XVI INTERNATIONAL GEOLOGICAL CONGRESS
GUIDEBOOK 9 - - NEW YORK EXCURSIONS

NEW YORK CITY AND VICINITY

International Geological Congress
XVI session
United States, 1933

Guidebook 9: New York Excursions

NEW YORK CITY AND VICINITY

Prepared under the direction of

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

For sale by the Superintendent of Documents, Washington, D. C. - - - - - Price 25 cents

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THIS GUIDEBOOK is published under the auspices of the United States Geological Survey, but it is not a part of the Geological Survey's regular series of publications, and the opinions expressed in it and the use of nomenclature do not necessarily conform to Geological Survey usage.

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NEW YORK CITY AND VICINITY

Prepared under the direction of Charles P. Berkey

INTRODUCTION

By Charles P. Berkey

In the expectation that many of the visiting delegates to the Sixteenth International Geological Congress would enter the port of New York and spend several days in this city, the geologists of the vicinity have organized a series of local excursions intended as a friendly offering and invitation to better acquaintance. They are arranged for the most part as half day and single day trips, so that a few of them can be taken without serious interference with other plans. The excursions are designed to acquaint visitors with the geographic and geologic surroundings of this great city by visiting some of the fine exhibits within easy reach.

The New York City region is one of great geologic complexity, in which ancient igneous rocks, as well as sedimentary rocks ranging in age from the Cambrian to the present day, with occasional breaks, are represented.

Structurally the region is equally complex, and in petrographic quality it would be difficult to find greater variety or greater difficulty of interpretation. The geomorphic features of the region, developed on this complex foundation and modified by epirogenic movement and glaciation, invite involved interpretation. There are also mineral deposits of unique character within easy reach of the city.

Virtually all the geologic features and products involve practical problems of great variety in connection with the physical development of this metropolitan area, and several excursions are intended to cover, as well as may be in the short trips offered, typical examples of these practical applications, as well as a general explanation of the structural foundations of the region.

The different papers that follow are intended to serve as guides to the excursions, but the order in which they appear in the guidebook is not the same as that in which the excursions will be given.

The orientation trips are intended to acquaint the visitor with the fine geographic situation of New York City as one of the great seaports of the world.

The guide for the excursion to scientific institutions of New York City and the guide for the excursion to the Catskills are printed separately.

A group of three excursions, covering the zinc deposits near Franklin, New Jersey, the minerals of the trap-rock quarries of Paterson, New Jersey, and the pegmatites of Bedford, New York, are intended to examine special local mineral deposits, all of which are as fine exhibits of the kind as can be found within the United States. The products range from simple quarry rock or crushed stone to high-grade ores. The deposit of zinc ores and related minerals at Franklin Furnace, New Jersey, is unique.

Another group of excursions is intended to cover the geology of New York City, the structural geology between New York and Schunemunk Mountain, and the stratigraphic and structural features between New York and the Catskill Mountains. The first of these treats the character and structure of the complex crystalline basement rocks in the immediate vicinity of New York City. The other two cover, in addition, the geologic features of the region northward as far as the Catskill Mountains. The geology to the north involves, besides complex crystalline rocks, a great series of sedimentary strata ranging from Cambrian through Devonian age. The structure includes complex folding and faulting, exhibited in Schunemunk Mountain, and the simpler structure represented in a maturely eroded plateau composed of little disturbed sediments, displayed in the Catskill Mountains.

Geomorphic features of the surrounding region are given special attention in the excursion covering the area from the Watchung Mountains to Sandy Hook, which furnishes an unusual variety of exhibits, including the Watchung basalt ridges, stream development exhibited by terraces and incised meanders along the Raritan River, coastal-plain features, fossil localities in Upper Cretaceous greensands, the continental terminal moraine, and shore-line features at Sandy Hook.

Two separate excursions cover the varved clays and other glacial features of the vicinity of New York and the glacial history of the Passaic Valley.

Probably no city in the world has had occasion to carry on engineering construction and related projects on a more extensive scale than New York. The total expenditure for strictly engineering projects, which are dependent in considerable part for their success and safety on an understanding of the geology of the district, amounts to many hundred millions of dollars. The variety of problems in which geology has been of service is so large and the work has been done on so extensive a scale that it seems desirable to present some of these studies in a separate contribution. Certain characteristic representatives of these practical problems will be seen on the excursion covering the engineering geology of New York City.

GEOGRAPHY OF NEW YORK CITY

By A. K. Lobeck

GEOGRAPHIC SETTING

New York, the largest city and the most important port of the United States, owes its preeminence to two sets of factors. One of these is remote, the other is local. New York was not always the largest city of the country, but when the Erie Canal was built about 1830 through the Mohawk Valley, the only easy route from the Atlantic seaboard to the interior of the country, this city immediately forged ahead of its competitors. This gateway to the West, though distant over 150 miles (241 kilometers), was accessible by way of the Hudson River and gave New York an unparalleled advantage. Water-borne traffic through the Great Lakes, the Erie Canal, and the Hudson River then constituted the bulk of New York's freight.

Locally, too, New York was ideally placed to handle heavy commodities by water. Situated on an island at the head of a bay and surrounded by deep estuaries leading inland in many directions, it provided literally hundreds of miles of water front for ocean-going ships. It is hard to conceive a location better suited to serve the export trade of a rapidly growing country. In every respect the other cities of the Atlantic seaboard were distinctly inferior.

With the decline of water transportation and the rapid development of railroads about the middle of the nineteenth century some of the factors which had been advantageous proved to be handicaps. The most important of these was the insular position, a handicap under which New York still suffers severely. For many years, until after 1900, the city could be entered by rail only from the north. Railroads from the south and west had their terminals on the New Jersey side of the Hudson River, and freight for New York had to be moved by lighters. But the momentum of its early development outweighed the drawbacks. Most of New York's freight now comes by rail or truck instead of by water, and from the south and west through New Jersey, rather than from the north. Some of the freight destined for

Manhattan Island or for shipment abroad must still be moved by boat or lighter across the Hudson River. Only on the New Jersey side of the Hudson can railroads discharge their freight directly to ocean-going steamers without the need of lightering it across the bay. The New Jersey region is therefore becoming a great shipping center, with large docks at Jersey City, Hoboken, Newark, and Bayonne. For practical purposes these places are all parts of the greater port of New York.

PHYSICAL SETTING

The key to an understanding of the physical setting of New York is the fact that three distinctly different geomorphic provinces converge at this point.

(1) From New England, with its complex of metamorphic rocks, there extends southward a narrow prong which terminates at the south end of Manhattan Island. (2) Long Island and Staten Island, comprising the boroughs of Brooklyn, Queens, and Richmond, are parts of the Atlantic Coastal Plain. (3) The region lying west of the Hudson River is part of the Triassic Lowland, with its tilted sandstones and high trap ridges, the easternmost of which constitutes the Palisades.

The entire region was covered by the continental ice sheet, which advanced southward to the position of New York City and left here a remarkably distinct terminal moraine that crosses Staten Island and Long Island and accounts for the "Narrows" between the Upper Bay and Lower Bay.

POLITICAL DIVISIONS

Greater New York consists of five boroughs—Manhattan, Bronx, Brooklyn, Queens, and Richmond.

The Borough of Manhattan coincides with Manhattan Island. This is the center of New York City and is the part usually thought of when people speak of New York. Manhattan Island extends for 13 miles (21 kilometers) from its southernmost point, which is called the "Battery," northeastward to the Harlem River at Spuyten Duyvil.

Geologically, Manhattan Island consists mainly of Manhattan schist and the underlying Inwood limestone. The limestone appears at the surface only in the northernmost part of the island, where the beds have been arched up and eroded. The Manhattan schist may be seen in most of the larger parks of Manhattan, notably from Inwood, at the north, along Riverside Drive south to 72d Street, throughout most of Central Park, Morningside Park, and elsewhere. In the southern and older part of Manhattan the schist is largely built over and is also covered by glacial drift. Practically all the larger structures have their foundations upon bedrock.

The financial and commercial center of New York is far down town, near the Battery. Here may be seen some of the highest buildings in the world and also some of the oldest buildings in America. A second great center of business activity, with many stupendous structures, lies around Grand Central Station, 3 miles (4.8 kilometers) or so north of the down-town district.

Owing to the great length of Manhattan Island the main thoroughfares run north and south. These are the "avenues." They are numbered from First to Twelfth, beginning on the east side, but there are in addition a few avenues interpolated between the numbered ones. Almost every avenue is used by a subway or elevated line. The "streets" run in an east-west direction, about 20 of them to a mile (12 to a kilometer). The first numbered street is about 2 miles (3.2 kilometers) above the Battery. The area south of that point is the oldest part of the city and is very irregular in plan. The names of many of the streets in that section, such as Wall Street, Canal Street, and Spring Street, are reminiscent of early days.

Three main railroad lines now bring their trains into the heart of Manhattan Island. The New York Central and the New York, New Haven & Hartford come in from the north over the Harlem River to the Grand Central Station at 42d Street and Fourth (or Park) Avenue. The Pennsylvania Railroad enters New York at 33d Street and Seventh Avenue by means of a tunnel beneath the Hudson River. Other main railroad lines, such as the Delaware, Lackawanna & Western, the Lehigh Valley, the West Shore, the Erie, and the Baltimore & Ohio, have their terminals on the New Jersey side of the Hudson River. Numerous smaller branches and railroad lines bring over a million commuters daily to New York from points within 50 miles (80 kilometers) or more beyond the city.

Four bridges connect Manhattan Island with its sister city Brooklyn, on the east. Three of these bridges—the Brooklyn Bridge, the Manhattan Bridge, and the Williamsburg Bridge—are far down town. The Queensborough Bridge crosses at 59th Street. There are also several smaller bridges over the Harlem River connecting with the Bronx. The Hudson River at 179th Street is spanned by the new George Washington Bridge, the longest suspension bridge in the world. Several tunnels for subway traffic run beneath both the East River and the Hudson River, and the Holland Tunnel for vehicular traffic runs beneath the Hudson.

Manhattan Island is therefore in no respect isolated, although it must be remembered that the cost of maintenance of all these transportation lines and the time consumed by the millions of people each day in getting to their work must all be added to the expense of doing business in this metropolis.

The Bronx, lying to the northeast of Manhattan Island, is built upon a series of ridges and valleys. The structure runs in a northeast-southwest direction, and this same structure extends well to the north, so that Westchester County has a decided grain or pattern of parallel ridges and valleys. The Bronx is essentially a residential section, but to the visitor it will be interesting because of the botanical and zoological gardens.

Brooklyn and Queens together cover the western end of Long Island. Except for a small area of igneous rocks in Long Island City this whole region is part of the Coastal Plain and in consequence is characterized by extensive flat, open spaces. The few areas that have not yet been built upon are devoted to truck gardening, and here also some of the chief airports of New York are situated.

Two spits or beaches project westward from the ocean margin of these plains, forming Coney Island and Rockaway Beaches. During seasonable weather these bathing resorts are thronged by untold swarms of people. Many others reside here during the entire year.

The terminal moraine of the continental ice sheet runs east and west through Brooklyn and Queens. It may be seen at Fort Hamilton, near the Narrows, and along its course are several parks and cemeteries—notably Prospect Park, in Brooklyn.

The borough of Richmond, which coincides with Staten Island, is the least developed part of New York City. Much of it is still open country and farm land. The northern part consists of a knob of serpentine several square miles in area. The southern part of the island is low and along the shore of Raritan Bay is fringed with beaches and low islands. The terminal moraine runs the entire length of Staten Island from the Narrows to Tottenville. Three bridges connect Staten Island with the mainland—one at Bayonne; the Goethals Bridge, to Elizabethport; and the Outer Crossing Bridge, to Perth Amboy.

In the Lower Bay, south of the Narrows, there are two small islands, Swinbourne Island and Hoffman Island, used as headquarters for the Quarantine Service. In the Upper Bay are Governors Island, a military post; Bedloe Island, upon which stands the Statue of Liberty; and Ellis Island, which is the headquarters of the Immigration Service.

The New Jersey side of the Hudson River consists of an almost continuous series of cities, including Bayonne (at the south), Jersey City, Hoboken, Weehawken, and lesser centers still farther north. Immediately west of these places are the Hackensack Meadows, beyond which lie Newark, Passaic, and Paterson, all closely associated with New York in an industrial and commercial way.

CLIMATE

New York City, like most of the Atlantic seaboard, receives abundant rainfall, the annual precipitation averaging over 42 inches (1.06 meters) evenly distributed throughout the year. Snow represents about 8 per cent of the total. The mean humidity is about the same for all months, averaging from 74 per cent in the morning to 66 per cent at noon. The sun shines for about 60 per cent of the possible total. Fog in the Lower Bay is sometimes heavy and occurs on the average about 25 days in the year. There is a wide range in temperature during the year, from a mean monthly temperature of 31° F. in February to 74° in July. Normally there are several days in the year having temperatures above 90°, and about 25 days during which the temperature does not rise above the freezing point (32°). The growing season at New York City averages about 210 days from frost to frost, but this rapidly becomes less a few miles inland.

The prevailing western and northwestern winds, coming from over the continent, counteract to some extent the influence of the Atlantic Ocean. The average wind velocity varies from 10 miles (16 kilometers) an hour in the summer to 15 miles (24 kilometers) in the winter. But velocities of 60 miles (97 kilometers) an hour are common, and every month of the year sees velocities in excess of 70 miles (113 kilometers) an hour.

WATER SUPPLY AND SEWAGE DISPOSAL

The water supply of New York City comes mainly from underground wells and surface drainage. The underground wells are limited largely to the Long Island and Staten Island regions, occupied by sedimentary strata. The surface drainage comprises the Croton and the Catskill systems. The Croton system covers about 375 square miles (971 square kilometers) of highland country in Westchester County, with many lakes and reservoirs. The Catskill system involves two very large reservoirs in the Catskill Mountains, 90 miles (145 kilometers) from New York.

Surrounded on all sides by tidal estuaries, New York readily disposes of its sewage. The disposition of garbage, however, by dumping it into the open sea some 20 to 30 miles (32 to 48 kilometers) beyond Sandy Hook, has been far from satisfactory, because of the resulting contamination of the numerous bathing beaches on Long Island and New Jersey. This condition is now being remedied by the building of incinerating plants.

PLAN FOR A 1-DAY TRIP

A general survey of New York City may best be gained by going first to the top of one of the highest buildings, such as the Empire State or the Chrysler. An hour should be allowed for this trip, which should be made with a suitable map at hand. On a clear day the entire area of the city can be seen, even as far as Staten Island, and occasionally to Sandy Hook. A pair of field glasses will be found very useful.

From this point the trip should be made by motor northward along Fifth Avenue and across 110th Street to Morningside Drive, thence to 120th Street and across to Riverside Drive near Grant's Tomb. During this part of the trip a brief stop on the schist upland of Morningside Heights, close to Columbia University, provides a view eastward over the low-lying land of Harlem, underlain by the Inwood limestone. The trip continues then along Riverside Drive and across the George Washington Bridge into New Jersey. This brings the visitor to the top of the Palisades and affords splendid views far up the Hudson. From this point the route runs southward along the Hudson Boulevard on the crest of the Palisades to the Holland Tunnel, in Jersey City. This trip opens up a magnificent panorama of Manhattan Island and provides glimpses of the New Jersey meadows and the Watchung Ridges lying beyond. The return to New York is made through the Holland Tunnel and thence to the Battery, at the southern tip of Manhattan Island. At this point it is well to embark on one of the small steamers that circumnavigate the island, a trip which consumes between two and three hours. Upon arrival again at the Battery, the visitor may proceed uptown to his destination or cross over into Brooklyn by the Brooklyn Bridge and return to New York by the Manhattan or Williamsburg Bridge. The entire day's trip can easily be made between 9 in the morning and 5 in the afternoon.

BIBLIOGRAPHY

The "Physiographic diagram of the United States" (small scale, with text), by A. K. Lobeck, will be useful in showing the geomorphic relation between New York City and the hinterland of the United States.

The "Physiography of the New York region," by Lobeck, Raisz, and Dickinson, with text and geomorphic diagram, makes unnecessary the inclusion of much detail in this account.

The "Aero view of Greater New York and environs," published by C. S. Hammond & Co., serves admirably as a general location map of the New York City area.

Hagstrom's street map of New York City gives detailed information of value to the stranger.

The topographic maps of the United States Geological Survey also cover the area. The special map of New York and vicinity shows the city and adjacent parts of New Jersey and Long Island. Smaller sheets covering each 15-minute quadrangle in the region are also published. The New Jersey State Conservation Department topographic sheet 26 covers the area adjacent to New York City and is especially to be recommended because it has recently been revised.

The geology of the New York City region is treated by George I. Finlay in the following section of this guidebook. For a more complete description see "The geology of New York City and vicinity," by Chester A. Reeds, one of the guide leaflets of the American Museum of Natural History.

The "New York walk book," published by the American Geographical Society of New York, will be a delightful companion to the stranger who has time to ramble and who wishes to see for himself the charms that happily still exist in the countryside around New York.

Besides this material, all of which the visitor can readily carry around on his person, much information will be found in "The regional survey of New York and its environs," an extensive study of the City of New York, in 10 volumes, together with "A regional plan of New York and its environs," in two volumes, with numerous maps and illustrations, a great reference work to be found in most libraries.

Two folios of the Geologic Atlas of the United States describe areas in this region—the Passaic folio (No. 157), by N. H. Darton, W. S. Bayley, R. D. Salisbury, and H. B. Kümmel, and the New York City folio (No. 83), by F. J. H. Merrill, N. H. Darton, Arthur Hollick, R. D. Salisbury, R. E. Dodge, Bailey Willis, and H. A. Pressey.

GEOLOGIC FEATURES OF NEW YORK CITY

By George I. Finlay

TOPOGRAPHY

Manhattan Island (pl. 1) is bounded on the west by the Hudson River, on the south by the Upper Bay, on the east by the East River, which connects the Upper Bay with Long Island Sound, and on the north by the small waterway known as the Harlem River, which connects the Hudson with the East River. The traveler coming by sea to New York enters the Lower Bay by a dredged channel, finds deep water in the Narrows between the Lower Bay and the Upper Bay, and by an inspection of the map may note the deep water of the Upper Bay and in the Hudson River adjoining Manhattan Island. The importance of New York as the seaport which handles the great bulk of the tonnage coming to the United States is due to the fact that the Hudson is a drowned river. The coast line of the region at the mouth of the river has subsided, and the former course of the river has been traced seaward for approximately 100 miles (161 kilometers) by soundings across the Continental Shelf. The silting up of the Lower Bay with sediments brought south by the Hudson and the action of the tides have made necessary the dredging of the Ambrose Channel in the Lower Bay. This provides a depth of 40 feet (12 meters) for vessels entering the port, and almost unlimited anchorage is available in the Upper Bay, as well as docking facilities of the first rank in Manhattan and Brooklyn and along the New Jersey shore opposite Manhattan Island.

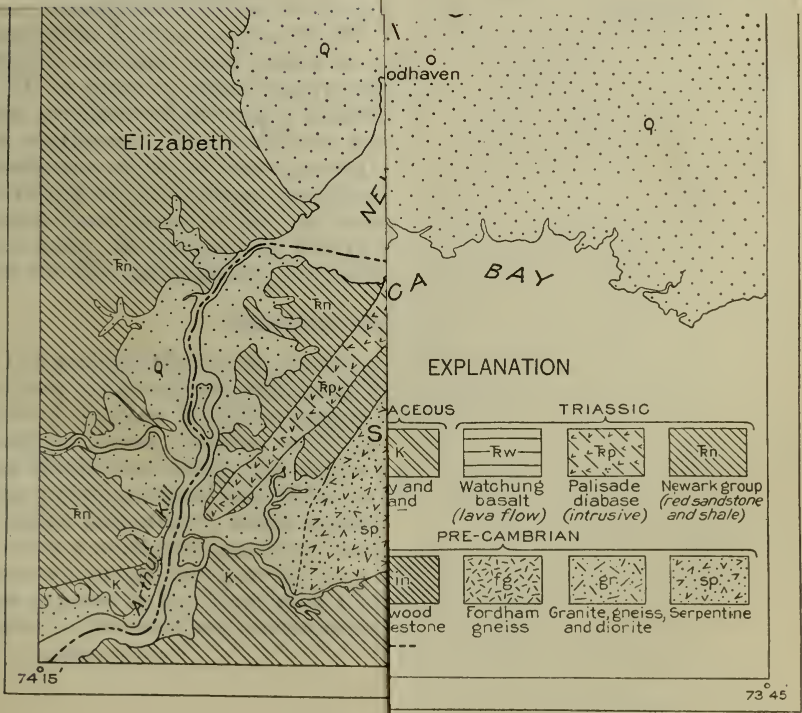
The topographic features of the New York City region show small relief. Between the Hudson River, the East River, and Long Island there is a series of flat-topped ridges whose direction is in general parallel with that of the Hudson River and the alinement of Manhattan Island itself, about N. 30° E. The reason for this trend is the strike of the underlying rocks of th district. The Harlem River and such small streams as the Bron have cut their valleys along the bands of the weaker rocks an follow them throughout a great part of their courses. The alti tudes toward the northern limits of this section are 300 feet (9 meters) or more.

Along the west bank of the Hudson River lie the Palisades, ridge of resistant rock, the cliff faces of which viewed from poin along the east bank of the Hudson are of superb beauty and co stitute the most imposing scenic feature of the New York Cit region. They may be seen to good advantage along the who course of Riverside Drive. West of the Palisades the country in general low-lying as far as the flat-topped ridge of resista

MAP SHOWING DRAINAGE I
Depth of water shown by contour li

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. From U. S. Geol. Survey Geol. Atlas, New York City folio (No. 83), fig. 1, 1902.



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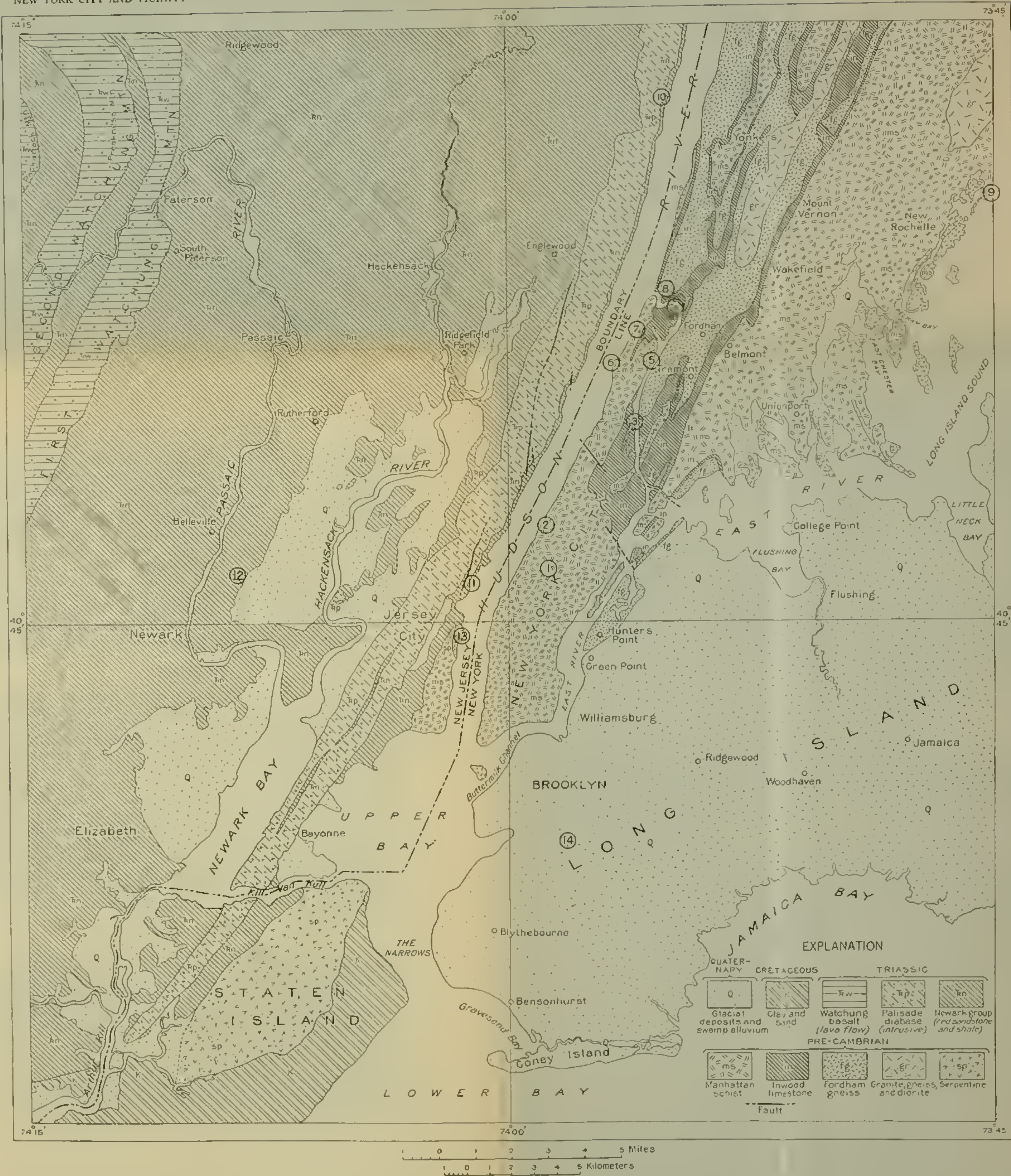

GEOLOGIC MAP OF NEW YORK CITY AND VICINITY

Generalized from U. S. Geol. Survey Geol. Atlas, New York City folio (No. 83), 1902. Numbers in circles indicate localities mentioned in the text.

rock in the First Watchung Mountain. The rock structure controls the topography of the region north and west of Long Island.

Long Island, on which the Borough of Brooklyn is situated, is almost entirely covered with glacial deposits. Its most prominent topographic feature within the New York City region is the terminal moraine of the Pleistocene ice sheet. A belt of irregular morainic hills from three-quarters of a mile to 2 miles (1.2 to 3.2 kilometers) in width extends eastward from the Narrows on Long Island and southwestward on Staten Island, where altitudes of 300 feet (91 meters) are not unusual. On Long Island near New York City the morainic hills are generally between 100 and 200 feet (30 and 61 meters) high. To the south of them is a glacial outwash plain of low relief standing but little above sea level.

STRUCTURE

Manhattan Island and the region of metamorphic rocks to the north and northeast of it constitute an area of close folding. The study of the distribution of the Fordham gneiss and overlying dolomite and schist, as shown on Plate 2, makes plain the linear arrangement of the members of the series. The general trend of the folding is about N. 35° E. The folds are closely appressed, and their axial planes as a rule dip eastward at angles of 70° or more or stand nearly vertical. Westward dips, however, are observed in certain localities. The folds pitch gently to the southwest. The Fordham gneiss, Inwood dolomite, and Manhattan schist, as they appear from north to south parallel to the course of the Hudson, are alined in their order of superposition in consequence of the southwestward pitches of the axes of their folds. In the Spuyten Duyvil region the Harlem River lies over the Inwood dolomite, the middle member of the succession.

GEOLOGIC HISTORY

The geologic history of the metamorphic rock series in so far as it has to do with the associated Triassic and later sedimentary rocks of the New York City region may be briefly outlined. The Fordham gneiss, together with the overlying Inwood dolomite and Manhattan schist, had before the end of the Paleozoic era been metamorphosed and folded as part of a range of mountains of alpine proportions, which probably extended for hundreds of miles in a northeast-southwest direction. It is the roots of this mountain range, laid bare by long continued erosion, which are now exposed in the New York City region. The Triassic sediments to the west rest unconformably upon this pre-Cambrian

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metamorphic series. They are continental deposits, fluviatile for the most part, and were accumulated in broad intermontane valleys between the range referred to above and similar mountain ranges along their western margin. The igneous activity that caused the Palisade intrusion and the outpourings of lava in the Watchung Mountains took place during Triassic time. The Cretaceous was marked by profound peneplanation, exhibited in the crest lines of the Palisade diabase sheet and the basalt ridges of the Watchung Mountains.

ROCK DISTRIBUTION

The visitor to the New York City region may most conveniently take up the examination of its underlying rocks in four districts, which correspond with the regional units marked out by its chief waterways. (1) The northeastern district includes Manhattan Island, which lies between the Hudson and East Rivers and Long Island Sound. Nearly all of it is within the limits of the Harlem quadrangle. This unit is made up almost wholly of such metamorphic rocks as gneiss, dolomite, and schist of pre-Cambrian age. (2) The northwestern regional unit lies west of the Hudson River and north of Staten Island and is included within the Paterson, Staten Island, and Harlem quadrangles. Its rocks are for the most part Triassic sandstones and shales intruded by the diabase of the Palisades and farther west capped by the effusive basalt of the Watchung Mountains. (3) Staten Island, included within the Staten Island quadrangle, is marked by a core of serpentine. West of this core is an area of Triassic sandstone with intruded diabase, the most southerly outcrop of the Palisades sheet. East and south of the serpentine core lies a band of Cretaceous clays. The terminal moraine laid down by the Pleistocene ice sheet extends from the Narrows to the southwestern tip of the island. (4) Within the New York City region Long Island is covered by stratified glacial drift, by till, and for the most part by the Pleistocene moraine. Bedrock exposures corresponding to the rock series of the first regional unit are of small extent. Deep borings on Long Island and small surface outcrops to the east of the region under consideration show the presence of Cretaceous and later clay, sands, and gravel under the cover of the Pleistocene marine and glacial deposits.

NORTHEASTERN DISTRICT

The pre-Cambrian metamorphic rocks to be seen in the northeastern regional unit are the Manhattan schist [1, 2, 3, 6],[1] Inwood dolomite [4], and Fordham gneiss [8].

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[1] Numbers in brackets refer to Plate 2.

The Fordham gneiss is a gray banded rock made up of quartz, microcline, small amounts of orthoclase and oligoclase, and biotite. Accessory minerals are zircon, apatite, titanite, and magnetite. Narrow banding is characteristic, and much variation is noted from place to place, depending upon the concentration of the biotite. This gneiss is clearly the oldest rock in the New York City district. There does not seem to be adequate evidence to place it with the other metamorphic rocks of the district as having been derived from an original sedimentary deposit, nor can its age be more definitely stated than that it is pre-Cambrian. It has an extended distribution along the Hudson River, as indicated on Plate 2.

The Inwood dolomite is well exposed in the most northeasterly section of Manhattan Island. Bands of it appear in many of the valleys in the New York City region, as it is the least resistant member of the series and has in general been deeply eroded. The Harlem River flows over this rock for much of its course between the Hudson and the East River [4, 8]. The thickness of the Inwood dolomite ranges probably from 150 to 500 feet (45 to 152 meters). The rock is white or gray, occurs in well-defined beds, is typically coarse grained, shows a variable magnesian content, and exhibits at many points impurities which appear as dark amphibolitic bands. The Inwood has been highly metamorphosed. Mica, diopside, tremolite, tourmaline, and quartz appear with it. Exposures of limestone in the Hudson Valley north of the Highlands, which may possibly be of the same age, contain Lower Cambrian fossils near their base and Ordovician fossils at higher horizons. In the city the uppermost members of the Inwood dolomite are interbedded with the overlying Manhattan schist throughout a zone 50 feet (15 meters) or more in width, in which numerous alternations of dolomite and schist occur.

The Manhattan schist is the most widely distributed member of the series in the northeastern unit. Exposures are very numerous on Manhattan Island in Central Park, along Riverside Drive, along Spuyten Duyvil Creek, and in Westchester County [1, 2, 5, 6, 7]. The shores of Long Island Sound also afford excellent outcrops. The Manhattan schist is the chief country rock in the Borough of Manhattan and is most frequently met in digging for the foundations of buildings. It is a schistose blackish rock that is composed essentially of biotite and quartz. Microcline may be present at certain horizons. Garnet in small crystals is the chief accessory mineral. The Manhattan schist is supposed by some geologists to be the greatly metamorphosed equivalent of the Hudson slate and shale found in the Hudson Valley 50 miles (80 kilometers) north of the New York City region.

Hornblende schist interbedded with the Manhattan schist is frequently found in the field. Less common are augitic rocks in lenses or bands, usually only a few feet in thickness. Such rocks are probably altered basic intrusives. Dikes of pegmatite several feet in width and smaller injected granitic bands are very common [5]. The pegmatitic minerals are chiefly microcline, quartz, and biotite, in crystals an inch (2.5 centimeters) or more in diameter. Few exposures of the Manhattan schist are unaccompanied by these pegmatitic bands, and in them many of the rarer accessory minerals are found. The rocks mentioned above cover only small areas. Two associated rocks, however, the Yonkers granite and the Harrison granodiorite, are exposed over areas several square miles in extent. The Yonkers granite or gneissoid granite is composed of microcline and other alkalic feldspars, quartz, biotite, and hornblende, with accessory garnet, zircon, titanite, and apatite. It is exposed in a band half a mile (0.8 kilometer) or more in width extending for more than 8 miles (12.8 kilometers) parallel to the course of the Hudson and 2 miles (3.2 kilometers) or more to the east of it in the region east of Yonkers and Hastings. The Yonkers granite may be genetically related to many of the pegmatitic dikes mentioned above. The Harrison granodiorite is an intrusive in the Manhattan schist in the town of Mamaroneck, along the eastern border of the Harlem quadrangle. It is a coarse-grained gray gneissoid rock containing alkalic feldspars, quartz, hornblende, and biotite with accessory garnet and titanite.

NORTHWESTERN DISTRICT

The country rock in the northwestern district is of Triassic age and has been named the Newark group from its occurrences near the city of Newark, New Jersey, 10 miles (16 kilometers) west of New York City. It is a group of red or brownish-red rocks, conglomeratic near Paterson, New Jersey, 10 miles north of Newark, but for the most part consisting of alternating weak reddish sandstones and shales and coarse arkose made up of angular pieces of quartz, feldspar, and mica with intermixed rounded quartz sand and clayey material. The bedding is very clearly marked, and the sandstone members of the series have been extensively used for building materials in New York City. The New Jersey outcrops extend across the State in a band 20 miles (32 kilometers) or more in width without interruption [11, 12]. Similar rocks are known in Pennsylvania and the States farther south, as also in Connecticut and Massachusetts and in Nova Scotia. These are terrestrial accumulations of fluviatile origin, many thousands of feet in thickness. In the New York

City region they are underlain unconformably by the metamorphic rock series described above. Their western boundary, beyond the limits of the New York City area, is marked by a fault contact, west of which is a series of crystalline rocks that can be traced northeastward to the Highlands of the Hudson and thence southward to the New York City area. The Triassic sediments dip 11° or 12° W. They are part of a tilted block downfaulted along its western margin. (See fig. 1.) Many fossil fresh-water ganoid fishes have been found in these sediments near Boonton, New Jersey. Gastropod shells have also been found in them, and near Fort Lee Triassic reptilian remains have been discovered. The extruded basalts and intrusive diabase that accompany them are likewise assigned to the Triassic. Within the New York City area the chief of these are the Palisade diabase and Watchung basalt, described below.

The Palisade diabase is a single intrusive sheet of resistant rock that crops out above the sediments of the Newark group along the Hudson River from Staten Island to Haverstraw, New York. The crest line of this continuous outcrop of diabase rises from near sea level at Bayonne, New Jersey, to a height of 540 feet (165 meters) near Alpine, 28 miles (45 kilometers) farther north. A cover of thousands of feet of sandstone has been eroded to expose it. It rests with a more or less ragged contact (fig. 2) upon the underlying sediments from points near sea level at its south end to points halfway or higher up on the slopes of the high cliffs opposite Hastings [10]. The underlying sediments are invariably baked for many feet below the contact. The observed thickness of this superb exposure of diabase ranges from 70 to 200

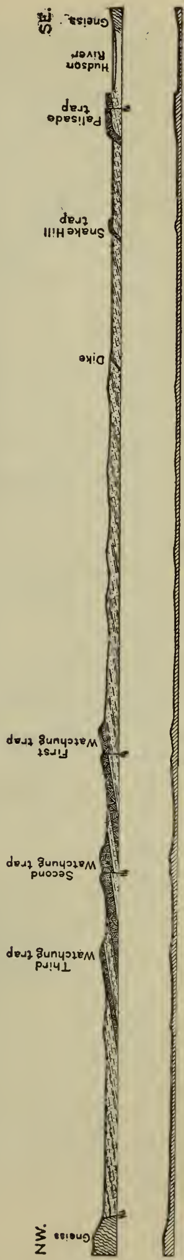

FIGURE 1.—Northeast-southwest section across the Paterson quadrangle and adjoining region, showing the relations of the igneous rocks to the sedimentary strata of the Newark group. Vertical scale three times the horizontal. True profile is indicated in lower section. From U. S. Geol. Survey Geol. Atlas, New York City folio (No. 83), fig. 3, 1902

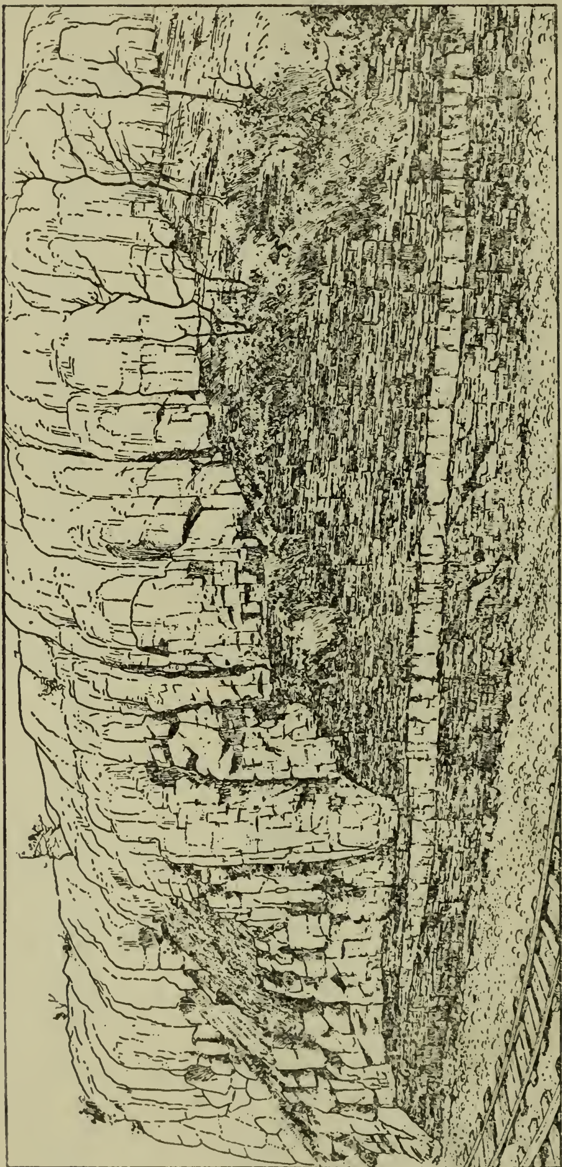

Figure 2.—Base of Palisade diabase, showing lateral ascent across the strata of the Newark group, Kings Point, Weehawken, New Jersey. From U. S. Geol. Survey Geol. Atlas, New York City folio (No. 83), fig. 7, 1902

feet (21 to 61 meters). Its source appears to have been along a fissure not far from the western margin of its outcrop. Railroad tunnel borings at several localities exhibit the contact line of its upper surface with the overlying sedimentary rocks. The crest line is slightly uneven as seen from the Hudson and is complicated at a few localities by minor faults. The Palisade diabase is a very dark or blackish-gray rock, extremely fine grained at its upper and lower contacts and moderately fine grained in its more central portions. The constituent minerals, which may often be noted in hand specimens, are seen under the microscope to be augite, labradorite and related calcic plagioclase, olivine, and magnetite.

The Watchung basalt crops out near Paterson, New Jersey, in three successive effusive sheets which form First, Second, and Third Watchung Mountains and whose combined thickness is about 1,600 feet (488 meters). (See fig. 1.) North and south of Paterson the flows extend for 25 miles (40 kilometers) or more, with their crest lines 400 feet (122 meters) or more above the surrounding rolling country. Good exposures of the base of the First Watchung sheet are found in the gorge below the falls of the Passaic River at Paterson. The rock rests conformably on sandstones, which have been only slightly baked. It is vesicular at its base, aphanitic, and nearly black in hand specimens. The vesicular character of the upper surface of these lava flows is clearly apparent at many localities. The tendency toward columnar jointing is in places well marked. Under the microscope a glassy base appears in stray patches, and the essential minerals are a light-green iron-lime-magnesia pyroxene, malacolite, plagioclase referable to labradorite, smaller amounts of more calcic plagioclase, and altered olivine. Magnetite is present, and serpentine and chlorite occur as alteration products.

STATEN ISLAND

On Staten Island, immediately south of Kill Van Kull, an area of about 8 square miles (21 square kilometers) is occupied by members of the Newark group and the associated diabase described above. The core of Staten Island is made up of serpentine. This is the largest exposure of the rock in the New York City region. Others are known at Stevens Point [13], Hoboken, opposite New York City; on Davenport Neck, on Long Island Sound, 20 miles (32 kilometers) from New York City; and on Manhattan Island between the southwest corner of Central Park and the Hudson River. At each of these places the rock is deeply decomposed. The color varies, according to the amount of weathering, from clear green to dull red where infi trated iron is present. Chromite, talc, and other minerals a: associated with it. The serpentine is an alteration product (basic eruptives whose nature is indicated by the occurrence (traces of bronzite, hornblende, and actinolite.

Cretaceous clays occupy the area lying between the serpentir core and the eastern and southern portions of Staten Islan(These plastic clays have in the past been worked extensivel; Over much of Staten Island they are concealed by the termin: moraine of the ice sheet and by glacial till, described below.

LONG ISLAND

Unlike the other units thus far described, Long Island : characterized by the occurrence of glacial deposits which almos completely cover the underlying formations. Opposite Mar hattan Island along the East River outcrops of Fordham gneis are found, but they are obscure and occupy less than 1 per cen of the total area. Long Island and Staten Island, as may b seen from Figure 13, are crossed by the terminal moraine of th ice sheet. The moraine is a conspicuous topographic feature o Long Island. It is a mile (1.6 kilometers) or slightly more i width, and though few of its hummocks are more than 100 t 125 feet (30 to 38 meters) in height it presents a bold front whe viewed from the flat lands of the outwash plain to the south c it. The drift in the moraine is usually much less than 75 fee (23 meters) thick. It consists of a belt of drift thicker and mor irregularly distributed than that lying north of it. The lin between the sheet of till to the north of the moraine and th inner edge of the moraine itself is not sharply marked. Th moraine is made up of sand, compact till, and stratified drift Boulders of Triassic red sandstone, diabase, and gneiss occur o its surface, but they are not notably abundant. Southward fron the moraine deposits of outwash gravel with waterworn pebble and sand slope away to the sea, 20 feet (6 meters) or more in th first quarter mile (0.4 kilometer) and about 20 feet to the mil (3.75 meters to the kilometer) farther south. Figure 13 show that the ice advanced southward in lobate form in the New Yor City region, reaching its southernmost point at Perth Amboy It was forced to turn somewhat eastward in ascending the west ern slope of the Palisades. Fragments of diabase were torn fron the Palisades ridge and carried to Manhattan Island, to point in the Bronx, and to Long Island. Glacial striae are common o the surface of almost every outcrop along the edge of the Pali sades as well as on almost every ledge on Manhattan Island. I places grooves 6 inches (15 centimeters) deep have been worn i ledges of Manhattan schist over which the ice passed [1]. Many erratics may be seen on Manhattan Island, notably in Central Park, and on Long Island near the New York City limits a few as much as 20 feet (6 meters) in length have been found.

STRUCTURAL GEOLOGY BETWEEN NEW YORK AND SCHUNEMUNK MOUNTAIN

By R. J. Colony

METROPOLITAN AREA AND THE WESTCHESTER, KENSICO, AND PEEKSKILL DISTRICTS

[A, B, C, pls. 3, 4] [2]

The entire area from Manhattan Island northward as far as Peekskill, a distance of 35 miles (56 kilometers), is underlain by a series of intensely metamorphosed, heavily injected, recrystallized, and thoroughly reorganized ancient sediments, which extend in a comparatively regular succession of nearly parallel ridges with a northeasterly strike, making a gently fluted surface of moderate relief that slopes in the direction of the strike toward the Hudson River and the sea.

Geologic column of the Metropolitan, Westchester, Kensico, and Peekskill districts

Age	Metamorphosed sediments			Igneous rocks
	Name	Thickness		
		Feet	Meters	
Paleozoic or later.				Peekskill granite and Cortlandt basic series (relative ages unknown).
				—Eruptive unconformity—
Pre-Cambrian (?)	Manhattan schist.	3,000	914	Pegmatites, Yonkers gneissoid granite, Ravenswood granodiorite (relative ages unknown).
	Inwood limestone.	700	213	
				—Eruptive unconformity—
Pre-Cambrian.	Fordham gneiss.	Unknown.		

[2] For convenience of description the region covered by this excursion has been divided into six districts. The areas of these districts are indicated by the letters A to F prefixed to the numbers on the route maps.

FORMATIONS

One of the members of the series, the Fordham gneiss, has been subjected to lit-par-lit injections of pegmatitic and granitic material, and all of them have been cut by later pegmatites, whose exact age is unknown. In addition the Fordham gneiss has been intruded by later granite, also of unknown age, and in the immediate vicinity of Peekskill a much younger series of basic eruptives, known as the Cortlandt series, cuts all the old metamorphic rocks of this particular area.

Fordham gneiss.—This is the oldest rock of the area under discussion. In its typical facies it is a black and white banded quartzose and granitic gneiss. In places it is schistose, and the formation as a whole is exceedingly complex both in composition and in structure.

In many places the rock has been so thoroughly impregnated with pegmatitic and granitic matter, in the form of lit-par-lit injections and dikelike and sill-like intrusions, that fully 60 per cent of it is igneous.

Inwood limestone.—Underlying the Manhattan schist and overlying the Fordham gneiss, and conformable with both, is a massive, strongly bedded, coarsely crystalline magnesian limestone. The upper part is generally very impure and in places contains considerable phlogopite. Where the rock is impure through the development of phlogopite and where limestone and schist occur interbedded as a transition facies, the upper part exhibits the folded structure characteristic of the immediately overlying Manhattan schist. But where the limestone is pure the structure is obscure and the rock is white, massive, and coarsely crystalline. It is cut here and there by massive dikes of pegmatite, and in the vicinity of some of these dikes the limestone is commonly charged with diopside and tremolite.

The Inwood limestone appears to lie conformably on the Fordham gneiss, but some geologists question whether it really is conformable. It is believed by some to be the equivalent of the Ordovician Wappinger limestone.

Manhattan schist.—This is the youngest member of the Manhattan-Inwood-Fordham series. It directly and conformably overlies the Inwood limestone, and together with the Fordham gneiss forms the ridges of the area. It is typically a dark, streaked, strongly micaceous, coarsely crystalline, markedly foliated rock and carries locally large quantities of quartz, feldspar, and garnet and in places epidote and fibrolite. It is filled with bunches, knots, streaks, and stringers of pegmatite and is cut by dikes and sill-like masses of pegmatite and fine-textured granitic matter. It contains a few layers of black hornblendic schist, roughly conformable to the foliation, which are believed to represent either metamorphosed sills of diabase intruded into the original sediments prior to their metamorphism, or basic injections from an igneous source intruded into the schist. The Manhattan is believed by some to be equivalent to the Hudson River slates and phyllites.

Ravenswood granodiorite.—A slightly gneissoid or foliated mass intrusive into the Fordham gneiss covers an area of about 6 square miles (16 square kilometers) in Brooklyn and vicinity. Beyond the fact that it is definitely younger than the Fordham gneiss its exact position in the geologic column is unknown. It may possibly be genetically connected with the Yonkers gneissoid granite.

Yonkers gneissoid granite (*Yonkers "gneiss"*).—An extremely variable and commonly strongly gneissoid rock intrusive into the Fordham gneiss in roughly sill-like relations covers a considerable area in Westchester County. The formation includes gneissoid pink granite, granodiorite, and diorite, with associated pegmatites and massive facies that are not gneissoid. The contacts between the Yonkers granite and the Fordham gneiss are not everywhere sharply defined, and in places the granite blends with the gneiss so intimately that clear-cut contacts can be found only where small apophyses cut through the gneiss.

Like the Ravenswood granodiorite, the Yonkers granite is younger than the Fordham gneiss, but its exact age is unknown.

Pegmatites.—Very coarse textured and finer-textured pegmatites, "sugary" granite, and pegmatitic graphophyric masses are abundantly distributed in the foliated, highly metamorphosed Manhattan-Inwood-Fordham series throughout the district.

Later igneous intrusions of uncertain age.—The Cortlandt series of basic eruptives occupy an area of about 20 square miles (52 square kilometers) between Peekskill and the Croton River, and a small exposure of them occurs on the west shore of the Hudson River at Stony Point, opposite Peekskill. They are intrusive into the Manhattan schist and have been productive of a complex set of endomorphic minerals along the margins of the intrusive where blocks of the schist were involved in the basic magma and partly or wholly assimilated. The products fo assimilation are concentrated in the contact zone, forming alumina-rich mixtures consisting in part of cordierite, albite, corundum, chloritoid, spinel, sillimanite, biotite, quartz, and magnetite. In the past such places have been a source of emery. The series includes a complete range of coarse-textured peridotites, pyroxenites, gabbros, diorites, norites, granodiorites, and quartz diorites.

The basic eruptives comprising the Cortlandt series are certainly younger than the Manhattan schist; they may be later than the period of Triassic faulting, but their exact age is not definitely known.

A white or pink, locally "golden yellow," massive coarse-textured soda granite occupies about 4 square miles (10 square kilometers) east of Peekskill and immediately north of the Cortlandt series. It is believed to be genetically related to the Cortlandt series and may be regarded as an acidic differentiate.

Quaternary deposits.—An uncompacted mantle of soil and glacial débris covers the whole region except where there are exposures of bedrock. There are two different types of glacial drift in the region—(*a*) an unsorted mixture of rock flour, sand, clay, pebbles, and boulders of the most complex kinds as to size, composition, and origin, deposited by the ice sheet as terminal and ground moraines; (*b*) modified drift, consisting of stratified and partly assorted gravel, sand, and clay, derived from the unsorted till.

The finer silt and clay, interstratified with and in places overlain by sand, are abundantly distributed along both sides of the Hudson River. Later erosion by the river has removed the greater portion of these deposits; but large quantities still remain above the present level and extend beneath the river. These deposits until recently supported an active brick industry.

MAJOR STRUCTURAL FEATURES

Folds.—All the formations except the Quaternary deposits and some of the later igneous intrusions are strongly folded. Deformation of several periods is reflected in the Manhattan-Inwood-Fordham series—(*a*) pre-Cambrian, marked by the folding and metamorphism of the original ancient sediments now constituting the Fordham gneiss, and possibly also the Inwood limestone and Manhattan schist; (*b*) post-Ordovician, marked elsewhere in the region by Taconic folding and by the time interval expressed by the unconformity between the Hudson River slates and phyllites and the Shawangunk (shon′-gum) conglomerate, of Silurian age; (*c*) post-Carboniferous, marked by thrust faulting of Appalachian type, and elsewhere in the region by the sharp folding and thrust faulting of the Shawangunk Range and the associated higher beds.

The axes of the folds trend northeast, and in places they are overturned toward the southeast.

Faults.—Faulting accompanied the folding in each period of deformation. Many of the faults are of large extent, crossing the country for miles. In this district the faults are chiefly thrust faults contemporaneous with the folding, but in the other districts, especially the Schunemunk and Triassic districts, normal faults of Triassic age are very conspicuous, and small-scale block faulting and thrust faulting of Appalachian type have produced structurally complex results.

HIGHLANDS DISTRICT

[D, pl. 4]

The Highlands district, which crosses the Hudson River diagonally between Fishkill and Peekskill, is more rugged than the one just described, being characterized by irregular mountain masses and lofty ridges, separated by very narrow valleys. Both ridges and valleys have a general northeast trend.

Geologic column of the Highlands district

Age		Sediments, more or less metamorphosed			Strongly metamorphosed rocks	Igneous rocks	Mixed rocks
		Name	Approximate thickness				
			Feet	Meters			
Paleozoic.	Ordovician.	Hudson River phyllite.	1,500	457			
	Cambro-Ordovician.	Wappinger limestone.	1,000	305			
	Cambrian.	Poughquag quartzite.	600	183			
		—Unconformity—				—Unconformity—	
Pre-Cambrian.	Pre-Cambrian intrusives.					Camptonitic dikes.	
						Storm King granite.	
						Canada Hill granite.	Reservoir granite.
							Diorite.
	Older gneisses.				Interbedded limestone.		
					Pochuck (=Grenville?) gneiss and schist.		

FORMATIONS

Pre-Cambrian formations.—The Pochuck gneiss, the oldest of the Highlands crystalline rocks, is complex, highly variable, banded and streaked, injected and impregnated gneiss, containing among its members dioritic gneiss, hornblendic gneiss, granitized gneisses and schists, garnetiferous gneiss, diopside-quartz rock, quartz-epidote schists, intensely silicated limestone, serpentinous limestone, and crystalline interbedded limestone. It is commonly heavily granitized.

A coarsely crystalline limestone, interbedded with the older gneiss, carrying various silicate minerals, is especially prominent in Sprout Brook Valley, on the northwest side of Gallows Hill, and appears in many smaller occurrences elsewhere.

Diorite is the oldest igneous representative in the Highlands district. It is everywhere associated and mixed with banded and streaked rocks belonging to the older metamorphic series, although there are small local patches that are purely diorites, which merge into some of the later invading units on the margins. It is believed that this is the earliest recognizable igneous unit that intruded the metamorphosed Pochuck sediments.

The Reservoir granite and Canada Hill granite and associated pegmatite are so difficult to differentiate in the field that they are here considered together. It is almost as difficult to distinguish one from the other under the microscope, so that doubt arises as to whether they are two separate granites. The Canada Hill granite is a medium to coarse textured massive to streaked gray rock, weathering to dull white, especially in the coarse quartz-feldspar facies. It is variable in texture, composition, and structure and in places contains remnants of the older rock that it penetrated. Biotite is the prominent ferromagnesian mineral, and older orthoclase is dusty and more or less replaced by fresh sodic microcline. The Reservoir granite is more variable in composition and structure, carries many relic structures of older rock, especially dark banded gneisses, commonly occurs penetrating and invading the older rocks, and may perhaps be a facies of the Canada Hill granite mixed with greater quantities of the older rocks. These granites have produced the greater part of the granitization of the older schists and gneisses. They were particularly effective in penetrating and assimilating the rocks which they invaded.

The Storm King granite is the latest of the intrusive granites of the Highlands district. It constitutes all of Storm King Mountain and the larger part of Crows Nest and Bear Mountain, on the west side of the Hudson River, and Mount Taurus and Breakneck Mountain, on the east side. It is a medium to coarse textured rock with a crudely developed, coarse gneissoid structure, rather dark in color and grayish to dark pinkish in general tone. It is characterized by soda-rich alkali feldspars, prominent hornblende, moderate amounts of quartz, and rarely allanite. Pegmatites are associated with it.

Numerous moderately basic and a few more acidic dikes cut the granites and gneisses of the Highlands district. In some places they are massive and undisturbed; in other places they are crushed in shear zones in common with the inclosing crystalline rocks. Some of these dikes may possibly be post-Ordovician, but their age can not be definitely determined in the Highlands.

Cambro-Ordovician rocks.—The Poughquag (po′quog) quartzite (Cambrian) is a strongly silicified quartz sandstone of variable thickness that lies below the Wappinger limestone, resting unconformably upon the upturned and eroded edges of the pre-Cambrian gneisses, except in places where the contact relations have been disturbed by faulting. This quartzite forms the southwestern margin of the Cambro-Ordovician block north of Peekskill, standing almost vertical against the gneiss and conformable with the overlying Wappinger limestone, whose beds are also almost vertical. The quartzite is believed to rest in unconformable contact on the gneiss at this point, although the relation is not absolutely certain. There has no doubt been considerable slipping along the contact, owing to the intense compression to which the members of the block have been subjected.

The Wappinger limestone comprises Black River limestones and Beekmantown and Lower, Middle, and Upper Cambrian dolomites. Many of the beds are fossiliferous. In the Highland and Schunemunk districts, however, the Wappinger limestone is a compact, fine-textured, massive to strongly bedded dark-gray limestone with few fossils and in places is finely crystalline and almost a micromarble. It has normally a maximum thickness of 1,000 feet (305 meters), but the apparent thickness of the limestone in the downfaulted block north of Peekskill is nearly 3,000 feet (914 meters), owing to isoclinal folding.

The Hudson River phyllite (Ordovician) is prevailingly a slaty shale, with a few beds of graywacke and sandstone. More rarely it is almost a true slate, and very rarely indeed it is a phyllite, as in the downfaulted block of Cambro-Ordovician rocks constituting Gallows Hill, immediately north of Peekskill.

Tertiary.—A so-called "Cretaceous" peneplain is still preserved to some extent on the summits of the crystalline rocks of the Highlands. Although it has suffered partial pre-Tertiary dissection, Tertiary deposits must have been laid down over this area and completely removed in preglacial time. The preglacial floor is therefore more complex than it would have been had it been formed during a single period of erosion.

Quaternary and later deposits.—The usual types of glacial drift, more especially modified drift distributed in the valleys, together with small amounts of later stream alluvium, occur in this district.

MAJOR STRUCTURAL FEATURES

Folds.—The only members of the pre-Cambrian complex that exhibit profound folding are the remnants of the older gneisses and their granitized equivalents. The later, massive igneous intrusives were little affected by either Taconic or Appalachian deformation. The structural features within these rocks are inherited, produced by very ancient pre-Cambrian deformation and more or less crudely preserved when these ancient, folded rocks were invaded by the later granites. The Cambro-Ordovician sediments of the infaulted block at Peekskill were folded, however, during the Taconic and Appalachian revolutions.

Faults.—The rocks of the Highlands district have been affected by faulting during four periods. The most ancient faults are pre-Cambrian, usually obscured by injection and recrystallization, so that the crush zones are as substantial as the unmodified rock. Some of these faults were encountered during the construction of the tunnels for the Catskill Aqueduct.

Later thrust faults are probably contemporaneous with the Taconic and Appalachian folding. They are especially prominent along the northern and western margins of the Highlands, where the gneisses and the Storm King granite have been overthrust upon the Cambro-Ordovician sediments. They likewise cut through the massif of the Highlands, and some of them have considerable extent and displacement.

Normal faults of Triassic age are the youngest in the region. Examples of these faults in the Highlands district are the two bounding the in-faulted block of Cambro-Ordovician sediments north of Peekskill, and the cross fault along Popolopen Creek, on the west side of the Hudson River.

Internal structures.—All the larger units composing the pre-Cambrian crystalline complex possess an amazing variety of internal structures ranging from perfectly massive habits through gneissoid structures, markedly streaky structures, and lit-par-lit structures to clear-cut banding. The streaky, lit-par-lit and

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banded structures, which are especially prominent in the Reservoir granite and granitized Pochuck, have originated through extensive mixing, injection, assimilation, and syntexis, so that no sharp boundaries exist between the various formations. The formation contacts are everywhere gradational except at fault contacts.

SCHUNEMUNK DISTRICT

[E, pls. 3, 4]

The Schunemunk district is structurally complex. The portion covered by the itinerary includes the fault valley between the northwestern escarpment of the Highlands and the fault block of Schunemunk Mountain; Schunemunk Mountain itself; a small downfaulted block known as Pine Hill; and a small and badly broken "syncline" called the Idlewild syncline. Time permitting, another small block called Pea Hill and the overthrust of Storm King Mountain on the Hudson River slates will be visited.

FORMATIONS

The geologic column extends from the pre-Cambrian into the Devonian, as shown in the following table:

Geologic column of the Schunemunk district

Age		Name	Approximate thickness	
			Feet	Meters
		Schunemunk conglomerate	300	91
		Bellvale flags (flaggy graywacke)	1,300	396
		Cornwall shale	200	61
		—Probable hiatus?—		
		Kanouse grit (coarse sandstone, Onondaga fauna)	(?)	
Devonian.		Schoharie and Esopus grits (best exposures at Highland Mills)	177	54
		Oriskany sandstone (fine gray-green sandstone)	188	57

Geologic column of the Schunemunk district—Continued

Age		Name	Approximate thickness: Feet	Approximate thickness: Meters
	Helderberg group.	Port Ewen limestone (not positively identified in this district)	(?)	
		—Hiatus—		
		New Scotland limestone (shaly limestone)	40	12
		Coeymans limestone (coarse, fossiliferous, cherty at top)	40	12
Silurian.		Manlius limestone (fine, gray, compact)	7	2
	Cement beds.	Rondout limestone (water lime)	13	4
		Cobleskill and Decker Ferry limestones (dark, massive, a few thin shaly layers)	35	11
		Binnewater sandstone (not positively identified in this district)	(?)	
		High Falls shale (typical red shale, sandy at bottom)	225	69
		Shawangunk conglomerate (coarse white conglomerate at bottom; red, sandy at top, grading into shale above)	300	91
		—Unconformity—		
Ordovician.		Hudson River slates (fine, dark, slaty, with a few massive graywacke beds)	3,000	914
Cambro-Ordovician.		Post - Wappinger camptonitic dike; Wappinger limestone (fine, massive, dense, gray)	1,000	305
Cambrian.		Poughquag quartzite (strongly indurated)	150	46
		—Unconformity—		
Pre-Cambrian.		See column for Highland district.		

Pre-Cambrian.—The pre-Cambrian formations are identical with those of the Highlands district, previously described. The crystalline rocks form the eastern and southern boundary of the Schunemunk area, presenting, on the eastern margin, a steep, bold westward-facing escarpment overlooking Schunemunk Mountain and the lowland to the west. They also occur in a series of isolated, stranded fault blocks distributed in a southwesterly direction along one of the major structural breaks of the region. The most northerly of these isolated blocks is Snake Hill, in the outskirts of the city of Newburgh, in the northeastern part of the district. Six other detached blocks of similar character and origin occur on the west side of Schunemunk Mountain.

Cambro-Ordovician.—The Poughquag quartzite (Cambrian) is not visible in the portion of the district covered by the itinerary. It occurs in the southern part of the area, where the quartzite rests unconformably upon the upturned and eroded edges of the gneiss. It possesses the same structural and lithologic characters as the quartzite forming part of the Cambro-Ordovician block north of Peekskill (pp. 40–41).

The Wappinger limestone (Cambro-Ordovician), the lithologic and structural characters of which have been described on page 26, forms the rock floor of the lowland south of Schunemunk Mountain and also occurs west, north, and northeast of the mountain. It floors the small fault valley between the east side of Pine Hill and the northwestward-facing escarpment of the crystalline rocks, and it occupies the fault valley between Schunemunk Mountain on the west and the crystalline rocks on the east, from Woodbury Falls northward as far as Mountainville. In the Schunemunk district it is essentially nonfossiliferous.

A small camptonitic dike cuts the Wappinger limestone about 1 mile (1.6 kilometers) south of the town of Monroe, in the southwestern part of the district, outside of the area covered by the itinerary. The dike is similar to the numerous basic dikes cutting all the pre-Cambrian formations of the Highlands district, and its occurrence, here recorded for the first time, raises a question as to the age of the many similar dikes in the crystalline rocks of the Highlands.

The Hudson River formation (Ordovician) is widely distributed in the Schunemunk district west, southwest, north, and northeast of Schunemunk Mountain. Its exact thickness is unknown, but in this district it is certainly over 3,000 feet (914 meters). It consists chiefly of dark slaty shale, in which secondary structures are usually so well developed that it is in places impossible to determine the bedding. Here and there massive graywacke beds are interbedded with the slates, and less commonly calcareous beds, which carry fossils, although the formation as a whole is very sparingly fossiliferous. According to Holzwasser (18)[3] the formation contains Snake Hill beds of

[3] Numbers in parentheses refer to bibliography, pp. 43–44.

Trenton age. The underlying Normanskill of Chazy and Black River age may also be present. It is well exposed on the east side of the river in the vicinity of Poughkeepsie. The rock has been strongly affected by dynamic movements of at least two periods; the beds are accordingly highly tilted, folded and crumpled, broken, faulted, and crushed. The original obscurity in bedding and the complex secondary structures that have obliterated much of the primary characters of the rock render impossible any correct computation of thickness.

Silurian.—The Shawangunk conglomerate is a moderately coarse rock, composed of pebbles of vein quartz and quartzite, compactly cemented with quartz, the whole forming a massive, hard gray to white, highly siliceous rock. At the top the beds grade by transition into the High Falls shale. The formation overlaps and rests unconformably upon the Hudson River formation, of Ordovician age. The Shawangunk occurs along the entire eastern side of the Pine Hill fault block. The beds dip very steeply, forming an eastward-facing high escarpment. The conglomerate also occurs in both limbs of the Idlewild syncline, attaining a maximum thickness in the west limb of nearly 300 feet (91 meters).

The High Falls shale is typically a bright-red shale, grading into red quartzitic sandstone and red conglomeratic sandstone at the base, where it passes into the Shawangunk conglomerate by almost imperceptible transition. The formation is essentially nonfossiliferous. About 70 feet (21 meters) of this shale is exposed in the Pine Hill block, east of Highland Mills, and 128 feet (39 meters) is exposed in the cut at the north end of the Idlewild block. At the south end of the Idlewild block, in the east limb of the syncline, the High Falls shale is faulted against the New Scotland limestone.

The Cobleskill and Decker Ferry limestones constitute the lower members of the "cement beds," which farther north, in the Catskill area, are composed of the Rondout water lime, Cobleskill limestone, Rosendale limestone, and Wilbur limestone. These limestones were formerly used in the manufacture of natural cement at Rosendale, near Kingston, New York. The Cobleskill and Decker Ferry are not separable in this district. Their total thickness is about 35 feet (11 meters). The rock is dark, weathering to brownish colors where exposed, more or less massively bedded, with thin layers of dark shale between some of the thicker beds. Abundant small corals appear in the upper 30 feet (9 meters). In the lower 4 or 5 feet (1.2 to 1.5 meters) there are only a few brachiopods.

The Rondout limestone is best exposed in the New Yor Ontario & Western Railway cut, but it may be traced southwar for about half a mile (0.8 kilometer), where it is cut off by a oblique fault in common with all the other beds from the Coe mans limestone down to the High Falls shale. The formation approximately 13 feet (4 meters) thick, rather massive, with di tinctive Rondout characteristics in the upper part but gradir into the Cobleskill at the bottom. It is somewhat fossiliferou especially in the lower part. There is a bed of sandstone abou 1 foot (0.3 meter) thick near the middle of the formation. Th "cement beds" are restricted to the Rondout, Cobleskill, an Decker Ferry limestones in this district; they have been identifie so far only in the north half of the east limb of the Idlewil syncline.

The Manlius limestone is likewise best exposed in the cut c the New York, Ontario & Western Railway that crosses th north end of the Idlewild block. The formation may be seen t best advantage in the east limb of the syncline, but one sma exposure has been noted in the west limb. It is abruptly term nated in the east limb a little more than half a mile (0.8 kilc meter) to the south by the fault previously mentioned. The lime stone is dark gray, massive, fine textured, and only 7 to 10 fee (2 to 3 meters) thick. The fact that there are fragments of lime stone with Manlius aspect in the base of the overlying Coey mans, together with the slight thickness of the Manlius in thi locality, suggests that more or less erosion of the upper beds c the Manlius occurred before the deposition of the Coeyman limestone. There is therefore a possible hiatus between the Coey mans and the Manlius in this district.

Devonian.—The Coeymans limestone is best exposed in th east limb of the Idlewild syncline, in the New York, Ontario & Western Railway cut across the north end of the Idlewild block and a short distance north and south of the highway about hal a mile (0.8 kilometer) south of the railway cut. The thicknes here is about 40 feet (12 meters). The upper beds are coars textured, cherty, and fossiliferous; the lower beds are much les cherty and finer textured.

The New Scotland shaly limestone in the region north of th Schunemunk district is separated by the Becraft limestone fron the overlying Port Ewen. In the Schunemunk area the Becraf has not been certainly identified. Hartnagel (17) refers to a fev very doubtful outcrops in the Idlewild syncline that might possi bly represent the Becraft, but its presence has never been con firmed. Nowhere else in the Schunemunk area is there any indi cation whatever of the presence of this formation. It is thought therefore, that a hiatus exists between the Port Ewen formation, whose presence in the section is itself somewhat dubious, and the New Scotland limestone.

The New Scotland beds are best exposed in the east limb of the Idlewild syncline, especially in the south end of the east limb, where the High Falls shale is faulted against the limestone. There is a little limonite along the fault contact, which was opened and worked for the limonite as early as 1837. The limestone is very shaly, brown weathering, and very fossiliferous. The exposed thickness is about 40 feet (12 meters). The New Scotland limestone is stratigraphically the highest formation visible in the Idlewild syncline, as the middle portion containing the higher formations is low, swampy, and entirely covered.

The Port Ewen beds (?), tentatively so assigned by Clarke (14) but possibly belonging to the Oriskany, comprise thin-bedded siliceous sandstone and intercalated thin shale beds, exposed in the south end of the railroad cut at Highland Mills. No limestone of Port Ewen type occurs here. The interbedded shale layers range from 1 to 3 feet (0.3 to 0.9 meter) in thickness. No Port Ewen limestone is exposed in the Idlewild syncline, but it may be present covered with soil and glacial débris.

The Oriskany sandstone in the railroad cut at Highland Mills consists of thick-bedded grayish-green sandstone with intercalated shale and thinner-bedded sandstone and a few fossiliferous lenslike masses. If the Port Ewen (?) beds are really Oriskany, as recent work seems to indicate, the Oriskany in the railroad cut at Highland Mills has an exposed thickness of 188 feet (57 meters). Farther north, between the north side of Pea Hill and the south end of the Idlewild syncline, there is a small exposure of conglomerate with quaquaversal dips in which a few poorly preserved Oriskany fossils have been found.

The Esopus and Schoharie grits are well exposed in the railroad cut at Highland Mills, where they have a thickness of 177 feet (54 meters). They are very fossiliferous in places, *Spirophyton caudagalli* being especially prominent in many of the beds. They pass by imperceptible gradation into the underlying Oriskany beds exposed in the same cut. They consist of thin to thick bedded dark-bluish to purplish sandstone with a few thin shale seams. The same formation is exposed on the west side of Pea Hill, just south of the Idlewild syncline.

The Kanouse grit, which takes the place of the Onondaga limestone in the Schunemunk region, is a gray sandy grit carrying fragmentary and sparsely distributed fossils, with, however, a few fossiliferous beds. There are exposures of such beds in the Pine Hill fault block, north of the railroad cut at Highland Mills, in the woods up the slope of the hill. Talus blocks at the foot of the almost vertical ledge carry numerous fossils indicating a Schoharie fauna. Only the face of a small ledge is exposed; the rest of the formation is concealed under a thick cover. It is possible that a hiatus exists between the overlying Cornwall shale and the Kanouse grit.

The Cornwall shale is a black to dark-gray fissile slaty shale, sparingly fossiliferous. The fauna is lower Hamilton. This shale underlies and surrounds the base of Schunemunk Mountain and forms part of Pea Hill, near the northeast end of the mountain, where it has an approximate thickness of 200 feet (61 meters).

The Bellvale flags consist of thin-bedded, flaggy hard grayish sandstones or graywackes, underlying the Schunemunk conglomerate. They form the major part of Schunemunk Mountain, where they have an estimated thickness of 1,300 feet (396 meters). The upper beds are massive and quartzitic, with a few beds of conglomerate. The lower beds are more flaggy with intercalated black slaty shale, merging into dark slaty shales below that constitute the Cornwall shale.

The Schunemunk conglomerate is made up of white quartz and reddish quartzite pebbles and small boulders ranging from 1 to 6 inches (2.5 to 15 centimeters) in diameter, closely packed in a red to brownish hard quartzitic matrix. In the basal beds the pebbles decrease in size and quantity and the matrix becomes a grayish sandy quartzite, which constitutes a series of transition beds to the underlying Bellvale flags. The conglomerate lies on the extreme summit of Schunemunk Mountain and has an estimated thickness of 300 feet (91 meters).

Quaternary.—The usual glacial dêbris, both sorted and unsorted, common to the whole region, and later stream deposits represent the Quaternary of this district.

MAJOR STRUCTURAL FEATURES

All the formations in the district except the glacial drift and the massive pre-Cambrian granites have been folded during three different periods—pre-Cambrian, post-Ordovician, and post-Carboniferous.

The pre-Cambrian folding is reflected only in the remnants of ancient schist involved with the later intrusive granites of pre-Cambrian age. As explained in the description of the structural features of the pre-Cambrian crystalline rocks in the Highlands district, the granites themselves present no evidence of folding; such structures as they possess are believed to be inherited from the schists into which they were intruded.

The post-Ordovician folding is presumably Taconic.

The Silurian and Devonian rocks of the district have all been much affected by Appalachian folding, but in many of the folds the distortion of the beds has been intensified by crowding during the block faulting of Triassic time. This is especially true in the several fault blocks in the area in which the beds stand at very high angles.

Faults are very prominent features of this district. Aside from possible pre-Cambrian faults, there are major structural breaks belonging to at least two periods—Appalachian and Triassic. If Taconic faults exist, as is quite possible, they have not been distinguished from the faults of Appalachian time.

The prominent structural zones in the Schunemunk quadrangle cross it with a southwesterly strike.

Schunemunk Mountain is the extreme northeastern end of a regional syncline that pitches southwestward, extending into New Jersey. The mountain is cut off by faults on all sides, and the basal beds of the northern part show the effect of much crowding and intraformational movement. The original dips of the beds of this portion of the syncline have been much accentuated by crowding and squeezing during the block-faulting movements of Triassic time, so that the Bellvale flags and Cornwall shales are almost vertical at the base of the mountain.

The Pine Hill fault block is a portion of the broken eastern limb of the same regional syncline.

Pea Hill and the Idlewild syncline constitute another broken and offset portion of the general syncline, forming an independent minor fault block cut off on all sides by faults.

The escarpment of pre-Cambrian crystalline rocks forming the eastern boundary of the Schunemunk district is a fault-line scarp; the crystalline rocks have been overthrust upon the Hudson River slates in the northeastern part of the district and upon the Wappinger limestone in the middle and southeastern part. The continuity of the thrust fault is interrupted by cross faults of Triassic age which offset the escarpment.

Another prominent thrust fault crosses the area several miles to the west of the one just mentioned, on the west side of Schunemunk Mountain. This fault also is broken and offset by many Triassic cross faults. A great normal fault of Triassic age trending northeast enters the district in the vicinity of the city of Newburgh, cuts off Snake Hill on its eastern side, splits at the north end of Schunemunk Mountain, and runs along both the east and west sides of the mountain. This fault likewise is broken and offset by Triassic cross faults. These structural conditions have produced the detached, isolated hills of pre-Cambrian crystalline rocks distributed along the line of the westernmost thrust, which begin with Cronomer and Snake Hills, in the vicinity of Newburgh, at the north, and which are scattered along the west side of Schunemunk Mountain. They are stranded fault blocks overthrust on the Hudson River slates on their west sides, usually faulted against the Wappinger limestone on their east sides along the great northeasterly normal Triassic fault just mentioned, and cut off and offset on their northeast and southwest sides by the slightly later cross faults of Triassic age.

Snake Hill, in the northern part of the Schunemunk quadrangle is brought into contact with the Hudson River slates on the west side by the thrust fault just mentioned and on the south end by a Triassic cross fault.

In the Storm King overthrust, which is parallel to but east of the thrust fault mentioned above, the Storm King granite is brought into fault contact with the Hudson River slates. Shattered blocks of Wappinger limestone, underlying the Hudson River formation, have been dragged up and forced into the Hudson River slates, which now completely surround them.

TRIASSIC DISTRICT

[F, pls. 3, 4]

Two formations are included in the itinerary in the Triassic district—(*a*) red sandstones and shales, including a little conglomerate, and (*b*) an intrusive sill of diabase—both members of the Newark group, which extends from Stony Point, New York, on the Hudson River, southward through New Jersey, Pennsylvania, and Maryland into Virginia. The escarpment of the diabase sill forms the west bank of the Hudson River from a point just below Haverstraw, where it makes a sweeping curve in a westerly direction, as far south as Jersey City. The section between Stony Point and Haverstraw is part of the Triassic lowland. The basal member of the Newark group is a conglomerate; under the diabase sill forming the Palisades of the Hudson the basal member is a coarse buff to pinkish arkose. By far the greater part of the formation consists of reddish to reddish-brown sandstones, in places micaceous, and shales, with a few intercalated beds of gray and buff sandstone and mottled shale.

Exposures are rare in the portion of the Triassic lowland between Stony Point and Haverstraw. There is, however, a small exposure of the conglomerate along the highway just north of Haverstraw. The basal conglomerate presumably rests unconformably upon the older rocks at Tompkins Cove, but the contact relations are obscure. Just south of Haverstraw the sandstones pass underneath the diabase sill.

The diabase is intrusive between the beds of the sandstone and shale, but in places the sill cuts across these beds, following a higher horizon. The diabase and the inclosing sandstone dip 8°–15° W., and not uncommonly the eastward-facing escarpment is offset and the base of the sill dropped to river level by Triassic faults, which cut across the strike of the formations obliquely. The largest fault of this character lies between Piermont and Sparkill, about 2 miles (3.2 kilometers) north of the boundary line between New York and New Jersey.

The maximum thickness of the diabase is not less than 800 feet (244 meters). It is very fine textured at and near the lower contact with the underlying sandstone, but it becomes coarser some 20 feet (6 meters) above the bottom. At 30 to 50 feet (9 to 15 meters) above the base there is an olivine-rich zone from 10 to 30 feet (3 to 9 meters) thick which extends almost the entire length of the sill from south to north. Above this zone the diabase increases in coarseness, and interstitial quartz and quartz in micrographic intergrowths with feldspar appear, the rock becoming very coarse textured toward the top of the sill.

Owing to the westward dip and the beveling of the top of the sill by post-Tertiary erosion, the contact with the overlying sandstone is covered in most places, but the lower contact is exposed at many places, affording opportunity for the observation of contact phenomena. Various sorts of hornfels have been developed. These owe their differences in composition and character to original differences in the composition of the shales and sandstones at slightly different horizons along the base of the sill. The hornfels derived from the shale is so fine textured that the metamorphic products composing it may be seen only in thin section. Albite, biotite, quartz, pyroxene, hornblende, tremolite, garnet, spinel, magnetite, specularite, muscovite, cordierite, scapolite, vesuvianite, sillimanite, andalusite, chlorite, calcite, titanite, and tourmaline have been recorded as occurring in the hornfels.

The sandstone was less affected than the shale by the emanations from the diabase, but it shows modification in the form of induration and mottling, and much of the feldspar in the arkosic varieties is recrystallized.

ITINERARY

METROPOLITAN DISTRICT (A)

1.[4] Northward from university on Amsterdam Avenue to 125th Street. One block to the east an eastward-facing escarpment of the Manhattan schist overlooks a wide valley floored with Inwood limestone.

[4] Numbers refer to Plates 3 and 4.

The cross depression, looking northeastward up Amsterdam Avenue, deepest at 125th Street, is due to erosion along the Manhattanville cross fault. The ridge of schist terminates abruptly at 123d Street. The schist is exposed on the east side (right) of Amsterdam Avenue between 121st and 123d Streets.

2. Eastward on 125th Street to St. Nicholas Avenue. The Manhattanville cross fault. (See fig. 3.)

3. Northward on St. Nicholas Avenue to 155th Street, where the Speedway is entered. The schist ridge is offset by the Manhattanville cross fault. Eastward-facing escarpment of schist on west side (left) of St. Nicholas Avenue. Inwood limestone (not exposed) floors the Harlem Valley.

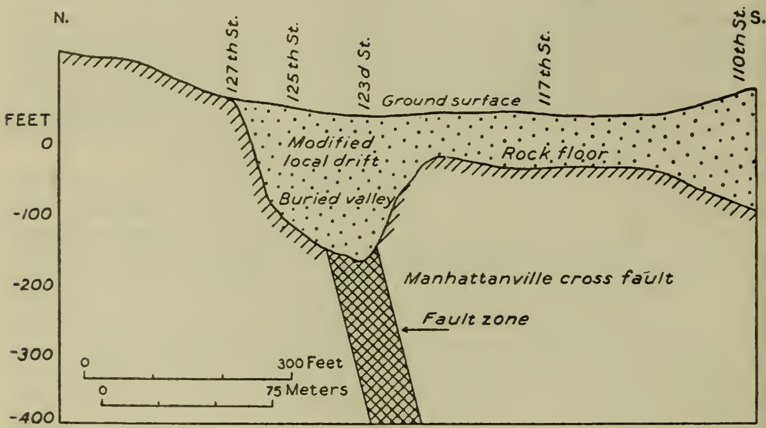


Figure 3.—Section showing buried valley at 125th Street and Manhattanville cross fault. (After Berkey)

4. Along Speedway to Nagle Avenue and 204th Street, turning east at 207th Street and crossing bridge over the Harlem River to Fordham Road. Along the Speedway Manhattan schist is exposed on the west side (left) in an eastward-facing escarpment, fronting the Harlem River. The river valley is cut on upturned Inwood limestone. (See fig. 4.) The ridge on the east side of the river is Fordham gneiss, exposed in a westward-facing escarpment. Pegmatite dikes and sill-like bodies occur in the schist.

5. Eastward on Fordham Road to Southern Boulevard and Bronx Park, the route crosses the strongly folded series of metamorphic rocks of the Metropolitan district in a direction almost at right angles to the axes of the folds. No exposures.

6. Bronx Park to Bronx River Parkway.

7. Northward on Bronx River Parkway to Mount Vernon. Fordham gneiss on the west (left). The Bronx River flows in a valley floored with Inwood limestone (no exposures). The westward-facing escarpment walling the east side of the valley is Manhattan schist.

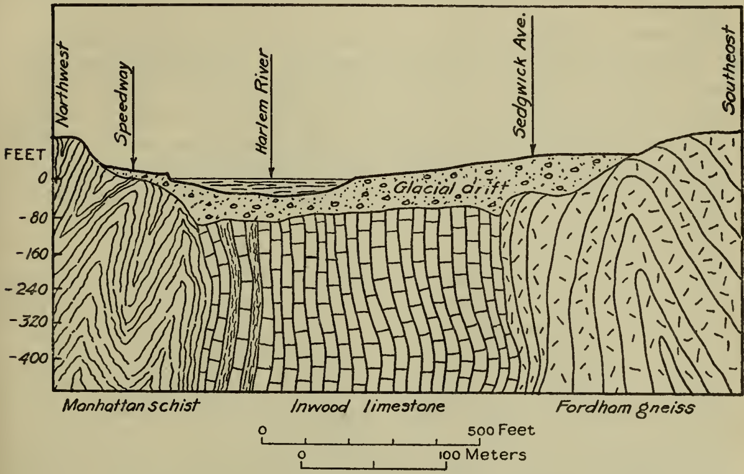


FIGURE 4.—Section at East 167th Street, south of High Bridge. (After Berkey)

WESTCHESTER-KENSICO DISTRICT

8. Mount Vernon northward along Bronx River Parkway to Kensico Dam and Reservoir. The route continues northeastward, essentially along the strike of the formations. Fordham gneiss forms the ridges on the west; Manhattan schist is on the east except in places where there are minor upfolds of the gneiss. Where the valley is wide the extreme width is due in part to the pitch of the folds, in part to an apparent increase in the thickness of the Inwood limestone by repeated folding.

KENSICO-PEEKSKILL DISTRICT

9. From Kensico Dam northward along east side of reservoir on highway 22. Near the Kensico Dam the highway turns northward and crosses the folds obliquely. Owing to this turn the Manhattan schist at the dam is on the west side of the valley, and the high ground on the east is Fordham gneiss. The valley is cut in Inwood limestone. The Yonkers gneissoid granite and its associated pegmatites are intrusive into the Fordham gneiss at this point.

At the north end of the Kensico Reservoir the route turns westward, crossing the northeastward striking folds obliquely, and continues in this direction as far as Briarcliff Manor. Here it turns northwestward and crosses the structure at right angles to the axes of the folds as far as Crugers, where the Cortlandt series is encountered just north of the tracks of the New York Central Railroad.

Between the Kensico Reservoir and Crugers a schist, probably the equivalent of the Manhattan schist; a crystalline limestone essentially the same as the Inwood limestone; and a gneiss equivalent to the Fordham gneiss occur repeatedly owing to folding and to numerous thrust faults with northeast strike. The sequence and the metamorphic and lithologic characters are the same as in the Manhattan-Inwood-Fordham series of the Metropolitan district.

The Cortlandt series is a basic igneous complex intrusive into the Manhattan schist and carrying in places inclusions of the schist and of Inwood limestone. It is composed of peridotite, pyroxenite, hornblendite, gabbro, norite in several facies, and diorite. The Peekskill granite is supposed to be an acidic differentiate of the series. Numerous small dikes of various sorts, of which pegmatite is the most common, cut the basic rocks. Abnormal contact rocks occur along the borders and here and there within the mass itself, the latter representing blocks of the schist that have suffered complete endomorphic changes. In the past such places were operated as a source of emery.

HIGHLANDS DISTRICT

10. The downfaulted Cambro-Ordovician block. (See fig. 5.) Cross bridge across Peekskill Creek; turn northeastward along southeast side of downfaulted block to pumping station. Observe Wappinger limestone on north bank of creek at pumping station, conformable with overlying Hudson River phyllite that constitutes Gallows Hill. Northeastward, crossing to northwest side of Gallows Hill, and southwestward along road to Sprout Brook. Observe interbedded Grenville limestone, with the gneiss overlying and underlying the limestone. Climb up hill to fault contact of pre-Cambrian crystalline rocks and Ordovician Hudson River phyllite. Through cut in Cambro-Ordovician block to bridge. Cross bridge over Peekskill Creek, to Bear Mountain Highway. Observe Wappinger limestone (Cambro-Ordovician) and Poughquag quartzite (Cambrian). Also pre-Cambrian quartzite, provided the exposures are not destroyed in 1933 by building. The chief features of interest connected with this infaulted block of Cambro-Ordovician sediments are as follows:

(*a*) The limestones on each side of the phyllite, one (the Wappinger) of Cambro-Ordovician age, the other (interbedded) of pre-Cambrian age, each totally different in appearance and physical condition. The interbedded limestone is between the Canada Hill granite on the northwest, and the Reservoir granite on the southeast. The Reservoir granite is in fault contact with the phyllite.

(*b*) The great fault, by which the phyllite, of Ordovician age, has been downthrown against the pre-Cambrian crystalline rocks.

(*c*) The Hudson River phyllite, the most strongly metamorphosed example of the Hudson River formation in the region.

(*d*) The Wappinger limestone, which is at least two and one-half times as thick as in any other known occurrence, owing to

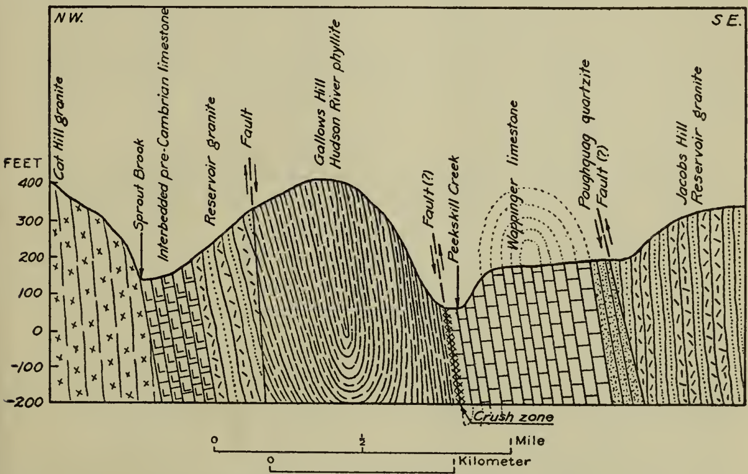


FIGURE 5.—Section across downfaulted block at Peekskill

folding; and the Poughquag quartzite, in close juxtaposition to a pre-Cambrian quartzite phase of the gneiss, called the Lowerre quartzite.

11. Northward along Bear Mountain Highway to Bear Mountain Bridge. Observe the complex pre-Cambrian crystalline rocks, including the Canada Hill granite.

12. Cross Bear Mountain Bridge and around Bear Mountain. Observe "Hell Hole," a deep, narrow ravine eroded along a fault zone; crush zones in Storm King granite; crushed camptonitic later dikes, cutting Storm King granite; and remnants of old schists involved with the granite. The rock of Bear Mountain is Storm King granite, but it is mixed with considerable older schists and gneisses.

13. From Bear Mountain southward along Seven Lakes drive to Queensborough, westward over road across the pre-Cambrian crystalline complex, and southward to western fault-line escarpment of the crystalline rocks; thence to Central Valley. The formations traversed consist of mixed granitized pre-Cambrian metamorphic rocks, with small irregular patches of granite and pegmatite.

SCHUNEMUNK DISTRICT

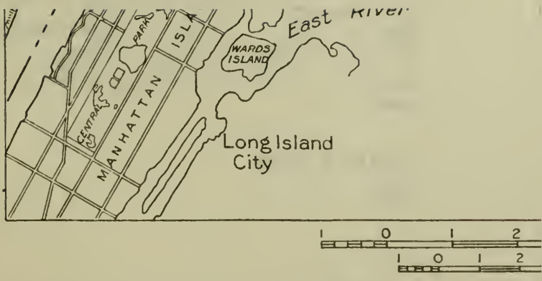
14. Fault valley and Pine Hill fault block. From Central Valley (Paleozoic sediments) to Highland Mills station. Inspect Oriskany, Schoharie, and Esopus beds at station. From station eastward and northward along old road on Pine Hill fault block, observe High Falls shale and Shawangunk conglomerate, downfaulted and upturned. Return to main highway, thence eastward and northward along east side of Pine Hill fault block, and around on north side, westward to State road. Paleozoic sediments of Pine Hill on south side of fault; pre-Cambrian crystalline rocks on north side of fault. Schunemunk fault block on west side of valley.

15. Schunemunk Mountain, Pea Hill, Idlewild syncline, and Snake Hill. North on State road between pre-Cambrian crystalline rocks on east and Schunemunk Mountain on west, to Mountainville. Leave route 32 at Mountainville, cross Newburgh branch of Erie Railroad, cross bridge over Moodna Creek; northward to Pea Hill to Mr. Ogden's place. Inspect Cornwall shale; if time permits, walk over Schoharie and Esopus shales to Moodna Creek. Observe upturned beds, fossils (*Spirophyton caudagalli*).

16. From Mr. Ogden's place to south end of Idlewild syncline. Observe Shawangunk-High Falls, in east limb, and High Falls faulted against New Scotland. Thence to Cornwall station and north to Snake Hill. (See fig. 6.) Observe Wappinger, overturned and faulted down against the pre-Cambrian crystalline rocks of Snake Hill; and Hudson River slates on west side over which the crystalline rocks are thrust. Example of "floating fault block."

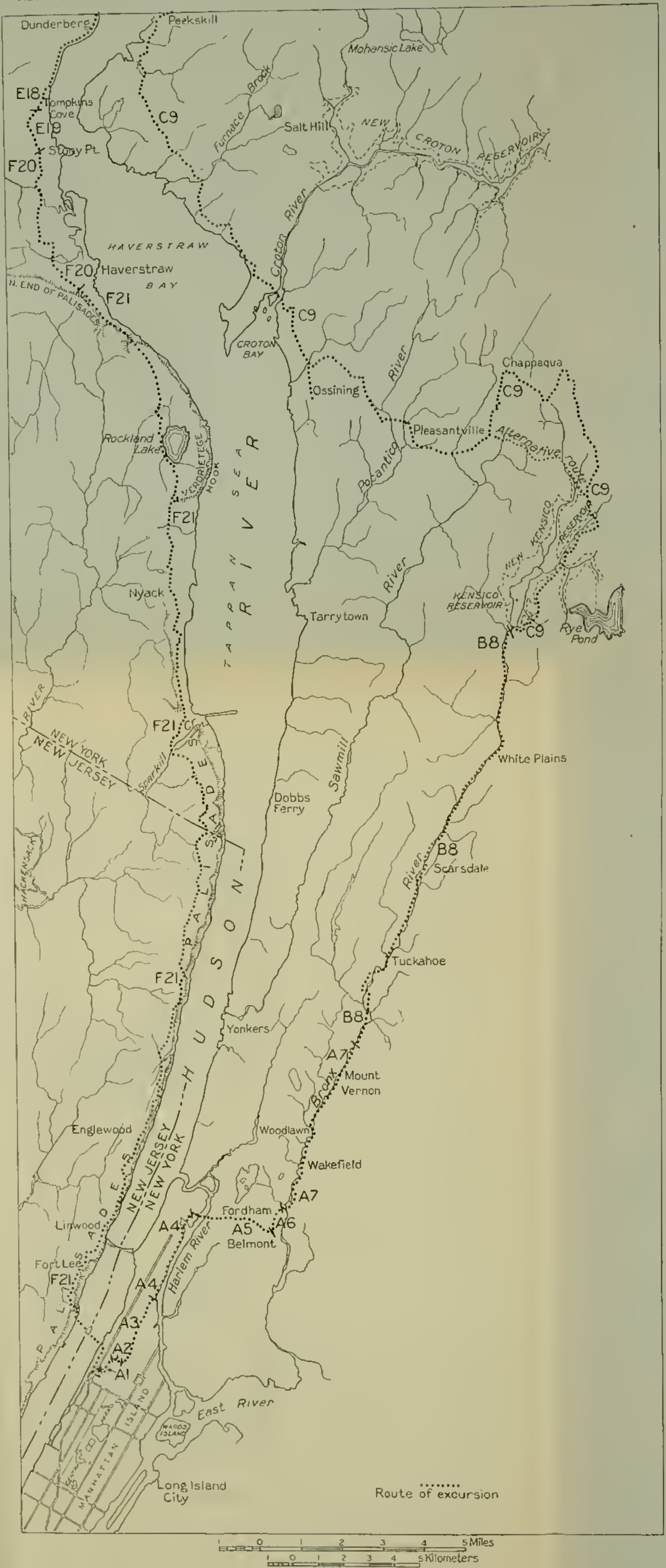
17. Storm King overthrust. Return on same road southward to Orr's Mills, thence eastward to Cornwall village, thence to Cornwall Landing, and short detour to observe Storm King granite overthrust on Hudson River slates.

18. Returning along Storm King Highway, passing Bear Mountain Bridge and inn, and south to Tompkins Cove. Pre-Cambrian crystalline rocks all the way. Several great faults crossed between these two points.



ROUTE MAP, NEW YORI

A1, etc., localities mentio



ROUTE MAP, NEW YORK TO DUNDERBERG

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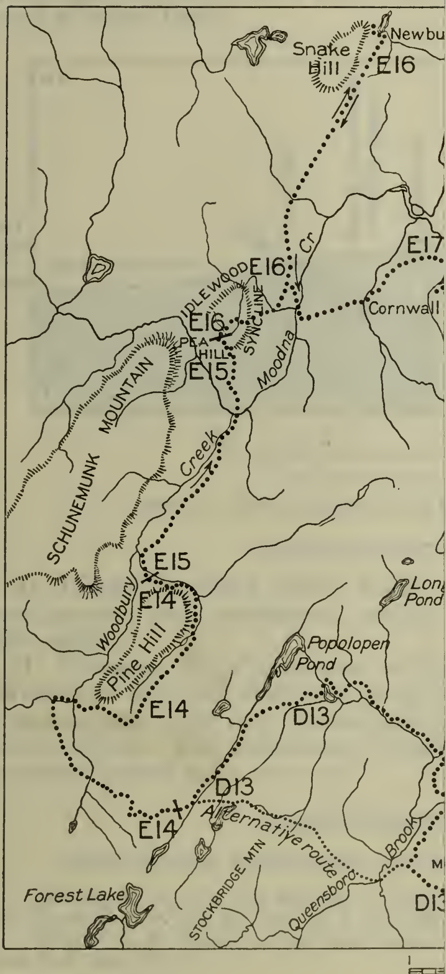
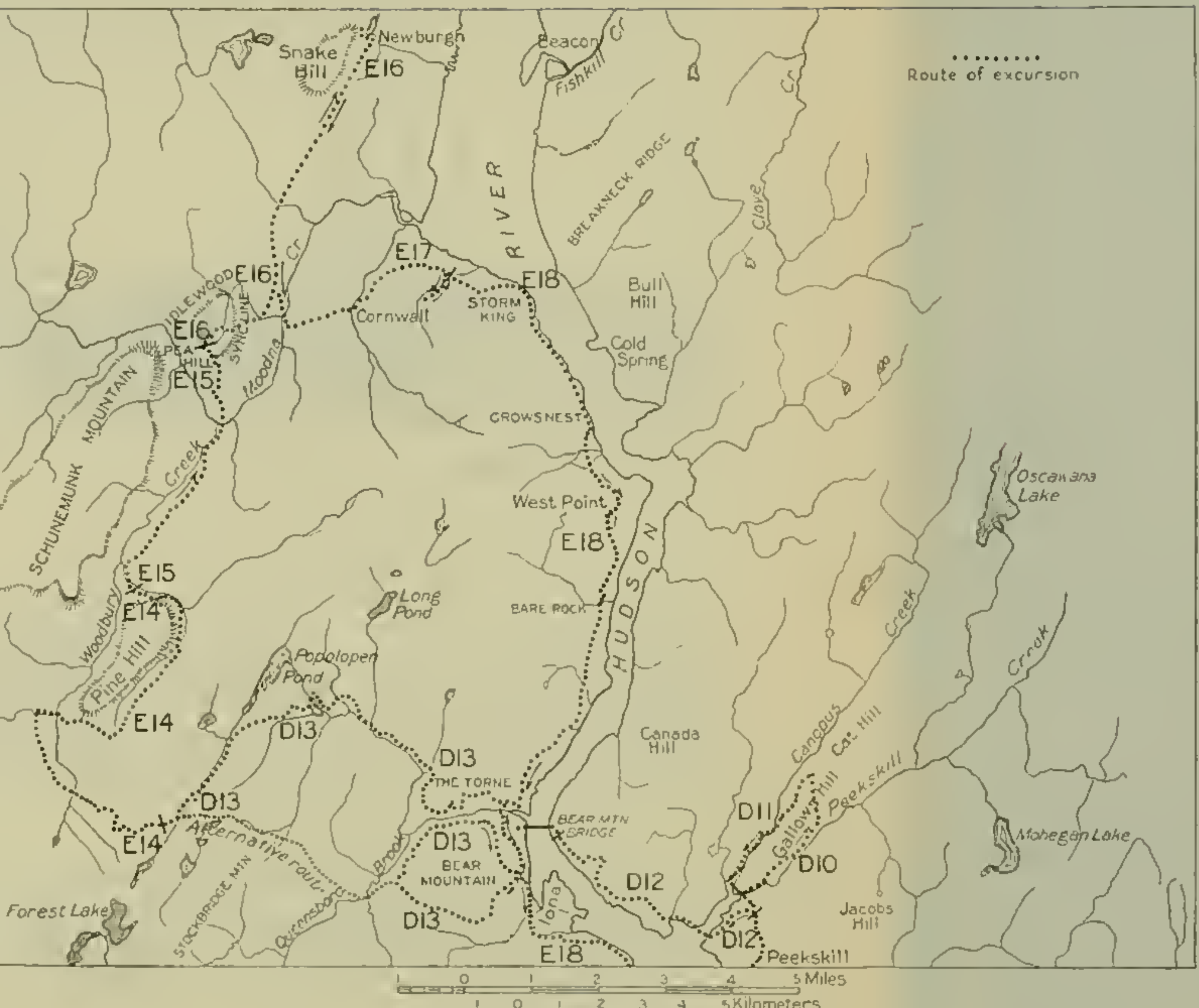


ROUTE MAP,
D10



ROUTE MAP, PEEKSKILL TO SCHUNEMUNK MOUNTAIN
D10, etc., localities mentioned in itinerary.

19. Tompkins Cove and Stony Point. An extension southwestward of the great fault separating the downfaulted Cambro-Ordovician block at Peekskill, on the northwest side, from the pre-Cambrian crystalline rocks. Small block of Hudson River-Wappinger, the Ordovician limestone extending a little to the south of Stony Point.

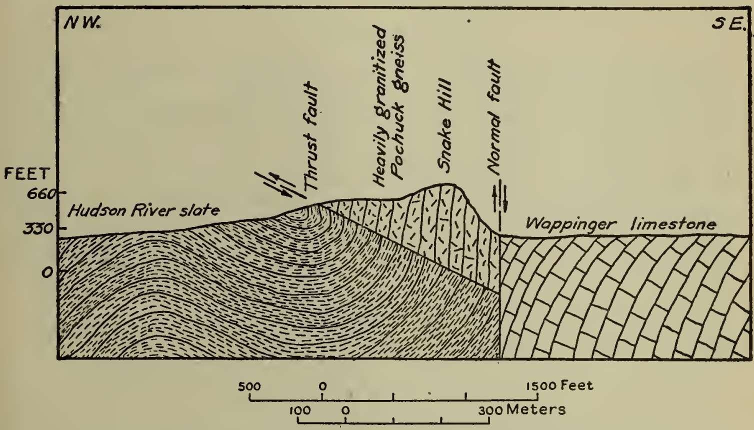


FIGURE 6.—Section across Snake Hill, Newburgh

TRIASSIC DISTRICT

20. Triassic Lowland, Stony Point to Haverstraw. Triassic conglomerate and sandstones, resting unconformably on the older rocks.

21. Palisades sill. Haverstraw to Edgewater. Just south of Haverstraw the north end of the great intrusive sheet of diabase is encountered. The route follows this sill southward to the end of the journey. The underlying Triassic sandstone may be seen at several places along the way.

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GEOLOGIC FEATURES FROM THE WATCHUNG MOUNTAINS TO SANDY HOOK

By A. O. Hayes

The first part of the excursion inland through the Piedmont country (see pl. 5) crosses the lower portion of the Newark group, continental sediments of Triassic age, and the associated intrusive diabase sill and extrusive trap rocks. The second part of the trip crosses the Coastal Plain, where the Raritan formation, of Cretaceous age, will be seen resting unconformably upon the Newark sediments, and fossil localities in the marine Upper Cretaceous greensands will be visited.

The terminal moraine of the Wisconsin ice sheet will be crossed inland and again along the coast. In addition, the party will examine the coastal features in the vicinity of Sandy Hook, where shore currents have added greatly to the length of this youthful peninsula in recent time.

ITINERARY

New York City to Newark.—From New York to Jersey City the route lies through the Holland Tunnel under the Hudson River. The estuary of the Hudson is filled with fine silt to a depth of over 200 feet (61 meters), covering an ancient rock-cut channel revealed by drilling. The Holland Tunnel rests in the silt. The Hackensack River between Jersey City and Newark and the Passaic River at Newark will be crossed by bridges, from which may be observed their wide valleys entirely filled except for a relatively small meandering waterway kept open by the tidal currents. The Raritan River and other streams show similar evidence of a drowned coast. At Jersey City the southern extension of the Palisade sill, which is intrusive into the Newark sediments, of Triassic age, is exposed in diabase outcrops.

Newark group.—The first rock outcrops seen are jointed diabase at Jersey City. These form part of a thick sill intrusive into sediments belonging to the lower part of the Newark group, of Upper Triassic age. The thickness of the Newark rocks is not exactly known but is estimated to approximate 15,000 feet (4,600 meters). The group is divided into three sedimentary formations—the Stockton at the base, an iron-stained sandstone, conglomeratic in part, intruded by a thick diabase sill; the Lockatong, a fine-grained silicified argillite, typically exposed at Princeton, where it is quarried for use as a building stone; and the Brunswick formation, composed largely of red sandstone and shale with interbedded lava flows. The intrusive diabase sills, stocks, and basaltic flows form a part of the Newark group, and these harder rocks have offered greater resistance to erosion and stand out as hills and ridges, giving a pleasing relief to the Piedmont region of central New Jersey. The Palisades of the Hudson are formed by a continuation of the westward-dipping sill. The outcrop of the sill can also be followed southward to Carteret, where it is overlain by the flat-lying sand and clay of the Raritan formation, of Upper Cretaceous age. The sill appears again south of New Brunswick. The lowered surface of the sill suggests that it was deeply eroded along the course of the present Raritan River by a larger stream prior to Upper Cretaceous time. The cultural features have masked much of the bedrock geology, so that few exposures of the Brunswick formation are seen in the vicinity of Newark.

Westfield to Plainfield.—At Westfield the Wisconsin terminal moraine is approached, and occasional boulders are to be seen. At Mountainside the highway has been cut through the knobs, exposing boulder clay. The kettle and knob topography typical of terminal moraines is to be seen for a distance of about 2 miles (3.2 kilometers). This moraine rises about 50 feet (15 meters) above the surrounding surface and extends across the entire State in a northwesterly direction, from Perth Amboy on the east to the Delaware River on the west.

Bound Brook.—From Mountainside to Bound Brook the First Watchung Mountain forms the prominent feature to the west. The steep hill slope is due to the outcrop of the edge of the northwestward-dipping basaltic lava flows. At Bound Brook the Brunswick shale and associated Watchung basalt are seen to dip about 12° N. The contact of the bottom lava flow and the shale may be seen on the north bank of the brook opposite the quarry and also on the quarry floor. A slight change in color from brick-red to a purplish tinge penetrating to the depth of a centimeter, more or less, is the only visible metamorphic effect of the flow on the underlying rock.

From Chimney Rock, a conspicuous remnant of erosion on top of the ridge opposite the quarry, several irregular flows can be seen. The flows are more easily weathered along their tops, owing to the fact that the scoriaceous upper part of each flow became filled with calcite and zeolites, and these soluble minerals have more easily weathered out. Two or more of the basal or earliest flows may be seen in the face of the quarry, which, however, exposes only about one-fifth of the total thickness of basalt of First Watchung Mountain. The overlying flows may be seen along the road that follows upstream over the ridge to the valley beyond.

From Chimney Rock the Second Watchung Mountain is visible parallel to the First. North-south transverse faults, or master joints, occur in the quarry, and the brook flows along their line of strike and suggests that the deep valley across the flows was initiated along such lines of weakness.

Native copper is found at a number of places beneath the lava flow and also is found in the vicinity of the diabase sills. J. V. Lewis concluded that the copper was due to later igneous intrusions from which the copper was deposited in joint cracks and faults.

Bound Brook to New Brunswick.—The route follows down the southwest bank of the Raritan River, and attention may be drawn to the geomorphic features. The valley is wide, and several terraces are seen, in the lowest of which the present stream follows incised meanders indicating the most recent regional uplift. The lowland extending south and east of the First Watchung Mountain is called the Somerville Plain. This was developed in late Tertiary time by uplift and dissection of an older peneplain, preserved now only by the accordant flat-topped ridges of the Appalachian and Watchung Mountains. This older dissected plain, named the Schooley peneplain, is thought by Douglas Johnson to have been preceded by a still older surface of erosion preserved now only beneath the Cretaceous sediments. The oldest peneplain, named the Fall Line peneplain, will be seen at Piscataway.

Rutgers Geological Museum.—Dinosaur footprints have been found in the Triassic Newark group from the earliest geologic studies in the region in both the Connecticut Valley and New Jersey, but footprints in Cretaceous sediments were not found until recently. In 1930 eight footprints were uncovered in the Hampton Cutter quarries at Woodbridge, New Jersey, and five of them are preserved in the museum at Rutgers University. Helgi Johnson, paleontologist at Rutgers, has given the following information regarding the tracks:

> Although the genus and species are indeterminable, the tracks can be said to belong to the Theropoda, or strictly bipedal carnivorous type of Dinosauria. The footprints would indicate an animal at least 20 to 25 feet [6 to 7.6 meters] in length and of fairly massive build, probably closely allied to *Allosaurus* but considerably larger and of later age. The track was embedded in the clay as the animal walked along the still moist surface, and owing to a submergence or the flooding of a delta it became filled in with rapidly drifting sands. The discovery throws some light on the correlation of the Cretaceous of the Atlantic coast with that of the western districts of the United States and also helps in the more complete understanding of paleogeographic conditions existing at the time of deposition of the clays of the Jersey coastal plain.

The Triassic rocks contain footprints of several species, including *Tridentipes ingens* E. Hitchcock, *Eubrontes giganteum* E. Hitchcock, *Anchisauripus minusculus* (E. Hitchcock), *Anchisauripus sillimani* (E. Hitchcock), *Eubrontes divaricatus* (E. Hitchcock), *Anomoepus intermedius* E. Hitchcock, *Anomoepus crassus* (C. H. Hitchcock), and *Batrachopus gracilis* (E. Hitchcock).

Unconformity between the Newark group and Raritan formation.—The Newark group is well exposed in the valley of Mill Creek, and the basal soft sands and clays of the Raritan formation may be seen resting apparently horizontally upon the truncated edges of the Newark indurated red sandstones and clays. It is supposed that the interval of erosion here represented extended through Jurassic, Lower Cretaceous, and Middle Cretaceous time. The highly cross-bedded nature of the sands suggests deltaic origin, and contemporaneous local lenses of clay appear to have been formed in lakes or bayous in the delta of some large Cretaceous estuary. The Cretaceous sediments dip gently to the southeast. The Raritan formation is approximately 500 feet (152 meters) thick, and the top of it crops out in the vicinity of Keyport. The absence of marine fossils suggests that the estuary contained a large stream of fresh water, preventing marine life until the subsidence of the region allowed an overlap of the greensands and shales, which are now found overlying the Raritan formation.

Keyport.—At Lorillard, east of Keyport, the Woodbury clay, of Upper Cretaceous age, is exposed in the pits of the National Fireproofing Co. A layer of black clay about 20 feet (6 meters) thick contains limonite concretionary nodules of varying size and abundantly fossiliferous. A few of the species found here are the following:

Pelecypoda:
- *Nucula whitfieldi* Weller.
- *Yoldia longifrons* (Conrad).
- *Cucullaea woodburyensis* Weller.
- *Axinea congesta* (Conrad).
- *Pecten conrădi* (Whitfield).
- *Cardium ripleyanum* Conrad.
- *Corbula lorillardensis* Weller.

Gastropoda:
- *Amauropsis meekana* Whitfield.
- *Turritella lorillardensis* Weller.
- *Fusus lorillardensis* Weller.

Cephalopoda:
- *Placenticeras placenta* (DeKay).
- *Baculites ovatus* Say.

Beers Hill and Crawford's Corner.—In a deep cut at Beers Hill, on the highway between Keyport and Holmdel, one of the best exposures of Upper Cretaceous strata occurs. Nearly 50 feet (15 meters) of the sediments exposed constitute the Redbank sand, which ranges from yellow and red ferruginous sands to greensands. Fossils are abundant in a layer of brown or yellowish sand, which is glauconitic and somewhat indurated, belonging to the Tinton sand member in the upper part of the Redbank sand. Some of the common fossils found are listed below:

Pelecypoda:
- *Axinea subaustralis* D'Orbigny.
- *Pecten venustus* Morton.
- *Cucullaea littlei* Gabb.
- *Cucullaea tippana* Conrad.
- *Trigonia cerulia* Whitfield.
- *Cardium kümmeli* Weller.

Gastropoda:
- *Margarita abyssima* (Gabb).

Crustacea:
- *Callianassa conradi* Pilsbry.
- *Callianassa mortoni* Pilsbry.

Cucullaea littlei Gabb is very common, also cylindrical tubes which are described by Weller (28, p. 147) [5] as "more or less cylindrical, vertical bodies, probably burrows of some sort or vegetable in origin." Many of the shells have been replaced by a blue mineral, the phosphate of iron, vivianite. Ten feet (3 meters), more or less, of Hornerstown marl, which is now considered Tertiary, extends to the top of the hill, which rises 390 feet (119 meters) above sea level. This formation is composed of a greensand, more or less indurated with iron, and is apparently unfossiliferous.

Crawford's Corner is one of the few localities where fossils are found in the upper part of the Wenonah sand. Imperfect internal casts and molds are reported in the grayish and yellow sands of this formation. About 25 feet (7.6 meters) of gray and dark greensand of the Navesink formation overlie the Wenonah conformably. The fossiliferous bed of this formation is limited here to about 2.5 feet in which the most abundant species are *Gryphaea convexa* Morton, *Ostrea mesenterica* Morton, and *Terebratella plicata* Say. *Belemnitella americana* Morton and 47 other species of Mollusca are reported but occur rather sparingly.

[5] Numbers in parentheses refer to bibliography, p. 52.

SANDY HOOK

On a clear day a good view can be obtained from Navesink Highlands across Raritan Bay, with Sandy Hook to the northeast and Coney Island on the north coast of the bay. Staten Island lies to the northwest. Sandy Hook extends 6 miles (9.6 kilometers) northward across the bay from Navesink Highlands and connects south of this point with a bay bar that joins the mainland in the vicinity of Monmouth Beach. It is formed primarily of sand eroded from the shore of southern New Jersey and carried northward by tidal currents.

Figure 7 shows that Sandy Hook is a complex, compound hooked spit. The two points on the west side are thought by D. W. Johnson to mark the ends of the hook in former times. Col. J. C. Johnson, formerly in command of Fort Hancock, on Sandy Hook, states that the earlier maps of the spit show that its tip in 1764 was at the old lighthouse, now about 1 mile (1.6 kilometers) south of the point of the peninsula, and about 1865 it was at the Civil War fortifications, now approximately half a mile (0.8 kilometer) from the north end. Island Beach and the beach on the northeast side of Navesink Highlands are the sites of the ends of the spit in still earlier stages of its development. The recurved hooks on the west side appear to have been formed by tidal currents and may have been modified also by littoral currents in the bay produced by northwest winds. At present the tendency is to broaden the end of the hook, which extends westward into the bay, by erosion at the point and deposition on each side. A protecting structure of timbers and stone blocks has been erected to prevent continued destruction of the point.

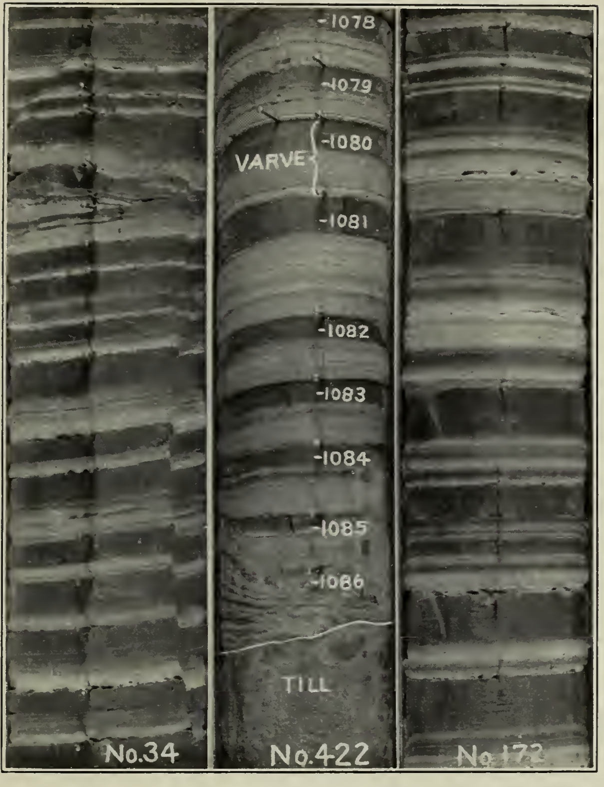
According to Colonel Johnson, Sandy Hook has been alternately an island and a peninsula, the narrow bar having been built up and destroyed by wave action several times. Since 1848 the hook has been consistently a peninsula, and it is now protected on the east side of the narrow portion of the bar by an artificially constructed wall of huge blocks of metamorphic and igneous rocks.

The fact that the channels of the Shrewsbury and Navesink Rivers have been diverted northward is clearly shown on Figure 7.

Wind action on the hook is not as extensive as might be expected. There are, nevertheless, small dunes, and undermining of concrete walks by wind action has been known to occur. The growth of vegetation is encouraged and is effective in holding the sand in place.

Whether the bar will continue to be extended depends on the ability of the tidal currents to scour and remove the deposits as they are dropped north of the present hook.

GEOLOGIC MAP OF A PART OF NORTHERN N



VARVED CLAY FROM THREE GLACIAL-LAKE BEDS NEAR NEW YORK CITY

The thick dark bands denote the winter accumulation; the intervening lighter-colored layers represent the summer deposition. A pin at the upper edge of each of the dark winter bands marks the limits of each varve. The distance between pins thus represents a varve, or annual deposit.

Section 34 contains 18 varves deposited in glacial Lake Passaic half a mile north of Mountain View, New Jersey. An offset in the layers near the right margin represents a fault; the joining of two dark winter bands in the upper right of the section is due to a lateral slide.

Section 422 is a bottom sample taken from clay deposited in Lake Hackensack, 1 mile north of Little Ferry, New Jersey. The bottom varve (−1086), which rests upon the glacial drift or till, has been disturbed by a slide. The numbers with negative sign represent the author's count of the varves below a datum plane for the Little Ferry district, described in American Museum Novitates No. 209, 1926. This section was cut by a special clay sampling tool, at a depth of 10 feet, below the lowest working level of the Gardiner clay pit.

Section 172, from the Archer pit, Haverstraw, New York, shows nine varves deposited in Lake Hudson. The varves in this sample are thicker than those in the other two samples. Sections 34 and 172 are gray in tone; section 422 is of a pronounced red color. The color of the clays is ascribed to the difference in the color of the underlying rocks, which were scored and scoured by the advancing glacier.

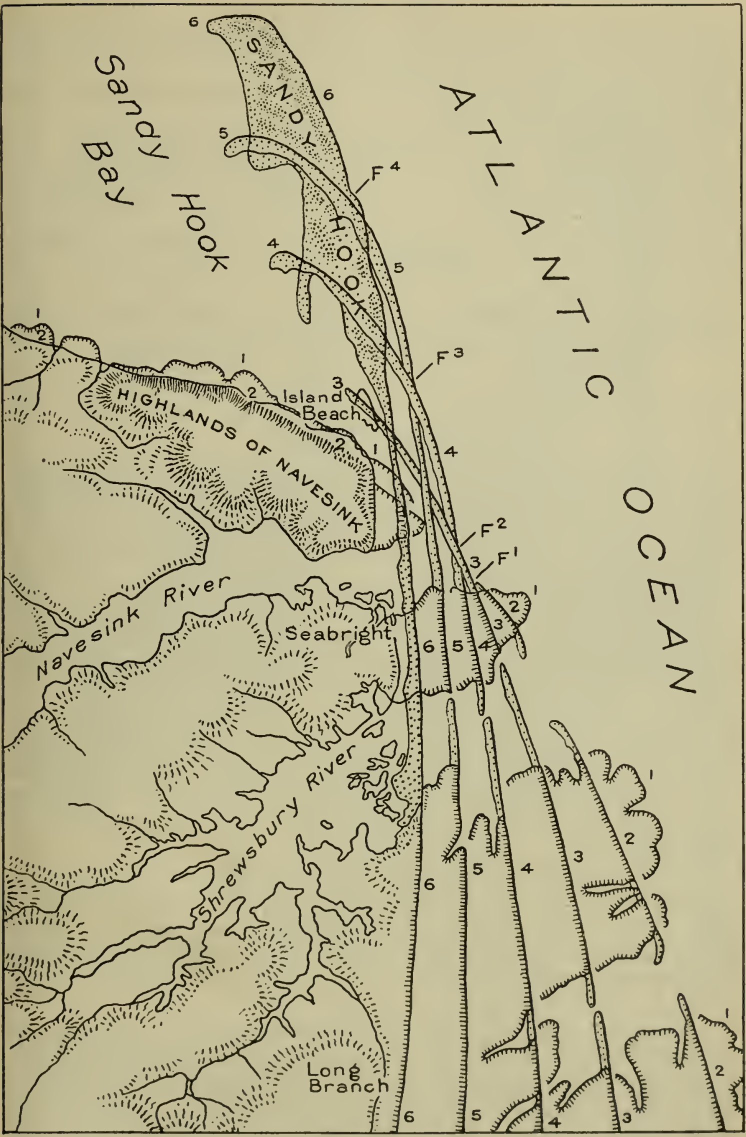


FIGURE 7.—Development of Sandy Hook spit. As the original shore between Seabright and Long Branch was cut back by wave attack, the zone of spit formation north of Navesink Highlands advanced toward the northeast. The fulcrum point, dividing the zone of retrograding shore line from that of prograding shore line, shifted progressively from F^1 to F^4. North of Island Beach is a small southward-pointing spit built by waves from the northwest out of material eroded from the recurved points of the main spit. After D. W. Johnson, Shore processes and shore-line development, fig. 57, 1919

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THE VARVED CLAYS AND OTHER GLACIAL FEATU IN THE VICINITY OF NEW YORK CITY

By Chester A. Reeds

INTRODUCTION

In the vicinity of New York City varved clays occur i lower levels of the former glacial Lakes Passaic, Hacken Hudson, and Flushing. (See fig. 8.) The clays were depo in these lake basins as the ice of the last glaciation (Wisco retreated slowly northward from the terminal moraine. Th deposits rest upon a ground moraine or till and range in thic from a few feet to 100 feet (30 meters) or more. The thic of the clay at any particular locality is dependent upon the tour of the bottom, the number of varves represented thickness of each varve, the amount of subsequent erosion Everywhere the clay beds are covered by a mantle of gravel, peat, or silt, which ranges in thickness from 5 to 1 (1.5 to 3 meters) or more, depending upon the locality. Expo are to be seen only where clay pits and other excavations been made.

In the Lake Passaic basin varved clays are excavat Berkeley Heights, near Little Falls, and near Mountain New Jersey. The clay used at the Parsippany brick wo obtained from a boulder clay or till. Varved clays of the P basin are best exposed in the pit half a mile (0.8 kilometer) of Mountain View.

The plains that surround the Great Swamp and extend f to 3 miles (1.6 to 4.8 kilometers) northwest of Berkeley He New Jersey, are underlain by a thick deposit of varved These deposits occur in that portion of the Lake Passaic which appears to the south of the terminal moraine sect tending from Summit to Morristown, New Jersey. Alo eastern and southern margins the lake was hemmed in b recurving and upturned basaltic ridges of the Watchung Mountains. As these clays represent outwash deposits from the con-

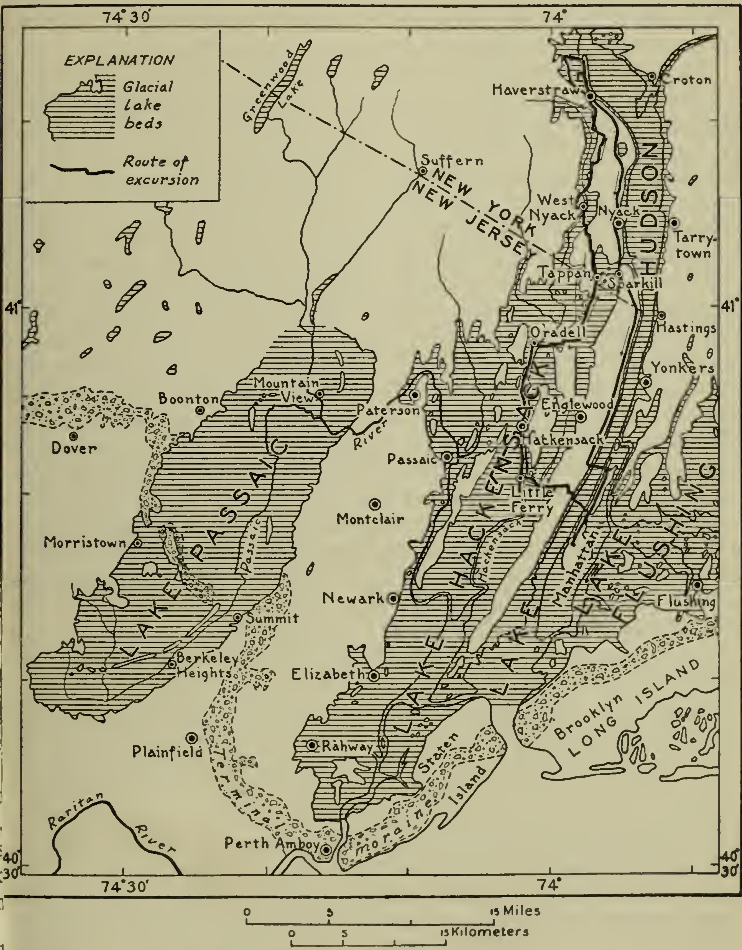


FIGURE 8.—Map showing the glacial lakes in the vicinity of New York City. The lake beds contain varved clays. An excursion route from New York City to the clay pits in the Hackensack and Hudson River Valleys is shown by a heavy line

tinental glacier when the ice front stood at the terminal moraine, the consistency of the clay and the character of the varves, particularly the summer layers, are somewhat different from those observed in the varved clays deposited in the Passaic lake basins to the north of the terminal moraine. They are, however, true varves, for the successive seasonal layers, representing alternating summer and winter deposition, are present in these deposits as in other varved clays.

In the Lake Hackensack basin varved clays are well exposed in five pits extending along the west bank of the Hackensack River in the vicinity of Little Ferry, New Jersey, from 1 to 3 miles (1.6 to 4.8 kilometers) south of Hackensack. North of Hackensack an exposure occurs at Oradell, New Jersey, in the west bank of the Hackensack River just below the reservoir dam. This exposure is about 20 feet (6 meters) above sea level, but the pits at Little Ferry are at or below sea level. For 25 miles (40 kilometers) south of Little Ferry the greater portion of the Hackensack Meadows is covered with brackish-water marshes. Varved clays are dug near the western margin of this basin opposite Carlstadt, New Jersey. Formerly varved clays were dug from a pit extending to a depth of 90 feet (27 meters) on the eastern margin of the basin near New Durham, New Jersey. Borings by the writer in these areas revealed 10 feet (3 meters) of surface sands resting upon 3 feet (0.9 meter) of peat. Underneath the peat varved clays were encountered. From these tests and deep-well borings in Newark, New Jersey, it is believed that the greater portion of the Hackensack basin south of Little Ferry is underlain by varved clays. Such clays are also reported in the valley of the Hackensack River at its junction with the Little Hackensack, near Valley Cottage, New York.

In the Lake Hudson basin the varved clays at Haverstraw, New York, extend along the west bank of the Hudson River a mile (1.6 kilometers) south and 2 miles (3.2 kilometers) north of the town and reach inland half a mile (0.8 kilometer) from the river front. These clays range in thickness from 50 feet (15 meters) on a 60-foot (18-meter) terrace facing the Hudson River in West Haverstraw to more than 100 feet (30 meters) in the low plain bordering the river bank. At Haverstraw clay pits affording good exposures of the varves are to be found in the terrace and on the river flood plain. In the vicinity of Newburgh varved clays are well exposed in pits on both sides of the Hudson River, particularly at Dutchess Junction, Beacon, Brockway, Quassic, and Roseton. Farther north varved clays are exposed in favored localities on both sides of the Hudson River as far as Albany.

In 1926 the 2,550 varves that occur in 45 feet (14 meters) of clay in the Hackensack Valley at Little Ferry were counted, described, and diagrammed by the writer (40).[6] An account

[6] Numbers in parentheses refer to bibliography, p. 63.

of Antevs's studies of these same deposits was published in 1928 (32). These deposits constitute the oldest described clays of the last glaciation. Earlier varves may in time be found in the submerged portion of the Hackensack Valley, which extends for 25 miles (40 kilometers) south of Little Ferry to the terminal moraine.

In the vicinity of Berkeley Heights, New Jersey, and the Great Swamp, samples of the oldest varved clays of the last glaciation have been collected by the writer for the American Museum of Natural History. These clays were deposited in the Lake Passaic basin, to the south of the terminal moraine, during the maximum extent of the ice. They have been sampled to a depth of 30 feet (9 meters); well records, however, indicate that in some places they are over 70 feet (21 meters) thick.

Antevs, in 1928, correlated the Hudson River clays at Haverstraw, New York, with clays at New Haven, Connecticut, and those at Roseton, a few miles above Newburgh, New York, with clays at Hartford, Connecticut. The writer has also studied the varved clays at Haverstraw, New York, diagrammed 736 of them and developed curves showing the climatic variations during the period of their formation. His studies, together with a reproduction of the graphs of the Haverstraw and New Haven varves by Antevs, appeared in 1929 (42).

The varved clays are unique in that they are seasonally banded and bilaminar for each year. Each bilamina had its origin in an annual retreat stage of the ice of the last glaciation. As the ice melted during the warm summer, fine sand and coarse clay particles were spread out over lake bottoms to form the sandy summer layer. During the cold winter little or no melting took place, and fine clay particles held in suspension in the lake water slowly settled to the bottom to form the winter layer of pure clay. Thus each paired band constitutes a varve or annual deposit. (See pl. 6.)

In Sweden De Geer (34–36) and his students have interpreted the significance of varved clay deposits, developed a method for their correlation in localities within the same climatic zone, and determined a period of 13,500 years for the retreat of the ice of the last glaciation from central Scania, the southernmost part of Sweden, to the present small ice caps in north-central Sweden (38).

In eastern North America Antevs (29, 30, 32, 33) compiled a varve record of about 26,000 to 27,000 years, with notable gaps, for the recession of the ice from the terminal moraine to Lake Timiskaming, Ontario. He correlates the morainic belts of the Ontario region with those of southern Sweden. According to his studies, the last ice sheet had its greatest extent and began to wane about 40,000 years ago.

PLEISTOCENE EVENTS IN THE VICINITY OF NEW YORK

Four glacial and three interglacial stages are represented on Long Island. The periods of glaciation correspond to the Nebraskan, Kansan, Illinoian, and Wisconsin of the central United States, and to the Günz, Mindel, Riss, and Würm of the Alps. Locally they have been named by M. L. Fuller, of the United States Geological Survey, the Mannetto, Jameco, Manhasset, and Wisconsin stages and are represented primarily by gravel and morainal deposits. The outwash, terminal moraine, till, and retreatal outwash deposits of the Wisconsin stage are far more extensive and more readily examined than the similar accumulations of the older stages, as they were the last and cover in large part those made during the preceding glaciations (37.)

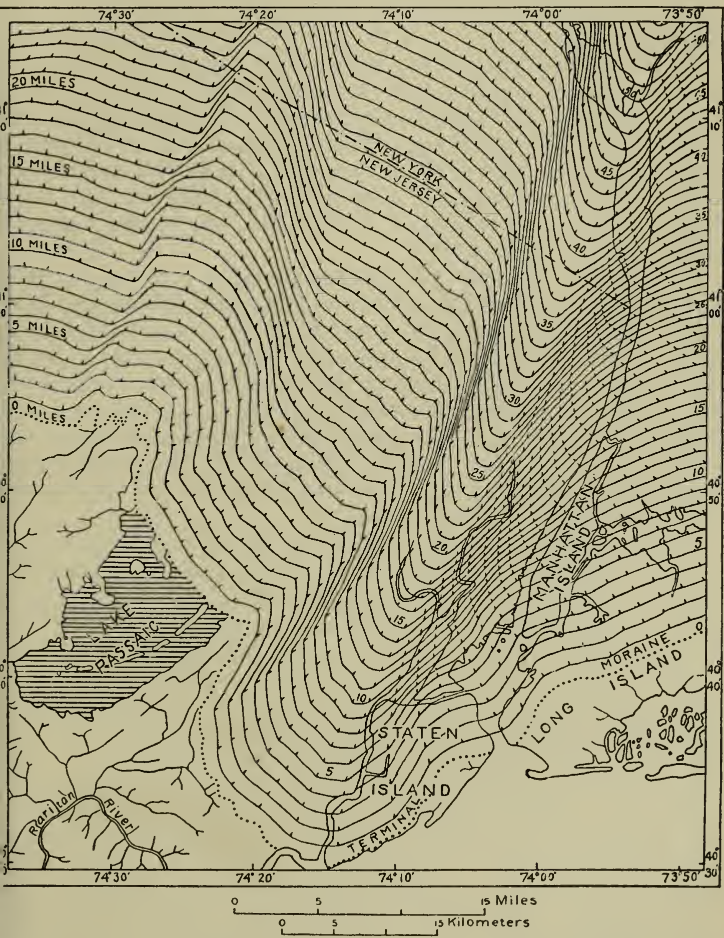
A summary of the glacial stages on Long Island and their equivalents in the Mississippi Valley States and the Alps is given in the following table:

Pleistocene stages

Epoch	Origin	Long Island	Mississippi Valley	Alps
Recent.	Postglacial.	Postglacial.	Postglacial.	Postglacial.
Pleistocene.	Glacial	Wisconsin	Wisconsin	Würm.
	Interglacial	Vineyard	Sangamon	Riss-Würm.
	Glacial	Manhasset	Illinoian	Riss.
	Interglacial	Jacob and Gardiners.	Yarmouth	Mindel-Riss.
	Glacial	Jameco	Kansan	Mindel.
	Interglacial	Post-Mannetto	Aftonian	Günz-Mindel.
	Glacial	Mannetto	Nebraskan	Günz.

Advance and retreat of the ice of the last glaciation.—An examination of Figures 8 and 9 will show that the southernmost points reached by the ice of the last glaciation were Princes Bay, Staten Island, and Perth Amboy, New Jersey. The terminal moraine, which indicates the southern limit of glaciation, is not only well developed at Perth Amboy, but it extends northeastward across Staten Island and Long Island and northwestward through Summit and Morristown, New Jersey. The front of the glacier thus assumed a sinuous lobate outline, owing no doubt to the rather broad, open features of the Hackensack Valley, throughout the

0 miles (80 kilometers) of its north-south extent, as compared vith the narrow and deep defile of the Hudson River, the major tream, to the east. The Palisades ridge, along the east flank of



IGURE 9.—Sketch map showing maximum extent of the ice of the last glaciation in the vicinity of New York City; direction of ice advance and retreat of the ice, measured in mile stages from the terminal moraine; and outline of extra-morainal Lake Passaic

he Hackensack Valley, and the Watchung Mountains and New ersey Highlands along the northwest margin, tended to retard the glacier as it moved southward in those areas. The directions of ice movement, derived from the glacial scratches or striae, are indicated in Figure 9 by the dotted radial lines. The Hackensack Valley thus became the main line of advance of the glacier, and, being lower than the adjacent areas, it contained the greatest thickness of ice.

At the present time no one knows how long the ice front stood at the terminal moraine; we can merely guess and say several thousand years. Neither does anyone know definitely where the ice front stood during the successive stages of the annual retreat northward. On Figure 9 the assumed stages, at intervals of 1 mile (1.6 kilometers), have been indicated, following in reverse direction the same radial lines (dotted) along which the ice is known to have advanced.

Glacial Lake Passaic.—When the ice front reached its maximum extent, a glacial lake known as Lake Passaic (see pp. 53, 57) partly filled the natural basin to the south of the terminal moraine, in the vicinity of Summit and Morristown, New Jersey. Its southern shore followed the recurved basaltic rock of the Second Watchung Mountain at an altitude of 345 feet (105 meters). (See fig. 9.) The lake waters did not rise above this height, for the Moggy Hollow outlet, at the southwest corner, permitted the water to flow out into a tributary of the Raritan River and eventually into the sea.

As the glacier retreated northward down the valley of the upper Passaic River, the waters of Lake Passaic followed the ice front as far as Pompton Plains (figs. 9 and 10) and filled the entire basin lying between the Watchung Mountains and the New Jersey Highlands up to an altitude of 360 feet (110 meters) above sea level. The present lowest point in the lake basin is 160 feet (49 meters) above sea level, so that the lake during its maximum extent must have had a depth of 200 feet (61 meters). In some places the shore line of this glacial lake is faintly preserved; in others it is well developed and must have existed for a considerable period. Detailed mapping of the shore line and deposits of this well-known glacial lake may be found in the Passaic and Raritan folios of the Geologic Atlas of the United States and volume 5 of the New Jersey Geological Survey. The basin has not been fully prospected for glacial clays. Some 222 varves, many of which were contorted, were examined in clay pits half a mile (0.8 kilometer) north of Mountain View and 1½ miles (2.4 kilometers) northwest of Little Falls, New Jersey. In 1927 a partial section of the clay deposits examined by the writer in Lake Passaic, to the south of the terminal moraine, revealed numerous varves, many of which were contorted.

Upwarped shore lines of Lake Passaic.—Since the glacier disappeared from eastern North America the shore lines of former glacial Lake Passaic have been warped upward—412 feet (126 meters) at their north end and 345 feet (105 meters) along their southern margin—a difference of 67 feet (21 meters). The lake had an extent of 30 miles (48 kilometers) along its northeast-southwest axis, or 26 miles (42 kilometers) on the meridian.

This represents a differential upwarping of the region in the vicinity of New York City, in a north-south direction, of approximately 2¼ feet to the mile (0.42 meter to the kilometer), or 20 feet in 9 miles (6 meters in 14 kilometers). This marked change in altitude of the land is known to have affected all the territory occupied by the continental glacier in central and eastern North America, extending from a zero or hinge line in central New Jersey up to an uplift of about 1,000 feet (305 meters) to the north of Quebec, Canada. Such differential changes in altitude are not confined to eastern North America, for the glaciated territory of northwestern Europe has been upwarped in a similar manner. It is believed that where the altitude of the land was affected most the ice was thickest. It was the removal of the load of ice and certain subcrustal or isostatic movements that took place within the earth that in all probability brought about the changes in altitude.

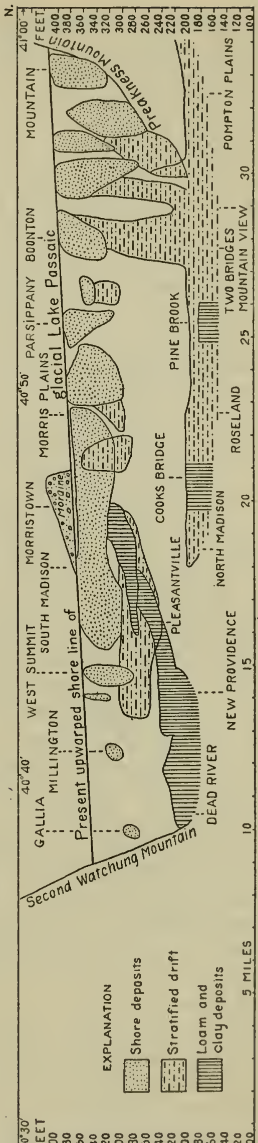


Figure 10.—Profile showing upwarped shore line and vertical distribution of the stratified deposits in glacial Lake Passaic. Data from glacial-geology sheets of the Passaic and Raritan folios (Nos. 157, 191), U. S. Geol. Survey Geol. Atlas

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Glacial Lake Hackensack.—Prior to 1922, when the writer began his investigation on the clays of the Hackensack basin, glacial Lake Hackensack had not been outlined or recognized. The varved clays, however, were deposited in a fresh-water glacial lake and not in an arm of the sea (31). Although the shore lines of this glacial lake have not been traced in detail in the field, the amount of postglacial upwarping in the Lake Passaic basin is known and can be applied to the Hackensack Valley.

Glacial Lake Hackensack, as shown on Figure 8, was outlined by the writer in 1924 (39). The approximate shore line starts with the Mauer delta deposit, which rises from sea level to 30 feet (9 meters), inside the terminal moraine less than 2 miles north of Perth Amboy. With this delta as a bench mark, the 20, 40, 60, 80, 100, and 120 foot contour lines on the topographic maps were followed for 9 miles (14 kilometers) each. The 120-foot contour encompasses the north end of the Hackensack Valley. The reason for changing contours every 9 miles is that the amount of postglacial uplift averages 20 feet (the contour interval) in 9 miles. Lake Hackensack as thus outlined contains not only several ridges as islands but also the glacial clays and the stratified sand, gravel, and delta deposits, which rise to successively higher and higher altitudes in passing from south to north.

The glacial clays, which occupy only the lowest levels, are reported in deep wells in South Newark; at Homestead the top of the clay is 10 feet (0.3 meter) below sea level; at Little Ferry approximately at sea level; at Oradell about 15 feet (4.5 meters) above; at Norwood 30 feet (9 meters) above; and at West Nyack 50 feet (15 meters) above.

The delta deposits and stratified sand and gravel rise to higher and higher levels toward the north. For example, the delta deposits in North Hackensack occur at 40 to 50 feet (12 to 15 meters) above sea level, whereas farther north the sandy delta plains in the vicinity of Tappan rise from 60 to 80 feet (18 to 24 meters) above sea level. The vertical relations of the various stratified deposits, as mapped on the glacial sheet of the Passaic folio, to the newly outlined shore line of Lake Hackensack, and the relation of similar deposits in Lake Passaic are shown in Figures 10 and 11.

In 1926 a composite section from five clay pits at Little Ferry, New Jersey, yielded a continuous series of 2,550 varves, representing as many years for the deposition of the clay. One varve was laid down each year as the ice front of the last continental glacier retreated northward up the Hackensack Valley (40).

Glacial Lakes Hudson and Flushing.—The same bench mark and methods of induction and deduction that were used in establishing the outline of Lake Hackensack were applied to the territory immediately east of the Hackensack basin and north of the terminal moraine. The results of this endeavor, as shown on Figure 8, give the suggestive outlines of variously connected bodies of fresh water which have been designated Lake Hudson and Lake Flushing. Varved glacial clays are not known to be exposed above sea level in the Lake Hudson basin south of Haverstraw, New York. There and to the north they are well developed at, below, and above sea level. In the Lake Flushing basin they have been noted by Antevs (29) in the valley of the Quinnipiac River at New Haven, Connecticut (32; 343 varves), and reported at Fishers Island, farther east, in Long Island Sound. Logs of wells in Brooklyn and farther east yield records of clay lying below the sand and gravel beds.

In New York City blue clay was encountered in 1925 by the engineers of the New York Central Railroad in test borings on the right of way at the foot of West 14th Street, 44 to 72 feet (13 to 22 meters) below sea level. Blue clay has also been found in borings along the east bank of the Hudson River off West 10th Street at 98 to 162 feet (30 to 49 meters) below sea level and off West Houston Street at 92 to 128 feet (28 to 39 meters). The exploratory borings for the Hudson River tunnels of the

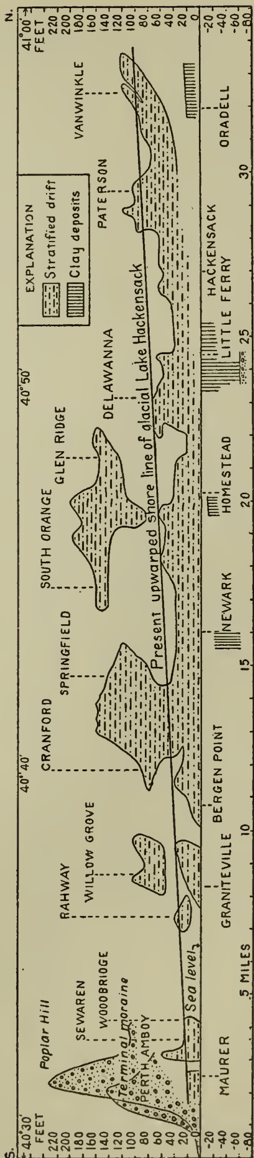

FIGURE 11.—Profile showing upwarped shore line and vertical distribution of the stratified deposits in glacial Lake Hackensack. Data from the glacial-geology sheet of the Passaic folio (No. 157), U. S. Geol. Survey Geol. Atlas, and the writer's field notes

Pennsylvania Railroad also revealed the presence of extensive beds of clay immediately overlying the basal till in the filled

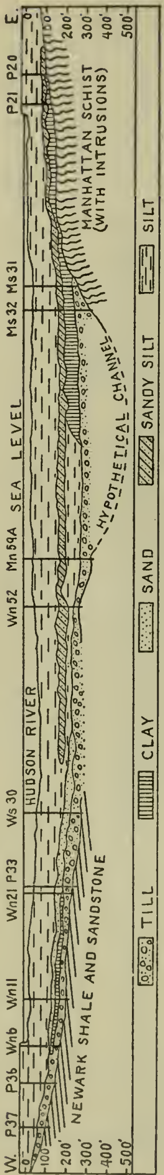

FIGURE 12.—Cross section of the deposits in the Hudson River, developed from exploratory boring for the Pennsylvania Railroad tunnels, 32d Street, New York City. (After G. S. Rogers)

channel of the river at depths of 175 to 200 feet (53 to 61 meters) on the west side, 125 to 175 feet (38 to 53 meters) on the east side, and 200 to 275 feet (61 to 84 meters) in the east-central part. (See fig. 12.) Clay is also reported overlying morainal material in the bottom of the filled East River channel. As the relation of these submerged clay deposits to the underlying till is similar to that found by the writer at Little Ferry, in the Lake Hackensack basin, he assumes that they are banded and of glacial origin.

The correlation of the varves in the clay pits at Haverstraw, New York, by the writer (41, 42) and by Antevs (32), working independently, has yielded 736 consecutive varves. A total of 736 varves does not represent the entire Haverstraw section, for varves containing quicksand in the summer layers appear below the lowest varves obtained. Antevs correlated the varves at Haverstraw, New York, with those at New Haven, Connecticut, and established their contemporaneity.

Postglacial stratified sands.—The varved clay deposits at Mountain View, in the Lake Passaic basin, are overlain by 5 to 10 feet (1.5 to 3 meters) of stratified sands. This is also true at Little Ferry, in the Lake Hackensack basin, where beds of sand 5 to 20 feet (1.5 to 6 meters) in thickness overlie the varved clays. At New Bridge, near the west bank of the Hackensack River, and at Oradell 5 to 20 feet of gravel appears above the clay deposits. At Haverstraw, in the Lake Hudson basin, and at points north of it beds of sand and gravel, ranging in thickness from 2 to 25 feet (0.6 to 7.6 meters) rest upon the varved clays. The stratified sands at Croton Point, Harmon, and Peekskill are very thick and rise to altitudes of a little over 100 feet (30 meters), the approximate position of the shore line of Lake Hudson at these places. They represent delta deposits made in the lake. Sandy varves about 1 foot (0.3 meter) thick, observed on Croton Point in borings made near sea level, indicate late glacial age.

The stratified beds of sand and gravel which rest upon the varved clay deposits are, without doubt, of postglacial age. As this appears to be true where the clay is exposed, it is also evidently true where the clay beds are concealed from view by sand and silt, as in the Hudson River opposite 10th, 14th, and 33d Streets, New York, and in the East River channel. The stratified sandy deposits that occur at higher levels in Manhattan and Brooklyn are also considered to be of postglacial age.

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GLACIAL HISTORY OF THE PASSAIC VALLEY AND RELATED GEOLOGIC FEATURES

By Henry B. Kümmel

The portion of New Jersey lying west of New York City and within a radius of 35 to 40 miles (56 to 64 kilometers) of the City Hall affords an excellent opportunity to study the drift deposits of at least two and probably three glacial epochs, significant changes of drainage due to the Wisconsin ice sheet, and lake-shore phenomena as developed by glacial streams, and by waves and currents in a relatively short-lived glacial lake of moderate size. The one-day excursion described herein is designed to enable participants to see these features.

GENERAL GEOLOGY

The geologic structure is simple. The region is underlain by a westward-dipping series of shale and fine-grained sandstone, with some coarser conglomerate beds, all referable to the Triassic period. Topographically these strata form a rolling lowland, interrupted by several even-crested monoclinal ridges which rise several hundred feet above their surroundings. These ridges are the outcropping edges of sheets of diabase and basalt intercalated in the sedimentary beds and dipping more or less conformably with them toward the west. Their even crests are remnants of the widespread Schooley peneplain, and the gaps by which they are traversed were cut by streams flowing across the peneplain, in the first cycle of erosion after its uplift and subsequent dissection.

The ridge along the Hudson, widely known as the Palisades, is an intrusive sheet of diabase, forced into the lower part of the sediments. Although it is in general conformable with them, there are many minor departures along both upper and lower contacts, which demonstrate its intrusive origin. On the other hand, the crescent-shaped ridges known as First and Second Watchung Mountains, which lie 10 to 15 miles (16 to 24 kilometers) west of the river, and the roughly parallel lower ridges farther west, known as Hook Mountain, Livingston Hill, and Long Hill, are all the edges of extrusive lava flows which successively spread over the floor of the intermountain valley in which the sedimentary series was accumulated, and which were successively buried beneath later accumulations of sand and mud. Subsequent tilting, profound faulting, and enormous erosion, during Cretaceous and Tertiary time, have brought these buried lava flows again to the surface.

Farther northwest, about 20 miles (32 kilometers) west of the Hudson River, is the eastern margin of the upland belt, known as the New Jersey Highlands. Its rocks are chiefly pre-Cambrian granite gneisses of several types, and the broader, flat-topped summits of the higher areas are remnants of the Schooley peneplain.

The eastward escarpment of the Highland belt and the crescent-shaped ridge of Second Watchung Mountain form a natural basin, 10 to 12 miles (16 to 19 kilometers) wide from northwest to southeast and 30 miles (48 kilometers) or more from southwest to northeast.

The drainage that now enters this basin from the Highlands on the northwest, as well as that which originates in the basin itself, follows an exceedingly roundabout course and finally escapes through gaps in Second Watchung Mountain at Little Falls and in First Watchung Mountain at Paterson. As explained in detail on pp. 68-75, the present drainage is due to changes in the topography because of the last glacial invasion.

Wisconsin ice sheet.—The extent of the Wisconsin ice sheet and the course of its terminal moraine on western Long Island and eastern New Jersey are best understood by reference to Figure 13. The Hudson River and the lowland formed by the Triassic rocks permitted this lobe of the ice to advance to the latitude of Perth Amboy and the southern part of Staten Island. The reentrant angle in the moraine north of Plainfield and on the west side of this lobe is due to the retardation of the ice by the First and Second Watchung Mountains.

From Short Hills, on the moraine at this reentrant angle, to Morristown the moraine crosses the Passaic basin and divides it into two parts, one without and the other within the moraine.

The terminal moraine has a width of 1 to 2 miles (1.6 to 3.2 kilometers) and rises 100 feet (30 meters) and, where it crosses the basin, even 200 feet (61 meters) or more above its surroundings. It is nearly everywhere marked by the typical knob and kettle topography. The drift in the moraine in places exceeds 300 feet (91 meters) in thickness.

Locally, as in the reentrant angle between First Watchung Mountain and the moraine itself, near Plainfield, it is bordered on its outer side by a wide outwash plain of sand and gravel which becomes progressively finer with increasing distance from the former edge of the ice.

West of Second Watchung Mountain the moraine forms a broad, flat-topped ridge, which divides the upper Passaic basin into two almost equal parts. Along this portion of its course the moraine is bordered on its outer margin by an outwash delta with a lobate front, which was manifestly built in standing water.

North of the terminal moraine the bedrock is covered by a mantle of ground moraine, or till, with local areas of stratified sand and gravel that form valley trains, plains, and kames or kame terraces.

Earlier glacial deposits.—Certainly one and probably two earlier glacial drifts are found in this region southwest of the Wisconsin moraine. These drift sheets differ from the Wisconsin

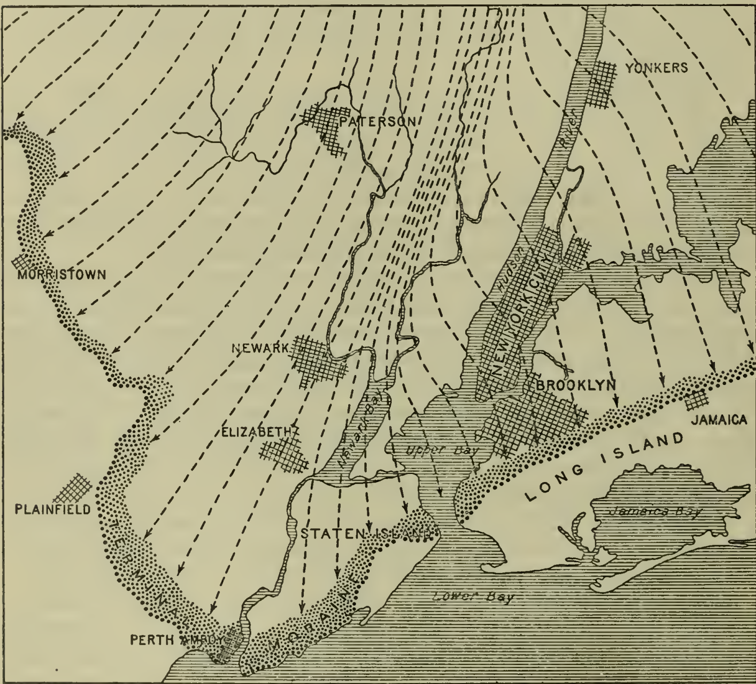

FIGURE 13.—Sketch map showing the terminal moraine and the direction of ice movement in eastern New Jersey and western Long Island. From U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), fig. 11, 1908

drift, in greater decomposition of the constituent materials, lesser thickness, and smaller areal extent. The Wisconsin drift forms a continuous sheet covering the rock completely over considerable areas and affording only small and scattered rock exposures where the drift is thin. The earlier sheets, on the contrary, are discontinuous and patchy. The discontinuity of the oldest sheet is clearly the result of extensive erosion. The drift is limited to broad hilltops and has a definite lower limit below which it does not extend. The conclusion is irresistible that the valley slopes below this lower limit have been excavated since the drift was deposited. The oldest sheet has been called Jerseyan and is perhaps Kansan in age, and the intermediate drift is regarded by Leverett as Illinoian.

Gaps in the trap ridges.—The wide gaps in First and Second Watchung Mountains at Paterson and Little Falls have already been mentioned. At Piermont on the Hudson, New York, a short distance north of the New Jersey line, the crest of the Palisade ridge is interrupted by a gap 2 miles (3.2 kilometers) or more in width, with the general altitude of its floor about 175 feet (53 meters) above sea level. This gap is about 15 miles (24 kilometers) northeast of the gap at Paterson and is comparable with it in width and altitude.

At Springfield, 15 miles (24 kilometers) southwest of Paterson, First Watchung Mountain is interrupted by a wide gap, somewhat drift-filled, the rock floor of which has an altitude of less than 100 feet (30 meters), with probably an inner gorge sunk about to sea level.

At Short Hills, immediately northwest of Springfield, there is a deep drift-filled rock gap in Second Watchung Mountain directly in line with the Springfield gap, and borings have revealed a corresponding gap in the Long Hill-Livingston Hill trap ridge, still farther northwest.

Douglas Johnson has recently advanced convincing reasons for the view that during the Schooley peneplain cycle of erosion the ancestor of the upper Hudson River flowed southwestward from its present valley, across the Palisade ridge at Piermont, across First and Second Watchung Mountains at Paterson and Little Falls, southward to Summit, and thence southeastward again across Second and First Watchung Mountains at Short Hills and Springfield. It maintained this course through the early part of the next erosion cycle, caused by the uplift and tilting of the Schooley peneplain, and persisted long enough to cut in these hard trap ridges gaps 2 miles (3.2 kilometers) or more in width and 300 to 400 feet (91 to 122 meters) or more in depth. Coincident with the cutting of these wide gaps in the hard rock, the softer sedimentary beds were eroded to corresponding depths over wide areas both east and west of the Watchung ridges.

Finally in this later erosion cycle the upper Hudson was captured and diverted to its present course by the headwater erosion of a vigorous stream working on the contact of the soft Triassic sediments and the underlying crystalline rocks, and not hampered by having to cross so many belts of resistant rock.

Subsequent to this act of piracy the Short Hills and Springfield gaps were traversed by the much smaller river resulting from the combination of streams entering the south half of the basin from the Highlands. The Little Falls and Paterson gaps may have been occupied by a stream entering the north half of the basin, as shown in Figure 14, or, as now seems more probable,[7] these northern streams also flowed through the Short Hills and Springfield gaps.

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

No lake could have formed in the drainage area of the river system that flowed through the Short Hills gap (unless in the upper courses of such tributaries as were obstructed at their lower ends) until after the ice had reached that gap and filled it. Then, and not until then, could a lake have existed in the basin southwest of the moraine. Once formed, the lake rose until it found an outlet. This was at Moggy Hollow, near Liberty Corner, about 12 miles (19 kilometers) southwest of Morristown. (See fig. 15.) As the ice made little advance after occupying the pass in Second Watchung Mountain, near Short Hills, neither the area nor the level of the lake was subject to much variation, and the edge of the ice stood where the moraine is now. During this time distinct shore features were developed about the lake. They are pronounced along the moraine between Summit and Morristown, and feeble, though distinct, at other points along Second Watchung Mountain and about the summits of Long Hill, which stood as islands above the lake. Here small gravel spits, hooks, and bars were formed in the narrow straits between these islands.

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[7] Borings in the narrow gap at Mountain View show that in preglacial time this gap had been cut to a lower depth than any depression known to exist in the floor of the Little Falls gap. Hence, contrary to earlier views, it is now believed that for a long period the Little Falls cut was a wind gap and after the capture of the upper Hudson was not reoccupied by a stream until the end of the Wisconsin glacial epoch.

FIGURE 14.—Diagram showing the supposed course of the drainage in the Lake Passaic basin before the last glacial invasion. From U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), fig. 15, 1908

Figure 15.—Stage of maximum advance of the ice. The edge of the ice was at the position of the terminal moraine, and the glacier filled the Short Hills gap The upper basin of Lake Passaic was shut in and occupied by a lake with its outlet to the west of Moggy Hollow. From U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), fig. 18, 1908

Figure 16.—Maximum stage of Lake Passaic. All outlets except that at Moggy Hollow were either blocked by the ice or filled with drift. From U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), fig. 20, 1908

Figure 17.—Late stage of Lake Passaic, when the retreat of the ice had freed the Little Falls-Paterson outlet. Shallow bodies of water still occupied the lower portions of the basin. From U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), fig. 21, 1908

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

At the time of its greatest extent Lake Passaic was about 30 miles (48 kilometers) long, 8 to 10 miles (13 to 16 kilometers) wide and 240 feet (73 meters) deep at the maximum and 160 to 200 feet (49 to 61 meters) deep over wide areas. (See fig. 16.)

It is easy to conceive of a very simple subsequent history for the lake. Its northern border might have followed the retreating southern border of the ice until the latter had passed Great Notch. The lake should then have discharged through this outlet, its level falling to 303 feet (92 meters) above the sea, the altitude of Great Notch, and the outflow through Moggy Hollow ceasing. Though there is no positive evidence of outflow through Great Notch, it must have taken place, unless an outlet under the ice was opened along the course of the present Passaic River. A little later, as the ice retreated farther, the Little Falls and Paterson gaps in Second and First Watchung Mountains were opened, and the lake must then have discharged its waters through the Passaic. Once this outlet was opened, the lake would soon have been mostly drained.

The actual history of the lake seems to have been a little less simple. At a number of places more or less well defined shore features are found at altitudes 65 to 75 feet (20 to 23 meters) lower than the highest line of the lake. At a time still later than that at which these features were formed, the waters of the lake seem to have risen again to a level corresponding with the Moggy Hollow outlet. These facts have been interpreted to mean that the level of the lake fluctuated to a considerable extent during its history. It is probable that these changes of level were connected with oscillations of the edge of the ice, which alternately opened and shut some outlets, possibly Great Notch or a subglacial outlet along the course of the present Passaic. A mile (1.6 kilometers) northwest of Little Falls till overlies lacustrine clay, showing that the ice subsequently advanced over an area from which it had retreated and over which the lake had spread. It is possible that the outlet by way of Little Falls was opened and closed again by the oscillation of the ice, though of this there is no positive evidence.

Whatever were the effects of the oscillation of its edge near Little Falls, the ice finally melted back beyond the present course of the Passaic, and when this happened, the intramorainic part of the lake was drained to the level of the outlet at Little Falls—about 185 feet (56 meters). If drift overlay the rock in the valley at this point, the outlet was a little higher than 185 feet at the outset, but the great volume of the outflow must shortly have swept away whatever drift there was in the valley at this point. The drainage of the intramorainic part of the lake must have been rapid, for on none of the many hills within the basin, rising to heights of 200 to 300 feet (61 to 91 meters), are there shore lines, though many of these hills are made up of loose sand and gravel, in which terraces could have been easily and quickly cut.

The remaining stages in the history of the draining of the basin of Lake Passaic belong not to the time when the ice was in the basin but to the time after it had withdrawn. To make the story complete, however, they may be outlined here. When the intramorainic part of the lake was in large part drained by the opening of the Little Falls outlet, shallow bodies of water occupied the lowest lands along the Passaic between Little Falls and the moraine. (See fig. 17.) When the outlet was at 185 feet (56 meters) above sea level, the water over Great Piece Meadows and Hatfield Swamp was 15 to 20 feet (4.5 to 6 meters) deep. As the outlet was lowered this shallow body was drawn down. Inasmuch as the outlet led over resistant rock, it was probably lowered slowly, and the shallow lake may have endured for a considerable time. A small lake more or less independent of that which covered Great Piece Meadows remained over the low belt between Second Watchung Mountain and Long Hill and southwest of the moraine along the courses of the present Passaic River and Black Brook. At the outset its level was at about 230 feet (70 meters) above the sea, where it was held by the moraine dam at Stanley, west of Summit. The greatest depth of this lake, which has been called Dead Lake, was not much more than 20 feet (6 meters). The outflow soon cut down the dam, lowering the lake and finally draining it altogether.

The longest-lived of these postglacial lakes was the one that occupied the area of Great Swamp northwest of Long Hill, which lasted while the outflow was cutting the narrow gorge at Millington, through the trap rock of Long Hill. At the outset the level was about 320 feet (98 meters) above the sea, but as the outlet was slowly cut down to its present level of 221 feet (67 meters) the lake was drained.

Postglacial warping.—The shore features of Lake Passaic are not now at a uniform altitude but rise northward from 345 feet (105 meters) above sea level at the south end of the lake to 412 feet (125 meters) at the north end, indicating a differential elevation or warping of the lake basin of 67 feet (20 meters) in about 30 miles (48 kilometers).

ITINERARY

The route west across the Hudson River by the George Washington Memorial Bridge affords a fine view of the river itself and the Palisades cliff. Interesting exposures of the irregular basal contact of the diabase on the highly indurated Triassic shale occur at the foot of the cliff just south of the bridge, but lack of time will prevent their inspection. From the western slope of the Palisade Ridge the even crest line of First Watchung Mountain is discernible across the drift-covered shale and sandstone lowland.

At Paterson we pause long enough to view the gap in First Watchung Mountain and its relation to the Piermont gap in the Palisades, 15 miles (24 kilometers) to the northeast, and to the Little Falls gap in Second Watchung Mountain, 3 miles (4.8 kilometers) to the southwest; also the conformable contact of the basalt on the underlying shale, and one or two minor faults, shown in the bluff on the south.

Second Watchung Mountain is crossed through the gap at Little Falls, and its back slope is ascended to Grand View, whence, if the day is clear, excellent views of the north half of the Lake Passaic basin are spread before the observers. Near by a roadside cut exposes the vesicular upper parts and the dense lower parts of two basalt flows separated by a thin bed of Triassic shale.

At Mountain View the route passes through a narrow gap in the third trap sheet, which was cut by one of the larger tributaries of the stream that excavated the Paterson and Little Falls gaps. In pre-Wisconsin time the drainage through this gap may have escaped through the Little Falls gap (fig. 14), but recent borings apparently indicate a narrow trench whose bottom is lower than that of any known rock trench at Little Falls, so that there is some reason for believing that the stream which cut it was a tributary of the river that flowed through the Short Hills gap, and that the Little Falls gap, after the capture of the upper Hudson River, was a wind gap.

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From Mountain View the route lies across the north half of the Lake Passaic basin and at Montville ascends to the top of a glacial delta, built to a level of 398 feet (121 meters) above the sea by glacial waters entering the lake. (See fig. 18.)

From Montville the west side of the lake basin is followed to Morris Plains, where in an embayment of Lake Passaic a great plain of coarse gravel was built by the glacial waters to a general level of 390 feet (119 meters) at the east front of the terminal moraine.

From Morristown to Short Hills, on the east side of the basin, the route follows the terminal moraine, here flanked on its outer margin by a series of lobate outwash deltas whose flat tops mark the former water level, here about 375 feet (114 meters) above the sea.

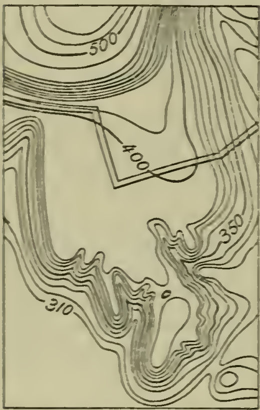


FIGURE 18.—Contour sketch of the delta found in Lake Passaic near Montville. From U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), fig. 14, 1908

At Summit and Short Hills the terminal moraine that fills the gap in Second Watchung Mountain can be seen, and thence the route is retraced to Chatham, from which the road southwestward follows the third of the basalt sheets, locally known as Long Hill. This is in the extramorainic part of the Lake Passaic basin (fig. 15), and the ancient shore line is marked by small accumulations of waterworn gravel of local origin. These are chiefly bars and spits between the islands formed by the higher parts of the ridge.

At Millington is the narrow, steep-sided trench which the outlet of the postglacial lake in the Great Swamp area cut to a depth of 100 feet (30 meters), after Lake Passaic had been drained.

At Basking Ridge pits have been opened in gravel deposits, regarded by Leverett as kames of Illinoian age. The lower stratified material is greatly disintegrated, boulders 6 or 8 inches (15 to 20 centimeters) in diameter readily crumbling to pieces. The upper portion is less weathered and more till-like. Whether this difference in disintegration is due wholly to variations in texture and permeability, or whether only the upper, less weathered material is referable to the Illinoian drift and the much disintegrated lower part is Jerseyan, is still an open question. Both parts, however, are more disintegrated than the Wisconsin drift.

A pit north of Liberty Corner gives an 8-foot (2.4-meter) exposure of poorly rounded trap gravel, accumulated in Lake Passaic as a bar on the west side of one of the trap-rock islands. Its surface indicates a lake level of 350 feet (107 meters) above the sea. West of Liberty Corner is the outlet of Lake Passaic, a flat-bottomed, steep-sided trench cut in the trap rock, having a present altitude of 331 feet (101 meters), the lowest point in the rim of the basin after the gaps at Little Falls and Paterson were blocked by the ice, and the Short Hills gap had been filled with morainic material.

Areas of a very old drift (Jerseyan, Kansan) occurring as discontinuous patches will be seen near the outlet of the lake but at levels well above its shore line, and also along the road south of Far Hills and west of First Watchung Mountain, entirely outside the lake basin.

From Far Hills the route follows the outer edge of the crescentic ridges through Somerville, Bound Brook, Plainfield, and Scotch Plains, the latter part of the way across the overwash plain of the Wisconsin glacier. The moraine is crossed north of Scotch Plains. At Springfield a brief pause will be made to note the open gap in First Watchung Mountain first occupied by the early Hudson River and later in early Pleistocene time by the much smaller Passaic.

The return to New York will be made either through the Holland Tunnel or over the George Washington Memorial Bridge.

ENGINEERING GEOLOGY OF THE CITY OF NEW YORK

By Charles P. Berkey

INTRODUCTION

The city of New York, because of its great population, its numerous commercial enterprises, and its possession of one of the world's greatest harbors, has made unusual demands for municipal facilities, which have been met by projects unique in the history of engineering.

The population of New York City (6,930,446 in 1930) has been increasing at the rate of about 117,000 annually for the last 30 years, thus adding a moderate-sized city every year. The demands resulting from this rapid growth have led to the development of projects of unprecedented magnitude which, during their construction, have encountered physical conditions usually considered unsurmountable. In no other city is construction carried so far underground or so many of the normal services operated in tunnels far below the surface. Some of these engineering projects have taken full advantage of favorable geologic conditions, and, in turn, they have exposed much of the underground structure and have given more precise information about local subsurface conditions than was known before.

The total of these engineering works is surprisingly large. In the metropolitan district there are over 5,000 miles (8,000 kilometers) of streets, 3,000 miles (4,800 kilometers) of which are paved; twelve large bridges, costing over $200,000,000, several of which at the time of building were the largest ever constructed; 730 miles (1,175 kilometers) of subway tracks for passenger traffic, with an investment of over $700,000,000; 3 miles (4.8 kilometers) of underground vehicular tunnels; nine railway terminals with five railway tunnels approaching or entering the city, two of which pass beneath the surrounding tidal rivers; 55 miles (89 kilometers) of aqueduct tunnels within the city limits, large portions of which are 500 to 700 feet (152 to 213 meters) below the surface. There are more than 200 buildings exceeding 25 stories in height, and 29,500 manufacturing plants. There is a total of 580 miles (933 kilometers) of water front with extensive pier facilities used by 89 navigation companies docking some 5,000 vessels in the course of a year.

These items serve to emphasize the enormous growth of the city of New York and the kind of engineering service and practical accommodation it requires. There is nothing new about the nature of the engineering projects, because all great cities demand facilities of similar kind, but the large scale on which they have been carried out and the extent to which they have been made to conform to the somewhat complicated local geologic conditions seem to give them more than passing interest. It is proposed to illustrate this side of the city's service by condensed discussion of such outstanding engineering projects as the Catskill Aqueduct, the George Washington Bridge, the Pennsylvania Railroad tunnel, and several other undertakings of similar importance as illustrating applied science.

The accompanying map (pl. 7) is intended to locate the principal structures referred to in this description and, in addition, to show the major elements of the local geology.

STREETS AND HIGHWAYS

Virtually the only problem of unusual character presented by the development of streets and highways in New York is that of handling greatly congested traffic, especially the necessity of carrying some of the thoroughfares either above or below ground so as to relieve the ordinary traffic of the surface. Early in the history of the city elevated railways were built nearly the entire length of the island, and these have been maintained to the present day. In later years a few additional structures have been built above ground for regular street traffic, and these are being developed on a still larger scale.

No unusual physical conditions have to be met beyond care to insure firm foundations, especially along the water front, where the overburden is deep and in places rather unsubstantial. There has been considerable encroachment on the water margins by artificial fill, and in places these fills overlap river muds and silts, which are poor supports for any heavy structure. These same conditions apply to structures of all kinds along the water front.

Within the limits of the city there are approximately 3,000 miles (4,800 kilometers) of paved streets, 2,000 miles (3,200 kilometers) of additional improved streets, 200 miles (320 kilometers) of surface street railways, 50 miles (80 kilometers) of elevated street railways, 20 miles (32 kilometers) of elevated street for regular traffic, and 730 miles (1,175 kilometers) of subway for passenger traffic.

BRIDGES

The most important engineering structures connected with the street and highway system, depending directly on natural physical conditions for their practicability, are the bridges. New York City has numerous bridges crossing its surrounding water bodies, some of which are the largest of their type in the world. The principal bridges carrying the traffic of the city are distributed as follows:

Name	Location	Purpose
East River bridges		
Brooklyn	Chambers Street	General traffic.
Manhattan	Canal Street	Do.
Williamsburg	Delancy Street	Do.
Queensborough	60th Street	Do.
Hell Gate	Ward's Island	Railroad.
Triborough	Ward's and Randall Islands.	General traffic.
Harlem River bridges		
Harlem (Willis Avenue)	127th Street	Do.
Second Avenue	129th Street	Elevated railway.
Third Avenue	130th Street	General traffic.

Name	Location	Purpose
Harlem River bridges—Continued		
New York Central	134th Street	Railroad.
Madison Avenue	138th Street	General traffic.
149th Street	145th Street, Manhattan, to 149th Street, Bronx.	Do.
Macombs Dam	155th Street	General traffic.
Putnam	158th Street	New York Central R. R.
High	168th Street	Aqueduct.
Washington Heights	181st Street	General traffic.
University Heights	207th Street	Do.
Broadway	North end of Manhattan Island.	Do.
Spuyten Duyvil	Spuyten Duyvil	Railroad.
Hudson River bridges		
George Washington	179th Street	General traffic.
Bear Mountain	North of Peekskill	Do.
Poughkeepsie	Poughkeepsie	Railroad.
Do	do	General traffic.
Staten Island bridges		
Kill Van Kull	To Bayonne	Do.
Outer Crossing	To Perth Amboy	Do.
Goethals	To Elizabeth	Do.

Brooklyn Bridge over the East River, until recently the most famous of New York bridges, was the first to accommodate general traffic. It is a suspension structure, with a total length of 6,016 feet (1,834 meters) and a span of 1,595 feet (486 meters). It was completed in 1883 at a cost of $25,000,000.

The Williamsburg Bridge, also over the East River, was the next suspension bridge to be constructed and was completed in 1903 at a cost of $24,000,000. It has a total length of 7,308 feet (2,227 meters) and a span length of 1,600 feet (488 meters).

High Bridge over the Harlem River is one of the older historic bridges of the city, completed in 1848, and was built to carry the Croton Aqueduct across the Harlem.

In 1909 two large bridges were opened across the East River—the Queensborough Bridge and the Manhattan Bridge, connecting lower Manhattan with Brooklyn. The Queensborough Bridge is of cantilever type and has a total length of 7,449 feet (2,271 meters) and a span of 1,182 feet (360 meters). The Manhattan Bridge is a suspension structure with a total length of 6,855 feet (2,089 meters).

The George Washington Bridge, crossing the Hudson at 179th Street, is New York's newest and largest suspension bridge. It has a span of 3,500 feet (1,067 meters) and is the longest single-span bridge in the world. The total length between anchorages is 4,760 feet (1,450 meters). It was completed in 1931 at a cost of over $60,000,000.

The Kill Van Kull Bridge, connecting Staten Island with Bayonne, New Jersey, also completed in 1931, is noted as the longest arch ever constructed.

Although these numerous bridges have been constructed under varying local conditions, only a few have presented geologic problems that seem to require special description for the present purpose.

EAST RIVER BRIDGES

The piers of the Brooklyn Bridge are solid masonry. The Brooklyn pier reaches sound rock, eminently suitable for any kind of foundation, but the Manhattan pier does not reach bed-rock because the depth is too great. The rock floor is covered with glacial drift, part of which is assorted sand and gravel of comparatively unsubstantial quality, but beneath this superficial deposit are beds of till and hardpan and coarse, assorted material which give a satisfactory foundation.

Similar conditions were encountered in building both the Manhattan and Williamsburg Bridges. In each the pier on the Long Island side stands on sound rock floor and that on the Manhattan side on glacial drift. By expanding the base of the pier a sufficiently large bearing surface was obtained to carry the structure successfully. No other geologic principles are involved.

The piers of the Queensborough Bridge stand on rock and have presented no difficulty.

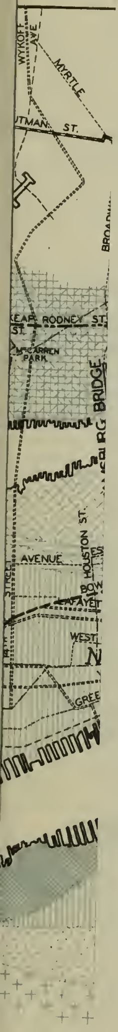
The Hell Gate Bridge is used by the Long Island Railroad and the New York, New Haven & Hartford Railroad to cross the East River from Long Island City to Ward's Island and thence to Randall Island and over the surrounding tidal channels to the mainland in the Bronx. The location was determined without complete information as to the character of the rock floor. It was known that the drift cover is thin in this section of the city and that the rock floor could be reached; but when the excavation for the pier on Ward's Island was made, it was found to be located on a fault zone, decayed and softened to such extent and great depth that it was necessary to excavate a much larger amount of the material than was contemplated in the original plan. The discovery of this condition and the measures taken for meeting it are said to have cost an additional $250,000. Since the days when this work was done the underground structure in the city has been much more completely explored, in consequence of the extensive tunneling operations. The fault zone encountered at this site is not anywhere observable at the surface, but the tunnels that have penetrated it in crossing beneath the East River in later years, particularly the Astoria Gas tunnel, have proved its extent and actual condition. Preliminary exploration of the type usual now would have discovered the zone at an early enough stage to modify either the location or design of the Hell Gate Bridge. After the location had been fixed, however, there was no alternative but to cure the weakness by suitable construction. This was done by deep excavation and by an arch structure across from one sound wall of the crush zone to the other, the pier being built in part on this support. The measures taken for providing sound foundations have proved to be eminently successful.

GEORGE WASHINGTON BRIDGE

The new George Washington Bridge, spanning the Hudson from 179th Street, Manhattan, to the Palisades on the New Jersey side, is the greatest of all the bridges of the city. Its towers rise 635 feet (194 meters) above the level of the river, and the roadway is 300 feet (91 meters) above water level. The bridge is anchored on the New York side by masonry load, and on the New Jersey side it is locked into the solid rock of the Palisade Ridge.

The Manhattan pier rests at the water's edge on crystalline schist of the Manhattan formation, which is sound and eminently suitable for such a foundation. The pier on the New Jersey side is located in the shallow waters of the river, and, to insure a safe support, it was necessary to excavate river silt, glacial drift, and loose ledge rock to depths of 25 to 85 feet (7.6 to 26 meters) below the surface of the water. This pier rests on the sandstone and shale beds of the Newark group, which in this section underlie the trap sheet of the Palisades and are unconformable on the crystalline rocks of the ancient floor represented by the same formations that appear on the Manhattan side of the river.

Extensive exploratory borings were made preliminary to final plans and specifications, and much attention was given to interpretation of the geologic data gathered in this manner. Thirty borings were made on the New Jersey pier site, for the purpose of determining beyond question the conditions to be met. It was found that both the sandstones and the shales are variable in thickness and quality and that the shales, in particular, do not furnish as substantial support as the associated sandstones and arkoses. Fortunately the sandstone members are the more numerous and make up the larger portion of the floor at the site.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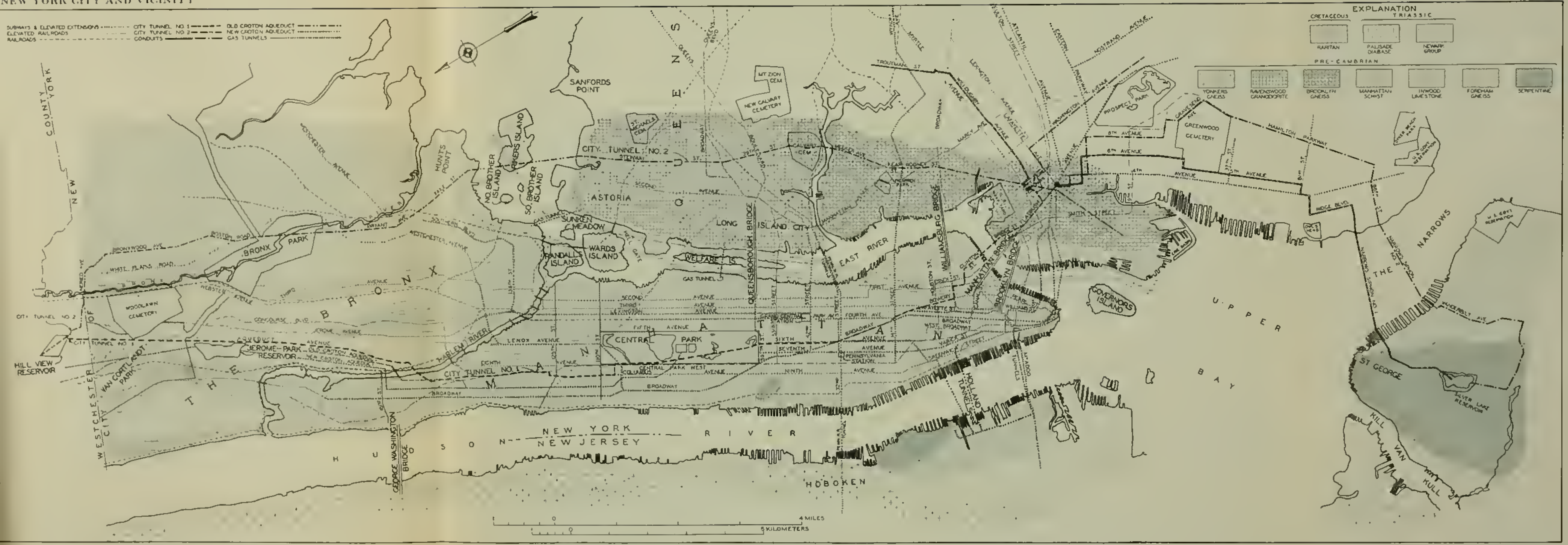
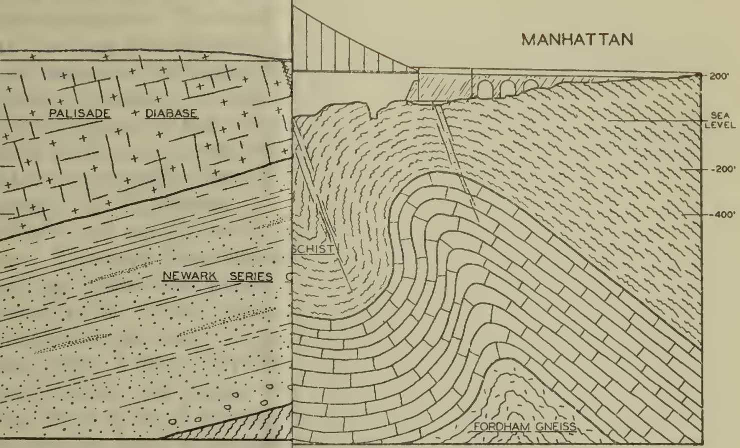
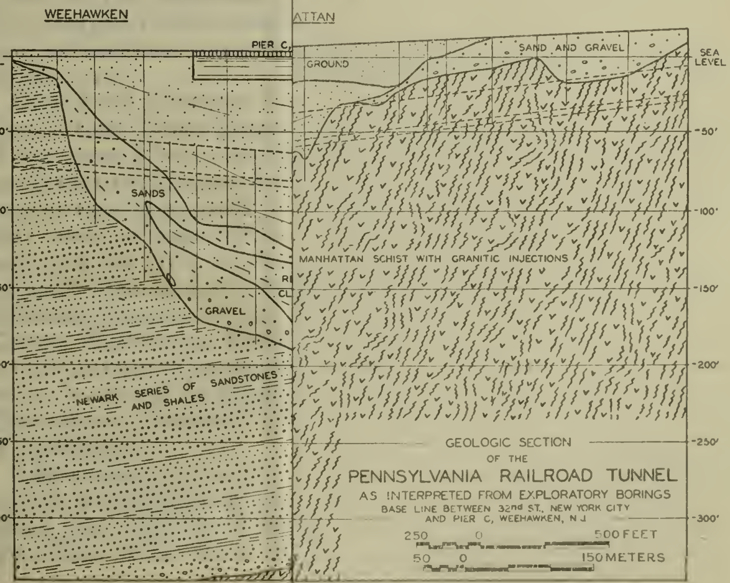
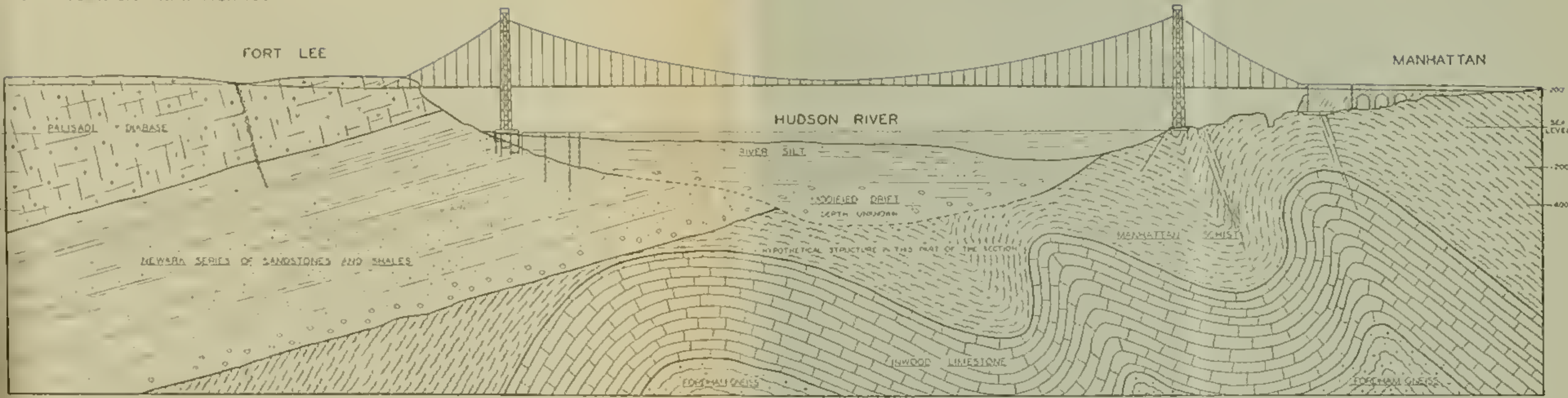


LOCATION MAP OF THE PRINCIPAL ENGINEERING STRUCTURES OF THE CITY OF NEW YORK

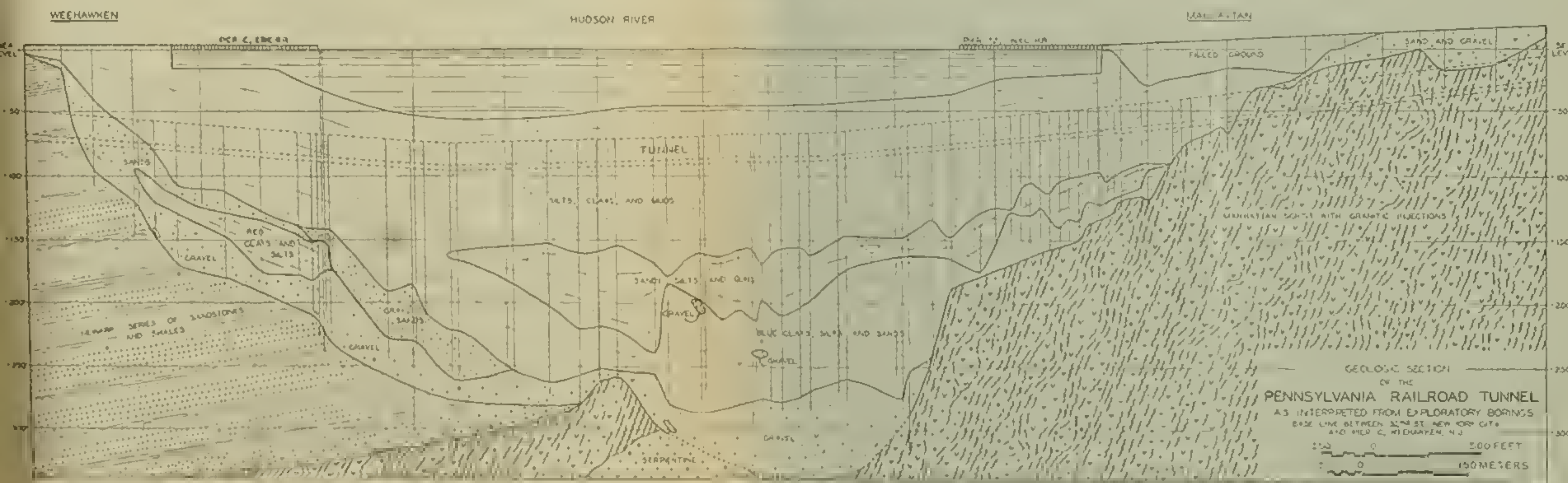




GEOLOGIC SECTION OF THE PENNSYLVANIA RAILROAD TUNNEL AS INTERPRETED FROM EXPLORATORY BORINGS BASE LINE BETWEEN 32nd ST., NEW YORK CITY AND PIER C, WEEHAWKEN, N.J.



A. IDEALIZED GEOLOGIC SECTION ACROSS THE HUDSON RIVER AT THE SITE OF THE GEORGE WASHINGTON BRIDGE



B

These beds dip at an angle of 15° under the Palisades, and thus their edges are exposed in the foundation, the floor of which steps down from one bed to another, exposing both the sandstone and shale members. In order to eliminate the uncertainty felt as to the bearing competence of the shale, all overburden and loosened material belonging to the floor was removed, as well as the exposed portions of the shale members, so that the pier rests directly upon the sandstone beds. Thus the pier steps down with these beds to a depth nearly 50 feet (15 meters) greater on the outer or riverside edge of the foundation than on the inner side, toward the Palisades.

Only one condition of special difficulty appeared in construction. The rock floor was reached by use of a coffer dam made by driving sheet-steel piling through the overburden of mud and glacial drift. Then the water was pumped out and the inclosed material excavated. The river silt was found to be so fluid, however, that a flow developed beneath one corner of the coffer dam, where the piling was prevented from reaching the solid floor by a nest of glacial boulders, and through this break the excavation filled so rapidly that some of the workmen could not escape. When the floor was finally stripped explanation was found for a fractured condition in the recovered core from certain exploratory borings. It was found that some of the superficial blocks of the sandstone ledges had been moved slightly. This was charged to the crowding of glacial ice. No other disturbance or weakness was evident. The foundation has proved to be satisfactory.

One of the questions always presented by a structure of this kind is that of the danger of faulting or differential movement of the ground between the two piers. It has been assumed by many that the Hudson River follows a great fault line. All recent information is opposed to this view. Although it is recognized that faults of large throw cross the river at several other points and that the river much farther north follows certain of them for short distances, it is believed that all of the evidence in hand indicates freedom from fault structure in the river at the George Washington Bridge. Furthermore, there is no evidence in this district of movement in recent time on any of the faults whose locations are known. On both counts, therefore, it seems allowable to conclude that the bridge is safe against this kind of movement.

The geologic structure at the site of the bridge is indicated on the accompanying cross section (pl. 8, *A*), which is generalized, but indicates correctly the features that are known on both sides of the river. The actual conditions and structure in the bottom of the gorge are inferred, for they have never been determined. No boring has ever gone down into the floor in the very bottom of the drift-clogged and silt-filled gorge of this ancient river.

KILL VAN KULL BRIDGE

The Kill Van Kull Bridge has both its principal piers on the solid igneous rock of the Palisade trap ridge. The peneplaned surface of this ridge dips gently to the south and passes beneath the surface on the Bayonne side but continues underground across the channel into Staten Island. Advantage was taken of this fine support. This bridge has probably a better foundation than any other bridge in the city.

UNDERGROUND TRANSPORTATION STRUCTURES

New York is a city of tunnels. The total length of transportation tunnels is about 100 miles (161 kilometers). Some of them, for railways, subways, and drainage, are shallow and present comparatively simple geologic problems. The major projects of this kind are as follows:

Railroad tunnels:
- New York Central Railroad, 42d Street to 110th Street.
- Pennsylvania and Long Island railroad systems, Hackensack Valley to Long Island City.
- West Shore Railroad, through Bergen Hill, Palisade Ridge.
- New York, Ontario & Western Railway, through Palisade Ridge.
- Erie Railroad tunnel and cut through the Palisade Ridge.

Subway tunnels:
- McAdoo Tunnels, under the Hudson River and through the Palisade Ridge to Newark.
- Interborough Rapid Transit Corporation tunnel.
- Brooklyn-Manhattan Transit Corporation tunnel.
- New Eighth Avenue subway.

Vehicular tunnel:
- Holland Tunnel under the Hudson River, connecting Manhattan Island and Jersey City.

Many of these tunnels would deserve separate geologic description if it were not for the fact that others have presented so much greater complexity and claim all the attention that can be given in a brief account.

RAILROAD TUNNELS

Most of the railroads entering the city of New York are surface lines requiring no more engineering originality than is usual on entering a large city. All the approaches were handled in this manner up to 1910, the New York Central and the New York, New Haven & Hartford Railroads reaching Manhattan

Island over bridges. The others all depended upon ferry service. About 20 years ago the Pennsylvania Railroad Co. abandoned its method of approach, which up to that time had been by ferry across the Hudson River, and constructed a tunnel allowing trains to run directly into the heart of the city. All the other roads approaching from the west still maintain terminals in Weehawken and Jersey City and reach New York by ferry service.

The Pennsylvania Railroad tunnel under the Hudson River is one of the pioneer projects of its kind. The approach from the west is through a tunnel a mile (1.6 kilometers) long from the Hackensack Meadows, on the west margin of the Palisade Ridge, to the Hudson River. The river margin itself is reached at a depth of about 75 feet (23 meters) below mean water level, and the tunnel reaches a maximum depth of 90 feet (27 meters), rising again on the New York side and reaching the Pennsylvania station through an open cut.

When the Pennsylvania Railroad tunnel was constructed it was connected by tunnel across town and under the East River with the Long Island Railroad, which up to that time had maintained a terminal in Long Island City. In this way both of these roads established their principal terminal at 33d Street and Seventh Avenue and handled all of this traffic underground, greatly relieving the congestion of their former approaches and giving the additional advantage of delivery to the heart of the city. In addition to this tunnel, the Pennsylvania Railroad makes connection in Jersey City with the McAdoo subway tunnels under the Hudson, which reach the lower Manhattan business district.

That portion of the tunnel on Manhattan Island presented no great difficulty, for it is largely in solid rock, partly open cut, encountering only the glacial cover and the Manhattan schist of the island. That portion passing beneath the Hudson River and the portion penetrating the Palisade Ridge, however, present more complicated conditions. The preglacial rock gorge is at least 300 feet (91 meters) deep and probably considerably more. This is too deep for a tunnel in rock for this purpose and too deep also for any system of supports for the tubes. The tunnel was driven through the river silt and mixed glacial débris for a distance of 6,000 feet (1,829 meters). Most of the material is unsubstantial silt and mud, unsuitable for the support of heavy structures. Each tunnel was driven through this mud under air and is essentially a steel tube suspended in the mud, depending for its stability on the balance between the weight of the tunnel and the counteracting support due to displacement. On both margins of the river the tunnel enters more substantial glacial drift and extends thence into sound rock. On the New Jersey side the tunnel passes into sandstones and shales beneath the trap and then through the trap ridge to the overlying sandstones of the Hackensack Valley, coming to the open air at a distance of a mile (1.6 kilometers) from the river.

This structure has been in use for more than 20 years and has behaved virtually as expected. It is affected slightly, as can be detected by delicate instruments, by the rise and fall of the tides, owing to the change in pressure thus developed on the river muds, but this movement has not disturbed the equilibrium of the structure, which is regarded as an entirely successful engineering accomplishment.

The exploratory borings made in connection with this piece of work give the most detailed data yet available on the composition and structure of the fill occupying the Hudson River gorge. The accompanying cross section (pl. 8, *B*) is an adaptation of the engineer's drawing covering these conditions.

SUBWAY TUNNELS

The subway systems of New York are largely shallow covered excavations constructed in open cut, but a few are actual tunnels.

There are eight subway tunnels under the rivers, and others are under construction. Some of these are in the rock floor and others penetrate the loose river fill. The Brooklyn-Manhattan Transit system has approximately 43 miles (69 kilometers) of covered subway and tunnel, and the Interborough Rapid Transit system 55 miles (88 kilometers). The new Eighth Avenue subway is about 10 miles (16 kilometers) long.

The average cost of a 4-track subway is $8,000,000 to $10,000,000 a mile. One of the most costly sections is the Nassau-Broad Street subway, completed in 1930 at a cost of $11,000,000 for 4,850 feet (1,478 meters). The street is only 40 feet (12 meters) wide and the subway is constructed in two levels. Part of the great cost was due to the necessity of underpinning buildings on both sides of the street. Over 30 miles (48 kilometers) of buildings in the congested districts of the city have been underpinned where subways have been constructed in loose unconsolidated ground.

On account of the shallowness and the open-cut form of structure the work has been undertaken with reasonable assurance and without elaborate preliminary geologic explorations. One of the chief dangers has originated in the jointing and strong foliation of the Manhattan schist. Master joints commonly extend for considerable distances and generally dip at a steep angle. At a few places where subway excavation ran parallel to such joints, great wedgelike masses slid into the excavation, and similar failure has occasionally endangered the support of the adjacent street and other structures. There is nothing peculiar about such behavior. The same conditions are met also in the tunnels, but on the whole an open cut, because of the removal of top support across the opening, is more likely to develop such failure than a tunnel.

At other places excessive decay of the floor rock has caused caving and slumping of the softened material, and the glacial overburden has presented the usual variety of problems, including slumping ground and water.

The oldest subway system has been in use for over 30 years and has required a surprisingly small amount of correction or repair.

The inception of the first Hudson River tunnel dates back to 1871 and is credited to DeWitt Clinton Haskin, under whose direction work was begun in 1874. Working shafts were sunk at the foot of 15th Street in Jersey City and Morton Street in New York, somewhat over a mile (1.6 kilometers) apart. Little was known about the nature of the material of the river bed, and no preliminary exploratory geologic investigations were made. Work progressed slowly until July, 1880, when a blowout occurred which cost 20 lives. Work was resumed, however, and at the end of two years about 2,000 feet (610 meters) of tube had been constructed. For eight years the work was suspended for lack of capital, but it was taken up again in 1890, and 2,000 feet more was finished when the company failed. In 1896 William G. McAdoo undertook the task of reorganization. The old tunnel was pumped out and kept in order and under observation until 1902, when final construction was resumed. The unfinished portion of the north tube and all of the south tube were completed by 1908.

These tunnels cross the river at two places, one at Morton Street and the other at Cortland and Dey Streets. Both are constructed in essentially the same manner as the Pennsylvania Railroad tunnel, partly in rock as open tunnels and partly with steel tubes through river mud, where the work was done under air by the shield method. The tubes are laid in the silts of the river and are connected with tunnels that traverse the lower portion of Manhattan Island as far north as 33d Street and, on the New Jersey side, along the river margin from Jersey City to Hoboken, connecting the Pennsylvania, Erie, and Delaware, Lackawanna & Western railway stations and penetrating also the Palisade Ridge to the Hackensack Meadows and across the valley to Newark.

No unusual geologic conditions were encountered except on the Jersey City side of the river, where the tunnel lining for a considerable distance was attacked by chemically active ground water, which destroyed the concrete and required extensive repair and protection. The trouble was probably not due wholly to natural causes but doubtless originated chiefly in the artificial fill of the river margin. Much of the ground in the vicinity had been filled in with ashes and cinders and garbage débris of all descriptions, some of which, under weathering, furnished the injurious constituents. It appeared, also, that manufacturing plants in the vicinity were not sufficiently careful about the disposal of waste, so that additional chemical content may have come from such sources. Measures were taken for improving the drainage, as far as possible preventing seepage of these waters through the concrete walls, and these methods have been sufficiently successful to keep the tunnel in safe operation.

VEHICULAR TUNNELS

Vehicular traffic over the East and Harlem Rivers has been cared for by a number of large bridges. Similar traffic across the Hudson has been confined to ferry service up to very recent years. The great increase since the common use of the automobile and truck has presented a problem requiring some other solution, either by bridges or by tunnels. The expense and difficulty of bridge construction over the Hudson early led to the consideration of vehicular tunnel projects. Several such projects have been considered. One, the Holland Tunnel, has been constructed and is operating with great success for the lower part of the city. Another, to be known as the Midtown Tunnel, is projected, and much of the exploratory work and planning has been done. This is to be located at 38th Street and probably will not be constructed for two or three years. The upper part of the city is adequately cared for by the George Washington Bridge, at 179th Street, completed in 1931, but some time in the future, perhaps at no very distant day, an additional vehicular tunnel or bridge will be called for to accommodate the intervening district—if a tunnel, at 125th Street; if a bridge, probably much farther downtown.

The Holland Tunnel starts at Canal Street on the New York side and penetrates beneath the Hudson River to Jersey City. It includes two tubes penetrating the silts of the river, one for east-bound traffic and the other for west-bound traffic. Work was begun October 12, 1920, under Chief Engineer Clifford M. Holland, who gave his life to this piece of work. It was finished under other hands. The twin tubes are each 29½ feet (8.95 meters) in diameter, exceeding the Pennsylvania Railroad tubes by 6½ feet (1.95 meters). Work was done under compressed air by the shield method. Great care was taken for the protection of the men against the accidents that have attended some of the earlier undertakings of this kind. No unexpected conditions of sufficient importance to disturb the plan or methods of construction were encountered in this project. The tunnels were completed in 1927 at a cost of $50,000,000 and have been in successful operation since that time. In 1930 more than 12,000,000 vehicles passed through the tubes.

AQUEDUCTS

In earlier days the residents of New York City were able to obtain an adequate water supply from wells, but as the city grew methods were adopted for bringing additional water from outside sources. These have now been developed to supply a safe yield of more than 1,000,000,000 gallons (3,800,000,000 liters) a day from storage reserves with a capacity of 130,000,000,000 gallons (492,000,000,000 liters). The whole system represents an investment of $500,000,000.

Early Water Systems

The first of these water supply projects on a comparatively large scale was the old Croton Aqueduct, finished in 1842, bringing water from the Croton River a distance of 30 miles (48 kilometers). In the course of time larger supplies were needed, and the new Croton Aqueduct was constructed, leading from a much larger reservoir on the Croton River created by the Cornell Dam, finished in 1907, 3 miles (4.8 kilometers) farther downstream.

Both of these aqueducts brought water from the Croton River through shallow tunnels and cut and cover structure, the older one entering the city across High Bridge over the Harlem River at 168th Street, and the new one crossing the Harlem River in a tunnel a short distance north of High Bridge. This new tunnel beneath the Harlem River was the first experience in deep tunnel construction for any purpose in the city. In the meantime additional supplies from wells were developed on Long Island, and the demands of the city have been supplemented from these sources. With continued growth of the city, it became necessary 30 years ago to look for additional supplies. Reconnaissance studies were made by a commission known to the engineering profession as the Burr-Herring-Freeman Commission, which recommended the Catskill region as the most promising source for the enormous supplies which seemed to be required.

Catskill Aqueduct

In 1905 the construction of the Catskill water-supply system was authorized. As finally developed it includes two large reservoirs in the Catskill Mountains—the Gilboa Reservoir, on Schoharie Creek, on the north side of the Catskills, and the Ashokan Reservoir, on Esopus Creek, on the southeast side. Water from the Schoharie drainage basin is delivered to Esopus Creek through a tunnel 18 miles (29 kilometers) long, passing beneath the highest range of the Catskills, thus adding these waters to those of Esopus Creek and the Ashokan Reservoir, the principal storage units of the Catskill Aqueduct system.

From that point the water thus gathered flows to the city of New York through a series of cut and cover aqueduct sections at hydraulic grade, grade tunnels through divides, and pressure tunnels under valleys where the surface is too low, a distance of 72 miles (116 kilometers) to the Kensico Reservoir, where storage for about a month's supply is provided. From this point the aqueduct continues a distance of 20 miles (32 kilometers) farther, to the north line of the city, where there is a small equalizing reservoir, known as Hill View. From this reservoir water is carried through the city by means of a distribution tunnel 18 miles (29 kilometers) long to the vicinity of Fort Green Park, in Brooklyn. The farthest extension of this system is by pipe line and tunnel ending at Silver Lake, on Staten Island. The total distance from the Gilboa Dam to the small storage reservoir at Silver Lake is 130 miles (209 kilometers). The Catskill Aqueduct proper, beginning at the Ashokan Dam and ending at Fort Green Park, Brooklyn, the terminal of the city tunnel, is 105 miles (169 kilometers) long.

The country crossed by this system, shown in outline in Plate 9, and in cross section in Plate 10, exhibits so great a variety of natural features and physical conditions that virtually every individual section of this aqueduct presented special geologic problems. This fact was early realized, and accordingly geologic service was established in the beginning. Consultants[8] already intimately acquainted with the geology of the region and having had more or less extended experience in engineering geology were attached to the staff, and studies in this field were carried on parallel with development of engineering plans. In this manner it was possible for the geologists to help direct the investigations, interpret the exploratory returns, and indicate the bearing of the

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[8] The consulting geologists on this work were the late Prof. James F. Kemp, of Columbia University, the late Prof. W. O. Crosby, of the Massachusetts Institute of Technology, and Dr. Charles P. Berkey, of Columbia University. Doctor Berkey is still serving the city of New York on various local projects.


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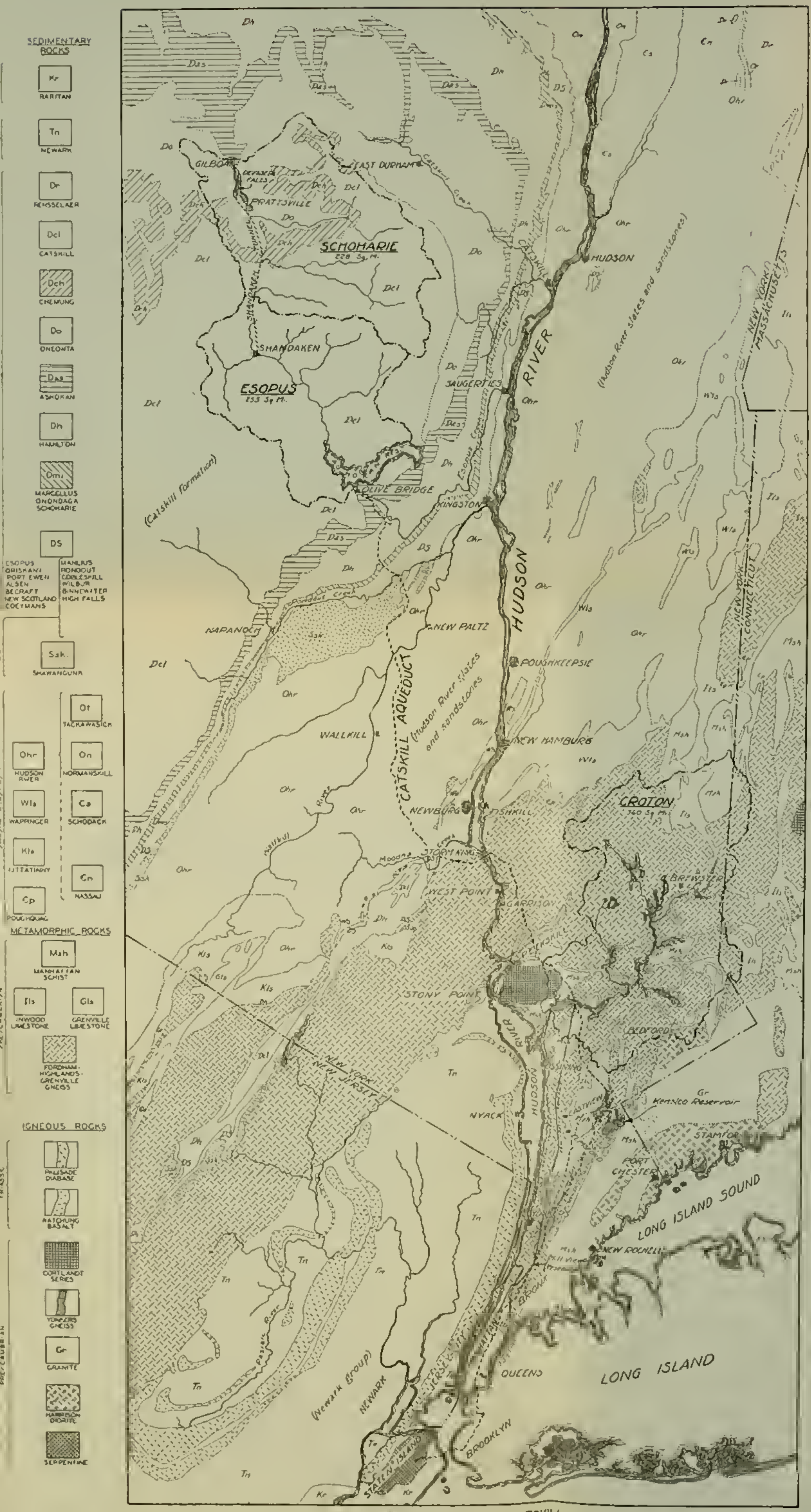

GEOLOGIC AND LOCATION MAP OF THE CATSKILL AQUEDUCT SYSTEM

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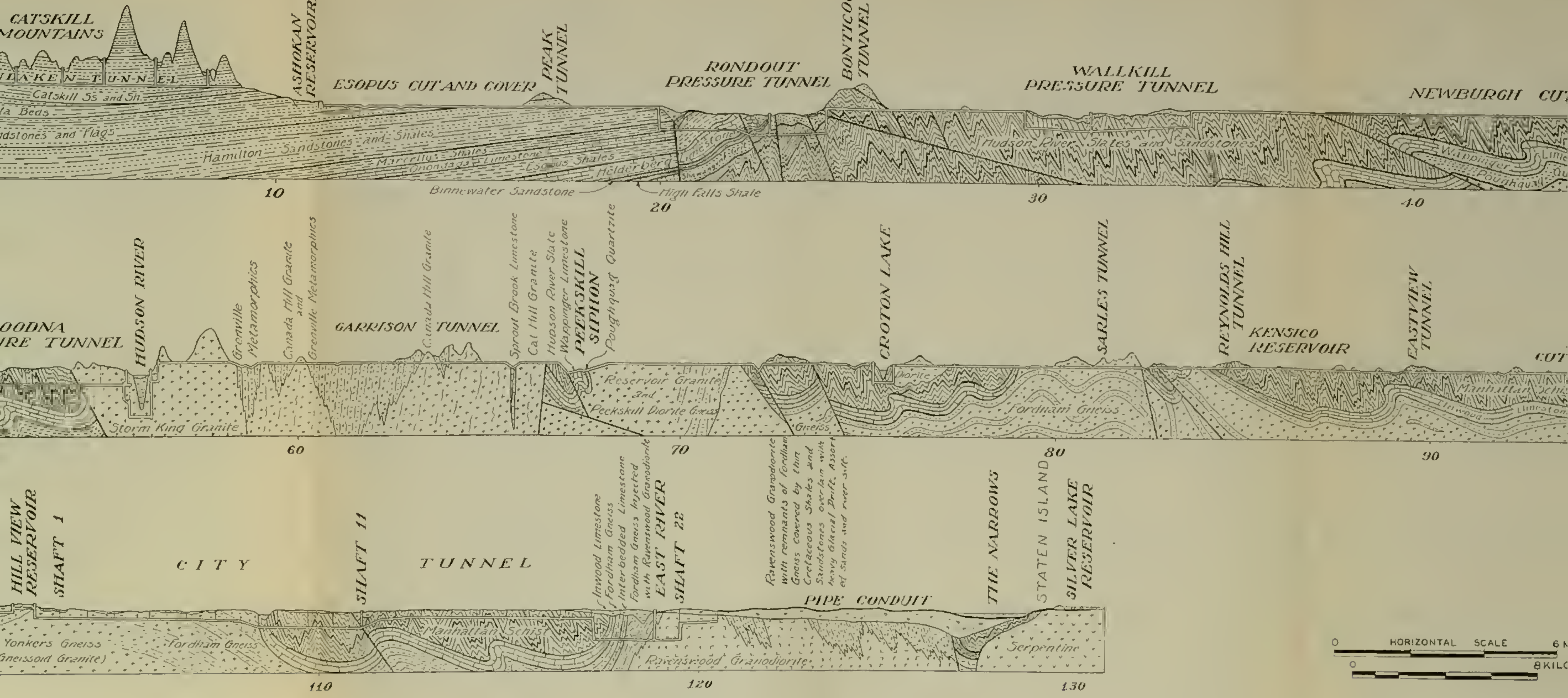

GEOLOGIC SECTION ALONG THE CATSKILL AQUEDUCT accumulated data on questions of design and plan and method of construction. Ultimately, as construction advanced, opportunity was afforded to check the original determinations against actual construction returns.

In this project virtually nothing was taken for granted. Every new step was the subject of special investigation with the avowed purpose of determining the conditions to be met; and, when these were determined, the plan of construction and design of the structure were brought into conformity with them. In this manner specifications could be drawn with sufficient accuracy to avoid most of the dangers, mistakes, and special claims commonly attending such work. Very few features or conditions were discovered in construction that were not indicated by the exploratory investigations, and such as were found proved to be of minor significance and were cared for at moderate expense.

The Catskill system is made up of the following individual units, some of which warrant brief description.

Dams and reservoirs:
- Gilboa Dam and Reservoir, on Schoharie Creek, the most distant source.
- Olive Bridge Dam and Ashokan Reservoir, on Esopus Creek, the head of the Catskill Aqueduct.
- Kensico Dam and Reservoir, at Valhalla, a special reserve supply near White Plains, 20 miles (32 kilometers) from the city.
- Hill View equalizing reservoir, on the north line of the city.
- Silver Lake Reservoir, on Staten Island.

Cut-and-cover aqueduct, 27 sections, aggregating 54.5 miles (88 kilometers) in length.

Pressure tunnels:
- Rondout Tunnel, under the Rondout Valley between the Catskills and the Shawangunk Range.
- Wallkill Tunnel, under the Wallkill Valley.
- Moodna Tunnel, under Moodna Creek and adjacent low ground to Storm King Mountain and the Hudson River gorge.
- Hudson River pressure tunnel, under the Hudson River at Storm King.
- Croton Tunnel, beneath Croton Reservoir.
- City Tunnel No. 1, and 18-mile (29-kilometer) tunnel under the city of New York.

Grade tunnels:
- Shandaken Tunnel, to carry the Schoharie supply back through the Catskill Mountains to Esopus Creek.
- Bonticou Tunnel, across the Shawangunk Range.
- Breakneck Tunnel, through Breakneck Mountain.
- Garrison Tunnel, through the central range of the Highlands.
- Hunter Creek Tunnel.
- Croton Lake Tunnel, under Croton Reservoir.

The system ends with a series of much shorter and less conspicuous sections of grade tunnels and pressure tunnels belonging to the Southern Aqueduct, reaching the north line of the city, where the Hill View Reservoir is situated and the long City

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Tunnel No. 1, penetrating virtually the whole length of the city, begins.

The major units in this system, especially those illustrating special geologic features or application, are individually described below.

GILBOA DAM

There is a drainage area of 250 square miles (648 square kilometers) tributary to Schoharie Creek above the former village of Gilboa. It was early appreciated that if the water from this area were to be conserved a large reservoir and a long delivery tunnel would have to be constructed. On preliminary study two sites were selected for special investigation, one at Devasego Falls, near Prattsville, and the other at the village of Gilboa, about 3 miles (4.8 kilometers) below.

Especially favorable relief features mark the Devasego Falls site. At this place Schoharie Creek flows for a short distance through a new rock gorge, eroded by the stream after being thrown out of its original course by the blocking of the valley with glacial deposits. The distribution of these deposits together with stream erosion in postglacial time has developed a basinlike form above this location, at Devasego Falls, leaving a natural dam at that place. Thus the whole setting looks superficially very favorable for the economical building of a dam.

Although the valley is blocked heavily with glacial drift, some of which at the surface is tight and suitable in every respect to serve as a part of the dam, the materials beneath this capping formation are exceedingly pervious and not suitable for service as foundation for so large a structure. Exploratory investigations showed that the preglacial channel is more than 100 feet (30 meters) deeper than the present one, and that most of the fill in the gorge, except the top 25 to 30 feet (7.6 to 9 meters) is made up of porous gravel and sand. So large a proportion is pervious that a cut-off wall to the rock floor would be required across the whole valley. After these conditions were disclosed by borings, tests were made to determine the quality of the ground with respect to leakage, and these tests confirmed the conclusions drawn from other evidence. On account of these conditions, it was decided to explore the alternative site at Gilboa.

At Gilboa the graywacke sandstone beds, characteristic of the Catskill country, commonly known in commercial circles as "Hudson River bluestone," were exposed on one side, and the stream flowed across solid rock ledges. Advantage therefore could be taken of sound rock for a portion of the foundation and one abutment. The opposite side of the valley was covered heavily with glacial drift and afforded no indication whatever of the exact position of the rock floor, the depth of the gorge, or the distance to the bounding walls of the valley. It was evident from the beginning, however, that the overburden was of very different quality from that at Devasego Falls, the whole of it being either boulder clay of the type of glacial till or assorted clays such as are deposited in quiet ponded waters. On additional exploratory investigation these conditions were fully proved, and it was concluded that this was the better location for the dam on Schoharie Creek. Part of the dam rests on rock, and part ends in a massive clay deposit and glacial till on the west side.

In construction, a portion of the east abutment rock was found to have abnormally open joints, which required special treatment. This condition is thought to have been caused by the crowding of glacial ice, moving slightly the horizontally bedded and jointed sandstone blocks of the projecting spur. There was no other evidence of movement except the gentle tilting that dates back to Permian time. Local deformation, resulting in the jostling of blocks in strongly jointed rock, due to the crowding action of glacial ice, is not a rare phenomenon. It has been noted also in the foundations of the George Washington Bridge. The clays of the west abutment were found to have a tendency to slump when saturated with water and on this account required more precaution in construction than was at first expected. With special treatment these conditions were met, and the bank was stabilized. The dam has been in operation successfully for several years.

SHANDAKEN TUNNEL

The Shandaken Tunnel takes its name from a village on the south side of the central range of the Catskills, where the outlet portal of the long tunnel from the Gilboa Reservoir delivers Schoharie water into Esopus Creek. The tunnel is 18 miles (29 kilometers) long, beginning 2 miles (3.2 kilometers) above the Gilboa Dam, and penetrates the gently dipping graywacke sandstone and shale beds characteristic of the Catskill region for the whole distance. The tunnel is virtually at grade, or only slight pressure, so that no special conditions are imposed. It passes beneath the main range, reaching a maximum depth from the surface of 2,000 feet (610 meters). On account of the dip of the strata and the normal variation in character of individual beds, the tunnel encounters all varieties of Catskill rock from hard sandstone to comparatively friable shale.

The conditions are simple, and normally little difficulty should have been expected. Nevertheless, one somewhat unusual condition was encountered. The rock is under so much pressure and unrelieved strain that there is a tendency to development of the so-called "popping rock." Slabs snapped off, and others continued to loosen from sound walls, thus endangering the workmen. This condition introduced enough difficulty to require more extensive timbering than was expected.

Only one other geologic feature invites special attention. This was the finding of salt water in the heart of the Catskill Mountains. The water is more salty than sea water and appears to represent a concentration of the original salt waters of the sea margin. The water recovered is believed to be connate water of Devonian age. This is the only place in all the tunnels of the system where there is any indication that the waters encountered represent entrapped waters of ancient geologic time. The composition is as follows:

Analysis of connate water of Devonian age, from South Tunnel, shaft No. 6, July 22, 1920

	Parts per million
Total solids	112,480
Chlorine	61,500
Sodium	39,590
Calcium	10,230
Magnesium	1,160

Potassium and aluminum were present in minute quantities, and sulphates and phosphates were also indicated qualitatively.

The Shandaken Tunnel was constructed by working from both portals and six shafts, the deepest of which was 600 feet (183 meters) deep. No unusual equipment or methods were required.

ASHOKAN DAM AND RESERVOIR

The principal storage reservoir of the Catskill system is the Ashokan Reservoir, with a dam at Olive Bridge. In preliminary studies it was found that the topographic features were favorable for a dam at three possible sites—an upper one at Broadhead Bridge, a middle one at Olive Bridge, and a lower one at Cathedral Gorge.

On casual inspection the advantage seemed to lie with Cathedral Gorge, where a long spur extends into the valley from the north side, almost closing it. The stream was pushed out of its normal course by glacial deposits, being compelled to start a new channel over the obstruction so far over on the south side that it soon discovered solid rock beneath and has eroded a narrow postglacial gorge in the rock floor. (See fig. 19.)

A similar obstruction exists at Olive Bridge, where the stream has eroded another postglacial channel in the rock wall of the valley. At Broadhead Bridge the valley was not so nearly closed. The final choice of site, however, was based not on these topographic features but on the quality of the overburden forming the several obstructions in the valley.

Early in the exploratory investigation the Broadhead Bridge location was eliminated, but the other two were investigated thoroughly by means of wash borings, core borings, test pits, shafts, and trenches. When the data were fully assembled, it became clear that the better physical conditions were to be found at Olive Bridge. At both places the present stream flows in a recently eroded rock gorge on the south side of the valley, and a much deeper channel of preglacial or interglacial origin is covered deeply with glacial deposits.

At Cathedral Gorge this ancient buried channel is about 75 feet (23 meters) deeper than the present one. (See fig. 19.) Its floor is covered with a deposit of sand and gravel of extremely porous character, to a total depth of nearly 200 feet (61 meters). This in turn is covered with ground moraine or till of much more substantial quality, giving the site a better appearance from surface indications alone than is otherwise warranted. The stream makes a sharp bend around the moraine-covered point or spur, and the present channel is cut considerably below the morainic cover into the sand and gravel beneath. Although the morainic ground is reasonably tight, the underlying gorge fill is very pervious. It was evidently not prcaticable, therefore, to construct a dam on this site unless provision were made to obstruct the underflow leakage that would be certain to penetrate along the old course of the stream through the narrow spur. The great depth of deposit requiring such treatment, and especially the expense and difficulty of making a dam at this place reasonably tight, ultimately led to the abandonment of this site in favor of Olive Bridge.

At Olive Bridge a ground moraine or boulder clay of the "hardpan" type, part of which is believed to have been laid down in standing water, forms the fill of the preglacial gorge. This material must have been deposited at a time when a tongue of ice, moving down the adjacent Beaverkill Basin, obstructed the main valley of Esopus Creek and formed a lake in about the position now occupied by the reservoir. The deposit made at that time overfilled the north side of the valley, so that the present Esopus Creek was compelled to take a course far over to the south side of the valley, where it has eroded a narrow postglacial channel in the rock floor. The older buried channel is 50 feet (15 meters) deeper than the new one and is filled from the very bottom with the boulder clay of exceptional quality already referred to. (See fig. 20.) The material is tight and very compact and is in fact a more effective barrier to water seepage

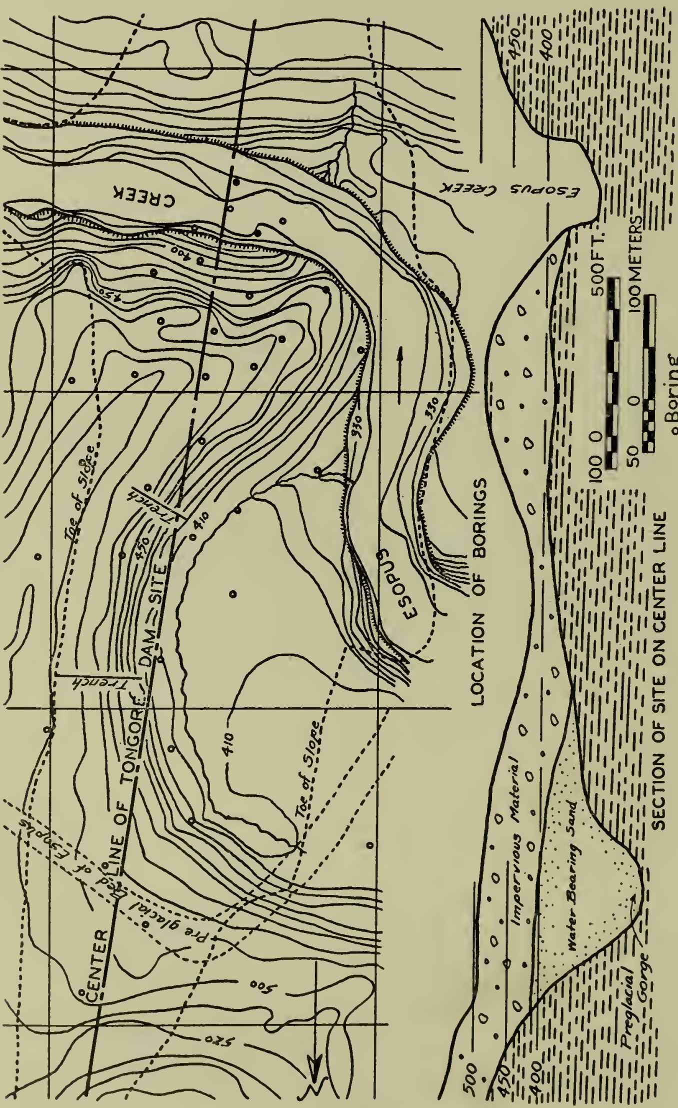


FIGURE 19.—Tongore dam site, at Cathedral Gorge

than any artificial structure that it is practicable to build in its place. It was therefore incorporated as a part of the dam.

The rock formation of the floor belongs to the shale and graywacke series that characterizes a large portion of the Catskill area. In obtaining foundations for the masonry portion of the dam it was necessary only to make the excavation deep enough to remove the superficial, somewhat weathered material and the uppermost shale members, so as to reach the more substantial graywacke sandstone for direct support.

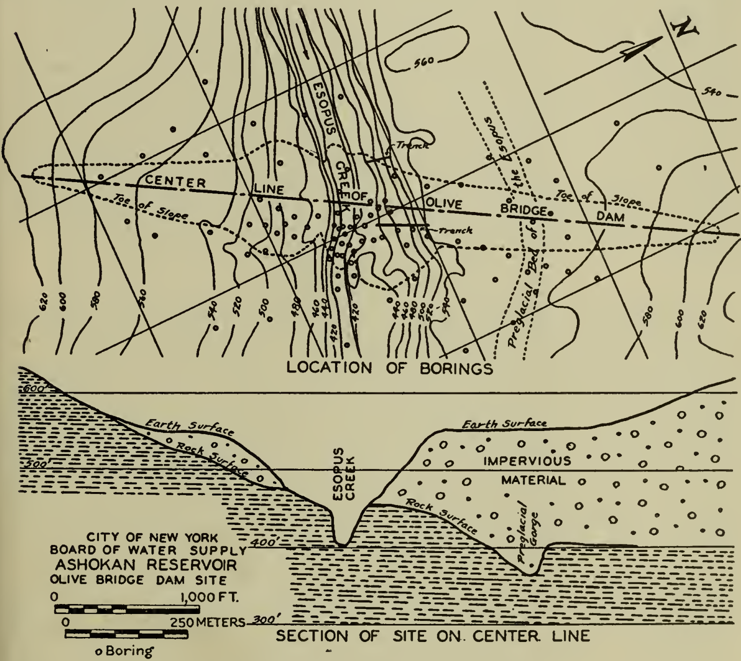


FIGURE 20.—Olive Bridge dam site

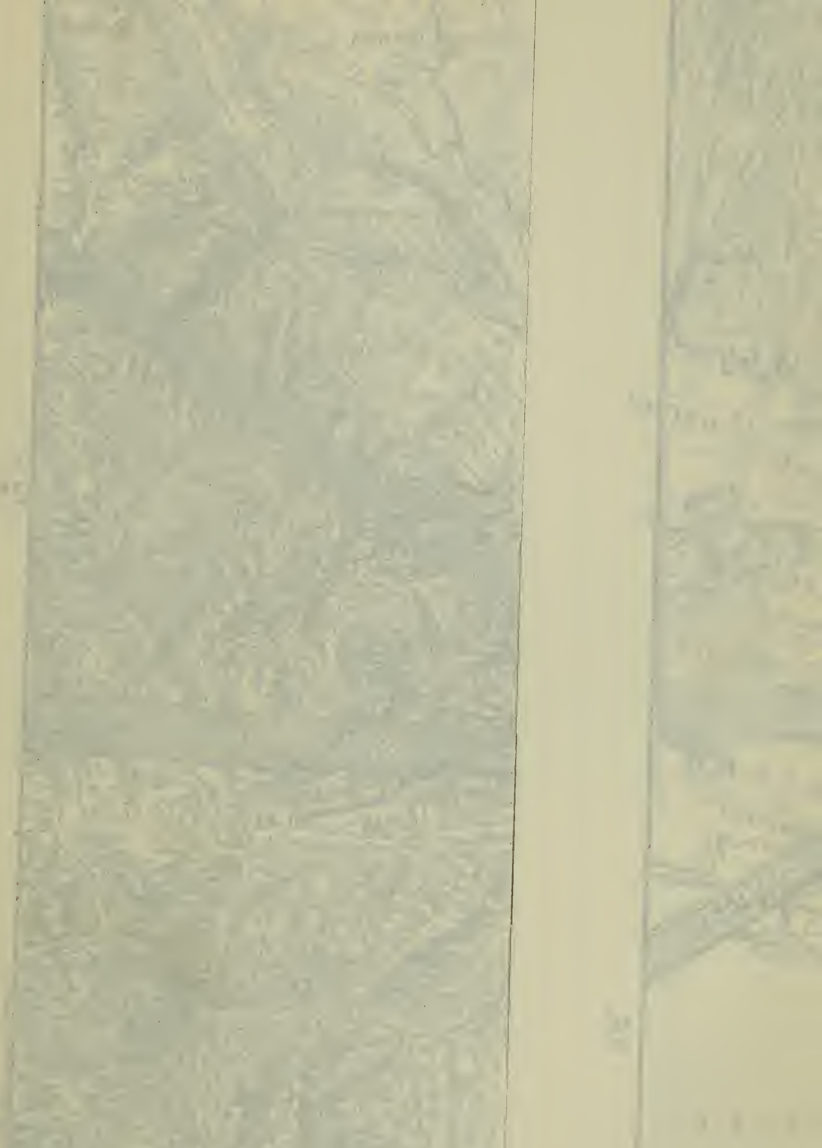
There is nothing in the formation likely to develop subsequent weakness or increasing leakage. Nevertheless, provision was made for grouting the joints, crevices, and bedding planes and for a suitable cut-off in the floor and abutments. On the north side the core wall for an earth embankment 1,000 feet (305 meters) long was established on the hardpan fill, and material of similar quality was obtained in the vicinity for building the earth structure. These two sections, therefore—the earth structure of the north valley side and the masonry structure occupying the gorge and the south valley side—constitute the Olive Bridge Dam. The dam is faced with concrete blocks instead of the local stone, but local stone was used for the cyclopean masonry and for the aggregate. It has been in successful operation for nearly 20 years. No questionable conditions have developed.

In raising the water level in the Ashokan Reservoir to 600 feet (183 meters) above sea level, several low places along the south and east sides of the Beaverkill Basin required special treatment. This took the form of dikes, of which 4 miles (6.4 kilometers) in all were constructed. Troublesome conditions were found at only two places. A deep notch was discovered in the old Beaverkill channel, requiring special cut-off treatment there. At the West Hurley dike a part of the protecting mantle on the rock floor within the reservoir had been removed in the course of construction of the dike, thus exposing the rock floor, and when the reservoir filled this ground leaked sufficiently to make special treatment advisable. The condition was cured by grouting through drill holes put into the floor through the dike.

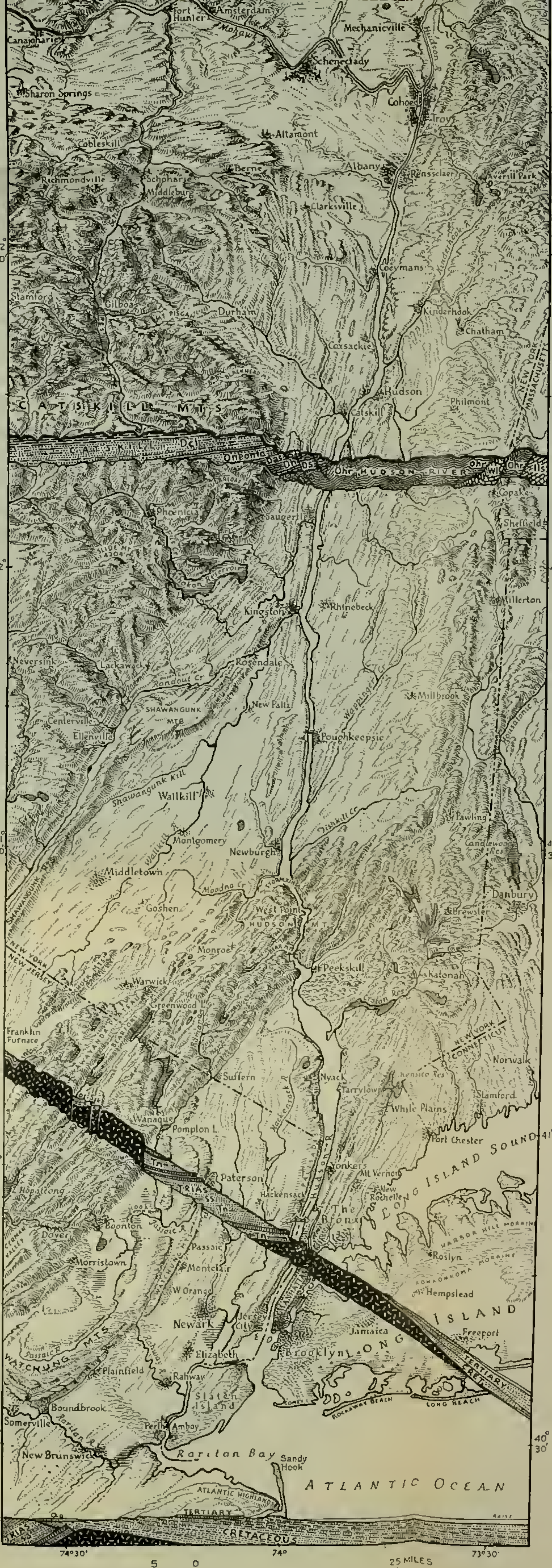
PRESSURE TUNNELS

The Hudson River with its tributaries presents an unusual pattern. The tributaries are adjusted to the geologic structure, so that the valleys in which they flow, especially in their lower courses, have a southwest-northeast alinement. The main stream crosses this system diagonally. The tributaries on the west side therefore join the main stream at a large obtuse angle, whereas those on the east side appear to have nearly the normal attitude but are similarly adjusted. The aqueduct coming from the Catskills, still farther west, therefore has to cross several of these valleys in gaining the river, instead of being able to follow a single divide between two streams. On the east side of the Hudson, where the tributaries join the main stream at about the usual acute angle, the aqueduct crosses the maximum number of valleys also. The aqueduct has been carried across three large valleys on the west side of the Hudson—the Rondout, the Wallkill, and the Moodna—by the construction of pressure tunnels; and a larger number of smaller valleys on the east side, all of which have been handled by pressure construction of some kind. These features are shown diagrammatically on Plate 11, which is intended chiefly to show the relief features and their relation to major geologic structures.

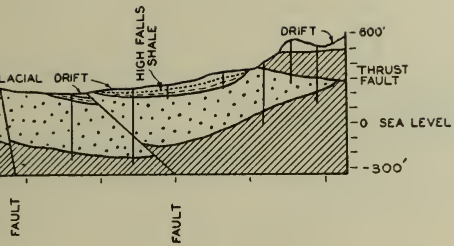
The first problem of considerable consequence along the aqueduct line after leaving the Ashokan Reservoir was presented at the south margin of the Catskill area, where it was necessary to



BLOCK DIAGRAM OF T



BLOCK DIAGRAM OF THE LOWER HUDSON RIVER REGION



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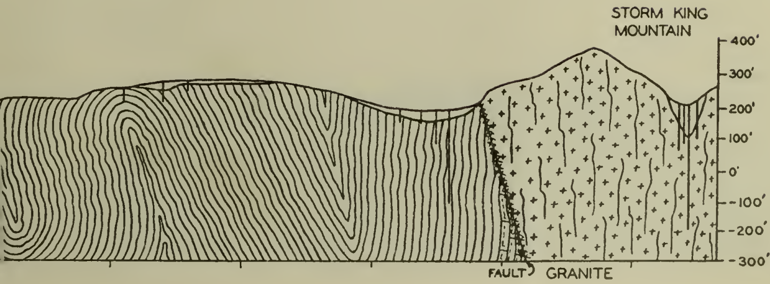
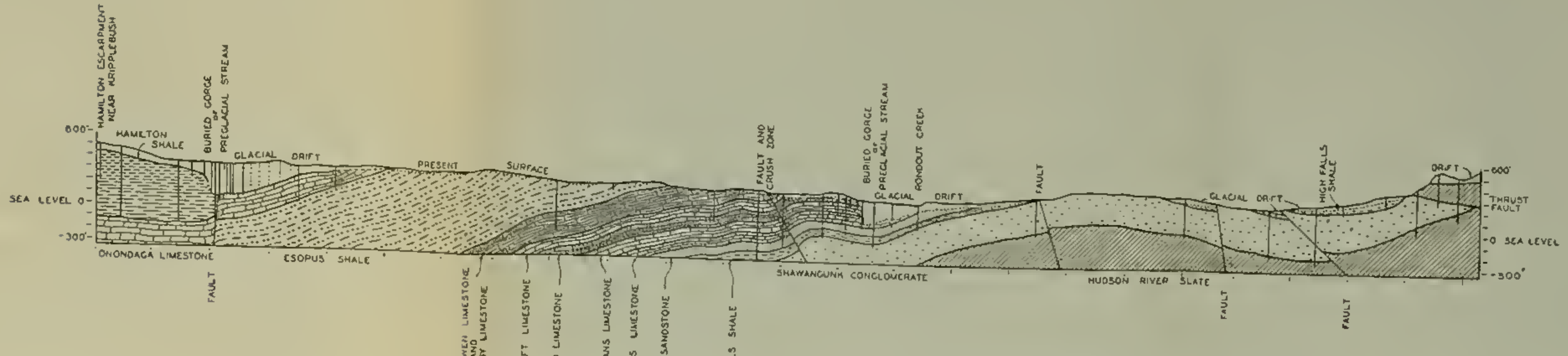


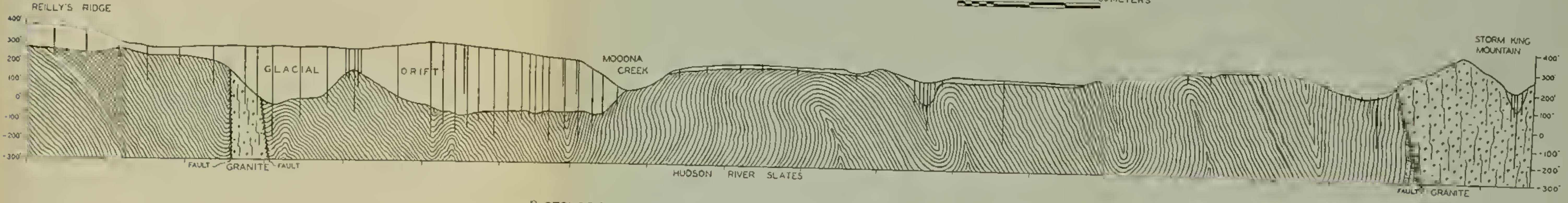


A. GEOLOGIC SECTION ACROSS RONDOUT VALLEY

CONSTRUCTED FROM DATA OF EXPLORATORY BORINGS

1,000 0 3,000 FEET

250 0 750 METERS



B. GEOLOGIC SECTION ACROSS MOODNA CREEK VALLEY

SHOWING PREGLACIAL VALLEY DETERMINED BY WELL BORINGS

1,000 0 3,000 FEET

250 0 750 METERS

cross the Rondout Valley. The approach to this valley is made through a series of cut and cover sections of aqueduct close beside Esopus Creek at grade. Water leaves Ashokan at an altitude of 560 feet (171 meters) and reaches Hill View, on the north line of the city, 92 miles (148 kilometers) distant, at 295 feet (90 meters). To accomplish this it was necessary to construct as much of the aqueduct as intervening topography would permit at only enough gradient to induce flow. Obstructing ridges and mountain ranges were penetrated by tunnels at grade or under only slight pressure. Depressions could have been crossed by building a bridge of proper height, as was done for the old Croton Aqueduct at High Bridge, or by carrying the whole volume through pipes of sufficient capacity and strength to stand the pressure and maintain the flow; but all the larger valleys were crossed by tunneling in the rock floor, making the structure tight, so that the water would come to grade again on the other side. For small shallow depressions steel pipes were used.

Rondout pressure tunnel.—The Rondout Valley is approximately 4 miles (6.4 kilometers) wide, and all points of it are far below aqueduct grade. When explorations were made for the purpose of determining the conditions to be met in constructing a pressure tunnel across this valley, it was found that the preglacial floor of the valley differed materially from that shown by the present topography. Two deep depressions are filled with glacial drift to depths of 100 to 200 feet (30 to 61 meters). At one point the floor is at sea level. These results indicated the approximate depth at which the tunnel should be placed to insure safety against the bursting pressure, but extensive additional exploratory work had to be done to determine the structure and quality of the rock to be penetrated. These showed conclusively that ten of the different rock formations usually recognized in the stratigraphy of the district would be penetrated by this tunnel, that a large thrust fault would be encountered at the east end of the tunnel in the upraise shaft, and that several small faults and minor folds would be encountered out in the valley. It was already known that all the formations dip west beneath the Catskill Mountain mass.

The most questionable physical conditions indicated by the borings were in the central part of the valley, where, under Rondout Creek, the porous Binnewater sandstone lies beneath a water-logged sand and gravel overburden. This water-charged mass in contact with the eroded edges of such porous strata is capable of furnishing enormous quantities of ground water. This was understood before construction began, so that it was possible to prepare for these conditions in construction, and also to modify the plan of working and fix the grade of the tunnel. To meet these conditions it was planned to cross this very pervious ground with a more steeply inclined tunnel than elsewhere, so as to give better drainage during construction. The west half of the tunnel therefore was placed at 150 feet (46 meters) below sea level, the central portion for a short distance was crossed with an incline reaching down to 250 feet (76 meters) below sea level, and the rest of the tunnel to the upraise shaft was carried at that level. This particular level was selected in order to place the tunnel continuously from that point within the Hudson River shales and sandstones and avoid the much harder overlying Shawangunk grit, which would have been more difficult and expensive to excavate. The tunnel encountered, without exception, the formations expected and the conditions predicted for them. The depth of 250 feet below sea level proved to be so close to the minimum depth allowable that the Shawangunk grit actually formed the roof of the tunnel for a stretch of nearly 500 feet (152 meters) in the lowest synclinal fold. The only feature found in actual construction whose importance was not fully realized from the preliminary exploration was the occurrence of caverns in the Helderberg limestones. These were encountered at 150 feet (46 meters) below sea level, or more than 300 feet (91 meters) below the surface of the ground and general water table. At one place in the tunnel a break developed in the walls adjacent to one of these caverns when the pressure of a full head was put on, and repairs had to be made.

The geologic structure of the valley, the formations penetrated, the structural features, and the relation of the tunnel to them are indicated on Plate 12, *A*.

Wallkill Valley pressure tunnel.—The Wallkill River flows for 70 miles (113 kilometers) northeastward to join the waters of the Hudson. Its broad open valley is underlain by Hudson River shales and sandstones, eroded much below aqueduct grade for a width of several miles, so that a pressure tunnel is required. The floor is heavily covered with glacial drift, and outcrops are scarce.

The rock floor profile was determined by the usual boring methods, which were easily carried on because of the simplicity of the glacial overburden. The only feature of significance is the depth of the preglacial channel, which is 79 feet (24 meters) below present sea level at the deepest point, nearly 20 miles (32 kilometers) above the junction of the stream with the Hudson.

The rock structure is so complicated by close folding and faulting that a reliable geologic cross section showing the precise position of the underlying formations could not be made. Three sedimentary formations of Paleozoic age lie beneath—the Hudson River shales and sandstones, of unknown thickness; the Wappinger limestone, approximately 1,000 feet (305 meters) thick; and the Poughquag quartzite, 600 feet (183 meters) thick. Although the so-called Hudson River formation exhibits considerable petrographic variety in the different members, it has thus far been quite impossible to construct a detailed column that is reliable enough to use in determining the structure. How far it might be, therefore, through the shales at any point to the underlying limestone was indeterminable by this method. It was assumed, however, that the whole tunnel would be in the Hudson River shales and sandstones, and this assumption proved to be correct.

The average type of rock in this formation is a rather fine-grained graywacke sandstone interbedded with argillaceous sandstones and siliceous shales, all standing at a steep angle, in many places vertical. Even with every foot of the formation thus exposed for a total distance of 4 miles (6.4 kilometers), it was not found possible to determine the structure with sufficient certainty to tell at what point the underlying limestone comes nearest the surface. The Hudson River shales and sandstones in this valley proved to be exceptionally favorable rock, however, for tunneling. There were fewer problems and difficulties encountered here than in any other tunnel of equal length on the whole aqueduct line.

Moodna pressure tunnel.—After crossing the Wallkill the aqueduct follows ground of sufficient altitude to permit construction of the cut and cover type of aqueduct for 17 miles (27 kilometers), to the margin of the Moodna Valley, 5 miles (8 kilometers) southwest of Newburgh. It appears that the preglacial Moodna Creek must have been a somewhat larger stream than the present one, for there is a wide valley here filled heavily with glacial drift. The distance across is nearly 3 miles (4.8 kilometers)—one side formed by ridges of Hudson River sandstone and the other by the gneisses and granites of the Highlands. Somewhere in the valley the other two underlying sedimentary formations had to be crossed unless they were faulted out. Preliminary investigations and earlier studies showed clearly that large displacements had to be taken into account. One great thrust could be located accurately at the surface, and another was detected by the explorations. Furthermore, it was evident that the ridge of ancient gneisses and granites represented by Snake Hill and its southwesterly continuation might cross the tunnel line somewhere in the bottom of the valley beneath the drift cover.

Great difficulty was experienced in obtaining the required information in this valley. In no other, except the Hudson gorge itself, was it found so difficult to determine the profile of the rock floor and the underlying structure. The overburden of glacial drift carried unusually large boulders, making the boring program difficult and expensive. For a considerable distance in the bottom of the valley the cover is 300 feet (91 meters) deep, and one of the borings penetrated a single boulder 34 feet (10 meters) through, lying in the drift 100 feet (30 meters) above the floor.

By the time borings on this line were well begun, explorations on the Hudson River at the proposed Storm King crossing had proved a depth of at least 500 feet (152 meters). This led to suspicion that there might be a very deep erosion trench in the bottom of the Moodna Valley. This idea was supported somewhat by finding an exceptionally long flat stretch in the floor of the valley. Continued exploration, however, proved the absence of the expected trench, the maximum depth being around 60 feet (18 meters) below sea level. With these facts determined, the grade of the tunnel was fixed at 225 feet (68 meters) below sea level.

The strip of ancient gneiss which had been looked for as a continuation of the Snake Hill ridge was located by exceptionally successful exploratory borings but proved to be surprisingly narrow. Furthermore, it is in contact on both sides with Hudson River shales, the uppermost of the three sedimentary formations, instead of exhibiting the proper stratigraphic succession. It was clear, therefore, that the two underlying formations either never existed at this point or had been faulted out. Heavy crush zones, indicating displacement, were found on both sides of the strip of gneiss. Both zones stand at comparatively steep angles, are in poor condition, and required timbering. The tunnel actually penetrated only about 500 feet (152 meters) of gneiss or granite. This is now known to be a characteristic structure in the belt of country north of the Highlands, where inliers of the ancient gneiss are found at several places in the Paleozoic sediments.

The structure could not be interpreted from this occurrence alone, but with the aid of better structural evidence at Snake Hill itself, 2 miles (3.2 kilometers) farther north on the same belt, it was shown that displacements of two periods are represented—a thrust fault of Appalachian type and Paleozoic age and a block fault of Triassic age. The two displacement lines strike so nearly parallel that long slivers of ancient rocks are left stranded out in areas of Paleozoic strata. The relations of the fault planes also indicate that some of them must be entirely cut off from their original and proper floor connections. In other words, some of these inliers of gneiss and granite have no roots but are virtually floating masses entirely undercut, so that they are surrounded and underlain by later rock formations. The structure as thus interpreted is shown in Figure 21.

On the east side of the valley next to the Highlands the tunnel penetrated a great fault zone representing a thrust of the pre-Cambrian gneisses and granites from the southeast, up and over the adjacent Paleozoic sediments. The position of this fault zone was known before explorations began, but it was mapped much more accurately at depth with the aid of exploratory borings, which showed that it had a dip of 45°. In this manner the

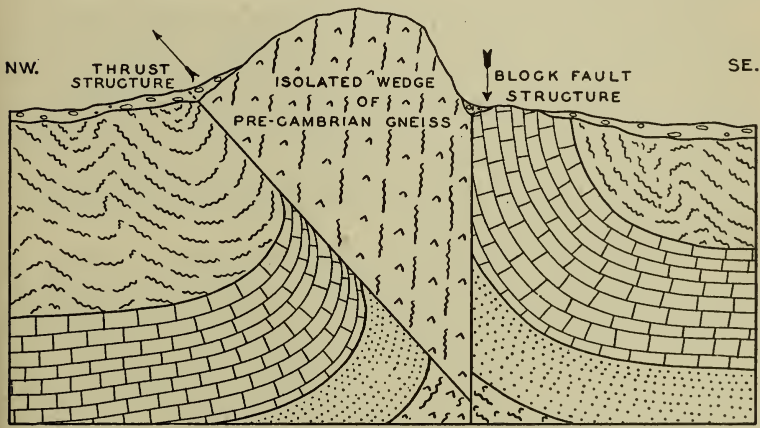


FIGURE 21.—Generalized structure section of the Snake Hill wedge, showing diagrammatically the result of two deformations—a thrust of Appalachian type and a block fault of Triassic type

complicated structure was partly worked out before construction began. At the only surface outcrop where this fault could be seen it was clear that the Poughquag quartzite (600 feet or 183 meters) and the Wappinger limestone (1,000 feet or 305 meters) were cut out by the thrust, for the granite mass lay in direct contact with Hudson River shales. The quartzite is not seen anywhere at the surface, but at another spot a block of limestone is exposed along the projected line of the fault. In the tunnel all the rock in this zone was so greatly deformed for a distance of more than 400 feet (122 meters) that it was absolutely impossible to determine its bedding structure with sufficient accuracy to reconstruct the section.

The amount of displacement is unknown but probably is at least 2,000 feet (610 meters) and may be much more. In all probability these thrusts, of which this is the most fully proved, although there are several of this type, give a sawtooth outline along the north margin of the Highlands and have caused much of the structural complexity represented by folding and faulting of the Paleozoic formations in this portion of the Great Valley, lying between the Highlands and the Shawangunk Mountain range. All the weaker formations are folded, overturned, crumpled, and otherwise deformed in an exceedingly complex manner, whereas the crystalline floor rocks are thrust faulted but not otherwise much deformed. The principal structural features are shown in Plate 12, *B*.

Despite the complexity of structure and the several important crush zones along faults crossed by the Moodna Tunnel, no unusual difficulty was experienced in construction, and only a few places required special treatment in the form of timbering or other safety provisions. All important changes of formation, including the location of the chief zones of weakness, were determined beforehand by exploratory borings and other preliminary studies, and the plan of construction and methods of handling were adjusted to care for them.

After the tunnel was driven, claims were registered by some of the residents of the immediately adjacent country complaining that the normal water table had been lowered so that their wells ran dry. There was doubtless basis for the claims of those close over the tunnel, for there was a moderate amount of seepage which must have withdrawn a part of the rather scanty underground supply carried by these strata. In shallow local wells obtaining a supply of water from the rock floor, therefore, the water table was lowered enough to interfere with the normal balance, and provision had to be made for other water supply.

It was originally expected that the cut and cover method would be used along the mountain side between Moodna Creek and the Hudson River; but on account of the steep slope, the comparatively short distance, and the saving of shaft footage, it was found more practicable to continue the Moodna Tunnel. In this section only one feature was encountered which at the time attracted special attention. This was a zone of deformation in the granites and gneisses of Storm King Mountain, immediately beneath a small side gulch known as Pagenstecker Gorge. There slight displacement had broken the solid rock, and large blocks had been shifted, leaving open spaces between them. When this place was reached in tunnel excavation, floods of water representing the accumulated storage in this crush zone came into the tunnel and drowned the workings. In fear of further trouble, the contractor put in a bulkhead for control and protection. The supply of water was limited, however, and soon fell to a very small amount, requiring no additional attention. This is one of the few places encountered in the tunnels of the Catskill Aqueduct where faulting of comparatively late date is marked by open jostled block structure instead of fine crushed and comparatively tight material.

Hudson River gorge.—On the plan finally adopted, the continuation of the Moodna Tunnel reaches the downtake shaft of the west side of the Hudson River at the base of Storm King Mountain, at a depth of 228 feet (69 meters) below sea level. This was the point selected, after study of the possibilities of the Hudson River, as a suitable place for the proposed pressure tunnel to carry the water across the Hudson River gorge.

An extended preliminary field study and a certain amount of preliminary exploratory work preceded the selection of this site. It was fully appreciated from this preliminary work that the gorge is deep and that although the river is not adjusted to a continuous fault zone, it follows fault lines in certain portions of its course and crosses country of simpler structure elsewhere. It was assumed at that time that fault zones ought to be avoided as sources of weakness, which, if crossed under the river, would probably introduce exceptional trouble in construction.

Some of the difficulties encountered in the limestones of the Rondout Valley led to the belief that limestone country should be avoided. This virtually eliminated the belt of limestone country north of the Highlands.

On the basis of preliminary field studies, therefore, the Storm King crossing was selected because it appeared, from field evidence, that at this place a tunnel could be driven in a single formation of essentially the quality of a granite without encountering a fault beneath the gorge.

It was commonly believed, however, that the Hudson River followed a great fault throughout much of its course and that this was the chief reason for its straight course and apparent independence of other structural control. In the preliminary studies, therefore, three important questions had to be determined before suitable specifications could be drawn—first, the depth of the channel, so that the grade of the tunnel could be fixed; second, the kind of rock to be penetrated, so that cost could be estimated; third, whether any special weaknesses or dangers were likely to be encountered, so that suitable provision for them could be made.

When explorations were undertaken at this particular site great difficulty was encountered in determining the depth of channel, and very much greater depth was found than was anticipated from previous geologic knowledge. The preliminary exploratory borings in the vicinity of New Hamburg, 10 miles (18 kilometers) farther north, gave no inkling of the great depth found at Storm King. No depth greater than 200 to 300 feet (30 to 61 meters) had been indicated, although it must be admitted that some of the preliminary borings were inconclusive. None of the wash borings were of any special value, because of the heavy bouldery material filling a part of the channel. Such material was found also at the Storm King site and made it exceedingly difficult and expensive to obtain reliable results.

The difficulty was increased because the Hudson carries a heavy river traffic. The boring equipment had to be anchored in midstream in the main traffic channel, where there was always danger of interference. Furthermore, the gorge is filled with mixed material in which large boulders are numerous. It was necessary to begin a boring with very large casing (18-inch or 45-centimeter) so that reductions could be made in passing through these obstructions.

After more than a year borings to bedrock were successfully made on both sides of the river, finding granite on both sides. The gorge was found to be at least 500 feet (152 meters) deep for a width of 3,000 feet (914 meters). How much deeper it might be out in the center of the gorge no one could tell. A boring placed in mid-channel finally succeeded in getting to greater depth, reaching 765 feet (233 meters) without touching the rock floor.

Before this was accomplished much time had been consumed with no result except an increased feeling of uncertainty about the depth of the gorge. This fact, together with the slow rate of progress being made by the borings, finally led to the adoption of another plan for testing the ground beneath the river. The final working shaft on each side of the river was put down to a depth of about 200 feet (61 meters), and at that level a room was cut in the side wall, where a diamond drill was placed. This was set up to drill at an angle so as to penetrate the ground beneath the gorge out under the river. The first two borings, one on each side, were set to reach a depth in the center of 1,400 feet (427 meters) below sea level. These were successfully run in sound rock, and it was then decided to drill two others at a smaller angle, cutting the central ground at a maximum depth of 950 feet (290 meters) below sea level. In these borings sound rock, of granite type, was found continuously across the gorge.

By this time the boring in the river had reached its maximum depth of 765 feet (233 meters) without touching bottom. With these data in hand, it was considered unnecessary to carry explorations further. To insure safety against bursting pressure, the grade of the tunnel was fixed at 1,100 feet (335 meters) below sea level. This level assured a cover of at least 150 feet (46 meters). How much more no one knows, for the bottom of the gorge is somewhere between 765 feet (233 meters) below sea level, reached by the boring in the river, and 950 feet (290 meters), reached by the inclined diamond drills. (See fig. 22.)

When construction was finished the conditions uncovered in the Hudson River pressure tunnel were essentially as indicated by the exploratory and other investigations. The Storm King granite is continuous across the gorge. There are no great faults in the gorge at this point. The rock is sound and presented no special construction problem.

At one step of the work, however, on the east side of the river, a joint system was encountered which carried stored water in sufficient volume to threaten drowning of the work. It was feared in the beginning that these and other joints might be fed from the river and furnish larger quantities of water. On this account a battery of pumps of large capacity was installed, but they were never called into use.

Only one other feature deserves special mention. This came from what is known as "popping rock." In certain places the rock is under pressure and in a condition of unrelieved strain to such a degree that, when its support is removed by excavation, portions of the walls crack off. This sometimes happens suddenly and from otherwise sound wall. Such ground is dangerous and required special treatment in the form of timbering. In a certain zone the solid granite spalled off from the walls in thin slabs with sharp edges, breaking quite independently of the internal rock structure. These slabs would fall unexpectedly from the roof or side walls, even after every loose piece had been carefully removed.

GRADE TUNNELS

Tunnels were constructed to carry the water at grade through divides. The first one of consequence is the Bonticou Tunnel through the Shawangunk Range, between the Rondout and Wallkill Valleys. Another is the Breakneck Mountain Tunnel, between the Hudson River crossing and the valley of Foundry Brook. Neither presented problems of special difficulty or unusual interest. The next one of importance, southward, is the Garrison Tunnel, penetrating the high ridge on the east side of the Hudson River back of the village of Garrison, between the

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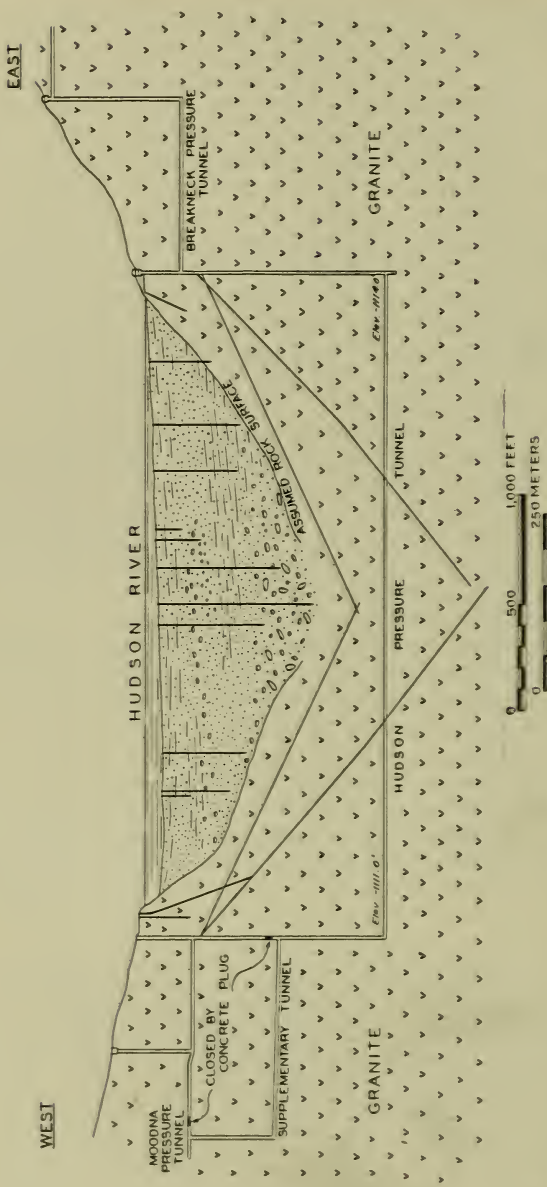

FIGURE 22.—Geologic section across the Hudson River at Storm King, based on exploratory borings for the Catskill Aqueduct

Hudson River Valley proper and that of Sprout Brook. Another still farther south was the so-called Hunters Brook Tunnel. A number of shorter ones were employed in the Southern Aqueduct, but the only one that requires special description is the East View Tunnel through the divide between the Kensico Reservoir and the valley of Sawmill River.

At the north end of the Garrison Tunnel and the south end of the Elmsford Tunnel the rock was so deeply and completely decayed that special provision had to be made for handling. In the Garrison Tunnel, for a distance of 500 feet (152 meters), the crystalline gneisses of the Highlands were softened. The structure of the rock was still preserved, but the rock was in such condition that it could be cut readily with a knife or shovel, and when wet would flow into the excavation. This decayed and softened condition was not confined to crush zones or areas of special weakness, but affected the whole formation and evidently represented a portion still remaining of the preglacial weathered surface. Almost everywhere glacial ice removed the residuary soil and decayed rock, scraping down to hard ledge and leaving the floor fairly smooth and sound. Here and there, however, patches of the surficial material escaped destruction and, where covered with glacial débris, could not be detected by surface inspection. Such places give much trouble in tunneling and represent conditions that must have prevailed almost everywhere in preglacial times, before the residuary mantle was removed.

Nowhere was this condition better exhibited than in the Garrison Tunnel, where material in such unsubstantial condition made progress slow, expensive, and dangerous and required virtually tight timbering for more than 500 feet (152 meters). In no other respect were conditions different from those at other places.

A very similar condition was found in the Hunters Brook Tunnel, but here the decayed condition was localized somewhat more narrowly along crush zones and deformed portions of the rock. The same difficulties were encountered in even worse form at one point because of the extremely unstable material and its tendency to flow into the tunnel. No new principles were involved, however, and the conditions found were troublesome chiefly because of the shallowness of the tunnel and the nature of the overburden.

In the Elmsford Tunnel, also, a similar condition existed. For a distance of several hundred feet at the south portal the Manhattan schist was found to be softened and decayed. The nearly vertical attitude of the original schist was preserved in the decayed material, but the tendency to develop slippery chloritic alteration substances added somewhat to the treacherousness of the ground, which had to be protected against slumping by close timbering.

Only one other special condition was exhibited by the grade tunnels. This appeared after excavation in a certain section of the East View Tunnel. Here the Manhattan schist, the only formation penetrated, is heavily charged with iron pyrite, which is attacked by weathering, with the production of sulphates and sulphuric acid. When this rock from the tunnel was dumped on the surface around the working shaft, it was exposed to still more active and rapid attack. The chemical reactions due to weathering produced a large supply of acid-bearing water, which joined the ground-water circulation and finally reached the tunnel. No effect of special importance was noted at first, and the tunnel was lined in the usual manner and left standing until the whole line should be put to use. In the course of time inspection of the tunnel showed that the concrete lining had weakened so seriously that repairs were required. Probably no serious injury would have resulted if it had not been for the excess supply of acidulated water furnished by the oxidizing material of the dump. Probably, also, there would have been no serious effect if the tunnel had been put into immediate operation, for in that case, because the tunnel is under slight pressure, the ground waters could not have entered.

This case serves to illustrate a principle, however, that is of somewhat wider application, for trouble with concrete linings of tunnels is not uncommon. The most serious trouble of this sort in any of the New York City projects was that of the McAdoo tunnels on the New Jersey side of the river between Jersey City and Hoboken. There a long stretch of tunnel lining was virtually destroyed by the attack of ground waters. This was charged to many possible and even to impossible sources, but the most likely was the leaching of overlying "fill," including ashes, cinders, and other débris and the waste from local manufacturing plants.

Such conditions are difficult to control. They are particularly destructive if limestone is used in the concrete aggregate, for then both the cement and the aggregate are affected. This was the case in the East View Tunnel, which was one of the few sections along the aqueduct line where limestone aggregate was used. Fragments in the original aggregate were completely softened, even though they were embedded in concrete, and this effect was produced within a year.

KENSICO RESERVOIR

A storage reservoir has been created 4 miles (6.4 kilometers) north of White Plains, on the Bronx River, by the erection of a dam at the village of Valhalla. This is known as the Kensico

Dam, built to impound an emergency supply of water sufficient for about a month.

The dam takes the place of a much lower structure belonging to an older supply system. It is located across the upturned edges of the local rock formations, which include the Manhattan schist, Inwood limestone, and Fordham gneiss. There is a fault and crush zone on the contact between the gneiss and limestone, along which there was enough decay and disintegration to require excavation to a depth of 75 feet (23 meters) in the rock floor. No other features required special attention on this ground.

The dam is a masonry structure built of Yonkers gneissoid granite and is one of the finest structures of its kind in the city system.

The accompanying geologic section (fig. 23) gives the structural relations of the geologic formations forming the foundations of the dam.

HILL VIEW RESERVOIR

At the north line of New York City, just within the bounds of the city of Yonkers, is the Hill View equalizing reservoir, holding about two days' supply of water. This reservoir stands on a drift-covered eminence 295 feet (90 meters) above sea level and furnishes the head for the city distribution tunnels, which in reality belong to the Catskill Aqueduct system.

City Tunnels for Water Distribution

Four aqueduct systems have been constructed for the delivery of water to New York City from distant sources. The earliest one, completed in 1842, is known as the old Croton Aqueduct and crosses the Harlem River at High Bridge, 168th Street. (See pl. 7.)

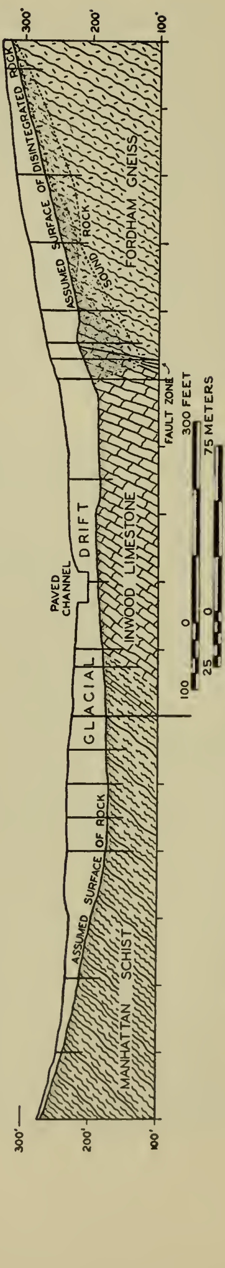

Figure 23.—Geologic section across the Bronx Valley at Valhalla, as indicated by borings

The second was the new Croton Aqueduct tunnel, completed in 1890, crossing the Harlem River at a depth of 150 feet (46 meters) below the river and passing down through the city to the reservoir in Central Park. This one is still in use. It is nowhere at great depth except under the Harlem River and appears to have presented no special difficulty in construction.

Since that time two pressure tunnels have been constructed from Hill View, at the north margin of the city, for the distribution of Catskill water. These are known as City Tunnel No. 1 and City Tunnel No. 2. No. 1 was completed in 1915, and No. 2, intended for the handling of an additional supply, is just now being finished. Both are excavated in the rock foundation beneath the city and extend from the Yonkers line to Brooklyn. They penetrate all the crystalline rock formations but do not reach any of the later sediments.

CITY TUNNEL NO. 1

City Tunnel No. 1 extends from Hill View Reservoir to the vicinity of Fort Green Park, in Brooklyn. The tunnel follows the street layout of the city, taking advantage of parks from Hill View directly to the Harlem River at 165th Street, thence directly across the Harlem River and down through St. Nicholas Park to Morningside, to Central Park, down Sixth Avenue to the Bowery, turning on Delancey Street to Allen and thence on the line of Clinton Street, and across the East River and the adjacent heavy drift-covered ground to Prospect Park in Brooklyn. There were 24 working shafts. The tunnel was laid out with careful regard for the geologic structure, especially the principal contact lines and known fault zones. The first step was taken by the engineers, who drew three trial lines, any one of which was possible in that they avoided other engineering interference and followed streets and open spaces, such as parks, where the city already had rights. The next step was the detailed geologic study for the purpose of judging which of the three lines presented the best physical conditions. This was followed by other alternatives and modifications of route before even the exploratory borings were begun. The final result of this preliminary study was the adoption of the line on which the tunnel was ultimately constructed.

It was found, after all known conditions were taken into account on the line of the tunnel, that there were four stretches requiring special exploratory investigation. These were located by field inspection in the low valleylike depressions, covered with glacial drift, where the underground structure could not be seen. In general such depressions indicate structural weakness—either a weak formation or a crush zone. Depressions that cross the formational trend, therefore, are looked upon with special suspicion. In virtually every place where such topography is prominent in the city weaknesses of this kind are discovered in the floor. This was not known when City Tunnel No. 1 was located, but the explorations of that time, together with the experience of constructing the tunnel, as well as other experiences, have shown that this condition prevails.

Four depressions were marked for special exploration—the Mosholu Parkway, the Harlem River, the 125th Street depression, and the lower East Side from the Bowery to the East River. The preliminary exploratory program carried out at these places showed that the Mosholu Parkway required no further investigation, but the other three places needed much additional study to determine the precise conditions to be met. At these places the rock floor is low, with a thick drift cover, and the rock in places showed excessive decay to unusual depth. These three places deserve additional description, for they illustrate very different structural conditions.

Harlem River crossing.—At the Harlem River the Inwood limestone, standing almost on edge, forms the floor of the gorge, with Fordham gneiss on the east side and Manhattan schist on the west. (See fig. 24.) The tunnel penetrates the whole thickness of the limestone, which is the weak member and which carries the river gorge. A fault follows the Manhattan-Inwood contact, localizing the only zone of very deep decay; the depth of decay in this contact and crush zone determined the grade of this section of the tunnel. No additional engineering difficulty was encountered, but the section exposed in this excavation furnished the most detailed complete column of the Inwood limestone ever seen in the region. Plate 13 records the detail of structure as seen in the tunnel.

Manhattanville depression.—At 125th Street, where the next depression crossing the island is located, the very first exploratory boring proved that the rock floor is far below sea level and that the depression is developed on a fault zone. If the overburden of glacial drift were removed, the waters of the Hudson River and Long Island Sound would flood this floor to a depth of nearly 200 feet (61 meters). The profile was readily determined by these exploratory investigations, as well as the position of the principal fault zone. (See fig. 25.) One of the most open broken conditions found in the city was encountered here, requiring heavy

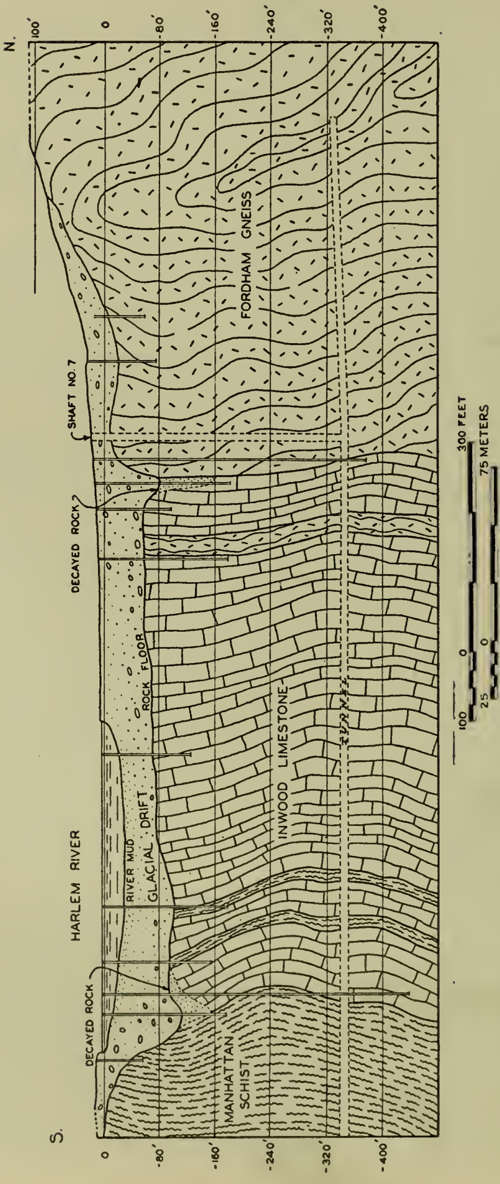

FIGURE 24.—Geologic section made from exploratory borings of pressure tunnel across the Harlem River at 171st Street, Manhattan

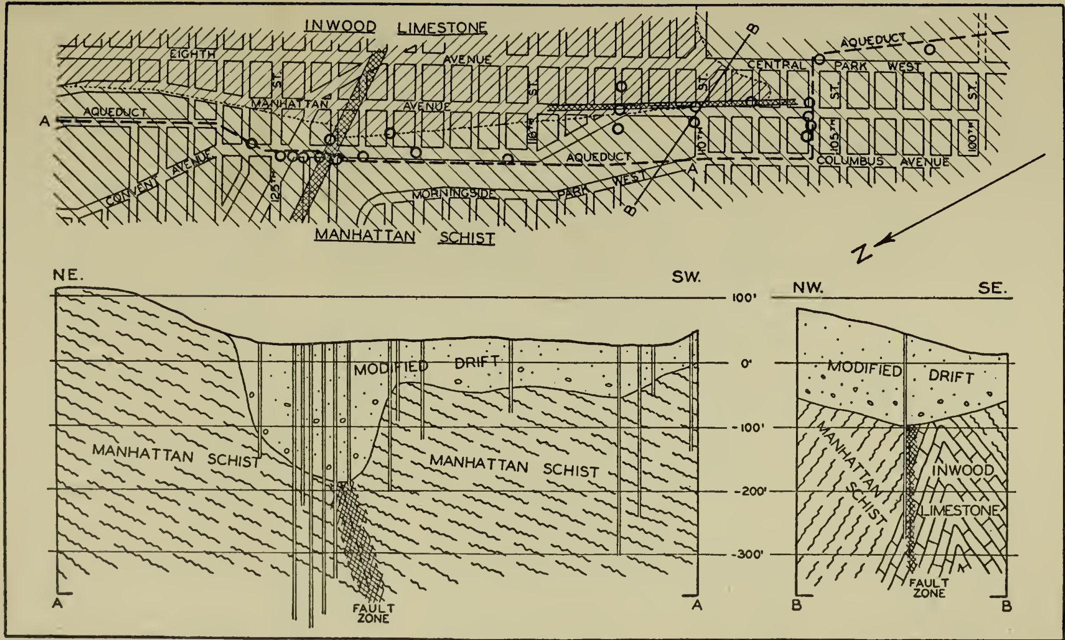

Figure 25.—Plan, profile, and geologic section across the Manhattanville fault zones, based on the exploratory borings for the Catskill Aqueduct

steel timbering for a distance of 200 to 300 feet (61 to 91 meters). These conditions controlled the grade of the tunnel in this section, where it was depressed to 350 feet (107 meters) below sea level, rising again to the south in Morningside and Central Parks to 250 feet (76 meters) below sea level, which was the grade maintained through the central portion of the city until the lower East Side was reached.

East River and the lower East Side.—There are no outcrops of rock in the south end of Manhattan Island. The areal geologic maps available when this work was begun were based on inadequate data and assumed that the limestone belts followed the course of the river. A restudy of all accessible data threw some doubt on these maps and suggested the possibility of a different areal distribution. The most suggestive data found at that time were the records of certain borings made by the Department of Docks, one of which indicated the presence of limestone near the Manhattan pier of Brooklyn Bridge.

With these suggestions a program of exploratory borings was laid out along the line projected for the tunnel on the Bowery, Delancey, Allen, and Clinton Streets, and across the East River. The first borings proved that the existing maps were wrong and indicated the advisability of continuing the exploration in considerable detail. The profile of the floor determined by these explorations showed that the preglacial channel of the East River does not follow the same course as the present East River in that part of the city, as assumed on the geologic maps, but continues in line with Blackwells Island to the Manhattan pier of Brooklyn Bridge, passing directly down through the lower East Side. When the explorations were finished they proved also that in this section there is much deeper decay than elsewhere and considerably greater variety of rock quality than is seen in the Fordham formation at other places.

A fault was encountered along the contact between the Inwood and Manhattan formations, reducing by displacement the thickness of the Inwood. In the vicinity of the East River the Ravenswood granodiorite, an intrusive rock prominent on the Long Island side of the river, was found to penetrate the regular type of Fordham gneiss. This intrusive forms the bottom of the East River, which has a comparatively shallow floor. The East River itself is a superimposed stream, its course being determined by uneven distribution of glacial drift and not primarily by underground structure and preglacial topography. The rock beneath the East River proved to be much more substantial and sound than that under the lower East Side.

On account of the numerous borings in which a low recovery of core was obtained, indicating poor rock condition, it was decided to place this portion of the tunnel at a depth certain to avoid difficulty. It was for this reason that the tunnel was finally carried across the East River from the Bowery at a depth of 700 feet (213 meters) below sea level. (See pl. 14.)

When the tunnel was finished and put into operation, only one section required additional treatment. Leakage developed along Sixth Avenue, raising the local water table a sufficient amount to cause complaint from property holders. Correction was made by placing a copper lining inside the tunnel, against the concrete, to control the seepage. This proved to be effective, and the tunnel, in its service of nearly 20 years since that time, has required no further correction.

CITY TUNNEL NO. 2

When the development of an additional water supply had to be considered, some 20 years after the planning of City Tunnel No. 1, the upper Delaware was selected as by far the most desirable source. Preliminary studies for storage and delivery have been based on this source, with delivery through a new aqueduct reaching the city at Hill View. From that common point, however, a new distribution tunnel was laid out through the newer sections of the city, alternative possible lines being studied in much the same manner as was followed for Tunnel No. 1. The location finally chosen crosses the Bronx River into the Bronx, thence southward to the East River, passing under Rikers Island, and thence through Astoria and Long Island City to the vicinity of Fort Green Park, not far from the terminal shaft of Tunnel No. 1.

In this new location a much larger proportion of the line is covered with a heavy overburden of glacial drift, where the underground structure had to be determined wholly by borings. These were carried through in due course, with more detailed investigations at the crossings of the Bronx River and the East River, the two most questionable spots. A large portion of the rest of the line on Long Island to Brooklyn was found to be so deeply covered that it became necessary to determine the rock-floor profile with more care than usual. For long stretches the floor, on the most easterly trial line, was found to be too low, inasmuch as there is a limit to the depth of safe working under air. It was necessary, therefore, to discover favorable places for the shafts. Furthermore, as the peneplaned floor slopes gently downward to the southeast, one of the major problems was to discover how far out toward the east the line could be located. Plate 7 shows the location of this line.

East River section.—Especially treacherous geologic conditions had to be met in the sections under the East River and the

Bronx River. At both places the tunnel crosses faults with extensive crush zones, along which the rock is badly decayed and softened to tunnel grade, 500 feet (152 meters) below sea level. In both places, the softened ground, overcharged with water, proved to be so dangerous that heavy steel construction was used for supporting and protecting the tunnel. In the ground under Rikers Island the excavation was enlarged and the walls virtually cased off by closely fitted steel, which enabled the work to be done with entire safety through a stretch of soft ground about 200 feet (61 meters) in lateral extent. At this place a thrust fault from the southeast pushes the gneisses up over the overlying limestone, bringing a schistose variety of the Fordham gneiss into contact with the schists of the Manhattan formation. The two types of rock resemble each other so closely in this vicinity that individual samples can not be distinguished with certainty. This led to some confusion of identification in the beginning, but, with the completion of the tunnel, the structural relations were fully exposed, so that there is no doubt of these facts.

Bronx River crossing.—At the Bronx River similar conditions were encountered, as was expected from the indication of the preliminary borings, though not necessarily on so large a scale. Here the tunnel crosses the full width of the Inwood limestone, with Fordham gneiss on one side and Manhattan schist on the other. The Inwood-Manhattan contact is conformable and sound, but the Fordham-Inwood contact is faulted, badly crushed, and very much decayed. Additional complications arose from the fact that an irregular pegmatite intrusion follows the contact at this spot, and this is more broken and more softened and decayed than the adjacent gneiss and limestone. Much of the material in this particular crush zone is a soft muck or gouge and had a tendency to slump into the tunnel when first encountered, making the task of excavation both difficult and treacherous.

The measures adopted for handling the situation included drainage borings in the roof to relieve the overcharge of ground water and the driving of sheet-steel piling horizontally into the softened crush-zone material. In this manner the whole tunnel was inclosed and protected through the dangerous ground to the solid rock formation beyond.

One of the important bits of information about the underground conditions in the city revealed by the work on this tunnel is the proof that there is decay and softening of the rock, of sufficient extent to require special construction methods, to a depth of at least 500 feet (152 meters) below sea level in certain places. It would not have been expected, from any work previously done in the city, that a tunnel driven at that depth would encounter such material.

Certain difficulties that developed when City Tunnel No. 1 was put into service were judged to be due to the shallowness of the tunnel, part of which was driven at 250 feet (76 meters) below sea level. These were the sections where difficulties were encountered, and they furnished the reason in large part for adopting a grade of 500 feet below sea level for Tunnel No. 2, in the hope of finding more uniform and better conditions at this greater depth. The results seem to justify this decision. In all probability much greater difficulty, and perhaps additional ones, would have been encountered with a shallower tunnel.

The tunnel is large, much of the ground is close-jointed, the tunnel runs nearly parallel with the structure, or schistosity, for long distances, and the schistosity structure dips to the side at an unfavorable angle. All these conditions are unfavorable, but the chief cause of trouble in construction arose from the fact that the tunnel so nearly parallels the structural trend.

Wherever the rock is somewhat weakened by decay, soft and slippery secondary minerals lubricate the joints, so that blocks thus bounded tend to fall out of the roof, endangering the workmen and requiring extensive protecting supports for long distances. These conditions were to be expected, of course, but the extent to which protective measures have had to be used could not be predicted in advance.

SEWERS AND DRAINAGE WORKS

The relief of the city and the surrounding district is favorable to the development of a sewerage system by ordinary means. No unusual geologic conditions have had to be faced in this work, except in the Passaic Valley tunnel for the city of Newark. This was driven as a tunnel in rock from Newark to the Upper Bay of New York and penetrated the well-known Newark sandstones and shales of the Hackensack Valley, the trap sill of the Palisade Ridge, sandstones again along the Hudson River margin, and Manhattan schist under the bay. In the portion of the tunnel beneath the bay exceptionally troublesome conditions were encountered, owing chiefly to the shallowness of the tunnel. The excavation struck much broken and decayed rock along crush zones, which had a tendency to cave and required heavy timbering.

It was not practicable to place a sewage tunnel at great enough depth to avoid these weaknesses, and when such ground was encountered beneath the bay, the usual difficulties were magnified by the danger of floods of water. These conditions are not unusual or rare but are the common accompaniments of deformation and decay. The deeper tunnels of the city have encountered comparatively little difficulty of this kind, although they found similar structural conditions at many places.

HARBOR IMPROVEMENTS

New York has one of the great harbors of the world. Manhattan Island is almost surrounded by navigable waters connected by narrow protected passages with the sea. The bays and rivers constituting the harbor are thus cut off from direct storm waves and are unusually safe. The chief problem in harbor improvement is connected with the enlargement and deepening of the channels of approach and providing adequate docking facilities.

There are three approaches to the Upper Bay, the principal one being that continuing the course of the Hudson River through the Narrows and the Lower Bay to the open sea beyond Sandy Hook. There are two other entrances, however, one by way of Long Island Sound and the East River and the other through Raritan Bay and Kill Van Kull. This latter, however, has no independent connection with the sea and gives only an additional approach without using the Narrows. No special problems are attached to the Kill Van Kull entrance to the Upper Bay, for the channel is shallow and narrow and does not lend itself to development for ocean-going vessels of great draft.

HELL GATE

The Long Island Sound and East River entrance formerly included the dangerous Hell Gate district of shallow waters, rock ledges, and swift, variable tidal currents. The removal of obstructions and deepening of the channel through this portion of the East River has been one of the most important developments connected with harbor improvement. In 1875 the principal and most dangerous obstructing ledges were blown out, but even with this removal the channel was unsafe and could not be used by vessels of heavy draft. The latest improvement has been the enlargement of the channel to a width of 1,000 feet (305 meters) and a depth of 40 feet (12 meters). Part of this work had to be done in solid rock. The accomplishment of this task by the engineers of the United States Army has been a difficult engineering feat—doubly difficult because it had to be done without serious interference with the traffic of the harbor. The work was finished in 1920.

The East River does not occupy the original stream course of preglacial time. The present river is essentially an overflow across the uneven deposits of the glacial drift and rock ledges. The tidal waters therefore swish back and forth across the ledges that were formerly a part of the side country. All these ledges have had to be removed or trenched deeply enough to maintain an effective channel for harbor traffic. The upper part of one of these reefs in the East River opposite Old Slip was removed after the subway tunnel to Brooklyn, which penetrated this reef, had been in use for some years. The work had to be carried on under water in a tidal river of extremely swift current. The distance between the bottom of the channel and the roof of the subway tunnel is only 15 feet (4.6 meters), yet the crystalline Manhattan schist constituting this reef was successfully removed to the required depth without any interference with subway traffic and without injury to the tunnel. This was one of the most carefully executed pieces of excavation work ever done in the city.

A claim based on a curious accident connected with the development of this river was made some years later. It appears that one of the night boats of the Fall River Line ran on a rock in the deepened channel above Hell Gate. As the vessel does not draw enough water to scrape bottom, the owners claimed that a large block of rock originally blasted from the channel had been dropped by accident or otherwise left behind by the contractors responsible for removing the loosened material. Whether or not this claim was well founded is a matter of little present concern, but the accident serves to emphasize the critically balanced conditions represented by the artificial channels of the harbor, for it was clearly possible for a vessel to be seriously damaged by a block of rock not more than 5 or 6 feet (1.5 to 1.8 meters) in largest diameter lying on the bottom of the channel. Many vessels plying these waters almost touch bottom, and on this account it is necessary in all of the channels to take account of the tides.

OUTER CHANNEL

The outer channel of the Hudson River through the Narrows and the Lower Bay has required dredging. The material is river silt and presents no other difficulties than those normal to such loose material. Many of the approaches to docks, especially those on the New Jersey side of the river, have required additional dredging, and some of them constant attention to keep channels open for the large vessels habitually using the dock facilities of the city.

OTHER DANGER POINTS

There are few danger points in the local waters in addition to those already referred to in the East River. Two or three in the Upper Bay and Lower Bay are suitably marked and in ordinary circumstances readily avoided by traffic. Bedloe Island, on which the Statue of Liberty stands, is one of these reefs. They are parts of the side ground along the original channels of the streams.

PIERS AND LANDINGS

Manhattan Island, on both sides, Long Island on the Brooklyn side, the west bank of the Hudson River through Hoboken and Jersey City, and part of Staten Island are bordered by many docks and landings. There are 413 piers on the New York side of the Hudson River and 172 on the New Jersey side. The largest vessels afloat can be accommodated in the principal approach channels and docks. Since the organization of the Dock Department, in 1870, over $193,000,000 has been expended on harbor improvements. New York Harbor is unique in the great number of long piers built far out into the river. The natural physical conditions are favorable for economical construction, because the river and bay margins are almost everywhere formed by glacial drift bordered and overlapped by river silt and mud, which allow the driving of piles and furnish sufficiently firm support for piers, warehouses, and other structures, and the comparatively loose silt and mud of the approach from the river can be readily dredged. These conditions are so widespread that it has not been necessary anywhere to resort to more expensive methods of preparing such accommodations.

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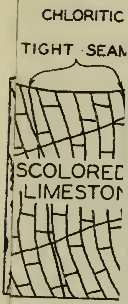

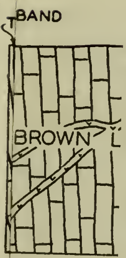

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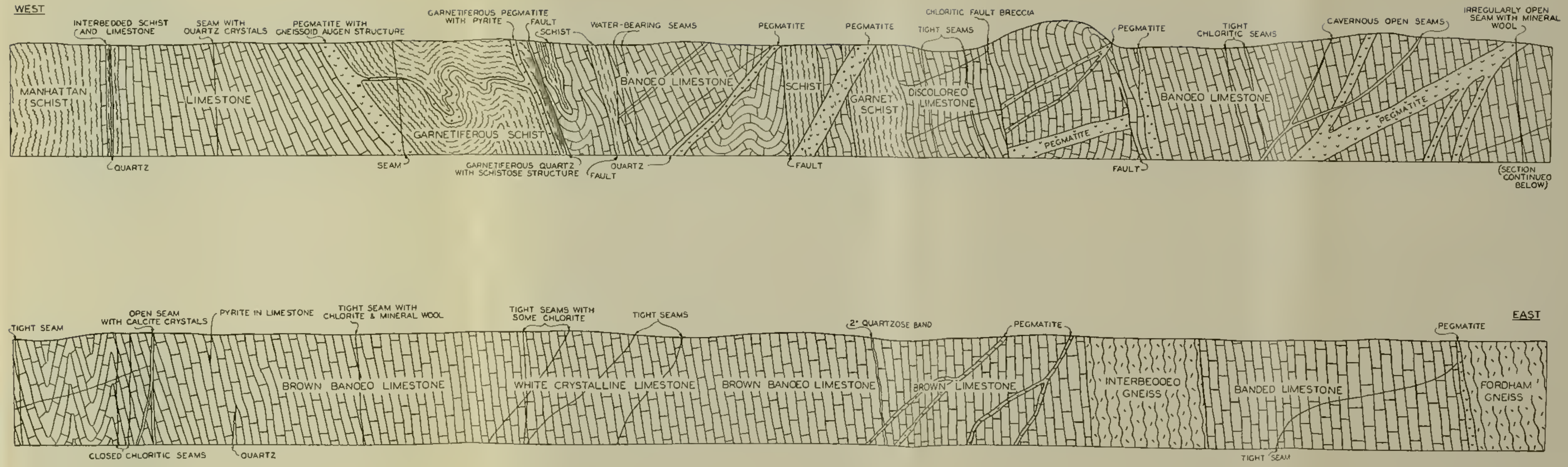

DETAILED GEOLOGIC STRUCTURE SECTION AS EXPOSED IN THE CATSKILL AQUEDUCT TUNNEL UNDER THE HARLEM RIVER NEAR 171ST ST., MANHATTAN

HORIZONTAL AND VERTICAL SCALE

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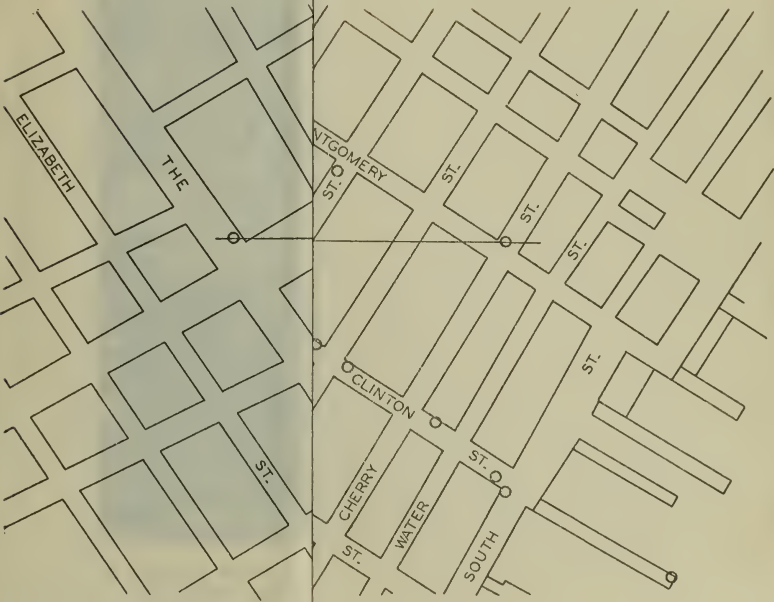
0 25 METERS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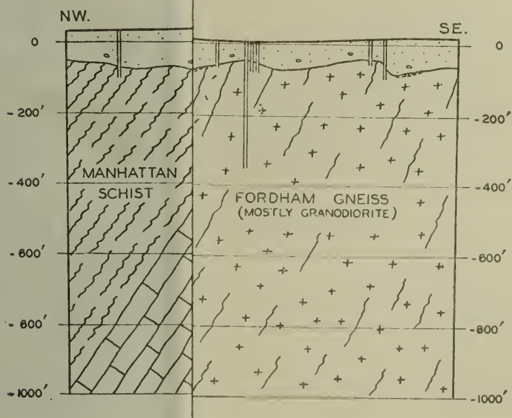
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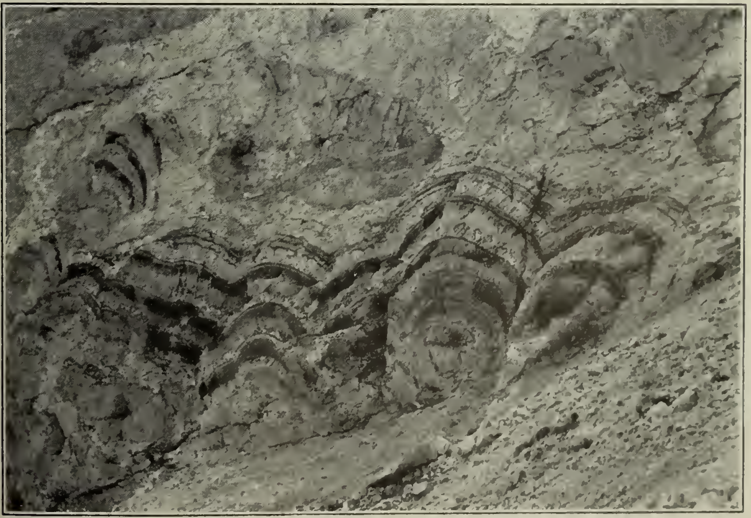
SCHIST
FORDHAM GNEISS
(MOSTLY GRANODIORITE)

GEOLOGIC SECTION OF LOWER EAST SIDE

BASED ON EXPLORATORY BORINGS FOR THE CATSKILL AQUEDUCT

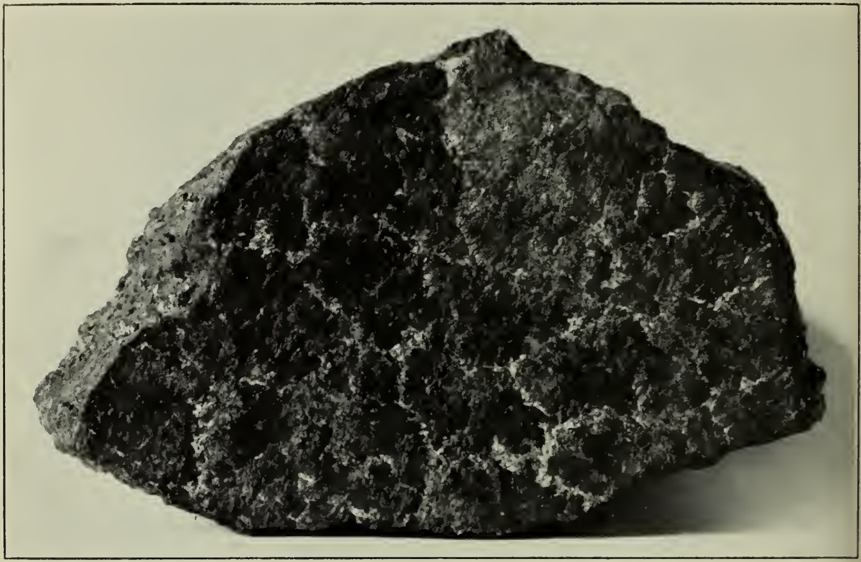
A. LARGE CRYSTAL OF MICROCLINE IN KINKEL QUARRY, SOUTH OF BEDFORD, NEW YORK

Shows radial growth of quartz, albite, muscovite, and some microcline about a central microcline crystal.



B. SPHEROIDAL CONCENTRIC STRUCTURE IN PEGMATITE, KINKEL QUARRY

Horizontal distance represented, about 14 feet. Photograph by F. W. Apgar



A

B

CYRTOLITE FROM KINKEL QUARRY, BEDFORD, NEW YORK

A shows "daisy formation" due to flattening of crystals against quartz contact. *B* is a radiograph of the same specimen, plate in X-ray envelope exposed 14 days. From Thomas I. Miller collection. Reproduced by permission of J. G. Manchester.

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THE PEGMATITES OF BEDFORD, NEW YORK

By William M. Agar

OCCURRENCE

Three pegmatite masses lie within an area half a mile (0.8 kilometer) square just south of Bedford, about 40 miles (64 kilometers) northeast of New York City. (See fig. 26.) These are quarried for feldspar and quartz.

Wherever visible, the contacts between the pegmatites and the surrounding rock are sharp, and the dikelike character of the southernmost and westernmost masses is evident. On the other hand, the eastern mass, in which the original Kinkel quarry is operated, is more likely an irregular stocklike intrusion.

The composition of the pegmatite is usually simple. Quartz, microcline, and albite, together with considerable muscovite, make up most of the rock, though 46 species and varieties of minerals, listed below, have been found. The greater part of the feldspar is microcline, and rose quartz of good color is fairly abundant. The rock includes several radioactive minerals, such as cyrtolite (pl. 16), which consistently holds 5.5 per cent of hafnia (HfO_2), uranophane, torbenite, and autunite.

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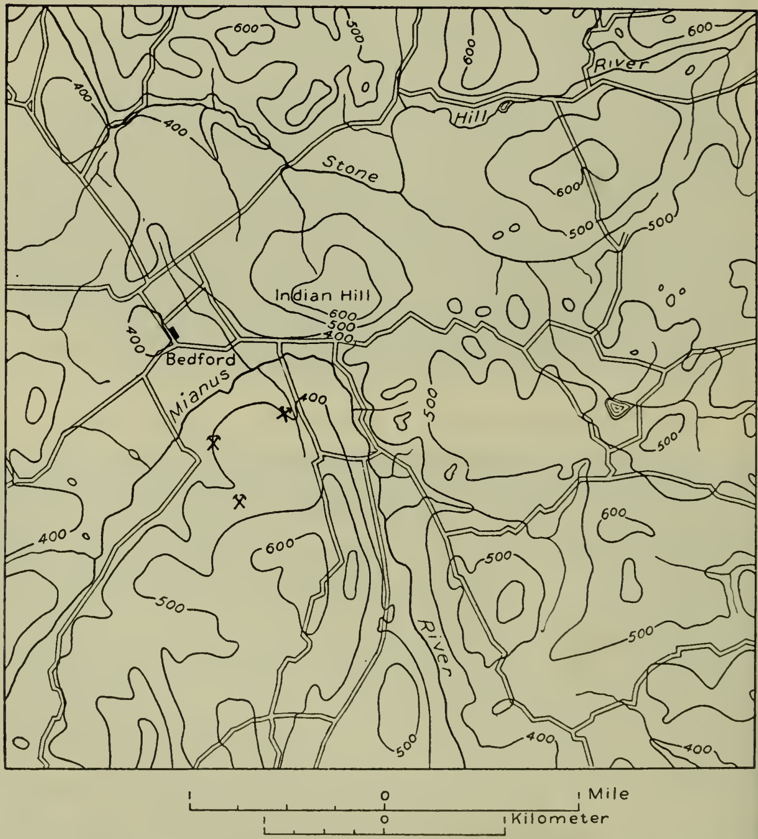

Figure 26.—Map showing location of pegmatite quarries south of Bedford

Minerals from Bedford, Westchester County, New York (64) [9]

[Kinkel, Bullock, Hobby, McDonald, Büresch, and Kelt feldspar mines and quarries. Varieties indicated by italics]

Albite.	Graphite.	Pyrolusite (dendrite).
Allanite.	*Green tourmaline.*	Pyroxene.
Almandite garnet.	Gummite.	Quartz.
Apatite.	Hornblende.	*Rock crystal.*
Aquamarine.	*Hyalite.*	*Rose quartz.*
Asteriated rose quartz.	Ilmenite.	Rutile.
Autunite.	Kaolinite.	*Smoky quartz.*
Beryl.	Limonite.	Titanite.
Biotite.	Magnetite (grains).	Torbenite.
Black torumaline.	*Menaccanite.*	Uraconite.
Citrine quartz.	Microcline.	Uraninite (?).
Cleavelandite.	*Milky quartz.*	Uranophane.
Columbite.	Muscovite.	*Washingtonite.*
Cyrtolite.	Orthoclase.	*Yellow beryl.*
Golden beryl.	Pyrite.	Zircon.

Intergrowths of quartz and feldspar are common. In the easternmost quarry there is a dump heap which gives an opportunity to study many specimens of these intergrowths. They appear almost certainly to be the result of late introduction of quartz rather than of simultaneous crystallization of quartz and feldspar.

The face of this quarry in places exhibits peculiar parallel scalloped growths (pl. 15, *B*) of finer grain than that of the pegmatite in which they are embedded. Their size ranges from a few inches to 1 foot (0.3 meter) or more between the horns of the individual scallops or crescents, which point downward. In places two or more are arranged one above another, and the nearly concentric crescents are separated by radially arranged quartz, albite, and muscovite of much coarser grain. The fine-grained segments are composed of microcline, orthoclase, albite, quartz, muscovite, and small reddish garnets.

The origin of these structures is in doubt. Their distribution and mineralogic character precludes the possibility that they are partly replaced inclusions. The minerals are all pegmatitic minerals, with the structure of crystallization modified somewhat through attack by end-stage solutions. Some of the anhedral to subhedral garnets in the fine-grained parts of the structures are chloritized. Muscovite has entered along the cleavages of the feldspars and partly replaced them, and quartz, and, to a lesser degree, albite have penetrated a little of the potassium feldspar. There is no sign, however, of wholesale replacement.

The northwest face of this same quarry exhibited, in the spring of 1931, a single crystal of microcline (pl. 15, *A*) 3 feet (0.9

[9] Numbers in parentheses refer to bibliography, pp. 127–128.

meter) across, which was completely surrounded by radiating quartz, feldspar, and mica, and the upper one-third of this by a flat crescent of fine-grained material. Quartz has penetrated the central microcline crystal, and the occurrence suggests control of the later crystallization by large, early formed microcline crystals.

AGE

The results of the analysis of the uranium-bearing cyrtolite from the Kinkel quarry, by O. B. Muench, have recently been published (65). Adolph Knopf, in a brief preface to that publication, pointed out that the lead-uranium ratio, 0.051, indicates an age of 380,000,000 years and that this ratio is almost identical with that (0.052) based on Hillebrand's analysis of uraninite from the pegmatite dike at Branchville, Connecticut, 11 miles (18 kilometers) northeast of Bedford. Both of these, according to this evidence, were introduced late in Ordovician time—that is, during the Taconic revolution.

COUNTRY ROCK

The country rock in the neighborhood of the three quarries is the Bedford augen gneiss. This rock underlies an irregular area southeast of Bedford, and its contacts with the surrounding formations are nowhere distinct. It is a composite injection gneiss—a variable mixture of schists of several types and uralitized pyroxene diorite intruded by and impregnated with granite and pegmatite. Many parts of the gneiss contain two generations of augen. The older, composed of partly sericitized andesine, date from the period of pyroxene diorite intrusion. The younger are soda-microcline augen that range from large (as much as 1½ inches, or 3.75 centimeters) pink single crystals or carlsbad twins of microcline, both with somewhat rounded, irregular boundaries, to small, ill-defined white masses. They are the result of the introduction of potassium feldspar and possibly of the reorganization of such material already present. These microcline augen are in places sheared, or lenticular and strained, but they are nowhere as greatly deformed as the rock in which they are embedded.

Barbour (60) has shown the similarity of the microcline of the augen to that of the pegmatite dikes and considers that this indicates a close genetic relationship. He regards the injection as preceding the intrusion and as occurring after the latest severe dynamic stress that affected the region but during a time of minor stress and readjustment.

The Bedford augen gneiss is not an isolated example of its kind. There are many entirely similar and some closely related rocks in southwestern Connecticut which are also the result of injection or infiltration of magma into some preexisting metamorphic rock.

It is impossible, as yet, to state the age of the injected rocks. Some are definitely pre-Cambrian, though all need not be. The history is complicated by the fact that there are pre-Cambrian granites and pegmatites, possibly two different series, which can not readily be told in all occurrences from the younger ones. It is believed that the type of injection described is not confined to the younger granite and its pegmatites, represented by the Bedford pegmatites.

These facts make the geology of the surrounding region extremely difficult to unravel. If the biotite schist at Bedford is pre-Cambrian it may not have assumed its present condition as an augen gneiss until the late Ordovician Taconic revolution, only a short time before the emplacement of the pegmatite dikes themselves.

MINERALS PRODUCED AND THEIR USE

The Bedford pegmatite quarries are among the largest of their kind. The old Kinkel quarry has been worked for more than 50 years. The rock is drilled and blasted, and, as the components are coarsely crystallized, the commercial minerals are usually easily separated.

Three grades of feldspar are produced. These are all alkali feldspar, microcline or albite, so that the grading depends upon the degree to which they are intergrown with quartz. Microcline occurs normally in large crystals free from quartz and constitutes the first grade suitable for pottery. The albite that contains little quartz is sold as enamel material, and that which forms graphic intergrowths with quartz is sold for the manufacture of glass, scouring soaps, etc. Quartz also occurs in large crystals and pure masses of considerable size. This is sold for wood filler and silica paint material. The quartz is shipped in the crude state, but the various grades of feldspar are ground at a mill near the Kinkel quarry.

The recent discovery of the economic value of beryllium has made the beryl from these quarries important.

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MINERALS OF THE TRAP ROCK QUARRIES OF PATERSON, NEW JERSEY

By A. C. Hawkins and H. P. Whitlock

INTRODUCTION

The region adjacent to Paterson, New Jersey, presents a varied topography. The city lies in the Piedmont province, within 8 miles (12.9 kilometers) of the southeastern rim of the Highland province.

The highest near-by point is in the Highlands, to the northwest (fig. 27), and is 1,220 feet (372 meters) above sea level. The Highlands are underlain by granite gneisses and other pre-Cambrian rocks, with some fragmentary Paleozoic rocks. The Piedmont Plateau, which has an altitude of 200 to 400 feet (61 to 122 meters) along its western margin, is much lower than the Highlands and has a smoother, more undulating surface. The boundary between the Highland and Piedmont provinces is a great fault zone with a throw measured in thousands of feet, the dislocation being downward to the east. The Piedmont province slopes from this margin eastward to sea level along the Hudson River near New York City.

Most of the ridges in the Piedmont trend northeast, with the strike of the rocks. The most prominent ridges are the First and Second Watchung Mountains, also locally known as the Orange Mountains. They average somewhat more than 500 feet (152 meters) in height above sea level and reach a maximum of 866 feet (264 meters) in High Mountain, which is visible from Paterson as a part of the Second Watchung Mountain, 3 miles (4.8 kilometers) northwest of the city. There is also a third Watchung ridge, locally known as Hook Mountain, which is caused by a thin lava flow, deformed by subsequent folding.

The Piedmont Plateau in New Jersey is underlain by rocks of Triassic age, comprising consolidated beds of mud and sand which were washed over this region as continental deposits and whose color is for the most part brownish red. With them are contemporaneous lava flows of a basaltic nature, which appear in the Watchung ridges in the vicinity of Paterson, and a diabasic gabbro sill about 1,000 feet (305 meters) thick, whose extent along the strike is 70 miles (113 kilometers) and which forms the Palisades along the west bank of the Hudson River from New York City northward. The red shales and sandstones, known as the Newark group from their characteristic development at Newark, New Jersey, occupy an area of about 1,400

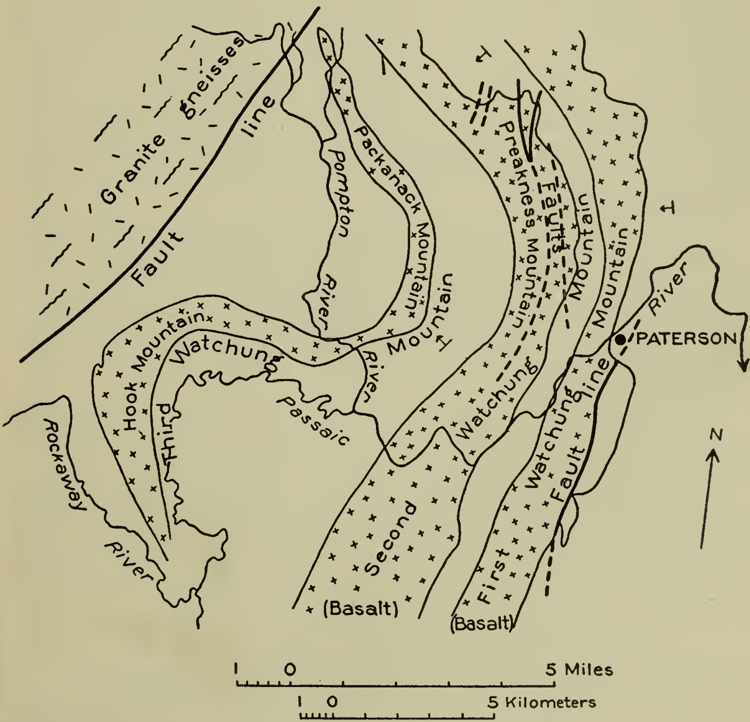

Figure 27.—Sketch map of Watchung basalt ridges, west of Paterson

square miles (3,626 square kilometers) across the north-central part of the State of New Jersey. The extrusive basalts cover an area of over 100 square miles (259 square kilometers), and have a total linear extent of 140 miles (225 kilometers). On account of the great resistance of the basaltic rocks to weathering, all the larger masses of these rocks form prominent ridges. These "trap rocks," including basalts and diabases, are confined to the Triassic area. The Triassic rocks in New Jersey have a dip of 10° to 20° toward the west and northwest, so that the Watchung ridges show steep slopes toward the east and southeast and more gradual dip slopes toward the northwest. North and northwest of Paterson the dip changes locally, inclosing a synclinal basin which lies to the west and southwest of the city and causing the strike of the rocks to swing to a northwesterly direction, which is followed by the basalt ridges. (See fig. 27.)

In northeastern New Jersey in general the sedimentary rocks of this Newark group are sandstones, shales, conglomerates, and arkoses. The predominant rocks in exposures near Paterson are sandstones with alternations of shale. The sandstone has been quarried to some extent for building material; this is the well-known brownstone of New York City. Conglomerates occur mainly at a horizon not far below the base of the First Watchung sheet, north and south of Paterson, and along the western margin of the Newark group.

In the northern Piedmont Plateau in general there is a thick covering of glacial ground moraine, whose material is reddish because of the color of the soft underlying rocks. Owing to the scarcity of connected outcrops, no definite stratigraphic succession of sedimentary beds has been determined in this area. There are also a few longitudinal faults which repeat the surface outcrops of the beds.

The sandstones and shales are, however, excellently exposed in Paterson in the gorge of the Passaic River below the falls, and in the face of Garret Rock, on the south side of the city.

Above the First Watchung basalt is sandstone, 600 feet (183 meters) thick, which has afforded some excellent building stone, as in the Haledon and Little Falls quarries. Between the Second and Third Watchung ridges there are fine-grained, thin-bedded sandstones, intercalated with soft red shale, having a total thickness of about 1,500 feet (457 meters). Similar sediments lie above the relatively thin Third Watchung basalt sheet. They contain some black layers with excellent fish and plant remains.

The basalt of the Watchung ridges is affected by joints which intersect it in several directions. Those of a general northeast trend have a high eastward dip normal to the general westward dip of the lava flows. In many places the lavas also show horizontal lamination and well-developed columnar structure. These basalt sheets are composite, the First Watchung ridge being composed of several relatively thin lava flows. The other basalt ridges of the series are also composite. Vesicular and ropy flow structure is shown on the upper surface of the flows, and many portions are rolled under at the bottom. There are also breccias and tuff beds. The breccias appear to be due to the flow of the lava into local bodies of shallow water (playa lakes) on a plain of continental deposition. Small but characteristic differences in chemical composition are associated with the different flows and with successive parts of the flows.

Petrographically the rocks are basalts or basalt porphyries, both glassy and holocrystalline, with diabasic or ophitic texture. Microscopically the rock ranges from a brown structureless or spherulitic glass to a fine-grained granular or ophitic augite-plagioclase rock, with magnetite grains and scattered olivine crystals. Numerous phenocrysts of augite or feldspar represent earlier stages of crystallization.

The metamorphic effects of the basalt flows upon the sediments below them are usually very slight. Changes in color due to the effects of the heat rarely extend downward more than 2 or 3 feet (0.6 to 0.9 meter) below the contact of the two rocks. In most exposures the contact is a smooth one, but locally it is undulating where the mud was soft when the lava flowed over it.

Several normal faults having a north or northeast trend have dislocated both the sediments and the lava flows near Paterson. A downthrow on the east side of each of these faults results in some apparent thickening of the basalts and repetition of their crest lines. One such fault cuts Garret Rock, just south of the city; the others are to the northwest, in the Second Watchung ridge.

It is now thoroughly demonstrated that the beautiful zeolitic minerals that occur in cavities of the Watchung basalt at West Paterson and adjacent localities in New Jersey were formed as the result of the flowing of the heated basalt into local playa lakes, whose waters contained sulphates both in solution and in the form of crystals.

PATERSON QUARRIES AND THEIR MINERALS

The group of trap-rock quarries in the Watchung basalt in and around Paterson have long been famous for excellent specimens of zeolites and other secondary minerals occurring in veins and cavities in the basalt and brought to light by the quarrying operations. As far back as 1825 we find, in Robinson's "Catalogue of American minerals with their localities," Paterson mentioned with a creditable list of species assigned to it. Many of the fine mineral specimens that were obtained from the basalt of the Paterson area prior to 1890 came from the Hoxie quarry and the McBride Avenue quarry, both of which have been idle for many years.

The quarries in the face of Garret Rock, known as the upper [2][10] and the lower [1] New Street quarries, began operations about

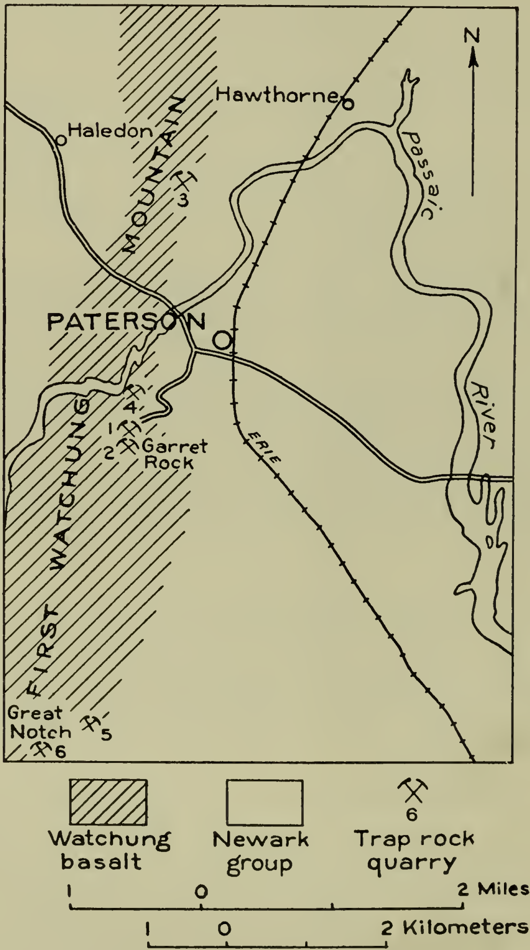

FIGURE 28.—Sketch map showing location of the Paterson quarries

1893 and have since that date produced the great number of magnificent specimens which under the locality designation of "Paterson, N. J.," or "West Paterson, N. J.," grace the public and

[10] Numbers in brackets refer to Fig. 28.

private collections of the world. The lower New Street quarry has been in operation the more constantly, particularly within the last 10 years. (See fig. 28.)

The quarry at Planten Avenue [3], Prospect Park, at the northwestern outskirts of Paterson, commonly known as the Prospect Park quarry, has been in operation since about 1920, but during this relatively short period it has been remarkable for several occurrences unusual to the diabase of the region, such as chrysocolla in finely colored masses and a very considerable vein of barite.

The quarry on Goffle Road, near the Hawthorne line on the northern outskirts of Paterson, known as Braen's quarry, is also to be classed as active in this group, although little first-grade material has been taken from it.

The minerals occurring at the Paterson quarries are listed below.

Albite. In drusy crusts of minute crystals at lower New Street quarry and Prospect Park.

Analcite. In well-crystallized white to colorless individuals as much as 2 centimeters in diameter in all the Paterson quarries.

Anhydrite. In grayish to white radiating masses showing rectangular cleavage at lower New Street quarry and Prospect Park.

Apophyllite. In magnificent crystals as much as 8 centimeters in diameter, colorless, white, or light grass-green from included chlorite, at upper and lower New Street quarries.

Aragonite. Found recently in fine snowy stalactitic shapes at lower New Street quarry.

Asbestos. In thin chrysotile veins at lower New Street quarry and Prospect Park.

Babingtonite. In tufted aggregates of black crystals with individual lengths of as much as 8 millimeters at upper New Street quarry. More rarely and in poorer specimens at lower New Street quarry and Prospect Park.

Barite. In abundant large crystals and crystalline masses at Prospect Park quarry and in small isolated crystals in upper and lower New Street quarries.

Bornite. In small masses at Prospect Park quarry; rare at lower New Street quarry.

Calcite. In a great variety of crystal habits at all the Paterson quarries. (See Bibliography, 107.)

Chabazite. Has been found at all the Paterson quarries; in beautiful deep salmon-colored twinned rhombohedral groups as much as 4 centimeters in diameter at New Street quarries.

Chalcocite. In small isolated masses at Prospect Park quarry.

Chalcopyrite. In small isolated masses at Prospect Park and lower New Street quarries.

Chlorite. An interesting but generally undefinable series of hydrous decomposition products in the mica division occurs in isolated tufts and crusts at all the Paterson quarries.

Chrysocolla. Small specimens of fine color associated with the copper sulphides at Prospect Park quarry; also rarely at lower New Street quarry.

Covellite. Small but characteristic masses at Prospect Park quarry.

Cuprite. Same as covellite.

Datolite. In all the Paterson quarries in greenish and colorless crystals of flat habit, tabular parallel to the orthodome x, and similar to those from Great Notch. (See Bibliography, 73.)

Deweylite. An alteration product found somewhat sparingly at lower New Street quarry and Prospect Park.

Diabantite. A dark-green chlorite identified as diabantite at lower New Street and Prospect Park quarries.

Epidote. Small specimens of massive epidote at lower New Street quarry.

Erythrite. One specimen has been found at lower New Street quarry and is now in Paterson Museum.

Galena. Small specimens of massive galena have been found at lower New Street and Prospect Park quarries.

Genthite. Thin crusts at lower New Street quarry.

Gmelinite. Well-developed crystals in pinkish individuals and groupings at lower New Street quarry. Much finer specimens were formerly found at the now abandoned quarry at Great Notch.

Goethite. Radiating tufts and aggregates at Prospect Park quarry.

Greenockite. Three or four minute crystals resembling those from Greenock have been found at lower New Street quarry; also yellow powdery incrustations. (See Bibliography, 106.)

Gypsum. Colorless selenite in abundant crystalline masses but without definite crystal planes at lower New Street quarry; more sparingly at Prospect Park.

Hematite. Films incrusting other minerals and as small translucent plates at all the Paterson quarries. At lower New Street quarry hematite films incrust quartz cyrstals in selective deposition on one rhombohedron of the termination only.

Heulandite. Found at all the Paterson quarries; in especially fine crystals and groups at lower New Street quarry.

Kaolinite. Decomposition product at Prospect Park quarry.

Laumontite. Fine specimens in white aggregates at lower New Street quarry.

Limonite. Small specimens at lower New Street quarry.

Magnesite. Insignificant specimens at New Street quarries. The occurrence at the upper quarry has been termed breunerite.

Malachite. Small incrusting patches at lower New Street quarry and Prospect Park.

Natrolite. Significant specimens at all the Paterson localities. At the New Street quarries crystal aggregates as much as 6 centimeters in length have been found. It has been suggested that some of these consist of twinned scolecite.

Opal. Crusts of hyalite at lower New Street and Prospect Park quarries.

Orpiment. Very rare at lower New Street quarry.

Pectolite. Abundant at the New Street quarries and has been found at all the Paterson localities. Fine specimens are generally obtainable, including the alteration stages known as manganpectolite and stevensite.

Phlogopite. One microscopic specimen in Paterson Museum.

Prehnite. Abundant at New Street quarries in a great variety of colors and aggregates. Specimens are generally obtainable. Also present at other Paterson localities.

Prochlorite. See Chlorite.

Pyrite. Rare as small incrusting crystals on minerals of lower New Street quarry and at Prospect Park.

Pyrolusite. Dendritic incrustations, notably at Braen quarry; rare and insignificant at lower New Street quarry.

Quartz. In many varieties at all the Paterson quarries. Fine deep-colored amethyst and smoky quartz were formerly collected at the McBride Avenue and New Street quarries. Also at New Street locality small crystals coated with hematite films on one rhombohedron only.

Scolecite. See Natrolite.

Serpentine. Various colors occur at all the Paterson localities. The best specimens have been collected from the Prospect Park quarry.

Silver. Two specimens at Prospect Park, one of which is in the Paterson Museum.

Sphalerite. A few insignificant specimens at lower New Street quarry.
Stilbite. Interesting and notable specimens in sheaf-like brown, yellowish, and white aggregates, comparable with the Nova Scotia occurrence, have been collected from all the older Paterson quarries. This is one of the outstanding minerals of this group of quarries.
Stilpnomelane. Small isolated patches of incrusting drusy chalcodite at lower New Street quarry.
Thaumasite. Confused masses of white acicular crystals, incrusting and inclosing other minerals, as well as white fine granular masses, at lower New Street quarry.
Thomsonite. Beautiful white silky aggregates, comparable to those occurring at Faroe Islands, at lower New Street quarry.
Vermiculite. See Chlorite.

DERIVATION OF SECONDARY MINERALS IN THE WATCHUNG BASALT

The problem of the derivation of the secondary minerals in the Watchung basalt has been studied by several investigators, among them Fenner (81),[11] who has dealt with the subject in some detail and has this to say on the initial stages in the paragenesis:

> Evidence along various lines leads to the belief that the processes of alteration were directed by the features impressed upon the solidified basalt by the presence of the bodies of water [playa lakes]. Among the spheroidal masses, a considerable amount of interstitial space had been left. Moreover, the crusts were much shattered, and frequently the interiors of the masses were penetrated by a multitude of cracks produced by shrinkage in cooling. Where the openings were of sufficient size to permit the free passage of superheated aqueous vapors from the water-impregnated sediments beneath, these gases appear to have rushed upward with great force and velocity, carrying with them quantities of finely comminuted dust from the lake beds and depositing it in the various interstices, in the form of a reddish-brown powder.

This action resulted in the first period of mineral deposition as enumerated by Fenner, called by him the boric acid period, characterized in its first stage by intense hydrothermal metamorphism and producing such minerals as albite, quartz, garnet, amphibole, specular hematite, and the sulphides. A later stage of this period laid down datolite, prehnite, and pectolite. Fenner not only recognizes a number of genetic stages of mineral deposition but attributes these, at least the postinitial stages, to the agency of circulating meteoric water. This view is in agreement with the explanations advanced by other writers in describing zeolitic formations in various parts of the world.

The period in which the rich and varied series of zeolites and other secondary minerals were laid down at Paterson must undoubtedly be considered as one of slow and interrupted surface-water deposition, in which the feldspar of the basalt as well as certain of the secondary minerals of the boric acid period

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[11] Numbers in parentheses refer to bibliography, pp. 137–139.

furnished dissolved matter to the meteoric circulating waters. This genetic phase has been studied by Fenner in much detail. He notes among the minerals deposited during this period analcite, chabazite, heulandite, stilbite, natrolite, laumontite, chlorite, and apophyllite, approximately in the order named. Fenner cites instances where analcite has been observed in process of alteration to natrolite. Chabazite, heulandite, and stilbite, although in general of a later phase of deposition, have also been observed partly replaced by natrolite, and all three are sometimes replaced by a later generation of calcite.

Laumontite represents a late stage in the zeolite period of deposition and in some places followed calcite of the most advanced period. Like natrolite it has replaced earlier zeolites.

Apophyllite is also a result of a late stage of the period of zeolite deposition. Fenner regards the small amount of fluorine involved in the formation of apophyllite (about 1.5 per cent) as possibly derived from some previously formed mineral.

The final period of deposition of secondary minerals is represented at Paterson by calcite, thaumasite, and gypsum, a group of lime minerals, the meteoric sources of which can not be questioned. It must be borne in mind, however, that there was a considerable overlapping of these various periods. Calcite, for instance, probably was deposited at various stages of the zeolite deposition period. Again, whereas datolite or prehnite or both are usually found next to the walls of diabase in a vein or vug, examples are by no means lacking of zeolites of the middle period occupying this position.

A problem that has caused much discussion in relation to the origin of the minerals of the Watchung basalt has to do with the character of certain regular crystal cavities early observed in the basalt of Paterson and its vicinity (94, 97). It was assumed from the first that these angular cavities represented the shapes assumed by crystals of a former mineral, which, after having been inclosed in quartz or prehnite, were dissolved away, leaving only angular hollows to mark the places where they had been. These angular tubes are either rectangular or rhomboidal in cross section, a fact that further complicated the problem of their derivation, because it was assumed that a single mineral in crystals of different habit was responsible for both types of impressions. They were successively pronounced impressions of thenardite, babingtonite, and other problematic mineral crystallizations. It is now well established, however, that the rectangular casts were formerly filled with anhydrite crystals, and that those of lozenge-shaped cross section were produced by glauberite crystals (97).

The genetic sequence of the secondary minerals at Paterson as recorded by Fenner is in the main in agreement with the work of students of these problems at other diabase localities. Walker and Parsons (100) in their work on the zeolites of the Nova Scotia basalts have established a sequence as follows: Diabantite, quartz, chabazite, stilbite, heulandite, analcite, apophyllite, mesolite, scolecite, laumontite, thomsonite, natrolite, calcite. The chief disagreement between this sequence and that of the New Jersey zeolites as stated by Fenner lies in the position of diabantite, which is placed by Walker and Parsons near the bottom of the series instead of close to the top as assumed by Fenner. It is unfortunate for the sake of comparison that prehnite, pectolite, and datolite are not present in the Nova Scotia series.

T. Hodge Smith (99) notes an occurrence of zeolites in the basalt of Ardglen, New South Wales, in which he has stated the zeolite sequence to be, for the middle flow, analcite, chabazite, calcite (first generation), natrolite, calcite (second generation). In the upper flow apophyllite follows natrolite. As far as a comparison can be made the sequence at Ardglen agrees well with that at Paterson.

A very interesting occurrence of diabase in comparison with the Watchung basalt is that which extends over Scotland approximately from the Firth of Clyde to the Firth of Forth. The rare cadmium sulphide greenockite, which appears at Paterson in very rare crystals, is also present in crystals associated with prehnite in porphyritic trap at Bishopstown and near Glasgow. It is unfortunate that the zeolites of these rocks do not appear to have been studied in detail as to their genetic sequence. Heddle (87) states that "apophyllite would be the very last zeolite to separate and solidify in drusy cavities," thus placing this mineral relatively in the same position in the Scottish series that it occupies at Paterson. Elsewhere the same authority states that laumontite overlies stilbite in the trap rocks of Inverness-shire and assigns stilbite and heulandite to the same generation, one or the other appearing the older in different places. All of this, as far as it goes, agrees with the genetic sequence at Paterson.

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ZINC DEPOSITS NEAR FRANKLIN, NEW JERSEY

By Paul F. Kerr

THE ROUTE

The excursion leaves Manhattan Island (see fig. 29) over the Hudson River Bridge. This bridge, joining the Palisades of New Jersey with Washington Heights, New York, was constructed by the Port of New York Authority at a cost of approximately $60,000,000. It is the longest suspension bridge in the world, having a span from support to support of 3,500 feet (1,067 meters). The four main cables are 3 feet (0.9 meter) in diameter, and each cable is made up of 26,474 galvanized steel wires. The zinc used on these cables weighed 1,700,000 pounds (771,000 kilograms) and was produced from ore from the New Jersey Zinc Co.'s Franklin mines.

The west approach to the Hudson River Bridge cuts through the Palisades of New Jersey. The Palisades have been formed by the erosion of an intrusive diabase which penetrated the shale and sandstone layers of the Newark group of New Jersey. From the Palisades westward the route passes across the Hackensack Meadows. Here the soft shales and sandstones of the Newark group (Triassic) have suffered erosion and formed a lowland crossed by sluggish tidal streams. From the Hacken-

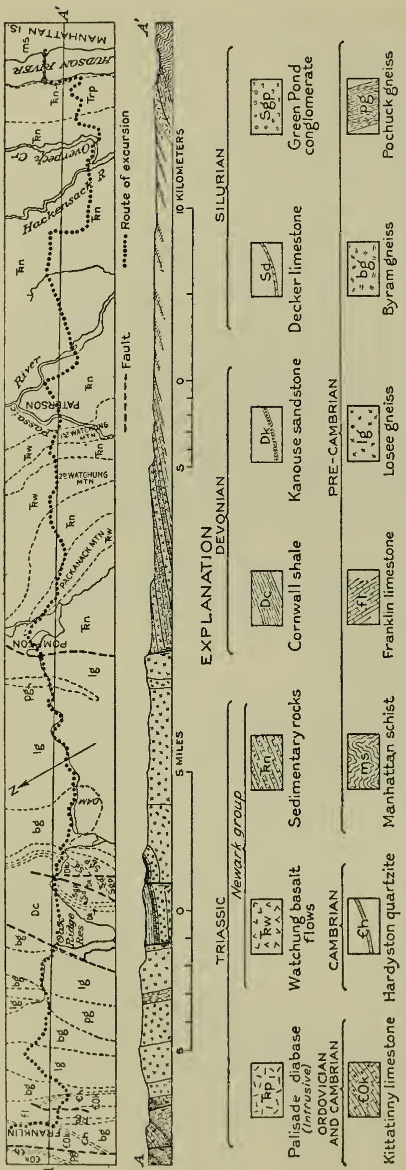

FIGURE 29.—Geologic map and section along route of excursion from New York to Franklin, New Jersey

sack Meadows westward the route traverses a succession of moderate depressions and elevations. The depressions are due to the erosion of the weaker shale members of the Newark group, and the elevations have been formed by the more or less resistant sandstone members. At Paterson the route crosses First Watchung Mountain, an extrusive sheet of basaltic rock in the Newark group. Many zeolitic minerals have been collected from the trap-rock quarries along the bluff west of Paterson.

The city of Paterson (population 138,513 in 1930) is one of the centers of the silk manufacturing industry in the United States. Several of the silk mills are located along the route.

After passing the First Watchung Mountain, the route continues westward, still crossing the Triassic lowland. The exposures of the Newark sedimentary rocks continue, interspersed with intrusive and extrusive sheets of Watchung basalt, which form the outstanding hills. At Pompton a large fault separates the crystalline rocks of the highlands from the sediments of the Triassic lowland. West of the fault the route passes through a continuous succession of pre-Cambrian gneisses with scattered exposures of Paleozoic strata. The outstanding formations of this region are the Byram gneiss and the Losee gneiss. The most striking of the Paleozoic strata is the Green Pond conglomerate, which forms several escarpments visible from the highway. At a distance of 47 miles (75 kilometers) from the Island of Manhattan the route descends from the Hamburg Mountains of the Highlands into the Wallkill Valley. The town of Franklin and the adjacent zinc mines are located along this valley.

FRANKLIN FURNACE

Franklin Furnace is the old name for the zinc-mining district centered around Mine Hill. In 1913 the borough of Franklin was organized, and the town that forms the center of the zinc-mining activities of the district has since been known as Franklin. The town, which in 1930 had a population of 4,176, is scattered over the low-lying and rolling hills that rise from the floor of the Wallkill Valley. The Mine Hill property of the New Jersey Zinc Co. is within the town, and Sterling Hill, another property owned by the same company, is 3 miles (4.8 kilometers) south, near the village of Ogdensburg. These two properties contain the only deposits of zinc ore known in the district.

HISTORY

The area between the Hudson River and the Delaware River comprised the western portion of a grant by King Charles II of England to his brother, James the Duke of York. The county of Sussex, in New Jersey, in which the town of Franklin is located, was included in this grant.

The date of discovery of the zinc deposits at Mine Hill and Sterling Hill is not known. Iron mining at Franklin, then known as Franklin Furnace, began early in the history of the country and ores from this section were utilized during the Revolution.

Shuster (128)[1] has summarized the history of Franklin as follows:

> The history of events as they relate to the mining industry of the Wallkill Valley may be divided into four periods of time.
>
> The first period, from the early settlement of the country to the end of the eighteenth century, included a term of years in which some attention was given to the exploitation of the zinc veins at Mine Hill and Sterling Hill and the discovery and early development of iron deposits.
>
> The second period extended from 1801 through the first half of the nineteenth century, when the mining, smelting, and forging of the iron became an important industry, not only in this district but in other sections of Sussex County. During this epoch, from 1800 to 1850, the unique ores and minerals of Mine Hill

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[1] Numbers in parentheses refer to bibliography, pp. 150–151.

and Sterling Hill were brought to the attention of the mining and scientific world. It was the era of exploration, investigation, and the development of experimental processes for the smelting and utilization of the zinc ore deposits. This work, to a great extent, was due to the personal efforts of Dr. Samuel Fowler and his associates.

The third period, from 1850 to 1897, saw the organization of many corporations, each having various ownerships of various titles. At the end of this period the value of the ores had been fairly well determined and the zinc-mining industry well established. The output of the mines gradually increased to meet the demands of commerce. During this period the legal complications among the conflicting interests of the various mining companies led to a series of lawsuits that intermittently covered a period of 40 years.

The fourth period takes us from 1897 to 1927. Prior to 1897 the operating mines at Sterilng Hill and Mine Hill were owned and operated by four different corporations, each having a subdivision of the ore bodies. In 1897 all interests of Sterling Hill and Mine Hill were united under the name of the New Jersey Zinc Co.

MINING AND MILLING

The mining methods in vogue at Franklin have been described by Haight and Tillson (113). In brief, the ore body is worked by a system of top slicing, the ore being drawn off through haulage levels to one main shaft, the Palmer shaft.

The inclined length of the Palmer shaft is 1,520 feet (463 meters). It is a 4-compartment shaft having an inclination of 47° 30′ with the horizontal.

Electric haulage systems run through the footwall beneath the ore body and parallel with it on the different levels. The broken ore is transferred by small tram cars from the working faces of the mine to the loading chutes. The ore from the chutes is dropped into the haulage cars of the electric trains, which haul it to large bins between the vein and the shaft, below the haulage tracks. Loading pockets supply the ore to 6-ton skips which are operated in the 4-compartment shaft. The mine water is pumped by three electric centrifugal pumps from a pumping station on the 1,050-foot (320-meter) level south of the Palmer shaft.

The ore at Mine Hill is treated in a modern mill. One of the features of the mill is the magnetic method of separation utilized for the concentration of the franklinite ore. Tables and jigs are employed for the treatment of the nonmagnetic minerals. It was in the mill at Franklin that the Wetherill magnetic separator was developed. It is also noteworthy that at one time Thomas A. Edison tried his hand at the treatment of the zinc ores.

The mill at Sterling Hill has a smaller capacity than the mill at Franklin but treats the same kind of ore.

Concentrates from both mills are shipped to the smelting plant of the New Jersey Zinc Co. at Palmerton, Pennsylvania. In addition to numerous zinc products obtained from the ore the manganese and iron that remain are smelted into spiegeleisen.

A desirable feature of the ore from this district is the almost complete absence of lead.

FORMATIONS

Underlying the Franklin limestone is the Pochuck gneiss (pre-Cambrian). The Pochuck is an injection gneiss, which has had a complicated history. It was probably at one time part of the same sedimentary series to which the Franklin limestone belonged, but has undergone several igneous invasions with a complete change in character.

The Franklin limestone is pre-Cambrian and is considered by some geologists to be equivalent to the Grenville series. It is called the "White limestone" by the miners.

The ore bodies at Sterling Hill and at Mine Hill occur in the Franklin limestone (fig. 30), which rests upon the Pochuck gneiss and is truncated above by an unconformity that separates it from the Hardyston quartzite and Kittatinny limestone. The contact between the Franklin limestone and the underlying Pochuck gneiss at Mine Hill dips steeply to the east, but there is no apparent unconformity. The lines of foliation in the gneiss agree with such meager evidences of stratification as may be observed in the limestone. Also, the inclination of the ore body in the limestone and the inclination of the magnetite layers that underlie the ore are, in general, parallel to the contact.

The Franklin limestone is predominantly a very pure nonmagnesian limestone. In many places, however, it is highly dolomitic. Extensive studies have been made of the magnesian and calcareous character of the Franklin limestone in relation to the ore, without apparently correlating any of the properties of the limestone in so far as dolomite and calcite are concerned with the distribution of the formation. The limestone is satisfactory for cement, and several quarries have been successfully operated.

The Hardyston quartzite is of Cambrian age and ranges in thickness from a few feet to 30 feet (9 meters). It underlies the Kittatinny limestone and rests unconformably upon the Pochuck gneiss and Franklin limestone in the vicinity of the ore body.

The Kittatinny limestone, of Cambrian and Ordovician age, is the "Blue limestone" of the miners. It has a thickness estimated by Kümmel at 2,500 to 3,000 feet (762 to 914 meters). The Kittatinny conforms with the Hardyston quartzite, and the two formations together truncate the ore deposit north of Mine Hill.

RELATIONS OF THE ORE DEPOSITS

The zinc ores occurring in the Franklin limestone are found in a body that imitates in shape a sharply folded sheet. At Franklin the trough of the fold crops out at the Buckwheat pit,

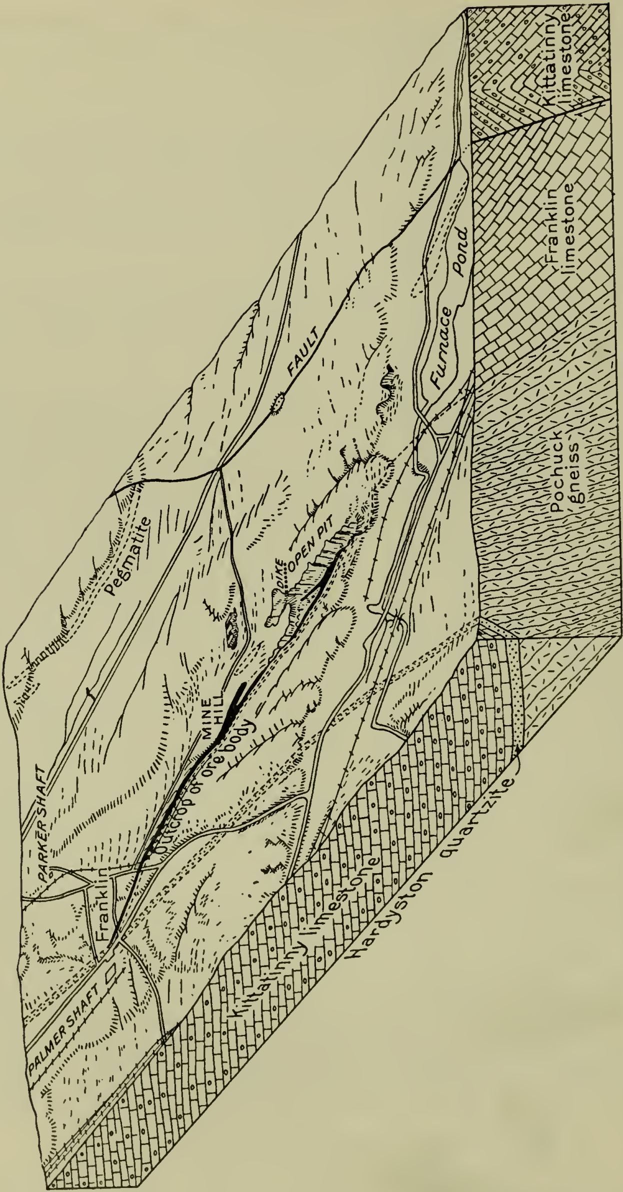

FIGURE 30.—Block diagram illustrating the general relations of the ore deposits at Franklin, the geography of the surface, and the contacts in the vicinity of the ore

the ore body extends thence downward and northward, toward the center of the present underground workings. The east limb of the fold is terminated at an inclined angle beneath the surface. The outcrop of the west limb extends from the open cut to the vicinity of the Palmer shaft, where it goes underground beneath the Hardyston quartzite.

The west side of the ore body is frequently referred to as a vein and in many respects resembles a vein in shape. It inclines toward the east, parallel to the contact between the Franklin limestone and the underlying Pochuck gneiss. Between the ore

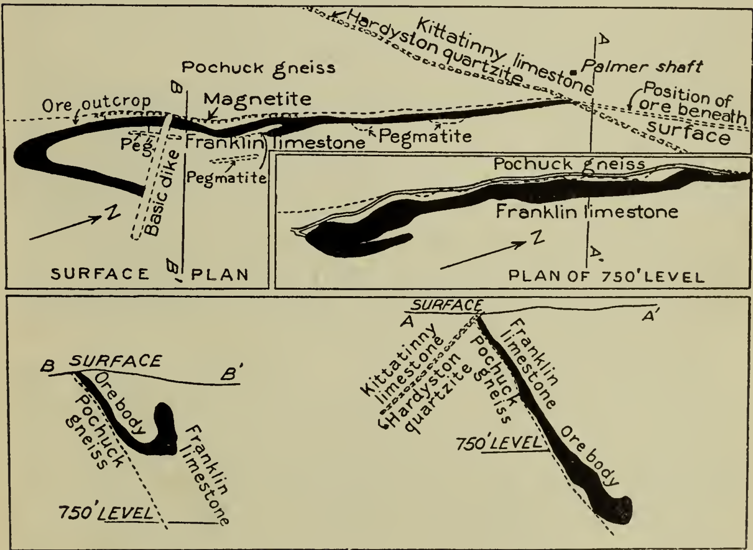

FIGURE 31.—Plans and cross sections of the ore deposits at Franklin. The plan of the surface shows the outline of the ore outcrops in relation to the contact between the gneiss and the Franklin limestone. The plan of the 750-foot level shows the same relation underground. A comparison of the sections indicates the pitch of the deposit

body and the gneiss and in some places in the gneiss itself is a layer of magnetite. Most authors agree that the magnetite was produced at a later period of mineralization than the zinc ore and is not related to the zinc ore body. It has been shown in the mine workings that the magnetite continues beyond the zinc ore body in a straight line and does not correspond to it in curvature. The 750-foot (229-meter) level is representative of the general relations of the ore body. Figure 31 shows a diagram of this level illustrating its relationship to the surface and sections of the ore deposit.

ORIGIN OF THE ORES

A comprehensive study of the origin of the ores involving modern petrographic methods accompanied by field work has been carried on by Ries and Bowen (126). These authors set up the following sequence of events as representing the history of the ore deposits: (1) Metamorphism of the Franklin limestone prior to the deposition of the ore; (2) deposition of the ore minerals, mainly by replacement of the limestone, possibly in some places in cavities; (3) intrusion of the syenite mass in the upper part of the Sterling Hill ore body; (4) folding of the limestone with the ore bodies, resulting in the development of the curious trough-shaped deposits at the two localities; (5) intrusion of the pegmatite at Mine Hill, accompanied or followed by deposition of silicates and some recrystallization of the ore minerals near pegmatite contacts; (6) deposition of later or secondary willemite in possible ore fractures, due either to solution and redeposition of earlier zinc ores, or to introduction of more zinc-bearing solution—the evidence not being as clear as might be wished; (7) fracturing of the ore bodies, accompanied in places by faulting; (8) introduction of sphalerite, pyrite, and chalcopyrite; (9) deposition of carbonates; (10) intrusion of basic dikes of possible Ordovician age; (11) erosion and subsequent slight weathering of the minerals in the ore deposits as shown by the finding of calamine, smithsonite, and azurite.

One of the most recent of the hypotheses that have been advanced to account for the ores as they are now found is that of Palache (123). He considers that metasomatic deposits of the hydrated zinc and iron minerals were formed by replacement of the Franklin limestone, and that simultaneously with the recrystallization of the inclosing limestone as a result of regional metamorphism these bodies were changed to their present mineral composition. The main ores he considers to have been produced by a combination of these two processes. He points out, however, the presence of a number of later and, so far as economic importance is concerned, lesser modifications, which have produced a diverse variety of minerals and numerous interesting mineral relationships. In this group occurred the invasion of pegmatites, resulting in recrystallization of primary minerals near the contacts and forming skarns by the interaction of ores and magmatic materials. Furthermore, pneumatolytic products of the pegmatite magma produced numerous veined minerals throughout the ore body. Later, as the temperature fell, hydrothermal veins of great variety were formed, producing an unusual assortment of minerals.

MINERALS

The region around Franklin constitutes one of the most famous mineral localities in the world. Palache (123) has recently published a list of minerals and a description of their paragenesis. Since Palache's list was published Bauer and Berman (108, 109, 110) have made several additions—beryllium-vesuvianite, barylite, mooreite, fluoborite, loseyite, ferroschallerite, and manganbrucite—and have also shown that clinozoisite should be eliminated from the list of Franklin minerals. The total number of minerals reported is now 143. Palache's list, with clinozoisite omitted, is quoted below.

Paragenetic table of Franklin minerals

1. Primary ores:
   - Franklinite (Zn, Fe, Mn)O.(Fe, Mn)$_2$O$_3$.
   - Zincite (Zn, Mn)O.
   - Willemite 2ZnO.SiO$_2$.
   - Tephroite 2(Mn, Zn, Fe)O.SiO$_2$.
2. Pegmatite contact minerals:

   Skarn—
   - Hyalophane (K$_2$, Na$_2$, Ba)O.Al$_2$O$_3$.4SiO$_2$.
   - Jeffersonite, Schefferite, Zinc-schefferite } (Ca, Mg)O.(Fe, Mn, Zn)O.2SiO$_2$.
   - Fowlerite (Mn, Fe, Ca, Zn)O.SiO$_2$.
   - Bustamite (Mn, Ca)O.SiO$_2$.
   - Manganese hornblende.
   - Manganese garnet.
   - Hardystonite 2CaO.ZnO.2SiO$_2$.
   - Tephroite 2(Mn, Zn, Fe)O.SiO$_2$.
   - Roepperite 2(Fe, Mn, Zn, Mg)O.SiO$_2$.
   - Glaucochroite MnO.CaO.SiO$_2$.
   - Vesuvianite, var. cyprine 3(Al, Fe)$_2$O$_3$.6(Ca, Zn, Cu, Mn)O.5SiO$_2$.2H$_2$O.
   - Manganophyllite = Mn-biotite. Var. caswellite, altered Mn-biotite.
   - Gahnite (Zn, Fe)O.(Al, Fe)$_2$O$_3$.
   - Magnetite FeO.Fe$_2$O$_3$.

   Recrystallization products—
   - Franklinite (Zn, Fe, Mn)O.(Fe, Mn)$_2$O$_3$.
   - Zincite (Zn, Mn)O.
   - Manganosite MnO.
   - Hematite Fe$_2$O$_3$.
   - Willemite 2ZnO.SiO$_2$.
   - Tephroite 2(Mn, Zn, Fe)O.SiO$_2$.

   Pneumatolytic products—
   - Margarosanite PbO.2CaO.3SiO$_2$.
   - Pectolite Na$_2$O.4(Ca, Mn)O.6SiO$_2$.H$_2$O.
   - Willemite 2ZnO.SiO$_2$.
   - Nasonite 5PbO.4CaO.PbCl$_2$.6SiO$_2$.
   - Barysilite 3(Pb, Mn)O.2SiO$_2$.
   - Glaucochroite MnO.CaO.SiO$_2$.
   - Tephroite 2(Mn, Zn)O.SiO$_2$.
   - Larsenite PbO.ZnO.SiO$_2$.
   - Calcium-larsenite (Pb, Ca)O.ZnO.SiO$_2$.
   - Roeblingite 7CaO.2PbO.2SO$_3$.5SiO$_2$.5H$_2$O.

2. Pegmatite contact minerals—Continued.
Pneumatolytic products—Continued.
Hancockite $4(Pb, Ca)O.4Al_2O_3.6SiO_2.H_2O$.
Prehnite $2CaO.Al_2O_3.H_2O.3SiO_2$.
Leucophoenicite $7(Mn, Zn, Ca)O.H_2O.3SiO_2$.
Clinohedrite $CaO.ZnO.H_2O.SiO_2$.
Hodgkinsonite $3(Zn, Mn)O.H_2O.SiO_2$.
Datolite $2CaO.B_2O_3.H_2O.2SiO_2$.
Cahnite $4CaO.B_2O_3.4H_2O.As_2O_5$.
Sussexite $2(Mn, Mg, Zn)O.B_2O_3.H_2O$.
Manganese-axinite $2Al_2O_3.4(Ca, Mn)O.B_2O_3.H_2O.8SiO_2$.
Cuspidine $4CaO.F_2.2SiO_2$.
Apatite $8CaO.2(Ca, Mn)F.3P_2O_5$.
Hedyphane $8(Ca, Pb)O.2PbCl.3As_2O$.
Svabite $8CaO.2(Ca, Mn)F.3As_2O_5$.
Franklinite $(Zn, Fe, Mn)O.(Fe, Mn)_2O_3$.
Fluorite CaF_2.
Barite $BaO.SO_3$.
Silver Ag.
Copper Cu.
Lead Pb.
Galena PbS.
Chalcocite Cu_2S.
Niccolite NiAs.
Chloanthite $NiAs_2$.
Sphalerite ZnS.
Chalcopyrite $CuFeS_2$.
Bornite Cu_3FeS_2.
Pyrite FeS_2.
Löllingite $FeAs_2$.

3. Hydrothermal vein minerals:
Albite $Na_2O.Al_2O_3.6SiO_2$.
Fowlerite $(Mn, Fe, Ca, Zn)O.SiO_2$.
Actinolite $(Mg, Ca, Fe)O.SiO_2$.
Tremolite $(Mg, Ca)O.SiO_2$.
Crocidolite $Na_2O.2FeO.Fe_2O_3.6SiO_2$.
Willemite $2ZnO.SiO_2$.
Friedelite $7MnO.MnCl.6SiO_2.4\frac{1}{2}H_2O$.
Schallerite $12MnO.9SiO_2.As_2O_5.7H_2O$.
Mcgovernite $21(Mn, Mg, Zn)O.3SiO_2.\frac{1}{2}As_2O_3.As_2O_5.10H_2O$.
Leucophoenicite $7(Mn, Zn, Ca)O.H_2O.3SiO_2$.
Gageite $8(Mn, Zn, Mg)O.3SiO_2.3H_2O$.
Hodgkinsonite $3(Zn, Mn)O.SiO_2.H_2O$.
Ganophyllite $7MnO.Al_2O_3.8SiO_2.6H_2O$.
Apophyllite $K_2O.8CaO.16H_2O.16SiO_2$.
Thomsonite $Na_2O.Al_2O_3.2SiO_2.2H_2O$.
Stilbite $(Na_2, Ca)O.Al_2O_3.6SiO_2.6H_2O$.
Epistilbite $CaO.Al_2O_3.6SiO_2.5H_2O$.
Heulandite $CaO.Al_2O_3.6SiO_2.5H_2O$.
Chlorite $5MgO.Al_2O_3.3SiO_2.4H_2O$.
Mn-serpentine $3(Mg, Mn, Zn)O.2SiO_2.2H_2O$.
Bementite $8MnO.7SiO_2.5H_2O$.
Talc $3MgO.H_2O.4SiO_2$.
Calcite $CaO.CO_2$.
Aragonite $CaO.CO_2$.
Dolomite $(Ca, Mg)O.CO_2$.
Siderite $FeO.CO_2$.
Rhodochrosite $MnO.CO_2$.

3. Hydrothermal vein minerals—Continued.
   - Smithsonite $ZnO.CO_2$.
   - Quartz SiO_2.
   - Zincite ZnO.
   - Hematite Fe_2O_3.
   - Hetaerolite $ZnO.Mn_2O_3$.
   - Goethite $Fe_2O_3.H_2O$.
   - Manganite $Mn_2O_3.H_2O$.
   - Pyrochroite $MnO.H_2O$.
   - Chalcophanite $(Mn, Zn)O.2MnO_2.2H_2O$.
   - Hedyphane 8 $(Ca, Pb)O.2PbCl.3As_2O_5$.
   - Arseniosiderite $8CaO.8FeO.6H_2O.3As_2O_5$.
   - Allactite $7MnO.4H_2O.As_2O_5$.
   - Chlorophoenicite $10(Mn, Zn)O.7H_2O.As_2O_5$.
   - Holdenite $8MnO.4ZnO.5H_2O.As_2O_5$.
   - Sussexite $2(Mn, Mg, Zn)O.H_2O.B_2O$
   - Barite $BaO.SO_3$.
   - Celestite $SrO.SO_3$.
   - Anhydrite $CaO.SO_3$.
   - Galena PbS.
   - Sphalerite ZnS.
   - Greenockite CdS.
   - Pyrite FeS_2.
   - Marcasite FeS_2.
   - Millerite NiS.
   - Tennantite $4Cu_2S.As_2S_3$.
4. Surface oxidation products:
   - Calamine $2ZnO.H_2O.SiO_2$.
   - Neotocite $MnO.SiO_2.nH_2O$.
   - Mn-serpentine $3(Mg, Mn, Zn)O.2SiO_2.2H_2O$.
   - Desaulesite=Ni-genthite $4(Ni, Zn, Fe)O.3SiO_2.6H_2O$.
   - Quartz SiO_2.
   - Cuprite Cu_2O
   - Hematite $Fe_2.O_3$.
   - Hydrohetaerolite $2ZnO.2Mn_2O_3.H_2O$.
   - Limonite $2Fe_2O_3.3H_2O$.
   - Chalcophanite $(Mn, Zn)O.2MnO_2.2H_2O$.
   - Psilomelane Mn-oxide.
   - Cerussite $PbO.CO_2$.
   - Malachite $2CuO.CO_2.H_2O$.
   - Azurite $3CuO.2CO_2.H_2O$.
   - Aurichalcite $5(Zn, Cu)O.2CO_2.3H_2O$.
   - Hydrozincite $3ZnO.CO_2.2H_2O$.
   - Smithsonite $ZnO.CO_2$.
   - Descloizite $4(Pb, Zn)O.H_2O.V_2O_5$.
   - Anglesite $PbO.SO_3$.
   - Gypsum $CaO.SO_3.2H_2O$.

At the picking table in Franklin the visitor has an opportunity to observe the output of the mine as it passes along a central rotating platform before entering the crusher. A number of rare specimens and several new minerals have been found by mineralogists at this point. Here it is that the output of the mine, as it were, passes in review. The common minerals seen on the picking table include willemite, franklinite, zincite, garnet, fowlerite, and calcite.

A large number of the mineral species found in Franklin fluoresce in ultraviolet light. The New Jersey Zinc Co. has placed an electric arc producing ultraviolet light in a darkened inclosure near the picking table for the convenience of workmen. It is worth while for the visitor to test the specimens picked up from the picking table with this light, as such an examination will often reveal unusual fluorescent minerals that might otherwise be overlooked.

ACKNOWLEDGMENTS

In the preparation of this guidebook great courtesy and consideration has been shown by the officials of the New Jersey Zinc Co., who have also made it possible for the party to visit the mine and mill at Franklin.

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