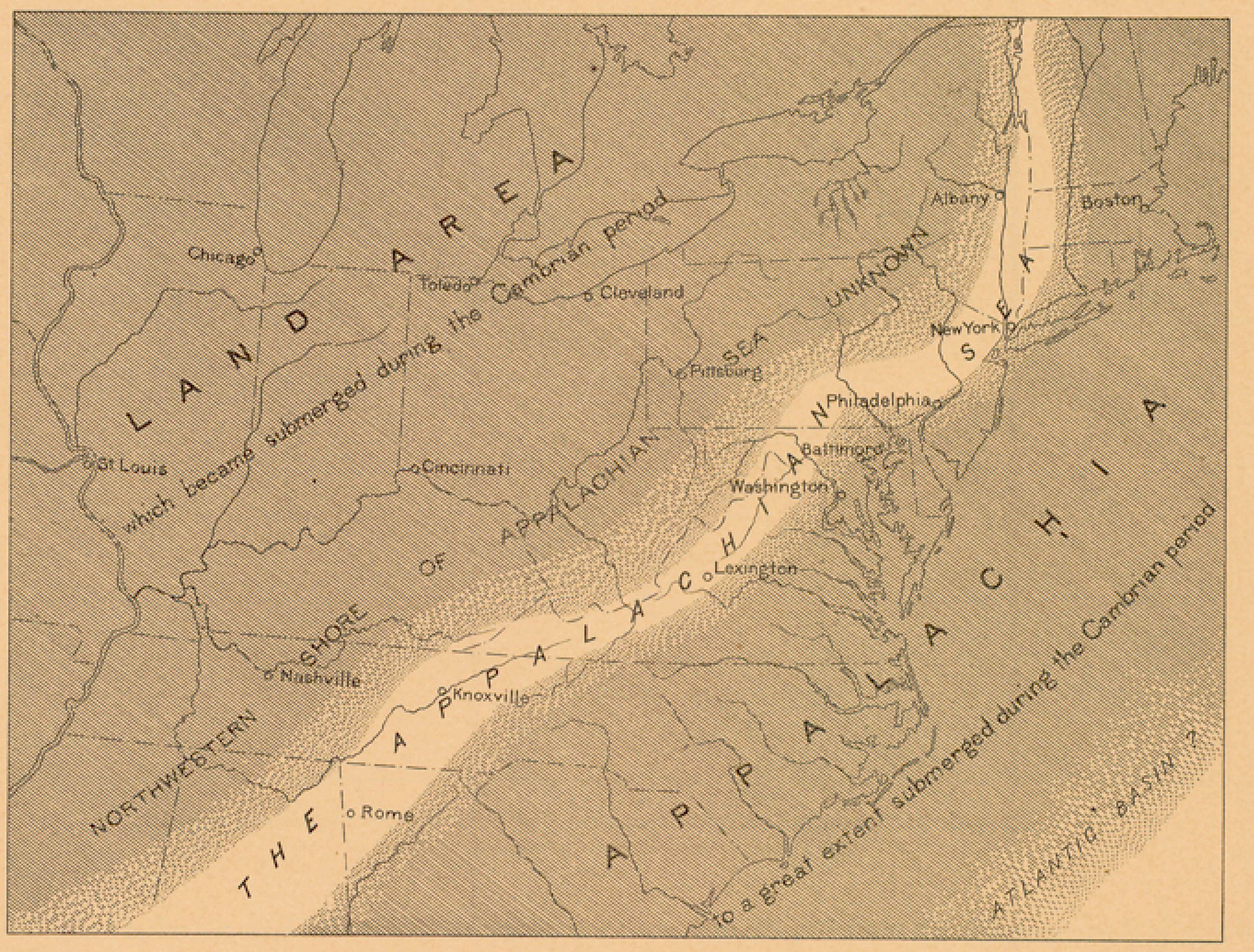


Fig. 2.—Map showing probable distribution of land and sea in the eastern United States during early Cambrian time and the changes which followed during that period. (After Walcott.)

Among the activities of which there is definite record we may place the intrusion of masses of igneous rock, which pressed from within the earth upward toward the surface, and which are now found in characteristic relations, occurring among the sediments of Silurian time as well as in the older rocks. The date of these intrusions can only be said to be later than Silurian and earlier than Triassic time. We might connect them with similar intrusions which occurred in Massachusetts about the close of the Carboniferous, but there is no definite evidence by which to do so with certainty. The portions of the intrusions which are now exposed were cooled and crystallized beneath the surface; the upper parts have been removed, and we can not say whether the eruptions reached the surface and found expression in volcanic phenomena or not.

The rocks of this region have suffered great compression, and have consequently been folded, crushed, and, with the growth of new minerals, transformed into gneisses and schists. That is, they have undergone the process of metamorphism in a high degree. Part of these effects may have been produced at any time later than the deposition of the Hudson schist, but in considerable measure the metamorphism is attributed to that strongly marked episode of mountain growth which occurred near the close of the Carboniferous period and which has sometimes been called the Appalachian revolution. Then from the St. Lawrence to Alabama, where now are the Appalachian and Allegheny mountains of New York, New Jersey, Pennsylvania, the Virginias, the Carolinas, and Georgia, the sediments of the interior sea and the older rocks which formed part of the continent were slowly compressed, so that, according to their nature, they took on cleavage, producing slates, schists, and gneisses, or became folded, giving rise to basins and arches of strata. These structures are like those illustrated in the vertical section on the second page of the "Explanation" printed on the cover.

The several kinds of rocks which formed during the long time preceding the Juratrias period, and which suffered the metamorphic changes thus briefly referred to, are described in the following pages by Professor Merrill.

Events of the Juratrias period.—After the development of the old Appalachian Mountains at the close of Carboniferous time, there was an interval during which the heights were worn down to mature or aged forms, and their waste was distributed in flood plains of rivers and in the sea. This condition continued throughout the earlier Triassic and preceded the accumulation of the late Triassic or early Jurassic rocks which are described under the term Newark group. The Atlantic basin may have encroached upon the continent in such manner that the coast which previously lay much farther east came to occupy a position nearer New York City, but the Atlantic sediments of this period are not known.

Following these geographic changes there came in New Jersey in sequence of time, and probably in natural succession of effects, the slow development of a basin which was occupied by water and was gradually filled by sediments that are described under the term Newark group. Similar depressions, which may or may not have been directly connected, were produced not far from the present Atlantic coast, from Nova Scotia to North Carolina. They formed lakes or estuaries, the fossils found in them being those of organisms which may have lived in fresh or brackish water, but are not distinctly marine, and the sediments exhibit features common to deposits in shallow waters that rise and fall, as well as to tide-swept bays. The southern basin was in part marshy, and vegetation, from time to time accumulating, produced the coal beds now found in the vicinity of Richmond, Va. In general the shores of the basins were low, bordered by extensive mud flats, and fringed with luxuriant vegetation, but beyond them were hills from which great quantities of sediment were washed. The familiar brownstone, soft red shales, and gray flagstones were the chief varieties of rocks then formed. During the existence of these basins there occasionally occurred volcanic eruptions which resulted in flows of lava at the surface as well as in intrusions of igneous rock among the Triassic sedimentary beds. These intrusives and lavas form the so-called "trap rock" of the Palisades of the Hudson, of the Watchung Mountains, and of other localities in New Jersey.

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 developed with a general northeast-southwest trend, and the blocks into which they divided the formation slipped past one another in such a manner as gradually to cause displacements, in some instances of 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 trap rocks must have maintained their altitude above the areas of soft sandstones and shales, as they do now; and as their distribution was somewhat 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.

The Newark sediments and their associated igneous rocks are described by Mr. Darton. (See page 6.)

Events of the Cretaceous period.—The geography of the Cretaceous period approached that of the present, as in the latter part of the Juratrias period and in early Cretaceous time the Atlantic had assumed a coast line not greatly different from the existing one, and the Atlantic Coastal Plain had then been developed in its earliest recognized phase; but from New Jersey southward it was submerged as far inland at least as Philadelphia, Baltimore, and Washington. The present Appalachian Mountains had not then begun to grow, but there were low hills wherever there were areas of hard rocks, and these hills were the surviving bases of the mountains developed during the Triassic age, and possibly of those which grew during the Appalachian revolution.

The relations of land and sea were maintained with very slight changes of level during the greater part of the Cretaceous period, and the elevations which had survived into the beginning of that time were consequently worn down by erosion to still more monotonous lowlands. The Highlands of New York and New Jersey, the mountains of Virginia and the Carolinas, are all of later growth. Upon the wide-spreading plain which then characterized the eastern United States the larger rivers of to-day probably had their origin. The coast of New Jersey was bordered by estuaries and lagoons, which also extended southward, and in which brackish-water deposits were laid down. These are represented on Staten Island by the Raritan clays, which are described by Professor Hollick. (See page 10.)

In later Cretaceous time the Atlantic advanced somewhat farther westward and marine sediments were deposited over a belt of considerable extent in Maryland and New Jersey, but they are not represented in the New York district.

Events of Tertiary time.—The wide plain which developed during the Cretaceous period has been called the Schooley plain, because its flat surface is well represented in the summit of Schooley Mountain in New Jersey. In general the recognition of this plain as a condition which once existed is based upon the long, even mountain summits of the Highlands, Schooley Mountain, the Watchung ridges, and the Palisades. Beyond the New York district the plain has been recognized in similar even-topped ranges as far south as Alabama. The later history, beginning with the Tertiary, takes account of the uplift of the Appalachian Mountain province and the development of the valleys along areas of soft rocks, while heights survive where the harder rocks afforded more resistance to degradation.

During the early Tertiary the growth of the existing Appalachian Mountains began by the uplift of broad areas, and the Schooley plain was thus warped from a flat to an exceedingly wide and low, dome-like surface. It did not immediately attain the altitude which it now has along the axis of greatest elevation, but was raised part way, and the movement then ceased for a time. Along the coast, portions of the lowlands were submerged beneath the sea, and again elevated, but the extent of the areas which the waters occupied can not be fully made out, as the deposits have been much eroded. The climate was prevailingly semi-tropical, and the lowlands were covered with luxuriant forests.

The rivers, which flowed in channels assumed upon the general slope of the Schooley plain, cut down through the surface of the plain into the hard and soft rocks lying across their paths, and became superimposed, as it is called, upon the underlying ribbed structure. By processes of adjustment, through 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 the pause in the elevation of the surface of the province, valleys were widely excavated, and a broad lowland was extended over the soft shales and sandstones of the Newark area in New Jersey. As this surface is well represented in the vicinity of Somerville, the name Somerville stage has been given to that particular phase of the topography.

The process of adjustment and erosion had proceeded so far as to outline the present heights and valleys in their broadest features, when mountain growth was renewed and there occurred the uplift which resulted 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 from the axis of uplift in the Highlands and Catskills southeastward and passed beneath sea level a short distance south and east of New York City. This episode of new mountain growth may have been the closing event of Tertiary time or the initial event of the succeeding and very recent Pleistocene period.

Events of the Pleistocene period.—The dominant fact of the Pleistocene period was the glaciation of northern North America and Europe. Ice sheets spread from different centers, not only once, but three or more times, and an appreciable interval of milder climate separated each ice advance from the preceding one. The latest of the continental glaciers, which centered in Labrador, extended southward in the vicinity of New York as far as Long and Staten islands. Perhaps one or more of the earlier glaciers had a similar extent, but the evidence is not everywhere definite, and the earlier Pleistocene history of this region is obscure. The glacier which advanced from the north over New York ground off the surface in some places and buried it in others beneath gravel, sand, and clay. The worn rock surfaces are characteristically marked and the deposits possess characters peculiar to materials carried by ice and deposited 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 by Professor Salisbury. (See pages 11–17.)

At an epoch not yet well determined the land stood about 200 feet higher than it now stands 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 now is the Battery, 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, Rockaway, 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 features which nature has so shaped that New York is the commercial center of the New World.

METAMORPHIC CRYSTALLINE ROCKS.

By Frederick J. H. Merrill.*

Southeastern New York.—The metamorphic crystalline rocks of southeastern New York lie east of the Hudson River, in New York, Westchester, Putnam, and Dutchess counties, whence they extend into Connecticut, and on the west of the river in Orange and Rockland counties, whence they extend southwesterly into New Jersey. The lowest formation is a coarse hornblende-granite, which forms the central mass of the range of mountains known as the Highlands of the Hudson, and in Breakneck Mountain is exposed through a vertical height of nearly 1200 feet. The rock is composed chiefly of quartz, feldspars, and hornblende, with accessory magnetite, apatite, and zircon. The hornblende is deep greenish brown in color and is nowhere present in large quantity, constituting less than 10 per cent of the rock. The prevailing feldspar is microperthite, a finely lamellar intergrowth of orthoclase and an acid plagioclase, either albite or oligoclase. Some plagioclase is always present in addition, and seems to be oligoclase in all cases. A little microcline, also, is always present. With these greater masses of hornblende-granite are associated other local masses of granite comparatively free from hornblende, which are extensively used for building stone. The granites are probably igneous and of great age. On the flanks of the granite masses are banded gneisses, consisting chiefly of quartz and orthoclase with biotite and hornblende, containing numerous beds of magnetic iron ore. These gneisses on the south side of the Highlands extend through Westchester County in a series of parallel folds with southwesterly trend, and here, as well as on the northern slope of the Highlands in Dutchess County, are overlain unconformably by basal quartzites of Cambrian age, which are bordered by Cambro-Silurian dolomite and Ordovician slate or schist. The principal valleys of Putnam County are synclinal in structure, and owe their origin to the solution and erosion of belts of dolomite, which are associated with quartzite and mica-schist and are correlated with similar rocks hereafter described as Cambrian and Silurian.

From the relation of the quartzite, dolomite, and schist of Westchester County to the underlying gneiss, which corresponds to the relation of the Paleozoic strata to the subjacent gneiss in western Massachusetts and in Dutchess and Putnam counties, and from stratigraphic continuity, it is believed that the crystalline dolomite of Westchester County is equivalent to the Stockbridge limestone of Massachusetts. This formation extends into southeastern Dutchess County, where its Cambro-Silurian age has been satisfactorily established. The schist and micaceous gneiss overlying the dolomite in the New York district, by like analogy and stratigraphic relation, is considered to be of Hudson River age and equivalent to the Berkshire schist.

Besides the old granites above mentioned there are in Westchester and New York counties many later eruptive rocks which occupy notable areas. Prominent among them is a red granite, consisting chiefly of quartz, orthoclase, and biotite, which is injected into and through the gneiss at many points, and at Ossining through the overlying dolomite. On Manhattan Island, at Inwood, granite dikes penetrate the dolomite. In the town of Yonkers is a large area of reddish granite rather gneissoid in texture, which is intrusive in the Fordham gneiss and is extensively quarried as a building stone.

The mica-schist has been especially subject to igneous intrusions. Within its areas occur the Cortlandt series of diorites and norites, described by James D. Dana and George H. Williams; the Harrison diorite, described in detail by H. Ries; the serpentines, derived by alteration from basic eruptives, and certain gray granites, which occur in bosses, lenses, and dikes in the southernmost part of Westchester County. Near the shores of Long Island Sound the Hudson schist is everywhere injected with bands, lenses, and dikes of pegmatite, granite, amphibolite, and pyroxenite.

All the crystalline rocks above described, with the possible exceptions of the Fordham gneiss and the later eruptive rocks, were originally sediments laid down in horizontal strata, the quartzite representing a beach deposit, the dolomite a deposit in water unaffected by wash from the land, and the schist a deposit of sandy mud in shoal water. These three rocks form a reliable record of a period of subsidence of the land and transgression of the sea, following which came a recession and emergence.

At various times between the later Silurian and the beginning of the Mesozoic these horizontal strata were laterally compressed. As a consequence they were thrown into parallel folds having a general northeasterly trend. With the Paleozoic beds the underlying rocks of greater age were also folded. As the cross sections show (see Structure Section sheet), the folds are closely compressed, and in many cases are overthrown, so that frequently the rocks on both sides of a fold dip in the same direction. Generally the axial planes of the folds dip to the east, but occasionally they dip to the west. Associated with the longitudinal folding of these rocks was a transverse folding, the general result of which was elevation at the northeast, so that the axes pitch or slope very gently to the southwest. There are local variations from this general condition, and some of the folds have locally a northeastward pitch, due to faulting or cross folding. But the general condition is well shown in the western ridge of Fordham gneiss, which in the town of Yonkers attains a height of 300 feet, and on Manhattan Island passes below sea level and does not reappear.

*The field work on the metamorphic crystalline rocks in the New York portion of the New York City district was done in cooperation with the New York State Museum.

As shown in the following scheme, the metamorphic, sedimentary, and laminated crystalline rocks within the area under discussion belong to three principal divisions, the pre-Cambrian, Cambrian, and Silurian. Of the pre-Cambrian, one formation has been distinguished as the Fordham gneiss. The older granites and gneisses do not occur in this area and are therefore not discussed. Of the Cambrian and Silurian there are two persistent formations, the Stockbridge dolomite, which is partly Cambrian and partly Silurian, and the Hudson schist; and a third, of slight development, the Poughquag quartzite, which underlies the dolomite.

Metamorphic crystalline rocks in the New York district.

Silurian	Hudson schist, containing garnet, fibrolite, cyanite, and staurolite.
Silurian / Cambrian	Stockbridge dolomite: crystalline limestone and dolomite, containing diopside and tremolite.
Cambrian	Poughquag quartzite.
Pre-Cambrian	Fordham gneiss.

PRE-CAMBRIAN ROCKS.

Fordham gneiss.—The Fordham gneiss, named from the place of that name, near which it is well exposed, is a gray, banded gneiss. The bands, as a rule, are thin, rarely exceeding 2 inches in thickness. They vary much in composition. Some of these are highly quartzose; some are composed largely of biotite, and some consist of pegmatite or granite, which seems to have been injected parallel to the regular banding of the gneiss.

The rock is composed of quartz, feldspars, and biotite, with some accessory zircon, less apatite and titanite, and very infrequently magnetite. Microcline is the most abundant feldspar, with some orthoclase and oligoclase. The rock is thoroughly gneissoid, the biotite and flattened quartzes having identical orientation and giving distinct foliation. A certain amount of segregation of the various minerals occurs, the biotite notably being concentrated along certain planes. Hornblende is an occasional constituent of this rock, but, though very prominent in some bands, does not occur as a general constituent. Garnet is present rarely and in but small quantity. As the schistosity of the Fordham gneiss has usually a very steep dip, the horizontal exposures of this rock show chiefly cross sections of the banding.

It is difficult to give the Fordham gneiss a systematic name which exactly indicates its age. If it is of sedimentary origin it may be called Algonkian, but it can only be said with certainty that it is pre-Cambrian.

The Fordham gneiss forms the high anticlinal ridge which borders the New York shore of the Hudson River from Yonkers southward to Spuyten Duyvil, and also that on the west side of the Bronx Valley. In the former ridge the gneiss disappears on the south at Spuyten Duyvil and does not reappear on Manhattan Island. The ridge west of the Bronx Valley bifurcates at the southern end of the western fork, is depressed below tide level by a cross synclinal fold at the Harlem River, ends on Manhattan Island in the low ridge which borders Seventh avenue on the west at One hundred and fifty-fifth street, and disappears by pitching below the general surface level about a mile southward. The eastern fork, owing to the same cross fold, disappears beneath the dolomite in Morrisania, but reappears near the Bronx Kills in Mott Haven, where it forms a low anticlinal ridge interrupted by the kills. It was represented on Manhattan Island by a few outcrops below high-water mark at the foot of East One hundred and twenty-second street, which are now removed. Some narrow anticlinal ridges of Fordham gneiss are seen on the islands in the East River, notably Blackwells, Wards, North Brother, and South Brother, and it is the only laminated crystalline rock at present exposed on Long Island. There it may be seen near the court-house in Long Island City and also along the shore of the East River from Ravenswood to Lawrence Point. It is also found in deep well borings on northwestern Long Island, where it is the subterrane.

CAMBRIAN ROCKS.

Poughquag quartzite.—The Poughquag quartzite is so named from its probable stratigraphic equivalence to the quartzite of Dutchess County, which bears the same relation to the dolomite above and the gneiss below as the quartzite within the Harlem quadrangle. The Dutchess County quartzite contains lower Cambrian fossils at Stissing, and is typically exposed on the northern flank of the pre-Cambrian highlands in a railroad cut at Poughquag. It is from this locality that the formation takes its name. This locality is advantageous as one from which the formation may be named, since it is approximately central to the areas of the quartzite formation extending from New York to New England, and the rock contains fossils.

The Poughquag quartzite has been found at several places within the Harlem quadrangle. At the north it is prominently exposed on the east side of the dolomite area at Hastings, its most northern outcrop having a thickness of about 30 feet. It has been observed at eight other localities, including Bronxville, Morris Heights, and Lowerre, from which last locality it was first described within the quadrangle.

The rock is a quartzite varying from almost white to brown in color; characteristically thin bedded, occasionally massive, often with muscovite or tourmaline developed along bedding and cleavage planes. In thickness it varies from 1 to 30 feet within the Harlem quadrangle, but at the typical locality over 100 feet are exposed. At its base this rock is usually sharply differentiated from the pre-Cambrian, but its top beds integrate with the lower part of the Stockbridge limestone.

SILURIAN ROCKS.

Stockbridge dolomite.—The Stockbridge dolomite, as it is here called, is composed of beds of limestone and dolomite in which the proportion of magnesian carbonate is often small. It is, so far as can be determined by stratigraphic continuity, equivalent to the Stockbridge dolomite of western New England and Dutchess County, N. Y., where the formation has yielded both Cambrian fossils from its lower part and Silurian fossils at higher horizons. In Westchester County the absence of fossils, which if present would hardly have withstood the extreme metamorphism, renders its exact age indeterminate. Since, however, the continuation of this formation in western New England has been known for many years as the Stockbridge formation, the same name is here applied to it in the New York district.

The Stockbridge is one of the most prominent formations of the district. Lithologically it is coarsely crystalline and distinctly bedded, and contains at many localities diopside and tremolite, and occasionally tourmaline. Of its maximum thickness little is definitely known. At Tuckahoe a thickness of 150 feet is shown in section. In the Harlem River a thickness of about 775 feet is found, in which, however, there may be repetition by crumpling.

The crystalline dolomite, though frequently well exposed, must often be traced by its absence as well as by its presence. Its solubility in water containing carbonic acid renders it an easy prey to the elements, and its position is almost everywhere emphasized by low ground. Throughout all the principal valleys small outcrops may be found, though usually for considerable distances it is buried beneath river gravel and alluvium. Where it has undergone the maximum of leaching the granular particles of limestone have disappeared entirely, and in their stead we find a mass of aluminous and magnesian material, whitish, green with scales of prochlorite, red with peroxide of iron, and sometimes black with separated carbon. In these conditions it is often mistaken for clay or kaolin, and was thus reported from the railroad cutting at Morrisania, from the Blackwells Island tunnel and from dredgings in the East River on the Middle Ground near Lawrence Point, from Shell Reef in the East River near the foot of Tenth street, and at the mouth of Newtown Creek. Along the Hudson River shore of Manhattan Island a white residuum has been found in the dredgings by the Dock Department. Similar material was also found overlying the Fordham gneiss in a deep boring on Tallman Island near College Point. On the uplands the presence of dolomite is often evidenced by coarse, yellowish-white sand, consisting of partially dissolved fragments. This may be seen on the plain east of Inwood and northward through Westchester County.

The distribution of the dolomite has had an important influence in determining the geographic situation of New York, as all the navigable channels about the city are submerged valleys which owe their positions to the ease with which it is eroded. Long Island Sound, near New York, possibly owed its existence to the same cause, as it appears to be the locus of a broad exposure of dolomite uncovered by the removal of the Hudson schist east of the Westchester shore.

Hudson schist.—The schist of the New York district is given the name Hudson because it continues northward and connects stratigraphically with the great area of slate and shale along the Hudson River which have been called respectively Hudson slate and Hudson shale. The Hudson schist, Hudson slate, and Hudson shale represent different phases of alteration of the same original rock, and together they form the Hudson formation. The Hudson formation continues into New England, and is there a schist, which has been called the Berkshire schist. The rock covers a larger area than any other within the limits of the Harlem quadrangle, and is the uppermost of the metamorphosed sedimentary formations.

The rock is essentially a mixture of biotite and quartz, but frequently contains enough orthoclase to give it the composition of gneiss. The principal accessory mineral is garnet, which occurs in crystals varying from one-sixteenth to one-quarter of an inch in diameter. Occasionally much larger crystals are found. Microcline, fibrolite, cyanite, and staurolite are also frequent accessories. The Hudson schist has a marked schistosity, which is frequently, though not always, nearly parallel to the bedding.

The aspect of this formation is intimately affected by numerous igneous intrusions and injections of granitic and basic material, which in some places are so numerous as to predominate over the schist. The small masses are, for the most part, parallel to the schistosity, though occasionally oblique to it. The larger areas usually have their longer diameters parallel to the strike of the schistosity. They are most abundant near the shores of Long Island Sound.

In the Harlem quadrangle the Hudson schist is the prevailing rock east of the dolomite valley in which lies the New York and Harlem Railroad. In this eastern area it is closely folded, and its bedding planes are mostly on edge. Near Port Morris it appears in a closely pressed synclinal fold, with northward pitch, which crosses Randalls and Wards islands and Little Mill Rock in Hell Gate. Flood Rock, which was removed in the improvement of Hell Gate channel, was part of this syncline. On Mill Rock the schist is much injected with amphibolite and pegmatite. The Hudson schist is also the prevailing rock of Manhattan Island.

The difficulty experienced by many geologists when they first enter the New York district in differentiating the Hudson schist from the Fordham gneiss and of appreciating the stratigraphic relations makes it desirable to give a brief statement of the more salient points in this connection.

While local granitic injection of the Hudson causes it, in hand specimens, to resemble some phases of the Fordham, careful areal study always reveals distinctive criteria. The Hudson schist is more persistently micaceous, while the Fordham gneiss is more quartzose and more uniformly banded. The foliation of the Hudson is also usually more crumpled than that of the gneiss. To secure a direct comparison in New York City one should go from the exposures of Fordham gneiss in the vicinity of One hundred and fifty-fifth street and Seventh avenue to the rock wall of Hudson schist on the west side of the Speedway.

The stratigraphic distinction is marked by the fact that nowhere in the Harlem quadrangle has the Stockbridge been found in actual contact with the Fordham, for the Poughquag always intervenes. About twenty localities of this quartzite are now known in Westchester County, and careful search along the flanks of the Fordham ridges will unquestionably disclose a greater number.

In contrast to these conditions at the base of the Paleozoic, the contact between the Stockbridge and the Hudson is never sharp, but occurs through a zone of transitional phases, such as calcareous schists and highly micaceous dolomites, varying from 10 to 50 feet in thickness. Frequently alternation of schist and dolomite occurs near the contact. Quartzite is never present. Both the gradual transition and the alternations are well shown on One hundred and sixty-seventh street from Jerome avenue to Morris avenue. The interbedding near the contact can also be well observed on either side of the railroad one-fourth of a mile south of Park Hill station and on One hundred and seventy-sixth street 100 feet east of Third avenue. Dana records several good examples of this feature in the dolomite outcrops formerly visible in Harlem, but now covered by buildings.

The sequence of the formations may be satisfactorily observed at the following localities: A few hundred feet northeast of the corner of One hundred and eighty-third street and Jerome avenue the Fordham gneiss is well shown, with synclinal structure pitching southward, and overlain in patches by thin quartzitic beds. The Stockbridge dolomite appears several hundred yards to the south, along the axis of this syncline, also with a southward pitch. Three members of the series are therefore shown here in their normal order of superposition.

A ridge of Fordham gneiss is shown on either side of Brown Place, and its northward termination appears on One hundred and forty-first street. The gneiss here pitches northward and is partly covered by quartzitic beds. The overlying dolomite is shown one block farther north.

High cliffs of Fordham gneiss border the north shore of Spuyten Duyvil Creek. The course of the creek is at any given point approximately parallel to the strike of the gneiss at that point, and the latter is everywhere seen to dip toward the creek. This definite relation between the windings of the creek and the variations in the strike of the gneiss is due to the fact that the creek occupies the position of dolomite beds which formerly overlay the gneiss, but which have been almost entirely removed from view by solution and erosion. Several small outcrops of dolomite can still be seen at low water on the south shore of the creek, dipping to the south under the cliffs of Hudson schist which line that shore. This Spuyten Duyvil locality is, therefore, of great geologic interest, as it shows the principal members of the series in their proper order of superposition, and also illustrates the direct relation existing between deep-water channels and dolomite beds within the Harlem quadrangle.

As shown by the map, the Hudson schist in that part of the Harlem quadrangle east of the Bronx River is, in places, much injected with granitic and basic material. In certain portions of the area, notably near the shore of Long Island Sound between New Rochelle and Larchmont, this very marked parallel injection gives the schist somewhat the appearance of the Fordham gneiss. The hypothesis might therefore be assumed, from an incomplete examination of the district, that the injected area is actually pre-Cambrian rock, upon which the uninjected Hudson schist rests through overlap or non-deposition of dolomite. But that the rock of this area is injected Hudson schist is proved by the fact that the rocks of the injected area (represented separately on the map) grade regularly into normal schist. In the vicinity of New Rochelle and Larchmont, as new exposures in street openings and excavations for house foundations reveal, here and there, fresh sections of the complex rock mass, thin bands of unaltered schist are seen between the granite or basic bands formed by injection. The injection is, therefore, a local phenomenon, and the injected rocks have no stratigraphic significance. That is to say, the rock of the injected areas does not underlie the Hudson schist, but is part of it. The borders of the injected areas show no unconformity or quartzite beds or basal conglomerates.

POST-HUDSON IGNEOUS ROCKS.

General statement.—Under this head are classified those rocks which are clearly intrusive in the Fordham gneiss, the Stockbridge dolomite, and the Hudson schist.

So far as we know, they belong to one general period of igneous activity, the time of which can not be stated with greater exactness than that it was posterior to the deposition of the Hudson schists, and therefore probably post-Silurian, and prior to a part of the dynamic disturbance and crumpling of these rocks through which the intrusives have become schistose and even crumpled. The igneous rocks which occur in the pre-Cambrian and Paleozoic rocks within the Harlem, Brooklyn, and Staten Island quadrangles may be classified as follows: Yonkers gneiss; granite (red and gray) in dikes and lenses; pegmatite in dikes and bosses; Harrison diorite; basic dikes, including amphibolites and pyroxenites; and serpentine, derived from basic intrusives.

Yonkers gneiss.—The Yonkers gneiss is technically a gneissoid granite. It is composed mainly of quartz and feldspars. The latter slightly predominate, with some biotite and hornblende, and occasionally garnet, zircon, titanite, and apatite in small quantity. The feldspar is mostly microcline, with some orthoclase and usually a little oligoclase. The rock is thoroughly foliated and gneissoid, the minerals showing parallel alignment.

The persistence of reddish orthoclase suggests that it has sprung from a common source with the numerous dikes of red pegmatite and granite of similar composition which penetrate the schist and dolomite in many points in Westchester County. In the particular area where this rock occurs most extensively it has been subjected to greater dynamic action than elsewhere and has been reduced completely to a gneissoid condition.

In the limestone near Ossining there is a granite composed of quartz, red feldspars, and biotite, with a little zircon and apatite. The quartz and feldspars make up most of the rock, the latter predominating. About half the feldspar is orthoclase, most of the remainder microline, with a little oligoclase. The rock is not at all gneissoid and the minerals show no signs of strain. In composition this granite approximates closely to the Yonkers gneiss and may be the unsheared original form of the latter.

Granite and pegmatite.—Gray and reddish granite in small dikes oblique to the banding of the gneiss and schist is rather abundant in these rocks, and is found in the dolomite near Inwood and elsewhere, but of more frequent occurrence are lenses and injections of granite and pegmatite parallel to the banding of the schist. Bosses of pegmatite frequently occur in the Hudson schist. A granite-injection area of considerable size occurs near Union Corners, and many have been found on Manhattan Island, especially near the Hudson River, on an area which is now built over and concealed from view. The small islands and reefs in the Upper Bay and most of those in Long Island Sound owe their existence to intrusions of granite and other eruptives in the schist, which by their hardness have resisted erosion.

The pegmatite occurs in dikes and bosses from 1 to 10 feet in diameter. They are most abundant in the Hudson schist.

Harrison diorite.—This rock is intrusive in the Hudson schist in the town of Mamaroneck. The rock consists of quartz, feldspar, hornblende, and biotite, with accessory titanite and garnet, and less frequently apatite. The feldspars are orthoclase and plagioclase (probably oligoclase-andesine) in about equal amounts, the two together making up nearly two-thirds of the rock. The mass which forms Milton Point, near Rye, has been subjected to much dynamic action and is well banded. The same rock is abundant along the shore of Long Island Sound between Portchester, N. Y., and Stamford, Conn. A small area of similar rock occurs at Ravenswood, Long Island, where it outcrops in a long, narrow ridge of northeasterly trend, and is intrusive in the Fordham gneiss.

Basic dikes.—Intercalated with and injected into the Hudson schist and also the Fordham gneiss, we find at a great number of localities on Manhattan Island and in Westchester County hornblendic and augitic bands and lenses of limited thickness, usually only a few feet. In composition and structure these rocks resemble diorites and diabases, and their general characters suggest that they were originally eruptive rocks, though at present they are in a foliated condition. Locally the magnesian silicates in these rocks are altered into epidote.

Serpentine.—Within the Harlem quadrangle serpentine occurs in the vicinity of New Rochelle on Davenport Neck, on the mainland immediately adjacent, and on Manhattan Island in an area now almost entirely covered by buildings, between Tenth avenue and the North River and Fifty-fourth and Sixty-second streets. At New Rochelle the serpentine has been derived from the alteration of rocks consisting of bronzite, hornblende, and actinolite, remnants of which may still be found. The area on Manhattan Island is evidently of similar origin.

Within the Staten Island quadrangle serpentine is found at Castle Point, Hoboken, and in the high central ridge of northern Staten Island. On Staten Island traces of olivine and actinolite have been found in the serpentine, which suggest its derivation. At Hoboken no traces of the original mineral have been found, but its origin is evidently analogous to that of the other masses.

The serpentine of Staten Island and Hoboken may be examined advantageously at the following-described places: An excellent exposure of fresh material is afforded by the excavations in Westervelt avenue, Tompkinsville. The cut which now extends from First avenue to Second avenue is being excavated for a new sewer to a depth of from 10 to 15 feet. The surface material is a decomposed serpentine which differs very slightly from the other exposures along the edge of the plateau running from Tompkinsville to New Dorp. The underlying rock, however, is much fresher and shows veinings of compact, light-green serpentine with a smooth conchoidal fracture. This is in places rather sparsely dotted with minute octahedral crystals of chromite. The serpentine varies rather widely in color and texture, a dull-red phase colored by peroxide of iron frequently showing against the green in irregular patches. The asbestos variety is common in this exposure, fibers 2 feet in length being in many cases obtained. The serpentine is here associated with white foliated talc, singularly brilliant and snowy in luster. The latter shows minute dendrites of pyrolusite, in this respect somewhat resembling the talc of St. Lawrence County. Deweylite also occurs in veins with a weakly effervescing carbonate which may prove to be magnesite. Some of the fragments of serpentine strongly suggest in form the unit prism of amphibole, and should they prove to be pseudomorphs after that mineral, would have considerable bearing on the derivation of this deposit of serpentine. Aragonite in a thin vein was found in one place.

On the southeastern slope of Todt Hill the serpentine is of much the same character as in the previous exposure, but in general more decomposed, the weathering apparently extending below the exposed surface. A typical outcrop occurs at the junction of the upper road with that from New Dorp to Castleton. In the vicinity of the limonite mines the material is stained red by iron. As at the Tompkinsville cut, small crystals of chromite are scattered through the serpentine.

At Castle Point, Hoboken, the serpentine outcrops are similar to the above. One in Hudson Avenue Park, just south of Stevens Institute, shows a thin incrustation of aragonite and extremely minute isolated crystals of calcite. These latter average about 0.1 millimeter in diameter, and under the 1½-inch objective are seen to consist of the low rhombohedron ½ R. The exposure on the point itself is somewhat more granular than the types previously described, and is pistacio-green in color.

ROCKS OF ECONOMIC USE.

Building stone.—In this district the principal natural product of economic importance is building stone, which is quarried in Stockbridge dolomite, Fordham gneiss, Yonkers gneiss, Harrison diorite, in some injected areas of Hudson schist, and occasionally in gneissoid phases of the schist itself.

The Stockbridge dolomite is now chiefly quarried for marble in the vicinity of Tuckahoe, and has been used for some important buildings, notably St. Patrick's Cathedral in New York City. Lime is also produced at one of the quarries. Many years ago lime from magnesian dolomite was produced at a number of points on the outcrops of the Stockbridge, but the necessity for business concentration and considerations of local convenience have diverted the lime industry to other parts of the State.

Gneiss, gneissoid granite, and granite are obtained at many places, some of which are noted below. The principal quarry in the Fordham gneiss is near Hastings, and furnishes an excellent light-gray stone. In the Yonkers gneiss several quarries produce a reddish gneissoid granite of excellent quality. The quarries in the smaller areas of intrusive granite furnish chiefly material for local use in the foundations of buildings. In the Harrison diorite, one quarry is operated near Larchmont, the product being used locally in buildings. The material is attractive in color and very satisfactory in respect to strength and durability. Between Mount Vernon and New Rochelle a quarry in a local mass of granite is operated for road metal, but little is used for structural purposes. In the gneissoid areas of the Hudson schist the quarries are purely local and the material is used only for buildings in the immediate vicinity. No considerable amount of capital has been anywhere invested, as the rock masses fit for structural use are small.

In addition to the building stones derived from the quarries in the crystalline rocks, the moraine material of Westchester County and Long Island furnishes an abundance of bowlders of diabase from the Palisades of New Jersey. This rock has been extensively used for building foundations and fences, and occasionally for dwellings. Its rich, dark color makes it a very attractive building stone, but its extreme toughness renders it expensive to work.

Building sand.—The alluvial deposits of the numerous stream valleys yield sand for building purposes, the consumption of which is very large, but the material is usually obtained on too small a scale at the different sand pits to make it possible to obtain any statistics of production. On Long Island stratified Pleistocene deposits yield immense quantities of building sand.

Iron ore.—On the serpentine hills of Staten Island limonite of good quality was formerly extensively mined. This ore of iron is a result of the alteration of the basic rocks from which the serpentine was derived.

Clay.—On Staten Island glacial clay is employed for the manufacture of common brick at Green Ridge and on the shore of Arthur Kill. Cretaceous clay is used at Kreischerville in making fire brick and stoneware. At Elm Point, Long Island, a variegated clay of Cretaceous age, outcropping in the face of the cliff, has been extensively worked for stoneware. It is shipped by water to factories at Astoria, N. Y., and Boston, Mass.

LATER PALEOZOIC CONDITIONS.

By Bailey Willis.

General statement.—In the New York district the beginning of the deposition of the Hudson formation, rather than its close, may be taken as the dividing line between the earlier and the later Paleozoic history. In this sense later Paleozoic time comprises the later part of the Silurian period, the Devonian, and the Carboniferous, including the Permian. During the earlier Paleozoic the New York district was submerged beneath an extensive interior sea; during some at least of the succeeding ages it formed part of a land area, which was bounded by shores, was traversed by rivers, and exhibited plains, hills, or mountains, according to the conditions of one epoch or another. This phase of the geologic history extended beyond the Paleozoic era into the Juratrias period of the Mesozoic, to the time of deposition of the Newark sediments. The events are not recorded in the New York district, but they may be inferred from strata occurring farther west.

Emergence from the Silurian sea.—The date at which the Silurian sea withdrew from the New York district can not be fixed. The Hudson formation comprises simply the latest Silurian rocks preserved in the region. Later strata may have been deposited and eroded, and to that extent the evidence is indefinite, but an isthmus is thought to have separated the Appalachian Sea from a sea which covered part of New England. (See map. fig. 2.) The inference that this isthmus existed is based partly on the fact brought out by Prof. H. S. Williams that Devonian fossils found in New York differ from those found in Maine, as they would not in like degree had the waters been connected; and the evidence of fossils corroborates that of the distribution and character of Devonian sediments, which, where they occur northwest of the Highlands, have the character of deposits made near shore. Thus the emergence is dated approximately as prior to Devonian time—that is, during the latter part of the Silurian period.

The character of the movement by which the relations of land and sea were changed was probably not such that narrow time limits can be set for it. The present Atlantic Coastal Plain, which has repeatedly been overflowed and abandoned by the sea, may be regarded as similar to the land surface which existed during the later Silurian where New York City now is; but that surface sloped northwestward to the Appalachian Sea, and whatever sediments the occasionally returning waters spread over the plain were soon eroded from the district about New York. The sands and conglomerates of the Medina formation occurring farther northwest represent these episodes of a coastal plain phase, and the thin clayey and calcareous sediments of the Niagara, Salina, and Helderberg extend the record of limited erosion to the Devonian.

Geography during Devonian time.—According to the sediments of the early Devonian epochs, the Appalachian land remained low and was worn to a still lower plain than that which it had exhibited in later Silurian time. This is true of all Appalachia for that part of the Devonian represented by strata of the Hamilton group, and it is true of southern Appalachia until a much later time; but, though that plain extended over New York State for an age, there came a change over the northern lands, in which New York shared. In the "Outline of geologic history" (p. 2) reference has been made to a mountain range which grew and wasted away in Devonian time. The inference that such a range then existed rests upon the great volume of sediments deposited in the Appalachian Sea during the later epochs of of the Devonian, which are known as the Chemung and Catskill. The unassorted mixtures of clay and sand which constitute the deposits are such as result from the decay of metamorphic rocks, and in being carried to the sea have undergone no more sorting than rivers might perform. They thus seem to be the immediate products of erosion, distributed directly by rivers, and they may be compared with the sediments which escape beyond the mouth of the Mississippi and are laid down near by; but there is a difference in the fact that the Gulf of Mexico is deep, whereas the Appalachian Sea was comparatively shallow. Shallow waters are indicated on the surfaces of strata by ripple marks and the trails of shell fish or annelids, and deposits exposed at low tide exhibit mud cracks. These evidences occur throughout the later Devonian beds, showing that the surface of the deposit was commonly near sea level, although the mass reaches a thickness of more than 5000 feet in New York State and of 10,000 feet in Pennsylvania. Thus the sediments accumulated in general about as fast as the bottom of the basin sank. On the one hand there was or had been a hilly or mountainous land, which was eroded; on the other, a broad and deepening gulf, which, however, as it deepened was filled with the waste of the land. The volume of that waste is so great that, if restored to the probable land area, it would constitute a mountain range at least as high as the mountains of North Carolina, which the Devonian mountains at one phase of their development may have resembled. Their foothills, or possibly their heights, rose above the site of New York City.

Geography during Carboniferous time.—The Devonian epoch of mountain growth had passed, but the waste from lands still sufficiently elevated to suffer erosion was being deposited in the northern Appalachian Sea when the faunas there existing passed through those changes of development and migration by which they assumed characteristics of early Carboniferous life. It seems that throughout the Carboniferous period the district about New York remained a land area and suffered many changes of altitude and aspect. While in part certain sediments, such as the Mauch Chunk formation, resemble those of the later Devonian, the greater mass of Carboniferous rocks in Pennsylvania is distinguished by the large amount of concentrated quartz that it contains, and other less enduring minerals are not common. They were no doubt originally associated with the quartz, but they have been removed by weathering, abrasion, and sorting, such as go forward chiefly in deposits on coastal plains. With this suggestion of a coastal plain may be combined the fact, indicated by coal beds, that extensive marshes with rank vegetation developed from time to time within the area of the Appalachian Sea, and thus the idea assumes definite shape that the Carboniferous landscape was one of broad lowlands with luxuriant growth, replaced at frequent intervals by stretches of shallow seas. The nearest comparison which we can make with existing physical conditions is with the flat shores of a tropical region like northern South America. This picture is incomplete, however, without a background of hills, which, if not constantly maintained by uplift, were from time to time elevated and eroded.

The close of the Carboniferous period coincides with the end of the Paleozoic era and with those great changes in organisms that mark the gap between ancient life and Mesozoic or middle life forms. It coincides, in the history of the Appalachian province, also with final retreat of the water from the Appalachian Sea, and thus it was a time of pronounced change in the physical geography of eastern North America. This also is the date of the so-called Appalachian revolution. The strata deposited during Paleozoic time, including the latest Carboniferous beds, are folded as by great compression along a zone which passes through New York west of the Highlands and up the Hudson–Champlain valley; and along an adjacent zone bounding the former on the southeast all the rocks have been metamorphosed by pressure and recrystallization, producing in many instances gneisses and schists. These are complex effects, possibly slowly developed under repeated occurrences of compressive stress, but they culminated at the close of the Carboniferous period. In the zone along which the strata were folded in parallel arches and troughs there developed corresponding hills and valleys, having trends which can still be determined from the folds. Thus we reach the earliest suggestions of the courses of rivers, from which, by many changes, diversions, and adjustments, some river systems of to-day may be remotely derived. It is not probable, however, that the Hudson or any other stream near New York can claim such antiquity. An article which describes the possible ancestors of the Susquehanna and its neighbors and indicates the lines of descent of the modern streams is published in the National Geographic Magazine, Vol. I, 1889, by Prof. W. M. Davis, under the title Rivers and Valleys of Pennsylvania.

The Carboniferous is succeeded among geologic periods by the Juratrias, commonly separated into the Triassic (earlier) and the Jurassic (later). The lapse of time until near the close of the former was recorded in eastern North America only in forms of the landscape, which have given place to much later plains, valleys, and hills, and consequently little more can be said than has already been stated in the "Outline of geologic history," to which the reader is referred (pp. 2–3). The record begins again with the deposition of the Newark group, which is described by Mr. Darton.

JURATRIAS ROCKS.

By N. H. Darton.

NEWARK GROUP IN GENERAL.

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

The Newark rocks in general are remarkably uniform in character. 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 west at angles of 10° to 15°, while in New England and Nova Scotia, and at some of the easternmost outcrops in Virginia and North Carolina, the inclination is in the opposite direction. The thickness of the sediments is great, but as yet has been determined only approximately, and only in portions of the belt. The great width of territory in which there are monoclinal dips would indicate a vast succession of sediments, but longitudinal faults frequently repeat the outcrops of the series.

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 at the close of Carboniferous time, and therefore must be of later date, and they are clearly older than the lowest Cretaceous formations, which overlap them unconformably. They are thus separated from earlier and later deposits by intervals of upheaval and erosion of unknown duration, 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 York district.—The Newark group in the New Jersey region occupies a broad belt extending across the north-central portion of the State from the Delaware River to the 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 the Hudson River and the low serpentine hills of Staten Island, and to the southeast are low plains composed of formations of the Cretaceous and Neocene periods. Over wide areas the dips of the strata are to the west and northwest, but in the central-western portion, about the Watchung Mountains, there is a low syncline with various minor flexures. There are extensive faults traversing the rocks, mostly along their strike and with downthrow on the east side. The abrupt margin on the northwest probably is defined by a fault on which the generally west-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 River, 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. From extensive studies by Henry B. Kümmel, of the New Jersey Geological Survey, 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 the Delaware River and northward to beyond the 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 two upper formations lose their distinctive characters. The Stockton formation comprises arkose sandstone with some red-brown sandstones and red shale, in no regular succession and presenting many local variations in stratigraphy. It lies on gneiss at Trenton, and is brought up again by faults in zones passing west of Hopewell and about Stockton. To the north it lies along both sides of the Palisade trap. The sandstones are often 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 the Delaware River and for some distance north consists mostly of dark-colored, fine-grained rocks of argillaceous nature but hard and compact. Some beds are massive and others are flaggy. They show mud cracks and other evidences of shallow-water deposition, but all their materials are clay and very fine sand. The Lockatong formation 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 above Stockton. In northeastern New Jersey the Lockatong appears to be thinner, and it is less characteristic, apparently being represented by a red shale belt extending along the valley west of the Palisade ridge. In its typical development the Brunswick formation consists mainly of a great thickness of soft red shales with occasional 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 NEW YORK DISTRICT.

General relations.—The rocks of the Newark group occupy the New Jersey area of the New York district, comprising the greater portion of the Paterson quadrangle and parts of the Harlem and Staten Island quadrangles. They also underlie the western portion of Staten Island.

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 owing to their hardness they give rise to high ridges, of which the Palisades and the Watchung Mountains are the most conspicuous. These are elevated 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, the course of the ridges being north and south in most cases. The following section illustrates the general structural relations of the sedimentary and igneous rocks:

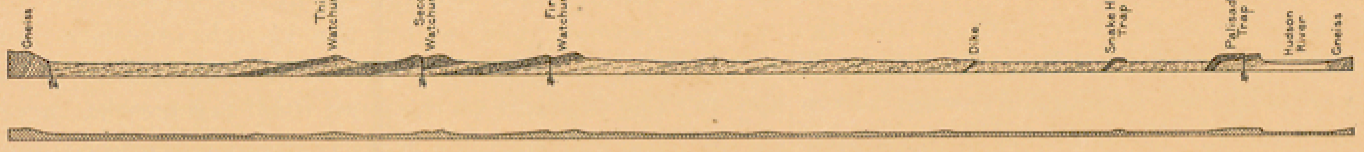


Fig. 3.—Northwest-southeast section across the Paterson quadrangle and adjoining region, showing the relations of the igneous rocks to the sedimentary strata of the Newark group.
Vertical scale three times the horizontal scale. True profile indicated in lower outline section.

This section shows the general dip to the west, the order of succession and relations of the larger igneous masses, and a typical igneous dike, and it illustrates the origin of the more prominent topographic features. The rock of the Palisades is an intruded sheet of diabase that was forced between the layers of sandstone and shale. The Watchung rocks are lava flows which were poured out over the sea bottom at three separate times during the accumulation of the sedimentary deposits.

The Newark strata lie on gneisses and other crystalline rocks of the series which rise to the surface on the east side of the 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 formation at the 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.

Sedimentary rocks.—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. The shales are often bright brownish red and the sandstones are of paler tints of the same color. Adjoining the intrusive igneous rocks most of the shales are nearly always greatly hardened and darkened in color, not infrequently so much so as closely to resemble the finer-grained varieties of the igneous rock in general aspect. The sandstones vary 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. It often occurs in thick beds, and usually with 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. Arkose sandstones occur at or near the base of the group along the shore of the 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 apparent lack of distinctive stratigraphic features in the northern extension of the Lockatong 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 represented by an unknown thickness of light brownish-red sandstone and shales not distinct from the Brunswick formation, which is much more sandy than in the region south.

The lowest Newark beds seen in this district are exposed along the shores of the Hudson River from Weehawken northward, and consist largely of coarse arkose containing angular fragments of quartz, feldspar, mica, and occasionally other minerals in small proportions. The quartz fragments are often half an inch in length. More or less rounded material, mainly quartz sand, is intermixed. Streaks of shaly matter occur, and the beds sometimes give place to cross-bedded coarse sands with shale intercalations. The thickness of this series of coarse deposits is not known, because there are no means for ascertaining the depth to the old crystalline rocks which outcrop on the opposite side of the Hudson River and underlie the arkose westward. The arkose beds are particularly well exposed in many low banks along the river from Fort Lee to the State line, and at intervals as far south as Hoboken.

The sedimentary beds lying next above the Palisade diabase are mainly arkose sandstones with local included beds of shales. The most extensive exposures are found in road cuts west of Alpine and in quarries and stream cuts a mile and a half east of Closter, where the rocks are coarse-grained, light-colored, massive sandstones, usually containing a large proportion of feldspar grains. Other exposures are at Ridgefield, in the streams east of Nordhoff and northeast of Granton, in the quarries in the Granton diabase, and at the entrances to the New York, Susquehanna

*The term "Newark group" is used in this text in the sense given it by I. C. Russell in Bulletin No. 85 of the United States Geological Survey, to cover the sedimentary and igneous rocks of Juratrias age of the Atlantic border. It is not desirable that it should be applied to any subdivision, nor to the sedimentary rocks as a whole, exclusive of the contemporaneous igneous rocks in areas in which such occur. The usage "Newark formation" which appears in the legend of the map was accepted before the question had been given critical consideration.

and Western and the West Shore railroad tunnels. On Staten Island the only outcrops are on the shore near Mariners Harbor.

In the wide area lying between the Palisades ridge and the Watchung Mountains there is a thick succession of alternations of 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 a coarse sandstone with occasional thin intercalations of shales. Owing to the scarcity of connected outcrops, no definite stratigraphic succession has been determined in this area; doubtless it is traversed by longitudinal faults, repeating the surface outcrops of the beds. Faults which appear to have but moderate throw are exhibited in railroad cuts west of Arlington and Hackensack and in road cuts east of Hackensack. The fault west of Arlington exhibits a zone of breccia several feet thick.

For some distance west of the inner slope of the Palisades ridge the rocks are usually 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 from Ridgefield Park, in the ridge west of Englewood and Closter, there are occasional 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 ceases and its place is taken by a wide area of lowlands with scattered drift hills. The sandstone lies on the shales which underlie the meadows. A portion of these shales is 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 a fault.

Next west lies another similar mass of sandstone, but much harder and thicker bedded, and of lighter color, extending through Newark, Avondale, and the western part of Passaic, which has been extensively quarried for building stone. Its upper beds merge into a thick mass of shales of red color, with alternating sandstones, which extend west nearly to the base of the First Watchung Mountain. This shale underlies Orange, Bloomfield, and the eastern portion of Paterson, but it is much hidden by heavy deposits of drift.

In Midland, Washington, and Saddle River townships outcrops are very rare, owing to heavy 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 the First Watchung Mountain the material is almost entirely sandstone lying on a conglomerate, which is exposed at the eastern entrance of the Great Notch and along Goffle Brook west of Hawthorne. 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 possibly separated from it by a great fault with downthrow on the east side. The First Watchung basalt is overlain by sandstones, which are exposed at Little Falls, Haledon, and Franklin Lake in small amount. The beds overlying the Second Watchung basalt are completely buried under drift in the Paterson quadrangle, but from outcrops farther north and south they are known to be thin-bedded, reddish-brown sandstones. They are supposed to be the uppermost sedimentary rocks in the Paterson quadrangle.

Watchung basalt.—In the western portion of the Newark area in northern New Jersey there are three prominent ridges known as the Watchung or Orange Mountains. These ridges are the edges of three thick and extensive sheets of lava, which were outpoured successively during the deposition of the Newark sediments, deeply buried in 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 deeply decomposed, eroded, and glaciated, these lava or trap sheets present all the usual evidences of extrusions contemporaneous with the inclosing sandstones. At their bases the lavas lie conformably on the bedding of unaltered or but very slightly altered strata and is vesicular; the upper portions of the flows are vesicular to a considerable depth; they present evidence of successive flows, in part on tuff deposits, and they are overlain by unaltered strata, which in some localities rest on an intervening breccia containing fragments of the igneous rock.

The stratigraphic position of these trap sheets in the Newark sediments is not satisfactorily determined. A short distance below the oldest flow there are coarse deposits — conglomerates and coarse sandstones, but these appear to be a local development in the higher members of the formation. The trap sheets themselves and the immediately associated strata constitute a series that appears to be relatively regular in order of succession and thickness of beds. These features are shown in the three columnar sections in fig. 4, the first near High Mountain, the second just south of Paterson, and the third opposite Orange. These sections are based mainly on detailed measurements with calculations from numerous dips, but also in part on the assumption that the three lava flows have their bases practically parallel.

There is, of course, the possibility that there is only one lava sheet with its outcrops repeated three times by two long parallel faults, but it is very improbable that two faults, or even one, would have such uniform throw and parallelism as to maintain the present regular succession for a distance of 60 miles.

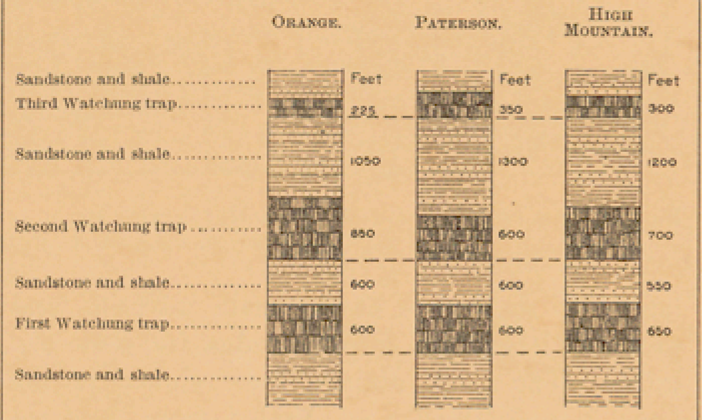


FIG. 4.—Sections illustrating the stratigraphy of the Watchung lava flows in Essex and Passaic counties, N. J.

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 surrounding rolling country, but notches, depressions, and high summits break the continuity of their crest line. This is notably the case at Paterson and Little Falls, where the Passaic River cuts across the two trap ridges through wide cross 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 sandstone and shale, on which the basalt 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 flow is crossed by the Passaic River in a wide, low gap, the river falling over the edge of the basalt sheet into a narrow inner gorge. (See figs. 19 and 20 on Illustration sheet 2.) The wide depression at Little Falls is similar topographically and is also traversed by the Passaic, but in this vicinity the trap sheet is comparatively thin and the diminution in elevation and width is only partly due to erosion. The relations, boundaries, and general structure of the Watchung basalt sheets are well marked for the greater part of their course, but there are some localities in which the outcrops are obscure or lacking, so that the relations could not be ascertained. Along the northern portion of the First Watchung Mountain the drift mantle is so heavy that even the approximate location of the boundaries between the sedimentary and igneous rocks could not be determined.

The relations of the First and Second Watchung lava flows to the underlying sediments are exposed at a number of localities in the Paterson quadrangle. At Paterson the best exposures are in the gorge immediately below the falls of the Passaic River, where the trap may be seen lying on the shale for several hundred yards, mainly on the south bank of the river. The rocks are perfectly conformable, and the sandstones are not baked, except perhaps slightly for the first 2 or 3 inches, while for a few inches above its smooth undulating lower surface the basalt is somewhat vesicular. The relations are strikingly in contrast with those presented in basal contacts below the Palisade diabase, where the igneous rocks frequently have cut across the sedimentary beds and baked them, often for many feet. In old quarries and railroad cuts along the face of Garret Rock, just south of Paterson, there are or formerly were many extensive exposures of the base of the lava sheet lying conformably on the unaltered sandstones. Some features of the lower contact are exhibited in a quarry near Upper Montclair, where the exposure of contact is over 150 feet long and there is perfect conformity. At one point the basalt lies on the sedimentary beds in a hollow, such as a lava mass might be expected to make in soft mud as it flowed over a sea bottom. The basalt is very vesicular and deeply decomposed for about 12 feet, and passes upward 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 great quarries northwest of Orange the contact is sometimes exposed, showing perfect conformity, entire absence of alteration in the sandstone, and some vesicularity in the basalt for a few inches from the contact.

The base of the Second Watchung sheet is very instructively exposed at Little Falls, mainly in the quarries along the north bank of the Passaic River a short distance below the falls. In the vicinity of this exposure neither the basalt nor the sandstone is noticeably altered in texture or color, and the contact is along a perfectly horizontal line. Westward, near the falls, and again farther east, the base of the sheet is a mass of vesicular rock, often exhibiting flow structure beautifully. 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 there is columnar basalt below the vesicular, ropy variety, but the dense columnar rock is usually above. A half mile below the falls, on the north side of the river, there is an exposure of the edge of the basalt sheet in which appear the relations shown in the following figure:

FIG. 5.—Diagram of cliff one mile below the falls of the Passaic at Little Falls, N. J., showing supposed tuff deposits overlying and penetrated by columnar basalt. (From a photograph, 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 trap 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 from this locality for many miles the drift and talus cover the basalt and lie so heavily against 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 latter is in the old quarries a mile and a half north of Haledon, where a mass of highly altered, vesicular basalt lies with perfect conformity on unaltered sandstone. In some portions of the exposures the greater part of the basalt is dense and columnar, but in others there is ropy flow structure in rock that is deeply vesicular. At one or two points the vesicular rock includes large masses of the dense rock. In the more deeply altered material there is often a heterogeneous mixture of fragments cemented into a breccia by zeolitic, quartzitic, and calcic impregnations. The Third Watchung basalt gives rise to the ridge west of Preakness, but, owing to drift covering, it does not exhibit its relations to the adjoining sedimentary rocks in the Paterson quadrangle. In other portions of its course it is seen to present characteristic features of an eruptive sheet, with ropy, vesicular surfaces lying with perfect conformity on unaltered shales and sandstone. The relations of the Watchung basalts to the overlying sandstones can not be determined in the Paterson quadrangle, owing to the extensive mantle of drift lying along the western slopes of all the ridges. There are, however, to the south, exposures showing the vesicular upper surface of the basalt overlain by entirely unaltered red shales. The most instructive exposures of these features are at Feltville, north of Plainfield, N. J. In several exposures of the original upper surface of the First and Second Watchung traps, in the vicinity of Paterson, the basalt presents a slag-like appearance, and there are many areas of vesicular trap a few miles north of the western part of Paterson. At the base of High Mountain there is an exposure in which the shales outcrop within 15 feet of the First Watchung basalt, or about 4 feet vertically above it, and there is no perceptible alteration or disturbance of any kind in the sedimentary beds. The outcropping edge of the Watchung basalts presents columnar structure which is usually well developed. For detailed description of these structures see paper by Prof. J. P. Iddings in American Journal of Science, 3d series, Vol. XXXI, 1886, pp. 321–331. One of the finest exposures is in O'Rourke's quarry west of Orange, as shown in figs. 17 and 18, on Illustration sheet 1. Here there are large columns at the base, merging quickly 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. 16 on Illustration sheet 1.) The superposed columns do not indicate successive flows, but in the Second Watchung basalt there is evidence of two flows, indicated by a vesicular surface high in the basalt mass. There are exposures of this relation at Little Falls, where at a height of about 150 feet above the base of the sheet there is a surface of vesicular rock, apparently including some fragmental materials, overlain by massive and columnar basalt supposed to be of a later flow. In places the Watchung basalts present a bedded structure, usually near the base. This is notably the case at Paterson, as is finely exhibited along West street.

The Watchung sheets appear to be traversed by small faults at several places, but the only clear exposures of faults are in Garret Rock, along the railroad cuts in the southern part of Paterson. Here the principal dislocation has a vertical displacement of about 70 feet, with the downthrow on the east side. The course of the fault southward is plainly marked by a continuous series of valleys in the mountain, which extend to beyond Montclair Heights station, where the fault passes out of the ridge into the drift-covered sandstone country. It causes gaps in the walls of Great Notch, where its amount is not far from 150 feet, not quite sufficient to bring to view the sandstone underlying the basalt. Two other faults are plainly visible in Garret Rock, but they are local and of small amount. The gaps and offsets in the ridges of the Second Watchung Mountain between High Point and Franklin Lake suggest the presence of faults, but owing to the lack of critical exposures their existence is uncertain.

The igneous rocks of the Watchung ridges appear to be very uniform in mineralogic character and are classed as basalt. This rock occurring in O'Rourke's quarry is described by Prof. J. P. Iddings in Bulletin No. 150 of the United States Geological Survey as follows:

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 3 or 4 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.

The chemical composition of this rock is shown in the analysis, made by L. G. Eakins:

Analysis of basalt from Watchung Mountain, New Jersey.

	Per cent.
SiO_2	51.36
Al_2O_3	16.25
Fe_2O_3	2.14
FeO	8.24
MnO	.09
NiO	.03
CaO	10.27
MgO	7.97
K_2O	1.06
Na_2O	1.54
H_2O	1.33
CO_2	....
Total	100.28

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

The diabase first appears on the surface at Staten Island, where it forms a low hill extending to the Kill van Kull. On Bergen Point it again rises in a low ridge, which gradually increases in elevation to the north and soon presents a low escarpment to the east. In Jersey City the altitude of the ridge is 200 feet. The escarpment reaches the Hudson River at Weehawken and thence continues northward with bold front to the State line, its elevation finally increasing to about 550 feet. In configuration the Palisade ridge is generally a single-crested or slightly corrugated ridge with gentle slopes on the west, often flanked by overlying strata, and with an escarpment on the east, in which a greater or less thickness of diabase caps the underlying strata. The columnar front, which is so characteristic of the ridge, begins in Jersey City, where for some miles the columns are moderately well defined. But it is along the Hudson River from Fort Lee to the State line that the great, even-crested face of the eastern edge of the sheet is a continuous cliff of huge columns extending down for 200 or 300 feet to the steep talus along the river.

Fig. 6 gives a general idea of the even crest line and escarpment, but the grandeur and prominence of the palisaded front are better shown in figs. 14 and 15, on Illustration sheet 1.

The Palisade diabase above the present surface is in greater part a thick sheet which was intruded between the strata. It was fed by dikes, of which a large one is exposed in places along the western side of the ridge. This dike appears to have a course closely approximating the present trend of the outcrop and to terminate above in the sheet. The dike and sheet structure is well exhibited along the West Shore Railroad tunnel through Bergen Hill at Weehawken.

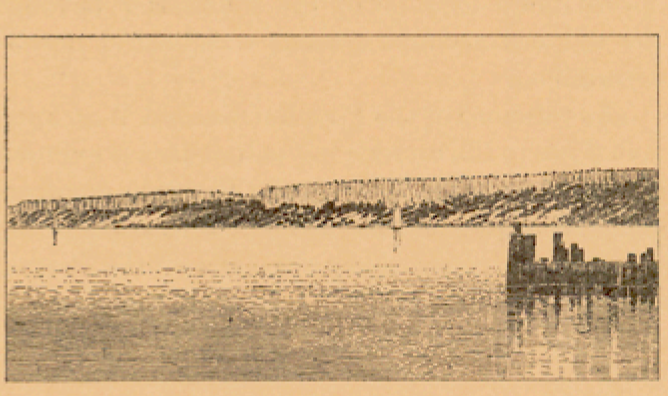


Fig. 6.—The Palisades, from the east side of the Hudson near Yonkers, N. Y.

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 dike and sheet at Granton, and it is undoubtedly the source of the several small sheets which are intruded in the underlying strata near Weehawken, Kings Point, and at other places. For many miles along the Hudson River the base of the sheet is frequently exposed, and while it preserves a practically uniform horizon in the lower part of the sandstones, many local irregularities are seen. In these the diabase crosses the underlying strata laterally, up or down, in some instances for a hundred feet. The sheet is not noticeably flexed in its course through New Jersey. It lies in beds dipping 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 cases confined to increasing or decreasing the elevation of the contact line in the face of the cliff, although in some cases they cause slight deflections of the crest line. Several faults occur, which somewhat modify the uniformity of the course and contour of the diabase outcrops.

The intrusive nature of the Palisade diabase is clearly exhibited in its relations to the sedimentary beds with which it is associated. The diabase is often exposed cutting across these beds for greater or less distances and sending branching dikes into them. There are many instructive exposures illustrating the relations of the base of the Palisade diabase to the underlying beds. The sedimentary rocks at the contacts are generally argillaceous shales overlying the basal arkose, and they are in most cases 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. 7. The two rocks are usually welded together along the contact, but generally the line of junction is plainly visible, particularly where the surface is weathered. Descending plates and dikes of diabase are of comparatively frequent occurrence, and irregularities in which the diabase breaks across the ragged edges of the strata for greater or less distances are found in nearly every exposure.

The first outcrops of underlying strata are 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 across the arkose in a very irregular manner. Several masses of arkose are included in the base of the diabase at this locality. To the south and for the next mile north the diabase appears to extend down considerably below the level of the meadows and lowlands at the foot of the ridge.

In the northwestern portion of Hoboken, near the electric railroad grade, the contact rises rapidly to 25 feet above the meadows, and for some distance 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 shales at intervals and sends into them 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 diabase is very fine grained, and at many points it includes small fragments of shales. The shales are baked to a high degree of hardness and are darkened to black, purplish, and gray, but some beds are light gray and gray-buff. They dip at a low angle to the west and exhibit a thickness of 50 feet. The lowest beds exposed are arkosic sandstones.

The contact finally rises to an altitude of 60 feet, and then, at the western end of Nineteenth street, in the southwest corner of Weehawken, the igneous rock descends across more than a hundred feet of shales into the arkose to about tide level. The cross contact is an exceedingly ragged one, the diabase penetrating the shattered edges of the shales and for some distance including great fragments of them. Owing to the increased thickness of the harder rock, the escarpment advances eastward for several hundred feet, forming the bluff on which the "Observatory" is 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 on 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. A short distance farther north 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 the Hudson River at the prominent headland of Kings Point. At the southern end of this point the bluffs are diabase from base to summit, but a few rods north the base of the sheet rises from tide level, below which it was carried by the fault, and crosses the strata as shown in fig. 7. 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 north, preserving throughout a nearly uniform horizon in the shale. Its thickness averages about 3 feet. Three-quarters of a mile 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.

North from the tunnel for some distance outcrops are infrequent, but the line of contact appears to remain essentially unchanged in position until near Guttenberg, where there are some indications of either a slight fault or a change in horizon. In the road below the quarries of Guttenberg there is a dike in the arkose underlying the main mass of diabase. This dike appears to be connected with the Palisade diabase above, but whether it is an ascending dike or a downward offshoot is not known. In the vicinity of Bulls Ferry there are extensive exposures of baked shales underlying the diabase, and the contact, although rarely exposed, appears to preserve a nearly uniform horizon. At the eastern entrance of the New York, Susquehanna and Western Railroad tunnel the contact relations are instructively exhibited and the beds are seen to be traversed by two small faults, which will be described later. The diabase and shale are here conformable. From this point to Fort Lee the contact extends along the slopes at an altitude about 60 feet above the river. An exposure exhibiting the relations was made by the excavations for the electric railroad which ascends the hill in this interval. The contact is very irregular, and a thin sheet of the diabase extends laterally from the main sheet into the shales. The sedimentary beds of shale on arkose are highly altered. At Fort Lee there is considerable local irregularity in the contact, and the diabase either descends for over a hundred feet across the beds to the east or, as is more probable, there is a fault which carries the diabase down in that direction. There is a break in the continuity of the crest line, a shallow depression extends up into the ridge, and the line of escarpment offsets several rods eastward to form the "Bluff" which marks the beginning of the Palisade front, extending thence far to the north. Near the lower end of the depression behind the "Bluff" there is, on the roadside, an obscure exposure in which the diabase breaks downward across the edges of the intensely baked shales for several feet. From Fort Lee to the State line, 12 miles north, the beds underlying the diabase are extensively covered with the heavy talus of diabase fallen from the cliffs above, but there are a few exposures of the contact in which the plane is seen to preserve a fairly uniform horizon in the shales, and the contact rises gradually northward. Opposite Englewood it is 120 feet above the river, and at Alpine 210 feet. The beds near the contact appear to be shales throughout, underlain by arkose, which outcrops frequently in the river bank in cliffs 15 to 20 feet high. There are probably many local irregularities in the diabase-shale contact, for every exposure exhibits more or less of them. Just north of the quarry below Linwood some very complex relations are exposed. A mass of sandstone and shale 60 feet long and 10 feet wide, and other small masses, are included in the diabase which ascends across the shales below and sends small sheets and dikes into the sedimentary beds. These beds are baked to great hardness and dark color, and they are much shattered at points along the contact. Due east-southeast of Englewood the contact is exposed in a road cut, crossing sandstone beds for a few feet, and in the quarry on the river shore east of Englewood there is a long exposure showing the diabase ascending gradually across baked shale on sandstone.

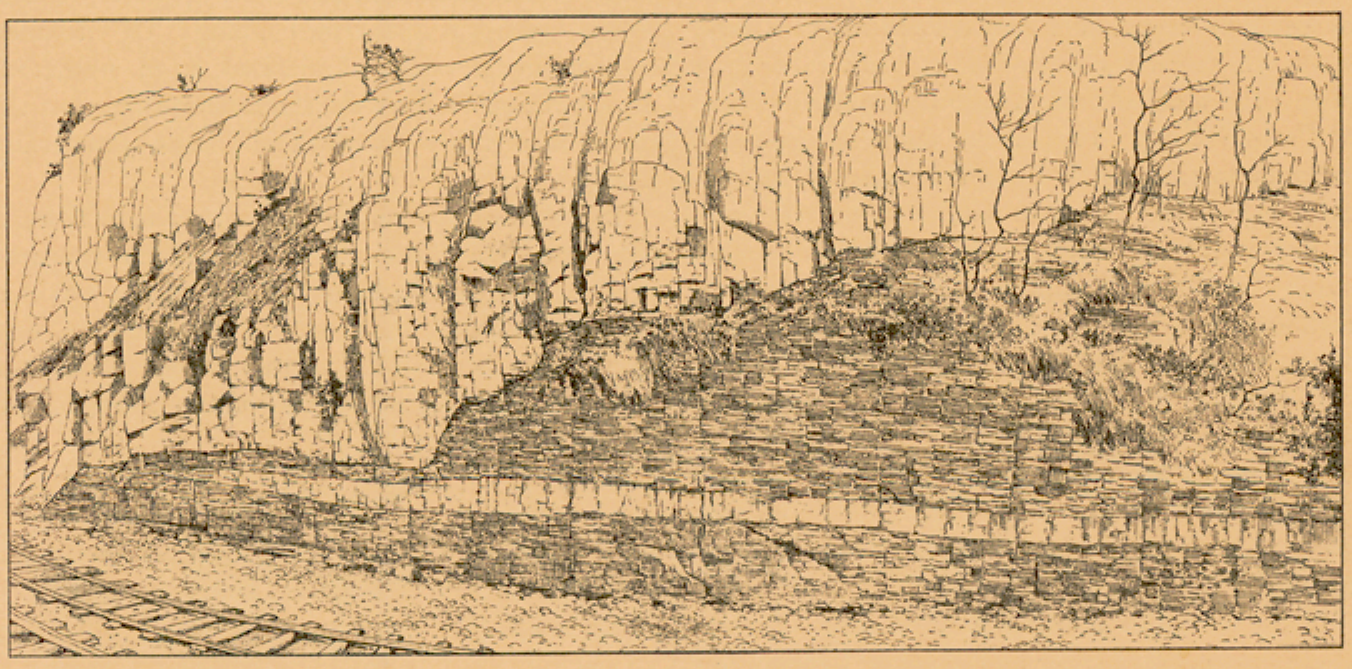


Fig. 7.—Base of Palisade diabase showing lateral ascent of the diabase across the strata of the Newark group. Kings Point, Weehawken, N. J., looking west. (From photographs.)

Owing to the extensive denudation to which the surface of the Palisade diabase has been subjected, overlying strata seldom extend far up its inner slope; generally they are either removed down to the level of the adjoining plain west or are hid by heavy masses of drift, which often extend for long distances along the western side of the ridge. However, there are sufficient, though scattered, exposures to indicate the structure of the trap and throw light on the relations of its upper surface. In every case the diabase is seen to cut across some of the beds, and when the sedimentary materials are argillaceous they are baked very hard and dark and are welded to the diabase at the contact. Along Bergen Point the western outcrops of Palisade diabase extend to the margin of Newark Bay. In the western portion of Jersey City diabase is bared to the base of the ridge, as shown by occasional outcrops, but is usually more or less thickly covered by drift deposits. 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 at a point 304 feet below the surface, after passing through alternations of sandstone and altered shales possibly penetrated by thin diabase sheets. The record, unfortunately, does not identify the beds very definitely. Nearly a half mile south of Schuetzen Park, in an old quarry near the roadside, there is an exposure in which the diabase is seen to be overlain by a small mass of baked shales. The shales dip southwest and are 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 north 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, described above. The next upper contact is exposed at the western entrance to the tunnel of the West Shore Railroad, where it presents the relations shown in fig. 13, on Illustration sheet 1. At this point the diabase becomes a large dike cutting diagonally across the overlying beds along a north-northwest course, and carrying the sheet to a higher horizon. The back of the dike has a steep inclination, about 60°, and the strata dip 15° to the northwest. The beds are coarse sandstones in which baking is confined to the immediate vicinity of the contact. At some points the sandstone and trap are welded together along a ragged contact, showing that the sharp break is not due to faulting. In a depression a mile northeast of Granton there is an exposure of the strata immediately overlying the diabase, and although the exact line of contact is not visible, considerable unconformity exists in both dip and strike, probably indicating the presence of the dike. 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 there are two small dikes extending from the main mass of diabase into the sandstone. They average about 6 inches in thickness, and after crossing 2 feet of the sandstone extend a short distance between the beds.

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 there is a heavy drift cover which hides the contact. On the roadside at a point just five-eighths of a mile east by south of Leonia station there are exposures in which a thin mass of baked shale lies conformably on the diabase surface. There are many minor irregularities and the two rocks are everywhere welded together.

In the bottom of the small depression a half mile west of Linwood the diabase and shale are exposed near together with every appearance of conformity. The shale here is faulted against diabase which outcrops in a narrow belt along the ridge next west of the depression. A short distance north shales in contact with diabase are exposed on the western slope of the ridge, in a stream bed three-quarters of a mile east of Nordhoff station. Here the baked shales are extensively exposed. At the contact the diabase is fine grained, as usual, and is welded to the blackened and hardened shales along a nearly smooth plane. The dip of the shales and that of the surface of the diabase are conformable in this vicinity.

There are a few exposures of diabase and shale at intervals in the next mile northeast of this locality, but no contacts are visible. In the vicinity of Englewood and for several miles north the heavy mantle of drift covers all the bed rock along the western slope of the ridge. A mile southeast of Tenafly the arkose and diabase are exposed near together, but their relations could not be ascertained. From this locality to the State line the drift covers the contact line and its vicinity, except along the road just west and south of Alpine and in the stream bed 2 miles east of Closter. Near Alpine baked sandy shales of reddish and purplish tints are exposed near the diabase at an altitude of 400 feet. The exposures east of Closter are in gullies on either side of the road and a few yards from it. The altitude is about 350 feet. There are shales baked to a purplish color associated with unaltered sandstone, all dipping N. 10° W., at an angle of 15°. The diabase rises steeply a short distance east, and as the interval is obscured by débris the contact relations are not exhibited.

There is much difficulty in attempting to estimate the original thickness of the Palisade diabase sheet. 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, which add to the difficulty of making accurate estimates. A well recently bored on Jersey City Heights penetrated 364 feet of trap and reached the sandstone below. The thickness increases northward, and at Fort Lee a well penetrated 875 feet of diabase to the underlying shale. As this is near the eastern margin of the diabase sheet, and the dip of the beds at the base of the sheet is greater than the rate of slope of the ridge to the west, it is probable that the thickness is considerably greater to the west and that in the vicinity of Taylorville it may be as much as 1100 feet. North from Englewood it is probable that the thickness of the diabase sheet is 1200 feet, but owing to variable dips it is difficult to make a precise estimate. At Alpine a thickness of about 1000 feet is indicated.

The Palisade diabase is traversed by a number of small faults with downthrow on the east side and mainly having a trend parallel to the north-northeast course of the ridge, but also extending diagonally into it on a north-by-east course. They usually give rise to marked topographic features, such as longitudinal depressions with subordinate escarpments and breaks in the crest line of greater or less prominence. There are also innumerable minor faults, marked by offsets in horizontal joint planes which are more or less conspicuous in nearly every cross-section exposure on the range. The following brief description of the faults in the diabase begins at the south.

A fault apparently extends continuously along the center of Bergen Point and Bergen Hill for several miles to and through Jersey City Heights. The first indications of this Bergen Hill fault, as it may be called, are in Bayonne, where a narrow strip of sandstone is seen extending along the center of the diabase outcrop and apparently protected from erosion by a fault scarp on the west side. The sandstone is exposed on Forty-fourth street near the Morris Canal. Southward from this exposure a strip of red soil extends for several miles, and northward soon begins a depression which crosses the Morris Canal cut as a break in the continuity of the diabase. At the next section across Bergen Hill, in the cut of the Newark branch of the Central Railroad of New Jersey, the line of fault is indicated by a wider and deeper space than at the canal, while in the cut of the Pennsylvania Railroad just east of Marion the depression between trap outcrops is 700 feet wide and was found to be underlain by thin-bedded sandstone dipping toward the diabase wall on the west side. A half mile north of the Pennsylvania Railroad cut, in the two tunnels, the line of fault is marked by a narrow belt of greatly disturbed and decomposed diabase, and a short distance north of these tunnels thin-bedded sandstones were found near the surface in excavating for a reservoir. Thence northward for several miles there are indications of a continuance of a débris-filled depression, but the termination of the fault could not be located. The amount of the dislocation is not known, as the absence of outcrops of inclosing strata on either side of the diabase sheet renders the exact relations indeterminable. 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. Just east of the eastern end of the Pennsylvania Railroad cuts in Jersey City there formerly was a small knob of diabase, known as Fairmount, which is now nearly leveled for a roundhouse. Its length is only a few hundred yards, and it is completely separated from the main ridge by tide marsh. This outlying diabase may be a small branch intrusion from the Palisade diabase, but it is more probably separated by a small fault. A short distance north of Hoboken the escarpment of the Palisade diabase offsets some distance, to the shore of the Hudson River, giving rise to the prominent feature known as Kings Point. Behind this point there lies a depression which extends up into the ridge northward, holding the little Awiehawken Creek, which rises near Guttenberg and flows through a marsh-filled depression for some distance and thence down a narrow and deep ravine to empty into the Hudson just below Kings Point. These features are due to a fault which extends along the depression for several miles. Baked shales are exposed in the ravine, and they were also found in the West Shore Railroad tunnel 2 miles north, dipping west under the diabase and cut off to the east by the fault by which the diabase is dropped some distance. A few years ago a well was sunk in the ravine behind Kings Point, just west of the fault plane, which penetrated 125 feet of baked shale without meeting any diabase; this is ample proof that the relations exhibited at the surface are not due to a change in the horizon of intrusion of the diabase sheet. The extremities of this dislocation have not been found; to the south it extends out into the low ground in the northern portion of Hoboken, and to the north there is nothing in the topography to suggest its extension beyond the western portion of Guttenberg.

A few miles farther north there is a fault which begins at Shady Side, on the shore of the Hudson River, and extends diagonally across the trap of the Palisade ridge to the vicinity of Englewood. The first evidence of this fault to the south is a moderately prominent break in the diabase escarpment a short distance north of Shady Side. There the shales and trap exhibit relations indicating a fault by which the trap is dropped about 150 feet on the east side of the depression that extends north-northwestward up into the ridge. The depression has an escarpment of diabase on its west side, which doubtless is due to an extension of the fault, its course to the north being marked by a line of depressions for the next 5 miles. West of Linwood the fault enters the shales overlying the diabase, causing the relations shown on the western end of section E—E of the Structure Section sheet. In the next mile the diabase ridge on the west side of the fault runs out and the fault, finally entirely in shale, is covered by the heavy mass of drift in the eastern portion of the village of Englewood.

At the eastern entrance of the New York, Susquehanna and Western Railroad tunnel there are two small faults, of which many of the relations are clearly exposed. One, in the mouth of the tunnel, is a small displacement of about 6 feet, with the drop on the east side. It is exhibited in both the sandstone and the overlying diabase, which are considerably broken in its vicinity. A short distance east of this fault is the other, which is much larger, amounting to about 100 feet, as nearly as can be estimated, and which has a similar drop on the east side. The fault plane itself is covered by débris, but several exposures of the diabase-shale contact very clearly indicate the nature of the displacement. The line of faulting extends up into the ridge, giving rise to a break in the escarpment and a small ravine with precipitous sides. It is probable that the offset in the cliff at Fort Lee, with the corresponding change in the position of the base of the diabase mass, is due to a dislocation similar to those above described, extending up into the ridge diagonally and having downthrow on the east side of about 80 feet.

The Palisade diabase is remarkably uniform in constitution, and although its texture varies somewhat it is a diabase throughout. Near its contact with the inclosing sedimentary rocks it is fine grained, sometimes for a considerable distance, and here it usually has also a bedded structure. Different portions of the sheet vary somewhat in texture, but the predominant character is a moderately coarse-grained, dark-gray rock in which the constituent minerals may be discerned. They are mainly plagioclase and augite with considerable hypersthene, and biotite, quartz, pyrite, and other minerals in very small quantities. The structure is ophitic ordinarily, but in the finer-grained variety near the shale contacts the rock is porphyritic, with phenocrysts of plagioclase and augite, and contains olivine and more biotite. It never has a vitreous groundmass like the Watchung basalt, a surface flow from the same or a similar magma. Some portions 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. A detailed petrographic description of an occurrence of diabase beyond the limits of the quadrangle, which may be applied in general to the Palisade diabase, is given by A. H. Phillips in the American Journal of Science, 4th series, Vol. VIII, 1899, pp. 267–285.

Granton sheet.—The Granton sheet of diabase constitutes a short ridge lying just west of the slope of the Palisade ridge a few hundred rods north of Granton station. It is an intruded mass which appears to be closely similar to the Palisade sheet in structure. On the steep western side of the ridge the back of a dike is exposed in the West Shore Railroad cut, breaking almost vertically across the shales, of which only a very small mass remains. On the eastern and northeastern sides the sandstone separating this diabase from that of the Palisades dips northwestward under the edge of the sheet. In the quarries at the southern end of the ridge the underlying beds are again exposed, dipping westward. The trap has been bared of overlying strata, and its outcrop terminates northward, southward, and eastward in escarpments, so that its original extent and relations to the inclosing strata are not now determinable. At its northeast corner, in a quarry, there is an exposure at which the sheet appears to send a small branch into the underlying sandstone, and there is considerable local irregularity along the lower contact. At the northwest corner the dike structure is exposed. Owing to lack of complete cross-section exposures, the thickness of the dike of this intrusive mass is not known, but judging from the occurrences of shale in the quarries at both ends of the ridge, it is not very thick. Probably also it does not extend far beyond the limits of the hill.

The rock of the Granton ridge is a moderately fine-grained diabase, very similar to much of that of the adjacent Palisade mass. It is dense and homogeneous throughout and presents no 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 probably about 100 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 some distance west of the inner slope of the Palisade diabase in Bergen Hill, near the latitude of Hoboken. The smaller hill is a diabase outcrop covering a few acres to a maximum height of 76 feet, and nothing is known of its structural relations. The larger hill is half a mile farther west, on the eastern shore of the Hackensack River, and has a diameter of approximately a half-mile. Its elevation varies between 100 and 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 in part by small remnants of sandstones and shales, and its structural relations are similar to those of the Granton ridge. The diabase forming the precipitous eastern side of the hill is a sheet with an irregular bedded structure, underlain by sandstones and shales, which are exposed in the old railroad cut at the northern end of the hill, where they dip N. 30° W., at an angle of 14°. On the northern side of the cut the contact with the diabase is exposed, and the line of junction, although somewhat ragged, is essentially conformable to the bedding. The dip soon carries the underlying strata beneath the surface westward, so that the southwest corner of the hill is entirely diabase. On the western slope the sandstone and shale outcrops begin again and extend northward, by the Penitentiary, and pass under a drift mantle which obscures all but the higher diabase ledges to the north and northeast. In the western face of the hill there is a large quarry which exhibits a portion of the sandstone beds abutting against the back of the dike constituting the western portion of the igneous mass, but possibly separated by a fault. Formerly this feature was finely exposed at the center of the quarry, but now the greater part of the sedimentary material has been removed. To the south the extent, thickness, and exact relations of the dike can not be ascertained at present; possibly in the course of quarrying operations its inner side will be exposed. The dike probably trends nearly north and south and lies entirely within the area now covered by the diabase sheet. This sheet is undoubtedly intrusive, as shown by its ragged contact with the shales of the railroad cut and by the baking of the strata in the immediate vicinity of the sheet, wherever exposed. Apparently the rock is precisely the same as the typical Palisade diabase. The thickness of the sheet in its present relation is now 200 feet, but doubtless its surface has been considerably degraded by erosion.

Arlington sheet.—Along the eastern slope of the sandstone ridge which borders the Hackensack Meadows, 3 miles west of Snake Hill, there are several small diabase sheets of intrusive origin. The first exposure toward the south is in a small opening just north of the railroad, where the edge of a sheet 6 feet in thickness is seen conformably intercalated between beds of coarse sandstone which are not perceptibly altered in its vicinity. A few rods farther north the edge of this sheet is again exposed in excavations for copper ore in Westlake's quarry. The relations at this place are shown in fig. 8. This sheet of diabase forced

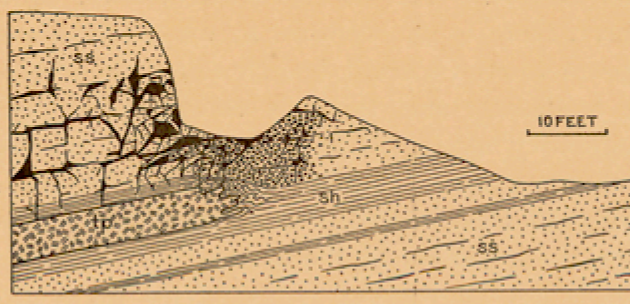


FIG. 8.—Sketch section in Westlake's quarry near Arlington, N. J., looking north. Shows crumpling of the shale at the front of the intrusive trap sheet, and impregnation of copper ore in the sandstone overlying the trap.
ss, sandstone; sh, shale; tp, trap sheet; black masses and spots, copper ore.

its way eastward near the junction of shales and sandstones, lifting the latter and probably causing the fissures which hold the plates and bunches of chalcocite. The diabase is a fine-grained, dense, bluish-gray rock 5 feet thick, with smooth surfaces, to which the strata were generally welded. The adjoining shales are intensely altered, but the alteration extends only a few feet from the diabase. In the cemetery a quarter of a mile north of Westlake's quarry are found other diabase outcrops, which extend northward for about a mile, with occasional exposures, to the old Schuyler mines. In the cemetery there are two smaller diabase masses associated with the main sheet. The dike apparently ascends along a line of fault and sends off a small sheet eastward. The main sheet in this vicinity is exposed in contact with the sandstones, in which it is conformably intercalated, and there is comparatively little disturbance of the bedding or alteration in color or texture. North of the cemetery the edge of the sheet forms a mural escarpment along the turnpike and its thickness increases to 20 feet. A short distance west is another small sheet in the overlying strata, which crosses the turnpike on top of the small 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. Over wide areas in this mine the surface of this sheet is smooth and conformable to the gently dipping sandstones, but there are irregularities in which the strata are crossed for a few feet, and 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 at one point 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 trap the exact relations of which could not be definitely determined on account of the drift and débris. It is on the crest of the first ridge east of the Hackensack River, in west-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 in thickness or a dike.

The following publications give additional details of the geology of the Newark group. Relations of the traps of the Newark system in the New Jersey region, by N. H. Darton: Bulletin No. 67 of the United States Geological Survey, 1890. The Newark system of New Jersey, by H. B. Kümmel: Report of the State Geologist of New Jersey for 1897. Some contact phenomena of the Palisade diabase, by J. D. Irving: School of Mines Quarterly, vol. 20, pp. 213–223.

ROCKS OF ECONOMIC USE.

Building stones.—There are extensive beds of sandstone in the Newark group which are suitable for building stone. They have been worked at several localities for many years and have yielded 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 the excavations were filled for city lots. The Little Falls quarries are not in active operation now, but in the past they yielded large supplies of excellent brownstone. At Avondale the quarrying is moderately active, both in the two old quarries east of the station and in an opening 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, now abandoned, along the northeastern slope of Garret Rock, and active quarries in the gorge along the Passaic River. Here the rock is rather coarse and mainly suited 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 removal of the heavy capping of igneous rock under which the stone pitches 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.

On the west slope of the Palisade ridge a mile and a half east of Closter there are two quarries, near together, which produce a moderate supply of light-colored, coarse-grained, feldspathic sandstone. The beds are thick, and large blocks of homogeneous texture are obtained. A similar stone is obtained at the quarry at Ridgefield. Throughout the area of the Newark group there are occasional small quarries and openings, the products of which are employed for local buildings and foundations.

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 Palisade front, diabase is blasted out, crushed, and loaded directly on scows for shipment to points about New York City. Unfortunately the quarrying operations have greatly disfigured the beautiful Palisades, so that recently laws have been passed which prohibit the removal of stone from the river face. The rock could be obtained and crushed farther back on the ridge and taken to boats by means of wire-ropes and chutes. The locations of quarries along the Palisade ridge are shown on the Historical Geology sheet.

The diabase at Granton and Snake Hill is worked to some extent for road metal, and there are several quarries on the Watchung ridges, notably about Paterson, at Upper Montclair, and on the west slope of the Second Watchung Mountain east and northeast of Preakness. At Graniteville, on Staten Island, the trap is extensively quarried and crushed for construction of the fine roads of Richmond Borough.

COPPER ORE.

Various copper minerals occur in the sandstone of the Newark group, mainly in connection with the igneous intrusives. One of the earliest copper workings in this country was the Schuyler mine, about a mile northeast of Arlington station. Extensive galleries were excavated and a deep shaft was sunk. The ore was malachite and chalcocite, with some cuprite, chrysocolla, and metallic copper, occurring in small amounts in sandstone adjoining the diabase sheet, but it was too widely scattered to prove profitable. In the year 1884 a small but rich deposit was worked out at the old Westlake quarry near Arlington, of which the relations are shown in fig. 8.

LATER JURATRIAS AND EARLY CRETACEOUS EVENTS.

By BAILEY WILLIS.

Potomac group and Schooley plain.—Over the Coastal Plain of New Jersey, Maryland, and Virginia there are spread sediments which by their physical relations and fossils are known to be much younger than the Newark rocks, yet older than the marine Cretaceous deposits. They were once described as a connected sequence of strata under the name Potomac formation, and there was much discussion as to their Jurassic or Cretaceous age. They are now known to constitute a group, divisible into several formations, of which some may perhaps be Jurassic; the succeeding ones are Cretaceous. The Potomac group is represented in the New York district by the Raritan clays only, but its relations elsewhere throw light on events which must otherwise be passed as unrecorded. The oldest Potomac strata rest on a surface composed of very ancient rocks, largely granite and gneiss, and consist in part of arkose, or sandstone composed of feldspar with other minerals washed from granite. The relations thus demonstrate the submergence, early in Potomac time, of a land surface which had been so long exposed to weathering that granites were decayed much as they now are in the same region. A glance at the earlier history which has been sketched shows that this episode of weathering may have been the last phase of a cycle of erosion which occupied Triassic time and was perhaps continuous with similar activities from the Paleozoic era. The surface on which the Potomac group rests is even, and when traced over considerable distances is found to be a buried coastal plain which now has an upward slope toward the northwest. Extending in that direction from existing Potomac strata are flat hilltops from which the Potomac has been eroded and which were therefore part of the submerged plain. Beyond any probable limits of extent of the Potomac, one finds hilltops with flat surfaces that accord in slope with those that were buried, and they also are seen to be representatives of the plain. These readily identified remnants rise higher and higher toward the west and become smaller, less numerous, and more widely separated by valleys. Nevertheless, if we do but conceive the valleys filled to the hilltops with the material which streams have carried away, the former plain may be restored, locally. So long as the summits of the existing hills or mountains fall into a generally even though sloping surface, we are justified in making this restoration, and it may lead us from the immediate coast back over a continuous plain indefinitely. In fact, the basal Potomac plain is thus traced far beyond the extent of the Potomac sediments, over the Appalachian Mountains, and it is recognized that the land in Potomac time was nearly flat throughout the province. As it was a land area, it reached this flatness through the process of erosion, which, working on a surface of hard and soft rocks, can smooth away the land only on a very gentle slope rising but slightly from sea level. Perfect evenness is rarely if ever thus attained. The technical term used to distinguish the almost plain surface is "peneplain," and hills which remain rising above the plain have been called "monadnocks," after Mount Monadnock, a characteristic height of the kind. That surface which lies beneath the Potomac strata and rises beyond them over the hilltops is known as the Schooley peneplain, or plain, from the fact that it is well represented in the flat surface of Schooley Mountain, New Jersey.

In the vicinity of New York City the Schooley peneplain lies at sea level along Long Island Sound and in Jersey City, and rises over the hills of gneiss and schist east of the Hudson, and also over the Palisade ridge, west of the river. From the Palisades it must be extended above the valleys of New Jersey to the even-topped Watchung ridges and beyond them to the summits of the Highlands. The valleys which are excavated below the once continuous surface of the Schooley peneplain are effects of erosion during later ages. Streams have been the chief instruments in their development, and it is through elevation of the land that the streams have been effectively applied to the task of carving out hills and valleys. The ultimate result of their work will be to reduce the land again to a plain.

The coast of the Schooley peneplain in Cretaceous time was probably in many respects like that which exists to-day on the New Jersey shore—an aged coast with long, well-established barrier beaches partly inclosing estuaries and lagoons. Among the latest sediments of the Potomac group laid down in these waters is the Raritan formation, which is named from the bay on which it is typically developed. In general it consists of white or colored sands and light-colored or darker-colored clays, occasionally containing leaves. Within the New York district it is represented on Staten Island, and its occurrence and relations there are described by Dr. Arthur Hollick.

CRETACEOUS DEPOSITS OF STATEN ISLAND.

By ARTHUR HOLLICK.

Raritan formation.—Theoretically strata of Cretaceous age are indicated as underlying all that area of Staten Island south of the serpentine hills and thence west to the shore of Arthur Kill. At Kreischerville and Green Ridge beds of clay and "kaolin" have been extensively exploited, and the identity of these beds with those of the Raritan formation of the New Jersey Cretaceous has been amply proved, not only by means of their stratigraphic relations and lithologic identity, but also by plant remains found in them. Amongst these remains may be mentioned *Sequoia heterophylla* Vel., *Widdringtonites reichii* (Ett.) Heer, *Eucalyptus geinitzi* Heer, *Proteoides daphnogenoides* Heer, etc.

Throughout nearly all the remainder of the area the underlying strata are covered by either morainal or stratified drift deposits, but the presence of Cretaceous strata beneath is almost conclusively proved by the fact that nearly all wells which have been driven through the surficial deposits show the presence of clay, gravel, or "kaolin" lithologically identical with those of Kreischerville.

Throughout the morainal and stratified drift deposits also, wherever these are found south of the theoretical Cretaceous border, masses of clay or "kaolin," sometimes incoherent, sometimes more or less hardened by the infiltration and oxidation of iron, are prominent constituents. That these are Cretaceous in age is proved by the presence in many of them of characteristic species of fossil leaves, such as *Liriodendropsis simplex* Newb., *Laurus plutonia* Heer, *Thinnfeldia lesquereuxiana* Heer, *Sapindus morrisoni* Lesq., *Moriconia cyclotoxon* Deb. and Ett., etc. They are especially abundant in the morainal accumulations at Tottenville, Princess Bay, and Arrochar. No indication, however, of any material which could be even provisionally referred to Cretaceous strata has ever been discovered in the morainal deposits to the north of the serpentine ridge, and it is evident that where such material occurs to the south it represents the masses and fragments which were eroded from the strata south of the ridge and carried forward either by the advancing ice front or by streams from the melting glacier.

The former presence of marine Cretaceous strata is also indicated in the vicinity of Arrochar by the occurrence, in the drift, of masses of hardened clay marl in which have been found *Cardium dumosum* Conr., *Ostrea plumosa* Morton, *Aphrodina tippana* Conr., *Gryphæa* sp., etc.

Full accounts of the discoveries of the facts outlined above, together with complete lists of the fossils identified, may be found in the Transactions of the New York Academy of Sciences, Vol. XI, pp. 96–104; Vol. XII, pp. 28–39, 222–237; Vol. XIV, pp. 8–20; in Annals of the New York Academy of Sciences, Vol. XI, pp. 415–430; Vol. XII, pp. 91–102; in Proceedings of the Natural Science Associaton of Staten Island, Vol. III, pp. 45–47; Vol. VI, pp. 62–63; and in Bulletin of the Geological Society of America, Vol. X, pp. 2–3.

With the information now in our possession we feel justified in concluding that Cretaceous strata, as represented by the plastic clays (Raritan formation), once extended up to the present southern border of the serpentine ridge, and that farther to the west they certainly extended as far north as the Fresh Kill marshes, while clay marl or marl (Matawan formation?) may have extended as far north as the present southeastern point of the island at the Narrows; and as both of these formations have been recognized farther to the northeast, on Long Island, we may further infer that they bordered Staten Island on its eastern shore, occupying part of what is now New York Bay.

Exact correlation of the Staten Island Cretaceous strata with those of other localities is difficult on account of the erosion and disturbance to which they were subjected during the Glacial epoch. If, however, the general trend of the New Jersey outcrops be extended theoretically through the island, it may be readily seen that the lower members of the plastic clays, represented by those of Woodbridge, Sayreville, Perth Amboy, and possibly South Amboy, would strike the western shore in the vicinity of Tottenville and Kreischerville, while the upper members, represented by those in the vicinity of Cheesequakes Creek, would extend along the southern shore from Tottenville to Arrochar, and the clay marl or marl, represented at Cliffwood, would just touch the island in the vicinity of the Narrows.

The clays and "kaolins" mined in the vicinity of Kreischerville and Green Ridge are of considerable economic importance. The name "kaolin" as here used is a trade term, which has reference to a highly siliceous, micaceous clay, and not to the mineral kaolin.

The following are analyses of a clay and a "kaolin" from Kreischerville:

Analyses of clay and "kaolin" from Kreischerville, Staten Island.

	Fire clay.	Kaolin.
Silica	64.28	82.51
Alumina	24.76	11.57
Ferric oxide	.83	.63
Lime	.73	.29
Magnesia	trace.	.78
Alkalies	2.35	2.66

The Cretaceous area is of importance as the region from which a permanent water supply may probably be obtained. Throughout the northern portion of the island the supply is dependent either upon surface drainage and relatively shallow driven wells in the drift or upon borings in the serpentine. In the first instance the supply is limited by the extent of the drainage area and is modified by the amount of rainfall, so that it varies with the local conditions. In the second instance no accurate prediction can be made, either as to the depth at which water may be struck in any locality or as to the probable amount which may be obtained, for the reason that there is no recognized water-bearing horizon in the rock, and the occurrence of water at any locality is apparently due to seams or crevices. Throughout the area underlain by Cretaceous strata, however, a reliable water supply may probably be obtained by wells driven to the proper horizon. On Staten Island glacial action has so disturbed and eroded the strata that throughout the drift-covered region it would be exceedingly hazardous to predict the depth at which this horizon should be found at any particular locality, but recently a well which yielded an abundant supply of water, in the vicinity of Richmond Valley, near Tottenville, was sunk 75 feet, from an elevation of about 40 feet above tide level. It did not reach the Cretaceous, however, and the exact nature of the material passed through could not be ascertained, except in such indefinite terms as "gravel," "hardpan," etc., but apparently all the material represented stratified drift. This fact is of considerable interest, as it indicates that the erosion of Cretaceous strata was extensive and that a greater depth would have to be reached in order to strike them undisturbed.

EVENTS OF LATER CRETACEOUS, EOCENE, AND NEOCENE TIMES.

By Bailey Willis.

Marine deposits.—The Atlantic Coastal Plain was to a greater or less extent submerged during successive epochs of later Cretaceous, Eocene, and early Neocene or Miocene time. The deposits of sediment made during the Cretaceous constitute wide areas of the fertile lands of central New Jersey, and they owe their fertility in great measure to the conditions of deposition. The beds are partly of clays and sands derived from the not distant 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 are known to 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. They do not live, however, in muddy waters. 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 plane surface.

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 on the highest Cretaceous beds, which it resembles in character. There follows an interval, extending through the later Eocene, regarding which the record is not clear, but during which the depth and extent of submergence were perhaps not materially different. Then came the beginning of the movements which have raised the wide plain of that time to the now existing mountain tops and, with many fluctuations, have placed the land in its present relation to sea level.

During early Neocene (Miocene) time marine deposits of considerable volume and wide extent were laid down on the Coastal Plain. They rest unconformably on the Shark River beds and, overlapping them, lie upon the Cretaceous deposits. They are products of more rapid wasting of the land than had occurred during the shortly preceding epochs, and thus indicate that the land surface yielding the sediment became higher, while, by spreading landward beyond the Eocene sediments, they indicate a broader submergence. From their development we infer 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 a vast, low plain characterized the eastern United States, and initiated the present cycle, which has thus far been one of uplift.

Mountain growth.—The development of the Schooley peneplain, which rose at first little above sea level but which might now be restored over the summits of hills and mountains, has been described. The recognition of its original position and present altitude gave new insight into the age and growth of the Appalachian Mountains, which had been attributed to the revolution at the close of the Carboniferous, but which are now understood to be effects of elevation during relatively recent ages. 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 elevation of the land. Whether the facts of sedimentation or those of landscape forms 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 the epochs passed. Still, the earth's surface in this region was not uniformly steady during those ages, for 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.

Effects of erosion.—Through the process of erosion all land masses waste away and are gradually lowered toward the level of the sea, but, wasting unequally, they become diversified with valleys and heights. Begun at the top, the carving progresses downward, and features are thus older above and younger below. The Schooley plain is not only the oldest of the landscape features 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. In the sculpture of valleys and slopes, heights above and distance from the sea are the conditions which ultimately control their depth and steepness, although the character of the rocks being carved is also a factor, and thus the forms of valleys constitute a record of the uplift or uplifts by which their development became possible. The destruction of the Schooley plain proceeded intermittently and resulted in more than one set of features, the younger set in each case being carved into the older, as for example a narrow 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 Profs. W. M. Davis and R. D. Salisbury, who have published their discussions in papers entitled, respectively, Rivers of New Jersey (Proceedings of the Boston Society of Natural History, Vol. XXXV, 1888–1889) and Physical Geography of New Jersey (Vol. IV of the Reports of the State Geologist, 1895).

The broad conclusions reached by these investigators as to the principal events of Neocene time have been sketched in the "Outline of geologic history" (pp. 2–3), and the reader is referred to the papers just cited for further information. While the subject belongs largely to a comparatively new branch of geology, physiography, the phenomena are very intricately related to rock structure, river action, sea level, and climate, and there are many important items, such as the development of the Hudson River, which await closer study.

The development of river systems and of relief had reached nearly, if not quite, the present degree of maturity when the processes were modified by the influence of the cold epochs that resulted in general glaciation of northern North America. Commonly known as the Glacial epoch, this time is here called the Pleistocene. Its events are described below by Professor Salisbury, and in his account are included descriptions of isolated gravel deposits which are older than Pleistocene, as well as an outline of post-Glacial changes.

PLEISTOCENE FORMATIONS.*

By Rollin D. Salisbury.

To the Pleistocene division of geologic time are referred most of the unconsolidated materials lying upon the bed rock described in the preceding pages. The Pleistocene formations of the New York City district are (1) partly of pre-Glacial age (at least antedating the last Glacial epoch), (2) partly of Glacial age and origin, and (3) partly of post-Glacial age. Of these several classes the glacial drift is, within this district, the most widespread.

OLDER PLEISTOCENE FORMATIONS.

Gravel above New Dorp, Staten Island.—There is a little gravel, chiefly of quartz and chert, in the driftless area above 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 late Tertiary or earliest Pleistocene, and accordingly is mapped as Beacon Hill or Bridgeton.

Pensauken formation.—The Pensauken formation is well exposed in several of the clay pits about Kreischerville, Staten Island, where it overlies the Cretaceous sand and clay and underlies the glacial drift. At the pits its thickness is usually 8 or 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. When the railway cut at Arrochar was fresh, gravel of the same sort was exposed. In spite of its meager exposure, the Pensauken sands and gravels are perhaps somewhat widely distributed on the island, though now concealed by younger formations. Though 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.

GENERAL CONSIDERATION OF GLACIAL FORMATIONS.

Drift.—The mantle of unconsolidated earthy and stony material which overlies most of the rock in the vicinity of New York City is known as drift. It is made up of clay, sand, gravel, and bowlders, sometimes separated from one another, but more often commingled in varying proportions. It is, for the most part, an orderless mixture of earthy material of various sorts and sizes. It is sometimes so thick as to effectually conceal the bed rock beneath, as about Brooklyn, and sometimes so thin that the underlying rock outcrops at frequent intervals, as on the Palisade ridge and over much of the area east of the Hudson and north of the East River.

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 from an extensive sheet of ice, a glacier of continental dimensions, which once occupied the drift-covered area.

Drift-covered area.—The accompanying map (fig. 9) shows approximately the area of North America formerly covered by ice and now covered by drift. From the map it is seen that the New York City district lies at the southern margin of the great drift sheet.

The condition of the northern part of the continent when the ice sheet was at its maximum was comparable to that of Greenland to-day. The larger part of the 500,000 square miles which this 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 slowly out toward the borders of the island, tending always to advance until its edge reaches a position where it is wasted by melting as rapidly as it advances.

*The Pleistocene field work in the New Jersey portion of the New York City district was done at the expense of the New Jersey Geological Survey.

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.

FIG. 9.—Map of area covered by the North American ice sheet of the Glacial epoch at its maximum extension, showing the approximate southern limit of glaciation, the three main centers of ice accumulation, and the driftless area within the border of the glaciated region.

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 snow 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 on the map, fig. 9. Its extent is known by the area of the drift which it left behind when it melted. In the West there was extensive glaciation in the Cordilleras. Details of the Glacial history of this region have not been worked out.

The map illustrates another point of significance. The edge of the drift sheet is somewhat lobate. The lobation was, indeed, more pronounced than this small map shows. Fig. 12 represents, on a larger scale, a smaller area about New York City, and shows the lobate form of the edge of the last ice sheet which covered this area.

Recurrent glaciations.—In the preceding paragraphs the ice sheet has been referred to as though 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. How many times glacial and genial climatic conditions alternated is not known, but within the United States the number of pronounced alternations was probably 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. How many times the area with which we are here concerned was overwhelmed by ice is unknown, but in closely adjacent regions the ice was present at least twice, at somewhat widely separated times.

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 roughness of all sorts. In the

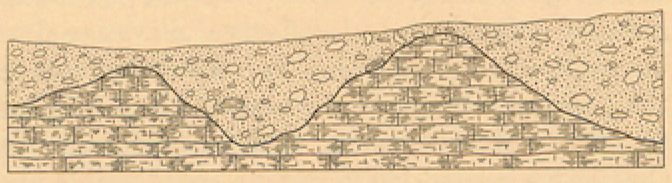


FIG. 10.—Thick drift, leveling up an uneven surface of rock, and thereby diminishing its relief.

second place, it sooner or later deposits the débris which it gathers in its movement and carries forward in its bottom. 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 equally. The result is that the configuration of the surface is often considerably altered by the passage of glacier ice over it. If the drift be thick it may level up an uneven surface of rock (fig. 10) or it may be so disposed as to increase the relief instead of diminishing it (fig. 11). If the drift be thin its effect on topography is less pronounced.

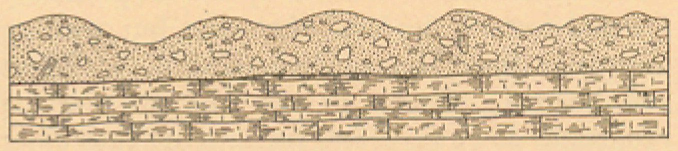


FIG. 11.—Thick drift increasing the relief of the surface.

The deposits occasioned by ice fall into two distinct categories, those made by the ice itself, and those made by the waters derived from the ice. The former are unstratified and unassorted; the latter are stratified and assorted. The former are moraines. Deposits made beneath the ice and back from its edge constitute the ground moraine or till, and are distinguished from the considerable marginal and submarginal accumulations made when the edge of the ice maintains a constant or approximately constant position for a considerable interval of time. This marginal and submarginal accumulation is the terminal moraine.

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. The heterogeneity of the drift arising from the diverse nature of the rock formations which contributed to it is lithological heterogeneity—a term which implies the commingling of materials derived from different rock formations.

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, in all cases, 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; while 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 contains. Many of them have some of their faces planed and striated. The more easily defined characteristics of glacial drift are, therefore, (1) lithological and (2) physical heterogeneity; (3) the shapes and (4) the markings of the stones which it contains; (5) its lack of stratification, except when water-laid.

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 often applied to the ground moraine. The ground moraine 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. Since 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 which reached that locality passed. 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. This leads to the conclusion that deposition must have gone on beneath the ice during its movement, even back from its margin. The fact that so little of the drift about New York City came from points as much as 100 miles to the north proves that a large part of the material gathered by the ice even so short a distance north of its edge was never brought down to the latitude of New York City.

Terminal moraines.—The marginal portion of the ice sheet was more heavily loaded—certainly more heavily loaded relative 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. Since the ice was continually bringing drift to this position 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 in 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.

From the conditions of their development it will be seen that terminal moraines may be made up of materials identical with those which constitute the ground moraine; and such is often the case. But water arising from the melting of the ice played a much more important rôle at its margin than farther back beneath it. One result of its activity may be seen in the greater coarseness which generally characterizes the material of the terminal moraine as compared with that of the adjacent ground moraine. This is partly because the water carried away some of the finer constituents, leaving the coarser behind. Further evidence of the great activity of water near the margin of the ice is to be seen in the relatively large amount of assorted and stratified sand and gravel associated with the terminal moraine.

The most distinctive feature of a terminal moraine is its topography. It is this, more than any other one feature, which distinguishes it from the ground moraine. While the topography of the moraine 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. The relief is sometimes scores of feet within short distances. The depressions inclosed by the elevations are frequently marked by marshes, ponds, and lakelets, wherever the material constituting their bottoms is sufficiently impervious to retain the water falling and draining into them. In other places the morainic features are more subdued, the relief being far from striking. The shapes and the abundance of round and roundish hills have locally given rise to such names as "The Knobs," "Short Hills," etc. In some places the moraine has been named the "Kettle Range," from the number of kettle-like depressions in its surface. It is to be kept in mind that it is the association of "knobs" and "kettles," rather than either feature alone, which is the distinctive mark of terminal moraine topography.

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 have been of unequal height and width at different points. In the second place, the margin of the ice, while maintaining the same general position during the making of a moraine, was yet subject to many minor oscillations. These oscillations were partly seasonal and partly through 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 variable 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 arose 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, since the larger part of the ice was ultimately converted into water, and to this was added the rains which fell on the ice border.

Stratified drift may arise 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.

There is more or less water both in glacier ice and beneath it. Much of the water in these various positions, as it issues from the ice, unites to form definite streams. It is the water at the edge of the ice and just beyond it which is chiefly concerned in the deposition of stratified drift.

The history of an ice sheet which has disappeared involved at least two distinct stages, (1) a period of growth and (2) a period of decadence. If the latter does not begin as soon as the former is complete, an intervening stage, representing the period of maximum extension, must be recognized. At each of these stages it is the water at the edge of the ice which is especially effective in the deposition of stratified drift.

The most extensive deposits made by water arising from glacier ice are made either as it 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, 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 in like situations. Such 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. 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 on the maps of this folio.

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 OF THE NEW YORK PORTION OF THE DISTRICT.

Distribution of the types of drift.—All of the New York City district except the southernmost part of the Brooklyn quadrangle and a small area in the southeastern part of Staten Island was covered by the continental ice sheet of the last Glacial epoch. The edge of the ice made a protracted halt at its position of maximum advance, as shown by the terminal moraine which it left. All the drift south of the moraine is stratified, while that lying north of it is partly stratified and partly unstratified. South of the moraine stratified gravel and sand, washed out from the ice by the waters issuing from it, were deposited over most of the land area which the ice spared. The only exceptions are (1) a small area at Rockaway, which, though low, is so far from the moraine that the gravel and sand were not carried out to it; and (2) another just north of the railway between New Dorp and Linden Park, Staten Island. This small area, less that a square mile in extent, was not covered by the ice, and was too high to be flooded by the waters draining from it.

Direction of ice movement.—On the map, fig. 12, the arrows show the direction of ice movement within the New York City district. The direction of movement is known both by the course of the striæ which the passage of the rock-shod ice left on the bed rock and by the direction

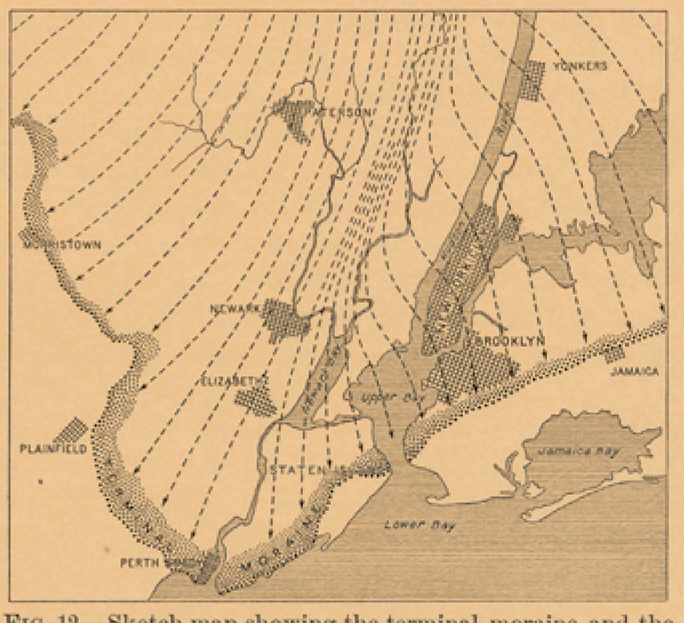


FIG. 12.—Sketch map showing the terminal moraine and the direction of ice movement in the vicinity of New York City.

The terminal moraine is indicated by the dotted belt extending from Morristown, through Perth Amboy, to Jamaica; the direction of ice movement, by the broken lines and arrows.

in which the material from the several formations was distributed. In general the movement was approximately at right angles to the course of the moraine. In the Harlem and Brooklyn quadrangles, therefore, and in parts of the others, the movement was east of south, the easting being locally (on some parts of the Palisade ridge) as much as 45°. In the western part of the Staten Island quadrangle and in most of the Paterson quadrangle the movement was generally south or a little west of south. In the northwestern part of the Paterson quadrangle the westerly divergence of the ice was much more pronounced.

Non-Glacial Pleistocene formations.—While the Pleistocene deposits of the New York City district are chiefly of Glacial age, and of glacial or fluvio-glacial origin, some of them, such as river alluvium, eolian sand, and the beach deposits, are of post-Glacial age. Though the materials of these various classes of deposits were largely derived from the glacial drift, the deposits, in their present form, are distinct from the drift for which the ice was directly responsible. Still other Pleistocene deposits of limited extent, already described, within the district under consideration antedate the great body of glacial drift.

The formations of Glacial age will be described under the following headings: terminal moraine, stratified drift (of fluvio glacial origin), ground moraine. The post-Glacial deposits will be referred to under the headings: alluvial plains, eolian sand, modern beach sand, and peat (pp. 16–17).

TERMINAL MORAINE ON STATEN ISLAND.

General relations.—The terminal moraine crosses Staten Island lengthwise, extending from Tottenville on the southwest to Stapleton on the northeast. Its length, owing to its sinuosities, is about 15 miles, though the distance between Tottenville and Stapleton, in direct line, is only about 13 miles. The vertical range of the moraine is from sea level at the ends of the island to 360 odd feet, above Garretsons. In general its crest is less than 100 feet above sea level west of New Dorp, and between 120 and 140 feet east of Garretsons. Its width varies from three-fourths of a mile just east of Garretsons to two miles or more in the vicinity of Woods of Arden and at the east end of the island.

Topographic relations.—Staten Island is divisible into two parts, a higher and a lower, by a line drawn from Fresh Kills through Richmond to Stapleton. From Tottenville to Richmond the moraine lies on the lower division of the island; from Richmond to Garretsons, on the higher; and from Garretsons to Stapleton, again on the lower. The map shows that while the course of the moraine is in general from southwest to northeast, there is a notable bend in its course where it curves back on the high land between New Dorp and Linden Park. The study of the position of the moraine in its relation to topography shows that this bend in the moraine occurs southeast of the highest point on the island. These relations are in no way accidental. The effect of the high land was to retard the movement of the ice, and the highest land retarded it most. In the lee of the highest point, therefore, the advance was least. It is significant that the ice surmounted the summit and started down its southern slope, but the thickness of ice which surmounted the highest land was so slight that it advanced but little beyond the summit, and at its position of maximum advance its edge rested on a descending slope.

The moraine as a topographic feature.—As a topographic feature the moraine is not usually very conspicuous. Its vertical range, 360 feet, is not primarily the result of the height of the moraine itself, but chiefly of the variation in the height of the base on which it rests. In other words, if the terminal moraine were removed the general configuration of the island would probably not be seriously altered. The moraine is, in fact, 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 short ridges associated with depressions which are sometimes pronounced but commonly feeble. It is not notably higher than the ground moraine north of it in the western part of the island, and it adds so little to the height of the high land between Richmond and Garretsons that it can hardly be said to be important topographically. Seen from the plain to the south, the moraine sometimes rises abruptly above its border. This is the case between Oakwood and New Dorp, where its south face is rather steep, locally rising 60 feet above the plain in a quarter of a mile. East of Garretsons, also, the outer face of the moraine is often conspicuous, sometimes rising 60 to 100 feet above the plain within a few hundred yards.

From the inside the moraine is less well marked topographically, the transition from ground moraine being generally gradual.

Topography of the moraine—While the moraine as a whole is but a belt of drift a little thicker than that to the north, and therefore often inconspicuous as a topographic feature, its own topography, looked at in detail, is distinctive. The characteristics of moraine topography have been mentioned. It remains only to refer to the places where the various phases of topography are well shown.

Between Tottenville and Giffords the moraine topography, while characteristic, is on the whole rather feeble. Illustrations of feebly expressed moraine topography, where the relief of the surface is 10 to 15 feet, may be seen about a quarter of a mile west of Richmond Valley station, at Pleasant Plains, three-fourths of a mile south of Princess Bay station, and south of Annadale. Between Giffords and New Dorp the moraine topography is more strongly developed. It is well seen just west of New Dorp, and thence to Linden Park its undulations are well accentuated. West and north of Garretsons adjacent knobs and basins show a relief of not less than 50 feet. From Linden Park to Fort Tompkins its surface is characteristically rough, with a relief of 20 to 40 feet. The tract between Arrochar and Grassmere gives as good a view of morainic topography as the island affords. (See fig. 22, on Illustration sheet 2.) Here the billows of earth rise and fall in graceful curves of notable magnitude, and the depressions are sometimes occupied by ponds and lakelets.

Characteristic morainic topography does not affect 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. On the northwest the terminal moraine is mapped as stopping where the drift ceases to be notably bunched. The inner line is somewhat arbitrary, and the student of the drift of Staten Island must not expect to find a notable change in the surface at the line which stands for the northwestern border of the moraine, though on the whole the roughness of the surface, so far as due to drift, is greater south of this line than north of it. On the southern slope of the moraine the distinctive topography is rarely well developed below an elevation of 30 or 40 feet. Below this level its surface may have been modified by the action of waves. East of Oakwood, where the moraine is bordered by a plain, or where it lies on high land, its outer border is usually well defined. The crest of the moraine is often not along the central line between its inner and outer borders, but is more commonly near the latter. Frequently, too, it has two or more crests instead of one. The tendency to a double crest is more marked to the west.

Composition of the moraine.—The moraine of Staten Island is made up primarily of clayey till, with less stratified drift than is common to terminal moraines in general. The till has usually a reddish color, due to the abundance of material derived from the red Triassic shale and sandstone of the northern part of the island, and especially from the area of New Jersey west of the Palisade ridge. Bowlders are less numerous than is characteristic of terminal moraines in general. This is especially true of the surface of the moraine. The paucity of surface bowlders results partly from the fact that many of them have been removed. The abundance of stone walls (in place of fences), especially in the eastern part of the island, shows that surface bowlders were once much more abundant than now. The bowlders of the moraine are chiefly of Triassic sandstone and trap, the latter mainly from the Palisade ridge, but subordinately from the trap of the island. There are also bowlders of gneiss and schist, and bowlders of white and purple quartzite apparently from the Oneida formation of the Schunemunk Mountain range. In the eastern part of the island there are bowlders of serpentine derived from underlying serpentine. 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 above New Dorp, and bits of shale and limestone from the middle course of the Hudson River. 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.

The constitution of the moraine is exposed in numerous cuts along the railways, in cliffs along the shore, and in numerous shallow road cuts. The most extensive exposures on the railways are west of Eltingville, northeast of Giffords, about Grassmere, at Clifton, Rosebank, and Arrochar; and along the coast, at Princess Bay Light (where underlying formations are exposed when the bluff is freshly cut) and at numerous points between Princess Bay Light and Seguine Point. At some of the sections there is seen to be a good deal of stratified drift mingled with the unstratified.

Thickness of drift in the moraine.—The thickness of drift in the terminal moraine is difficult of estimation. It is known at ten points, the maximum being 75 feet; but the average is probably considerably less than this maximum.

TERMINAL MORAINE ON LONG ISLAND.

The terminal moraine on Long Island, so far as it falls within these quadrangles, has an average width of about a mile and a maximum width of a little more than two miles.

The moraine as a topographic feature.—Unlike the terminal moraine on Staten Island, the moraine here is the most conspicuous topographic feature of the west end of Long Island. It is the ridge popularly known as the "backbone" of the island. On the south it is skirted by the plain of stratified drift, above which it rises abruptly, often as much as 60 to 80 feet, and sometimes as much as 125 feet. From the south, therefore, the moraine is not only conspicuous topographically, but it constitutes the one feature of notable relief in this part of the island. A good conception of the outer face of the moraine may be gained from the Long Island Railroad east from East New York. Only at the extreme west end of the island is the outer border of the moraine ill defined.

From the inside the moraine is less conspicuous topographically, though even from this side it appears as a broad ridge with a gentle slope to the north. Since the moraine east of Brooklyn is very generally forested, it is often conspicuous on this account, even where its ridge-like character is not pronounced.

Between Fort Hamilton and Evergreen Cemetery much of the surface of the moraine has been modified by grading; but the characteristic rolling topography is well seen along the outer part of the moraine from a point east of Fort Hamilton to Greenwood Cemetery, and again immediately east of Prospect Park. In the park, too, it is well seen at some points, especially to the southeast, where the graceful curves of its hillocks and hollows are one of the attractive elements of the surface. Farther east it is well developed at Cypress Hills Cemetery and most of the way from that point to Maple Grove. It is well seen along the trolley line between Richmond Hill and Ridgewood, and along all the railway lines which cross it east of Evergreen Cemetery. It is also well developed north of Jamaica and Hollis.

Composition.—The moraine is composed primarily of compact till with a somewhat sandy matrix. Locally, as at Bay Ridge, and often near the inner border of the moraine, stratified drift is abundant. The surface of the moraine, like that on Staten Island, has fewer bowlders than the surface of terminal moraines in general. In a few places, however, they have their normal abundance, as about Cypress Hills Cemetery and north of Richmond Hill. This may not be a permanent feature of the moraine even here, since they are liable to removal. Wherever fresh exposures of the material of the moraine are found the moraine about Brooklyn is seen to be made up chiefly of reddish till, often covered with a few feet of yellow loam. The redness decreases notably eastward. Bowlders of various sorts are present, some of them being large. Triassic sandstone is the commonest stony constituent of the drift in the western part of the Brooklyn quadrangle, trap being second in importance. Bowlders of gneiss and schist are relatively more abundant farther east, and east of Brooklyn they predominate. At many points the constitution of the moraine shows that the ice which made it passed over Cretaceous clay, even where the clay itself is not exposed.

Thickness of drift in the moraine.—The thickness of the drift in the moraine of this part of Long Island is much greater than that on Staten Island. Depths exceeding 80 feet are known at several points, and the drift has locally been penetrated 90 feet without reaching its bottom. The crest of the moraine sometimes reaches an altitude of about 200 feet, but it is not known that the drift reaches this thickness. A part, perhaps a considerable part, of this elevation may be due, so far as now known, to underlying formations.

Influence of the moraine on the development of Long Island.—The moraine has controlled in large measure the development of the island. The surface of the moraine is so uneven that it was not well adapted to cultivation, and was very generally left in forest, while the less rolling lands on either hand were brought under cultivation. The moraine and its accompanying plain have been a large factor in determining the position of roads and railroads. Here, as generally throughout the United States, the terminal moraine has been a favorite place for cemeteries, partly because the land is high and sightly, and partly because it is not readily available for agricultural purposes. Of late years only has advantage been taken of its unique topography for the building of beautiful country homes and extensive public parks.

STRATIFIED DRIFT SOUTH OF THE TERMINAL MORAINE.

Terminal moraines are often bordered on the outside by plains or valley trains of stratified drift carried out beyond the ice by the water arising from its melting. On both Long Island and Staten Island the outlying stratified drift is in the form of a plain, rather than valley trains, since valleys seem not to have been at hand to determine the course of drainage from the ice.

Staten Island.—The considerable plain of stratified drift which skirts the moraine of Staten Island on the south, between Fort Tompkins and Great Kills, has a gentle slope seaward, and ends in a marsh which is shut in at the south by the beach ridge of recent origin. The greatest width of the plain, near New Dorp, is about 1½ miles. The plain 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 deposited.[1] At its moraine edge the plain is made up of coarse gravel, but with increasing distance from the moraine the material becomes finer, grading off into sand. The sand and gravel of the plain are often covered with clay loam, so that the coarser materials below are shown only in excavations. The depth of the stratified drift is unknown, but it is known to exceed 30 and 40 feet at many points, and its base is therefore often below sea level.

This plain is one which might give rise to various interpretations. It has not the even slope away from the moraine which is characteristic of overwash plains. It is not unusual for such plains to have some undulations near their moraine edges; but in this case the undulations are often conspicuous half a mile from the moraine, the depressions being such as to occasion swamps and even ponds. Again, the surface of the plain is covered with several feet of clay loam, often stiff enough for brick clay. This is like the loam over the moraine near the west end of the island, and perhaps at other points. The disposition of the stratified drift south of the driftless area near New Dorp is not exactly what would have been expected if it were deposited by running water. Though in these minor particulars this plain departs somewhat from the normal outwash plain, the departures are so slight as not to negative the conclusion that this was its origin. They are enough, however, to raise the query whether the plain has not been submerged to the extent of 40 feet or so since the ice departed. Against this view stands the fact that distinct shore features are absent. To suppose that it has been submerged is to suppose that the submergence and subsequent emergence were accomplished without the development of distinct shore features, such as beach lines, spits, or cliffs.

Long Island.—The moraine in the Brooklyn quadrangle is everywhere bordered on the south by a plain of stratified drift. It slopes away from the moraine, at first more steeply, and then more gently. Its decline in the first quarter of a mile is often as much as 20 feet, and a further decline of an equal amount is accomplished in another mile. The moraine edge of the plain has an elevation varying from 20 to 80 feet, but most commonly between 60 and 80 feet. So distinct is the line of junction of plain and moraine that it has sometimes been interpreted as a shore line; but the line departs too much from horizontality to bear this interpretation, unless, indeed, it has undergone notable deformation since its development.

[1] The stratified drift of this plain and of the corresponding plains on Long Island is not referable to the time of "glacial retreat," as stated in the legend of the maps.

The plain is composed of gravel and sand, similar in kind to materials of the same grade of coarseness in the moraine. The material of the plain is coarser near the moraine and finer farther from it. The gravel and sand are stratified, and often cross stratified, the laminæ generally dipping seaward.

The depth of the stratified drift of the plain is not known. Excavations do not generally reach its bottom, and the records of wells are usually not decisive. At the Flatbush waterworks 55 feet of gravel and sand which appear to be of aqueo-glacial origin have been reported. At Jamaica the depth of gravel is equally great, but it is not known that all of it is of glacial origin. Near the east edge of the quadrangle, south of Hollis, there is evidence that the gravel washed out from the moraine is thin, and that at a slight depth below the surface there is non-glacial gravel similar to that at Far Rockaway.

The gravel and sand of the plain are often covered by a thin layer of loam, similar to that on the corresponding plain of Staten Island. Similar loam runs up locally and irregularly over the moraine, with no well-defined limits.

Like the corresponding plain on Staten Island, this also departs in some respects from the normal outwash plain. The surface of the plain is somewhat uneven. Elevations are less common than depressions, but neither is confined to the moraine edge of the plain. Some of the more conspicuous depressions occur about half a mile west of East New York, near the moraine at Richmond Hill, and south of the railway between Richmond Hill and Jamaica. Near the outer edge of the plain there are occasional points that are higher than areas north of them; yet these swells are covered by gravel which had its source in the moraine. Another peculiar feature is found in certain rather notable valleys and valley-like depressions which do not appear to be utilized by drainage at the present time. Some of them may perhaps have been developed by normal drainage before the cultivation of the land, but others are closed at both ends. The topography of this plain raises the same questions as that of Staten Island.

GROUND MORAINE.

The ground moraine or till lying north of the terminal moraine is not unlike the latter in constitution, but it differs from it chiefly in its smoother topography and lesser thickness.

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 portion in the northeastern. In general the material of the drift of the western part of the island was derived chiefly from the Triassic shale and sandstone lying west of the Palisade ridge in New Jersey. The till sometimes rests on 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 nearly absent, while 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 frequently appears at the surface about Graniteville, and again between New Brighton and Tompkinsville.

The topography of the area north of the moraine is primarily the result of the configuration of the formations beneath the drift. The drift modifies it but little. The ice modified the surface of the underlying formations to an unknown extent.

Long Island.—The area of ground moraine in the Brooklyn quadrangle is not extensive, and a part of that which exists has been so modified by culture as not to be available for illustrative purposes. It is notably thicker than the ground moraine of Staten Island, and its influence on the topography is more considerable. Thicknesses exceeding 100 feet are reported from north of Middle Village. Typical ground-moraine topography is well seen between Bushwick on the south and Middle Village and East Williamsburgh on the north, and again in an area between Blissville, Woodside, and Laurel Hill. About Astoria and between Little Neck and Flushing bays, also, there are considerable areas where ground-moraine topography, little influenced by the underlying rock, prevails. In both the areas last mentioned the hillocks of ground moraine occasionally assume an elliptical form, about twice as long as broad, the longer axes being parallel to the direction of ice movement. Such hills of ground moraine are called drumlins. One of the best examples of a drumlin in this region is the hill at Lawrence Point. Other examples of drumlins, or of drumloid hills, occur three-fourths of a mile farther south, half a mile northwest of Steinway, and north of College Point, where Tallman Island appears to be a drumlin. The elongate hill just southwest of Tallman Island also has something of the drumloid form. Other hills apparently of till, as at Willets Point and south of Broadway, trend in the same northwest-southeast direction. Locally, as between College Point and Whitestone and about Steinway, the topography simulates that of the terminal moraine.

In this part of Long Island the till is generally compact and reddish, though the redness is less pronounced to the east, and practically disappears east of Little Neck Bay. Bowlders of gneiss and trap abound, the latter especially west of Flushing Bay. Some of the bowlders of the ground moraine are very large. There is one near Whitestone Point 20 feet in greatest diameter, and another of similar size at Elm Point, east of Little Neck Bay. At many points masses of Cretaceous clay, derived from the Cretaceous formations which underlie this part of the island, are found in the till.

East of the Hudson and north of East River and the Sound.—Between the Hudson on the west and East River and the Sound on the south the till is so thin as to constitute no more than a discontinuous mantle, which scarcely masks the surface of the rock. Outcrops of rock are common throughout the area, not only on the ridges, but in the valleys as well. The topography of the region is determined almost wholly by the rock beneath, and hardly at all by the drift, which has no further influence on the configuration of the surface than to even up, to a slight extent, the roughnesses of the rock. In contrast with the western end of Long Island, this area shows the effects of glacial erosion, rather than of glacial deposition. On the whole, the till, especially west of the Bronx, is rather thicker on the west sides of the ridges than on the tops and east sides. It occasionally reaches thicknesses of 40 or 50 feet, but its average is probably less than 10 feet. Where it is thin it is often made up almost wholly of angular and unworn débris derived from the rock immediately beneath. Where it is thick there is more material which has been transported farther.

Along the Hudson south of Fort Washington the till is generally red or reddish, like that farther west and south. But north and east of this point the redness diminishes perceptibly, and is nowhere conspicuous east of the Harlem River. This distribution of débris derived from the Triassic formation to the west—for this is what gives the drift its red color—is as significant of the direction of ice movement as the striæ are. East of the area where the till is red it has a grayish or brownish color—the color of the crystalline rock formations from which its materials were mostly derived. The till here is not generally so clayey as that of Long and Staten islands, but is gritty and sandy, the product of the crushing and grinding of schist and gneiss. As is common where till has this constitution, it often shows foliation—that is, an indistinct cleavage structure apparently induced by pressure.

Bowlders are, on the whole, abundant. In the southern and western parts of the area those of trap predominate; elsewhere, those of gneiss and schist. They are plentiful at a few points, as half a mile north of Bronxville, where there are at least two which have a maximum diameter of 20 feet or more. In the southwestern part of Bronx Park there is a good example of a perched bowlder, which has a maximum diameter of 10 feet.

STRIÆ.

Distribution and direction.—In keeping with the thinness of drift and the frequency of rock exposures, glacial striæ, or rather glacial grooves, abound in the area east of the Hudson and north of East River and the Sound. (See figs. 23 and 24, Illustration sheet 2.) The finer striæ and the polish which the ice originally gave the rock are generally weathered away. The striæ run obliquely across the trend of the ridges, ranging from S. 15° E. to S. 45° E., with an average direction S. 25° to 35° E., while the ridges have a trend of about the same amount to the west of south. The course of the striæ is influenced somewhat by the topographic situations in which they occur, the easting being least at the west bases of the ridges.

The striæ may be seen at many points in Central Park and at most locations where rock is exposed and its surface not deeply weathered. They are often seen to best advantage in temporary excavations, where the drift has been recently removed. In such cases the surface of the rock beneath has been protected from weathering by its mantle of drift, and the rock surface has therefore undergone little change since the ice departed.

Striæ on bed rock are not known in that part of Long Island shown on these maps. They are known at some points on Staten Island, where they may be seen to best advantage on the surface of the trap at the quarries about Graniteville.

MIXED DRIFT.

In most of the area underlying the heart of Brooklyn the drift is mapped as composed of undifferentiated till and stratified drift. Were the surface in this part of the area unmodified by human agency some other classification might have been possible, but within the limits of the city, data for other classification are not available. Within the city there is often a thickness of 3 to 8 feet of till, overlying stratified sand and gravel.

Another area where stratified drift and till are intimately mingled is north of the moraine in the eastern part of the Brooklyn quadrangle. In this region the drift often has a morainic topography. This association of stratified drift and till just inside the terminal moraine is one which is common in similar positions elsewhere. As soon as the ice had receded a little from the terminal moraine which it had already made, drainage southward was blocked by the moraine, and the water between the ice on the north and the moraine on the south modified to a notable extent the drift of this intervening belt.

In many places not shown on the map there is really more or less mixing of stratified and unstratified drift. For example, there is often stratified drift beneath the surface in areas where the drift is mapped as till. Similarly, there is much till beneath the sand and gravel in some areas mapped as stratified drift. In such cases it is practicable to map only the surface member of the complex drift series.

STRATIFIED DRIFT NORTH OF THE TERMINAL MORAINE.

Staten Island.—Stratified drift has little representation north of the moraine on Staten Island. In the northwestern part of the island there is some drift of this sort, associated with dune sand. One other small area of stratified drift is noted on the map. There are other localities where indications of stratified drift may be observed, but the material is not extensive enough to be mapped, or is so equivocal that trustworthy determinations can not be made.

Long Island.—There is some stratified drift north of the moraine on Long Island, but much of it is without distinctive features beyond its sandiness. It was deposited by water after the ice had melted from the areas which it occupies. In the area about Corona the surface is somewhat undulatory, and next Flushing Bay so much so as to assume a kame phase—that is, it is disposed in hillocks, associated with depressions. Small areas of stratified drift occur at two points east of Little Neck Bay. Farther east and north they grade off into undulatory areas of semi-kame phase. At Whitestone Point there is a notable little kame more than 20 feet high, into the northern base of which the waves have cut.

A part of the neck of land between College Point and Whitestone is stratified drift. Near College Point it assumes a kame phase. This kame tract is perhaps to be associated with the semi-morainic area farther east, and with that at Steinway farther west, the belt representing a position where the edge of the ice halted temporarily in its recession. At College Point there are two small kames, surrounded by stratified drift which does not belong to the kame category. Berrian Island seems to be a kame, and there is another a little to the southwest.

East of the Hudson and north of East River and the Sound.—The stratified drift of this area commonly occupies the lower lands, though it is not confined to any particular level. Near salt water it is mostly below an altitude of 40 feet and the material is mostly sand. The southern part of New York City, to a point somewhat north of Union Square, is underlain by stratified sand and gravel, not exposed except in temporary excavations. Stratified drift is said to attain a thickness of 163 feet on Duane street, the greatest thickness that has been reported. It is to be noted, however, that much of the low land north of East River and the Sound is not occupied by stratified drift.

Where this phase of the drift occupies higher levels it is chiefly confined to the valleys, occurring at higher and higher levels as the valleys are traced toward their heads.

Along the valleys the stratified drift is often disposed in the form of terraces. Along the Hudson near Hastings, at an elevation of 90 to 100 feet, there are patches of stratified drift with terraciform disposition. Farther south along the Hudson, as at Yonkers and Mount St. Vincent, drift has a similar disposition at a lower level. There is a narrow belt of stratified drift along the Bronx from Scarsdale, where it has an elevation of about 170 feet, to Mount Vernon, where it has an elevation of about 90 feet. Much of the way it has hardly the normal form of a terrace, but rather an irregular surface, as if there were not free drainage through the valley when it was deposited. Similar deposits occur about Grassy Sprain Reservoir, where they often have a kame tendency. This belt of stratified drift connects with that of the Bronx, declining southward. At Bedford Park there is gravel much coarser than that which belongs to the Bronx of this latitude, which was probably deposited independently of that in the main valley. There is more or less stratified drift in almost all the valleys leading southward. In many cases it is thin, and does not make well-defined terraces. It is often undulatory, and there are here and there small kames, but the topography is generally not distinctively kame-like, and often not terraciform. Well-developed kames are rare. There is one 25 to 30 feet high on Sawmill River at St. Johns Cemetery, and one between Hunt Point and Barreto Point, and there are belts or patches of drift with semi-kame habit north of Mount Vernon and above Tuckahoe.

At a few points along East River and the Sound there are very small patches of stratified drift which suggest submergence. They do not rise above an elevation of 20 to 30 feet, and are oftener absent than present, even at this altitude.

SURFACE LOAM.

Staten Island.—Over the surface of the drift there is, at many points, a thin layer of yellowish or brownish loam which hardly seems to be a part of it. The loam is too thin, too discontinuous, and generally too equivocal in character to be shown on the maps. It is well developed on the north side of Staten Island, especially between Elm Park and Snug Harbor, and about West New Brighton. It is discontinuous, but often reaches a thickness of 6 or 8 feet. Indications of the same loam are found up to heights of 120 feet at least, but it has no definite upper limit. It is not certain that this loam is different from that which covers the plain of stratified drift about New Dorp.

Long Island.—Loam of the sort referred to in connection with Staten Island is more or less widely distributed on Long Island, but is thin and discontinuous. It is most conspicuous where the underlying drift is red, for here it is distinguished by its yellow color. Where the underlying drift is gray the loam has a tendency to brownness. As on Staten Island, it is not limited to any particular level, but runs up to 120 feet at least. It occurs on the terminal moraine at various points about Brooklyn, and on the ground moraine at points about Astoria.

East of the Hudson and north of East River.—Loam comparable to that of Long and Staten islands is found along the east side of the Hudson, and again on the east side of the Harlem, sometimes resting on till and sometimes on rock. At places it is several feet in thickness, but usually not more than 2 or 3 feet. In some situations, as about Spuyten Duyvil, where it is coarser than elsewhere, it is perhaps of eolian origin, but it occurs in other situations where the position and relations do not suggest wind work. In the northeastern part of the Harlem quadrangle it is found in places up to 140 feet at least.

The loam sometimes contains stony material, especially in its base. It is not certain that all of it had the same origin. Different parts may have originated in different ways, and if so it does not constitute a distinct formation.

NON-GLACIAL GRAVEL.

Cape May formation.—There is a small area of gravel not of glacial origin in the vicinity of Rockaway, Long Island. It lies at a low level, and is composed mostly of quartz pebbles and sand. Its topography is slightly undulatory, like that which is common in much of the lower part of the Coastal Plain farther south. The configuration of the surface was probably developed beneath water, and is comparable to that which is now submerged. The gravel of this locality belongs to the Cape May formation, a formation of non-glacial origin but of late Glacial (or younger) age. It has much greater development on the coast of New Jersey and farther south than within the New York City district.

GLACIAL PHENOMENA OF THE NEW JERSEY AREA.

Topography.—The topography of the New Jersey part of this district is somewhat unlike that of any portion of the New York part, though it differs less from the area north of East River and the Sound than from that of Long and Staten islands. Like the area across the Hudson, it consists of a series of ridges and valleys, the general course of which is north-northeast and south-southwest; but unlike the New York area, the ridges are less broad than the valleys. The underlying formations too are different, and this difference is reflected in the character of the drift, though much of the drift of Staten Island and Brooklyn came from New Jersey.

The more conspicuous ridges of the area, the Palisade ridge and the Watchung Mountains, are of trap rock, as the geologic map shows. Between them there are subordinate ridges of sandstone. Both the main and the subordinate ridges of rock owe their existence primarily to pre-Glacial river erosion, which carried away the less resistant rock adjacent to the ridges, while the ridges were left because of the superior resistance of the rock of which they are composed.

Disposition of the drift.—In general the drift may be said to be relatively thick in the valleys and relatively thin on the ridges, and to be deeper in the former positions, where the valleys are wide, and shallower in the latter, where the ridges are narrow and steep. In other words, the low areas were built up by drift deposition more than the high areas, and the greater depressions were built up more than the lesser. As a result, the present relief is notably less than it would be were the drift removed. If this were done the ridges would remain very much as they now are, while the lowlands and valley bottoms would be considerably lower—indeed, portions of the low lands would be covered by the sea. This would be true of the Newark Meadows, of a considerable tract west of them, of a narrow belt up the Hackensack, and of a few other lesser areas. The removal of the drift would occasion much more notable changes in the geography of this area than in that of Staten Island or of the area north of East River and the Sound.

Speaking in general terms, the drift of the ridges is generally till, or ground moraine, while a considerable part of that at the surface in the valleys and on the lowlands is stratified gravel and sand. Till is, however, not wanting at the surface on the lowlands, and stratified drift is not wholly absent from areas which are well above the valley bottoms. Beneath the surface there is often till, even where the surface material is stratified.

Stratified drift is more abundant and assumes more varied phases in this region than in the New York portion of the district. Besides the areas of stratified drift which have no distinctive topographic form beyond that of plains—the normal form for water-laid deposits—there are numerous kames, one or two eskers, and occasional deltas.

GROUND MORAINE OR TILL.

Composition.—The till of this area is generally so red as to attract the attention of any student of drift familiar with its phases in most other regions. The striking color is due to the redness of the underlying Triassic sandstone and shale (see Historical Geology map) which contributed most of the material of the drift. It is true that the trap is not red, but the trap contributed to the drift much less than the sandstone and shale, both because its area is less and because it is a more resistant formation and yielded débris to the ice less readily. This last consideration is in some measure offset by the fact that the trap constitutes conspicuous ridges, and, by resisting the progress of the ice, subjected itself to severe erosion.

To the prevalent redness of the till there are two exceptions: (1) On the trap ridges, where the drift is thin, it is sometimes made up chiefly of trappean detritus, in which case it is brown or brownish yellow. Where the drift on the trap ridges is thick it is often distinctly red. (2) In the northwestern part of the Paterson quadrangle the drift is made up largely of débris from the crystalline rocks of the Highland area to the north. Here it has a grayish-brown color.

Except on the Palisade ridge, the movement of the ice corresponded approximately with the direction of strike of the rock beneath. As a result, there is relatively little débris in the drift derived from formations other than the Newark sandstone and shale and the trap. There is, however, enough detritus from other formations to deserve mention.

The axis of the ice lobe with the products of which we are dealing lay just west of the Palisade ridge (see fig. 12), and essentially parallel to it. The axis was in a broad depression the position of which was determined by the position of the trap ridges on either side. Along the axis the movement of the ice was parallel to it and to the strike of the rock. On the east side of the axis the ice diverged markedly to the eastward, crossing the Palisade ridge at a notable angle, but on the west side the divergence was so slight as not to depart notably from the direction of the strike of the sandstone beneath.

North of the area here under consideration, in that part of New York which lies immediately west of the Hudson, the movement of the ice was less nearly in harmony with the strike of the rock. Before reaching the Newark group, which extends but a little north of the New York–New Jersey line, the ice had come over the crystalline schists and gneisses of Rockland and Orange counties, and some drift material was brought into New Jersey from these formations. Another formation which the ice covering this area had crossed before entering the State is the conglomerate of Schunemunk Mountain (the Oneida formation). The northern end of the outcrop of this formation lay in the path of the ice which affected this area. Since this formation is of hard rock, its outcrop constituted ridges; and as it was crossed by the ice, its crest was severely abraded. The hardness of the rock which the ice tore from its surface favored its preservation in the form of bowlders. This formation, however, yielded an abundance of bowlders, quite out of keeping with the smallness of its outcrop along the path of the ice. Since the bowlders were taken from a ridge which projected high up into the ice, some of them were carried forward well above the bottom of the ice, and so were transported farther than would otherwise have been the case. Besides the materials of local origin, therefore, the drift of this locality has constituents from the crystalline rock and from the Oneida formation of New York, as well as from some other formations which made less conspicuous contributions.

In the immediate vicinity of the trap ridges the drift is sometimes largely trappean. Where the movement of the ice was parallel to them, as south of Paterson, relatively few trap bowlders were scattered on either side of the ridges. Where the ice crossed the ridges obliquely, as northwest of Paterson and along the Hudson, trap bowlders were carried across the ridges and distributed beyond. Thus the material from the Palisade ridge, in so far as it was shifted by the ice, lies partly on the ridge, especially on its eastern part, but more largely east of the Hudson. Since the trap is much more resistant than the sandstone and shale of this region, it furnished relatively more bowlders and relatively little of the fine material of the drift.

Many of the principles governing the composition of till and its relations to the formations which furnished its materials are so well illustrated by the till of the Palisade ridge that a few paragraphs will be devoted to their consideration.

The west base of the northern part of the ridge is made up of sandstone, as shown on the geologic map. Its upper slopes and crest, and at the south end the whole of the ridge, are of trap. The ice moved diagonally up the western slope of the ridge (fig. 12) and over its crest to the east. It therefore tended to carry Triassic sandstone débris up over the ridge. At the west base of the ridge the till, where the underlying rock is sandstone, is made up chiefly of débris from this formation, over which the ice had been passing for some distance, and very subordinately of débris from the crystalline schists and gneisses of the regions already mentioned. As the ice passed from the sandstone to the trap, it carried material from the former onto the latter, and at the same time began to acquire the material from the trap. Along the junction of sandstone and trap, and for some distance east of it, sandstone material predominates in the till, but with increasing distance from the contact the percentage of sandstone becomes less and that of trap more, until at the crest of the ridge the till is often mainly trappean. This is likely to be the case where the till is thin, but where it is thick, as at points near the south end of the ridge, the red sandstone and shale débris predominates on the crest and even at the eastern base of the ridge. From the foregoing statements it is evident that the ice carried the red sandstone débris from the lowland west of the ridge, and from the lower slope of the ridge, up to its summit. The red till on the ridge, and the relations of the trap and sandstone to each other and to the direction of ice movement, afford some basis for estimating the amount of upward movement suffered by débris from the Triassic sandstone, though they do not afford a measure of the lifting power of the ice. Near the north end of the ridge, material from the sandstone occurs at least 300 feet above the highest outcrops of sandstone which could have furnished it. The sandstone may have been carried up still more, since the exact level from which any particular part of it started is not determinable.

At Stevens Point, Hoboken, there is a small outcrop of serpentine rock. The drift on this outcrop contains material derived from it, just as the drift from the trap contains material derived from that formation. Débris derived from the serpentine of this locality was carried to the southeast, in the direction of ice movement, and is found in the drift of Brooklyn and Staten Island.

The till of the Palisade ridge is relatively thick (30 to 40 feet) at and near its western base, thins to its crest, where its amount is small (0 to 10 feet), especially where the crest is narrow and the slopes are steep, and is generally absent from the eastern or Palisade face. Near the south end of the ridge, where it is low, there is less difference between crest and slopes.

There are a few conspicuous bowlders on the trap ridge, some of them in nicely balanced positions. Such bowlders are known as perched blocks. A perched bowlder of Triassic sandstone, 8 by 12 by 12 feet, occurs east of Englewood, near the east side of the ridge. Another conspicuous bowlder of the same rock occurs one-third of a mile northwest of Linwood, and a notable bowlder of gneiss, 12 by 20 by 6 feet, lies a few hundred yards east of Tyler Park station.

On the more westerly trap ridges at and near Paterson the till is commonly very thin, especially on the crest and steep faces. In many places, indeed, and for considerable areas it is nearly absent. At the bases of the ridge, again, it is present in greater quantity.

On the sandstone areas the till is, on the whole, thicker than on the trap, though its continuity is occasionally interrupted by protruding ledges of sandstone. Thus sandstone outcrops frequently in the ridges both east and west of Hackensack, on the steep slope west of Cresskill, and at other points in similar topographic situations. The outcrops of sandstone are, however, much less frequent than those of trap. With the exception of the area already noted northwest of Paterson, the till is almost uniformly red. Its matrix is sometimes gravelly, sometimes sandy, and sometimes clayey. In general it is not particularly rich in bowlders.

Even where the till is composed chiefly of the red sandstone and shale, and where it is relatively homogeneous lithologically, it may be heterogeneous physically. In one place its constituents were ground to fineness, while in another they were not so completely comminuted. Locally it is made up chiefly of little-worn masses of sandstone moved but slightly from their original positions. Where its materials were derived more largely from shale it is more clayey; where from sandstone, more sandy. The proportion of foreign bowlders, too, varies from point to point.

The stony type of till is more common where the drift is thin, or in the lower part of the section, than where the till is thick. This phase of till may be seen in some of the quarries about Newark. The clayey type of till may be well seen about Elizabeth, where the underlying rock is shale; the more sandy type is prevalent farther north, where the underlying rock is sandstone. The till about Elizabeth departs somewhat from normal till, and in many places has the appearance of having been beneath water since its deposition by the ice.

Within the sandstone area, as on the trap ridges, there are occasional bowlders large enough to be conspicuous. The most notable one is that on the road just west of Glen Rock, 3 or 4 miles northeast of Paterson.

MIXED DRIFT.

In many places within this area the drift is not readily separable into stratified and unstratified. Good exposures would doubtless show the constitution to be one thing or the other, but in the absence of exposures there is much confusion. Such an area occurs a half mile east of Cresskill station, and many other small areas occur along the junction of till with stratified drift, as marked on the map. In many cases, too, the boundary between the stratified and unstratified drift is very indefinite. Stratified and unstratified drift often alternate in the section. In such cases, only the uppermost type of drift can be mapped.

STRATIFIED DRIFT.

In valleys.—Stratified drift occurs along most of the drainage lines, and in such positions lies at lower levels in proportion to its proximity to salt water. The drainage is principally to the south, and the stratified drift lies at progressively lower altitudes in this direction. Thus along the west base of the Palisade ridge it runs from elevations of 20 or 30 feet at tide water to 70 and 80 feet at the northern limit of the Paterson quadrangle. About Hackensack and along the Hackensack Valley most of the surface drift is stratified up to levels of 60 feet, though this general rule has exceptions, as the map shows. Along the Passaic the stratified drift does not follow contour lines closely, and till appears at the surface at some points, below the level of stratified drift at others. While as a rule the surface of the stratified drift in the valleys declines regularly to the south, its surface is often far from plane.

While the stratified drift of this region, like the stratified drift in general, is mainly sand and gravel, there are also considerable bodies of clay. This is extensively exposed only in the vicinity of Little Ferry and Hackensack, where it is used for brick; but similar clay has a wider extent than these exposures show. It probably underlies most of the Great Meadows to the south, and some portions of the sand and gravel of the Hackensack Valley farther north. It is so slightly exposed that its relations are not readily seen, and they are not well understood. The clay is apparently identical in kind, and probably in origin, with that of the Hudson Valley above Haverstraw and with that of the Connecticut Valley. It was certainly deposited in standing water into which glacial drainage discharged. It contains no fossils, though admirably adapted to their preservation had they ever been present. It is hard to see how they could have been absent if the water in which the clay was deposited was salt, for animals adapted to fossilization abound along the Greenland coast near the ice front, and there is no apparent reason why they should have been absent here. For a body of fresh water to have existed where these clays are there must have been a land barrier to the south, shutting out the sea in that direction and shutting in the fresh ice water from the ice to the north. Such a lake might have been free from life. The clay may have been deposited in an estuary, when the water was ice cold, and fresh or brackish. In this case the land was somewhat lower than now, at the time of the deposition of the clay.

In hillocks.—In addition to the bodies of stratified drift which occupy valleys and lowlands and which were deposited chiefly beyond the ice after it began its retreat, there are numerous kames or hillocks of stratified gravel and sand. Kames are well developed at Highwood (Cherry Hill), about Demarest, where a belt of kames has the general habit of a moraine, at various points about Orange, Paterson, Garfield, and in an area 3 miles northwest of Oradell. Some of the kames of the region formerly most conspicuous have been largely removed, the gravel and sand having been utilized for various purposes. This is true of some of the kames which formerly existed in Paterson. Some of these have been removed since the map was made.

Kame areas are areas where there are aggregations of hillocks which individually simulate kames. The Demarest kames are an example. Such areas are believed to have been developed at the edge of the ice.

There are considerable areas where the stratified drift assumes a kame-like phase without being disposed in the form of distinct kames. These are areas of markedly undulatory stratified drift, and are often associated with kames. Such areas occur a mile north of Schraalenburg, 3 or 4 miles northwest of Paterson, and at other points shown on the map. An area west of Cedar Grove is to be especially mentioned. Here the sand and gravel appear to have been deposited against the side of a body of ice which occupied the valley after the slope above had been laid bare by the melting of the ice. Such deposits have sometimes been called stagnant ice deposits, because when they were made the ice against which they were banked was probably stagnant.

In ridges.—One well-marked though small esker occurs within the district. It is in the valley of Saddle River, between Lodi and Rochelle Park, on the west side of the stream. 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 eskerine 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 believed to have built up their beds, and to have flowed on the tops 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 stand 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 deltas.—In the northwestern part of the Paterson quadrangle there is some gravel and sand which has the general form of a delta. It was deposited in the extinct Lake Passaic, which occupied this region in the late days of the Glacial epoch. The Paterson Surficial Geology map shows the position of a part of the shore line of the lake, the water of which lay to the west. The delta form of the drift is best seen at a point rather more than a mile north of Preakness. The abrupt and lobate front of the plain 2 miles northwest of Preakness is of the type characteristic of deltas.

The flat of gravel and sand about Franklin Lake, near the northwest corner of the same quadrangle, is probably also an old lake bed. The region now drains to the north. When the ice had retreated to a position north of the trap ridge lying just south of the present lake, it occasioned a basin between itself on the north and the trap ridge on the south. Into this lake the sand and gravel were washed from the north until a large part of the basin was filled. The present lake basin may represent the site of an ice block left behind as the ice retreated. It was surrounded and perhaps buried by the sand and gravel, and when it melted gave origin to the basin.

In the northern part of Hackensack, a half mile south of Fairmount, there is a body of stratified drift which has much the form of a delta. It is not easy to see how any body of water in which a delta might have been made could have stood here unless one or the other of the alternatives suggested in connection with the Hackensack clays be adopted. On the other hand, the form of this body of gravel and sand is perhaps hardly demonstrative of its delta origin.

At other points in the vicinity there are suggestions of shore phenomena, though they are few and mostly indecisive. One is a low spit-like ridge east of the Hackensack at Little Ferry, about 20 feet above tide. Others, in the form of terraces, occur along the west base of the Palisade ridge at intervals between Bergen Point and Englewood. While there are some phenomena in this region which suggest submergence after the withdrawal of the ice, they do not seem altogether conclusive, and the question of post-Glacial submergence is regarded as an open one.

SURFACE LOAM.

Character and occurrence.—At many points on the Palisade ridge and west of it the uppermost part of the drift is so unlike that beneath as to suggest a difference in origin. This upper part, where it is distinctive, consists of loam, usually yellowish. It is far from continuous, its distribution is irregular, and its distinct character is often open to question. In texture it varies from sandy to clayey. It contains few stones, and where its development is most distinct, none at all. When stony matter is present it is generally confined to the basal part. The loam is nowhere distinctly stratified, and rarely shows any trace of structure. It is found up to heights of 240 feet, though it is absent from more than half the surface below that level. Even within this range it is more common at low levels than at high, and is prone to occupy depressions in the surface of the underlying drift. It lies now on till and now on stratified drift. It has a thickness varying from zero to 8 or 10 feet. It is well shown in the quarries about Avondale, and may be seen at many other points about Newark.

Its origin is doubtless similar to that of the loam of the other parts of this district. It contains within itself nothing which determines what this origin was, nor is it certain that it all originated in the same way. The following hypotheses of its origin have been considered: (1) It is the weathered part of the drift; (2) it is post-Glacial wash; (3) it is of eolian origin; (4) it is a deposit made by water subsequent to the melting of the ice; (5) it is superglacial material blown on the ice and let down on the land surface when the ice melted; and lastly, (6) different parts of it originated in different ways. Among these hypotheses the phenomena of this area are not decisive.

POST-GLACIAL HISTORY.

Post-Glacial submergence.—There is within this district no decisive evidence of post-Glacial submergence. There are certain topographic features, as about Canarsie and south of Jamaica, Long Island, which might be thought to suggest submergence. For example, south of Jamaica there is a swell rising to a height of 40 feet above tide, which is several feet higher than the country north of it; yet material derived from the glacial drift to the north covers the mound. The material is water deposited, and subaerial drainage could not have carried it where it now is. On the other hand, there are no decisive shore features. The drift hills on the north side of the island show no evidence of wave cutting, though they seem to be favorably situated for receiving and retaining the marks of submergence. North of the sound the same conditions exist. Here and there are small patches of gravel at levels 20 feet or so above sea, which suggest submergence to this extent. Such deposits of gravel occur in New Jersey at Little Ferry and north of Snake Hill. As already pointed out, the plains south of the terminal moraine on Staten and Long islands have often been interpreted as evidence of submergence during Glacial or post-Glacial time; but they can not be regarded as decisive. The possible delta at Hackensack has a similar bearing. The surface loams already referred to at various points likewise suggest, without demonstrating, submergence of the area during late Glacial times or since. On the whole, so far as this district is concerned, the evidence on this point must be looked upon as indecisive.

Stream erosion.—The amount of erosion accomplished by the streams in post-Glacial time is not great, many of them having deepened their channels hardly at all. On the gravel plains south of the terminal moraine on Long and Staten islands the valleys have rarely been cut to a depth of more than 10 feet. In the moraine itself subaerial erosion has been trivial. The same is true of the streams on Staten Island and of most of those on the mainland farther north. The Harlem River may have lowered its channel 20 feet in places, but generally less. Similar figures hold for Tibbit Brook, while Sawmill River has lowered its channel perhaps twice as much in some places. The maximum post-Glacial lowering of the Hudson appears to be in the vicinity of Yonkers, and can hardly exceed 60 feet. Probably no stream within the New Jersey part of this district has lowered its channel more than 60 feet, and in few places has the deepening amounted to more than 20 feet.

Shore erosion.—Erosion by waves has also been slight. The cliff at Princess Bay Light, Staten Island, has been cut back somewhat by the waves, and waves and currents have caused the shore to recede on both sides of the Narrows between Staten and Long islands. At Willets Point and a few other places along East River similar wave-work has been accomplished. In general it may be said that abrupt cliffs, even though low, facing the ocean or sound, or any body of standing water, are evidence of recent wave cutting.

Alluvial plains.—Along many of the streams there are narrow alluvial plains, developed since Glacial time. In keeping with the limited amount of stream erosion, the alluvial plains are for the most part narrow, and the alluvium is usually shallow.

Weathering.—Post-Glacial weathering has affected the surface of the drift notably to the depth of 2 to 4 feet. This effect is seen in the leaching of the soluble constituents from the till, in some bleaching, and in the disintegration of some of the stones which it contains. Post-Glacial weathering is also shown on the surface of the bed rock where it is bare. Where it has been continuously exposed it has commonly lost the polish and the striæ which the ice gave it, though the weathering has not been enough to obliterate deep grooves where they were developed. The extent of post-Glacial weathering on trap is well seen beneath and about the large bowlder east of Englewood, N. J., already mentioned. Here the surface of the trap beneath the bowlder still retains the striæ given it by the ice, while the surrounding surface of the trap which has not been shielded from the sun and the rain by the bowlder, has lost its polish and its striæ.

Eolian sand.—Wind-blown sand is common along the west side of Staten Island, but its thickness is slight, and its distribution so irregular that it forms but a discontinuous layer over the area which it covers. Its thickness rarely exceeds 10 feet, and is oftener less than half this amount. The rolling topography characteristic of dunes is rarely well developed, but may be seen about Long Neck, Howland Hook, Bloomfield, Old Place, and north of Kreischerville. The topography of the moraine about Tottenville is often obscured by dune sand.

In the Brooklyn quadrangle dunes are well shown in but one locality, at Rockaway Beach. They are especially well shown at the west end of the beach, and again in a small area east of Arverne. Next the ocean the dunes are ridge-like in form, 10 to 20 feet high, and 200 feet back from the shore. Behind the frontal ridge they are more irregular. Less well developed dunes occur at Gravesend Beach, where they are seen along the railway. They are low and inconspicuous. At other points, as south of Jamaica and near Springfield, the surface has been somewhat modified by wind-blown sand, but not in an important way.

In the Harlem quadrangle wind-blown sand is most conspicuous west of Fordham, on the west side of the Harlem River, but there is more or less sand of the same origin along the river much of the way from Morris Dock to Van Cortlandt Park. It nowhere forms conspicuous dunes, and does not generally occur in sufficient quantities to be mapped. The eolian sand of this vicinity sometimes rests on rock and sometimes on till.

Eolian sand occurs in notable quantity at two points in New Jersey. The first occurrence is east of Newark Bay, the second between Hackensack and Little Ferry. In the latter place especially the dunes are conspicuous. These dunes were formed after the melting of the ice which made the drift of this locality. There are also very small dunes east of the Hackensack at Hackensack. Eolian sand occurs along the Passaic at various points between Passaic and Paterson, but not in quantity sufficient to constitute dunes.

Modern beach sand.—The beach sand which skirts much of the southeastern shore of Staten Island has been washed up by the waves since the ice melted. Deposition along the beach is still in progress, and the marshes which the beach has shut in behind itself are being filled up by sediments washed in from the land to the north, and blown in from both sides, and by the accumulation of organic matter which grows there.

Similar beaches are shown in the Brooklyn quadrangle in the vicinity of Rockaway and at Coney Island. The Rockaway Beach has been largely modified by the wind. The sand of this beach has been washed from the shore to the east and shifted westward to its present position by waves and shore currents. The origin of the sand of Coney Island is less evident. The position of this beach does not indicate that its sand was washed from the shore of some other part of the island, since it is nowhere connected with a cliff. It nevertheless contains some material derived from the drift. Since the waves here do not now work on the stratified drift of the mainland of the island, it has been suggested that the area of this beach was once a part of the mainland to the north, and that this recent sinking of the land has isolated it. On the other hand, the sand may have been derived from the bottom near its present position.

Peat.—In many of the marshes and meadows there are considerable accumulations of organic matter resulting from the growth and partial decay of the vegetation. This sometimes overlies stratified drift and sometimes till. The larger areas are on Long Island north of Rockaway Beach, and the Newark Meadows.

Made land.—There are numerous areas about New York City where the surface has been mapped as "made land." This means that the surface at these points has been filled in, generally built up from water or swamp level, by human agency. The boundaries of these areas are probably not always accurate. They have been largely taken from old maps, which antedated the filling.

PHYSIOGRAPHIC FEATURES OF THE DISTRICT.

By Bailey Willis and R. E. Dodge.

New York Harbor.—The Hudson is unlike rivers in general, because the tide ebbs and flows for 150 miles from its mouth, and the upper branches are small as compared with the great arm of the sea, which is salt from the ocean to Poughkeepsie. East River, Harlem River, and the kills about Staten Island also are inlets through which the salt water flows; and it is this system of channels at ocean level, including the mouth of the Hudson, which constitutes New York Harbor. New York's commerce depends upon the relation of land and sea. Were the land raised a hundred feet the waterways would become unnavigable streams and the shore line would retreat far out beyond Sandy Hook; were the land sunk a few fathoms Manhattan Island would be changed to a group of islets and reefs. While such changes are not likely to become notable in any time reckoned by man, they have occurred and probably now are slowly progressing, the present stand of the water level being a stage of that latest subsidence which has admitted the sea to the valleys of the Hudson and its branches. Not long ago, geologically considered—probably shortly before or during the earlier part of the Pleistocene period—the land stood materially higher with reference to the sea than it now stands. Speaking in terms of geology, the Hudson then flowed, as normal rivers do, constantly seaward, and entered the ocean many miles southeast of the Lower Bay. It cut a deep channel, and received a principal tributary through East River from the direction of the Sound, as well as the combined volume of the streams now emptying into Newark Bay. It had had a complex history, dating back to the Schooley plain (upon which it probably began its course across the Highlands), involving adjustment to belts of weak rock, such as dolomite and arkose, and possibly including effects of that faulting which has been described as traversing the Newark rocks and of which there is some evidence in the physiographic relations of Staten Island. All that early history of the river awaits elucidation. Later the established channel was occupied and possibly deepened by glacier ice, at least by the last general glacier, which in melting lingered in the valley after shrinking from the neighboring hills, and this ancient valley was to a great extent filled by clays which the glacier contributed. The recent stages of elevation and subsidence by which the land has reached its present relation to the sea are not known in detail, but it is now a partly sunken land.

The hills which rose above the old valleys have become islands and peninsulas having extensive shores adaptable to the various uses of man, and the submerged lowlands constitute the great harbor about which the cities crowd. We find here, among the rock-bound inlets and islets of East River, a type of shore such as exists in Maine, but is there developed more intricately and with stronger relief; and about the Lower Bay and Newark Bay we find another type, which characterizes generally the estuaries of the middle and southern Atlantic coast, such as the Delaware and the Chesapeake. Both types belong to the class known among physiographers as drowned shores, a designation which signifies that they are more deeply submerged now than they were at some shortly preceding epoch.

Development of shore features.—The shore, where waves and currents meet the land, is a line of attack, resistance, and change. On new shores the irregular outline of the land gives the sea many opportunities to cut away headlands, and with their substance to build bars, spits, and beaches. Along a matured shore this work has been accomplished and the coast line is shaped to even-curving contours which offer the least resistance to the flow of waters. A rocky shore retains the irregularity of youth longer than a sandy one exposed to the same conditions of attack, and any kind of shore is less rapidly modified by the waves of a river than by those of an ocean. By the partial submergence of the New York district a new shore was established about hills of hard rock and also along slopes of clay, sand, and gravel, and while the former chiefly adjoin narrow channels, the latter face the Atlantic throughout long stretches.

Youthful shores and aged ones are continuous along the same coast, and each class is adaptable to uses which the other can not equally serve. Along the irregular water line of Manhattan Island deep channels skirt shallow bays and marshes, which are bays that have been filled with sediment by such streams as the Bronx. The filling is a step toward straightening the shore, and man has seized the opportunity to extend the available land area by completing what the rivers began, as is well illustrated by the distribution of made land shown on the Surficial Geology sheet. From the shallows wharves are built out to deeper water, giving the fretted outline noticeable along the Hudson and East rivers.

The southern sides of Long and Staten islands, on the other hand, illustrate the condition of a shore that is advanced in development. The weak materials there opposed to the powerful waves of the ocean have been distributed in bars and beaches that conform to the water's control. By reference to a map of the Atlantic, one may see that New York Harbor occupies a northwestern angle, toward which southeasterly winds sweep from a great distance. The shores of New Jersey and Long Island form the sides of the angle and deflect the shore currents which the winds establish, and the currents in turn carry along the sands which waves wash from steeper parts of the coast. Headlands have been cut off, and the material has been transported to the mouths of shallow bays, where it has been built first into a bar, then into a spit attached at one end to the shore, then into a long, almost continuous barrier beach, broken only by narrow openings through which the tide ebbs and flows. Rockaway Beach, Coney Island, the beach in front of Great Kills, and Sandy Hook illustrate this action of the sea. They point inward from the ocean, in the direction toward which they have been extended, and on the seaward side are smoothed by the sweeping current. Where the waters build around the ends they are hooked, and the inner margins are irregular, being composed of the points of successive hooks. When built against the land such a beach is continuous, but when extended across the mouth of a bay, as Rockaway Beach is across Jamaica Bay, it can not connect uninterruptedly with the farther shore, on account of tidal currents. At high tide Jamaica Bay contains a volume of water which as the tide falls returns to the ocean and runs rapidly out through Rockaway Inlet, scouring the bottom. If in time of storm the hook be so extended as to narrow the inlet, the tidal waters again widen their channel.

Between Rockaway Beach and Sandy Hook the wind-driven shore currents meet and deposit some of the materials swept thus far. The Hudson brings sediment to the same place, and if its flow be checked by opposing shore currents or rising tide a deposit may form, and thus the bar grows. But as Rockaway Inlet is kept open by the waters pouring out from Jamaica Bay, so the bar is kept down by the much larger volume of water returning at each ebb tide from the extensive estuary of the Hudson. The sea could not close up the mouth of so great an inlet, as it sometimes does those of the smaller ones, but it does obstruct it, and the distribution of shoals and channels results from conflicting eddying currents. An understanding of these processes, in order that deep channels may be maintained through proper engineering operations, is of the highest importance to New York City.

Relations of valleys.—In the area east of the Hudson, shown on the Harlem atlas sheet, Stockbridge dolomite lies in long, narrow belts between Hudson schist and Fordham gneiss, and each belt is followed by a valley. This relation has been pointed out by Dr. Merrill, who also ascribes the courses of East River and the Lower Hudson largely to the occurrence of dolomite along the channels they occupy. The dolomite is a rock which is much more soluble in atmospheric waters than any of those with which it is associated, and which is also more readily abraded. Through this characteristic weakness depressions develop on its surface with relative ease, and they become lowlands among heights of harder rock. It probably happened that originally the rivers of the area had other courses indifferently across the dolomite, schist, and gneiss, but such is the manner of growth of streams and valleys that, though they were once so situated, the larger ones must have become rearranged in precise adjustment to the lines of weak rock. Bronx River affords examples both of the adjustment and of a departure from it, and may serve to illustrate also the process by which adjustment is brought about. The Bronx flows for many miles on a belt of dolomite from above Scarsdale, but near Bedford Park it enters the area of Hudson schist, in spite of the fact that the weaker dolomite extends continuously to Harlem River. The valley above Bedford Park is adjusted to the arrangement of rocks; below Bedford Park, across the Hudson schist, it is not, but it might become so by a diversion which would turn the river into a channel along the dolomite belt and make it tributary to Harlem River. This diversion might come about naturally were the land raised relatively somewhat higher above sea level, so that the Harlem should become an active stream, cutting a canyon. Branches would then grow from it, as gullies grow in a steep bank, and they would grow fastest along the weak dolomite. Thus, between Harlem River and Bedford Park a brook would develop which would cut a ravine at a rate determined by its volume, its fall, and the nature of the rock it abraded. Bronx River would be engaged in a similar task, deepening its channel from the Sound upstream, and as compared with the branch of the Harlem would have the advantage of greater volume, but the disadvantage of working on harder rock. If the disadvantage counterbalanced the advantage, the lower channel of the Bronx would not be cut back to near Bedford Park as soon as would be that of the brook running to the Harlem, and the latter would divert the Bronx and complete its adjustment to the belt of dolomite.

Adjustment of valleys to belts of easily eroded rocks is a condition which is reached only through prolonged competition among growing river systems, and when it is so perfectly accomplished as it is east of the Hudson it indicates that the streams have been long at work carving this intricate mosaic of rock masses. But though the rivers are old, the channels may be in part newly cut, and this fact is illustrated in the ravine of the Bronx in Bronx Park, by the steep banks and cascades, which are transient features of the early life history of a valley. Above the ravine are potholes worn by waters which flowed at a higher level before the deeper cut was made. The youthful aspect of this channel contrasts peculiarly with the matured character of the system of which it is part, and shows that the Bronx adopted its lower course across the area of Hudson schist only at a recent date, and as a result of conditions that forced it out of an older valley. Those conditions are found in the effects of the ice which covered the area during the last glacial occupation, and they have been discussed by Professor Kemp in an article on the Glacial or Post-glacial Diversion of the Bronx River, published in the Transactions of the New York Academy of Sciences, Vol. XVI, 1898. The older valley is the depression which follows the belt of dolomite from Bedford Park to the Harlem, and thus it appears that, were the adjustment of the Bronx to that course to occur, it would constitute a reversion to an arrangement that formerly existed.

Beyond the limits of these maps, but still in the area of metamorphic crystalline rocks, valley adjustment may be traced in remarkably perfect development in Sawmill River above Yonkers, and in other streams, including part of the Hudson gorge in the Highlands between West Point and Fort Montgomery. The latter is described by Dr. Merrill in the Bulletin of the Geological Society of America, Vol. X, 1898; and he also, in referring to cases where streams cross belts of hard rocks, finds evidence showing that the transverse channels are developed along zones of weakness due to folding or shearing. In so far as this is true it is evidence of the perfection of adjustment, but there are other cases, like that of the Bronx, in which newly established channels exist in consequence of obstructions by which the streams were turned aside during the Glacial epoch.

In the area west of the Hudson, where the shales, sandstones, and traps of the Newark group offer unequal resistances to cutting by streams and to erosion in general, valleys are widely developed on softer rocks. The streams, however, can not avoid crossing the belts of hard trap, and at such places they form falls, two of which are illustrated in figs. 19, 20, and 21 (on Illustration sheet 2). Both of these falls are on Passaic River, the largest stream of the region, which above Little Falls is formed by the confluence of its northern (Pompton River) and southern branches. It has been shown by Professor Davis that the southern branch has greatly extended its headwaters at the expense of other less vigorous streams, such as the Rahway, which once had sources in the Highlands but now rise among the Watchung Mountains. The Passaic's southern fork, being aided by the large volume of the northern one, deepened a water gap across the Watchung barriers to a level below that to which the Rahway could cut in the same time, and, growing at its outer extremity as a branch grows on a tree, it reached and diverted the upper portion of the Rahway, as well as similar parts of other streams. These examples of capture and diversion of streams are discussed in detail in the article on Rivers of New Jersey, already referred to.

Water gaps and wind gaps.—A water gap being defined as a notch in a ridge through which a stream flows, a wind gap may be similarly defined as one through which only the wind draws. The former is a cut to the base of the ridge on the upstream side, the latter a depression in the crest. The water gap is produced chiefly by the stream that flows through it, and commonly shows that the course was determined on a surface even with or above the present summit; the wind gap may be due to local weakness, in consequence of which the rock of the crest weathers away more rapidly at one point than it does in general; but wind gaps are frequently abandoned water gaps, and in this relation they are significant of changes in the adjustment of streams.

First Watchung Mountain affords good examples of water and wind gaps at Paterson and in the Great Notch near by. The water gap of the Passaic at Paterson is the depression made by the river in cutting down the ridge from the level of the Schooley plain, on which its general course was established, and the process of cutting is well illustrated at the falls and in the widening gorge below them. The Great Notch is a wind gap of such width and form that it clearly was the work of a large stream, which can not be represented by the little brook that now runs through the lower part of the gap. It was produced by a river which flowed from the direction of Little Falls, but which has been diverted to the course of the Passaic at Paterson.

Relations of heights.—In the description of the early Cretaceous conditions on the Atlantic slope the fact was brought out that a vast low plain then characterized the region. There were no mountains at that time, but that plain is recognized as now extending high above the valleys over the hills east of the Hudson, from the Palisade ridge to the Watchung ridges, from them to the Highlands, and widely over the mountain summits. It has been raised by a process of mountain growth, which has amounted to 2000 feet or more in the Highlands, but which along Long Island and the south shore of Staten Island has been inappreciable, and its present form, if it were completely restored by filling the valleys, would be that of a very broad, low dome. The seaward margin of this plain, the Schooley peneplain, was buried under later Cretaceous sediments before it was elevated, and may now be observed beneath them near sea level. From this position along the present shores it rises northwestward over hilltops and ridges, as described. At once the oldest and in general the uppermost of the physiographic features of the province, it is identified in any view by its elevated position, which should correspond with the profiles of the highest ridges, approximately but not closely, since they on the one hand may represent low hills which were slightly higher than the surface of the peneplain, and on the other may have suffered more or less erosion and have thus been reduced to a level below that which it would occupy.

Below the highest ridges that in any view of eastern New Jersey represent the Schooley plain, one may observe others, which also have even crests and hills approaching the same lower uniform altitude. Intermediate in position between the greater heights and the valleys, they are intermediate in age as well, and are remnants of surfaces which were planed at some stage in the progress of mountain growth. Through the study of processes of erosion they are recognized as having been leveled nearly to sea level, as the floors of valleys which were greatly widened during a pause in the upward movement of the land mass and which have been more deeply sculptured in consequence of further uplift. The most conspicuous of these old valley plains has been described as the Somerville peneplain, and it may be seen by placing oneself at the level of the hilltops formed by the sandstone of the Newark group, particularly near Somerville, and looking across them.

In general the height of any point above the sea is a result of the total effects of uplift of the land in broad masses, less the amount taken away by erosion, through weathering, washing, and glaciation. Particular cases in which there may be other conditions that influence altitude are those in which there has been a local movement up or down along a narrow belt. Such instances involve the development of a bend or break in the rocks, technically known respectively as a monocline or a fault, and though they have not been definitely recognized as affecting surface features in the vicinity of New York, they should not be excluded from consideration. In his account of the Newark group Mr. Darton describes the normal faults which divide the beds into long blocks, of which in each case the eastern one of two has sunk down with reference to the one west of it. The date at which these breaks first occurred is thought to have been soon after the close of the Newark epoch, and any unevenness of the surface resulting from them was in that case smoothed away in the development of the Schooley plain, but displacements of this character are in many instances repeated after long intervals along the same breaks, and the rocks themselves may afford no evidence of distinct movements unless intermediate sediments extend across the line of dislocation. In the vicinity of New York an important means of recognizing the occurrence of monoclines or faults of this nature is through the relations of plains of erosion. For example, on the south side of Staten Island the Schooley plain lies beneath the Raritan clays, below sea level, and it also must pass over the island at or near the summit of the hills of serpentine and other hard rocks beneath the moraine, at an elevation of about 300 feet, northwest of Garretsons. The slope between these altitudes contains a marked bench, bearing two terraces, one slightly above the other, between 180 and 220 feet above sea, and appearing from the gravel and residual loam upon it to be an old surface of erosion. The rise from the Schooley plain below tide to this bench is much steeper than any general deformation of that surface, and represents a local bending or faulting of the rocks since the time the bench was developed at a low level. An earlier movement of the same nature may be indicated in the rise of 80 feet from the bench to the top of the serpentine hills. The commanding height of Staten Island seems thus to be due to unequal or unlike movements by which its mass has been raised relatively above the area of its southern plain, while the latter possibly was depressed. The lowlands of the Hackensack Meadows, the Palisade ridge, the Hudson channel, and possibly other features, may in part owe their respective altitudes to local uplifts or depressions, as well as to the more certain and obvious effects of general elevation and erosion.

Relations of physiography to culture.—Mention has been made of some of the more important ways in which the arrangement of drainage and relief about New York has influenced the cultural conditions, especially as seen in the distribution of agriculture and manufacturing, the crowding of cities about commercial centers, and the positions of suburban towns. There are also many details of local relations that illustrate the dependence of life on surface features.

The uplands of the area have remained unoccupied, except by isolated individuals, until crowding in the lowlands has pressed people to make use of the higher ground, as in the Borough of Manhattan, where Morningside Heights and Washington Heights are just beginning to be occupied, especially by charitable and educational institutions. The earlier lines of transportation avoided these heights, as is shown by the course of Broadway, as well as by the more recently established route of the elevated railroad, which follows the lowland close to the eastern edge of the heights. The hills of Central Park and of the eastern portion of the moraine in Brooklyn have been occupied as parks, because they are ill adapted to division into city lots, and the variety of relief within a small area gives a favorable setting to landscape gardening. The same use of rough land for park purposes is seen in the more recently established Botanical Garden and Zoological Park along the Bronx.

The arrangement of avenues in the Borough of Manhattan is parallel to the trend of depressions following the strike of weak zones in the rocks and the shore of the Hudson. With the exception of Broadway, they run N. 30° E., and not north and south, as is so commonly supposed. The streets, naturally arranged at right angles with the avenues, cross the lines of relief, and deep rock cuts are occasioned on many of the streets of upper Manhattan.

The barrier beaches that have already been described are recreation grounds for the city residents, as are all similar beaches within easy reach of large cities; and the elevated regions within sight of the water, as on Staten Island, are occupied as residential sites.

The Narrows of New York Harbor are bordered by elevated moraine tracts, and thus furnish excellent sites for harbor defense, like Fort Hamilton and Fort Tompkins; and the shallow waters of the Upper Bay form an excellent anchoring ground for vessels awaiting loading and unloading.

Many more instances of the detailed relations between surface features and culture might be given, but those chosen illustrate the more important ways in which such influence may be seen.

WATER SUPPLY OF NEW YORK CITY.

By Henry A. Pressey.

There is, perhaps, no more important consideration in the founding and growth of a city than the municipal water supply. The city of New York, located on a rocky island, is not favorably situated for the collection and use of surface streams. From the time of the establishment of the first water-supply system to the present day a part of the water has been collected from underground sources; but these, while important in the early history of the city, now furnish a comparatively small percentage of the total consumption of water. The first municipal supply in New York was provided in 1799, when the city, having a population of 60,000, purchased 2000 shares of the stock of the Manhattan Company, and this company constructed a well 25 feet in diameter and 30 feet deep in Center street and pumped the water to a tank on Chambers street, from which it was distributed through pipes of bored logs. The population and the demand for water increased rapidly, so that greater supply was required, and in 1830 the city constructed a well at Thirteenth street near Broadway, 60 feet in diameter and 112 feet deep, 97 feet being through rock; at 100 feet below the surface two lateral galleries were tunneled out from the main well, each 75 feet long. The water from this well, amounting to somewhat over 10,000 gallons a day, was very hard, and was conveyed in cast-iron pipes over a portion of the city. The Manhattan Company also sank a well at Broadway and Bleecker streets, 442 feet deep, through rock, which yielded 44,000 gallons a day. Four years later the city drilled 100 feet in the Thirteenth street well, increasing the supply to 21,000 gallons a day; and at about the same time a well was dug at Jefferson Market, 30 feet deep, from which some water was derived.

The supply of water from these various sources was so limited that 1600 hogsheads of water were brought in daily from wells in the country and sold; and 1415 hogsheads of water were daily imported from wells in Brooklyn to supply shipping. The shortage of water from these various sources led the common council to have examination made for the introduction of other supplies, and a plan for procuring water from the Croton River was adopted by the common council in 1835 and ratified by popular vote. Construction was begun at once, and water was introduced into the city through the Croton Aqueduct in 1842. This aqueduct is still available for use.

About thirty years later it was seen that an increased supply would soon be required, and studies were immediately begun. In 1883 the legislature created an independent aqueduct commission to construct a new aqueduct and additional storage reservoirs. In 1884 construction of the new aqueduct was begun under this commission. It has a capacity of 290,000,000 gallons a day, and began the delivery of water in 1890. In 1891 the aqueduct commission was reorganized, and is now engaged in the construction of a storage reservoir, which would probably have been completed in 1903 had not recent changes in design delayed its completion about two years. When this reservoir is put in service, probably in 1905, it is thought that the entire practicable yield of the Croton watershed will be available for the use of New York City.

At the present time there are seven reservoirs in the Croton watershed (including the Cornell, now constructing), which, with certain natural lakes that have been made tributary to the Croton supply, have an aggregate watershed of 360 square miles and a total storage capacity of 73,736 million gallons. In addition to this, a supply has been introduced from the Bronx and Byram rivers, yielding about 17,000,000 gallons a day. Originally this was used by Bronx, the surplus being delivered to New York, but at the present time the demand by the Borough of Bronx is greater than can be collected from these two small basins, so that about 10 or 12 million gallons a day are supplied to the Borough of Bronx.

Brooklyn had no public water supply until after its population reached 200,000. In 1859 a public system was completed by the city, the supply being taken from the ponds and streams on the south side of Long Island, east of the city. Since that time the yield of surface water has been supplemented by pumping ground water from driven wells along the line of the conduit which conveys the water from the ponds; and a further supply is furnished by water obtained from wells at two pumping stations in the southern part of the city. Three private corporations furnish water, drawn from wells, for portions of Brooklyn. The entire supply of the borough is pumped either into reservoirs or directly into the mains.

The Borough of Queens has only a small supply obtained from wells and pumped directly into the mains, the works being owned partly by the city and partly by private corporations.

The Borough of Richmond has a small supply derived from wells.

About 5.89 per cent of the total water supply of Greater New York is furnished by private companies, these companies depending solely upon ground-water sources.

Summarizing the preceding, we may say that the present supply of New York is obtained from four general sources: first, the watershed of the Croton River; second, the watersheds of the Bronx and Byram rivers; third, the watersheds of a series of small streams upon the southern shore of Long Island; fourth, the ground water which is found underlying a stratum of clay on Long Island and on Staten Island.

This brief history of the water supply of Greater New York has been given as an introduction to a short statement of the possible sources of a future supply of water for the city. The present demand is dangerously close to the capacity of the sources now available, and within the next few years must be met by a material increase.

New York City.

Temporary expedients have been adopted in Brooklyn whereby the supply has been increased sufficiently for present purposes, and it is possible that in portions of Brooklyn, of Queens, and of Richmond for a few years a sufficient supply can be procured from uncontaminated ground water, but this can be considered only a temporary source of water for these boroughs, so long as the present methods of collection are followed, and it would seem that it is only a question of a few years before the surface waters must be collected from some of the streams on the mainland and conducted to the island boroughs. There are several considerations which may be urged against the extension of the present ground-water supply on Long Island: the legal difficulties which may arise, and which have been forshadowed by several suits for injunction within the last few years; the danger of pollution of the water when the territory becomes more densely populated, and the fact that the cost of such a system would probably not be less than the development of a surface supply. The same arguments might also be used against a ground-water supply on Staten Island. In fact, there seem to be many reasons why a mainland surface supply for all the boroughs of New York would be advisable, though, as suggested by John R. Freeman, a large supply of water for Brooklyn, of good quality, could probably be economically obtained from the gravels on Long Island lying within 70 or 100 feet of the surface and above the layers of impervious clay. This source of supply at least warrants further investigation. The present ground supply will tide over the few years necessary for the completion of the storage reservoirs and long conduits, or a new ground-water supply.

In considering the future demands of the city, several additional sources have been suggested, some of which will be briefly considered here, viz: Housatonic River, Tenmile River, Wallkill River, Rondout Creek, Esopus Creek and Catskill Creek, the Hudson River or some of its upper tributaries, Lake George, Lake Champlain, and the Great Lakes. The three last-named sources have been discussed in print at some length[1]. It has been shown that the supply from Lake George would not be adequate; that Lake Champlain is at too low an elevation for economical use, and that the supply from the Great Lakes would entail great and unnecessary expense. The water from the Hudson might be taken near its headwaters and conducted to New York City by a long aqueduct, or the intake might be located just above Poughkeepsie, in which case the water would have to be pumped from the river and filtered before delivery to the city. In either case it is important to know the discharge of the river at various seasons of the year, in order to determine the quantity available, and also the effect of the diversion of water upon the regimen of the river.

The United States Geological Survey has for several years been measuring the daily flow of streams throughout the United States. The results of these measurements are used for different purposes, including irrigation, water power, and sanitation. Measurements of flow of the Schroon River at Warrensburg and of the Hudson at Fort Edward and Mechanicville have been made, also of the Mohawk and its chief tributaries at various points, and the results of these have been published in the Annual Reports of the Survey.

[1] The sources for additional water supply for New York City have been discussed in the report upon New York's water supply made to Bird S. Coler, comptroller, by John R. Freeman, M. Am. Soc. C. E., March, 1890, and in a report on the water supply of the City of New York by the Merchants' Association of New York.

At the request of officials of New York City, gaging stations were established on the streams mentioned, lying north of New York City, and at a distance which does not preclude their use as sources of supply.

Gaging stations and catchment areas on streams near New York City.

Stream.	Location of gaging station.	Catchment area, in square miles.		
		Above proposed reservoir.	Above gaging station.	Above mouth of stream.
Tenmile River	Dover Plains, N. Y.	200	195	195
Housatonic River	Gaylordsville, Conn.	1,020	1,020	1,580
Catskill Creek	South Cairo, N. Y.	140	260	394
Esopus Creek	Kingston, N. Y.	242	312	417
Wallkill River	New Paltz, N. Y.	464	735	779
Rondout Creek	Rosendale, N. Y.	184	365	a369
Fishkill Creek	Glenham, N. Y.	158	198	204

a Above junction with Wallkill River.

The Housatonic, Tenmile, and Wallkill rivers are interstate streams. The first receives tributary drainage from New York, but does not itself flow through New York State. The Tenmile River lies mostly in New York, though the lower few miles of its course and its mouth are in Connecticut. The Wallkill River has its headwaters in New Jersey, but the most of its channel and watershed and its outlet are in New York.

Reconnaissance of each of these streams was made in June, 1901, and stations were selected at points where measurements could be most accurately made, and as far as practicable at points where it was thought knowledge of the flow would be most desired in the future study of these watersheds as sources of increased supply for New York. The results of the observations at these stations have been published in the Water-Supply Papers of the Survey. The height of the water at each station has been noted twice each day by a local observer, and current-meter measurements made at frequent intervals by a resident hydrographer. From these meter measurements a station rating curve has been drawn, which shows the relation between the height of the water in the river and the discharge. From this curve and the daily mean gage height the flow of the river for each day of the year since the establishment of the station can be determined. These data will be of the greatest importance to the engineers selecting the supply, as they furnish the first continuous record of the flow of these streams, and give a basis upon which can be computed the available supply from each stream. This, with the topographic maps of the Survey and the detailed surveys of the reservoir sites, will give complete data for the estimate of the quantity of water that can be supplied by each of these drainage basins and of the relative cost per million gallons of the supply from each.

In addition to the measurement of discharge, there have been made determinations of the turbidity, color, alkalinity, and hardness of the water of each of these streams. These investigations are being continued, and it is thought that the data will prove valuable in the final selection of the new supply. Laboratory analyses have been made with the cooperation of George C. Whipple. The results are given in the Water-Supply Papers of the Survey.

The Passaic, the chief river of northern New Jersey, meanders through a flat, somewhat marshy country of Triassic red sandstone, while the Pompton, its chief tributary, is a rapid stream with clear waters, flowing from the Highlands, with forested watershed, and bed largely of crystalline rocks. A gaging station was established by the Survey at Two Bridges, at the junction of these two streams, in 1901, and records of flow have been kept since that time[1].

The Passaic River furnishes the water supply for several of the cities and towns in northern New Jersey, and has also several large waterfalls which furnish power for manufacturing purposes. Paterson and Passaic receive their domestic supply from the Passaic River above Little Falls, and Jersey City gets its supply from the same place at present, as do also Bayonne and the settlements in the western portion of Kearney Township. Jersey City will in about two years be supplied from its own works which are now building on the Rockaway River at Boonton. Newark and several adjoining villages receive a supply from the Pequannock River and its branches in the Highlands of New Jersey. The supply for Hoboken is obtained from the Hackensack River at New Milford, by an aqueduct supplying also West Hoboken, Union, Guttenberg, Weehawken, North Bergen, Hackensack, Englewood, Rutherford, East Rutherford, Carlstadt, Hasbrouck Heights, Little Ferry, Bergen Township in part, Lodi Township, Maywood, Riverside, Delford, Schraalenburg, Bergen Fields, Tenafly, Englewood Cliffs, Leonia, Ridgefield Park, Ridgefield, Fairview, and Cliffside. Orange is supplied from the west branch of the Rahway River; Montclair obtains water from a branch conduit from the Newark Aqueduct. Elizabeth now obtains its principal supplies from a number of wells, 46 to 480 feet deep.

Northeastern New Jersey is covered by a heavy mantle of glacial drift, the gravels and sands of which usually contain water supply for local use. The rocks of the Newark group contain water mainly in the porous sandstone beds. Some wells obtain large volumes of water from the same. In Paterson a well 2400 feet deep was driven, but the only available supply was found at 900 feet. Saline water was found at 2050 feet.

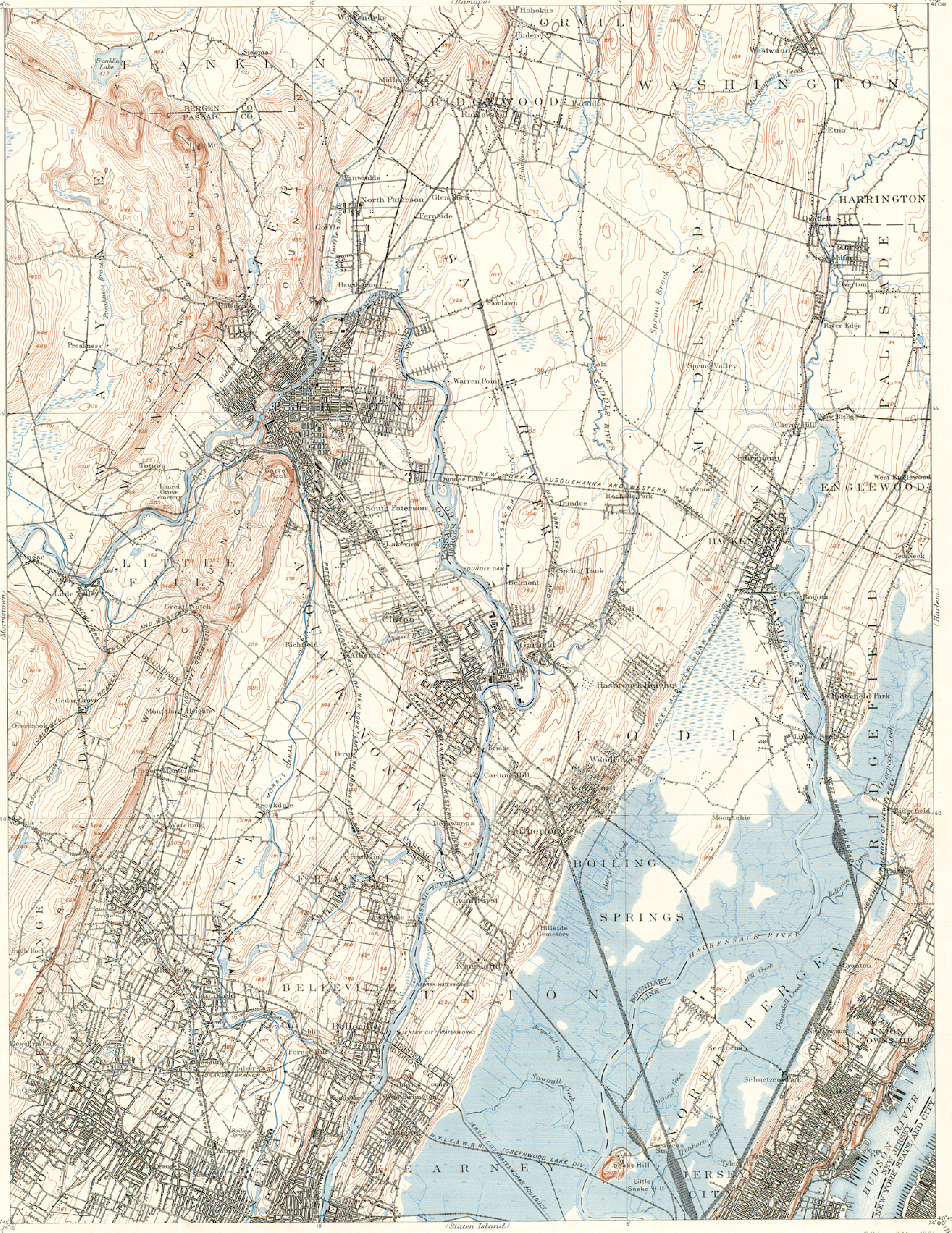
August, 1902.

[1] Earlier records on these streams were published in a report of the Geological Survey of New Jersey, Vol. III, 1894.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

TOPOGRAPHIC SHEET

NEW JERSEY - NEW YORK
PATERSON QUADRANGLE



H. M. Wilson Geographer in charge.
Triangulation by the U.S.C.&G.S.
Topography by Geol. Survey of New Jersey,
and by Frank Sutton, W. E. Horton, R. D. Cummin, and E. B. Clark.
Surveyed in 1887, 1889, and 1897.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of May 1901.

LEGEND

RELIEF
(printed in brown)

673
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

Lakes and reservoirs

Aqueducts

Springs

Salt marshes

Fresh marshes

CULTURE
(printed in black)

Roads and buildings

Private and secondary roads

Railroads

Street railroads

Bridges

Ferries

Dams

State lines

County lines

Township lines

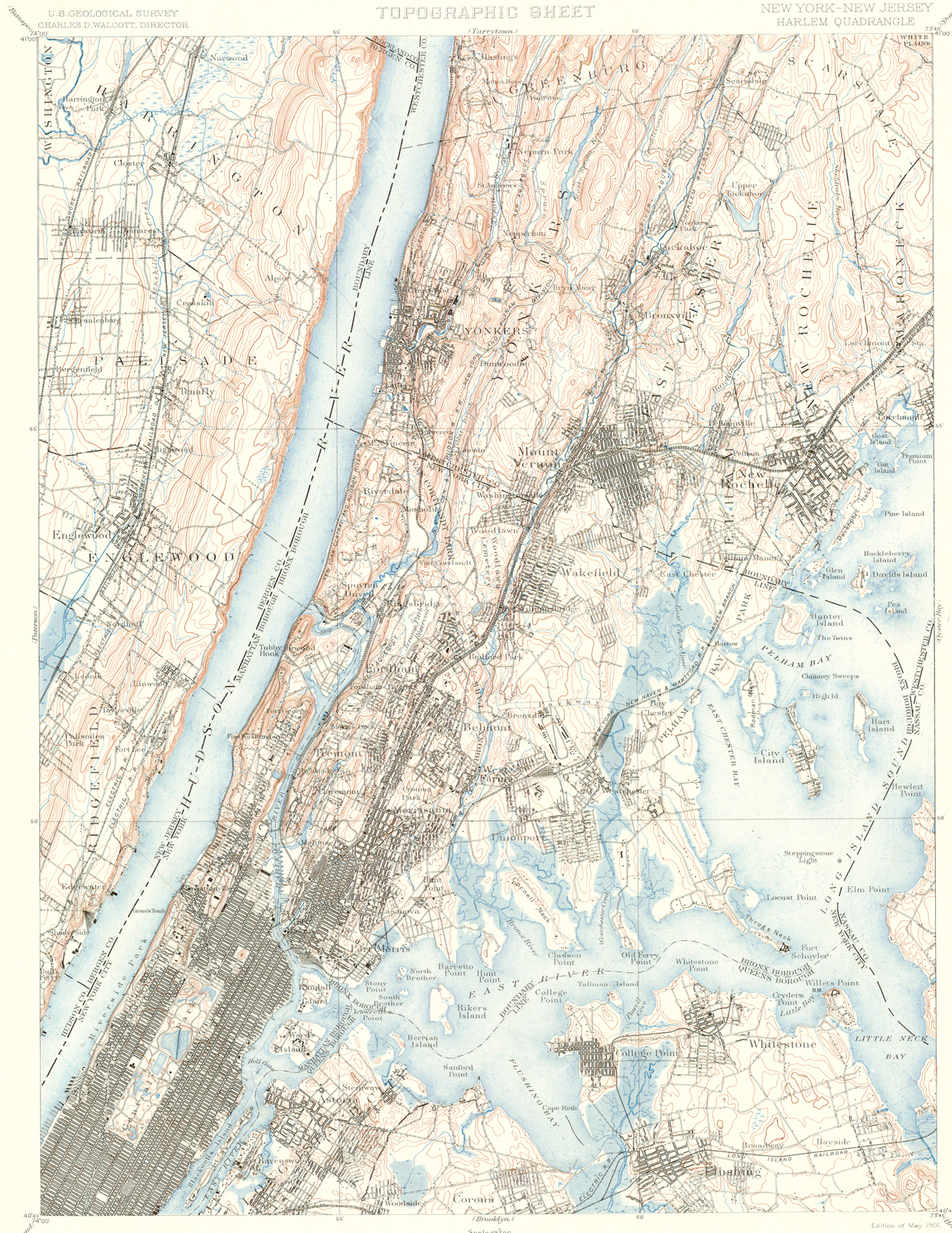
Park and cemetery lines

Triangulation stations

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

TOPOGRAPHIC SHEET

NEW YORK-NEW JERSEY
HARLEM QUADRANGLE



LEGEND

RELIEF
(printed in brown)

Figures
(showing heights above mean sea level instrumentally determined)

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

Cliffs

DRAINAGE
(printed in blue)

Streams

Canals

Aqueducts

Lakes and reservoirs

Springs

Salt marshes

Fresh marshes

CULTURE
(printed in black)

Roads and buildings

Private and secondary roads

Railroads

Street railroads

Tunnels

Bridges

Ferries

Dams

State lines

County lines

Township lines

Borough lines

Park and cemetery lines

Bench marks

Lighthouses

H. M. Wilson, Geographer in charge.
Triangulation by the U. S. Coast and Geodetic Survey.
Topography by the U. S. Coast and Geodetic Survey, N. Y. City Government, S. H. Bodfish, Frank Sutton, R. D. Cummin, E. B. Clark, and J. W. Thom.
Surveyed in 1888-89 and 1897 in cooperation with the State of New York;
Campbell W. Adams, State Engineer and Surveyor.

Scale $\frac{1}{62500}$

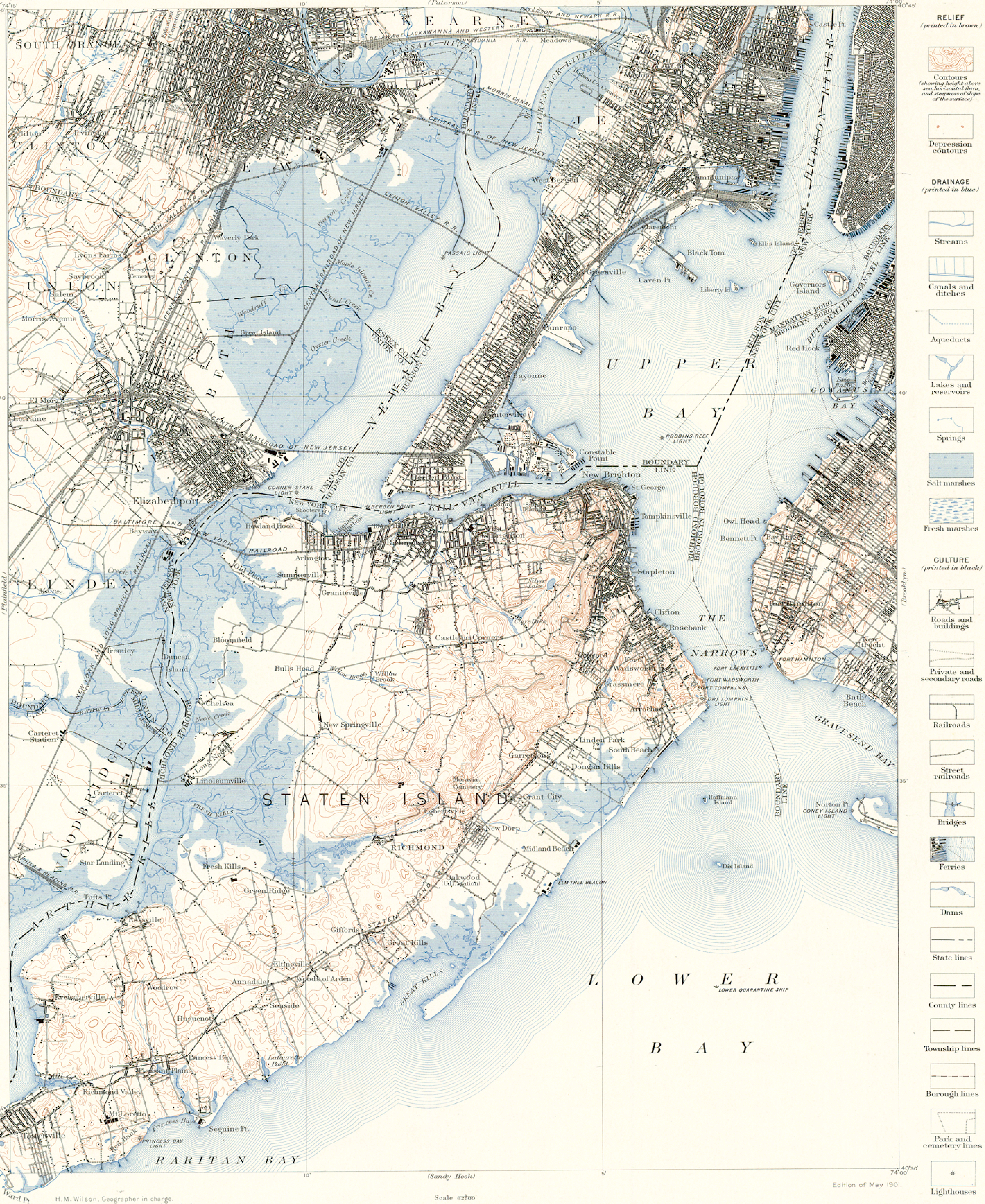
Contour interval 20 feet.
Datum is mean sea level.

Edition of May 1901.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

TOPOGRAPHIC SHEET

NEW JERSEY - NEW YORK
STATEN ISLAND QUADRANGLE



H. M. Wilson, Geographer in charge.
Triangulation by U. S. Coast and Geodetic Survey.
Topography by U. S. Coast and Geodetic Survey,
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U.S. GEOLOGICAL SURVEY
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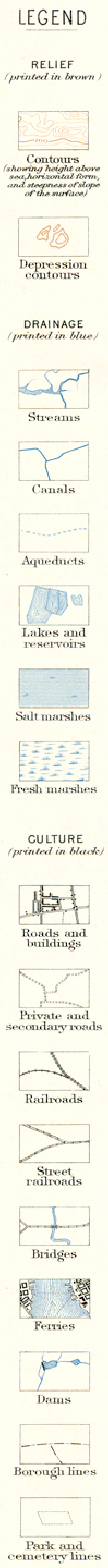
TOPOGRAPHIC SHEET

NEW YORK
BROOKLYN QUADRANGLE



H. M. Wilson, Geographer in charge.
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Edition of May 1901

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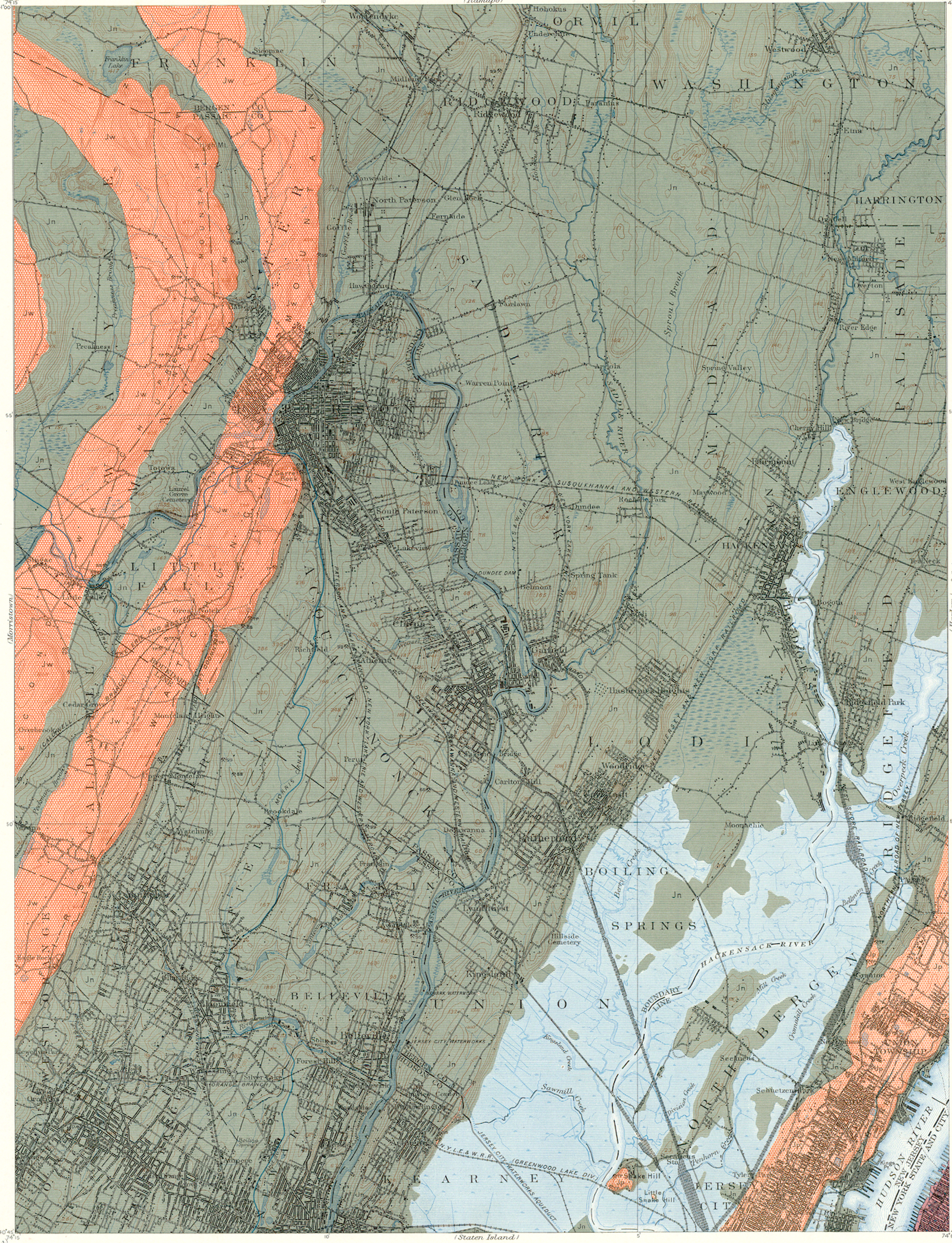
HISTORICAL GEOLOGY SHEET

NEW JERSEY - NEW YORK
PATERSON QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines. Metamorphism is indicated by short dashes combined with the parallel lines)

Jn Newark formation (red sandstone and shales) — JURATRIAS

Sh Hudson schist (mica-schist, consisting of biotite and quartz, with garnet, staurolite, fibrolite, and cyanite) — SILURIAN ?

IGNEOUS ROCKS

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

Jp Palisade diabase (intrusive sheet, forming the Palisades, and small dikes) — JURATRIAS

Jw Watchung basalt (three successive lava flows interbedded in the Newark formation) — JURATRIAS

Faults

Hypothetical boundaries (beneath deep drift)

⚒ Quarries, and clay pits,
TP Trap rock (diabase and basalt) used for roads
SS Sandstone for building stone
CL Cretaceous clay used for firebrick and stoneware

H. M. Wilson Geographer in charge.
Triangulation by the U.S.C. & G.S.
Topography by Geol. Survey of New Jersey
and by Frank Sutton, W. E. Horton, R. D. Cummin, and E. B. Clark.
Surveyed in 1887, 1889, and 1897.

Scale $\frac{1}{62500}$

Miles

Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Dec. 1901.

Darton

Geology by N. H. Darton and Frederick J. H. Merrill.
Surveyed 1885-1898.

U.S.GEOLOGICAL SURVEY
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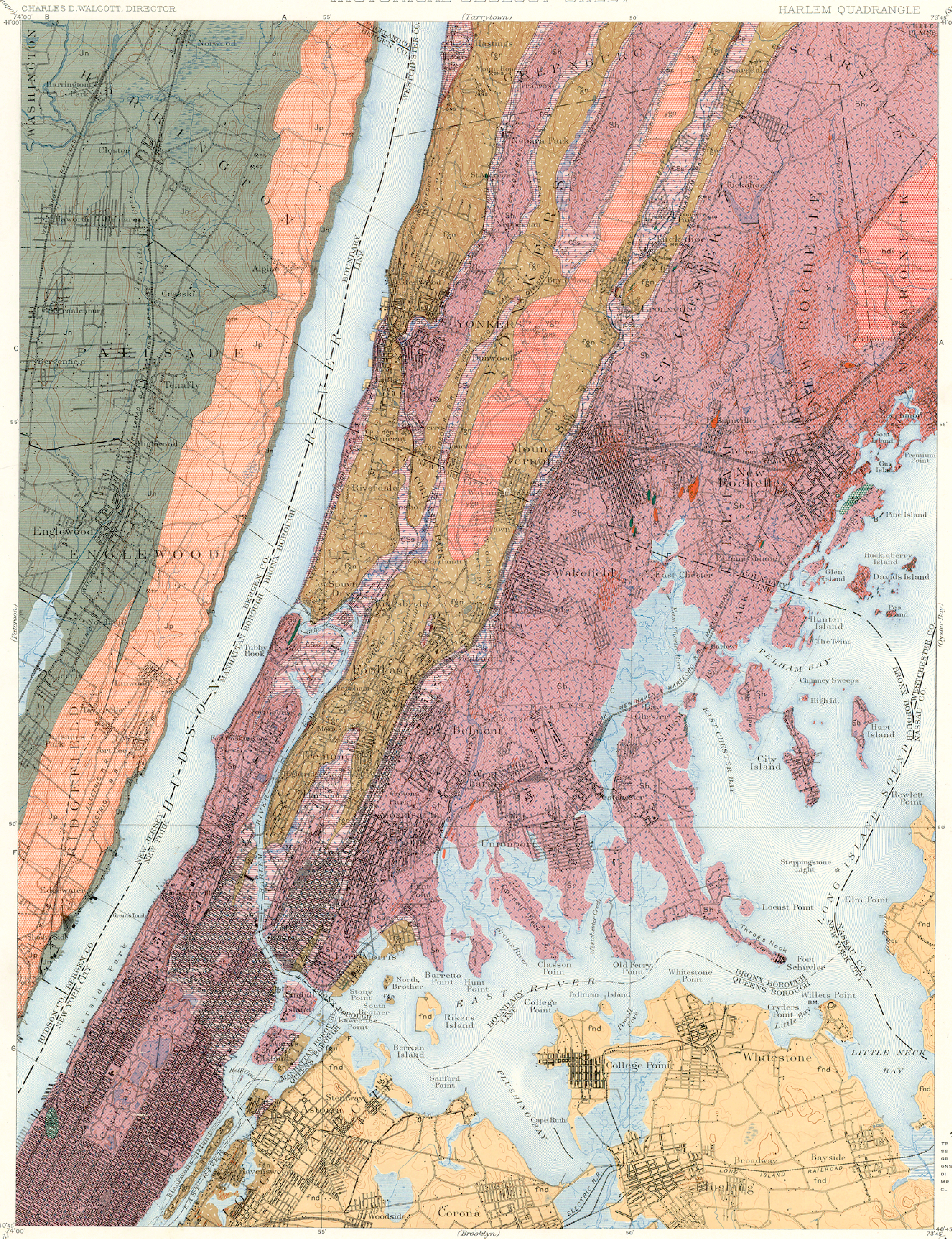
HISTORICAL GEOLOGY SHEET

NEW YORK-NEW JERSEY
HARLEM QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines. Metamorphism is indicated by short dashes combined with the parallel lines.)

CRETACEOUS ?

rt — *(variegated clay, probably Raritan formation)*

JURATRIAS

Jn — Newark formation *(red sandstone and shales)*

SILURIAN

Sh — Hudson schist *(mica-schist, consisting of biotite and quartz, with garnet, staurolite, fibrolite, and cyanite)*

CSs — Stockbridge dolomite *(coarsely crystalline dolomite, often containing diopside and tremolite)*

CAMBRIAN

Cp — Poughquag quartzite *(thin-bedded white to brownish quartzite)*

IGNEOUS ROCKS

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

JURATRIAS

Jp — Palisade diabase *(intrusive sheet, forming the Palisades, and small dikes)*

SILURIAN OR LATER

sp — Serpentine *(resulting from local alteration of hornblende, bronzite, and allied minerals in basic dikes and masses)*

b — Basic dikes *(hornblendic and augitic dikes, usually strongly foliated)*

gr — Granite dikes and bosses *(white to reddish granite and pegmatite)*

Close parallel granitic injections in Hudson schist

ygn — Yonkers gneiss *(banded gneiss of quartz, microcline, and orthoclase, with biotite and hornblende in small quantities)*

hdi — Harrison diorite *(coarse-grained granite-diorite, often much foliated)*

ANCIENT CRYSTALLINE ROCKS

(Areas of ancient crystalline rocks of unknown origin are shown by patterns of short dashes.)

PRE-CAMBRIAN

fgn — Fordham gneiss *(gray banded gneiss of orthoclase, quartz, and biotite)*

fnd — Formation not determined *(areas deeply covered by drift, and artificially made land)*

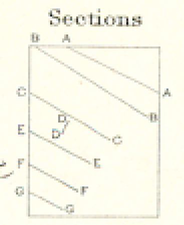
Faults

Hypothetical boundaries *(beneath water-ways)*

⚒ Quarries and clay pits

TP	*Trap rock (diabase and basalt) used for roads*
SS	*Sandstone for building stone*
GR	*Granite for building stone and road material*
GNS	*Gneissoid granite for building stone*
DI	*Diorite for building stone*
MR	*Marble for building stone*
CL	*Cretaceous clay used for firebrick and stoneware*

Sections



H.M.Wilson, Geographer in charge.
Triangulation by the U.S.Coast and Geodetic Survey.
Topography by the U.S.Coast and Geodetic Survey, N.Y.City Government, S.H.Bodfish, Frank Sutton, R.D.Cummin, E.B.Clark, and J.W.Thom.
Surveyed in 1888-89 and 1897 in cooperation with the State of New York; Campbell W.Adams, State Engineer and Surveyor.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Feb. 1902.

Darton
Merrill

Geology of New York by Frederick J.H.Merrill.
Assisted by E.M.Blake, H.Ries, and E.C.Eckel.
Surveyed 1883-1900.

Geology of New Jersey by N.H.Darton.
Surveyed 1885-1899.

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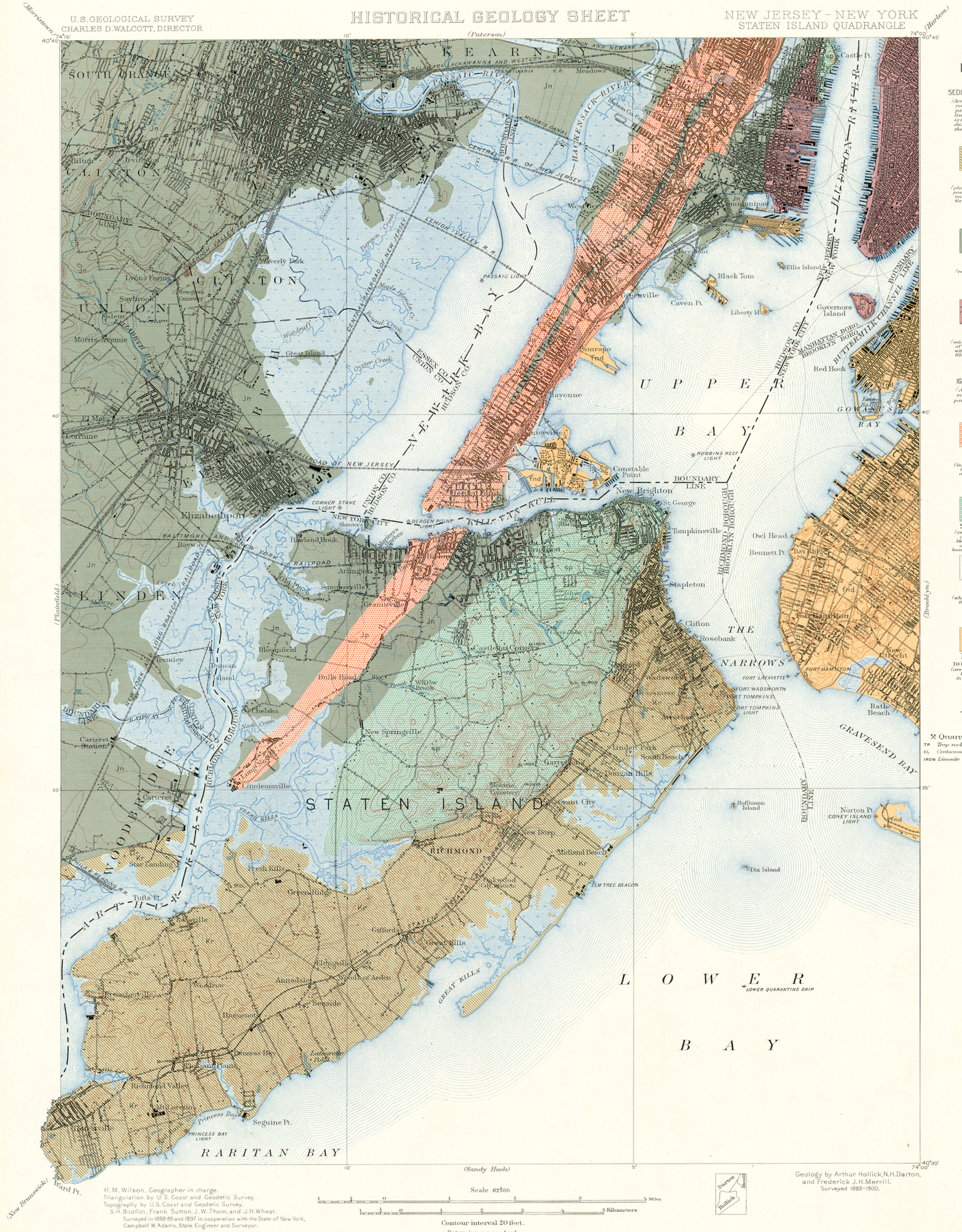
HISTORICAL GEOLOGY SHEET

NEW JERSEY - NEW YORK
STATEN ISLAND QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines. Metamorphism is indicated by short dashes combined with the parallel lines.)

CRETACEOUS

Kr — Raritan formation *(plastic clay and gravel; possibly including clay marl of the Matawan formation in eastern portion)*

JURATRIAS

Jn — Newark formation *(red sandstone and shales)*

SILURIAN

Sh — Hudson schist *(mica-schist, consisting of biotite and quartz, with garnet, staurolite, fibrolite, and cyanite)*

IGNEOUS ROCKS

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

JURATRIAS

Jp — Palisade diabase *(intrusive sheet forming the Palisades and small dikes)*

SILURIAN OR LATER

sp — Serpentine *(resulting from local alteration of hornblende, bronzite, and allied minerals in basic dikes and masses)*

gr — Granite dike *(white to reddish granite and pegmatite)*

fnd — Formation not determined *(areas deeply covered by drift and artificially made land)*

Faults

⚒ Quarries, clay pits, and mines

TP *Trap rock (diabase and basalt) used for roads*
CL *Cretaceous clay used for firebrick and stoneware*
IRON *Limonite*

H. M. Wilson, Geographer in charge.
Triangulation by U. S. Coast and Geodetic Survey.
Topography by U. S. Coast and Geodetic Survey.
S. H. Bodfish, Frank Sutton, J. W. Thom, and J. H. Wheat.
Surveyed in 1888-89 and 1897 in cooperation with the State of New York,
Campbell W. Adams, State Engineer and Surveyor.

Scale $\frac{1}{62500}$

Miles: 1 ½ 0 1 2 3 4
Kilometers: 1 ½ 0 1 2 3 4 5

Contour interval 20 feet.
Datum is mean sea level.

Edition of Dec. 1901.

Darton Merrill Hollick

Geology by Arthur Hollick, N. H. Darton, and Frederick J. H. Merrill.
Surveyed 1883-1900.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

HISTORICAL GEOLOGY SHEET

NEW YORK
BROOKLYN QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines. Metamorphism is indicated by short dashes combined with the parallel lines.)

Sh — Hudson schist *(mica-schist, consisting of biotite and quartz, with garnet, staurolite, fibrolite, and cyanite)*

CSs — Stockbridge dolomite *(coarsely crystalline dolomite, often containing diopside and tremolite)*

SILURIAN

IGNEOUS ROCKS

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

gr — Granite dikes and bosses *(white to reddish granite and pegmatite)*

SILURIAN OR LATER

ANCIENT CRYSTALLINE ROCKS

(Areas of ancient crystalline rocks of unknown origin are shown by patterns of short dashes.)

fgn — Fordham gneiss *(gray banded gneiss of orthoclase, quartz, and biotite)*

PRE-CAMBRIAN

fnd — Formation not determined *(areas deeply covered by drift and artificially made land)*

Hypothetical boundaries *(beneath water ways)*

H. M. Wilson, Geographer in charge.
Triangulation by the U.S. Coast and Geodetic Survey.
Topography by the U.S. Coast and Geodetic Survey, N.Y. City Government, S. H. Bodfish, Frank Sutton, and J. W. Thom.
Surveyed in 1888-89 and 1897 in cooperation with the State of New York; Campbell W. Adams, State Engineer and Surveyor.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
Edition of Dec. 1901.

Geology by Frederick J. H. Merrill.
Surveyed 1883-1900.

U.S. GEOLOGICAL SURVEY
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SURFICIAL GEOLOGY SHEET

NEW JERSEY - NEW YORK
PATERSON QUADRANGLE

(Greenwood Lake) 74°15' 41°00'

(Ramapo)

(Tarrytown) 74°00' 41°00'

(Morristown)

(Harlem)

LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles)

PLEISTOCENE

Post-Glacial Epoch

Pml — Made land

Pal — Alluvium *(in stream bottoms)*

Ps — Swamp muck *(tidal flats not included)*

Pd — Dunes and dune sand

Epoch of Glacial Retreat

Plp — Shore deposits of Lake Passaic *(stratified sand and gravel)*

Shore line of Lake Passaic *(broken line indicates approximate location)*

Psd — Stratified drift *(locally very thin, with occasional rock exposures)*

Epoch of Late Glacial Occupation

Pdk — Stratified drift with kame-like habit

Pk — Kames *(irregular hills or mounds of stratified drift)*

Pe — Eskers *(ridges of stratified drift)*

Pdt — Stratified drift and till *(undifferentiated)*

Pdr — Drumlins and drumloids *(elongate elliptical hills of till)*

Ptt — Thin till *(with numerous rock exposures)*

Pt — Till *(with occasional small rock exposures)*

PRE-PLEISTOCENE

bd — Bed rock *(larger exposures of bed rock, in places covered by thin till or stratified drift)*

CLAY *Clay pits in surficial deposits*
S-G *Sand and gravel pits*

Letter symbols in parenthesis indicate the formations which underlie swamp muck and dune sand.

(Plainfield) 40°45' 74°15'

(Staten Island)

(Brooklyn) 40°45' 74°00'

H. M. Wilson, Geographer in charge.
Triangulation by the U.S.C.& G.S.
Topography by Geol. Survey of New Jersey
and by Frank Sutton, W. E. Horton, R. D. Cummin, and E. B. Clark.
Surveyed in 1887, 1889, and 1897.

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1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Oct. 1901.

Geology by Rollin D. Salisbury
and Charles E. Peet.
Surveyed in 1894.

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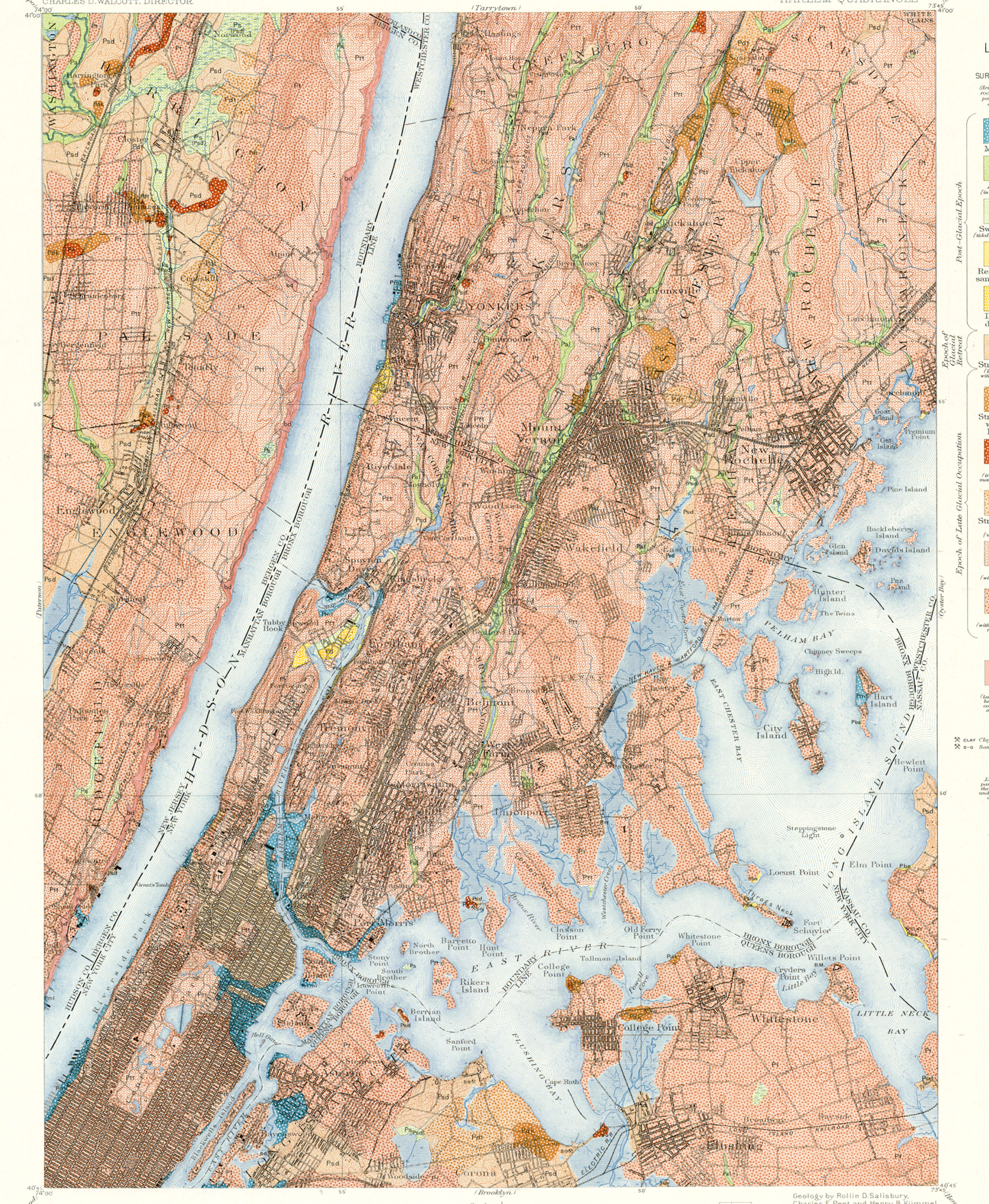
SURFICIAL GEOLOGY SHEET

NEW YORK-NEW JERSEY
HARLEM QUADRANGLE



LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles.)

PLEISTOCENE

Post-Glacial Epoch

- Pml — Made land
- Pal — Alluvium *(in stream bottoms)*
- Ps — Swamp muck *(tidal flats not included)*
- Pbs — Recent beach sand and gravel
- Pd — Dunes and dune sand

Epoch of Glacial Retreat

- Psd — Stratified drift *(locally very thin, with occasional rock exposures)*

Epoch of Late Glacial Occupation

- Pdk — Stratified drift with kame-like habit
- Pk — Kames *(irregular hills or mounds of stratified drift)*
- Pdt — Stratified drift and till *(undifferentiated)*
- Ptt — Thin till *(with numerous rock exposures)*
- Pt — Till *(with occasional small rock exposures)*

PRE-PLEISTOCENE

- bd — Bed rock *(larger exposures of bed rock; in places covered by thin till or stratified drift)*

⚒ CLAY *Clay pits in surficial deposits*
⚒ S-G *Sand and gravel pits*

Letter symbols in parenthesis indicate the formations which underlie swamp muck and dune sand.

H. M. Wilson, Geographer in charge.
Triangulation by the U.S. Coast and Geodetic Survey.
Topography by the U.S. Coast and Geodetic Survey, N.Y. City Government, S. H. Bodfish, Frank Sutton, R. D. Cummin, E. B. Clark, and J. W. Thom.
Surveyed in 1888-89 and 1897 in cooperation with the State of New York; Campbell W. Adams, State Engineer and Surveyor.

Scale $\frac{1}{62500}$

1 — 0 — 1 — 2 — 3 — 4 Miles

1 — 0 — 1 — 2 — 3 — 4 — 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Oct. 1901.

Kümmel
Peet

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

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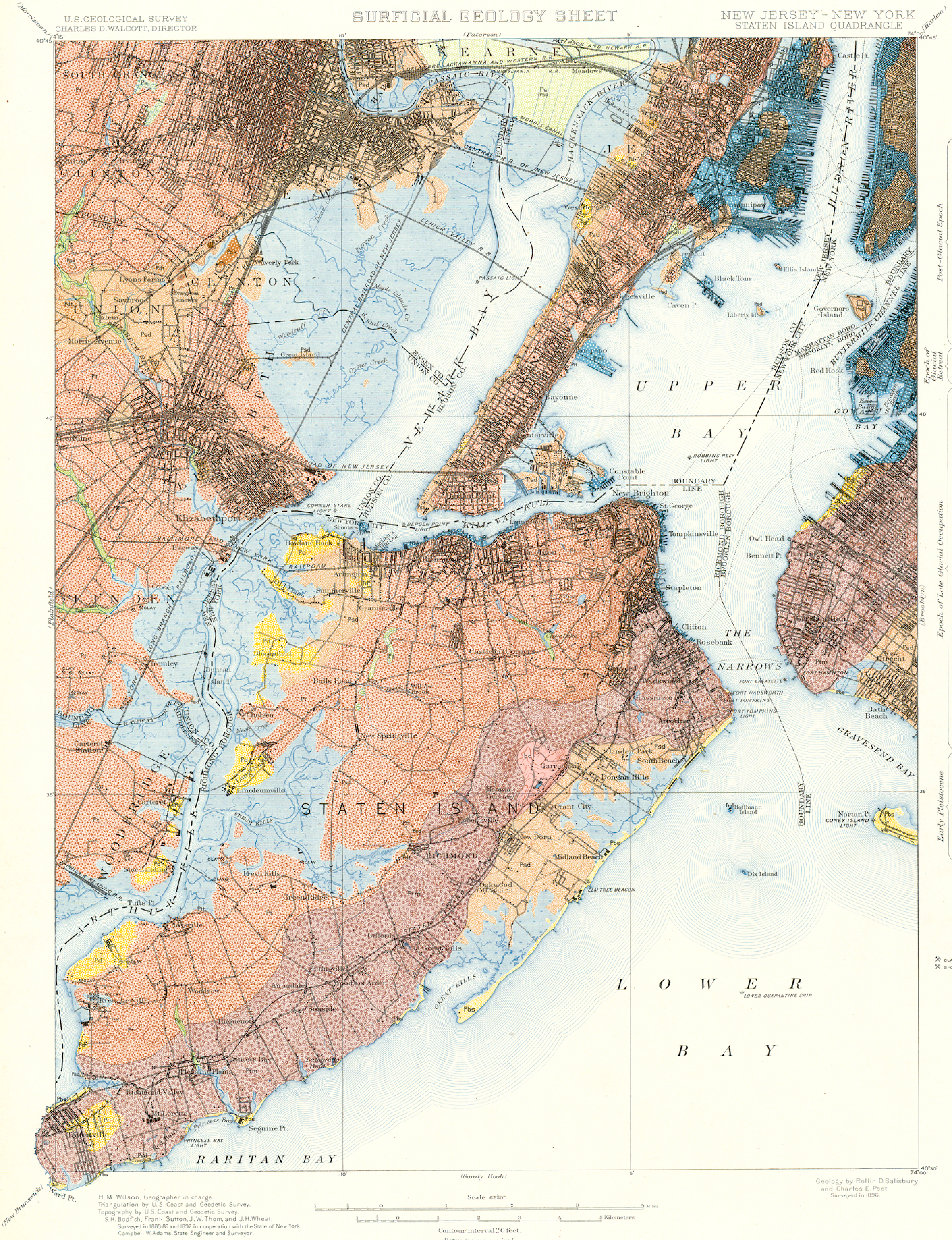
SURFICIAL GEOLOGY SHEET

NEW JERSEY - NEW YORK
STATEN ISLAND QUADRANGLE



LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles.)

PLEISTOCENE

Post-Glacial Epoch

- Pml — Made land
- Pal — Alluvium *(in stream bottoms)*
- Ps — Swamp muck *(tidal flats not included)*
- Pbs — Recent beach sand and gravel
- Pd — Dunes and dune sand

Epoch of Glacial Retreat

- Psd — Stratified drift *(locally very thin, with occasional rock exposures)*

Epoch of Late Glacial Occupation

- Pdk — Stratified drift with kame-like habit
- Pk — Kames *(irregular hills or mounds of stratified drift)*
- Pdt — Stratified drift and till *(undifferentiated)*
- Pdr — Drumlins and drumloids *(elongate elliptical hills of till)*
- Ptt — Thin till *(with numerous rock exposures)*
- Pt — Till *(with occasional small rock exposures)*
- Ptm — Terminal moraine *(belt of thick drift with very irregular topography)*

Early Pleistocene

- Pp — Pensauken formation *(sand and gravel thinly covered with till)*
- Pb — Bridgeton or Beacon Hill gravel

PRE-PLEISTOCENE

- bd — Bed rock *(larger exposures of bed rock; in places covered by thin till or stratified drift)*

CLAY — *Clay pits in surficial deposits*
S-G — *Sand and gravel pits*

Letter symbols in parenthesis indicate the formation which underlies swamp muck

H. M. Wilson, Geographer in charge.
Triangulation by U. S. Coast and Geodetic Survey.
Topography by U. S. Coast and Geodetic Survey.
S. H. Bodfish, Frank Sutton, J. W. Thom, and J. H. Wheat.
Surveyed in 1888-89 and 1897 in cooperation with the State of New York
Campbell W. Adams, State Engineer and Surveyor.

Scale $\frac{1}{62500}$

Contour interval 20 feet.
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Edition of Oct. 1901.

Geology by Rollin D. Salisbury
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Surveyed in 1896.

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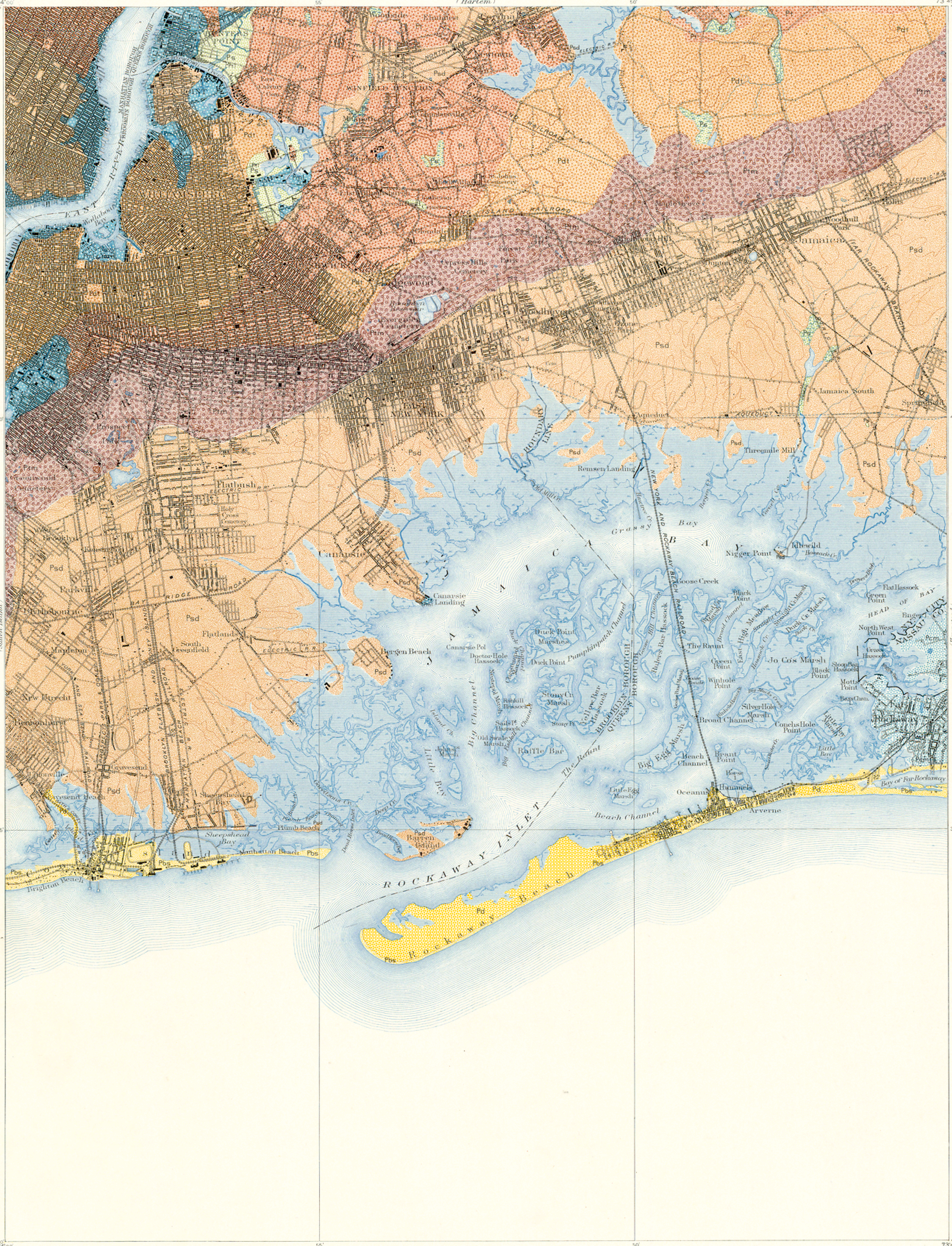
SURFICIAL GEOLOGY SHEET

NEW YORK
BROOKLYN QUADRANGLE



LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles.)

PLEISTOCENE

Post-Glacial Epoch

- Pml — Made land
- Ps — Swamp muck *(tidal flats not included)*
- Pbs — Recent beach sand and gravel
- Pd — Dunes and dune sand

Epoch of Glacial Retreat

- Pcm — Cape May formation *(gravel and sand of marine shallow-water origin)*
- Psd — Stratified drift *(locally very thin, with occasional rock exposures)*

Epoch of Late Glacial Occupation

- Pdt — Stratified drift and till *(undifferentiated)*
- Pt — Till *(with occasional small rock exposures)*
- Ptm — Terminal moraine *(belt of thick drift with very irregular topography)*

s–g *Sand and gravel pits*

Letter symbols in parenthesis indicate the formation which underlies swamp muck.

H. M. Wilson, Geographer in charge.
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Scale $\frac{1}{62500}$

Miles 1 ½ 0 1 2 3 4

Kilometers 1 ½ 0 1 2 3 4 5

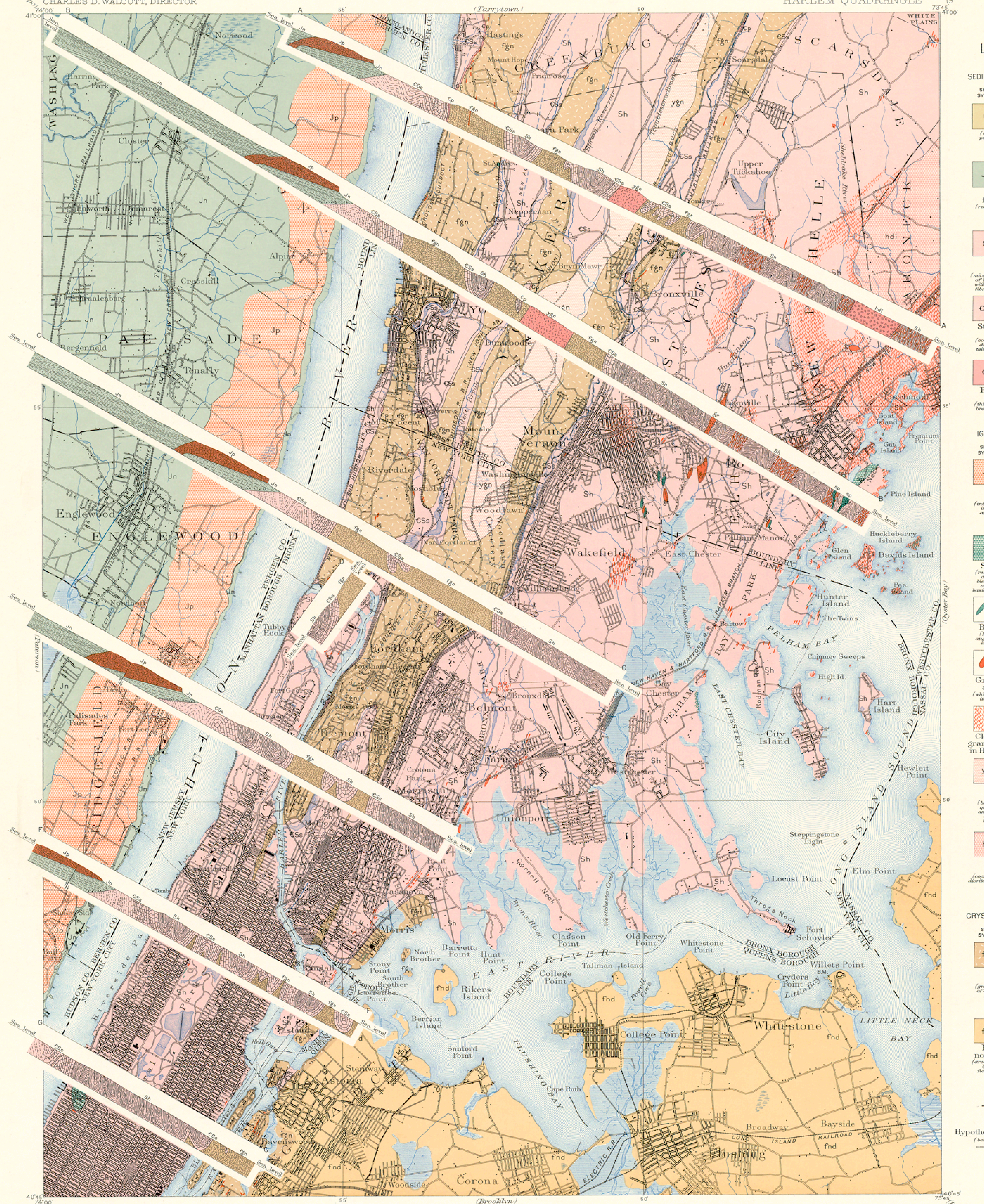
Contour interval 20 feet.

Datum is mean sea level.

Edition of Oct. 1901.

Geology by Rollin D. Salisbury and Charles E. Peet.
Surveyed in 1897.

STRUCTURE-SECTION SHEET



LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL — SECTION SYMBOL

CRETACEOUS?
- rt (variegated clay, probably Raritan formation)

JURATRIAS
- Jn — Newark formation (red sandstone and shales)

SILURIAN
- Sh — Hudson schist (mica-schist, consisting of biotite and quartz, with garnet, staurolite, fibrolite, and cyanite)

CAMBRIAN
- €Ss — Stockbridge dolomite (coarsely crystalline dolomite, often containing diopside and tremolite)
- €p — Poughquag quartzite (thin-bedded white to brownish quartzite)

IGNEOUS ROCKS

SHEET SYMBOL — SECTION SYMBOL

JURATRIAS
- Jp — Palisade diabase (intrusive sheet, forming the Palisades, and small dikes)

SILURIAN OR LATER
- sp — Serpentine (resulting from local alteration of hornblende, bronzite and allied minerals in basic dikes and masses)
- b — Basic dikes (hornblendic and augitic dikes, usually strongly foliated)
- gr — Granite dikes and bosses (white to reddish granite and pegmatite)
- Close parallel granitic injections in Hudson schist
- ygn — Yonkers gneiss (banded gneiss of quartz, microcline, and orthoclase, with biotite and hornblende in small quantities)
- hdi — Harrison diorite (coarse-grained granite-diorite, often much foliated)

ANCIENT CRYSTALLINE ROCKS

SHEET SYMBOL — SECTION SYMBOL

PRE-CAMBRIAN
- fgn — Fordham gneiss (gray banded gneiss of orthoclase, quartz, and biotite)

- fnd — Formation not determined (areas deeply covered by drift, and artificially made land)

Faults

Hypothetical boundaries (beneath water ways)

H.M. Wilson, Geographer in charge.
Triangulation by the U.S. Coast and Geodetic Survey.
Topography by the U.S. Coast and Geodetic Survey, N.Y. City Government, S.H. Bodfish, Frank Sutton, R.D. Cummin, E.B. Clark, and J.W. Thom.
Surveyed in 1888-89 and 1897 in cooperation with the State of New York; Campbell W. Adams, State Engineer and Surveyor.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Edition of May 1902.

Darton | Merrill

Geology of New York by Frederick J.H. Merrill.
Assisted by E.M. Blake, H. Ries, and E.C. Eckel.
Surveyed 1883-1900.
Geology of New Jersey by N.H. Darton.
Surveyed 1885-1899.

FIG. 13.—UPPER CONTACT OF PALISADE DIABASE IN RAILROAD CUT EAST OF NEW DURHAM, N. J.

Looking north. Shows dike-like attitude of the trap at its western exposure, cutting up through the Newark formation.

FIG. 14.—THE PALISADES OF THE HUDSON FROM THE NEW JERSEY SIDE.

Looking south. The vertical cliff of diabase and the steep talus-covered slope are well shown.

FIG. 15.—THE PALISADES OF THE HUDSON, SEEN FROM YONKERS, N. Y.

Shows the even crest line of the plateau surface and the tree-covered talus below the cliff.

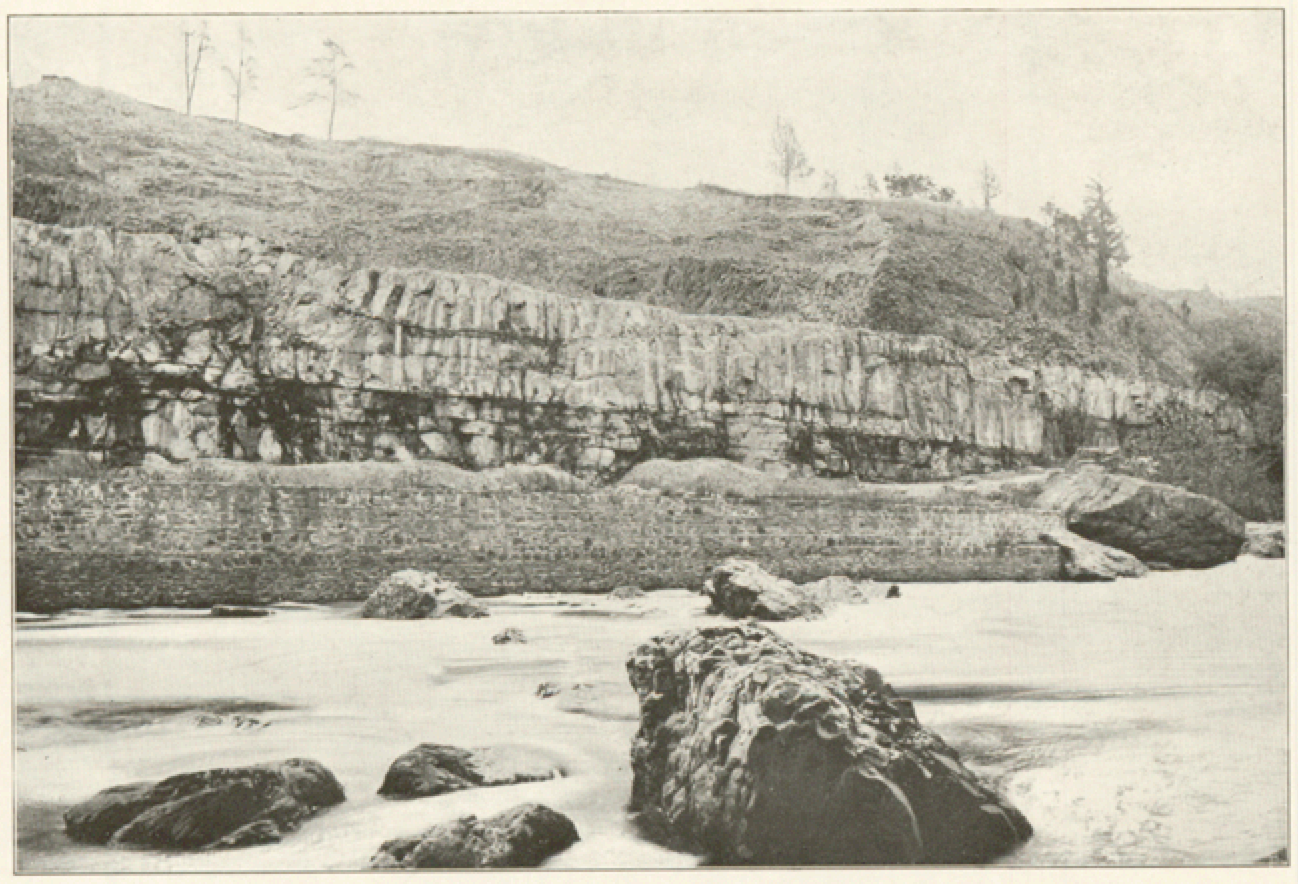


FIG. 16.—CONFORMABLE CONTACT OF BASALT OF THE FIRST WATCHUNG FLOW ON NEWARK SANDSTONES, BELOW FALLS OF THE PASSAIC, PATERSON, N. J.

The sandstone forms the base of the section immediately above the retaining wall and is overlain by massive-bedded lava, with finely columnar basalt on top.

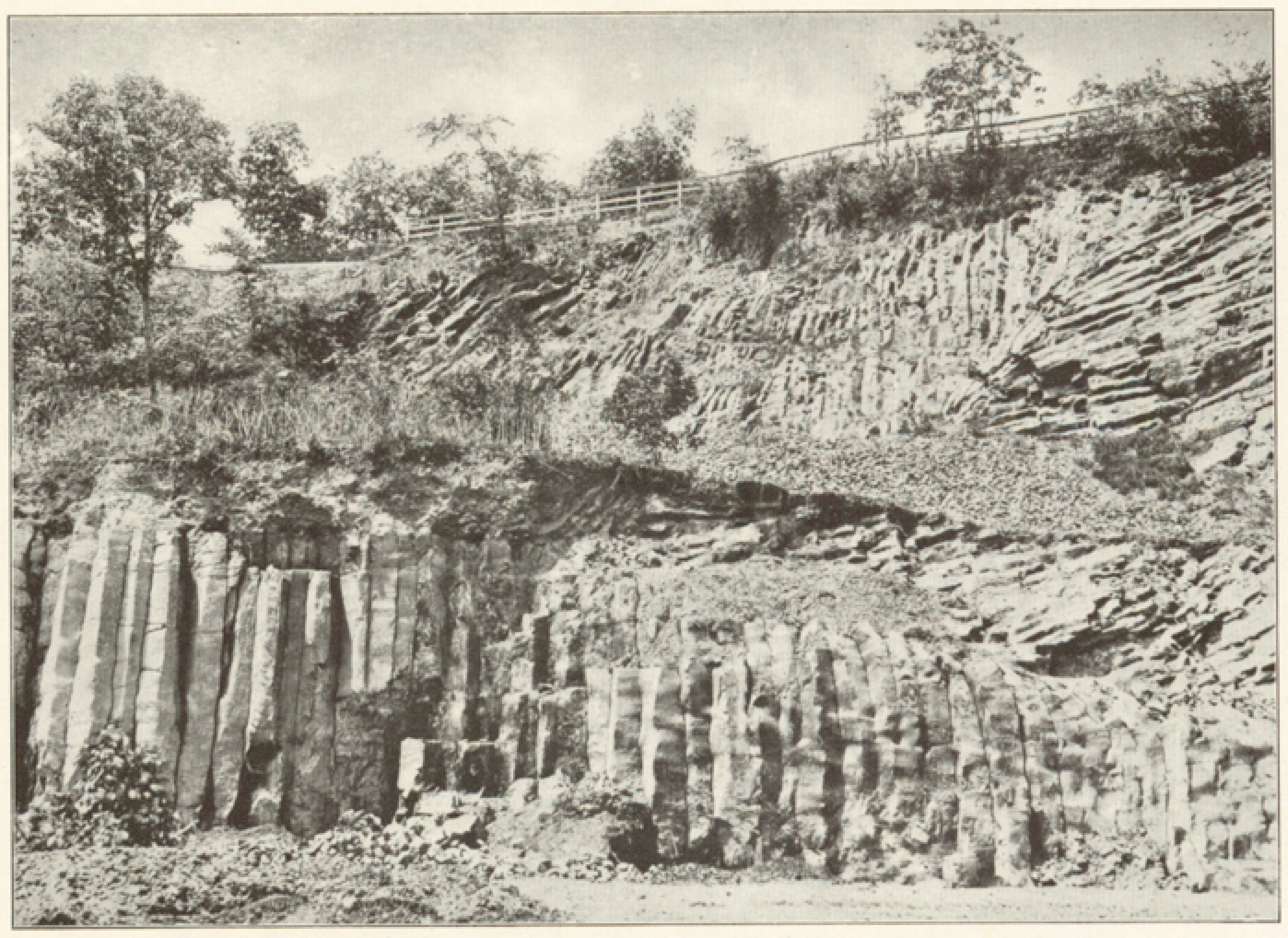


FIG. 17.—BASALT COLUMNS OF FIRST WATCHUNG FLOW, O'ROURKE'S QUARRY, WEST OF ORANGE, N. J.

Shows a lower flow with large vertical columns overlain by another flow with small radial columns.

FIG. 18.—NEAR VIEW OF COLUMNAR BASALT AT BASE OF FIRST WATCHUNG FLOW, O'ROURKE'S QUARRY, WEST OF ORANGE, N. J.

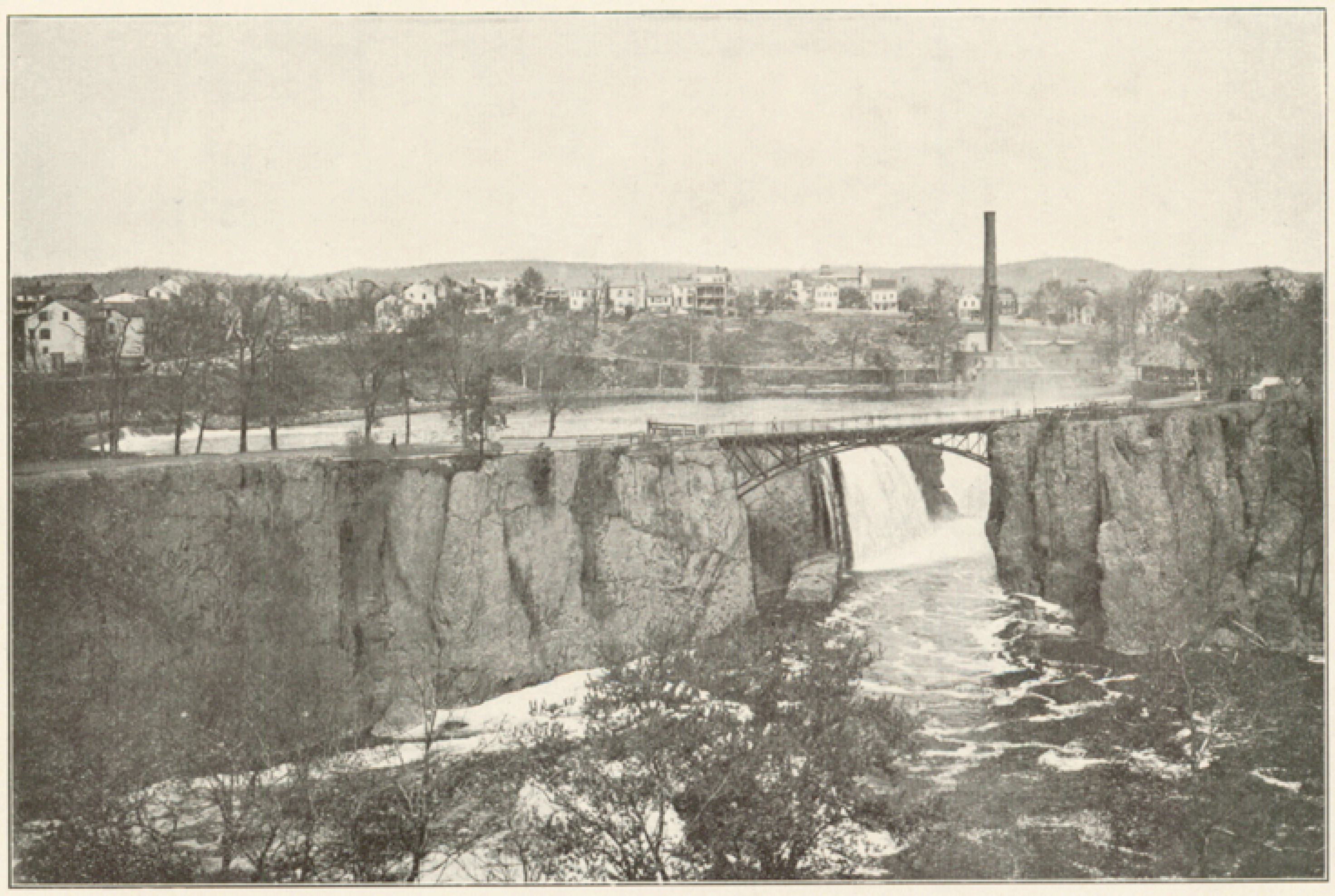


FIG. 19.—GREAT FALLS OF PASSAIC RIVER, PATERSON, N. J.

Shows the escarpment of the Watchung basalt, the wide gorge cut by the stream, and the narrow cleft into which the fall has retreated in following a maior joint system.

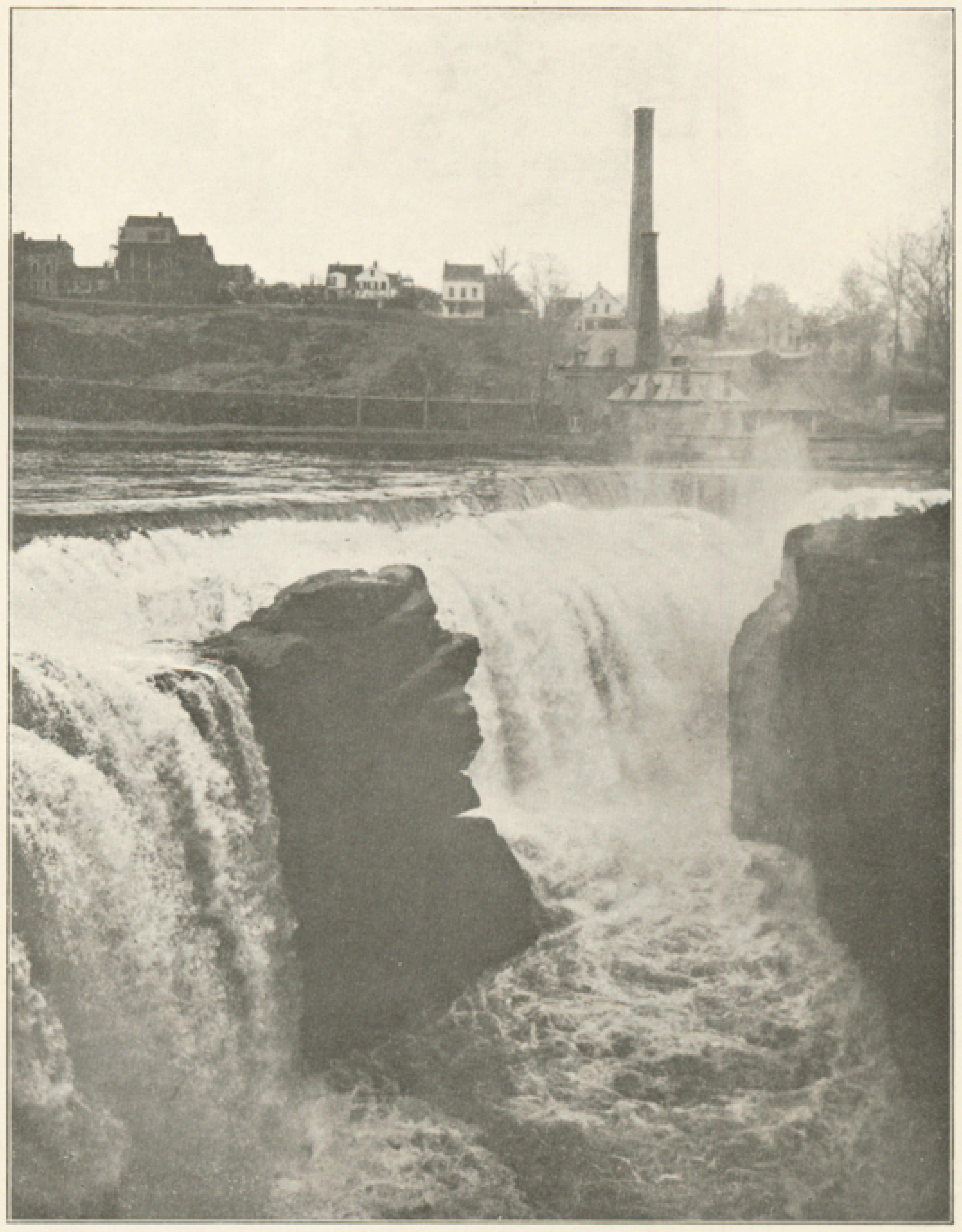


FIG. 20.—NEAR VIEW OF GREAT FALLS OF PASSAIC RIVER, PATERSON, N. J.

Looking along the narrow cleft into which the water falls.

FIG. 21.—LITTLE FALLS OF PASSAIC RIVER, AT THE TOWN OF LITTLE FALLS, N. J.

Looking up the river at a low stage. Shows the gorge cut by the river in the Watchung basalt, and the structure of the basalt.

FIG. 22.—TERMINAL MORAINE NEAR GRASSMERE, STATEN ISLAND, NEW YORK.

Looking northeast toward the heights of the island. Shows the irregular hillocks, ponds, and large bowlders characteristic of the moraine.

FIG. 23.—GLACIATED SURFACE OF HUDSON SCHIST, BRONX PARK, NEW YORK CITY.

Looking southeast. Glacial striæ appear as grooves crossing the lamination of the schist. The rounded profile is characteristic of glaciated rock masses.

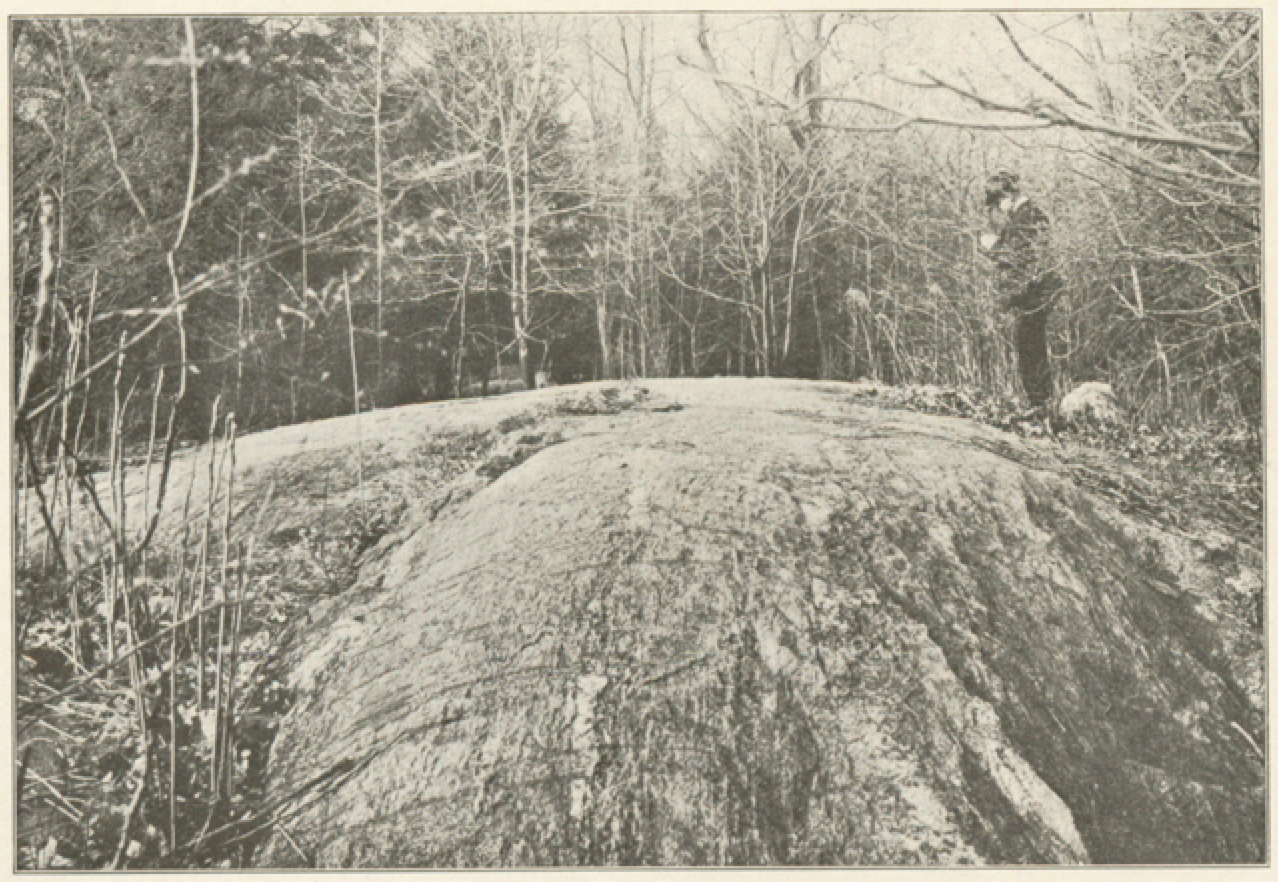


FIG. 24.—GLACIATED SURFACE OF HUDSON SCHIST, BRONX PARK, NEW YORK CITY.

Looking northeast along the lamination of the schist, which is typically developed and brought out by weathering. Glacial striæ extend across the rock in the foreground. The rounded profile is characteristic of glaciated rock masses.

redeposited as beds or trains of sand and clay, thus forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels in the ice, and forms characteristic ridges and mounds of sand and gravel, known as osars, or eskers, and kames. The material deposited by the ice is called glacial drift; that washed from the ice onto the adjacent land is called modified drift. It is usual also to class as surficial rocks the deposits of the sea and of lakes and rivers that were made at the same time as the ice deposit.

AGES OF ROCKS.

Rocks are further distinguished according to their relative ages, for they were not formed all at one time, but from age to age in the earth's history. Classification by age is independent of origin; igneous, sedimentary, and surficial rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to call the mass throughout its extent a *formation*, and such a formation is the unit of geologic mapping.

Several formations considered together are designated a *system*. The time taken for the deposition of a formation is called an *epoch*, and the time taken for that of a system, or some larger fraction of a system, a *period*. The rocks are mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for its deposition are given the same name, as, for instance, Cambrian system, Cambrian period.

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

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those 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 [illegible]he systems together, forming a chain of life from [illegible]e time of the oldest fossiliferous rocks to the [illegible]esent.

[illegible]Vhen two formations are remote one from the [illegible] and it is impossible to observe their relative [illegible]ns, the characteristic fossil types found in [illegible]ay determine which was deposited first. [illegible] remains found in the rocks of different [illegible]vinces, and continents afford the most [illegible] means for combining local histories [illegible] a general earth history.

Colors and patterns.—To show the relative ages of strata, the history of the sedimentary rocks is divided into periods. The names of the periods in proper order (from new to old), with the colors and symbol assigned to each, are given in the table in the next column. The names of certain subdivisions and groups of the periods, frequently used in geologic writings, are bracketed against the appropriate period names.

To distinguish the sedimentary formations of any one period from those of another the patterns for the formations of each period are pri[illegible]d in the appropriate period-color, with the ex[illegible]tion of the one at the top of the column (Pleistocene) and the one at the bottom (Archean). The sedimentary formations of any one period, excepting the Pleistocene and the Archean, are distinguished from one another by different patterns, made of parallel straight lines. Two tints of the period-color are used: a pale tint is printed evenly over the whole surface representing the period; a dark tint brings out the different patterns representing formations. Each formation is furthermore given

Period.		Symbol.	Color.
Cenozoic	Pleistocene	P	Any colors.
	Neocene { Pliocene, Miocene }	N	Buffs.
	Eocene, including Oligocene	E	Olive-browns.
Mesozoic	Cretaceous	K	Olive-greens.
	Juratrias { Jurassic, Triassic }	J	Blue-greens.
Paleozoic	Carboniferous, including Permian	C	Blues.
	Devonian	D	Blue-purples.
	Silurian, including Ordovician	S	Red-purples.
	Cambrian	Є	Pinks.
	Algonkian	A	Orange-browns.
	Archean	Æ	Any colors.

a letter-symbol composed of the period letter combined with small letters standing for the formation name. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

The number and extent of surficial formations, chiefly Pleistocene, render them so important that, to distinguish them from those of other periods and from the igneous rocks, patterns of dots and circles, printed in any colors, are used.

The origin of the Archean rocks is not fully settled. Many of them are certainly igneous. Whether sedimentary rocks are also included is not determined. The Archean rocks, and all metamorphic rocks of unknown origin, of whatever age, are represented on the maps by patterns consisting of short dashes irregularly placed. These are printed in any color, and may be darker or lighter than the background. If the rock is a schist the dashes or hachures may be arranged in wavy parallel lines. If the metamorphic rock is known to be of sedimentary origin the hachure patterns may be combined with the parallel-line patterns of sedimentary formations. If the rock is recognized as having been originally igneous, the hachures may be combined with the igneous pattern.

Known igneous formations are represented by patterns of triangles or rhombs printed in any brilliant color. If the formation is of known age the letter-symbol of the formation is preceded by the capital letter-symbol of the proper period. If the age of the formation is unknown the letter-symbol consists of small letters which suggest the name of the rocks.

THE VARIOUS GEOLOG[illegible] SHEETS.

Areal geology sheet.—Th[illegible]s sheet 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 particular colored pattern and its letter-symbol on the map 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 symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology sheet.—This sheet represents the distribution of useful minerals, the occurrence of artesian water, or other facts of economic interest, showing their relations to the features of topography and to the geologic formations. All the formations which appear on the historical geology sheet are shown on this sheet 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 symbol for mines is introduced at each occurrence, accompanied by the name of the principal mineral mined or of the stone quarried.

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 name 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 the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting 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 in the front of the picture, with a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground by a vertical plane, so as to show the underground relations of the rocks.

The kinds of rock are indicated in the section 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:

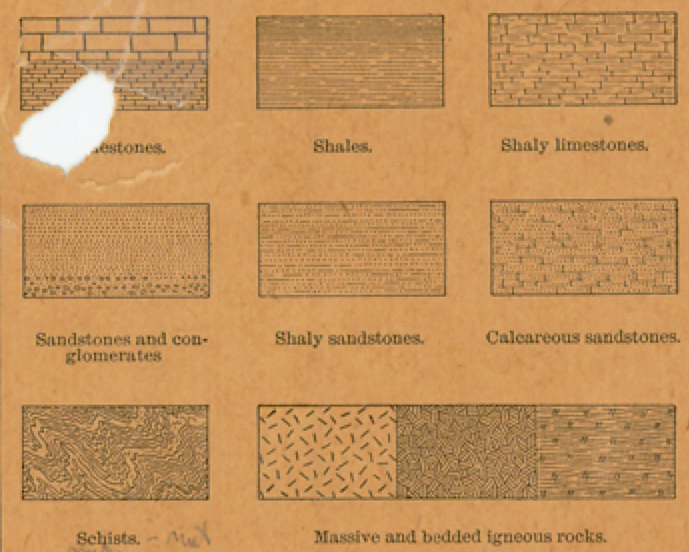


Fig. 3.—Symbols used to represent different kinds of rock.

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 beds of sandstone that rise to the surface. The upturned edges of these beds form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shales.

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*.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. 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 regarded as proof that forces exist which 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 slipped past one another. Such breaks are termed *faults*.

On the right of the sketch 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.

In fig. 2 there are three sets of formations, distinguished by their underground relations. The first of these, seen at the left of the section, is the 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 swelled upward 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 strata thus rest upon an eroded surface of older strata 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 this pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that an interval of considerable duration 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, marking a time interval between two periods of rock formation, is another unconformity.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections in the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profiles of the surface in the section correspond 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 rock formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thicknesses of the formations, and the order of accumulation of successive deposits.

The rocks are described under the corresponding heading, and their characters are indicated in the columnar diagrams by appropriate symbols. The thicknesses of formations are given in figures which state the least and greatest measurements. The average thickness of each formation 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 is placed at the bottom of the column, the youngest at the top, and igneous rocks or surficial deposits, when present, are indicated in their proper relations.

The formations are combined into systems which correspond with the periods of geologic history. Thus the ages of the rocks are shown, and also the total thickness of each system.

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

CHARLES D. WALCOTT,
Director.

Revised January, 1902.

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