GEOLOGICAL SURVEY OF NEW JERSEY

HENRY B. KÜMMEL, STATE GEOLOGIST

BULLETIN 14

THE GEOLOGY OF NEW JERSEY

A summary to accompany the Geologic Map (1910-1912) on the scale of 1:250,000, or approximately 4 miles to 1 inch.

Ent Proc

BY

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Preface.

In the twenty-four years that have elapsed since the publication of the last geologic map of New Jersey great progress has been made in the science of geology and much careful, detailed work has been done in all parts of the State, including special investigations of many important problems. With the aid of more accurate maps it has been possible also not only to correct the errors of the earlier editions but to represent the various formations of the State with a much greater degree of refinement than heretofore.

The earlier State maps issued by the Geological Survey were drawn to the scale of five miles to the inch. The base map for the present edition has been prepared by reducing the topographic atlas sheets of the State from the scale of one mile to the inch (1:63,360) to the scale of 1:250,000, or approximately four miles to the inch. The larger scale has been adopted for the sake of clearness and greater accuracy of detail. The particular scale chosen (1:250,000) is an exact multiple of the one-millionth international scale, and the map therefore may be the more readily compared with the corresponding maps of other countries.

As indicated in the title of the map, the geologic data have been compiled from both the published maps and the unpublished manuscript data in the possession of the Survey. The published geologic folios and those in process of publication, under the joint auspices of the Geological Survey of New Jersey and the United States Geological Survey, have been followed as far as they go; that is, for the areas covered by the Franklin Furnace, New York City, Trenton, Passaic, Philadelphia, and Raritan folios. Other parts of the State have been covered by the field work of the several geologists named: Dr. William S. Bayley, the pre-Cambrian areas of the Highlands; Dr. Henry B. Kümmel, State Geologist, the Paleozoic, Triassic, and Quaternary areas; Professor Rollin D.

Salisbury, the Quaternary formations; and Mr. G. N. Knapp, the Cretaceous, Tertiary, and Quaternary areas of the Coastal Plain.

Special acknowledgments are due to the engravers, Messrs. Hoen & Company, of Baltimore, Md., for their painstaking care at every stage of the difficult and complicated task of reproducing the map and for the excellent workmanship that is apparent in both the engraving and the printing.

THE AUTHORS.

Trenton, New Jersey, April 1, 1914.

The Geology of New Jersey

By

J. VOLNEY LEWIS and HENRY B. KÜMMEL

ROCKS AND ROCK STRUCTURES.

For the benefit of the nontechnical reader brief explanatory statements are here included concerning the more common types of rocks and their structures. For a fuller consideration of these topics, as well as those of the geologic forces and processes and the great field of historical geology, reference must be made to textbooks and the larger manuals.

SEDIMENTARY ROCKS.

ORIGIN.

The sedimentary rocks include all those varieties that have been formed in layers, beds or strata, by the accumulation of mud, sand, and gravel—chiefly washed down from the land by rivers—and the limy oozes of the sea. Such an arrangement in beds or strata is called *bedding* or *stratification,* and rocks possessing this structure are said to be stratified. Similar sediments are now being deposited in seas and lakes and on low lands in many parts of the world.

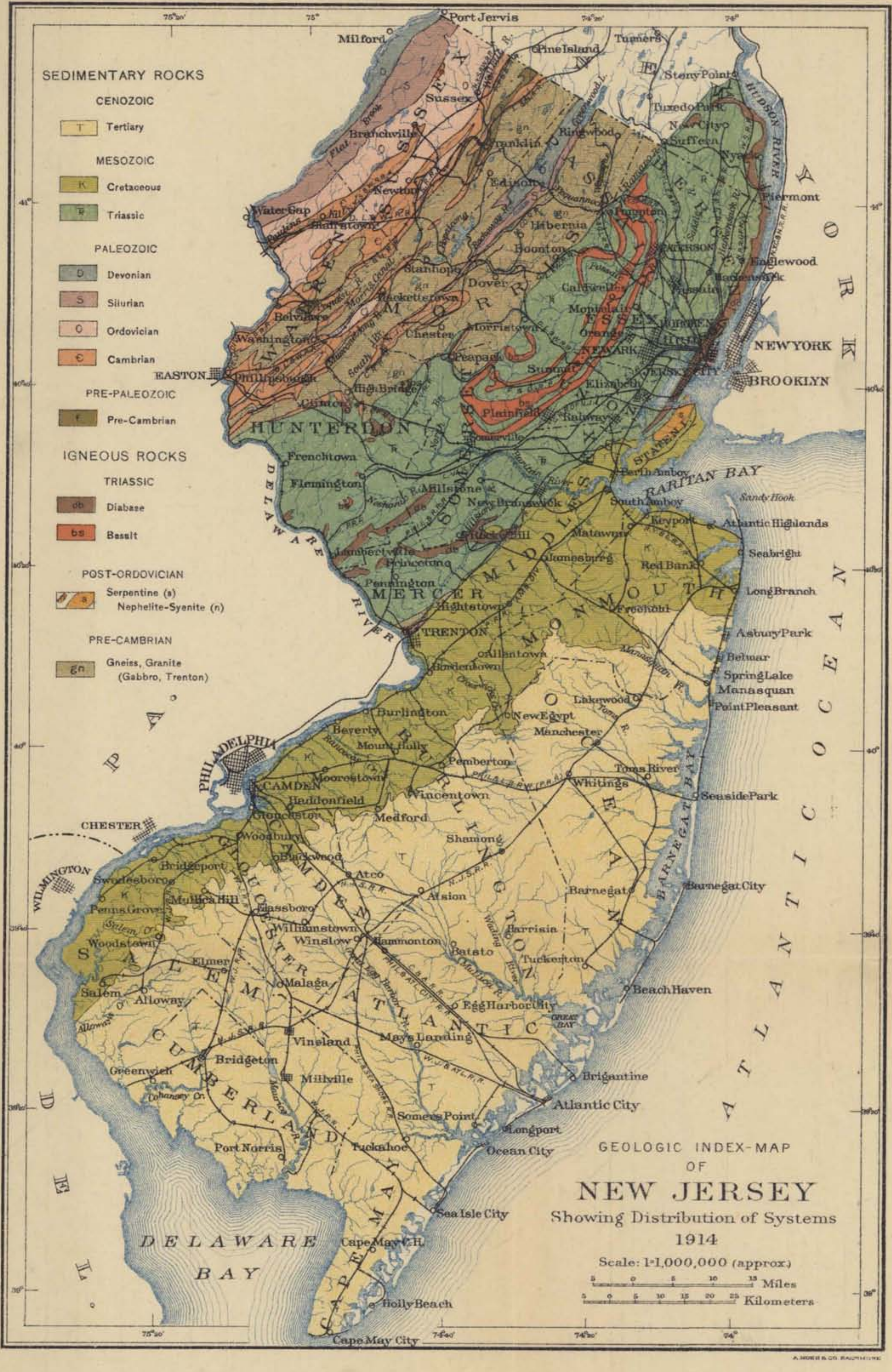
Accumulations of soft mud or clay or of loose sand and gravel, while technically rocks, because they are composed of rock materials, are not included in the ordinary meaning of that word. The greater part of such stratified rocks, however, particularly the bulk of those that were formed in the earlier periods of geologic history, have become solidified into stone. This is due in part to pressures to which they have been subjected, but in greater part to the deposition between the particles of a small amount of mineral matter from solutions that have penetrated into the porous mass, cementing them more or less firmly together.

Marine Sediments.—Most of the sedimentary formations of New Jersey contain sea shells or fragments of other marine animals, showing that they were formed in the sea, which at various times in the past has covered all parts of the State, although not all at any one time. Thus the sedimentary rocks (shales, limestones, sandstones, and conglomerates) that are so abundant in the northwestern counties, particularly in Sussex and Warren, and in parts of Hunterdon, Morris, and Passaic, were deposited chiefly in a northward extension of the Gulf of Mexico, which in several periods of the Paleozoic era expanded into a great sea that covered much of the interior of the continent. On the other hand the extensive deposits of sand, gravel, clay, and marl that constitute the whole of the State south of a line through Trenton and New Brunswick (Pl. II)—about three-fifths of its entire area—were accumulated at a much later time and, with the exception of the Raritan clays and sands, chiefly in the borders of the Atlantic Ocean, which covered all of this Coastal Plain region and its southward continuation to the Gulf of Mexico.

Continental Deposits.—In contrast with these areas of sedimentary rocks in the northwest and in the south, there is a middle belt of country extending across the State from the Delaware to the Hudson in which red shales and sandstones of Triassic age are prominent (Pls. I, II). These are older than the Coastal Plain formations, which overlap them on the south, but much more recent than the rocks of Sussex and Warren counties. They contain scattered remnants of land plants in places, and many footprints of land animals. The muds as they accumulated were often dried and cracked by the sun, and there are other characters that show that the beds in this region were deposited on low lands by streams that washed down the mud and sand from higher grounds and spread them over wide areas at times of high water. Fossil fishes that are found here and there lived in the streams and small ponds or lakes.[1]

Glacial Deposits.—Still another type of sedimentary deposit is represented in the surface materials that cover much of the country north of a curved line through Perth Amboy, Plainfield, Summit, Morristown, Dover, Hackettstown, and Belvidere (Fig. 6), These are the accumulations of sand, gravel, clay, and bowlders, mingled together in all proportions in the glacial *till* or *drift* that forms a sheet over much of the surface, and in the hummocky hills and ridges of the *terminal moraine.* All of this material was scoured from the soil and broken from the underlying bedrocks of

1 Geologists formerly supposed that local bays extended into this region from the Atlantic coast of that time; but since no distinctively marine fossil has been found, there is no evidence in support of this hypothesis. (See p. 60, 93.)


SEDIMENTARY ROCKS
CENOZOIC
T Tertiary
MESOZOIC
K Cretaceous
Triassic
PALEOZOIC
D Devonian
S Silurian
O Ordovician
€ Cambrian
PRE-PALEOZOIC
Pre-Cambrian
IGNEOUS ROCKS
TRIASSIC
db Diabase
bs Basalt
POST-ORDOVICIAN
Serpentine (s)
Nephelite-Syenite (n)
PRE-CAMBRIAN
gn Gneiss, Granite
(Gabbro, Trenton)
GEOLOGIC INDEX-MAP
OF
NEW JERSEY
Showing Distribution of Systems
1914
Scale: 1:1,000,000 (approx.)
Miles
Kilometers
Port Jervis
Milford
Turners
Pine Island
Stony Point
Tuxedo Park
New City
Suffern
Nyack
Piermont
Sussex
Branchville
Franklin
Ringwood
Newton
Water Gap
Blairstown
Hibernia
Pompton
Boonton
Paterson
Englewood
Hackensack
Stanhope
Dover
Hackettstown
Caldwell
Passaic
Montclair
Belvidere
Washington
Chester
Morristown
Orange
Hoboken
NEW YORK
BROOKLYN
Peapack
Newark
Jersey City
EASTON
Phillipsburg
High Bridge
Summit
Elizabeth
Clinton
Plainfield
Rahway
HUNTERDON
Somerville
Frenchtown
Perth Amboy
RARITAN BAY
Flemington
Millstone
New Brunswick
South Amboy
Sandy Hook
Keyport
Atlantic Highlands
Matawan
Lambertville
Princeton
Jamesburg
Seabright
Red Bank
Pennington
MERCER
Long Branch
Hightstown
Freehold
TRENTON
MONMOUTH
Asbury Park
Allentown
Belmar
Bordentown
Spring Lake
Manasquan
Point Pleasant
Lakewood
New Egypt
Burlington
Beverly
Manchester
Mount Holly
PHILADELPHIA
Pemberton
Toms River
CAMDEN
Moorestown
Whitings
Vincentown
Seaside Park
Haddonfield
Gloucester
Medford
CHESTER
Woodbury
Shamong
WILMINGTON
Bridgeport
Atco
Swedesboro
Atsion
Barnegat
Barnegat City
Mullica Hill
Penns Grove
Glassboro
Williamstown
Winslow
Hammonton
Harrisia
Woodstown
Batsto
Tuckerton
Elmer
Salem
Malaga
Beach Haven
Alloway
Egg Harbor City
GREAT BAY
Vineland
Mays Landing
Bridgeton
Greenwich
Millville
Brigantine
Atlantic City
Somers Point
Longport
Ocean City
Port Norris
Tuckahoe
Sea Isle City
DELAWARE BAY
Cape May C.H.
Holly Beach
Cape May City
ATLANTIC OCEAN
NEW YORK
DELAWARE RIVER
SUSSEX
WARREN
MORRIS
PASSAIC
BERGEN
ESSEX
HUDSON
UNION
SOMERSET
MIDDLESEX
OCEAN
BURLINGTON
CAMDEN
GLOUCESTER
SALEM
ATLANTIC
CUMBERLAND
CAPE MAY
STATEN I.
BARNEGAT BAY
PA.
DEL.

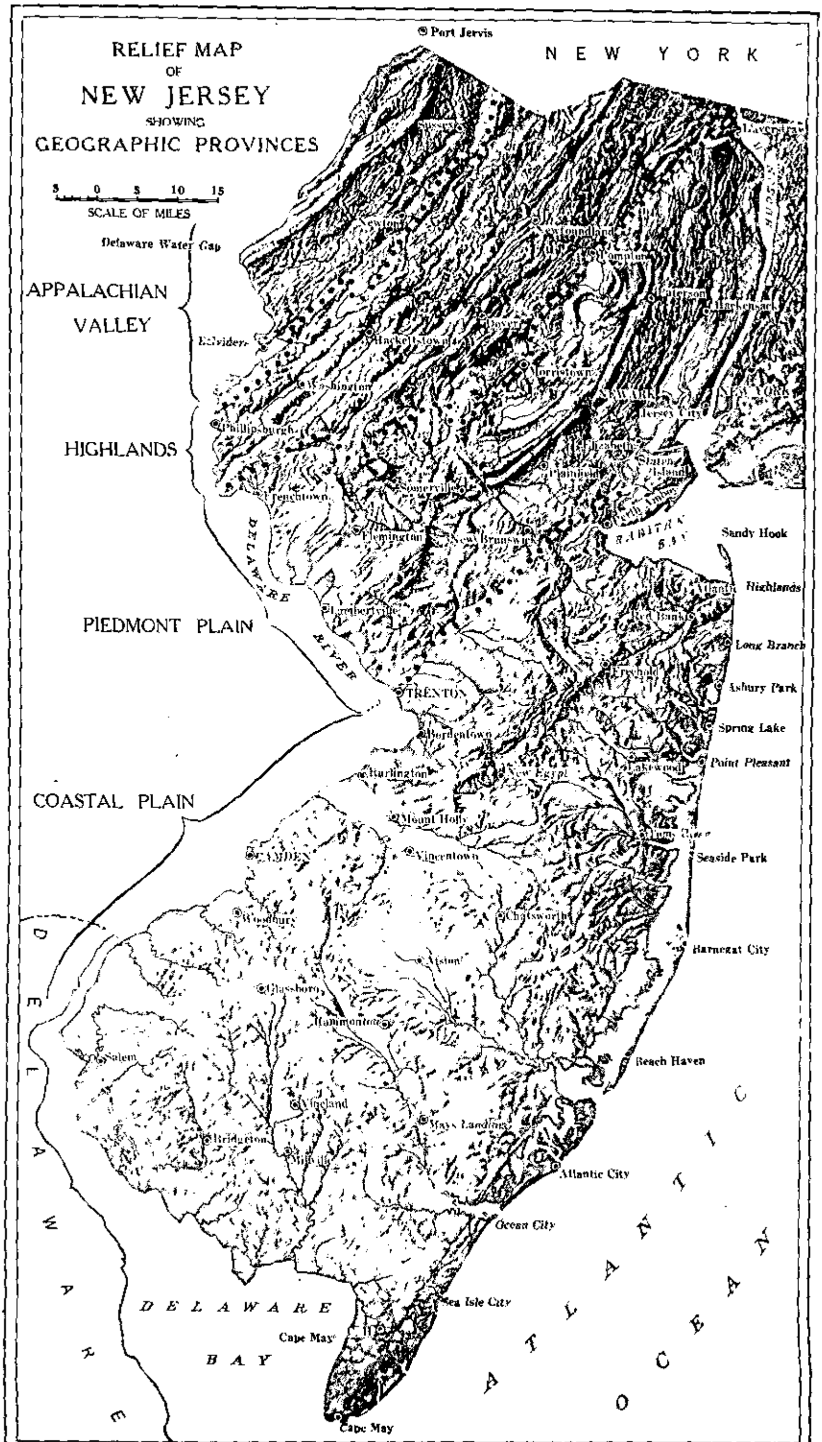


Plate II. Geographic Provinces of New Jersey this region and of the country north of it in very recent geologic time by the slow movement of a great continental glacier or ice sheet, thousands of feet thick, similar to the ice caps that now cover Greenland and the Antarctic continent. The waters that flowed constantly from the melting borders of the ice sheet and those produced by its final melting and disappearance carried with them more or less of the material transported by the glacier. The finest material, carried in suspension, was ultimately deposited as beds of clay and silt in areas of still water, as lakes, ponds, and the sea. Coarser materials were laid down, chiefly along the courses of the glacial streams, as beds of sand and gravel. The water-laid deposits form the *stratified drift* so commonly associated with the glacial till.

All of these glacial deposits are unconsolidated. They range in thickness from a few inches to an extreme known depth of 460 feet, but the average thickness is probably not more than 15 or 20 feet. In general the drift is somewhat deeper in the valleys than on the adjacent slopes and uplands.

Deep wells in the southern part of the State penetrate successive layers of sand, gravel, clay, and greensand (glauconite) marl to depths of hundreds of feet. In some localities a litttle of the sand and gravel near the surface has been consolidated by iron oxide into the condition of stone, but the total quantity of solid rock in this region is insignificant, and hence the formations represented on the map of the Coastal Plain (south of the line through Trenton and New Brunswick) are unconsolidated beds.

THE SOLID ROCKS.

North of the line through Trenton and New Brunswick the bedrock is everywhere solid. In most places it is covered with soil or with glacial drift from a few inches to many feet in thickness, but in the more hilly and mountainous regions the bare rock appears at the surface in numerous places.

As indicated by the colors and symbols on the map, many divisions or formations have been distinguished in this region. There are not so many different kinds of rocks, however, as there are divisions; for in nearly all the formations various beds occur that are composed of the same kinds of rock as similar beds in other formations. Beds of sandstone or limestone, for example, are constituents of many of the divisions that are shown on the map. The variety of rocks is far greater in the northern part of the State, however, than in the unconsolidated materials of the Coastal Plain.

The principal kinds of the solid sedimentary rocks are briefly described in the following paragraphs.

Sandstone.—As the name suggests, this rock is a more or less consolidated sand. It is formed by the natural cementing together of sand grains sufficiently to make them adhere in a solid mass. For example, a bed of sand with only a small amount of clay mingled with it, when subjected to a great weight of later deposits or other pressure, will form a fairly firm, compact rock; but the clay softens so easily that the rock soon crumbles on exposure to the weather. A common cementing material in sandstone is calcium carbonate, or carbonate of lime, which is slightly soluble in water and may be deposited between the grains where such a solution seeps through a bed of loose sand. In some sandstones the cement is silica. Most sand grains are particles of the mineral quartz, which is also silica. Hence when the silica cement is so abundant as to fill the spaces between the grains the stone is practically solid quartz and is called *quartzite.* Iron oxide or hydroxide is the cement in some sandstones; these are strongly colored red or brown and are often called *brownstone.* A sandstone in which numerous grains of feldspar are mingled with the quartz is called *feldspathic sandstone* or *arkose,* and where pebbles are mingled with the sand the rock is called *pebbly sandstone.*

Conglomerate.—A rock composed chiefly of pebbles, with more or less sand filling the spaces between, when cemented into a solid mass, is called conglomerate. Thus it is like a pebbly sandstone but contains a larger proportion of pebbles. There are all intermediate gradations from the finest grained sandstones to conglomerates containing large pebbles and, more rarely, even bowlders up to several feet in diameter.

Shale.—Ordinary clay or mud, when consolidated, becomes shale. It is generally in very thin layers and scales off badly on exposure to the weather. It may be grayish, black or red in color, according to whether the original mud was ordinary clay, more or less blackened by decomposing organic matter, or stained red with iron oxide. *Sandy* or *arenaceous shale* contains a considerable amount of fine sand mingled with the clay, and all gradations are found between this and true sandstone. *Calcareous shale* contains varying amounts of calcium carbonate (carbonate of lime), and with increasing proportions of this constituent it grades into limestone. *Argillite* is a compacted mud rock without thin lamination. It crumbles irregularly on exposure and breaks with a curved (conchoidal) fracture when struck with a hammer. The argillite of New Jersey, which is particularly abundant in the plateau region of Hunterdon County, is far more durable than shale and its greater resistance to weather accounts for the higher altitude of the country west of Flemington. Argillite has been quarried extensively at Princeton for building purposes.

Slate is shale that has been greatly changed (metamorphosed), so that it differs in two important respects from the original rock: (1) It is much harder and does not readily crumble and shell off when exposed to the weather; (2) It has acquired a structure known as *slaty cleavage,* whereby it splits readily into thin sheets. This is a secondary character and has no relation whatever to the lamination or bedding of the original shale. It is caused by the compression to which the rock has been subjected, so that the slate in different localities, or even in different parts of the same quarry where the strata have been folded, may have a cleavage which makes any angle whatever with the original bedding and lamination. The usual colors of slate are various shades of gray, black, green or red, depending chiefly on the color of the original shale from which it was formed.

Limestone.—This is commonly a compact rock composed of calcium carbonate or of the carbonates of calcium and magnesium combined in various proportions; in the latter case it is called *magnesian limestone* or *dolomite.* Limestone differs from the sedimentary rocks described in the preceding paragraphs in that it is not formed from mud, sand, etc., washed from the land.[1] It forms in the sea, chiefly from the limy mud or ooze produced by the constant grinding in the surf of shells, corals, and other limy parts of both plants and animals. This action goes on with great vigor on beaches and reefs during storms, and the fine powder produced is drifted out by the undertow into deeper water, where it settles and afterwards consolidates into limestone. Coarser fragments and

[1] Some very dense nonfossiliferous limestones have been supposed to have been formed of fine limy mud eroded from preexisting limestones on land and deposited in an adjoining sea. Some other limestones probably also represent chemical deposition from sea water.

even whole shells and other remains of organisms accumulate in reefs and shell beds and in the shallow waters near them and become cemented into fragmental shell or coral limestone. Where clay from the land becomes mingled with the limy ooze the rock becomes an *argillaceous limestone*. *Siliceous limestone* contains some variety of silica, commonly either in the form of intermingled sand grains (*sandy* or *arenaceous limestone*) or in particles from the hard parts of siliceous sponges and other organisms that live in the sea. In the latter case the silica may be dissolved and redeposited in such a way as to appear in the solid limestone in the form of irregular lumps and streaks of chert, flint, or hornstone; whence the name *cherty limestone*.

Marble is a limestone in which the carbonate has been crystallized into grains, which may be fine like the particles in lump sugar or so coarse that individual grains measure an inch or more in diameter. It is generally lighter in color than the limestone from which it is formed; thus a gray limestone may produce a snow-white marble. Many marbles, however, are streaked with gray on account of a little of the dark carbonaceous matter of the original limestone remaining either in the amorphous form or crystallizing into flakes of graphite; others are mottled or stained with a reddish or brownish color, due to the presence of iron oxide. The term marble is often used in a much broader and more indefinite sense, particularly for any limestone that will take a polish and produce pleasing effects in interior decorative work.

IGNEOUS ROCKS.

ORIGIN.

Igneous rocks have been formed by the solidification of intensely hot liquid rock material or magma. They are either *extrusive*, formed by surface flows of lava from fissures and volcanoes; or *intrusive*, that is, similar material that has spread through fissures, between strata, or in irregular forms among the rocks, and cooled there, often far below the surface. It is only after long periods of crumbling and washing away of the overlying rocks that intrusive masses become exposed at the surface.

Where the intrusive rock occupies a fissure with approximately parallel walls it is called a *dike;* where it fills a large and irregular conduit the mass is termed a *stock.* Where molten magma traverses stratified rocks it may be intruded along bedding planes; such masses are called *sills* or *sheets* if of comparatively uniform thickness, and *laccoliths* if they occupy large chambers produced by the pressure of the magma.

Extrusive igneous rocks cool so rapidly that they are very fine grained and dense looking, and in places where they fail to crystallize at all they may be even glassy. The basalt flows of the Watchung or Orange Mountains are good examples of dense extrusives. Intrusive rocks, on the other hand, having stopped deep below the surface, cool slowly and hence generally have a distinctly grained texture. Well known examples are the diabase of the Palisades, Rocky Hill, and Sourland Mountain and the granites that occur in many places in the Highlands of Morris, Passaic, and Hunterdon counties.

Volcanic eruptions of the explosive type also produce fragmental igneous rocks by violent ejection of lava high into the air in the form of minute particles and spray and larger masses. These fall upon the surrounding country, often covering it for a distance of many miles with a bed of so-called *volcanic ash* several feet thick. The larger fragments, known as *bombs,* fall nearer the source and mingle with the ash.

CLASSES.

Acid igneous rocks are chiefly light colored and the minerals that compose them contain much silica in their composition. In many there is free silica in the form of the mineral quartz. Granite and syenite are good examples among intrusive rocks; rhyolite, andesite, and most of the so-called "porphyry" of the western mining regions are acid extrusive or volcanic rocks.

Basic igneous rocks are heavier than the acid ones and much darker than most of them, consisting chiefly of minerals with a low percentage of silica and much lime, magnesia, and iron. They are often called collectively *trap rocks.* Diabase is a good example of basic intrusive rock occurring abundantly in the Triassic of New Jersey; gabbro and diorite are less abundant in the State. Basalt is an extensive basic volcanic rock of the Triassic formations.

RELATIONS TO OTHER ROCKS.

It is obvious that extrusive volcanic rocks will cover the surface of older rocks and that they in turn may become covered by later accumulations, either of sedimentary beds or of other volcanics. Intrusive rocks, however, since they do not reach the surface at the time of their formation, may stop in the midst of rocks of any preceding age whatsoever. Hence in contrast with sedimentary and volcanic rocks, intrusive rocks do not follow the *law of superposition* whereby the later (younger) formations overlie the earlier (older) ones. All kinds of massive igneous rocks differ from sedimentary rocks in the absence of regular layers or stratification. However, successive flows of lava, one on top of another, such as may be found in many volcanic regions, produce a rude resemblance to bedding. On the other hand repeated eruptions of ash and other fragmental volcanics give rise to genuine stratification, whether the materials fall upon the land or into the water.

ROCK STRUCTURES.

General Statement.—The arrangement of the rock formations in New Jersey is shown partly on the map and partly in the sections at the bottom of the map.[1] Thus the strips of color on the map show that nearly all the formations extend in a northeast-southwest direction, so that any particular formation underlies an elongated strip of country extending in many cases entirely across the State. For example, in Kittatinny Mountain the Shawangunk conglomerate and the High Falls sandstone and shale come into the State from Pennsylvania at Delaware Water Gap, extend northeastward in continuous strips across the northwestern part of the State and across the boundary into New York. Likewise the various sand, clay, and marl formations of the Cretaceous lie across Delaware River below Wilmington, Del., and form continuous belts northeastward to Raritan Bay and beyond. Most of the other formations are similarly arranged. (Compare index map, Pl. I.)

The structure of the formations beneath the surface, however, cannot be shown on the map, and for this purpose the vertical sec-

[1] The large geologic map of the State on scale of 4 miles equals 1 inch is referred to, not the outline map on Plate I.

tions are appended at the bottom of the sheet. A geologic cross-section (or structure section) shows the arrangement of the rocks downward from the surface along a vertical plane. If deep canals, extending below sea level, were cut across the State along the northwest-southeast lines marked AA, BB, CC, etc., on the map, the sides of these cuts would show the rocks arranged approximately as represented in the corresponding sections at the bottom of the map.

Jointing, or the presence of cracks in various directions, is a structure that is found almost universally in rocks of every kind. Such a crack or *joint* may be so open on the weathered outcrop as to show very prominently, but many of them in mines and deep quarries are almost or even entirely invisible. In many formations joints are arranged with remarkable regularity and give the outcrops a striking resemblance to masonry.

The Four Geographic Divisions.—The striking differences in the surface features—hills, plains, mountains—that characterize the different portions of the State are the result of long-continued exposure to weathering and erosion of rocks that vary greatly in resistance in the different regions and that also have very different structures or modes of arrangement. As explained on pages 24 to 30, New Jersey may be divided on the basis of both geology and topography into two distinct provinces or districts—the Appalachian province and the Coastal Plain. The former is further subdivided into four parts, three of which are represented in Kittatinny Valley, the Highlands, and the Piedmont Plain of New Jersey (Pl. II). In the Highlands the principal rocks are of pre-Cambrian age, the oldest in the State; Kittatinny Valley and Kittatinny Mountain are composed of Paleozoic strata; the Piedmont Plain consists of Triassic strata and associated igneous rocks; and the Coastal Plain is underlain by great thicknesses of Cretaceous, Tertiary, and Quaternary formations, chiefly unconsolidated.

The structure of each of these regions is briefly described in the following paragraphs, beginning, however, with the simplest, the Coastal Plain, and proceeding in reverse order to the successively older and more complex districts.

Structure of the Coastal Plain.—Sections CD and EE at the bottom of the map show that the unconsolidated beds of clay, sand, gravel, and marl in the southern part of the State are nearly horizontal, but have a gentle slope toward the sea. Hence the Cretaceous strata (Kmr, Kmv, etc.) for example, not only extend across the State in a northeast-southwest direction, as shown on the map, but also eastward toward the coast, beneath the later Tertiary deposits. Deep well borings show their presence all the way to the coast and also the fact that they increase in thickness in this direction. How much further they extend beneath the waters of the Atlantic is not known, but they are doubtless an important component of the continental shelf. Section EE also shows the Pensauken (Qps) and the Cape May (Qcm) lying on the eroded surface of the underlying Cretaceous formations, showing that a period of weathering and erosion intervened between the deposition of the Cretaceous and that of the overlying strata. Such a structural relation is called an *unconformity*.

For the sake of distinctness these sections have been drawn with the vertical dimensions greatly exaggerated, and this makes the slope or dip of the beds seem much steeper than it really is. Wherever the formations may be seen in pits or other excavations they appear to the eye to be horizontal, although from the records of numerous borings they are known to slope toward the coast 10 to 40 feet to the mile.

Structure of the Piedmont Plain.—In contrast with the undisturbed structure of the southern part of the State, sections AA, BB, and CC show a wide range of complication. In the Piedmont or Triassic belt, which stretches northward from a line through Trenton and New Brunswick (Pl. II), the strata are chiefly red shale and sandstone, with sheets of trap rocks. These have been tilted up at the southeast so that they now dip or slope almost uniformly toward the northwest at an angle of about 10 or 15 degrees, forming a *monocline*. There are also some slight wave-like undulations in the strata, and in addition they have been disturbed in places by *faults*; that is, the rocks have been subjected to stresses so great that they have been broken by fissures that extend downward to unknown depths, and the opposite sides of these fissures have moved upon each other, so that the faulted strata are no longer continuous at such places (Fig. 1). The continuation of any particular stratum of rock is higher or lower or otherwise displaced on the opposite side of the fault. Most of the Triassic faulting is of the *normal* type shown at A, Fig. 1, and the total displacement or movement in some of them has amounted to many thousand feet. Along Delaware River in the

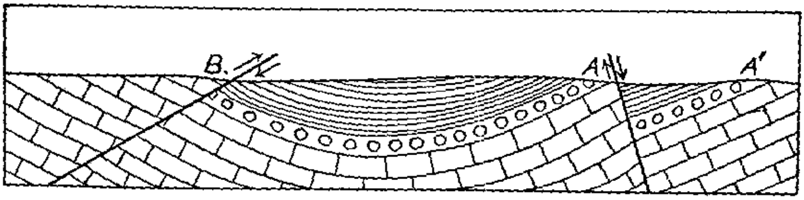


Fig. 1. Normal and thrust faulting.

vicinity of Lambertville, for example, repeated faulting and erosion have brought to the surface some of the lower Triassic strata and the accompanying intrusive sheet of diabase at four places within a distance of 12 miles. This is shown on both the map and section CC.

Structure of Kittatinny Valley.—The structure of the Paleozoic shales, sandstones, and limestones in the northwestern portion of the State, in addition to both normal and *thrust* or *reversed* faulting (Fig. 1, A, B, above), is further complicated by folding; that is, the strata have been thrown into up-and-down, wave-like undulations (Fig. 2), with the folds or wrinkles elongated in a northeast-southwest direction (see "Structure of the Paleozoic Formations," p. 57). These folds and faults are a part of the structure of the great Appalachian Mountain system (Fig. 3, p. 20), and the long-continued crumbling and wearing of these struc-

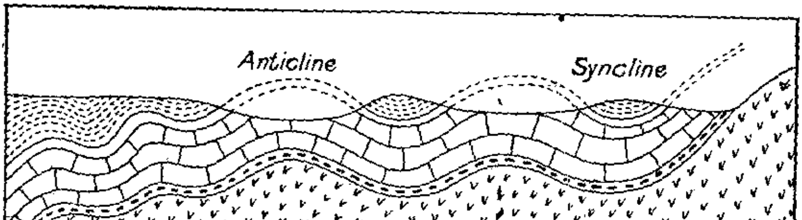


Fig. 2. Folded strata.

tures at the surface has caused the different formations to appear as elongated northeast-southwest strips across the country. The hardest layers naturally have worn least rapidly, so that they are

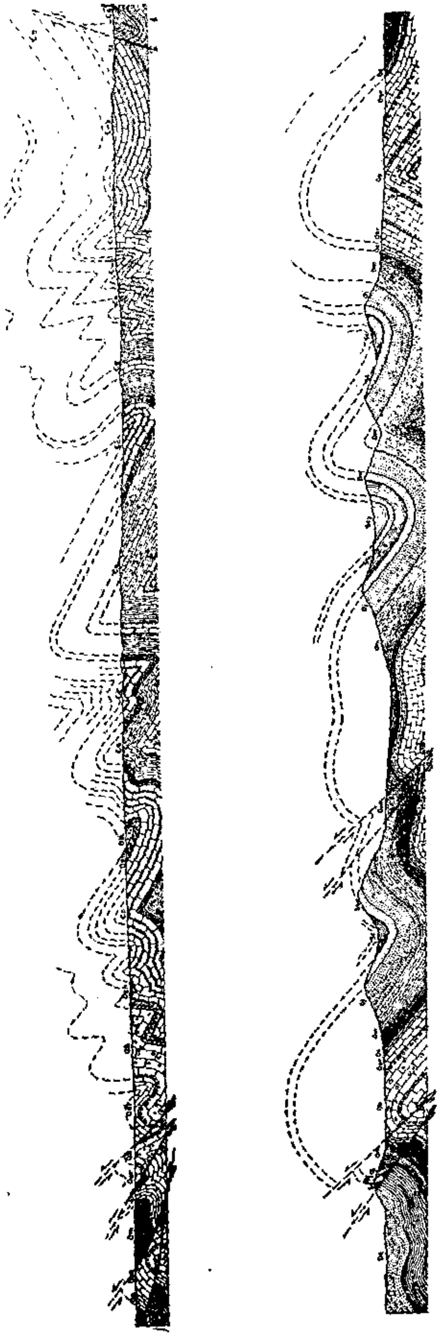


Fig. 3. Appalachian Folds and Faults. (From U. S. G. S. Geol. Folio No. 170).

now the highest ridges, while the soft shales and somewhat soluble limestones have been worn down more rapidly and form the bedrock of the valleys and the lower lands generally.

Structure of the Highlands.—Between the slightly tilted and faulted Triassic strata of the Piedmont and the folded and faulted Paleozoic strata of the Appalachian belt lies the region known as the Highlands. There are long strips of Paleozoic sediments here too—remnants of beds that once extended widely over this region, but now are found chiefly in the interhighland valleys. The principal formations of the Highland mountains and plateaus, however, are gneisses, most of which have the composition and appearance of granite, but differ from granite in having a parallel structure known as *foliation;* that is, the minerals composing the rocks are partly arranged in parallel sheets having a rough resemblance to bedding or stratification in the sedimentary rocks. The planes of this foliation are generally very steeply inclined, and over most of the region they dip steeply toward the southeast, as shown in the sections. The structure is crumpled and folded in places, and is further complicated by faults and by many intrusions of igneous rocks.

THE GEOLOGIC TIME SCALE.

From the study of the stratified rocks and their contained fossils in many countries geologists have been able to construct a chronological table of the principal events in the three last great eras in the earth's history—the Paleozoic, the Mesozoic, and the Cenozoic. Much is also known of pre-Paleozoic geology and for some regions the outlines of this ancient geologic history have been deciphered for vast periods of time. This is particularly true of the Lake Superior region and, to a less extent, of several other regions of the United States and Canada. Owing to the scarcity and imperfect preservation of the fossils, however, or even their entire absence from these ancient rocks in many regions, no classification is yet possible of the pre-Paleozoic rocks and the vast eras of time which they represent that is of general application.

The three later and better known *eras* have been divided into *periods* and these, in turn, into *epochs* and *stages.* Hence these terms are used in referring to the divisions of time in geologic history and to express the age of the rocks formed in these times. All the stratified rocks belonging to any period are called a *system*, systems are divided into *series*, and these into *groups* and *formations*. This is the present usage of the United States Geological Survey, but there is considerable diversity of opinion among geologists as to the order in which some of these terms should be arranged, both in the time scale and the rock scale.

The names of the eras and periods in general use in this country are given in the following table in the natural order of the formations; that is, those terms that refer to the latest divisions of time and the youngest of the rock formations are placed at the top and the earlier ones below, in the order of antecedence, to the oldest at the bottom:

PERIODS AND SYSTEMS.

Cenozoic Era	Quaternary
	Tertiary
Mesozoic Era	Upper Cretaceous (Cretaceous)
	Lower Cretaceous (Comanchean)
	Jurassic
	Triassic
Paleozoic Era	Permian
	Upper Carboniferous (Pennsylvanian)
	Lower Carboniferous (Mississippian)
	Devonian
	Silurian
	Ordovician
	Cambrian
Proterozoic or Algonkian Era	
Archean Era	

THE GEOLOGIC MAP OF NEW JERSEY.

1910-1912.

SCALE: 1:250,000, OR APPROXIMATELY 4 MILES TO 1 INCH.

The geologic map of New Jersey is intended to show by means of colors and symbols the kinds of rock and the age of the various formations that underlie all parts of the State and also certain prominent superficial deposits. The colors and symbols are explained and the formations which they represent are named and briefly described in the column headed "LEGEND" at the left margin of the map. The relative age of these formations is also shown by the order of arrangement in the columns, the more recent being placed at the top and those of successively earlier age arranged in order toward the bottom.

There are two exceptions, however, to this general rule: (1) The most recent formations of all, including the glacial deposits in the northern part of the State and the superficial sands and gravels that cover large areas over the southern part, are shown in a double column under the name "Quaternary" in the lower left-hand corner of the map. (2) Igneous rocks—that is, those rocks that have been formed by the cooling and solidification of hot liquid magma—are grouped by themselves below the column of sedimentary or stratified rocks, the different members of the group being arranged in the order of relative age.

GEOGRAPHY OF NEW JERSEY.

LOCATION AND AREA.

New Jersey is a portion of the Atlantic slope of North America (Fig. 4, Pl. II) and lies between the parallels of 38° 55′ 40″ and 41° 21′ 22.6″ north latitude and the meridians of 73° 53′ 39″ and 75° 35′ 00″ west longitude. The State is limited by natural boundaries—rivers, bays, and the ocean—on all sides except the northeast, where the New York-New Jersey line runs across the country from the Hudson to the Delaware, a distance of 48 miles.

The extreme length of the State from the most northerly point near Port Jervis to Cape May, is 166 miles. From Trenton to the head of Raritan Bay, across the narrowest part of the State, the distance is only 32 miles. The portion of the State north of this line is nearly square and is about 55 miles across in a northwest-southeast direction and 65 miles from northeast to southwest. The southern portion of the State, which is 36 miles across from Bordentown to the shore, gradually broadens southward to a maximum width of 57 miles a little south of the line from Camden to Atlantic City. The length of this southern part, from Raritan Bay to Delaware Bay, is 100 miles.

The land area of the State is 7,514 square miles, and 710 square miles of water—bays, harbors, lakes, etc.—lie within its borders, making a total area of 8,224 square miles.

GEOGRAPHIC PROVINCES.

The Atlantic slope of the United States is included in two geographic and geologic provinces: (1) the Coastal Plain, which borders the Atlantic from the Gulf of Mexico to the Hudson and which is represented northward to Massachusetts Bay by several islands and the peninsula of Cape Cod; (2) the Appalachian province, which extends from the Coastal Plain westward to the Mississippi lowland and from central Alabama northeastward into

Canada. The boundary between the two provinces runs obliquely across New Jersey in a nearly straight line through Trenton and New Brunswick, (Pl. II, Fig. 4).

Each province is a fairly distinct geologic and physiographic

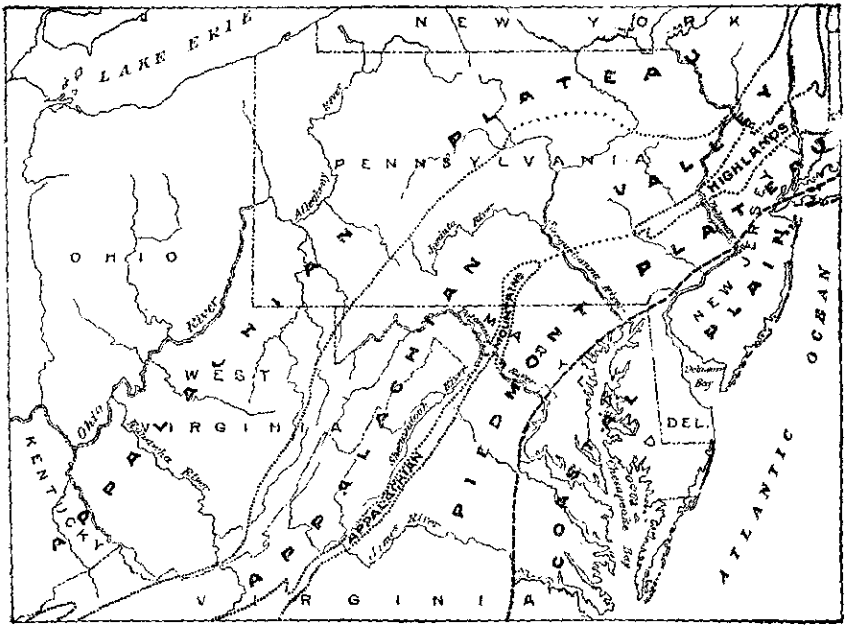


Fig. 4. Map of the northern part of the Appalachian province, showing the physiographic divisions and its relation to the Coastal Plain.

unit whose general geologic history, as recorded in its rocks, its structures, and its physiography, is nearly the same throughout all its parts. The two provinces differ from each other, however, in their rocks and geologic structure and hence have had dissimilar histories.

APPALACHIAN PROVINCE.

The four major divisions of the Appalachian province, named in order from west to east, are (1) the Appalachian Plateau, (2) the Appalachian Valley, (3) the Appalachian Mountains, and (4) the Piedmont Plateau. All but the first of these enter New Jersey.

The Appalachian Valley.—This is a broad belt of valleys and subordinate ridges lying between the Appalachian Mountains on the east and the Appalachian Plateau on the west and extending throughout the length of the province. Its surface is in general much lower than that of the adjacent divisions, though in parts of its length the crests of some of the subordinate ridges have about the same altitude as the Appalachian Plateau to the west. These ridges and the intervening valleys are narrow, and like the great valley itself, have a pronounced northeast-southwest trend.

From Virginia southwestward the minor ridges become progressively lower and the belt as a whole is occupied by a broad valley—the Valley of East Tennessee and the Coosa Valley of Georgia and Alabama. From Virginia to New York State the western side of the valley belt is broken by high, sharp ridges and only the eastern side is occupied by the great valley, to which various local names are given. Northeast of the Hudson the divisions of the province lose much of their definite character, but the Appalachian Valley is continued in the Champlain Valley of western Vermont.

In New Jersey (Pl. II) the Appalachian Valley contains a large part of Warren and Sussex counties and has an area of 635 square miles—a little more than one-twelfth of the State. Its eastern part is occupied by the broad Kittatinny Valley and the western part by the narrow valley of the upper Delaware, the two being separated by the bold, even-crested ridge of Kittatinny Mountain, which, although one of the ridges of the Appalachian Valley belt, reaches a greater altitude than the Highlands east of the valley.

The portion of Kittatinny Valley within the State is 40 miles long and about 12 miles wide. Its plains and bottom lands lie between 400 and 600 feet above sea level and its hills and ridges rise to an elevation of 800 and 1,000 feet. The valley lands in the narrow upper Delaware Valley are about 500 feet above sea, while the river itself drops from 409 feet at the New York State line to 287 feet at Delaware Water Gap. The even crest of Kittatinny Mountain, the bold ridge that separates the two valleys, is 1,600 to 1,800 feet high and attains a maximum elevation of 1,804 feet in High Point, the highest in the State. The mountain varies in width from 1 to 5 miles (Figs. 9 and 10).

The Appalachian Mountains.—The Appalachian Valley is bounded on the east by the Appalachian Mountains, which in the middle Atlantic States form a rather narrow belt of irregular, more or less interrupted ridges, nowhere of great altitude, but as a rule rising rather abruptly from the lower country on either side. South of the Potomac the belt is broader, in western North Carolina reaching a width of 60 miles and culminating in the highest summits of eastern North America. In the southern Appalachians the rather sinuous divide between the streams flowing to the Ohio and those flowing directly to the Atlantic is called the Blue Ridge. For much of its length the Blue Ridge defines the eastern limit of the Appalachian Mountain belt and forms a bold scarp facing southeast, toward the Piedmont Plateau.

In New Jersey (Pl. II) the Appalachian Mountains form a belt from 10 to 25 miles wide, known as the *Highlands*, which crosses the northern part of the State southeast of Kittatinny Valley. The Highlands have an area of 900 square miles (about one-eighth of the State) and an average elevation of about 1,000 feet above sea level. They are chiefly in northern Hunterdon, Morris, and Passaic counties and the southeastern borders of Warren and Sussex. Their maximum elevation is 1,496 feet midway between Canistear and Vernon in Sussex County. Bearfort Mountain reaches 1,491 feet and there are several points on Wawayanda and Hamburg mountains in Sussex over 1,400 feet above sea level. Sparta Mountain, 2 miles southwest of Stockholm, is also 1,406 feet, but none to the south and east of these reaches 1,400 feet. The Highlands gradually descend to Ramapo Mountain on the southeastern border, with a maximum elevation of 1,171 feet, and to Musconetcong Mountain at the southwest, with a maximum altitude of 987 feet and its southwest end near the Delaware a little below 800 feet. The valleys range from 500 to 800 feet above sea level. The lower Pohatcong, Musconetcong and Wanaque valleys are below 500 feet.

In general the Highlands consist of several broad, rounded or flat-topped ridges, rising 400 to 600 feet above the lowlands on either side and separated from each other by deep and generally narrow valleys. The larger topographic features of the Highlands, like those of the Appalachian Valley, show a marked northeast-southwest trend, although the ridges are much broader and more massive and many of the minor features are irregular. Some of the prominent valleys, as the Rockaway, the Pequannock, and the Delaware, are transverse to the general trend. Near the Delaware the Highlands are lower and are broken by broad interhighland valleys. They continue southwestward into Pennsylvania for a few miles as low, irregular ridges; northeastward in New York they extend to and across the Hudson, beyond which they lose their distinctive character.

The Piedmont Plateau.—The easternmost division of the Appalachian province, lying east and southeast of the mountain belt, is the Piedmont Plateau. In New Jersey and southward it is bounded on the east by the Coastal Plain. Its surface is that of a dissected plateau or plain which slopes gently eastward or southeastward from the base of the Appalachian Mountains and is broken here and there by knobs or ridges that rise several hundred feet above its surface. In the southern Appalachian region, where it lies well inland, the Piedmont Plateau stands at a considerable altitude and constitutes a true plateau, but toward the northeast it becomes a low plain, more or less hilly, and in the vicinity of Newark Bay it falls to sea level.

In New Jersey (Pl. II) this Piedmont Plain, as it may be more appropriately called, occupies the southeastern portions of Hunterdon, Morris, and Passaic counties, large areas of Mercer, Somerset, and Middlesex, and the whole of Union, Essex, Hudson, and Bergen counties. It is chiefly a lowland of gently rounded hills separated by wide valleys, with some ridges and isolated hills rising conspicuously above the general surface, which slopes gently from about 400 feet above sea level at its northwestern margin to about 100 feet along its southeastern border near the Delaware and to sea level about Newark Bay.

The Piedmont Plain constitutes about one-fifth of the State, an area equal to both the other divisions of the Appalachian province. The low hilly or rolling plain that constitutes the greater part of its surface is divided into several somewhat distinct portions by higher ridges, several of which are locally called mountains. The general level of both the ridges and the plain declines toward the southeast. North of Paterson and Hackensack much of the country is about 300 feet above sea level, while the flats of the upper Passaic Valley and the broad rolling plains of the Raritan Valley are mostly below 200 feet. Along the lower course of the Hackensack the plain dips below sea level and south of Englewood large areas are covered by tidal marsh.

The Watchung Mountains attain their maximum elevation in High Mountain, a peak north of Paterson, which is 879 feet above sea level. Camp Gaw Hill is 752 feet. Between Paterson and Summit First Mountain ranges from 550 to 691 feet; further south its crest is between 450 and 539 feet. The corresponding portions of Second Mountain have elevations of 500 to 665 feet and 530 to 635 feet, respectively. The Palisades decline from 547 feet near Closter to 40 feet above tide at Bayonne. The crest of Cushetunk Mountain is mostly above 600 feet and rises to a maximum of 839 feet. Sourland Mountain has a maximum elevation of 563 feet near its northeast end and most of its crest is above 450 feet. The Hunterdon Plateau, which occupies the west side of Hunterdon County, has a maximum elevation of 913 feet; at Cherryville it is 706 feet and it declines southwestward to about 500 feet near the Delaware.

THE COASTAL PLAIN.

The Piedmont is the most easterly division of the Appalachian province. Between it and the coast, from New York Bay southward, lies the Coastal Plain, which forms the eastern margin of the continent and in both geologic and geographic features is essentially unlike the Piedmont. Its surface has a gentle slope to the southeast, along some parts of its inland border as much as 10 or 15 feet to the mile, but generally over the greater part of its surface the slope does not exceed 5 or 6 feet to the mile.

The surface of the Coastal Plain extends eastward with the same gentle slope beneath the water of the Atlantic for about 100 miles, where, at a depth of approximately 100 fathoms, it is bounded by a steep escarpment, along which the ocean bottom slopes abruptly to abysmal depths. This submerged part of the Coastal Plain is known as the *continental shelf*. In the South the subaerial portion expands to 150 miles, while the submarine portion dwindles in width and along the eastern shore of Florida almost disappears. Northward the submarine portion increases in width, while the part above sea diminishes and beyond New Jersey becomes only a fringe of islands and the peninsula of Cape Cod. Further northward the subaerial portion disappears altogether through the submergence of the entire Coastal Plain.

The moderate elevation of the Coastal Plain, which in few places reaches 400 feet and is for the most part less than half that amount, has prevented the streams from cutting valleys of any considerable depth. Throughout the greater portion of the plain, therefore, the relief is inconsiderable, the streams flowing in open valleys that lie at only slightly lower levels than the broad, flat divides.

All of New Jersey (Pl. II) southeast of a line through Trenton and New Brunswick, about three-fifths of the entire area, belongs to the Coastal Plain. It includes the southern portions of Mercer and Middlesex and the whole of the counties further south. Its surface is in general a dissected plain that rises gradually from sea level at the coast to about 300 feet in central New Jersey. At its inner margin, where it borders upon the Piedmont Plain to the northwest, it includes a broad shallow depression lying less than 100 feet above sea level and extending from Raritan Bay to the Delaware at Trenton. The southwestward continuation of this low belt forms the lower Delaware Valley, the axis of which lies below tide level. Hence, the Coastal Plain of New Jersey falls to sea level on the east, west, and south and rises barely to 80 feet along the axis of the depression at its northern border.

Over half of the Coastal Plain within the State lies below 100 feet and the main divide between the east and west slopes is less than 100 feet above sea level between the headwaters of Rancocas Creek and Mullica River. Northward the divide rises in Monmouth County to a maximum at Crawfords Hill, one of the Mount Pleasant hills, which has an elevation of 391 feet. Hills between Clarksburgh and Perrinesville reach an elevation of 354 feet and the Navesink Highlands 259 feet. In these three localities there is considerable ground above 200 feet.

Conspicuous features of the Coastal Plain are the marshes bordering the stream courses and the numerous bays and estuaries due to the submergence of valleys carved at a time when the plain stood at a higher level than the present. Delaware Bay, the old lower course of the Delaware, and Raritan Bay, the drowned portion of the Raritan Valley, are conspicuous examples and many smaller ones lie between. The continental shelf bears the wave-built sand bars that fringe the coast and the sand flats and marshes that in places unite the bars to the Coastal Plain.

DRAINAGE.

Hudson and Delaware rivers flow in a general southerly direction obliquely across the eastern part of the Appalachian province, and the part of the province in New Jersey is drained by tributaries of these rivers or of Newark and Raritan bays. The Kittatinny Valley is drained in part northeastward into the Hudson, in part southwestward into the Delaware. The western part of the Highlands is drained by tributaries of the Delaware, the southern and southeastern Highlands by tributaries of the Raritan, and the northern and northeastern Highlands chiefly by tributaries of the Passaic. The Raritan and Passaic flow into Raritan and Newark bays, respectively.

Three-fourths of the broad low belt that stretches across the State from Trenton to Raritan Bay, along the northern border of the Coastal Plain, is drained by tributaries of the Raritan, while short tributaries of the Delaware drain a smaller area about Trenton. This divide is continued southward approximately parallel to the Delaware and to the coast and separates the plain into two unequal slopes, the shorter and steeper one forming the east side of Delaware Valley and draining by numerous short tributaries into that river and the longer and gentler slope draining directly into the Atlantic, except the tributaries of the Raritan at the north and Maurice River at the south, the latter flowing into the lower Delaware Bay.

Throughout most of its length the divide between the two slopes of the Coastal Plain lies within 15 miles of Delaware River, but the Rancocas has pushed its headwaters back to double this disance so that the divide south of Whitings lies within 15 miles of Barnegat Bay. The principal rivers draining the long southeastern slope are the Maurice, the Great Egg Harbor, and the Mullica, while the smaller Toms, Manasquan, and Navesink lie further north where the Coastal Plain is narrower and the eastern slope shorter.

References.—Descriptions of the geographic features of the State and their relations to the geology may be found in the following publications of the Geological Survey:

The series of Geologic Folios, begun in 1908.

"Physical Geography of New Jersey," by Rollin D. Salisbury. Final Report of the State Geologist, vol. iv, 1898, 170 pp.

"Topography, Magnetism, Climate" and "Physical Description," by C. Clarkson Vermeule. Final Report of the State Geologist, vol. i, 1888, pp. 39-199.

GEOLOGY OF NEW JERSEY.

GEOLOGIC SUMMARY.

APPALACHIAN PROVINCE.

As indicated in the geographic descriptions of the preceding pages, the several divisions of the Appalachian province—the Appalachian Plateau, the Appalachian Valley, the Appalachian Mountains, and the Piedmont Plateau—can be distinguished geologically in a broad way, but throughout the province as a whole they exhibit no sharp geologic differences. In the central and southern Appalachians the Piedmont Plateau and the Appalachian Mountain belt are not separated by a sharp geologic boundary, and in many places geologic formations also extend continuously from the mountain belt into the Appalachian Valley.

In the general region including northern New Jersey, southeastern New York, and eastern Pennsylvania, the conditions are somewhat different. Each of the physiographic subdivisions is strikingly different from the others in geologic character, although even here absolute lines cannot be drawn, as some formations are common in a small degree to all three.

The Highlands.—The Highlands of southeastern New York, northern New Jersey, and eastern Pennsylvania (Fig. 4, and Pl. II) are formed chiefly of highly metamorphosed rocks of pre-Cambrian age, which occupy a roughly hook-shaped area extending northeastward from the Reading Hills in Pennsylvania to southern Dutchess County in New York, thence recurving southward to Manhattan Island.

The rocks consist of gneisses and schists, possibly in part of sedimentary origin, with some marble or crystalline limestone, and of intrusive igneous rocks, for the most part gneissoid. They have been greatly deformed, probably more than once, and are now complexly folded and faulted. Infolded with the pre-Cambrian crystalline rocks and for the most part occupying the narrow valleys that separate the ridges of the Highlands are strips of more or less metamorphosed Paleozoic strata (Pl. I). The folds have the general northeast-southwest trend characteristic of the Appalachians and are roughly parallel to the trend of the Highlands as a whole. The foliation planes of the gneiss dip southeastward generally but not universally.

Kittatinny Valley.—Throughout its length the Appalachian Valley is underlain by early Paleozoic strata, chiefly of Cambrian and Ordovician age. The minor valleys within the great valley are floored with less resistant rocks, such as limestone and soft shale, and the minor ridges that rise between them are formed of sandstone, hard shale, and less soluble limestone.

In the northern New Jersey region the Kittatinny Valley is occupied chiefly by limestone and shale of Cambrian and Ordovician age, Kittatinny Mountain is formed by resistant sandstone and conglomerate of Silurian age, and the adjacent portion of the Delaware Valley is occupied by shale and limestone of early Devonian age (Pl. I). These strata, which are of the same age as those infolded with the pre-Cambrian rocks of the Highlands, have been considerably folded and faulted but little or not at all metamorphosed. The folds and faults here, as in the Highlands area, have a general northeast-southwest trend. The oldest rocks are exposed along the eastern side of the valley at the western base of the Highlands. Northwesterly dips predominate.

Piedmont Plain.—The rocks of different parts of the Piedmont differ widely in age. Southwest of the Delaware the region is occupied largely by metamorphic igneous and sedimentary rocks similar in most respects to many of those of the Appalachian Mountains (Highlands), but it includes several large areas of Triassic rocks, a few smaller ones of highly metamorphosed Paleozoic strata, and a great abundance of intrusive granite. Similarly east of the Hudson the region that corresponds geographically and geologically to the Piedmont and that may be considered its northeastern extension is occupied chiefly by igneous and metamorphic rocks of pre-Cambrian and Paleozoic age, with included areas of Triassic rocks and others of highly metamorphosed sediments regarded by some geologists as Paleozoic and by others as pre-Cambrian.

In northern New Jersey, however, the Piedmont Plain is underlain almost wholly by Triassic strata and associated volcanic and intrusive igneous rocks. Near Trenton a small area of pre-Cambrian schists forms the northeastern extremity of the great pre-Cambrian area of the Piedmont Plateau of the southern Atlantic States, and several small areas of more or less metamorphosed Paleozoic sediments lie along the inner margin of the Piedmont at the southeastern base of the Highlands.

The Triassic area of New Jersey is part of a belt occupied by Triassic strata extending from the Hudson across New Jersey, Pennsylvania, and Maryland into Virginia. The rocks consist of shale, sandstone, and conglomerate, with intercalated volcanic flows and intrusive sills. The strata and the included igneous rocks have been tilted, as a rule northwestward, and here and there warped into gentle folds, with more or less faulting. Although there are numerous local variations the general trend of the folds and the strike of the tilted strata is northeast and southwest, as in the other districts, and a northwesterly dip prevails.

The Paleozoic strata occupying several areas along the base of the Highlands have been complexly folded and faulted and dip in various directions, although the prevailing dip is westward or southwestward.

THE COASTAL PLAIN.

The Coastal Plain is formed chiefly of beds of clay, sand, gravel, and other lightly cohering rocks of Cretaceous, Tertiary, and Quaternary age. These strata occupy a belt beginning at Raritan Bay and extending southwestward along the coast into Mexico. Northeast of Raritan Bay similar strata underlie the southern parts of Staten Island, Long Island, and probably the other islands off the southern coast of New England, as well as the Cape Cod peninsula.

In New Jersey the beds lie nearly level, sloping gently southeastward to the coast. They are not appreciably deformed.

SURFICIAL DEPOSITS.

Throughout northern New Jersey the valleys of the larger streams are floored with alluvium, and deposits of sand and gravel form terraces along the slopes bordering some of the valleys. Much of the surface, especially that north of an irregular belt of hilly glacial moraine extending from Perth Amboy through Morristown, Dover, Hackettstown, and Belvidere (Fig. 6), is mantled by a deposit of glacial drift, in some places sufficiently thick to obscure entirely the relief of the bedrock surface. Scattered bowlders of glacial origin are found in many places south of the line of the moraine.

The Quaternary formations of the Coastal Plain and the recent beaches, dunes, swamps, and marshes are also chiefly thin veneers of sand, gravel, and mud overlying the great thicknesses of Cretaceous and Tertiary strata which form the main body of the area.

CLASSIFICATION OF GEOLOGIC FORMATIONS.

The geologic formations of New Jersey have been classified as shown in the following table, in which the most recent formations are placed at the top and those of successively earlier periods arranged in the order of superposition, with the oldest at the bottom. The figures show the thickness in feet. The groups of letters in parentheses are the symbols by which the corresponding formations are designated on the map.

SEDIMENTARY ROCKS.

CENOZOIC.

QUATERNARY (Q)

Recent: Existing swamps and marshes and the recent portions of beach sands (Qbs) are the only recent formations shown on the map.

Pleistocene

Glacial

Wisconsin Drift 0—460 ft.
Till (not shown on map.)
Terminal Moraine (Qtm)
Recessional Moraine (Qrm)
Stratified Drift (Qsd)
(Unconformity)
Jerseyan (Early) Drift (Qed)
(Unconformity)

Non-Glacial

Beach Sand and Gravel (Qbs)
(Unconformity)
Cape May Formation (Qcm) 0—20 ft.
(Unconformity)
River Drift (Qrd)
(Unconformity)
Pensauken Formation (Qps) 0—20 ft.
(Unconformity)
Bridgeton Formation (Qbt) 0—30 ft.
(Unconformity)

TERTIARY (T)

Beacon Hill Gravel (Tbh)	
(Unconformity?)	
Cohansey Sand (Tch)	100—250 ft.
(Unconformity)	
Kirkwood Sand (Tkw)	100 ft.
(Unconformity)	
Shark River Marl (Tsr)	11 ft.
(Unconformity)	

MESOZOIC.

CRETACEOUS (K)

Manasquan Marl (Kmq)		25 ft.
Vincentown Sand (Kvt)		25—70 ft.
Hornerstown Marl (Kht)		30 ft.
Tinton Loam	(Krb)	10—20 ft.
Red Bank Sand	(Krb)	0—100 ft.
Navesink Marl (Kns)		25—40 ft.
Mount Laurel Sand	(Kmw)	5—60 ft.
Wenonah Sand	(Kmw)	35—20 ft.
Marshalltown Formation (Kmt)		30—35 ft.
Englishtown Sand (Ket)		20—100 ft.
Woodbury Clay (Kwb)		50 ft.
Merchantville Clay (Kmv)		60 ft.

Magothy Formation (Kmr) 25—175 ft.
(Unconformity)
Raritan Formation (Kmr) 150—250 ft.
(Great Unconformity)

JURASSIC (?)

Possibly present in the uppermost beds of the Newark Group.

TRIASSIC (Newark Group) (Tr)

Brunswick Formation (Trb.) 6,000—8,000 ft.
Lockatong Formation (Trl) 3,500 ft.
Stockton Formation (Trs) 2,300—3,100 ft.
(Great Unconformity)

PALEOZOIC.

PERMIAN, CARBONIFEROUS — Not represented in New Jersey.

DEVONIAN (D)

Upper Delaware Valley

Marcellus Shale (Traces) (Dmo)
Onondaga Limestone (? ft.) (Dmo)
Esopus Grit (Des) (375 ft.)
Oriskanv Formation (170 ft.) (Dob)
Port Ewen Shale (80 ft.) (Dob)
Becraft Limestone (20 ft.) (Dob)
New Scotland Formation (160 ft.) (Dnc)
Stormville Sandstone (0—10 ft.) (Dnc)
Coeymans Limestone (40 ft.) (Dnc)

Green Pond Mountain Region

Skunnemunk Conglomerate (Dsk) (1,500 ft.)
Bellvale Sandstone (1,800 ft.) (Dbp)
Cornwall Shale (1,000 ft.) (Dbp)
Kanouse Sandstone (Dkn) (215 ft.)

SILURIAN (S)

Manlius Limestone (35 ft.)	(Sbd)	*Decker Limestone* (? ft.)	(Sd)
Rondout Limestone (39 ft.)		(Unconformity?)	
Decker Limestone (52 ft.)		*Longwood Shale* (200 ft.+)	
Bossardville Limestone (12—100 ft.)			
Poxino Island Shale (? ft.)			
High Falls Formation (Shf) (2,300 ft.)			
Shawangunk Conglomerate (Ssg) (1,500 ft.) (Unconformity)		*Green Pond Conglomerate* (Sgp) (1,200—1,500 ft.)	

ORDOVICIAN (O)

Martinsburg Shale (Omb) 3,000 ft.
Jacksonburg Limestone (Ojb) (125—300 ft.)
(Unconformity)

Hudson Schist (Ohs) (? ft.)
(In Hudson County)

CAMBRO-ORDOVICIAN (CO)

Kittatinny Limestone (COk) 2,500-3,000 ft.
(Unconformity?)

CAMBRIAN (C)

Hardyston Quartzite (Ch) 5—200 ft.
(Great Unconformity)

PRE-PALEOZOIC.

Wissahickon Mica Gneiss (wgn) ? ft.
(In Mercer County).
Franklin Limestone (fl) ? ft.

IGNEOUS ROCKS.

TRIASSIC (TR)

Basalt Flows and Dikes (Trbs)
Diabase (Intrusive) (Trdb)

POST-ORDOVICIAN

Serpentine (sp) (In Hudson County)
Nephelite Syenite (ns) } (In Sussex County)
Basic Volcanic Breccia (bb) }

PRE-CAMBRIAN

Granite (gr)
Gabbro (gb) (In Mercer County).
Losee Gneiss (lgn)
Byram Gneiss (bgn)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN.

PRE-CAMBRIAN

Pochuck Gneiss (pgn)

DESCRIPTION OF FORMATIONS.

The rocks of the various formations in the preceding table are here described in order, beginning with the oldest, the Franklin Limestone. As in the table, the letters in parentheses are the symbols by which the corresponding formations are designated on the map. An outline of the geologic history of the region and descriptions of the ores, clays, building stones, marls and other economic products are considered separately in succeeding chapters.

PRE-CAMBRIAN ROCKS.

The pre-Cambrian[1] rocks of New Jersey comprise certain small areas of white crystalline limestone (marble) with closely associated quartzites and conglomerates (chiefly in Sussex County) and a great complex of granitoid gneisses and pegmatites, which contain most of the iron ore and which, because of their resistance to erosion, now constitute the Highlands of the State.

[1]The conclusions of Spencer and Bayley as to the origin and relative age of the pre-Cambrian rocks are accepted, and free use of their published reports has been made in preparing the paragraphs relating to these formations.

Franklin Limestone (fl).—The Franklin or "white" limestone in its more common facies is a white, highly crystalline, coarsely granular limestone or marble, ranging in composition from a nearly pure calcium carbonate (calcite) to the double carbonate of lime and magnesia (dolomite). Some of it is rather siliceous and in a few places thin beds of sandstone have been noted. At Franklin Furnace and Ogdensburg (Sterling Hill) it contains large beds of zinc ore (see "Zinc Ore," p. 124) and in a few places magnetic veins (see "Iron Ore," p. 123) are also present. Graphite is widely disseminated in the limestone, and this with mica, pyroxene and chondrodite shows a foliated structure in the rock at many places. (See also "Marble," p. 133; "Cement Rock," p. 131; "Talc, Serpentine and Soapstone," p. 134; and "Hematite Ores," p. 123)

The Franklin limestone is overlain uncomformably by basal members of the Cambrian system. It contains some interbedded masses of gneiss and has been invaded by numerous bodies of igneous rock (chiefly pegmatite), neither of which is associated with the Cambrian formations. On the other hand, the Hardyston quartzite, the lowest member of the Cambrian, locally contains fragments derived from the pegmatite and even fragments of the coarse grained limestone itself. The Franklin limestone was metamorphosed to its present condition long before the deposition of the oldest Cambrian sediments of the State.

The Gneisses.—The gneisses appear in many varieties and these are so intricately mingled that detailed representation of their distribution on the geologic map is quite impracticable. The most noteworthy variations are differences of color, and inasmuch as color-distinctions have been found to correspond broadly with fairly definite lithologic differences, they have been used as a guide in classifying the gneisses for the purposes of description and mapping.

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

Each of these varieties of gneiss commonly occurs more or less intermingled with the others, the different facies or varieties appearing in tabular masses which are interlayered on both a large and a small scale. In general, however, one kind preponderates in any particular area and in some places forms considerable masses without intermixture.

With few exceptions the gneisses correspond accurately in their mineral and chemical composition with common types of coarse-grained igneous rocks like the granites and diorites. The light-colored granitoid rocks included under the names Losee gneiss and Byram gneiss are present in large amounts. There can be little doubt that they were formed chiefly by the solidification of invading molten silicate solutions or igneous magmas. Evidence of crushing in the minerals of these gneisses is almost entirely wanting, and appearances strongly favor the belief that their gneissic foliation is an original structure produced by the movements accompanying the intrusion and solidification of the magma. (See "Granite," p. 132.)

The dark Pochuck gneisses have the composition of igneous diorites or gabbros, but whether they have been derived from igneous or sedimentary originals or, as is believed, in part from both, their present characteristics in most places are the result of metamorphism, involving secondary crystallization. Foliation is everywhere present in these dark rocks, and parallel to this structure they have been injected in all proportions by sheets of light-colored materials similar in composition to facies of the Losee gneiss. They are also interlayered with both the Losee and Byram gneisses on a broad scale, and the Franklin limestone is similarly interlayered with the granitoid gneisses, so that the dark Pochuck gneisses and the Franklin limestone together seem to constitute a matrix holding the intruding granitoid gneisses in the form of relatively thin but extended plates. Hence both the Pochuck gneiss and the Franklin limestone are regarded as older than the granitoid gneisses, but their original relations to each other are not now determinable.

Apparently the dark rocks must already have been foliated before they were invaded by the lighter gneisses, since the interlayering of the granitoid materials is so regular that the presence of some structural control would seem to have been a necessity. During this injection, however, the early texture of the rock was broken down, important additions or subtractions of materials may have occurred, and a later crystallization ensued contemporaneously with the crystallization of the injected material. The forces that caused the flowage of the invading magma probably continued to operate after crystallization had begun, and practically until it was complete, so that the injection of the granitoid material, the pressing out and kneading of the masses of the matrix, and the development of textural foliation in both were phenomena connected in origin with a single cause.

The Franklin limestone locally retains traces of original stratification, showing its sedimentary origin; but the lamination observed in masses of this rock is regarded as mainly a sort of flow structure developed through the crystallization of the limestone masses while they were being molded under the action of deforming stresses and at the same time traversed by hot, mineral-charged waters derived from the invading Losee and Byram magmas. The facts are believed to warrant the conclusion that the white limestone and the various gneisses with which it is associated, together with the ore deposits which they enclose, crystallized in their present state and received their present forms and structures as geologic masses during a single period of regional deformation.

All kinds of crystalline rocks in the Highlands contain deposits of magnetic iron ore (see "Iron Ores," p. 123) but they are specially abundant in the Byram and Losee gneisses.

References.—Fuller treatment of the pre-Cambrian geology of New Jersey will be found in the following publications of the Survey:

Geologic Folios: No. 1, Passaic Folio, 1908, pp. 1-6; No. 2, Franklin Furnace Folio, 1908, pp. 1-8; No. 5, Raritan Folio, 1914, pp. 5-10.

"Iron Mines and Mining in New Jersey" by William S. Bayley, Final Report of the State Geologist, vol. vii, 1910, pp. 117-193.

Paleozoic Formations.

DISTRIBUTION.

The Paleozoic rocks in New Jersey comprise representatives of the Cambrian, Ordovician, Silurian, and Devonian systems. No strata of Carboniferous or Permian age occur in the State. The Paleozoic systems outcrop in three general regions (Pl. I), as follows:

(1) In a few small areas southeast of the Highlands, between the pre-Cambrian crystalline rocks and the Mesozoic (Triassic) strata.

(2) In narrow belts within the Highlands, chiefly in the valleys.

(3) In the broad Appalachian Valley belt northwest of the Highlands, comprising Kittatinny Valley, Kittatinny Mountain, and the upper Delaware Valley to the west of it.

CAMBRIAN SYSTEM.

Character.—The Cambrian rocks are a part of a great belt of similar strata that extends without interruption from Canada to Alabama. In New Jersey and adjoining regions the strata are chiefly thick limestones but include much thinner beds of shale, sandstone, and quartzite at the base. Further south the clastic rocks increase greatly in thickness and the limestones form proportionally less of the system. Along the entire length of the belt the Cambrian strata rest unconformably upon the eroded surfaces of the underlying rocks, and everywhere the materials of the basal beds were derived almost entirely from those rocks.

Hardyston Quartzite. (Ch).—The Hardyston quartzite is the lowest formation of the Cambrian system present in New Jersey, and is probably to be correlated with the Poughquag quartzite of Dutchess County, New York, and the Chickies quartzite of Pennsylvania. It rests unconformably on the pre-Cambrian complex and is the oldest fossiliferous rock in the State. It varies considerably in composition and thickness. Typically it is a quartzite, at many places conglomeratic and containing pebbles of quartz, feldspar, granite, gneiss, and slate. Locally the formation is a calcareous sandstone. It is commonly but not invariably feldspathic (arkose). In some localities this arkosic character is so marked that it is not readily distinguishable from granite. Beds of slate also occur in its upper portion.

The thickness of the Hardyston quartzite ranges from a few feet to 200 feet or more. It has been thought to grade into the overlying Kittatinny limestone through the upper slaty and shaly layers, several of which are in places interbedded with limestone layers, so that its upper limit seems to be indefinite. Its contact and exact relations to the Kittatinny, however, have not been observed in the field, since this boundary seems to be everywhere concealed by superficial deposits. It contains fossils of a species of *Olenellus* and hence is regarded as of Georgian (Lower Cambrian) age. Ulrich believes that there is a hiatus here corresponding to the rest of Lower Cambrian and all of Middle Cambrian time, and that the overlying Kittatinny limestone corresponds to the Potsdam sandstone and Little Falls Dolomite (Upper Cambrian) of New York.

Kittatinny Limestone (COk).—As explained above. the Hardyston quartzite seems to grade upward into the massive gray magnesian limestone of Kittatinny Valley, although they may possibly be separated by an unconformity. The limestone, in turn, is apparently continuous to the unconformity at the base of the Jacksonburg ("Trenton") limestone. The Kittatinny limestone has commonly been called the blue limestone in contradistinction to the white Franklin limestone. Its thickness is estimated at 2,500 to 3,000 feet, but the structure is so complicated by folds and faults that it is impossible to measure the thickness accurately. The presence of thin shales and scattered seams of sandstone in the great mass of limestone shows that there was a slight influx of land sediment at recurrent intervals during its deposition. In some places layers and nodules of black chert are abundant. (See "Limestone," p. 133; and "Hematite Ores," p. 123.)

The known fossils of the Kittatinny limestone are not numerous and are found at but few localities and only far above the base of the formation, but they suffice to establish the Upper Cambrian age of the portions in which they occur. Beneath these no Middle Cambrian fossils have been found in the great thickness of apparently unfossiliferous beds down to the *Olenellus* zone of the Hardyston quartzite below, which is considered to be of Lower Cambrian age. If there was no break in sedimentation a Middle Cambrian fauna would naturally be expected to occur between the *Olenellus* fauna below and the *Dikellocephalus* fauna above.

In one locality (near Columbia, Warren County,) a fauna of Ordovician (Beekmantown) age has been found near the top of the Kittatinny limestone. According to Ulrich there is an unconformity in New York and Pennsylvania, and presumably also in New Jersey, between the Cambrian portion of the Kittatinny limestone and that referable to the Ordovician and he would limit the name Kittatinny to the Cambrian (Ozarkian) portion.

ORDOVICIAN SYSTEM.

General Character.—In New Jersey the base of the Ordovician lies somewhere below the top of the Kittatinny limestone, but in the absence of extensive collections of fossils its exact position has been accurately determined in only a few localities.

The rocks of the Ordovician system in New Jersey are chiefly shale, slate, and sandstone, although the lower part contains some limestone. They therefore present a marked contrast to the underlying Cambrian sediments, which consist chiefly of limestone. They are a part of the great area of Ordovician sediments—principally shale—which extends from Canada to Alabama and which, together with the Cambrian rocks, forms the floor of the Appalachian Valley.

Jacksonburg Limestone (Ojb).—Above the Ordovician (Beekmantown) limestone that has been described above as apparently constituting the top of the Kittatinny limestone, and separated from it by a break (unconformity) in the sedimentation indicated by a basal limestone conglomerate, is a dark-blue or black fossiliferous limestone, correlated with the Lowville, Black River, and lower Trenton limestones of New York, and long classed as "Trenton." Some layers of this rock contain 95 per cent. or more of calcium carbonate. Calcareous shale occurs interbedded in the limestone and above it to the top of the formation. The sequence of conglomerate, limestone, and shale is a variable one, but so far as observed the transition to the overlying formation is everywhere through a series of calcareous shale which becomes less and less limy toward the top. (See "Cement Rock," p. 131.)

The thickness of the Jacksonburg formation varies from 135 to 300 feet or more. It contains an abundant fauna, 98 fossil forms having been described by Weller. At the type locality the lower strata for a thickness of 58 feet carry a Lowville-Black River fauna and the higher beds have a lower Trenton fauna. It is also correlated with the upper part of the Shenandoah limestone where that formation is typically developed.

Martinsburg Shale (Omb.)—The Jacksonburg limestone passes upward through the calcareous shales mentioned above into a great thickness of shale, slate, and sandstone, which has commonly been known as the "Hudson River Slate," but which has more recently been correlated with the Martinsburg shale of West Virginia and now takes that name.

The formation ranges from the finest grained shale and slate to fine sandstone. On the whole the shale and slate are black and more abundant in the lower part, whereas the sandstone beds are dark bluish-gray, many of them calcareous, and occur more commonly higher in the formation (see "Sandstone," p. 132). Considering the formation as a whole the gritty beds are much less abundant than shale and slate.

Slaty cleavage is the predominant structure in all but the sandy beds and the true bedding planes are in many places difficult to detect. At some localities the planes of cleavage are approximately straight and parallel and the rock of such even texture that commercial slates have been obtained in considerable quantities (see "Slate," p. 133; and "Mineral Paints," p. 136). The whole formation is so crumpled and cleaved that no accurate estimate of its thickness can be made, but it is probably at least 3,000 feet thick and it may be more.

Four species of graptolites found in the lower portion of the Martinsburg shale near Branchville, Sussex County, are, according to Ulrich, of Trenton age; hence the beds in which they occur correspond to a portion of the typical Trenton limestone of central New York. A few miles north of the New York-New Jersey state line, *Schizocrania* and graptolites characteristic of the Utica shale of the Mohawk Valley have been found in beds close to the overlying Shawangunk conglomerate.

Other species of graptolites characteristic of the Normanskill fauna have been collected by Weller near Jutland, Hunterdon County. Since the Normanskill fauna is now regarded as of Chazy age by Rudemann, it appears that shales that are in reality older have been mapped as Martinsburg in the vicinity of Jutland and Clinton.

SILURIAN SYSTEM.

General Statement.—Contrary to long-prevalent and apparently well-established belief, the lower and perhaps the middle portions of the Silurian system are not represented in New Jersey. Their absence in this and adjoining regions is indicative of somewhat widespread earth movements (unaccompanied in this region by folding), which raised the region above the zone of sedimentation and closed the period of deposition represented by the Martinsburg sediments, or possibly by overlying beds that were later removed by erosion. In middle or late Silurian time, when deposition began again, beds of coarse conglomerate were laid down and these were followed by sandstones, shales, and limestones, the earlier sediments being those of a great alluvial fan or a low-grade delta upon the borders of the Appalachian Gulf.[1] These conditions of deposition prevailed with but slight changes of elevation into Devonian time.

The Silurian formations of New Jersey occur in two distinct regions, as follows:

(1) In Kittatinny Mountain and in Wallpack Ridge, the latter of which lies along the northwestern border of the State in the upper Delaware Valley.

(2) In the narrow down-faulted and down-folded outlier of Paleozoic rocks in the Green Pond Mountain-Greenwood Lake region in the midst of the Highlands.

In Wallpack Ridge these formations aggregate 4,200 feet or more in thickness, while in the Green Pond Mountain region they do not exceed 1,800 feet.

Shawangunk Conglomerate (Ssg).—The Shawangunk conglomerate, erroneously called the "Oneida Conglomerate" in many previous publications, is chiefly a coarse quartzite and conglomerate composed of small white quartz pebbles embedded in a siliceous matrix. Its color is generally steel-blue, but some beds have a

1 Clarke, N. Y. State Museum Bulletin 107, p. 303.
Grabau, Bull. Geol. Soc. Am., vol. 24, p. 473.

yellowish tinge and reddish layers occur near the top. Layers of black shale a few inches in thickness are locally intercalated between thick beds of conglomerate and grit.

Between this formation and the underlying Martinsburg shale there is a gap representing the upper part of the Ordovician period and perhaps all of the Silurian below the Salina of the full New York section; but there is no marked divergence of dip and strike where the two formations outcrop in proximity to each other, and where they have been seen together the contact is nearly conformable, although the conglomerate clearly rests on the eroded surface of the shale. The beds overlying the Shawangunk conglomerate are red sandstone and shale and the transition from the Shawangunk is made through a series of alternating red sandstones and gray conglomerates, so that its upper limit is not sharply defined. Its thickness is probably 1,500 to 1,600 feet.

At the Delaware Water Gap and at Otisville, New York, a eurypterid fauna has been found in the black shale intercalated with the conglomerate. In the Otisville section this fauna, which elsewhere appears in only a thin bed at the base of the Salina, is repeated many times through a thickness of 650 feet. Recent studies by Van Ingen tend to show that the lower part of the Shawangunk may be of Clinton age. The Shawangunk conglomerate is followed by 2,500 feet or more of shales and limestones which are also referable to the Salina, hence for this region the conglomerate represents only the lower portion of that group.

High Falls Formation (Shf).—The red sandstone and shale that immediately overlie the Shawangunk conglomerate have until recently been regarded as the equivalent of the Medina sandstone of New York and have been so called; but for the reasons just cited it is evident that they are much younger than the Medina and that they must be included in the Salina group. Moreover, they lie some distance below a limestone which is correlated with the Cobleskill of the New York section. The name High Falls has been applied to the red shales that overlie the Shawangunk conglomerate in Ulster County, New York, and this name has been adopted for New Jersey in place of Medina, which is not applicable.

The lower beds consist of hard red quartzitic sandstone, intercalated with some green or gray sandstones and softer red shales that become more abundant in the upper portion of the formation. It has an estimated thickness of 2,300 feet at Delaware Water Gap. The formation is not known to contain fossils, but its age is fixed by its stratigraphic position. A sandstone in this formation contains copper ore on Delaware River above Water Gap (see "Copper Ores," p. 125).

Green Pond Conglomerate (Sgp).—The formation known as Green Pond conglomerate occurs in the isolated belt of Paleozoic rocks that extends through the north-central portion of the pre-Cambrian Highlands of New Jersey and passes into New York along the west shore of Greenwood Lake. It is 1,200 to 1,500 feet thick and in constitution is similar to the Shawangunk conglomerate, with which it is correlated and with which it was doubtless once continuous. The conglomerates in both areas are believed to represent the dissevered remnants of a great alluvial fan or aerial delta deposited upon the borders of the inland Paleozoic sea, which stretched an undetermined distance toward the northwest.

Longwood Shale (Sd).—Immediately overlying the Green Pond conglomerate and conformable with it is a soft red shale in which an irregular cleavage is generally so highly developed that the bedding planes can be determined only with difficulty. Its thickness has been estimated as over 200 feet. The formation is not known to contain fossils, but as it rests directly upon the Green Pond conglomerate and is followed by a limestone carrying a Salina fauna, it is probably of Silurian age. Its stratigraphic position is in general the same as that of the High Falls formation. The two appear to be synchronous and were perhaps originally continuous, having been entirely removed by erosion from the intervening region. The Longwood shale was doubtless much eroded before the deposition of the next overlying formation, the Decker limestone, which probably rests upon it unconformably.

Poxino Island Shale (Sbd).—The top of the High Falls formation in New Jersey is everywhere buried by glacial drift, which also conceals the beds immediately above. The next recognizable formation is the Poxino Island shale, a buff or greenish calcareous shale in thin layers and, so far as known, nonfossiliferous. Its outcrops along the base of Wallpack Ridge in the upper Delaware Valley are few, small, and widely separated, and very little is known regarding it. In the adjoining portion of Pennsylvania it is reported to be 200 feet in thickness and to rest on a thin limestone formation which in turn rests on the High Falls shale. It is not known to occur in the Green Pond Mountain region.

Bossardville Limestone (Sbd).—A fine-grained, compact, bluish gray, banded limestone, known as the Bossardville, lies unconformably (?) upon the Poxino Island shale in Wallpack Ridge. It increases in thickness southward from 12 feet at the New York state line to about 100 feet where it crosses Delaware River into Pennsylvania. Owing to its marked banding it was for many years known as the "Ribbon" limestone and was correlated by Cook and later geologists with the Ribbon or Manlius limestone at Rondout, New York. In reality it lies below the Manlius. It is only sparingly fossiliferous but is immediately succeeded by a series of beds containing a well-defined Salina fauna. It has not been recognized in the Green Pond Mountain belt, but this may be from lack of exposures.

Decker Formation (Sbd), (Sd).—Under this name a series of beds has been described that are chiefly limestones at the northeast and calcareous sandstones at the southwest. Their thickness is 52 feet at the Nearpass quarry near Port Jervis, N. Y., where the section can be accurately measured. Thin bands of more or less fissile green shale separate the limestone beds. A thin bed of reddish, crystalline, highly fossiliferous limestone about the middle of the series is a striking feature.

The lower 42 feet of these beds as exposed at the type locality are correlated[1] with the Wilbur limestone (the so-called "Niagara" or "Coralline" limestone of Hall and other authors) and the "black cement" beds; that is, the Salina "water-lime" of the Rondout section of New York. These form the top of the Salina group, the base of which in New Jersey is the base of the Shawangunk conglomerate. The uppermost 10 feet of the Decker series contains fossils, particularly in the lower half, that render necessary their correlation with the Cobleskill limestone of eastern New York.

In the Green Pond Mountain region isolated outcrops of impure limestone occur overlying the Longwood shale but nowhere seen in contact with it. These contain a fauna that correlates them with the lower beds of the Decker formation; that is, with the

[1] Hartnagle, N. Y. State Museum Bulletin 69, p. 1152.

part referable to the Salina group, and with the Wilbur limestone of the upper part of the Salina formation of eastern New York.

Rondout Limestone (Sbd).—Along the upper Delaware the beds immediately above the Decker limestone and referred to the Rondout consist of more or less earthy shales and limestones, the thickness of which is 39 feet. In general they are only sparingly fossiliferous, although in some beds the crustacean *Leperditia* is abundant. A typically marine fauna with an abundance of brachiopods, trilobites, etc., is conspicuously absent from these beds. In general lithologic features this formation resembles the Rondout as developed in New York, but the cement beds that are so characteristic of this formation further north are not present here.

Manlius Limestone (Sbd).—The Rondout is succeeded conformably by a somewhat thin-bedded, knotty, dark-blue or almost black limestone, 34 to 35 feet thick where best exposed. It is the bed that constitutes the quarry stone of Wallpack Ridge and its outcrop is marked by a line of quarries and lime kilns. It is referred to the Manlius or "Tentaculite" limestone of the New York series, although well-preserved specimens of the characteristic fossil, *Tentaculites gyracanthus* Eaton, are rare. In the lower beds there is evidence of environmental conditions similar to those of the Rondout. In the middle portion *Leperditia* is still abundant, but is associated with a prolific brachiopod fauna, suggestive of recurrence of the more typical marine conditions. In the upper beds *Leperditia* has entirely disappeared and the fauna is typically marine.

No beds referable to the Rondout or Manlius have been found in the Green Pond Mountain region, although their attenuated representatives may occur.

DEVONIAN SYSTEM.

The Devonian formations of the upper Delaware Valley are of marine origin and are chiefly fossiliferous calcareous shales and limestones having a thickness of about 1,000 feet. Those of the Green Pond Mountain region are chiefly sandy shales, sandstones and conglomerates, carrying comparatively few fossils, and aggregating over 4,000 feet in thickness. Most of them belong to higher stratigraphical horizons than the beds in the Delaware Valley.

In the Upper Delaware Valley.

The Helderbergian or lowermost Devonian faunas in New Jersey are essentially the same as those in New York and the same faunal zones are recognized. The first formation carrying these faunas is the Coeymans limestone.

Coeymans Limestone (Dnc).—In the Nearpass section the Coeymans limestone has an estimated thickness of 40 feet, though only the lower beds are exposed. It rests conformably upon the Manlius limestone, from which it differs lithologically in its coarser and more crystalline texture and lighter color. In many places chert is mingled with the limestone. The Coeymans fauna is far more prolific than that of the Manlius and differs markedly in composition, the most characteristic species being *Gypidula galeata*. A coral bed in the base of the formation contains more or less completely silicified masses of *Favosites helderbergiae* and a concentrically laminated stromatoporoid.

Stormville Sandstone (Dnc).—In the southern half of Wallpack Ridge in New Jersey a thin sandy layer occurs at the top of the Coeymans limestone. It is in general an inconspicuous formation owing to its thinness and the heavy deposits of glacial drift. It becomes more conspicuous toward the south, and according to White[1] it gradually replaces the overlying calcareous and shaly strata in its southward extension in Pennsylvania until it occupies the entire interval between the Coeymans limestone and the Oriskany sandstone. It has not been recognized in the Nearpass section near Port Jervis nor at any point north of Hainesville, New Jersey.

New Scotland Beds (Dnc).—The New Scotland beds that overlie the Coeymans limestone in the Nearpass section consist of about 20 feet of very hard cherty limestone followed by a series of calcareous shales having an estimated thickness of 140 feet. Nowhere in the State is there exposed a continuous section of these beds, as is the case with several of the lower formations. The fauna is a prolific one and is especially characterized by the abundant representation of the genus *Spirifer*. Its differences from the Coey-

[1]Second Geol. Survey of Penn, Report G6, pp. 132, 133.

mans fauna are of such an essential character as to indicate a separate immigration from the exterior into this region.[1]

South of Hainesville, as indicated above, a thin sandy bed (Stormville) intervenes between the Coeymans limestone and the New Scotland beds and gradually replaces the latter. At Flatbrookville, where these strata cross the Delaware into Pennsylvania, the lower cherty limestone member of the New Scotland beds has disappeared and the Stormville sandstone contains a fauna characterized by *Spirifer macropleurus*.

Becraft Limestone (Dob).—A hard gray cherty limestone overlies the shaly layers of the New Scotland beds, forming a resistant stratum that outcrops at many places along Wallpack Ridge. Its entire thickness has never been observed, but it is estimated to be about 20 feet. Its fauna is closely allied to that of the New Scotland Beds, a few new forms appearing and a few old ones disappearing. There is also some difference in the proportionate number of individuals of some species, notably of *Leptaena rhomboidalis*, which becomes especially abundant. The bed is correlated with the Becraft limestone of New York.

Port Ewen Beds (Dob).—A series of strata, nowhere exposed, occupies the interval between the Becraft limestone and the base of the Oriskany. They are probably shaly beds that disintegrate easily and thus become covered with débris. Their thickness is roughly estimated as 80 feet. The only basis for their correlation is their position, which corresponds to that of the Port Ewen ("Kingston") beds of New York. In Pennsylvania the same beds have been called the Stormville shales by White.[2]

Oriskany Formation (Dob).—A series of strata aggregating about 170 feet in thickness succeeds the Port Ewen beds and is referred to the Oriskany. For the most part these strata are siliceous limestones, but the top of the formation along the southern half of Wallpack Ridge becomes a sandstone. The sandy facies is said to become more marked to the southwest in Pennsylvania and to embrace lower and lower beds until all the strata to the top of the Coeymans limestone are sandstone.

The fauna of the Oriskany beds in New Jersey comprises three well-defined faunal zones, the lowest characterized by *Dalmanites*

[1]Weller, Geol. Survey of N. J., Paleontology, vol. iii, p. 90.
[2]Second Geological Survey of Pennsylvania, Report G6, p. 131.

dentatus, the second by *Orbiculoidea jervensis*, and the third by the great abundance of *Spirifer murchisoni*. In the Nearpass section the beds bearing the *Dalmanites dentatus* fauna are about 30 feet thick and form the crest of a high ridge, which is the southern extension of the "trilobite ridge"[1] east of Port Jervis. There is a mingling of Helderbergian and Oriskanian forms in this fauna and there has been some difference of opinion as to whether these beds should be placed in the Port Ewen or Oriskany, but recent workers[2] unite in referring them to the Oriskany.

Esopus Grit (Des).—The Esopus grit, which overlies the sandstones and siliceous limestones of the Oriskany, forms the crest of Wallpack Ridge for the greater part of its extent in the State. It is a nearly black, gritty rock with well-developed cleavage, which obscures the bedding planes. Where these planes can be distinguished the fucoid "caudi galli" markings can be recognized in many places on them. Apart from these markings fossils are very rare. The average thickness of the formation in New Jersey is estimated to be 375 feet.

Onondaga Limestone (Dmo).—The Onondaga limestone overlies the Esopus grit along the northwestern slope of Wallpack Ridge. Toward its base the formation is somewhat shaly and there is apparently a rather gradual transition from the grit to the limestone. The latter is hard, cherty, and regularly bedded in layers ranging from 3 to 12 inches in thickness. The beds are assigned to the Onondaga on the basis of their position and lithology rather than on faunal evidence, since the recognizable forms are not sufficiently characteristic for close correlation.

Marcellus Shale (Dmo).—Fissile black shale referable to the Marcellus has been reported to occur in New Jersey along the bed of Delaware River a few miles below Port Jervis, but in recent years the exposures have apparently been buried by the silting-up of the channel. This is the highest of the Devonian beds exposed in the State along Delaware River, but in the Green Pond Mountain area still younger formations occur.

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[1]Shimer, New York State Museum Bulletin No. 80, pp. 175f.

[2]Weller, Geol. Survey of N. J., Paleontology, vol. iii, p. 96; Shimer, op cit., p. 184.

In the Green Pond Mountain Area.

Kanouse Sandstone (Dkn).—The Kanouse sandstone, the lowest Devonian formation of the Green Pond Mountain region, is a thick-bedded, fine-grained conglomerate below and a greenish sandstone above, having a thickness of about 215 feet. Although fossils are not rare, as a rule they are obscure and many of them are so greatly distorted that their identification is impossible. So far as recognized they indicate an Onondaga fauna, and these beds may be interpreted as the shoreward correlatives of the Onondaga limestone. In the reports of the Geological Survey of New Jersey this formation was formerly called the "Newfoundland Grit."

Its outcrops form a narrow belt parallel to the Decker limestone but slightly separated from it. In the upper Delaware Valley, as noted above, there are seven formations aggregating nearly 900 feet in thickness between the Decker limestone and the Onondaga. In the Green Pond Mountain region none of these seven has been recognized, and if present at all it can only be in very attenuated form.

Cornwall (Pequanac) Shale (Dbp).—The Kanouse sandstone apparently grades upward into a black and dark-gray, thick-bedded, slaty shale (the "Monroe" shale of Darton and others, the "Pequanac" shale of the geologic map and some earlier reports). Cleavage is generally strongly developed so that the bedding planes are not everywhere readily discernible. The thickness is estimated at 1,000 feet. The formation is probably conformable upon the Kanouse sandstone but the contact has nowhere been observed. It contains a somewhat meager fauna among which, however, is the characteristic Hamilton species, *Tropidoleptus carinatus*, so that its reference to this epoch is beyond question.

Bellvale Sandstone, (Dbp).—The Bellvale sandstone is scarcely more than a continuation of the Cornwall (Pequanac) shale, but the beds are coarse and more sandy.' The average thickness is estimated at 1,800 feet. The few fossils that are found are all Hamilton species. Hartnagel[1] thinks the higher beds are probably as late as Portage.

Skunnemunk Conglomerate (Dsk).—The Bellvale sandstone grades upward into a coarse purple-red, massive conglomerate,

[1]Education Department, State of New York, Handbook 19, 1912, p. 69.

the white quartz pebbles of which are in places as large as 6 or 7 inches in diameter. Beds of red quartzitic sandstone alternate with the conglomerate and there are many gradations between the two. It forms the great mass of Bearfort Mountain in New Jersey and of Bellvale and Skunnemunk mountains in New York. It is the youngest Devonian formation in New Jersey and rests upon beds known by their fossils to be of Hamilton age. Hartnagel (loc. cit.) says: "It is quite probable that in part it represents the Portage with the upper beds as late as the Catskill."

STRUCTURE OF THE PALEOZOIC FORMATIONS.

The Paleozoic rocks of New Jersey have the northeast-southwest structure lines characteristic of all parts of the Appalachian province, due primarily to a system of folds and faults that trend in that direction. Few of the folds are symmetrical, southeastward dips being generally less steep than northwestward dips, so that the axial planes of the folds are inclined to the southeast (see Fig. 3).

The folding took place during the Appalachian revolution in late Carboniferous and Permian time (see p. 91). It is most marked in the beds farthest southeast and diminishes rapidly toward the northwest. Some overthrust faulting occurred during the folding, so that portions of the Kittatinny limestone are now found resting upon the later Martinsburg shale (Fig. 5 and section BB on the geologic map). The most striking examples of this movement are the large limestone area north of Hope and several smaller ones near Johnsonburg in Warren County. The entire mass of Jenny Jump Mountain has been shoved northwestward and rests upon younger beds (limestone and shale) which pass beneath the older gneiss along its western flank. The same line of overthrust can be traced southwestward to the Delaware along the northwest slope of Scott and Marble mountains. Another line of similar faulting occurs along the southeast side of Musconetcong Valley, where for considerable distances the Hardyston quartzite and the lower part of the Kittatinny limestone have been folded under and overridden from the southeast by the gneissic mass of Schooley Mountain. A portion of the overridden limestone beneath the gneiss was disclosed years ago in boring the Musconetcong tunnel of the Lehigh Valley Railroad.

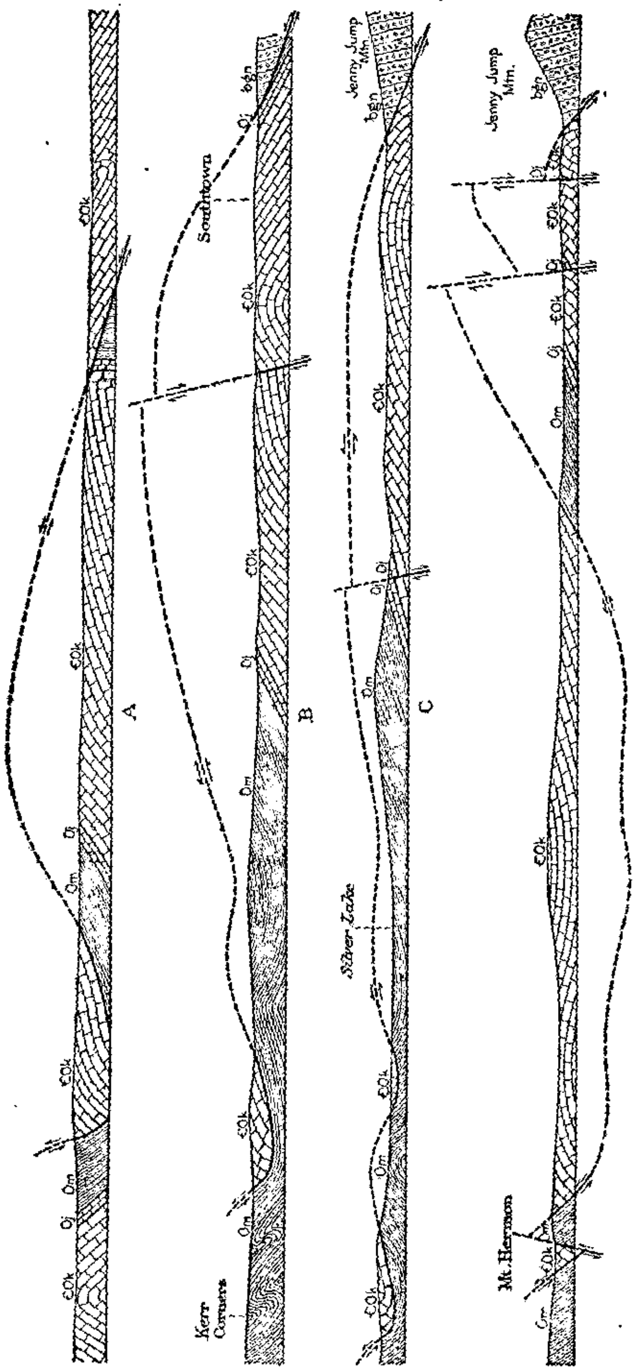

Fig. 5. Overthrust Faults of Kittatinny Valley.

More conspicuous, however, than the overthrusts are dislocations due to nearly vertical faults parallel or oblique to the axes of the folds, in which as a rule the northwestern side has been uplifted relatively to the southeastern. These faults have broken the Highlands and Kittatinny Valley into a series of long narrow blocks that have been gently tilted to the northwest. Partly as a result of the folding and partly due to this faulting and tilting, narrow belts of the Paleozoic strata that covered the whole area of the present Highlands at the close of the Paleozoic era have been carried down below the level of the adjacent crystalline rocks and thus been preserved from the erosion that has removed the great mass of these strata from the Highlands. These faults are probably a result of the disturbances that brought the Triassic sedimentation to a close, in the Mesozoic era (see p. 95, and sections AA, BB, and CC on the map).

References.—The Paleozoic formations of New Jersey are more fully described and discussed in the following publications:

Geologic Folios, Geol. Survey of N. J.; No. 1, Passaic Folio, 1908, pp. 6, 7; No. 2, Franklin Furnace Folio, 1908, pp. 10-12; No. 5, Raritan Folio, 1914, pp. 10-13.

"The Paleozoic Faunas," by Stuart Weller. Geol. Survey of N. J., Paleontology, vol. iii, 1903, 462 pp.

"Rocks of the Green Pond Mountain Region," by Henry B. Kümmel and Stuart Weller. Annual Report of the State Geologist of N. J. for 1901, pp. 1-52.

"Paleozoic Formations," by Stuart Weller. Annual Report of the State Geologist of N. J. for 1899, pp. 1-54; the same for 1900, pp. 1-8.

"Eruptive Rocks of Sussex County," by J. E. Wolff. Annual Report of the State Geologist of N. J. for 1896, pp. 89-94.

"Early Paleozoic Delta Deposits of North America," by Amadeus Grabau, Bulletin Geol. Soc. Am., vol. 24, 1913, pp. 377-398.

"Revision of the Paleozoic Systems," by E. O. Ulrich, Bulletin Geol. Soc. Am., vol. 22, 1911, pp. 281-680.

"Paleogeography of North America," by Charles S. Schuchert, Bulletin Geol. Soc. Am., vol. 20, 1910, pp. 427-606.

Mesozoic Formations.

The Mesozoic era in New Jersey is represented by formations referable to the late Triassic (possibly in part to Jurassic) and the Cretaceous periods.

TRIASSIC SYSTEM (Newark Group).

Sedimentary Rocks.

General Character.—The rocks of the Newark group, which are chiefly if not wholly of Triassic age, occupy the broad Piedmont belt southeast of the Highlands and extend diagonally across the north-central portion of the State (Pls. I, II) in a northeast-southwest zone, their southeastern margin being approximately a line drawn from Trenton to Jersey City.

These Triassic rocks extend from the Hudson southwestward through New Jersey, Pennsylvania, and Maryland into Virginia, and appear in detached areas in Nova Scotia, Massachusetts and Connecticut, Virginia, and North Carolina. The belt in which they occur is, therefore, over 1,000 miles long, but the Triassic areas are now widely separated and may never have been directly connected throughout the whole length of the belt.

The formation comprises both sedimentary and igneous rocks, the former chiefly shale and sandstone and the latter extrusive basalt and intrusive diabase. They rest unconformably upon the early Paleozoic and the pre-Cambrian crystalline rocks along the southeastern margin of the Highlands and they are in part unconformably overlapped by beds of Cretatceous age. The structure is chiefly monoclinal, the strata being inclined at low angles toward the northwest, but locally broad shallow folds have been developed. The beds are broken by many nearly vertical normal faults, the amount of dislocation varying from a few inches to several thousand feet.

The rocks are sparingly fossiliferous, footprints of reptiles, a few species of fish, a small crustacean, and a few remains of land plants being the chief elements. The formation is generally considered to be of late Triassic age, and by some the upper parts are regarded as Jurassic; hence the name Jura-Trias, by which the Newark group as a whole is often called. On the basis of lithologic character the strata have been divided into three parts, as follows:

Stockton Formation (Trs).—The Stockton beds at the base of the Newark group in New Jersey consist chiefly of light-colored arkosic sandstones and conglomerates with interbedded red sandstones and shales. The thickness is estimated at 2,300 to 3,100 feet. (See "Sandstone," p. 132.)

Lockatong Formation (Trl.).—The Lockatong beds overlie the Stockton and consist of black shales, hard, massive, dark argillites, flagstones, and, in a few places, very impure thin limestone layers. The formation has an estimated thickness of 3,500 feet. (See "Argillite," p. 133.)

Brunswick Formation (Trb).—The Brunswick beds are chiefly soft red shales with interbedded sandstones, the latter more abundant and, on the whole, somewhat coarser, toward the northeast. The formation has a thickness that has been estimated to be 6,000 to 8,000 feet, being equal to, if not greater, than the combined thickness of the other two divisions. It also outcrops over much the widest area in the Piedmont, and hence is the most conspicuous of the Triassic formations. (See "Sandstone," p. 132; and "Mineral Paints," p. 136).

Massive conglomerates (Trc) occur at various points, chiefly along the northwestern border adjoining the Highlands, and replace the beds of all the preceding divisions at various horizons. Ripple marks, mud cracks, rain-drop impressions, reptile footprints and stems of land plants are not uncommon in the finer shales and sandstones, while cross-bedding, plunge-and-flow structure, and great variations of texture are characteristic of the coarser beds. These are, in the main, unquestionably of continental origin; that is, they were deposited by streams on the surface of the land rather than in the sea or other body of standing water. They were probably spread over a broad piedmont plain in the form of nearly flat coalescing alluvial fans by the vigorous streams that washed down sediments from the uplifted crystalline foreland.

Associated Igneous Rocks.

Three or more periods of eruption at considerable intervals of time resulted in the formation of three great sheets of basalt (one of them double), each of which is conformable to the beds on which it rests and each of which was in turn buried by continued sedimentation. The intrusion of the great Palisade sill of diabase, which breaks somewhat obliquely across the strata in places, occurred probably toward the close of the period of sedimentation.

Crushed trap rock (diabase and basalt) is the chief economic product, although the copper deposits have attracted considerable attention from time to time. Sandstone is quarried to a limited extent from the Stockton and Brunswick beds and argillite from the Lockatong. (See "Trap Rocks," p. 132; "Copper Ores," p. 125; "Sandstone," p. 132, and "Argillite," p. 133.)

Structure.

The Newark rocks of New Jersey form an extensive monoclinal structure with low dips to the northwest. The monocline gives place to local flexures in some portions of the region, especially in the Passaic Valley west of the Watchung Mountains, where a gentle downward flexure has formed a broad, shallow, platter-shaped syncline, and further south near the western margin of the group where smaller local undulations are found. (See sections AA, BB, and CC at the bottom of the geologic map.)

The monocline is traversed by great faults with a throw or displacement of several thousand feet and many minor dislocations. The two most important of these faults trend in a northeast-southwest direction, nearly parallel to the strike of the strata, through Flemington and Hopewell, respectively. The downthrow is on the southeast side in all except a few of the minor dislocations. The greater part of the northwestern boundary of the Newark area, along the border of the Highlands, is also formed by a series of northeast-southwest faults, with a strong downthrow on the southeast. Some of these faults appear in section CC at the bottom of the geologic map, and their effects in displacing the strata and in some places producing a repetition of the surface outcrops of the formations are among the most pronounced characteristics of the section.

The intrusion of the diabase has caused many local disturbances of the strata, partly by flexures and partly by dislocation, especially where the igneous rock increases in thickness or breaks across the beds from one horizon to another. The crescentic outcrops of the great basalt flows of the Watchung Mountains and of the smaller sheets of New Germantown and Sand Brook (the latter erroneously represented on the map as intrusive) are due to the gentle folds in which these rocks have been involved, together with the accompanying sedimentary beds.

JURASSIC SYSTEM.

Some geologists have regarded the upper parts of the Newark group as of Jurassic age, as explained on a preceding page; whence the name Jura-Trias which is often applied to it. Apart from these beds, however, no rocks of Jurassic age are found in the State.

CRETACEOUS SYSTEM.

General Character and Relations.—The beveled edges of the Triassic shale, sandstone and diabase are overlapped unconformably along their southeastern margin by strata of Cretaceous age. These outcrop along a belt of country with an average width of 12 or 15 miles extending southwestward from Raritan Bay, in Monmouth and Middlesex counties, passing just south of Trenton, and skirting the lower Delaware River, to Salem County. This belt is widest at the northeast and is considerably narrower along the western border of the State.

The beds are unconsolidated sands, clays, and greensand (glauconite) marls which dip 25 to 50 feet per mile to the southeast and which have an aggregate thickness of 500 to 1,000 feet, the greatest thickness occurring in the northeastern portion of the area. The lowermost beds (Raritan) are referred to the upper part of the Lower Cretaceous (Comanchean) and are of nonmarine origin. The middle and upper portions, however, belong to the Upper Cretaceous and contain an abundant marine fauna.

Raritan Formation (Kmr).—The Raritan formation is of continental origin and extremely variable, consisting chiefly of light-colored sands and clays, some of the latter being highly refractory. (See "Clays," p. 126.) There is, on the whole, a preponderance of clays in the lower and of sands in the upper half of the series. (See "Underground Waters," p. 127.) Since the formation was laid down on an irregular surface the thickness is variable, ranging from 150 to 250 feet at the outcrop, but increasing to the southeastward as shown by well borings, to over 500 feet. Northeastward from Princeton Junction it rests unconformably upon the beveled Triassic strata across nearly the whole width of the State; but in the vicinity of Trenton and further southward it lies upon the ancient crystallines of early Paleozoic or pre-Paleozoic age. It dips 40 to 50 feet per mile toward the southeast, the basal beds having the steeper inclination.

The known fauna is very limited, consisting of a few pelecypods (some of which are of brackish-water types, while two are typically marine), a plesiosaurian bone, and possibly an insect. Its flora, on the other hand, embraces a wide range of genera and species, especially of dicotyledons, many of which are closely related to modern forms. It has been regarded by Ward as late Lower Cretaceous and, therefore, approximately equivalent to the Gault of England, but Berry[1] on the basis of its plant remains regards it as younger than the Gault and correlates it with the lower Cenomanian of Europe, which would place it in the Upper Cretaceous rather than in the Lower Cretaceous period.

Magothy Formation (Kmr).—The Magothy formation was until recently included in the Raritan. It is partly of continental and partly of marine origin and includes beds of sands and clays, many of them lignitic, with some glauconitic (greensand) beds toward the top. (See "Clays," p. 126.) On the shores of Raritan Bay these beds attain a thickness of 175 feet, but diminish to the southwest and along Delaware River they are only 25 to 30 feet thick. The Magothy rests unconformably upon the Raritan, but the discordance is not great and probably indicates only a slight land movement.

A marine fauna of 43 species, possessing close affinities to that of the Ripley beds of the South and to the Senonian of Europe,

[1] Berry, E. W., Geol. Survey of New Jersey, Bulletin 3, 1911, p. 2.

is found on the shores of Raritan Bay, but further southwest the deposits are apparently estuarine. The flora is abundant and represents a more recent aspect than that of the Raritan. It is regarded by paleobotanists as showing Cenomanian affinities, so that conclusions as to its age drawn from its fauna and its flora are not in accord.

Merchantville Clay (Kmv).—The Merchantville is a black glauconitic, micaceous clay about 60 feet thick. It is generally greasy in appearance, massive in structure, and weathers to an indurated brown earth. It is conformable to the Magothy formation below and to the Woodbury clay above. Its fauna is large and varied, and although it contains many forms common to the beds above and below, its most characteristic species are conspicuous for their absence or great rarity in the adjacent strata. The Merchantville clay represents the lower part of the Crosswicks clay of Clark, forms the base of the Clay-Marl series of Cook, and is the lowest of the five formations in New Jersey that are correlated with the Matawan formation of Maryland. (See "Clays," p. 126.)

Woodbury Clay (Kwb).—The Woodbury is a black nonglauconitic, jointed clay about 50 feet thick, which weathers to a light chocolate color, and when dry breaks into innumerable blocks, many of them showing a curved or conchoidal fracture. Its fauna of 95 marine species is more closely allied to that of the Magothy than to the subjacent Merchantville. It is conformable with both the Merchantville below and the Englishtown above. It is the upper part of the Crosswicks clay of Clark and forms part of the Clay-Marl series of Cook. It is also one of the formations correlated with the Matawan of Maryland. (See "Clays," p. 126.)

Englishtown Sand (Ket).—The Englishtown is a conspicuous bed of white or yellow quartz sand, slightly micaceous and sparingly glauconitic. Locally it has been cemented in part by iron oxide into massive stone. In places it contains thin laminae of fine brittle clay. So far as known it contains no fossils. It decreases in thickness from 100 feet near Atlantic Highlands to less than 20 feet in the southern portion of the State. It represents the lower part of the Hazlett sand of Clark and forms a part of Cook's Clay-Marl series. It was formerly called the Columbus sand and is the equivalent of a part of the Matawan formation of Maryland. (See "Clays," p. 126; and "Underground Water," p. 127.)

Marshalltown Formation (Kmt).—The Marshalltown ranges from a black sandy clay to an argillaceous greensand (glauconite) marl. Locally it is abundantly fossiliferous, its characteristic species being in part recurrent forms from the Merchantville and in part new forms that again recur in a higher formation, although absent or inconspicuous in the immediately succeeding beds. Its thickness is 30 to 35 feet. It is a portion of the "laminated" sands that formed the upper part of the Clay-Marl series of Cook, although in the southwestern portion of the State he referred these beds to the Navesink (Lower) marl. It was included in Clark's Hazlett sands, a subdivision of his Matawan. (See "Clays," p. 126; and "Greensland Marl," p. 135.)

Wenonah and Mount Laurel Sands (Kmw).—Above the Marshalltown clay-marl there is considerable thickness of sand regarding which there has been some difference of opinion. The terms Wenonah and Mount Laurel have both been applied to it in whole or in part. Lithologically it is of rather uniform character, although the lower part (Wenonah) is generally a fine micaceous sand and the upper part (Mount Laurel) is coarser and contains considerable greensand (glauconite). Paleontologically, however, these two portions are quite distinct. (See "Underground Water," p. 127.)

The Wenonah fauna is largely recurrent from the Woodbury, with comparatively few prominent species common either to the Marshalltown immediately below or the Mount Laurel and Navesink next above. The same elements are prominent again still higher in the Red Bank. The Mount Laurel fauna is identical with that of the Navesink above and is closely allied to the Marshalltown but contains a foreign element, chief among which is the cephalopod *Belemnitella americana* and the brachiopod *Terebratula plicata*, so that the indistinct lithological difference between the Wenonah and Mount Laurel sands is of considerable paleontological significance. The combined thickness of these formations is 40 to 80 feet, the Mount Laurel being limited to a very thin bed at Atlantic Highlands (Cook's Sand-Marl) but increasing much in thickness toward the southwest. The Wenonah sand is the highest bed correlated with the Matawan of Maryland, while the Mount Laurel is the base of the Monmouth.

Navesink Marl (Kns).—The Navesink formation consists of greensand (glauconite) marl, mixed with varying amounts of quartz sand and fine earth, the latter of which contains much calcium carbonate in a powdery state. Where purest the marl has a dark-green to bluish-black color. The upper part of the bed contains progressively less greensand and is more clayey. The fauna is large (121 species, Weller) and is allied with that of the Marshalltown and Merchantville beds, while the characteristic forms of the Magothy, Woodbury and Wenonah are absent. The formation has a maximum thickness of about 40 feet, diminishing southward to 25 feet or less. It corresponds in general to Cook's Lower Marl, although locally beds referred by him to the Lower Marl have proved to be the Marshalltown. It rests conformably upon the beds below and grades upward into the Red Bank sand, or where that is absent, into the Hornerstown marl. (See "Greensand Marl," p. 135.)

Red Bank Sand (Krb).—The Red Bank sand is for the most part a fairly coarse yellow and reddish-brown quartz sand, locally indurated by the infiltration of iron oxide. The lower beds are in many places somewhat clayey, and the Red Bank fauna has come chiefly from the clayey layers. In its essential features it is a recurrence of the *Lucina cretacea* fauna[1] of the Magothy, Woodbury, and Wenonah formations, and differs in important respects from the Navesink fauna immediately below. It occurs in the northern part of the Coastal Plain, where its maximum thickness is 200 feet, but it thins out southwestward and disappears midway across the State. It is the Red Sand of Cook and earlier writers, but does not include certain sands in the southern portion of the State that were erroneously correlated by Cook with the Red Sand of Monmouth County. With the overlying Tinton bed, it is the uppermost of the beds correlated with the Monmouth formation of Maryland. (See "Underground Waters," p. 127.)

Tinton Bed (Krb).—A bed of green indurated clayey and sandy marl (glauconite) having a thickness of 10 to 20 feet, overlies the Red Bank sand in Monmouth County. Its fauna is more closely allied to that of the Navesink than of the Red Bank and is characterized by large numbers of crustacean claws of the genus *Callianassa*. It is Cook's "indurated green earth," regarded by him and other writers as part of the Red Sand, but in view of its faunal and lithologic differences it is here given recognition but is not separately represented on the map.

Correlation of Magothy to Tinton Formations.—The assemblage of fossils making up the faunas of the beds from the Magothy to the Tinton, inclusive, constitutes a larger faunal unit much more sharply separated from the faunas above and below than are any of its constituent faunules from each other. Weller has shown that this larger faunal unit is made up of two or more distinct facies, one of which, the *Cucullea* fauna, is characteristic of the more glauconitic beds; namely, the Merchantville, Marshalltown, Navesink and Tinton, while the other facies characterized by *Lucina cretacea* or its associates occurs in the clays or clayey sands of the Magothy, Woodbury, Wenonah and Red Bank formations.

The two facies existed contemporaneously and migrated backward and forward across the region of the present outcrop of these beds in New Jersey as deeper or shallower water conditions prevailed. The larger faunal unit is closely related to the Ripley fauna of Alabama, Mississippi, and Texas. On faunal evidence all the formations from the Magothy to the Tinton, inclusive, are referable to the Senonian of Europe, although on floral evidence the Magothy might be correlated with the older Cenomanian.

Hornerstown Marl (Kht).—The Hornerstown is a bed of glauconite (greensand) with clay and sand having a total thickness of 30 feet or less and much like the Navesink. Its fauna, however, while meager, is totally different in its essential characteristics from the fauna of all the underlying formations. *Terebratula harlani, Cucullea vulgaris* and *Gryphea dissimilaris* (Weller) are characteristic forms. A shell bed at the top of the formation is a conspicuous feature at many localities. At the north it rests with apparent conformity on the Tinton; where that is absent it lies on the Red Bank, and further south, owing to the disappearance of the Red Bank, it is continuous with the Navesink. It is conformably overlain by the Vincentown except where overlapped by Miocene (Tertiary) formations. It is the Middle Marl of Cook, the Sewell Marl of Clark, and is part of the Rancocas group. (See "Greensand Marl," p. 135.)

Vincentown Sand (Kvt).—The Vincentown sand presents two facies: (1) a calcareous or lime sand, semi-indurated and largely a mass of broken bryozoan, echinoid, coral and other calcareous remains; (2) a glauconitic quartz-sand facies. The two occur in alternating layers, although the former is more common in the basal portion, particularly to the south, while the quartz-sand facies preponderates in Monmouth County. The fauna of the lime-sand facies contains large numbers of bryozoa, echinoids, and foramenifera, while in the siliceous facies elements of the Hornerstown fauna occur in association with forms characteristic of the calcareous facies. Its thickness varies from 25 to 70 feet, but numerous well borings have shown that it thickens down the dip, that is, toward the southeast. It rests conformably upon the Hornerstown marl and is overlain conformably by the Manasquan marl or overlapped by Miocene (Tertiary) beds. It includes the "lime sand" and "yellow sand" of Cook, the former of which was included by him as a part of the Hornerstown (Middle) marl. (See "Underground Waters," p. 127.)

Manasquan Marl (Kmq).—The Manasquan marl in its lower portion (13 to 17 feet) is composed chiefly of glauconite (greensand), but the upper part (8 to 12 feet) is made up of very fine sand mixed with greenish-white clay, piles of which look like heaps of ashes, whence the name "ash marl." Fossils are not abundant and are poorly preserved, the commonest occurring also either in the Hornerstown or Vincentown. Its thickness is about 25 feet. It corresponds to the "green" and "ash" marls of Cook's Upper Marl bed and is the youngest of the Cretaceous formations exposed in New Jersey. It probably rests conformably upon the Vincentown and at most exposures is succeeded unconformably by Tertiary or Quaternary deposits, although locally it is overlain by a bluish marl of Eocene (Tertiary) age without apparent unconformity. (See "Greensand Marl," p. 135.)

Correlation of Hornerstown, Vincentown, and Manasquan.—The faunas of these three formations are closely related and form a larger fauna sharply separated from the Ripleyan fauna of the underlying Magothy to Tinton beds. This fauna has not been recognized south of Maryland. It shows certain affinities with the lower or Maestrichtian division of the Danian series of western Europe (Weller).

References.—For fuller description and discussion of the Mesozoic formations of New Jersey, see the following publications:

The Geologic Folios: No. 1. Passaic Folio, 1908, pp. 7-13; No. 3. Philadelphia Folio, 1909, pp. 8-15; No. 4. Trenton Folio, 1909, pp. 11-14; No. 5. Raritan Folio, 1914, pp. 13-16.

"Petrography of the Newark Igneous Rocks of New Jersey," by J. Volney Lewis. Annual Report of the State Geologist for 1907, pp. 97-167.

"Origin and Relations of the Newark Rocks," by J. Volney Lewis, Annual Report of the State Geologist for 1906, pp. 99-120.

"Fossil Fishes. Triassic Fishes of New Jersey," by C. R. Eastman. Annual Report of the State Geologist for 1904, pp. 27-130.

"The Newark System," by Henry B. Kümmel. Annual Report of the State Geologist for 1896, pp. 25-88; Same for 1897, pp. 23-160; Same for 1898, pp. 43-58.

"Fossil Fish Remains of Cretaceous, Eocene, and Miocene Formations of New Jersey," by Henry W. Fowler, with a Chapter on Geology, by Henry B. Kümmel. Bulletin Geol. Survey of N. J. No. 4, 1911, 185 pp.

"Flora of the Raritan Formation, by Edward W. Berry. Bulletin Geol. Survey of N. J. No. 3, 1911, 233 pp.

"Cretaceous Paleontology of New Jersey," by Stuart Weller. Geol. Survey of N. J., Paleontology vol. iv, 1907, 871 pp., with separate volume of plates.

"Paleontology of the Cretaceous and Tertiary," by Robert P. Whitfield. Geol. Survey of N. J., Paleontology, vol. i, 1886, 338 pp.; vol. ii, 1892, 402 pp.

"Fossil Plants. Flora of the Cliffwood Clays," by Edward W. Berry. Annual Report of the State Geologist for 1905, pp. 97-172.

"Fauna of the Cliffwood Clays," by Stuart Weller. Annual Report of the State Geologist for 1904, pp. 131-144.

"Upper Cretaceous Formations and Faunas of New Jersey," by Stuart Weller. Annual Report of the State Geologist for 1904, pp. 145-160.

"Upper Cretaceous Formations," by William B. Clark. Annual Report of the State Geologist for 1897, pp. 161-210.

"Cretaceous and Tertiary Geology," by William B. Clark. Annual Report of the State Geologist for 1892, pp. 167-246; Same for 1893, pp. 329-356.

Cenozoic Formations.

The formations of Cenozoic age in New Jersey include: (1) marine Tertiary sands, gravels, marls, and clays, forming the most extensive areas of the Coastal Plain, with gravel (Beacon Hill) at the top probably of continental origin; (2) Quaternary deposits of nonglacial continental origin of widespread occurrence over the Coastal Plain, and glacial accumulations over much of the northern part of the State; (3) Recent alluvium and surface wash (not shown on the geologic map) and swamp and marsh accumulations.

TERTIARY SYSTEM.

General Distribution.—Beds of Tertiary age are widely distributed in southern New Jersey, (Pl. I) where they overlie the Cretaceous formations southward and southeastward of the diagonal belt in which these outcrop. At the north they rest upon beds ranging in age back to the Hornerstown marl, while in the southern portion outliers are found upon formations as old as the Mount Laurel sand.

Shark River Marl (Tsr).—This formation is limited in outcrop to small areas near Long Branch and Farmingdale, in Monmouth County, where a mixture of greensand (glauconite) and light-colored earth 11 feet in thickness and carrying early Tertiary (Eocene) fossils rests without apparent unconformity upon the "ash" marl of the Manasquan. The conformity, however, is only apparent, since well borings indicate that the Shark River probably overlaps the Cretaceous. Clark does not consider it possible to correlate the Shark River marl with any other known Eocene deposits, and regards it as probably older than the Eocene of Maryland. By some authors, however, it has been placed above the Maryland Eocene.

Kirkwood Formation (Tkw).—Under the name Kirkwood have been included all beds of demonstrable Miocene (middle Tertiary) age that outcrop in New Jersey. These beds vary in character in different regions, but they are predominantly fine micaceous quartz sands, in many places delicately banded in shades of salmon-pink and yellow. Black lignitic clays occur in many localities at or near the base of the formation. In the southern portion of the State (Salem County) the Kirkwood consists of a thick bed (80 to 90 feet) of chocolate or drab-colored clay, above which there are (or were formerly) exposures of fine clayey sand containing great numbers of shells (the Shiloh Marl of many reports), which, in the localities where it occurs, forms the upper bed of the Kirkwood. The total thickness of the formation along the outcrop is 100 feet or more. On the basis of the abundant fossils in the beds at Shiloh, the Kirkwood is believed to correspond in a general way with the Calvert formation of Maryland, the lowest division of the Chesapeake group. (See "Clays," p. 127; and "Underground Water," p. 127.)

Well borings at Atlantic City, Wildwood, and other points along the coast have demonstrated the presence there of a great thickness of Miocene strata apparently not represented in outcrop. At Atlantic City clays, sands, and marls from depths of 390 to 1,225 feet below sea level carry Miocene fossils, and at Wildwood those from 300 feet to 1,090 feet (and perhaps to 1,244 feet) are Miocene. From the fossils it is evident that strata referable to the St. Mary's, Choptank, and Calvert horizons of the Chesapeake group are present.

Cohansey Sand (Tch).—This formation, which overlies the Kirkwood at its outcrop, is composed chiefly of quartz sand with local laminae and thicker lens-shaped beds of light-colored clay and occasional lenses of gravel. It forms the surface of the Coastal Plain in New Jersey over a wider area than any other single formation. Obscure casts of molluscan shells have been found in it but these are of no value in determining its age. Plant remains from near Bridgeton indicate a flora comparable with that of certain upper Miocene localities of Europe. It dips southeastward 9 or 10 feet per mile and overlies the Kirkwood with seeming unconformity. (See "Clays," p. 127; "Glass Sand," p. 135; and "Underground Water," p. 130.)

Inasmuch as sands and clays similar to the Cohansey are revealed in borings along the coast and there overlie clays carrying Miocene fossils characteristic of the St. Marys, the highest division of the Chesapeake group, the Cohansey apparently belongs to a still later stage of the Miocene, or perhaps even to the Pliocene (late Tertiary). It is possible, however, that as now defined it may represent, in part at least, the shoreward facies of the fossiliferous Miocene clays found in the borings along the coast, and that it should be correlated with the Choptank and St. Marys of Maryland. In the light of all data at present available, however, the former view seems the more probable.

Beacon Hill Gravel (Tbh).—Under this name certain beds of gravel and sand occurring as outliers on the higher hills of Monmouth County have been described. Later, however, the sand beds were correlated with the great body of sand now included in the Cohansey, leaving only the gravel in the Beacon Hill formation. It consists chiefly of quartz, but contains much chert and some pebbles of hard sandstone and quartzite. The chert pebbles are invariably much decayed and many of them very soft. Also many of the quartz and quartzite pebbles are more or less corroded. The formation occurs as isolated remnants on some of the highest hills of the Coastal Plain. It is probably of Pliocene (late Tertiary) age and is perhaps to be correlated with the Lafayette formation further south.

QUATERNARY SYSTEM.

The Quaternary formations of New Jersey consist of: (1) superficial Pleistocene deposits of both glacial and nonglacial origin—the former occurring in the northern counties, the latter chiefly on the Coastal Plain. These deposits are shown on the map by a series of overprint patterns through which the geology of the underlying formations is also shown. (2) Recent alluvium along many streams, beach deposits, and swamp accumulations.

The glacial and glacially-derived deposits are here described first.

Glacial Pleistocene Deposits.

Jerseyan (Early) Drift (Qed).—Glacial drift, both stratified and unstratified, greatly antedating the moraines of the last, or Wisconsin, stage of glaciation, occurs in discontinuous patches south of the latter to a maximum distance of 23 or 24 miles. In the Highlands it is thicker and more continuous in the wider valleys than on the ridges, while on the Triassic (Piedmont) plain it caps isolated and somewhat flat-topped hills in relations that indicate prolonged erosion since its deposition.

The great age of at least some portions of this drift is indicated by the fact that since it was formed the main streams have sunk their channels 100 feet and have opened wide valleys on extremely gentle gradients. The complete oxidation and leaching that it has undergone and the disintegration of even large bowlders of gneiss and granite deep within its mass are other evidences of great age. It is believed to be equivalent in age to one of the earlier drifts of the Mississippi Valley, not improbably the Nebraskan (sub-Aftonian), but on this point there is no definite evidence.

Wisconsin Drift.—A great terminal moraine (Qtm) of the age of the Wisconsin ice sheet crosses the State (Fig. 6) in a curved

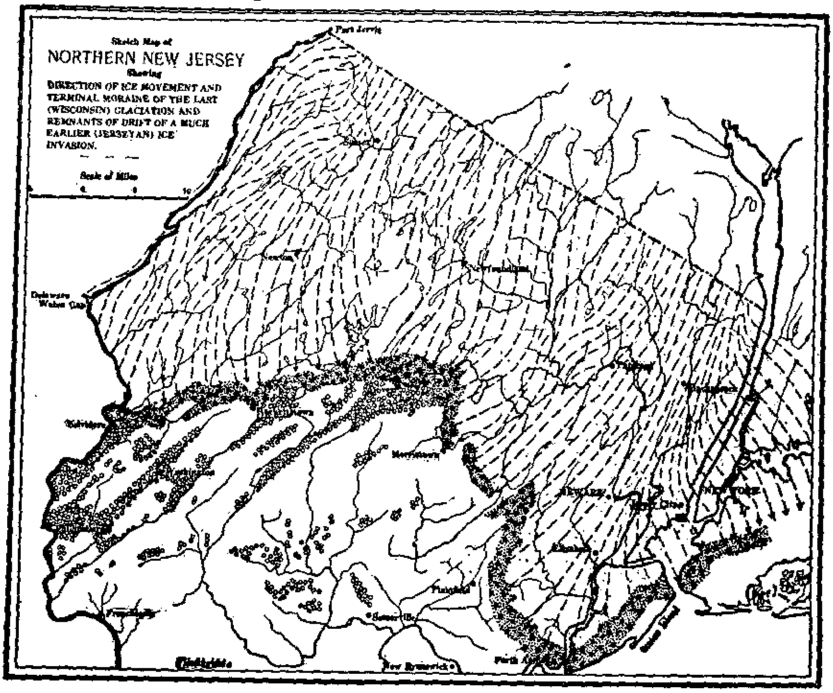

Fig. 6. Map showing Ice Movement, Terminal Moraine, and Jerseyan Drift.

line through Perth Amboy, Plainfield, Summit, Morristown, Dover, Hackettstown, and Belvidere. South of the moraine narrow valley trains of glacial gravels characterize some of the southward drainage lines, notably Delaware Valley, and locally overwash plains (Qsd) are conspicuous topographic features (Plainfield and vicinity). North of the moraine the rock surface is covered very generally by the usual assemblage of drift deposits, stratified and unstratified.

The unstratified drift or till consists of a clay-like rock flour (glacial clay) with which are mingled in variable proportions sand, gravel, rock fragments, and bowlders, some of which have a diameter of several feet. Most of the recognizable fragments are like the underlying bedrock or that of the areas lying immediately to the northward. Only a small percentage of the material has been transported many miles. Except in the moraine belt the sheet of till has *not* been represented on the geologic map, but it must be understood as covering the surface north of the moraine in practically all areas not covered by the stratified drift. Locally, however, the underlying rock outcrops in relatively small exposures.

The stratified drift (Qsd) comprises beds of clay, sand, and gravel that in the process of deposition were assorted and laid down by water flowing from the ice sheet as well as those portions of the till that were eroded and redeposited by the glacial waters. This class of deposits marks the lines of glacial drainage and temporary lakes and swamps and occurs chiefly in the valleys. Its distribution is shown on the map. (See "Clays," p. 127.)

At least two definite pauses in the retreat of the Wisconsin ice sheet are marked by recessional moraines (Qrm) and valley trains that head in them. The warped shore lines of Lake Passaic, an extinct glacial lake of the upper Passaic Valley, indicate a differential elevation of the northern part of the State of about 2 feet per mile since the retreat of this ice sheet.

Nonglacial Pleistocene Deposits.

The nonglacial Pleistocene deposits consist of gravel, sand, and some clay, deposited chiefly by rivers but partly at least in estuaries. Three formations have been distinguished, partly on lithologic and partly on topographic grounds. These are the Bridgeton, the Pensauken, and the Cape May. Each represents a time in which both erosion and deposition occurred in this region, but in which deposition predominated. They were separated by intervals in which erosion prevailed over deposition, although the latter did not cease. Consequently, there are, in addition to the deposits referred to these formations, others accumulated locally during intervals of erosion whose lithologic, topographic, and age relations are not so clear. Changes of elevation are believed to have accompanied and to some extent to have caused the alternate periods of erosion and deposition, but it is not believed that subsidence was so great as to have depressed below sea level all the region in which these beds are now found.

Bridgeton Formation (Qbt).—The Bridgeton formation is essentially gravel and sand, ranging in thickness up to 30 feet, the materials having been derived from the Beacon Hill, Cohansey, Kirkwood and the various Cretaceous, Triassic, Paleozoic and crystalline pre-Cambrian formations. The material from the crystallines and the Triassic is almost invariably friable and crumbles readily. Some bowlders are so large and of such a character as hardly to have reached their present position without the aid of floating ice. The formation occurs as outliers capping hills and divides, and is manifestly now only a remnant of an ancient deposit formed in large part by rivers. (See "Molding Sand," p. 133.)

The Bridgeton is comparable in a general way to the Sunderland of Maryland, although their limits may not be the same and somewhat diverse views of origin are held by workers in the respective fields. After the deposition of the Bridgeton there was a long period of erosion during which much of the Bridgeton was removed, particularly in Delaware Valley and along the broad belt of low land stretching across the State from Bordentown and Trenton to Raritan Bay.

Pensauken Formation (Qps).—The Pensauken formation is chiefly gravel and sand, although locally it contains beds of clay. It ranges in thickness from 0 to upwards of 20 feet. In many places it much resembles the Bridgeton and cannot everywhere be distinguished from it on lithologic grounds. Where both are present, however, it invariably occurs at lower levels and has suffered less erosion. Its deposition obliterated the smaller and partially filled the larger valleys eroded in post-Bridgeton time, forming broad flood plain deposits along the drainage lines. The coastal portion of the State was more or less submerged during this period of deposition, but the Pensauken formation is probably due primarily to stream deposition rather than to marine or shore conditions. Since glacial material occurs in it sparingly it is correlated with a glacial epoch—one, however, that long antedated the Wisconsin drift sheet. It corresponds roughly in age with the

Wicomico of Maryland. The Pensauken deposition was followed by a long period of uplift during which the formation was much eroded and nearly all of it was removed from some areas. (See "Clays," p. 127; and "Molding Sand," p. 135.)

Cape May Formation (Qcm).—Following the post-Pensauken uplift was a slight submergence to the extent of 40 or 50 feet below the present elevation of the land. During this period terraces of gravel and sand with some clay were formed at many points along the coast and in valleys that were not submerged. These deposits range from 0 to 20 feet or more in thickness. They constitute the Cape May formation and are believed to correspond in age with those of the last glacial age (Wisconsin) or possibly to its later stages. The estuarine terraces along Delaware Bay are continuous with those along Delaware River above Trenton and these, in turn, head in the terminal moraine of the Wisconsin ice sheet. In the vicinity of Trenton there is no sharp line between the stratified glacial drift (Qsd) of Delaware Valley and the Cape May formation (Qcm). The latter, however, contains much less glacially derived material than the former and is composed chiefly of material from the Cretaceous and older nonglacial Pleistocene formations.

Along the coast and lower Delaware River the terraces are not more than 40 feet above sea level, and are lower than the Pensauken terraces in the same region; but along the tributary streams they rise to much greater elevations, and in some localities are as high as the Pensauken or Bridgeton. (See "Clays," p. 127; and "Molding Sand," p. 135.)

Recent Formations.

As noted on a preceding page, the distribution of recent deposits in New Jersey is not indicated on the map, with the exception of existing swamps and marshes and such portions of the beach and dune sands (Qbs) as are of modern origin. Although erosion is now the dominant process over the State, many of the streams have laid down floodplain or bottom-land deposits, particularly in the broader and flatter parts of their courses, and the process is still going on. Mud, sand, and gravel are also being washed into ponds and lakes, but the greater part of such material is swept down into the bays and harbors or carried out beyond the coast line into the borders of the Atlantic, where it is gathering in widespread formations that may be added in the future to the Coastal Plain. The recent deposits of the Coastal Plain are in many places not readily separable from the Cape May formation.

Structure of the Coastal Plain.

In general the structure of the Coastal Plain is exceedingly simple. The unconsolidated beds of sand, gravel, clay, and marl are without folds or faults and lie in very nearly the attitude in which they were originally deposited. In the outcrops the strata appear to be horizontal, but there is a slight coastward dip, ranging from 40 to 50 feet to the mile in the earlier Cretaceous (Comanchean) formations to 10 to 15 feet per mile in the later Tertiary deposits. The direction of the dip, although in general easterly, is somewhat more northerly in the Lower Cretaceous formations than in the Upper Cretaceous and the early Tertiary (Eocene), but it gradually swings back to a more northerly direction again in the upper Miocene (middle Tertiary).

The mantle of Quaternary formations slopes gradually either seaward or locally toward the channels of the various estuaries. These formations occur as a veneer over the older deposits.

As a result of uplifts and depressions the landward margins of the formations show much complexity, with a marked change in the sequence of deposits from point to point. In places the deposits of a transgressing sea have completely buried and overlapped the earlier strata so that these fail to appear at the outcrop although they may be found in well-borings further east. In this manner various formations of the Coastal Plain are found to disappear as their outcrops are traced northward or southward. There are also many unconformities between the strata, corresponding to intervals of uplift and erosion.

References.—Further descriptions and discussion of the Cenozoic formations may be found in the following publications:

Geologic Folios of New Jersey: No. 1, Passaic Folio, 1908, pp. 14-20; No. 2, Franklin Furnace Folio, 1908, pp. 13-18; No. 3, Philadelphia Folio, 1909, pp. 11-15; No. 4, Trenton Folio, 1909, pp. 14-17; No. 5, Raritan Folio, 1914, pp. 16-18.

"Fossil Remains of the Cretaceous, Eocene and Miocene Formations of New Jersey," by Henry W. Fowler, with a chapter on Geology by Henry B. Kümmel. Bulletin Geol. Survey of N. J., No. 4, 1911, 192 pp.

"Paleontology of the Cretaceous and Tertiary," by Robert P. Whitfield. Geol. Survey of N. J., Paleontology, vol. i, 1886, 388 pp.; vol. ii, 1892, 402 pp.

"Cretaceous and Tertiary Geology," by William B. Clark. Annual Report of the State Geologist for 1892, pp. 167-246; Same for 1893, pp. 329-356.

"Glacial Geology of New Jersey," by Rollin D. Salisbury. Final Report of the State Geologist, vol. v, 1902, 802 pp.

"Surface Geology," by Rollin D. Salisbury. Annual Report of the State Geologist for 1892, pp. 35-166; 1893, pp. 35-356; 1894, pp. 1-150; 1895, pp. 1-16; 1896, pp. 1-24; 1897, pp. 1-22; 1898, pp. 1-42.

"On Drift or Pleistocene Formations of New Jersey," by Rollin D. Salisbury. Annual Report of the State Geologist for 1891, pp. 35-108.

GEOLOGIC HISTORY OF NEW JERSEY.

General Outline.

In pre-Cambrian times the ancient sedimentary rocks of northern New Jersey, including considerable masses of limestone and some highly carbonaceous beds, were extensively intruded by massive igneous rocks, which now make up the great bulk of the gneisses, and the whole complex was later subjected to great deformation and accompanying metamorphism.

At the beginning of the Cambrian period the region, after having been subjected to prolonged erosion, was invaded from the southwestward by an interior sea and was submerged[1] for a long time, during which a thick series of sediments was laid down. These subsequently became consolidated into the stratified rocks of the Cambrian and Ordovician systems. Near the close of the Ordovician period the land was uplifted a little and the sea with-

[1] The successive uplifts and subsidences to which New Jersey has been subjected in the course of geologic time are graphically shown in Fig. 7, p. 80.

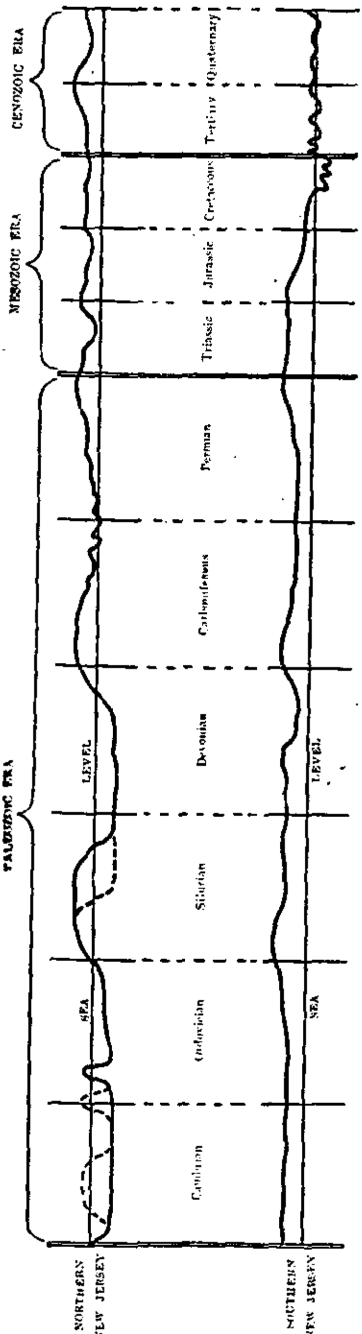

Fig. 7. **Diagram showing elevation and subsidence during geologic time.**

drew for a time. Some of the mountain-making folds in the early Paleozoic strata of eastern New York and western New England were formed at this time, but there seems to be no evidence that such deformation occurred in New Jersey.

Late in the Silurian period, after a long interval of erosion during which some of the material of earlier strata was removed, the interior sea again invaded northwestern New Jersey and another considerable series of sediments was deposited, while gradually the shore line of the encroaching sea was pushed eastward beyond Greenwood Lake and Green Pond. Toward the close of the Devonian period the sea again withdrew from the region, and the absence of all strata of later age indicates that either no later deposition took place or, if it did, the strata have been entirely removed by subsequent erosion. During the closing periods of the Paleozoic era extensive folding and faulting of the older strata resulted in the formation of the Appalachian Mountains and the uplift of a large part of eastern North America into permanent dry land.

Late in the Triassic period sediment that was being washed from the worn-down Appalachian Mountains was deposited on low flat plains or basin-like depressions in the present Piedmont region, together with much sand, gravel and mud from the old crystalline highlands that lay to the eastward, off the present coast. During this deposition sheets of volcanic lava flowed repeatedly over the surface of the low land and became interbedded with the sediments, while other portions of the igneous magma spread laterally among the sediments and formed thick intrusive sheets, or sills. The whole series of Triassic strata was somewhat tilted and extensively faulted by land movements that occurred at the close of the period.

After another long interval of erosion beds of clay, sand, and gravel were spread upon the low lands of central and southern New Jersey in late Lower Cretaceous (Comanchean) time. This was followed in the Upper Cretaceous period by an encroachment of the Atlantic from the southeast, and in the shallow borders of the sea that overspread this region great thicknesses of sand, clay, and greensand (glauconite) marl were deposited. With renewed uplift the surface of the land was worn to a lower level and the landward edge of the recently deposited strata was removed by erosion.

Early in the Tertiary period, during another subsidence, the borders of the Atlantic again covered the region of southern New Jersey and extensive deposits of sand, gravel, and clay were again spread over the submerged Coastal Plain. Minor oscillations of land and sea, with alternations of erosion and deposition, continued throughout the Tertiary and into the Quaternary. These movements are recorded not only in the deposits and unconformities of the Coastal Plain but in the physiographic features and stream gravels that were formed at those times.

During the Pleistocene epoch a great sheet of land ice advanced southward over the northern quarter of the State (Fig. 6), slightly modifying the topography and leaving extensive deposits of glacial drift. At least two such ice advances are recorded in the drift deposits now existing in the State.

Pre-Cambrian Time.

The earliest event that is decipherable in the geologic history of New Jersey was the deposition of a great series of sedimentary rocks, doubtless thousands of feet in thickness, remnants of which constitute the Franklin limestone and the associated strata of the present time, and possibly others represented by some of the Pochuck gneiss. These rocks are now part of the Highlands, but most of them were formed in the sea, and since many of the strata are composed of fragmental material it may safely be inferred that there existed at this time a land surface by the erosion of which material was furnished for the making of some of the sediments; but neither the location of that land area nor the extent of the seas in which the sediments were deposited can now be determined, so remote in geologic history is this event.

The sediments were later subjected to forces that folded, compressed, and metamorphosed them, and this was followed, possibly after a long interval, by an invasion of lava-like igneous magmas which have become consolidated into the widespread gneisses of the Highlands. It seems certain that the sediments were more or less metamorphosed before their invasion by the gneissic magmas, since the intrusion was evidently directed by the foliated structure of the intruded rocks. During the invasion, which was, doubtless, slow and long-continued, some of the sedimentary rocks were dissolved in the intruding magma. Those that were not dissolved suffered more intense alteration than they had previously undergone and thus attained their present highly crystalline, metamorphic character.

At this time, too, the magnetite and probably also the zinc ores were deposited by hot mineral-bearing solutions that were gradually given off by the magmas as they cooled and solidified. The distinctly crystalline granitic texture of the gneisses shows that the cooling porcess was a slow one and took place deep beneath the surface of that time. The slow creeping movements of the intruding magmas, and possibly the regional compression to which they were subjected while they were crystallizing, produced in them the parallel arrangement of the minerals that is known as the gneissic structure or foliation.

The intrusion of the gneisses was doubtless accompanied by considerable elevation of the whole region affected. Later through immense periods of weathering and erosion the greater part of the sedimentary strata was removed, and thus large areas of the gneisses became exposed at the surface. The region may have been worn down to almost a plain (peneplain), but many minor irregularities at least still existed when depression of the land brought on an invasion of the sea over most of the present Highlands and westward at the beginning of Cambrian time. This uneven land surface is inferred from the variations in thickness and in lithologic character of the earliest Cambrian sediments about the shores of this early inland sea.

Paleozoic Era.

CAMBRIAN PERIOD.

After the immense period of erosion in late pre-Cambrian time a narrow sea came inland over Alabama and gradually extended along the belt now occupied by the Appalachian Mountains and northeastward to Labrador, covering the northern part of New Jersey. Southeast of this sea and separating it from the Atlantic Ocean was an ancient land area known to geologists as Appalachia; to the northeast was another body or group of lands, or an extension of Appalachia, which has been called Acadia. The formation of this inland sea and the accumulation of sediments therein marks for New Jersey the beginning of Paleozoic time. In this sea was deposited the Hardyston quartzite. The differences in lithologic character of the formation and its range in thickness within short distances indicate a wide range in sedimentary conditions, such as would prevail near a shore of varied topography.

As sediments accumulated in this narrow inland sea it gradually broadened and the shore encroached upon the land until it ultimately lay to the southeast of the present Highlands, as is shown by outcrops of the quartzite at Trenton, New Jersey, and in Westchester County, New York. In fact there is some reason for believing that there was at this time communication between the inland sea and the Atlantic Ocean, possibly by a strait across northern New Jersey, separating Appalachia and Acadia. In any event, the southern part of the State perhaps still remained dry land, constituting a part of Appalachia that doubtless extended further eastward than the present continental shelf. As the early Cambrian quartzite (Hardyston) is not very thick and passes somewhat abruptly into interbedded shale and limestone, it is inferred that the land was low and that the eastward encroachment of the inland sea was relatively rapid.

The thick Kittatinny limestone (2,500 to 3,000 feet) succeeds the Hardyston quartzite and as yet no evidence of a break in sedimentation has been observed between them in this region. From this it might be inferred that the sea occupied this region continuously during the whole of the Cambrian period. It is true that no fossils of Middle Cambrian age have been found in the limestone and it is possible that an unrecognized time interval exists between it and the Hardyston quartzite or within the limestone itself. If such a hiatus exists, and there is some evidence of it from other regions, the Hardyston sea withdrew from New Jersey and land conditions prevailed throughout Middle Cambrian time before the return of the Upper Cambrian sea in which a large part of the Kittatinny limestone was laid down.

During the accumulation of the limestone comparatively little land-derived material was deposited in this area, but inasmuch as wave marks occur at various horizons the sea must have been shallow: It is inferred that the adjoining land remained low, with the shore further distant than during the deposition of the sands of the Hardyston quartzite, and perhaps even the southern portion of the State was also submerged. The thin shales and scattered seams of sandstone interbedded with the limestone, however, show that there was an influx of land sediment at recurrent intervals. In places a Beekmantown fauna is found in beds near the top of the Kittatinny limestone. No evidence of any break in sedimentation has been observed in this region to mark the passage from Upper Cambrian to Ordovician time, and the physical facts as found in New Jersey seem to indicate the continuation of marine conditions without interruption.

ORDOVICIAN PERIOD.

Pre-Beekmantown Emergence.—Investigations in adjoining states have led some geologists to conclude that there was at the close of Upper Cambrian time a widespread emergence of the land and withdrawal of the interior sea from the region of the St. Lawrence Valley, New York, northern New Jersey, Pennsylvania and adjacent states, far to the west and south, following which the region was again submerged in Ordovician time and the limestone with the Beekmantown fauna deposited (Ulrich and Schuchert); but, as stated above, positive evidence of this has not yet been observed in New Jersey. It must be recognized, however, that the base of the beds referable to the Beekmantown has not been seen in this State, and nothing is positively known regarding its exact relation to the underlying limestone.

Pre-Jacksonburg Erosion Interval.—The basal conglomerate of the Jacksonburg limestone, which rests on the Kittatinny limestone in many localities, and the slight unconformity between the two denote emergence of the sea bottom and erosion, after the deposition of the beds carrying the Beekmantown fauna, followed by shore conditions and an advancing strand line in the regions where the conglomerate occurs. Outcrops in southeastern New York, as well as near the Delaware, show that these movements extended beyond the limits of New Jersey. Preceding the formation of the Jacksonburg limestone the upper part of the Kittatinny limestone was so much eroded in places that the portion referable to the Beekmantown varies greatly in thickness, and in some places may have been entirely removed. With the return of marine conditions there were formed low limestone islands and reefs around which the conglomerate was deposited, generally without marked structural unconformity,[1] but erosional unconformity and the profound faunal change at this horizon indicate that the break in the record was long enough for the removal of beds of considerable thickness and for the incursion of a new and abundant fauna of very different facies from the preceding one.

In the Green Pond Mountain region this movement seems to have been more pronounced than in Kittatinny Valley, and the period of erosion much longer. In that region there is no record of the Jacksonburg and the Kittatinny limestone has only a fraction of the thickness it possesses elsewhere. Moreover, there are only doubtful occurrences of the Martinsburg shale there. These facts are interpreted to mean that here the erosion interval was so prolonged as to remove most of the Kittatinny limestone and to prevent the deposition of the Jacksonburg limestone entirely and of the Martinsburg shale in great part at least.

Deposition.—In the Kittatinny Valley region the changes that closed the deposition of the Jacksonburg limestone and began that of the Martinsburg shale were gradual and gentle, but were widespread, since limestone is succeeded conformably by shale from Vermont to Alabama. A northwestward recession of the shore line from its position far to the southeast, a probable shoaling of the water, and a greater altitude of the adjoining land brought about the deposition of siliceous silt and sand from Appalachia in place of the calcareous sediments that had been forming in the sea. The change in sedimentation began in this region at a much earlier time than in the typical Trenton area in New York, for here the lower Martinsburg shale contains a fauna which is characteristic of a portion of the typical Trenton limestone of central New York.

The Taconic Revolution.—At the close of the Ordovician period there were extensive crustal movements resulting in the formation of north-south mountain folds in the Taconic region of the eastern border of New York and western New England and extending northeastward into Canada. This is the earliest mountain folding

[1]In the limestone quarry at Sarepta, Warren County, the Jacksonburg limestone rests unconformably upon the beveled edges of the underlying Kittatinny limestone. The contact is well exposed and the unconformity unmistakable.

in North America that can be assigned to a definite geologic period. That these movements also affected northern New Jersey and raised it above sea level for a long time is shown by the lack of deposits belonging to the great time interval between the Martinsburg shale and the Shawangunk conglomerate.

SILURIAN PERIOD.

In central New York and elsewhere are found strata of the later Ordovician and the lower of the two major subdivisions of the Silurian period. During a large part, if not all, of this time New Jersey was a land area undergoing erosion. If any portion was invaded by the seas of this period it was probably for only a short time and subsequent erosion has removed all trace of any deposits that may have been formed. So far as information from this region goes it was a land area from late Utica until Salina time.[1]

In the Green Pond Mountain-Greenwood Lake region land conditions may have prevailed continuously from the close of the Kittatinny limestone deposition, although there is some evidence that for a short time at least shales, supposed to be of Martinsburg age, were deposited. Since the Green Pond conglomerate rests in some localities upon pre-Cambrian gneiss and in others upon the Kittatinny limestone, and since it is believed to be the same formation as the Shawangunk conglomerate and hence of probable Salina age, it is inferred that land conditions continued in the Green Pond Mountain region until late in the Silurian period, and that erosion was sufficient to remove all the earlier Paleozoic formations over wide areas. The Shawangunk and Green Pond conglomerates are probably remnants of a great alluvial fan that was spread upon the lowland adjoining the inland Salina (or Clinton) sea, or they may represent a great delta built out from the shore of this sea or estuary. In either case, the source of the sediments was the higher land of Appalachia to the southeast.

Still later in Silurian time, with the encroachment of the seas across the low plains of the Shawangunk and Green Pond conglomerates, the overlying red sand and mud of the High Falls and

[1] This is on the assumption that the Shawangunk conglomerate is of Salina age, as held by Clarke on the basis of the Eurypterid fauna found at Otisville, New York. If it is of Clinton age, as claimed by Van Ingen, the erosion interval was much shorter.

Longwood sandstone and shale were deposited. These were followed in turn by the limy sediments that now constitute the Bossardville, Decker, Rondout, and Manlius limestones of the upper Delaware Valley. For the most part the seas in which these limestones were laid down were not normal marine waters. Excepting the Decker, which contains a marine fauna, these limestones are either barren of fossils (Bossardville) or contain a fauna that is notably different from the marine faunas and that probably indicates enclosed bays and brackish-water conditions. Towards the upper part of the Manlius limestone marine forms make their appearance, and their abundance indicates that at the close of Manlius time normal marine conditions had been re-established in northern New Jersey. Whether south Jersey was a portion of the great land area of Appalachia or was also submerged during this period is unknown, because the older rocks of that region are deeply buried beneath the more recent sands, clays, and marls of the Coastal Plain.

DEVONIAN PERIOD.

The marine conditions that prevailed in northern New Jersey and eastern New York during the deposition of the upper part of the Manlius limestone continued in early Devonian time and the Coeymans limestone, Stormville sandstone, New Scotland shale and limestone, Becraft limestone, Port Ewen shale, and Oriskany limestone were laid down in the region of the upper Delaware Valley. The Stormville sandstone probably represents a slight emergence or shoaling of the sea, with corresponding elevation of adjacent portions of Appalachia and shifting of the coast northwestward toward this region—a movement that was greater in Pennsylvania than in New Jersey, but sufficient to substitute a deposit of sand for one of calcareous mud in the region southwest of Hainesville, Sussex County, while the deposition of limestone north of that point was not interrupted. The Port Ewen shale represents another minor oscillation and change of conditions resulting in the deposition of shale rather than limestone; and the Esopus grit, which separates the Onondaga limestone above from the Oriskany limestone below, is indicative of a greater movement and one affecting a wider area.

Following the accumulation of nearly 400 feet of sandy mud in the upper Delaware Valley, there was a deepening of the waters in this region, a widespread expansion of the interior sea, and the deposition of the Onondaga limestone, a formation that stretches west through New York, north to Hudson Bay, and south through the lower Mississippi Valley. In the broad interior sea of this period there were developed coral reefs in extraordinary profusion, although none have been recognized in the New Jersey limestone referable to this time.

Conditions prevailing in the Green Pond Mountain belt during early Devonian time are not so clearly indicated as in the Delaware Valley. None of the lower Devonian formations nor of the Silurian above the Decker limestone have been recognized. Although some or all of the intervening formations may be present in attenuated form, yet in the absence of full information it is uncertain whether or not this region was land during a portion of early Devonian time. It is fairly well established, however, that during Onondaga time, while limestone was being deposited in the region of the upper Delaware Valley and westward, fine sandy sediments were laid down in the Green Pond-Greenwood Lake region, forming the Kanouse sandstone.

At the close of Onondaga time there was a shoaling of the sea and an incursion of land-derived sediment due to the broad uplifting of the old lands of Appalachia to the southeast and Acadia to the northeast. In the upper Delaware Valley the black mud of the Marcellus shale succeeded the limy ooze of the Onondaga limestone, but in the Green Pond Mountain region conditions were not greatly changed and the Kanouse sandstone was followed by the great thickness of the Cornwall (Pequanac) shale. The growing uplift of the bordering land gradually increased the erosive power of the rivers and great quantities of mud and sand were carried down and spread out on the newly formed delta lands and in the shoaling waters of the retreating sea. With the continual sinking of the belt of sedimentation beneath these deposits they accumulated in Maryland, eastern Pennsylvania, New Jersey, and New York to a thickness of more than 10,000 feet in places. This great thickness was not reached in New Jersey, but the Bellvale sandstone and the Skunnemunk conglomerate now exposed in Bearfort Mountain west of Greenwood Lake represent a portion of the deposits of this period—apparently part of a piedmont gravel plain that lay between the flat delta surface and the high land of Appalachia to the southeast and formed by numerous short streams that built coalescing fans. The great thickness and coarseness of the Skunnemunk conglomerate imply land of high relief and rivers of strong grade coming down from mountainous lands that lay off the present Atlantic coast.[1]

CARBONIFEROUS PERIOD.

The later Paleozoic history of the State cannot be read from the sedimentary record within its borders. It seems to have become a land area in late Devonian time and possibly no part of it was again submerged during the Carboniferous period. In closely adjoining portions of Pennsylvania, however, during Mississippian or Subcarboniferous time great thicknesses of conglomerate, sandstone, and shale (the Pocono and Mauch Chunk formations) accumulated in the shallow borders of the interior sea and in part perhaps upon adjacent lowlands. In the northern anthracite area of Pennsylvania, 40 miles northwest of New Jersey, they have a thickness of 1,200 feet. These sediments were washed down from the highlands of Appalachia to the east, which doubtless included most of New Jersey, but it is quite possible that the northwestern border of this State received similar sediments during a part of this time, probably upon low coastal plains bordering the sea that lay off to the northwest. If strata of this age were ever formed within New Jersey, however, they have been entirely removed by subsequent erosion. Renewed emergence of the land, which greatly restricted, if it did not entirely obliterate, the eastern interior sea, brought the period of Mississippian deposition to a close.

In Pennsylvanian (Upper Carboniferous) time a return of the sea is shown in neighboring parts of Pennsylvania by the Pottsville conglomerate (200 feet thick) formed over wide areas by the deposits that accumulated along the advancing shore line. Above this lies a great succession of alternating beds of shale, sandstone, conglomerate and limestone, with occasional beds of coal. These are known as the Coal Measures and their eroded remnants in the northern anthracite basin still have a thickness of 1,800 feet. They show that the shallow interior sea was repeatedly succeeded by low-

1 Joseph Barrell, American Journal of Science, vol. xxxvi, 1913, pp. 465, 466.

lying, poorly drained lands, with numerous extensive peat swamps, and these in turn were followed by resubmergence and the return of marine conditions. This alternate advance and retreat of the shore line was far-reaching and many times repeated during Pennsylvanian time, and marine waters or the coal-forming swamps may have occupied the nearer portions of New Jersey from time to time; but, if so, all traces of the sediments and coal beds, which would preserve the evidence of such conditions, have been removed by the vast erosion to which this region has been subjected since the Carboniferous period.

PERMIAN PERIOD.

The Appalachian Revolution.—No Permian formations occur in New Jersey. The nearest are in western Pennsylvania and it is not at all probable that deposits of this period ever extended as far east as New Jersey. The orogenic or mountain-folding movements that eventually resulted in the formation of the Appalachian Mountains had probably begun as early as the middle of Carboniferous time, and "toward the end of the Carboniferous there was in the low-lying Appalachian coal field a slowly progressive movement of elevation, resulting in the draining and drying up of most of the region over which the peat bogs had been extended. The movement spread east, north, and south, leaving in the middle of the region a smaller area in which the conditions of the coal measures continued very much as before."

* * * * * * *

"At the end of the Lower Permian the entire series of the coal measures east of the Mississippi River was elevated and the deposition of strata apparently ended, though there is no way of determining exactly when this elevation took place, nor how great a thickness of beds has been removed by denudation since the upheaval." (Scott.)

During the long lapse of Paleozoic time the region of the interior sea, west of Appalachia, and particularly the eastern part of it, although many times uplifted into dry land, had been on the whole a region of subsidence in which sediments many thousand feet thick had accumulated. Finally, came the uplift that followed the deposition of the Pennsylvanian series of the Carboniferous and raised the surface of the entire region above sea level. This differed from all former elevations of this region in the mode of its accomplishment and the permanence of its results. Under the influence of horizontal compression the thousands of feet of sedimentary strata in this and adjoining regions, together with the pre-Cambrian floor on which they rest, were bent into the great mountain-making folds of the Appalachians (Fig. 3), and the whole folded belt was thus squeezed into an area many miles narrower than it had been before. There was a corresponding bulging upward of the compressed region, and the growing young Appalachians may once have rivalled the Alps in height and ruggedness. This, however, depended upon the ratio between the rate of uplift and the rate of downwear under the vigorous attack of the forces of denudation.

The great mountain folds or wrinkles extended in a northeast-southwest direction, and many of them were pushed over somewhat toward the northwest so that their axial planes are generally inclined more or less steeply to the southeast. Along lines of structural weakness the strata were closely folded, fractured, and overthrust along great fault planes, which were themselves in some places involved in the later movements and sharply folded (Fig. 5). Cleavage was developed by the compression of the finer-grained rocks, giving rise to slate which is of considerable economic importance in some regions. (See "Structure of the Paleozoic Formations," p. 57.)

The disturbances were greatest to the southeast, as is shown by the fact that the Paleozoic rocks in this region are more distorted in the small areas southeast of the Highlands than in Kittatinny Valley. Further northwest the compression was much less and the strata in northeastern Pennsylvania were merely uplifted and thrown into broad wave-like undulations, which become gentler and gradually die out westward. This great series of movements, involving compression, folding, faulting and uplift, began in Pennsylvanian time but took place chiefly in the Permian period. It has been variously called the Appalachian revolution and the post-Pennsylvanian or post-Carboniferous deformation, and its completion marked the close of the Paleozoic era.

MESOZOIC ERA.

TRIASSIC PERIOD.

Erosion—During the crumpling and uplifting of the Appalachian folds, and through most of subsequent time, both the Highlands and the Appalachian Valley belt have remained dry land, and the higher portions in every period have been subjected to varying degrees of erosion. During the closing stages of the Paleozoic era, particularly in the Permian period, the young and vigorously growing Appalachian Mountains were attacked with equal vigor by the elemental forces of destruction, which continued to wear down the region of the present Highlands and mountains far into the Triassic period before the deposition of the Newark sediments began on the lower land to the southeast. Hence the whole area of the present Highlands and the Piedmont Plain had apparently been worn down to almost a smooth plain on which the Triassic shale and sandstone now overlap the beveled edges of folded and faulted Paleozoic strata as well as eroded pre-Cambrian rocks.

Deposition.—The Appalachians were doubtless worn down by this time, except for the influence of a gradual or occasional uplift by the continued action of the declining orogenic forces to which the mountain folds owed their origin. The re-elevation of the old land of Appalachia and the depression of the present Piedmont region to the low level at which sediments washed from the higher country began to accumulate upon it may have been due in part also to warping due to these forces. Some of the characters of these sediments, particularly their prevailing bright red color and the general absence of organic matter, seem to point to a dry climate in which occasional torrential rains brought down the debris from the higher lands and spread it in broad alluvial fans upon the adjacent plains.[1] Here and there along the northwestern border of

[1] See Annual Report of the State Geologist for 1906, pp. 97-129. The evidence for this view is also well summarized by Schuchert in a discussion of the Newark strata of Connecticut, which are in every way comparable to those of New Jersey. He says: "None but animals and plants that inhabit the land are here seen, and when these are considered in connection with the exceedingly common sun-cracked layers of mud, less frequent raindrop impressions, local accumulations of semirounded bowlders, and the nearly constant lens-shaped bedding of the imperfectly assorted sands and conglomerates between the muddier

these plains, where swift streams debouched from the adjoining Highlands, coarse gravels composed of quartzite and limestone accumulated, but the bulk of the sediment seems to have come from Appalachia to the east. Reptiles, some of them of gigantic size, wandered across the soft mud flats, leaving as a record of their progress many footprints, which in some places are perfectly preserved in the strata.

Under the steadily increasing load of sediments and the continued action of the forces that were warping the surface of the land, long northeast-southwest belts of the Piedmont region in New Jersey and neighboring states were gradually carried down by faulting and folding in narrow trough-like depressions. Concurrently with these movements of depression the incipient basins were being continually graded up by the deposition of sediment, which thus attained great thickness along these narrow belts. Considerable material was supplied from the lands to the northwest, as shown by the quartzite conglomerates, but the gneisses and granites on that side were not then exposed to erosion, and the great bulk of the feldspathic and micaceous sandstones that make up so much of the Newark rocks must have come from higher lands that still existed to the southeast (Barrell).

From time to time sufficient surface depressions were doubtless formed on the low plains of accumulation to guide the courses of streams and to contain local shallow lakes and ponds. Thus in certain restricted localities large numbers of well-preserved fish remains are found. The abundance of the fossils in certain layers may represent the occasional drying of the ponds, but is more probably due to the wholesale destruction of fish life by earthquakes accompanying the faulting, the remains being buried by the mud that roiled the water and choked them and by the next succeeding sediments. In the Piedmont of Virginia and North Carolina Triassic swamps gave rise to accumulations of vegetation that are

layers of wider areal extent, the evidence is positive that the Newark series is fluviatile in nature and must be eliminated from marine deposits and Triassic seas." (Bulletin Geol. Soc. of America, vol. 20, 1910, p. 438; also compare pp. 578, 579.)

It is to be noted further that favorable conditions for mud-cracking over wide areas are found only in playa basins and upon the subaerial portions of deltas, where all parts are alternately covered by water and by air for considerable periods of time. Compare Joseph Barrell, American Jour. Science, vol. xxxvi, 1913, p. 438.

now represented by beds of coal, but none seems to have existed in the New Jersey region.

Vulcanism.—During the later portion of this period of deposition occurred the first and only known volcanic activity in New Jersey since pre-Cambrian time. Three or more periods of eruption resulted in the flow of thick and extensive lava sheets upon the sediments, each eruption being followed by a quiescent period during which sedimentation proceeded as before and the lava flow was buried. A portion of the molten magma that failed to reach the surface was intruded between the strata as an extensive sheet of somewhat irregular outline, forming the great Palisade sill, which stretches beyond the boundaries of the State both to the northeast and to the southwest. Fissures in the strata were also filled by sheets of upwelling lava which solidified into thin vertical dikes, many of which are offshoots of the great intrusive sill.

The flows and intrusive sheets, in their present eroded and somewhat reduced condition, are restricted to the areas of the Newark sediments, but a few dikes of similar character that cut the adjoining gneisses to the northwest probably also belong to this period of igneous activity. So, too, the nephelite-syenite mass (ns) along the contact of the Martinsburg shale and the Shawangunk conglomerate, west of Beemerville in Sussex County, and the neighboring dikes and breccias, as well as the basic dikes about Hamburg, Franklin Furnace and adjacent localities may date from this period.

Post-Newark Faulting and Erosion.—The period of Newark sedimentation was brought to a close near the beginning of the Jurassic—possibly in early Jurassic time—by a crustal fracturing on a large scale and a tilting of the fractured blocks. The individual fault-blocks are many miles in width and the tilting probably gave rise to mountainous elevations at their upturned edges.

Faulting was not restricted to the present area of the Newark formations, but affected also the adjoining regions to the northwest, where the Appalachian folds and overthrust faults of the post-Pennsylvanian deformation are cut by normal faults that are probably referable to the close of this period.

At this time also occurred the depression and final disappearance of the old land of Appalachia to the southeast and the near approach of the Atlantic Ocean to its present shores.

JURASSIC PERIOD.

Erosion.—After the disturbances terminating Triassic deposition, as described above, the history of northern New Jersey cannot be inferred from the sedimentary record, since the deposits of the later periods are, in the main, lacking in this region. Hence the geologist is limited chiefly to the evidence of topographic forms which, except in very minor features, are the result of long-continued sub-aerial erosion. Some conclusions may be drawn concerning the various stages in the progress of this erosion history when these topographic forms are considered as parts of the great Appalachian province.

Uplift of the low intermont plains of deposition, accompanied by northwestward tilting and normal faulting, terminated the accumulation of the Newark sediments, caused the displaced strata to be greatly uplifted and subjected to vigorous erosion, which beveled off the upturned edges, uncovered again the margins of the buried basalt sheets, exposed even the deep-seated intrusive sill of diabase, and eventually removed the whole formation except from those long narow belts where down warping and faulting had given rise to great local thickening of the sediments and had dropped them down between adjacent areas of crystalline rocks, which have protected them from complete destruction.

Jurassic Peneplain.—A vast amount of denudation occurred in Jurassic time and the constructional topography that must have resulted from the post-Newark movements, both in the Triassic areas and throughout the Appalachian province, was largely, if not entirely, obliterated before the deposition of the Lower Cretaceous (Comanchean) sediments of the Coastal Plain. These sediments now overlap the beveled edges of the Triassic beds along their southeastern margin, and outlying remnants show that they formerly extended much further northwestward than at present.

It has not been determined with certainty just how far the faulted block topography of the post-Newark deformation was reduced toward base level before the beginning of Lower Cretaceous deposition. Possibly it was entirely obliterated and the region reduced to one of moderate or even low relief. From the little that is known about the crystalline floor on which the Raritan (Lower Cretaceous) beds rest it seems to be an approximately smooth surface, with low hills and shallow valleys. It is probably safe to conclude, therefore, that Jurassic (and early Lower Cretaceous) erosion planed across the Newark rocks and removed them entirely from an area of considerable width to the southeast of their present outcrop, and perhaps brought the region of the present Highlands and Kittatinny Valley to a rolling plain.

LOWER CRETACEOUS (COMANCHEAN) PERIOD.

Raritan Deposition.—Early in the Lower Cretaceous period, perhaps marking its beginning, a warping of the land involved an uplift of the axis of the Appalachian province and perhaps a depression of the coastward region. In the uplifted area the velocity of the streams was increased, while the relatively flat and depressed coastward tract became a zone of lodgment for the sediments that were washed down by the rejuvenated streams. Lakes, marshes, and perhaps estuaries were features of the region, and in them and on the bordering lowlands beds of gravel, sand, and clay were deposited.

Sedimentation inaugurated by this movement apparently did not affect New Jersey until considerably after the beginning of Lower Cretaceous time, or if it did the beds were completely overlapped and concealed by later deposits of this period known as the Raritan formation. The presence of feldspar (or kaolin from the decay of feldspar in place) in the coarse sand and fine gravel of the Raritan formation shows that erosion at this time sometimes exceeded rock decay and indicates high land and large areas of granite-gneiss to the west, whence the sediments were derived. The thickness to which these sediments accumulated in New Jersey is unknown, but it certainly exceeded 200 feet, since that is approximately the thickness of the eroded remnant along the present outcrop.

Post-Raritan Erosion.—The upper surface of the Raritan formation was apparently eroded before the overlying Magothy sand and clay were deposited. Moreover, the fossils found in the Magothy indicate the prevalence of marine conditions and a somewhat later period of time than the Raritan. Hence there seems to be good evidence for the conclusion that, following the deposition of the latter, the zone of accumulation became for a time a zone of denudation.

UPPER CRETACEOUS (OR CRETACEOUS) PERIOD.

Post-Raritan Subsidence and Deposition.—Following the erosion of the upper Raritan beds a progressive subsidence of the south-eastern border of the land occurred with an accompanying invasion by the waters of the Atlantic, establishing a condition that continued throughout Upper Cretaceous time. Just how far the sea advanced to the northwest at this period is unknown. Davis has cited certain peculiarities in the arrangement of the streams draining the Watchung Mountains and the nearer portions of the Highlands which suggest that Cretaceous or later sediments may have covered the whole of the Triassic belt and overlapped the margin of the Highlands. Certain it is that the sea extended further northwest than the present outcrop of the Magothy strata and that at this period all of south Jersey and a considerable portion of north Jersey as well, reaching far toward and possibly overlapping the borders of the Highlands, were submerged. Concurrent uplift of the axial region of the Appalachian province furnished the vast amount of sediment that accumulated on the submerged Coastal Plain in this period.

Beds of sand, clay, and greensand (glauconite) marl, variously interbedded and commingled, constitute the Upper Cretaceous sediments. Some formations are comparatively free from glauconite, others are composed in large part of this mineral. Observations in existing seas indicate that deposits of glauconite are being formed today on portions of ocean floors adjacent to the coast where land-derived materials are being deposited in only moderate amounts. But little of this mineral is formed at depths greater than 900 fathoms and most of it is produced near the border of the continental shelf (the submerged border of the continent) at about 100 fathoms. From this it is inferred that during certain intervals of Cretaceous time, represented by the Navesink marl, the Hornerstown marl, and the Manasquan marl, southern New Jersey was submerged to a depth of about 600 feet and the shore of the Atlantic lay far back upon the Highlands, or possibly beyond, and in a similar position across Pennsylvania and southward.

During alternating periods, represented particularly by the Woodbury clay, the Englishtown sand, the Wenonah sand, the Red Bank sand, and the Vincentown sand, which contain comparatively little or no glauconite (greensand), the water was shallower, the shore nearer, and sediment in greater amounts was washed from the land into the sea that overspread this region. This alternate deepening and shoaling of the waters implies oscillations of the shore line upon the low-lying coast across a zone many miles wide.

The above conclusions, based upon the character of the successive formations, are strengthened by a careful study of the numerous marine fossils which they contain. The strata from the Magothy to the Tinton, inclusive, contain a complex assemblage of organisms with two distinct facies. One of these, a *Cucullea* fauna, characterizes the more glauconitic formations—the Merchantville, the Marshalltown, the Navesink, and the Tinton—and may be regarded as a deeper water fauna. The second faunal facies, characterized by *Lucina cretacea* or its associates, occurs in the clays and clay sands of the Magothy, the Woodbury, the Wenonah, and the Red Bank formations and was a shallower water fauna.

Both of these facies probably lived side by side in their respective zones off the shore and migrated back and forth across the Coastal plain region with the gradual advance and retreat of the sea. During the periods of depression the deeper water with accompanying glauconitic sediments and the *Cucullea* fauna gradually entered this region from the southeast and occupied a belt that had formerly been occupied by the shallower water fauna and in which chiefly land-derived sediments had been deposited. With a later period of emergence the faunas shifted to the southeast and the shallow water facies again occupied the region.

With the deposition of the Hornerstown marl a new fauna made its appearance in the Cretaceous seas of this region, quite different from that in the formations below, but so far as has been determined there was no interruption in sedimentation. The records in the strata do not throw any light on the disappearance of the previous fauna. The occurrence of the Vincentown sand between the Hornerstown and the Manasquan marl beds indicates that the oscillations of the shore and the alternate deepening and shoaling that characterized the earlier epochs continued through the later part of Upper Cretaceous time.

Erosion.—During the long period represented by the Upper Cretaceous sediments deposited on the submerged margin of the lowland, erosion continued on the inner portion, bringing it nearly to base level. The alternating depressions and elevations recorded in the sensitive time scale of the marine sediments were unquestionably marked by corresponding disturbances of the normal erosion cycle, but apparently none of these was of such moment as to find topographic expression of sufficient permanence to be recognizable at this late day.

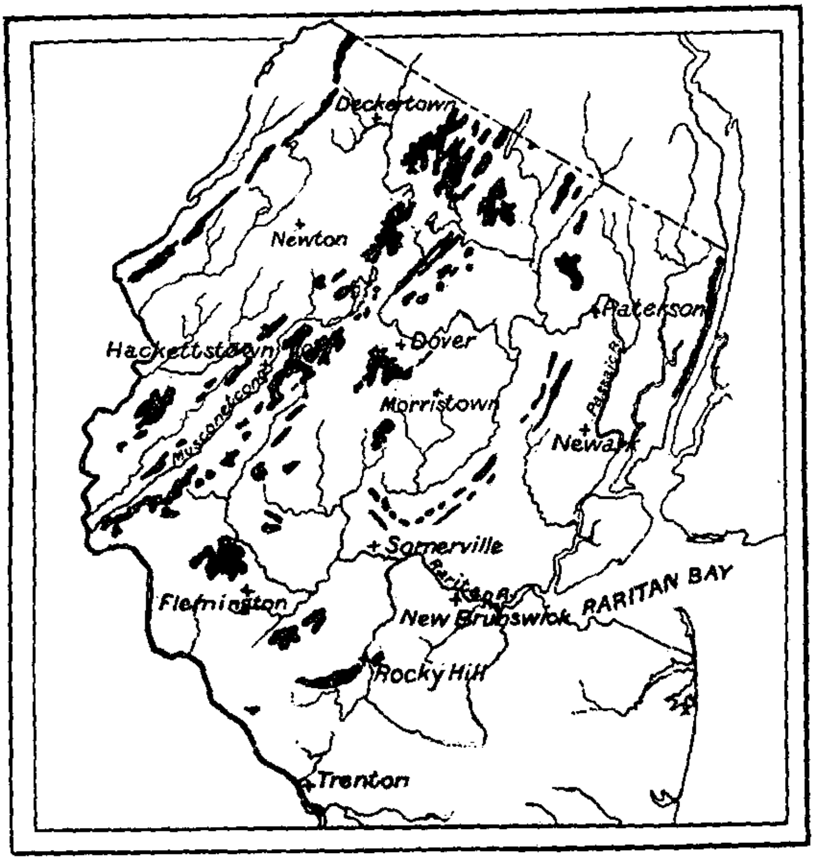

Fig. 8. Remnants of the Schooley Peneplain.

The Schooley Peneplain.—So far as has been determined from the topography, erosion continued without notable interruption in the region that was not submerged until at the end of Cretaceous time a wide area, extending far beyond the limits of New Jersey, had been reduced to a low undulating plain—the Schooley, Kittatinny, or Cretaceous peneplain—the last name being derived from the period of its formation and the other two from mountains whose summits are well-preserved remnants of the old peneplain.

The even crest line of Kittatinny Mountain, near the northwestern border of the State, the broad, flat-topped summits of the Highlands, the even crests of Green Pond Mountain and the higher trap ridges (Watchung Mountains and the Palisades) and the general level of the Hunterdon plateau west of Flemington (see Figs. 8, 9) are all believed to be remnants of a widespread peneplain

Fig. 9. Profile across Northern New Jersey, showing by dotted line the uplifted and tilted Schooley Peneplain before erosion.

resulting from long-continued erosion of older and higher land masses. Its dissected remnants are an important topographic feature throughout the Appalachian province from New York to Alabama.

If the broad expanse of Kittatinny Valley, the narrower interhighland valleys, and the wide red shale lowland of the present Piedmont region were all filled again to the level of the upland ridges the old plane would be restored as a gently warped surface, sloping to the southeast and diversified by knolls. If this old restored surface were bodily depressed to a flat, low-lying plain near sea level, northern New Jersey would return to the topographic monotony to which erosion had brought it toward the end of the Upper Cretaceous period. Some low rounded hills in the southern Appalachian region probably represented unreduced portions of an earlier (Jurassic or Comanchean) peneplain.

Toward the end of this cycle, as the country became lower and flatter, erosion was exceedingly slow; hence there was deep decay of rocks and the consequent accumulation of a heavy mantle of soil.

The elevation and warping of this peneplain, together with the uplift of the submerged Atlantic border of the continent, stopped the accumulation of Cretaceous sediments, added the Coastal

Plain to the land, and at the same time inaugurated a new cycle of erosion in the uplifted inland region. The uplift of the Appalachian axial region at this time and similar later movements, particularly that which occurred at the close of the Miocene or in the early Pliocene epoch, have caused the streams to sink their valleys deeply along the belts of softer rocks, leaving the upturned edges of the harder strata to stand as the mountain ridges of the present time, their generally even crest lines rising approximately to the level of the old uplifted Schooley peneplain, which had been planed down across folds and faults in both hard and soft strata. Thus the mountains of today are but the rejuvenated roots of the old structures.

"We look in vain in the Appalachians for the mountains made by the original folding. It was once thought that their time-worn slopes rose still from the present valley floors, even where the folding dated from the close of the Ordovician. Then it was seen that most of the Appalachian Mountains were the remnants of a dissected plateau which had in the late Mesozoic been a plain of erosion lying near the level of the sea. The mountains existing from the Appalachian revolution were then regarded as those higher masses rising in isolated groups above the plateau. But with further searching the mountains of even Permian folding are found to recede continually like the proverbial foot of the rainbow." (Barrell.)

CENOZOIC ERA.

In the northern part of the State the history of the Cenozoic era, as of the Mesozoic, was chiefly one of erosion, certain stages of which are recorded in the resultant topographic forms. In the southern portion the record was largely one of sedimentation, interrupted by important but relatively briefer periods of erosion. Between these extremes the middle portion, corresponding roughly to the Piedmont belt of Triassic rocks, was alternately the seat of great erosion and extensive deposition. In this region it is possible to correlate in some degree the erosion record of the north with the sedimentary record of the south and so to construct a connected geologic history.

TERTIARY PERIOD.

Eocene.

Early Tertiary Erosion.—With the uplift and warping of the Schooley peneplain Cretaceous sedimentation in this region came to an end. As the peneplain and its submerged seaward border were elevated, the uplifted surface consisted of two distinct portions—the part that had remained land and had been subjected to continuous erosion, and the part that had been submerged and had become covered with its heavy mantle of Cretaceous sediments. On the low flat peneplain there were sluggish streams meandering through broad shallow valleys. As the land rose these streams were quickened into activity and began to cut their channels deeper. With the gradual emergence of the new Cretaceous coastal plain these streams extended their courses seaward along routes that were determined by the slight inequalities of its topography and the general inclination of its surface.

It is probable that during the development of the Schooley peneplain the streams had in large measure become adjusted to the geologic structures so that they followed the belts of softer rocks; for in the course of their development in regions of tilted and folded strata of varying degrees of hardness, streams tend to shift their channels into such positions. Thus the Paulins Kill, the Pequest, and the Musconetcong rivers followed for the most part belts of limestone and shale, and after the uplift they persisted in their courses. West of Kittatinny Mountain, which doubtless still formed a low divide on the peneplain, a large stream probably followed the outcrop of the soft Marcellus and Salina shales, approximately as does the present Delaware. This stream, or the master stream to which it was tributary, crossed Kittatinny Mountain at the site of Delaware Water Gap, but at a level approximately 1,200 feet above the present river level.

Since the uplift of the peneplain involved a downward tilting of the land surface toward the southeast, this stream, the ancient Delaware, unquestionably flowed southeastward from the gap, much as it does today. Culvers Gap, in Sussex County, marks the course of another stream on the Schooley peneplain which then crossed the belt of hard Shawangunk conglomerate at an elevation about 400 feet above the present level of the gap. The ancestors of the present Pequannock and Rockaway rivers apparently followed courses across the belt of crystalline rocks in directions that were more or less transverse to the geologic structure of the uplifted peneplain. How far these courses were determined by the uplift, and how far they had been acquired during the preceding cycle of erosion cannot now be stated.

The uplift rejuvenated the streams and inaugurated a new cycle of erosion. It was at this time that the Delaware and its tributaries began the long task of excavating the great depression west of Kittatinny Mountain and the equally difficult task, although of lesser volume, of cutting the narrow gorge through the harder and more massive rocks at Delaware Water Gap; that the Culvers Gap stream begun the cutting of its gap across the same hard rocks; that the streams of Kittatinny Valley began to work out the great trough that now separates the Highlands from Kittatinny Mountain; that the Musconetcong and Pohatcong rivers began the excavation of their inter-Highland valleys; and that the German Valley-Greenwood Lake depression was commenced. At the same time the transverse streams crossing the crystalline rocks of the present Highlands, the Pequannock and the Rockaway, began the difficult task of lowering their valleys through the resistant gneiss.

New streams established on that portion of the uplifted peneplain that had been submerged and covered with Cretaceous sediments, as well as those that crossed it from the older formations to the northwest, chose courses that were determined by the inequalities of the new surface and without regard to the buried structure of the hard rocks. Where the Cretaceous beds were thin the streams soon cut through them to the older rock structure below. In these cases the stream courses were determined, not by the structure of the formation on which they were superimposed, but by the attitude and surface topography of strata that were afterwards entirely removed.

Shark River Submergence.—Early in the Tertiary period the cycle of erosion was interrupted in the eastern part of the State by a slight submergence during which strata of Eocene age (Shark River marl) were deposited in eastern Monmouth County. This marl is now found as far west as Farmingdale and the shore of the Eocene sea must have been somewhat further inland, but how far we have no means of determining accurately. Since the Shark River formation is not of great thickness the submergence was presumably not of long duration. Upon the withdrawal of the sea the upper part of the Eocene beds were subjected to denudation. Meanwhile erosion continued, of course, without interruption in the area that was not submerged.

Miocene.

Kirkwood Submergence.—In Miocene time the sea again invaded the southern portion of the State, the submergence reaching across the beveled edges of the Cretaceous strata, which thus became successively overlapped by the deposits of this epoch. The sea reached the southeastern borders of the Triassic belt and probably covered a portion of this formation, but its northern limits cannot be definitely determined. During this submergence beds of fine micaceous sand, alternating in some places with layers of clay ranging from a fraction of an inch to many feet in thickness, were deposited over the southern part of the State, the deposits attaining a much greater thickness along the present southern coast than in Monmouth County or inland. Although the Cretaceous strata had suffered considerable erosion during the periods of emergence preceding and following the Eocene submergence, the surface on which the Kirkwood beds were laid down was relatively level, apparently much less uneven than the rougher parts of the present Coastal Plain.

Post-Kirkwood Emergence.—In southern New Jersey the Kirkwood is followed unconformably by the Cohansey sand, but the unconformity is not marked. Hence it is inferred that there was a relatively brief emergence following the Kirkwood deposition, during which the sea may not have withdrawn entirely from the present limits of the State.

Cohansey Submergence.—Following the emergence in post-Kirkwood time, the sea again invaded the southern half of the State, and in its waters the gravel, sand, and clay of the Cohansey formation were deposited. Identifiable remnants of the Cohansey do not occur as far northwest as do the Kirkwood outliers, and it may be that during the Cohansey submergence the sea did not reach as far inland as during the Kirkwood. On the other hand, small patches of sand and scattered pebbles more nearly resembling the Cohansey than the Kirkwood have been found at several places on the Triassic formations, and even along the margin of the Highlands, so that there seems to be considerable evidence in favor of the conclusion that the Cohansey sea submerged the belt of Triassic shale, except for the Hunterdon plateau west of Flemington, and reached the border of the Highlands. During this submergence Rocky Hill ridge, the Watchung Mountains (probably as far north as Paterson), and Sourland Mountain apparently received at least a thin mantle of these sediments.[1]

The Harrisburg Peneplain.—During the accumulation of the Kirkwood and Cohansey strata in the southern portion of the State the northern part was undergoing erosion. The streams continued the work begun with the uplift of the Schooley peneplain at the close of the Cretaceous period, and by the close of the Cohansey had made considerable progress in the development of the present system of mountains and valleys. During the early part of the Tertiary period a wide lowland seems to have been developed on the softer rocks at a level now represented by the broad summits

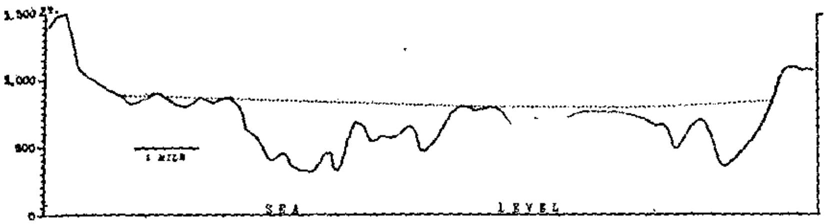

Fig. 10. Profile across Kittatinny Valley, showing by dotted line the Harrisburg peneplain, and existing remnants.

of the Martinsburg shale belts in Kittatinny and Musconetcong valleys at an elevation 500 to 600 feet lower than the Schooley peneplain (Fig. 10).

In the harder rocks of the Highlands the streams eroded narrow valleys to depths presumably accordant with this level, but the time

[1]The evidence in favor of this hypothesis is chiefly the occurrence of scattered pebbles resembling those in the Cohansey (or the Beacon Hill gravel, which immediately followed the Cohansey sand). The fact must not be overlooked, however, that very similar quartz pebbles occur in the basal beds of the Cretaceous and that they may be really remnants of the Cretaceous deposits on the submerged margin of the Schooley peneplain.

was not sufficient to develop well-marked plains or terraces and hence this level has not been recognized on the steep sides of the narrow Highland valleys. In the belt of the softer Triassic rocks also, so far as it was not submerged, a plain at an accordant level was probably developed, but later erosion has apparently destroyed all traces of it. This level is believed to be the equivalent of the peneplain developed in the vicinity of Harrisburg, Pennsylvania, and it has, therefore, been called the Harrisburg peneplain.

It is not possible to assert positively that the Kirkwood and Cohansey sedimentation in southern New Jersey was exactly synchronous with the completion of the Harrisburg peneplain further north, but they were both the results of forces at work during the early and middle portion of the Tertiary period, and hence their essential contemporaneity is inferred.

Pliocene.

Post-Cohansey Uplift and pre-Bridgeton Erosion.—The cycle of erosion during which the Harrisburg peneplain was developed and the Kirkwood and Cohansey beds were deposited was terminated —apparently in early Pliocene time—by an upward arching of the Appalachian region. The upward movement involved at length the northern part of New Jersey and rejuvenated the streams that drained it. The surface, deeply mantled with residuum accumulated during the peneplaining stage, readily furnished load to the streams in their flood stages. The streams upon reaching the southeastern margin of the peneplain, which was not affected by the uplift, and the adjoining low, flat, and recently emerged sea bottom spread much of their load of sediment over a wide zone of deposition upon the land. With continued uplift the inland border of this zone was continually shifted seaward and the inner margin of the deposits was eroded. The Beacon Hill gravel, which now caps some of the highest hills on the Coastal Plain is believed to represent remnants of fluviatile deposits made at this time, and to be the correlative of the Lafayette gravel further south.[1]

As a result of the uplift just mentioned the streams in northern

[1]In the earlier reports of the Geological Survey (1892-1900) the Cohansey sand was included in the Beacon Hill formation. The evidence of separation is by no means decisive, and perhaps it should not be made; but the later classification seems on the whole to harmonize better with the facts in other regions.

New Jersey that had reached the base level indicated by the Harrisburg peneplain recommenced their work of reducing the land mass to a new level. Probably during this stage or late in the preceding Harrisburg cycle, a stream worked headward along the strike of the High Falls shale, west of Kittatinny Mountain, intercepted and captured the upper portion of the stream crossing the mountain through Culvers Gap, and by this act of river piracy and the shifting of divides resulting from it, changed the water gap into a wind gap. In Kittatinny Valley and the Highlands it is not possible to differentiate the erosion during this cycle from that later—in early Quaternary time—and it can only be said that where the Harrisburg peneplain had been developed it was much dissected, and that in the harder rocks where it was absent the streams continued the work of deepening their valleys. On the softer shales of the Triassic belt, however, more rapid progress was made and the Harrisburg peneplain was probably reduced nearly to a new base level, above which remained the resistant trap ridges and the plateau of hard sandstone and argillite west of Flemington. The crests of these retained nearly the altitude of the old uplifted Schooley peneplain.

Remnants of the pre-Bridgeton surface have not been recognized with certainty in the Triassic belt, but if any of the higher outlying areas of yellow gravel referred to the Pensauken are in reality Bridgeton the surface on which they rest represents the level established at this time. It was probably a little, but not much, above that determined by the next epoch of erosion in the interval between the Bridgeton and Pensauken stages of deposition.

In the Coastal Plain in pre-Bridgeton time, except for occasional small areas capping isolated hills, the Beacon Hill, Cohansey, and Kirkwood formations were removed from a wide belt northwest of a line from Long Branch through Freehold, Clarksburg, Mullica Hill, Woodstown, and Alloway. The region of the Clarksburg and Mount Pleasant Hills had been dissected to depths 200 feet below the present summits, but we do not know how much higher the summits were then than now. Adjacent to the Delaware there was developed a broad lowland tract, the surface of which is now from 110 to 135 feet above the sea in the Camden region. On the southeast this lowland was bordered by land some 50 feet higher. Northeastward it was probably continuous with the lowland that extends along the inner margin of the Cretaceous strata to Raritan River. During this period the streams flowing directly to the ocean, like Maurice River, Mullica River and others, were likewise developing valley plains along their courses.

QUATERNARY PERIOD.

Bridgeton Deposition.

Early in Quaternary time the streams in the southern and central portions of the State ceased to erode and began to aggrade the lowland by depositing the sand and gravel that constitute the Bridgeton formation. To what extent this was due to changes of elevation of land and sea or to climatic changes is uncertain. There was probably a moderate submergence, particularly of the lower courses of the rivers. Those heading far to the north, as the Delaware and its larger tributaries, may have been greatly overloaded by material derived from an early Glacial ice sheet, since some of the material in the Bridgeton seems to have been transported by floating ice. When the submergence reached its maximum there was probably a broad sound between Raritan Bay and Trenton, connecting with another arm of the sea in the lower Delaware Valley. The change of level at its maximum was such that most parts of the State that are now 200 feet or less above the sea were probably then submerged. If so deposition by rivers prevailed over this area during the early stages of subsidence and by the sea during the maximum submergence.

Post-Bridgeton Uplift.

Somerville Peneplain.—After the deposition of the sediments now constituting the Bridgeton formation there was an emergence of the land and the newly-deposited beds, as well as others above the sea, were subjected to erosion. The land stood for a time at least as high as now, as shown by the depth of the valleys then excavated. This interval of erosion was long enough to remove whatever of the Bridgeton formation had been deposited on the Triassic rocks, and to develop a broad plain at a level probably a little below the surface on which the Bridgeton deposits had been made.

In the valley of the Raritan and its branches this new level is now represented by the low flat divides between Bedminster and Flemington, approximately 300 feet above the sea. South of Millstone and east to New Brunswick and Metuchen and west of Skillman corresponding surfaces are found at elevations of about 130 feet, while for a few miles southeast of a line from New Brunswick to Trenton the present elevation of the old plain is less than 100 feet and it is now mantled with Pensauken gravel.

On the Coastal Plain most of the Bridgeton that had been deposited on the Cretaceous area was also removed and wide valleys were cut distinctly below the level of the pre-Bridgeton valleys. Most of the material eroded during this epoch was carried to the sea, but subordinately, especially during its later stages, some of it was deposited in the valleys on land. Locally there is evidence of a slight uplift late in the cycle, which permitted the streams to excavate narrow gorges in the peneplain. Thus at Kingston a valley 60 feet deep seems to have been cut in the peneplain previous to the Pensauken deposition.

The erosion surface developed in this post-Bridgeton (pre-Pensauken) time has commonly been called the Somerville peneplain. Most of the erosion by which it was developed from the uplifted Harrisburg peneplain was accomplished in late Tertiary time, and the surface at the close of the Pliocene may have approximated very closely the level on which the later Pensauken formation was deposited. Nevertheless, the final stages in the development of this well-marked plain are referable to the erosion that followed the deposition of the Bridgeton gravel in early Quaternary time.

Pensauken Deposition.

Following the post-Bridgeton stage of erosion, described above, there was a period characterized pre-eminently by deposition in the central and southern portions of the State. This was probably occasioned by a slight submergence, which resulted in drowning the rivers in their lower courses. As a consequence, they ceased to erode and began to fill up their valleys. Deposition occurred also in the bays that occupied the drowned portions of the valleys and along the submerged seaward margin of the State. It is not now possible to determine accurately which of the deposits of this age are fluviatile and which estuarine or marine in origin, but it is probable that all three classes of deposits were made in the State at this time.

During maximum submergence, as in Bridgeton time, it is not improbable that a sound extended across New Jersey from Raritan Bay to the Delaware at Trenton, and that south of it there were islands, large and small. Since, however, the Pensauken gravel does not occur at such great elevations as the Bridgeton it is inferred that the submergence was not so great, and at its maximum the sea may have covered only those portions of the State that are now less than 130 feet or thereabouts in elevation. Indeed, it is by no means demonstrated that it reached this amount, although there are many facts that point to this conclusion.

Jerseyan Glacial Stage.

After the deposition of a part of the Pensauken, but coincident with at least its later stages, climatic conditions caused the development of glacial conditions and northern New Jersey was invaded by an ice sheet that advanced approximately to latitude 40° 35′ (Fig. 6). In Delaware Valley it reached a point below Riegelsville where obscure glacial striæ have been observed on a ledge of gneiss. Further east evidence of its presence has been found as far south as Pittstown, Lansdown Junction, Lebanon, White House, Readington, and Raritan. Cushetunk Mountain apparently stood as a barrier forming a re-entrant angle in the ice front, on either side of which ice lobes advanced several miles further south. East of Somerville it probably did not reach as far south as the late Wisconsin ice sheet, since the Jerseyan drift has not been found there south of the terminal moraine of Wisconsin age.

The ice sheet, particularly near its margin, was, doubtless, much thicker in the inter-Highland valleys and on the Triassic plain than on the Highlands and the drift deposited was correspondingly thicker and more continuous. Locally the ice overrode beds of Pensauken (or Bridgeton) gravel without disturbing them and buried them in drift, but for the most part it did not reach those portions of the Triassic lowland covered by this gravel. The Jerseyan drift ends indefinitely and in scattered bowlders, owing partly to the great erosion to which it has been subjected and partly to the fact that no massive moraine marked its southern margin. Only a short interval, therefore, separated the time of the ice advance from that of its retreat.

Post-Jerseyan Interglacial Stage.

About the time of the withdrawal of the Jerseyan ice sheet the land was uplifted to an elevation somewhat above its present level. The result of this uplift was the great erosion of the Jerseyan drift and the Pensauken formation. North of the Triassic belt, where erosion in Tertiary time had not progressed far enough to develop well-marked plains at the Somerville level, the events of the interglacial age are not so clearly marked as further south. Nevertheless, it is demonstrable that in Musconetcong and German valleys the streams eroded wide valleys through the Jerseyan drift and into the underlying rock in the interval between the Jerseyan and the Wisconsin ice invasions.

On the Triassic plain only patches of the Jerseyan drift are now found, and the larger streams of that region now flow at levels more than 100 feet below that of the lowest summits on which this drift occurs. Moreover, the valleys are wide and their slopes are gentle, showing that the drainage system is well advanced. The area now below the drift level is several times as extensive as the area that rises above it. It is evident, therefore, that since the deposition of the Jerseyan drift the region covered by it on the Somerville peneplain has been very extensively eroded. Similar evidence is given by the widely scattered remnants of the Pensauken formation on the Triassic lowland. North of Rocky Hill the few areas now rising to the 130-foot level about Franklin Park, Clyde, East Millstone, Raritan, Manville (Findern), New Durham, and Plainfield, have remnants of the Pensauken gravel, and the surface on which they rest is a part of the Somerville peneplain on which the Pensauken was deposited. Between them and at lower levels are wide areas of bare Triassic shale vastly exceeding in extent the Pensauken remnants.

Not only has the Pensauken been removed, but the Somerville peneplain beneath has been so dissected by erosion that few remnants persist except where the Pensauken gravel beds are found. Since, however, the uplift and emergence that permitted this erosion were not great and the land was not high no great relief has been developed.

While a small amount of this erosion has been accomplished in recent times, by far the greater part is referable to the age immediately following the post-Pensauken uplift. In forming a judgment as to the length of time necessary to accomplish the amount of erosion shown it must be remembered that much of the region is 20 to 30 miles from the sea and that the altitude is not great. While the rock is shale and, therefore, easily eroded, the streams had comparatively low gradients and the forms of the valleys show that erosion was slow. The conclusion is, therefore, inevitable that the time between the deposition of the Jerseyan drift and the Wisconsin drift was very much longer than the time that has elapsed since the withdrawal of the Wisconsin ice sheet.

In the Coastal Plain the evidence of great erosion since the deposition of the Pensauken is equally convincing. Along the lower Delaware below Camden a wide plain bordering the river was brought down nearly to base level. North of Camden erosion had not proceeded so far but mature valleys had been developed and, owing to the peculiar geologic conditions, broad flats had been produced along the upper courses of the Pensauken, Rancocas, Assiscunk, and Crosswicks creeks.

While the interglacial age was primarily one of erosion, there was deposition of sand and gravel along the rivers in favorable localities. Late in this age, after the work of erosion had been largely accomplished, the main streams crossing the Triassic lowland, notably the North and South branches of the Raritan, aggraded their valleys somewhat, the average thickness of the filling (Qrd) being probably less than 20 feet, although locally it was nearly double that amount. In part this valley filling was derived from the Jerseyan drift, and was brought down into the valleys after they had been excavated to their present level. On the Coastal Plain also certain alluvial deposits have been recognized that are probably referable to this age, although these are not represented on the geologic map of the State.

Wisconsin Glacial Stage.

Incursion of the Ice Sheet.—During the Wisconsin stage of the Glacial epoch the ice sheet advanced only to the line of the terminal moraine (Fig. 6), or locally and for brief intervals a mile or two beyond it. That its southern margin maintained a constant position for a considerable lapse of time is proven by the moraine itself. In its advance it completely buried or carried away whatever of the older drift remained in the region covered by it, for nowhere north of the moraine has the Jerseyan drift been recognized beneath the Wisconsin drift. During its occupancy of the region the mantle of disintegrated rock was removed from wide areas and the firm rock beneath was somewhat eroded. Less commonly the disintegrated material was not completely removed, and, on the whole, the amount of erosion due to the ice was not great.

If it be assumed that all the Wisconsin drift of the State is the result of erosion of the rock beneath, or putting it a little differently, if it be assumed that none of it was derived from regions north of New Jersey, the average erosion over the whole surface affected would probably not exceed 25 feet. Much of the drift did come from regions to the north but this was in part counterbalanced by the fine rock flour carried away by streams from the melting ice and deposited beyond the borders of the State. It is probable that the actual amount of erosion was somewhat less than 25 feet. Comparison of the general character of the topography in areas north and south of the moraine leads also to the conclusion that in this region the ice sheet did not greatly erode the surface over which it passed. Although the average erosion was small, that along certain lines, particularly in the valleys, probably was in excess of the average.

Direction of Ice Movement.—In general the ice sheet moved across northern New Jersey in a direction a little west of south (Fig. 6). The lowland belts, like Kittatinny Valley and the Triassic area, were occupied by great lobes of ice from the axes of which it diverged to the right and left. The effect of this along the margins of the great valleys was to carry the ice from the lowland onto the adjoining highland. This divergence was so marked along the eastern side of the lobes that the direction of movement in places was strongly to the southeast. Since the lowland belts afforded less obstruction to its onward movement the ice advanced further south along them than where the elevation was greater, and as shown by the moraine its margin was strongly lobate at its maximum extension. Thus the terminal moraine is 25 miles further south at Perth Amboy than across the Highlands from Dover to Hackettstown.

Glacial Lakes.—Temporary lakes were formed during the Glacial epoch in several valleys which drained northward and whose lower courses were therefore blocked by the ice. In some cases continued advance of the ice sheet filled the valleys and obliterated the lakes, but with the retreat of the ice the lakes came into temporary existence again unless their valleys were left completely filled by drift.

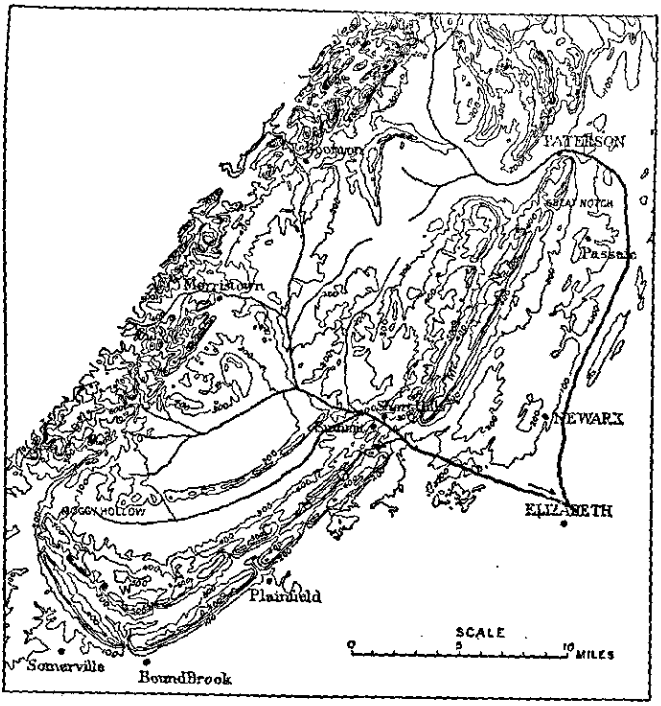

Fig. 11. Diagram showing the supposed course of the drainage in the Passaic basin previous to the last glacial invasion.

Temporary lakes of this character are believed to have existed in the Wallkill valley, the Black River valley near Succasunna, and the Pequest valley above Great Meadows (Danville). In the latter case the lake was formed behind the moraine after the ice had withdrawn a short distance from the region, but it was finally drained by the cutting down of its outlet across the moraine above Townsbury. At its highest stage its level was approximately the present elevation of 550 feet.

The largest glacial lake in New Jersey, however, and the one whose history has been most carefully worked out was Lake Passaic, which occupied the upper Passaic valley between the Highlands on the northwest and Second Watchung Mountain on the south and east (Figs. 11-15).

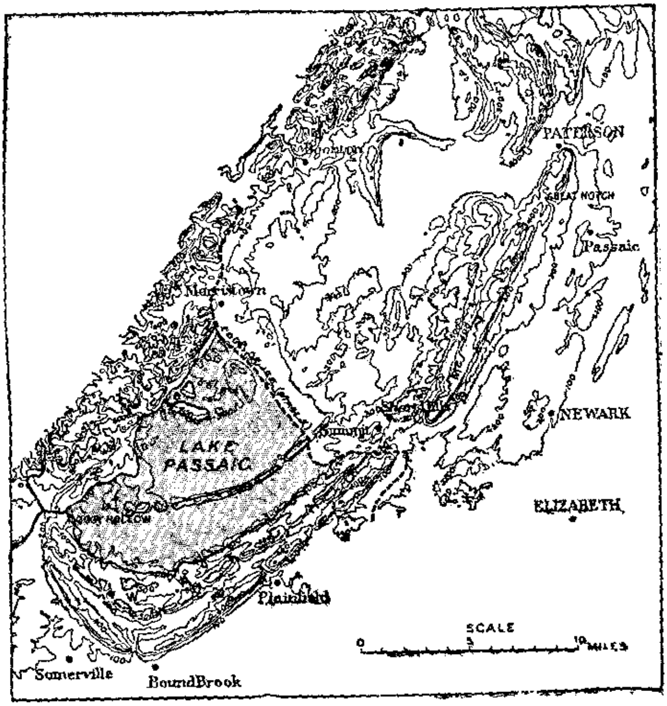

Fig. 12. Stage of maximum advance of the glacier.
The edge of the ice was at the position of the terminal moraine, and the glacier filled the Short Hills gap. The upper basin of Lake Passaic was shut in and occupied by a lake with its outlet to the west at Moggy Hollow.

The present drainage of the lowland west of Second Watchung Mountain now escapes in a roundabout way through gaps at Little Falls and Paterson, but in pre-Glacial and probably also in inter-Glacial time, there were gaps, now filled with drift, in First and Second Watchung mountains at Milburn and Short Hills, deep enough to drain the southern half of the basin, and formerly occupied by the master stream of the region (Fig. 11). If the drift filling in these gaps is all of Wisconsin age, as seems probable, Lake Passaic did not come into existence until the ice advanced to the line of the moraine between Short Hills and Morristown (Fig. 12) and filled the Short Hills gap. Once formed in the southern portion of the basin the level of the lake rose until it overflowed at the lowest point of the rim, which is Moggy Hollow, 7 miles north of Somerville and 2 miles east of Bedminster, where there is a current-swept pass across Second Mountain, the bottom of which is 331 feet above sea level. At its maximum height the lake level

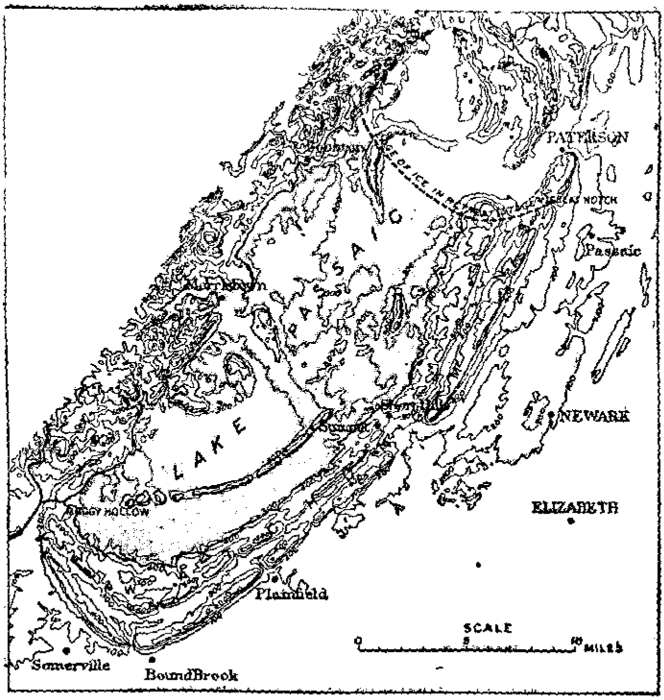

Fig. 13. Expanded stage of Lake Passaic.
The retreat of the ice had left the Short Hills gap filled with drift.

was not more than 25 feet above the bottom of the outlet. The waters escaped through this channel to the North Branch of the Raritan and thence to the sea. As the ice melted back from the moraine the Moggy Hollow pass remained the outlet, since the former gap at Short Hills was closed with drift. The lake, therefore, increased in area and maintained essentially the same level as the ice withdrew (Figs. 13, 14).

When the ice front had finally retreated far enough to lay bare the outlet at Little Falls the lake basin north of the moraine was drained (Fig. 15) to the level of the outlet, about the present elevation of 185 feet, and the existence of Lake Passaic as a glacial lake was terminated. But preceding the final draining of the lake there seems to have been a stage when the level was 65 to 75 feet lower than the maximum, after which the water rose again to approximately its former height. It is probable that these changes of level

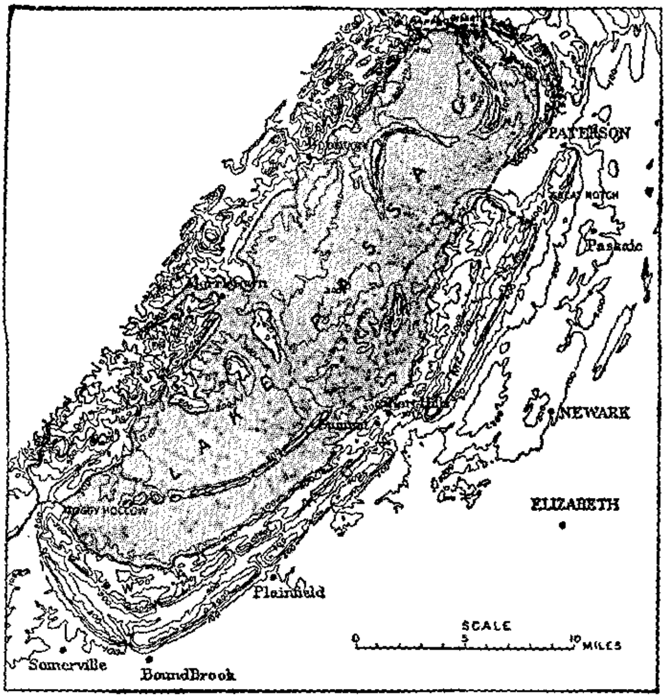

Fig. 14. Maximum stage of Lake Passaic.
All outlets except that at Moggy Hollow were either blocked by ice or filled with drift.

were connected with oscillations of the edge of the ice, which alternately opened and closed some outlet—possibly one at Great Notch or a subglacial channel along the course of the present Passaic.

After the portion of the lake basin north of the moraine was in large part drained by opening the Little Falls outlet, shallow lakes still existed in its lowest parts (Fig. 15). South of the moraine there was a long narrow lake between Long Hill and Second Watchung Mountain at an elevation of about 230 feet and having its outlet across the moraine west of Summit. This lasted until its outlet across the drift dam was lowered to essentially its present level. North of Long Hill a lake existed for a long time in the area of Great Swamp, since it is probable that some part, if not all, of the narrow gorge of the Passaic at Millington is of post-Glacial origin.

Withdrawal of the Ice Sheet.—Some of the events attending the withdrawal of the ice sheet have been mentioned in connection with the draining of Lake Passaic. As the ice front receded a compara-

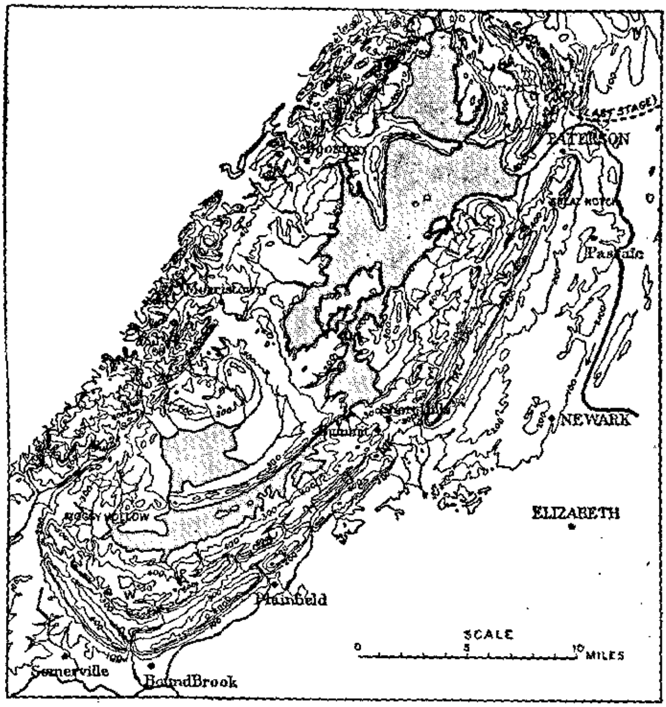

Fig. 15. Late stage of the lake, when the retreat of the ice had freed the Little Falls-Paterson outlet.
Shallow bodies of water still occupied the lower portions of the basin.

tively thin sheet of till (not represented on the geologic map) was spread over the region north of the terminal moraine. Glacial drainage was concentrated in the southward draining valleys, some of which were much obstructed by stagnant and semi-detached masses of ice around and between which and the valley sides kames and kame terraces were formed. Where the drainage was unimpeded the valleys were also aggraded, since the streams were heavily overloaded with rock débris from the glacier. Such a valley filling commonly called a "valley train," extended down many valleys far beyond the maximum limits of the ice advance. That of the Delaware, formed at the period of maximum ice advance, extends to Trenton, where it merges into estuarine deposits of the same age but of slightly different origin.

The withdrawal of the ice was not at a uniform rate but was accompanied by pauses in its retreat during which there were formed recessional moraines of more or less pronounced character. There was an extended pause of the ice front between Newton and Branchville, in Sussex County, as shown by the recessional moraine which, with some interruptions, can be traced from Ogdensburg through Lafayette, Halsey, and Balesville to Culvers Lake. Moraine deposits north of Dingmans Ferry and Layton probably represent the position of the ice front at this time in the upper Delaware and Flatbrook valleys. East of the Highlands there was a notable halt along a line connecting Waverly, Connecticut Farms, and Springfield; another near Woodside, Riverside, Bloomfield, and Montclair. Neither of these pauses can be connected with any degree of certainty with those of Sussex County.

Cape May Submergence.—The Wisconsin glacial stage, or at least its later portion, was one of subsidence in the southern portion of the State to an extent of 40 or 50 feet below the present level. During this time deposition was in progress along some parts of the coast, as in the Cape May peninsula, and erosion in others. Deposition was also in progress in many of the valleys that were not submerged. At this time was developed the 60-foot plain of gravel about Trenton, extending northeast to Bakers Basin. It is composed in part of glacial material brought down the Delaware from the moraine at Belvidere and in part of nonglacial material from the southeast. At this time also the 30-foot and 40-foot plains of sand and loam about Burlington, Florence, and Kinkora, and the conspicuous plains at Salem, now at an elevation of 20 to 30 feet, were developed. The 40-foot terrace about the south shore of Raritan Bay is referable to the same period, as is also much of the low-lying belt about the coast, ranging from 30 to 50 feet in elevation, and due partly to deposition and partly to erosion of pre-existing deposits.

Recent Post-Glacial Epoch.

Post-Cape May Uplift and Warping.—Since the withdrawal of the Wisconsin ice sheet there has been an emergence of the land accompanied by a differential uplift to the north. Explicit evidence of this is found in the present attitude of the shore lines of Lake Passaic. When formed these were essentially horizontal, but they now rise toward the north end of the lake, the maximum increase of elevation being 67 feet in 30 miles. Along the coast the present elevation of the Cape May terraces proves an emergence at least equal to their present elevation above the sea level, while the depth below the present sea level to which they have in places been eroded and the size of the drowned valleys incised in them indicate that during this emergence the land for a time stood somewhat higher than it does at present.

Recent Subsidence.—The emergence just referred to was apparently followed by a slight subsidence, but not equal to that in Cape May time. The result of this has been to drown somewhat the mouths of the coastal streams and to permit the formation of peat beds along the coast, composed in part of non-marine water plants, at some depth below sea level. Although this subsidence took place at a time comparatively recent, geologically speaking, there seems to be no conclusive evidence that the coast is now sinking, and many facts from which this inference was formerly drawn are now known to be susceptible of a different interpretation.

Other post-Glacial Changes.—All in all other post-Glacial changes in the State have not been extensive. In some places in southern New Jersey, chiefly along the coast, wind-drifted sand and small dunes constitute somewhat conspicuous deposits, but the largest dunes rarely exceed 20 feet in height. On the whole, post-Glacial erosion is exceedingly small. In many places streams have not lowered their channels at all, but on the contrary have aggraded them. Along the larger rivers there has been more erosion. The Delaware has cut its channel from the level of its highest gravel terraces to its present bed, locally as much as 100 to 120 feet. Smaller streams have done correspondingly less. In general it may be said that most of the valleys have been deepened a little, and some of them locally a considerable amount; many ravines and small valleys have been developed; and a few lakes and ponds have been drained by having their outlets deepened to the level of their bottoms.

The Wisconsin drift has been leached and oxidized to depths of 2 or 3 feet, and in places to 5 or 6 feet, and exposed surfaces of the more resistant rocks, left smooth and polished by the ice, have been so roughened that all traces of striæ have been obliterated as a rule, although the characteristic rounded outlines of the ledges—the *roches moutonnées*—are commonly preserved.

Alluvial deposits, mostly narrow strips, have been formed along the larger streams, and some shallow lakes and ponds have been silted up and transformed into swamps or meadows. In others beds of peat to a maximum known depth of 27 feet have accumulated.

Along the coast a line of barrier beaches has been built from Manasquan southward and from Long Branch northward, enclosing broad and shallow lagoons or bays. Some of these have been largely silted up by sediment from the land, wind-blown sand from the beaches, and the growth of aquatic plants. Between Manasquan and Long Branch the mainland has suffered by attacks of the sea, and even within the memory of persons still living the loss of land has been considerable.

ECONOMIC GEOLOGY.

Only brief mention is made here of the occurrence and distribution of metallic ores and other minerals of economic importance in the State. References are inserted, however, to the chief publications of the Geological Survey in which further information may be found in the form of more complete reports and maps. Reports on the progress and general condition of the mineral industry in the State, together with statistics of production, were published in the Annual Report of the State Geologist for many years up to and including 1909; since that date annual bulletins on the subject have been issued. The Annual Report for many years also contained information on artesian and other wells and underground water supplies.

Metallic Ores.

At the present time New Jersey produces ores of iron and zinc. Copper ores are also known and have been mined at various places in a small way.

IRON ORES.

Magnetic Iron Ore (Magnetite.)—Deposits of magnetite occur at many places in the crystalline pre-Cambrian rocks of the Highlands, chiefly in the Byram and Losee gneiss, although some ore-bodies are also known in the Franklin limestone. The important deposits form lens-shaped or pod-shaped masses lying in the foliation planes of the gneiss, which generally dip steeply toward the southeast. The longest axis of these masses also "pitches" toward the northeast. The ore-bodies or "veins", as they are called, are mainly distributed in narrow northeast-southwest belts or ranges in the gneiss. These ranges vary from one-fourth of a mile to 2 miles in width and up to 30 miles or more in length and are separated by wider belts of barren rock.

Active mining is now carried on at Oxford, in Warren County; at Mount Hope, Hibernia, and Wharton, in Morris County; and at Ringwood, in Passaic County.

Hematite Ores.—The so-called hematite ore of New Jersey is limonite, or brown hematite, the hydrous oxide of iron. Most of the deposits occur as lens-shaped or irregular masses along the bedding planes of the gray Kittatinny limestone, particularly at the top or the bottom of the formation. Some are also associated with the white Franklin limestone and others are found along the contact of the pre-Cambrian crystallines of the Highlands and the Triassic beds to the southeast.

These ores are not being utilized at the present time in New Jersey, although the corresponding deposits are profitably mined in both New York and Pennsylvania, as well as in other states southward to the great mines at Birmingham, Alabama.

Bog Ores.—Deposits of bog iron ore occur in the bogs, swamps, and meadows in many localities throughout the State, particularly in the Coastal Plain, where they were mined in the early days. None of them has been worked, however, in recent years.

References.—"Iron Mines and Mining in New Jersey," by W. S. Bayley. Final Report of the State Geologist, vol. vii, 1910, 512 pp.

Geologic Folios: No. 1, Passaic Folio, 1908, pp. 23-25; No. 2, Franklin Furnace Folio, 1908, pp. 20-24; No. 5, Raritan Folio, 1914, pp. 23-29.

"Report on Iron Mines," by George E. Jenkins. Annual Report of the State Geologist for 1899, pp. 151-170.

"Active Iron Mines," by George E. Jenkins. Annual Report of the State Geologist for 1891, pp. 235-253.

"Iron Mines and Iron Ores," by F. L. Nason. Annual Report of the State Geologist for 1890, pp. 51-127.

ZINC ORES.

In the mining industry of New Jersey zinc has been for many years the leading metal. Large deposits of zinc ore occur in the Franklin limestone at two localities 4 miles apart—Franklin Furnace and Ogdensburg, in Sussex County. At both places the ores occur in bed-like bodies that have been bent sharply downward into trough-like synclinal folds. The ore minerals are franklinite (containing oxides of zinc, iron, and manganese), willemite (zinc silicate), and zincite (red oxide of zinc). Active mining operations for many years past have been restricted to the deposit at Franklin Furnace, although recently (1913) the Ogdensburg mines have been reopened.

The richness and great abundance of these zinc ores have led, first and last, to the expenditure of large sums of money in prospecting the adjacent territory. The zinc ores occur only in the white Franklin limestone, and the whole area of this formation has been carefully examined without revealing any surface evidence of additional deposits. Extensive diamond drilling has also been done on all sides of the known deposits, but, so far as has been made known, without avail.

References.—"The Mine Hill and Sterling Hill Zinc Deposits of Sussex County, New Jersey," by Arthur C. Spencer. Annual Report of the State Geologist for 1908, pp. 23-52.

"Zinc-bearing Ores," by Arthur C. Spencer. Geologic Atlas of New Jersey, Folio No. 2 (Franklin Furnace Folio), 1908, p. 7.

COPPER ORES.

Mining and prospecting for copper have been carried on at a number of places, chiefly in the Triassic (Piedmont) belt across the north-central part of the State. A deposit that has also attracted atention at times is found on Delaware River a few miles above the Water Gap.

The Triassic ores occur in shales and sandstones, in most cases intimately associated with some form of the igneous trap rocks, and are of two general types: (1) Native copper in sheets and stringers through the shales and to a slight extent in the superjacent trap rock, as at the Somerville mine, in Somerset County; (2) Chalcocite (copper glance, the black copper sulphide) in veins and disseminated through shales and sandstones, as at the Griggstown mine, in Somerset County, and the Arlington (Schuyler) mine, in Hudson County. In both types of deposit there are silicate and carbonate ores found as secondary alteration products near the surface.

At the Pahaquarry mine, 7 miles above Delaware Water Gap, on Delaware River, the ore is chalcocite in disseminated grains and forming thin seams and veins in a hard sandstone of the High Falls formation, of Silurian age.

Some early attempts to mine copper in New Jersey were in a measure successful, but for more than 50 years past every undertaking has led to disappointment and failure, and at the present time no work for copper is being done in the State.

References.—"The Newark (Triassic) Copper Ores of New Jersey," by J. Volney Lewis. Annual Report of the State Geologist for 1906, pp. 131-164.

"Copper Deposits of New Jersey," by W. H. Weed. Annual Report of the State Geologist for 1902, pp. 125-139.

"The Pahaquarry Copper Mine," by Henry B. Kümmel. Annual Report of the State Geologist for 1908, pp. 133, 134.

NONMETALLIC MINERALS.

CLAYS.

Distribution.—Clay suitable for common brick is found in local deposits of various kinds in nearly all parts of the State;

but the great clay industry centers in the formations of the Coastal Plain and particularly in the clay-bearing members of the Cretaceous system, which forms a belt across the State southwestward from Raritan Bay and down Delaware River along the western border to Salem County.

Among the older formations but little clay has been utilized and that chiefly for local supplies of building brick. Certain clays from the surface decomposition of the shaly Jacksonburg limestone and the Martinsburg shale of the Ordovician system and from the Brunswick shale and trap rocks of the Triassic system have been worked in a few places for this purpose.

Cretaceous Clay.—In the great center of the industry about the lower Raritan River and Raritan Bay the Raritan and Magothy formations are the chief clay producers. The clays are of various kinds, ranging from the nearly white or steel-blue fire-clay of the highest grade, through stoneware and terra-cotta clays, to black sandy clay containing considerable pyrite and marcasite (iron sulphides) and used only for common brick. Some of the sand beds are pure quartz sand, constituting a high-grade fire sand; others are micaceous, lignitic or arkose. Some of the latter, composed of coarse grains and even pebbles of quartz and decomposed feldspar crystals, form the beds of so-called "feldspar" used in the manufacture of firebrick. The lower and, in general, the lighter colored sands and clays (Raritan) are characterized by numerous alternations and abrupt transitions of strata, both vertically and horizontally, and by the absence of definite and orderly arrangement of beds over extended areas.

These clays are worked chiefly in the northeastern portion of Middlesex County, about Woodbridge, Sayreville, South River, Perth Amboy, South Amboy, and Cliffwood. To a small extent they have also been worked east of Trenton and at a few places down Delaware River toward Camden. Other and higher formations, however, particularly the Merchantville and Woodbury, are more important producers along the west side of the State. The clays of these latter formations are utilized chiefly for brick and fireproofing along the south shore of Raritan Bay in Monmouth County, in southern Middlesex and Mercer counties, and in western Burlington and Camden counties.

Local beds of clay in the Englishtown formation are used for brick south of Woodbury, Gloucester County, and clays in the overlying Marshalltown are available for similar purposes in parts of Burlington and Camden counties.

Tertiary Clay.—The Kirkwood formation furnishes brick clay from the "Asbury" clay beds, a few miles west of Asbury Park, Monmouth County, and from the "Alloway" clay, which outcrops at the surface from near Ewans Mills, Gloucester County, to Alloway, Salem County.

The Cohansey formation contains brick clays in many places, some of them of considerable extent, in the sandy pine district of Ocean and Atlantic, southern Burlington, Camden, and Gloucester, and central Cumberland counties.

Quaternary Clay.—Thick beds of clay are worked in the Pensauken formation at Fish House, 3 miles above Camden. The Cape May formation also furnishes clay about Kinkora, Burlington County, and around the southern borders of the State in Salem, Cumberland, and Atlantic counties.

Glacial clays are extensive at several points in northern New Jersey, and are utilized to a considerable extent in the Hackensack and Passaic valleys.

Recent clays, consisting chiefly of small impure deposits of only local importance for building bricks, occur widely scattered over the State: (1) In flood plains of streams, where the clays are commonly shallow and sandy, or even stony; (2) In swamps, marshes, and meadows—generally sandy and containing much vegetable matter; (3) At the foot of slopes, where it has been washed down from higher ground.

References.—"The Clays and Clay Industry of New Jersey," by H. Ries, H. B. Kümmel, and G. N. Knapp. Final Report of the State Geologist, vol. vi, 1904, 548 pp.

Geologic Folios: No. 1, Passaic Folio, 1908, pp. 25, 26; No. 2, Franklin Furnace Folio, 1908, p. 26; No. 3, Philadelphia Folio, 1909, p. 21; No. 4, Trenton Folio, 1909, pp. 22, 23; No. 5, Raritan Folio, 1914, p. 31.

UNDERGROUND WATER.

The amount and availability of underground water in the State are determined largely by the character of the rocks and their structural relations in the four principal topographic divisions; namely,

(a) the three divisions of the Appalachian province—the Appalachian Valley, the Highlands, and the Piedmont Plain—and (b) the Coastal Plain.

Water of the Appalachian Valley.—In the Appalachian Valley, comprising Kittatinny Mountain, Kittatinny Valley, and the valley of the Delaware above Water Gap, and constituting a large part of Sussex and Warren counties, the principal rocks are not very porous and hence do not carry a large volume of underground water. The water that does penetrate into the bedrock does so chiefly by following the minute joint cracks, many of which in the limestones have been opened by solution into channels and cavities. Here and there are also fault fissures that admit considerable water. The structure, however, is of little assistance to the geologist in locating underground supplies, and too few deep wells have been sunk in this region to show whether or not such waters occur in any considerable quantity.

Water of the Highlands.—The prominent northeast-southwest valleys in the Highlands are underlain by bedrock formations similar to those in the Appalachian Valley, and hence, in these valleys, the same ground-water conditions prevail. In the mountain ridges and higher plateau country, on the other hand, the principal bedrock is gneiss. The several varieties of gneiss are even less porous than the formations of the Appalachian province, and no definite water-bearing beds occur. This condition is offset in part at least by the fact that the rocks are broken by numerous joint cracks and fault fissures, which admit considerable amounts of underground water. Hence borings made indiscriminately in the Highlands may be expected to yield about as high a percentage of satisfactory wells as in the Appalachian zone.

The numerous iron mines of this region show that the presence of underground water, while very general, is by no means uniform; for some of the mines are comparatively dry, whereas others that cut important fault fissures encounter large volumes of water. Therefore, while deep wells may find water at almost any point, they are much more likely to develop a large supply if they are sunk along a zone of faulting. Experience has demonstrated that the chances of obtaining a supply decrease progressively below 250 or 300 feet.

Water of the Piedmont Plain.—The bedrock of the Piedmont

Plain consists chiefly of the shales and sandstones of the Triassic (Newark) system, and some of these are no more porous than the rocks of the Appalachian zone, while others carry considerable amounts of water. No well-defined water-bearing beds are known; but the strata are broken by numerous minute joint cracks so that they carry more ground water than the rocks of either the Appalachian belt or the Highlands. Hence a moderate supply of water can generally be obtained almost anywhere in the Piedmont, at depths of a few hundred feet at most. Moreover, the rocks are softer and can be drilled more easily and cheaply than those of the more northerly districts. These statements do not apply, however, to the areas of igneous or trap rocks (basalt and diabase) in the Triassic formations. These rocks are exceedingly hard and tough, and a number of wells that have been driven in them at great expense and to depths of hundreds of feet have failed to find an adequate supply of water.

Flowing wells of great volume have been obtained at a few places in the Piedmont belt—usually, however, not in the Triassic bedrock, but in the Glacial deposits that overlie portions of the region. This is particularly true of the upper Passaic Valley, where beds of open gravel and sand covered by impervious layers of clay furnish favorable conditions for the accumulation of large supplies of water under considerable pressure. Abundant water is also obtained in some places by pumping from wells in the sands and gravels of the stratified drift. Good examples of this type are found near Plainfield and Elizabeth. Some flowing wells, like those at Hopewell, are probably located on or near great faults.

Water of the Coastal Plain.—The Coastal Plain, constituting more than three-fifths of the area of the State, presents in many respects a striking contrast with the other three divisions of the Appalachian province that have been referred to in the preceding paragraphs. With very slight exceptions the strata have never been consolidated into firm rock, but still consist of beds of loose sand and soft clay and marl. Furthermore, these beds still lie in nearly horizontal position, with only a gentle slope toward the coast—undoubtedly almost the exact attitude in which they were originally deposited. From the point of view of underground waters the most important difference of all consists in the fact that many of the sandy and gravelly beds in the Coastal Plain are so porous as to have a great capacity for storing water, and furthermore, are so interlaminated with impervious beds of clay and marl that vast quantities of this water are held under such pressure as to furnish abundant artesian flow. In the Coastal Plain of New Jersey alone more than 1,000 wells draw their supply from these beds, and the number is constantly increasing.

Sections CD and EE at the bottom of the map show the simple structure of the region; but for the sake of distinctness the gentle eastward slope or dip of the beds, which is imperceptible to the eye, is greatly exaggerated in these sections. It is evident from these sections that all of the formations, wherever they may outcrop at the surface, extend southeastward and underlie the Coastal Plain in that direction. Hence deep wells near the coast may penetrate not only the Tertiary formations that cover all that region, but may reach far down into the underlying Cretaceous strata.

Cretaceous Water-bearing Beds.—The Raritan formation contains a number of water-bearing beds, but these are less regular and continuous than those of any other formation of the Coastal Plain. The Englishtown is also a sand bed which is 100 feet thick in Monmouth County, where it is an important water horizon; to the southwest it gets thinner, however, and disappears entirely in Gloucester County. The Mount Laurel and Wenonah sands, on the other hand, are about 80 feet thick in the southwest and are important water-bearing strata, while to the northeast they are less important because of decrease in both thickness and permeability. The Red Bank sand is an important water horizon in the northeast, where it is a sand bed 100 feet thick; but it thins out southwestward and disappears near the northern border of Burlington County. The Vincentown sand is an important water bed throughout the whole length of the Coastal Plain.

Tertiary Water-bearing Beds.—In the Tertiary system, which covers considerably more than half the area of the Coastal Plain, the Kirkwood contains several beds of water-bearing sand. It is an important source of water at Atlantic City and southward along the beaches. The Cohansey also carries water in several beds and rivals the Kirkwood as a source of water on the beaches.

Prediction of Water Supply.—In spite of the great simplicity of structure in the Coastal Plain there are two serious difficulties that sometimes interfere with the successful prediction of an underground water supply for any particular locality and the depth at which it will be found.

(1) Numerous well borings show that many of the beds increase in thickness toward the coast. The rate of this thickening is not sufficiently well known to furnish a basis for a satisfactory estimate of the depth at which any particular bed will be found in a given locality.

(2) The permeability, and consequently the water-holding capacity, of the beds is greatly affected by variations in the proportions of sand and clay from one region to another. It will be impossible to predict with confidence whether or not any particular water-bearing bed will contain water at a given locality until the extent of the clayey parts of these beds becomes better known from an increased number of borings.

References.—"Underground Waters of New Jersey," by G. N. Knapp. Annual Report of the State Geologist for 1903, pp. 73-84.

"Artesian Wells of New Jersey," by Lewis Woolman. Annual Report of the State Geologist for 1898, pp. 59-144.

"Water-supply from Wells," by C. C. Vermeule. Annual Report of the State Geologist for 1898, pp. 145-182.

"Chlorine in the Natural Waters of the State," by William S. Myers. Annual Report of the State Geologist for 1900, pp. 189-196; Same for 1899, pp. 141-150.

Geologic Folios: No. 1, Passaic Folio, 1908, pp. 26, 27; No. 2, Franklin Furnace Folio, 1908, pp. 26, 27; No. 3, Philadelphia Folio, 1909, pp. 21-23; No. 4, Trenton Folio, 1909, pp. 23, 24; No. 5, Raritan Folio, 1914, pp. 31, 32.

CEMENT ROCK.

Among the nonmetallic minerals of the State cement rock stands next to clay in value of the marketable products. The rock that furnishes the bulk of the materials used in the manufacture of Portland cement is the earthy limestone or calcareous shale in the upper portion of the Jacksonburg formation. It is quarried at the cement works at Alpha, Vulcanite, and New Village, all of which are located near Phillipsburg, Warren County. The limestone that is added to the cement rock is obtained in part from the white Franklin limestone of Sussex and Warren counties, the chief quarries of which are located near Oxford, McAfee, Hamburg, and Franklin Furnace.

References.—"Report on the Portland Cement Industry," by

Henry B. Kümmel. Annual Report of the State Geologist for 1900. pp. 9-101.

"Portland Cement Industry," by S. Harbert Hamilton. Annual Report of the State Geologist for 1903, pp. 112-118.

STONE.

Large amounts of stone are annually quarried and crushed in the State for road construction, concrete, and railroad ballast. Building stone forms a much smaller proportion of the product, although the State does not lack excellent stone of this character.

Trap Rock.—This name is applied in the trade to the dark, heavy igneous rocks of the Triassic system, which are designated on the map as basalt and diabase. Much the greater part of this stone that is quarried is crushed for use in concrete, road building, and railroad ballast; smaller amounts are converted into paving blocks, and a little is used as rubble. Producing quarries are located at many places in Somerset, Hunterdon, Passaic, Essex, Hudson, Morris, Bergen, Union, and Mercer counties.

Granite.—Granite and granite-gneiss (the Byram and Losee gneiss) are quarried from time to time for local building purposes at many small quarries in the Highlands. Gray and white are the most common colors, but various shades of pink are found at several localities. Attractive pink granite has been produced for shipment at quarries in the vicinity of Pompton, in Passaic County. Gneiss is quarried and crushed at a number of places and used for the same purposes as crushed trap rock. Active quarries are located in Passaic, Morris, and Sussex counties.

Sandstone.—Practically all of the sandstone quarried in the State comes from the Triassic rocks of the Piedmont, and the quarries are located near the large centers of population which furnish the chief markets. Brownstone, the reddish-brown to chocolate-colored sandstone of the Brunswick formation, once so popular for building purposes, is now used to only a limited extent; but in the Stockton formation white, creamy, and light gray stone abounds and offers promise of a steady building-stone industry.

More than half of the sandstone quarried is used for building, while other portions are converted into curbing or flagging or crushed for concrete and road building. The thin-bedded sandstones in the upper parts of the Martinsburg shale have been quarried to a considerable extent for flagstone, chiefly in the vicinity of Quarryville, in Sussex County.

Argillite.—The dark greenish-gray to chocolate-brown argillite of the Lockatong formation, Triassic system, has found a limited local use as a building stone since colonial days. In recent years extensive use has been made of this stone in the newer buildings of Princeton University, including the graduate-school group and the handsome Cleveland Tower. The high school building and several residences are also constructed of it, the stone being supplied from three active local quarries. The same formation has been quarried extensively for crushed stone at Byram, Hunterdon County, and a portion of the product of the Princeton quarries has also been crushed.

Limestone.—In addition to the cement rock and pure limestone used in the Portland cement industry (p. 131) large quantities of limestone are produced for blast-furnace flux and agricultural uses, and smaller amounts for road construction, concrete, and building purposes. Considerable quantities of limestone are also burned for lime, which is used in building and manufacturing and as a fertilizer. Stone for flux and the pure limestone used in cement manufacture are obtained chiefly from the white Franklin limestone, which is quarried at several localities in Sussex County and at Buttzville (near Oxford), in Warren County. For other purposes both this stone and the gray magnesian Kittatinny limestone are used, the chief producers of the latter being Warren and Hunterdon counties.

Slate.—Roofing slate is produced from the Martinsburg formation at Lafayette and Newton, in Sussex County. Some large quarries and several smaller ones were formerly worked at a number of other places southwestward through Warren County to Delaware River. The great hardness of most of the New Jersey slate adapts it to a variety of uses to which the softer slates are unsuited, such as steps, floorings, railings, and flagging, in which resistance to wear and weather are prime requisites. It is not, however, so easily sawed into slabs as the softer kinds.

Marble.—The white Franklin limestone is thoroughly crystalline and, strictly speaking, it is, therefore, a true marble, but it has been used so little for building that it is seldom called by that name.

It is quarried in many places for use as flux in blast furnaces and for the manufacture of lime and cement, as described in the preceding paragraphs. The almost snowy whiteness of this stone would produce handsome effects in building and where it is not too much broken by joint cracks it might well be quarried for this purpose, particularly the finer-grained varieties.

An attractive pink variety of this stone, mottled with green and black minerals, ocurs near Great Meadows (Danville). in Warren County. It takes an excellent polish and is capable of being used with beautiful effect for interior decoration. A little of it was shipped for this purpose many years ago, but it is not being quarried at the present time.

Talc, Soapstone, and Serpentine.—At several places in the Highlands these materials occur in small isolated patches of the Franklin limestone; but they are quarried only along Delaware River just above Phillipsburg, in Warren County. The lighter-colored portions of the stone, consisting of an intimate mixture of talc, serpentine, and tremolite, are ground to a fine powder, known as "mineral pulp," for use in the manufacture of paper, rubber goods, soap, paints, etc. The darker-green and mottled rock is polished and used in part for decorative purposes in building.

References.—"Building Stones of New Jersey," by J. Volney Lewis. Annual Report of the State Geologist for 1908, pp. 53-124

"The Fire-resisting Qualities of Some New Jersey Building Stones," by W. E. McCourt. Annual Report of the State Geologist for 1906, pp. 17-76.

"Properties of Trap Rock for Road Construction," by J. Volney Lewis. Annual Report of the State Geologist for 1908, pp. 165-172.

"The Talc Deposits of Phillipsburg, N. J.," by F. B. Peck. Annual Report of the State Geologist for 1904, pp. 161-185.

"The Chemical Composition of the White Crystalline Limestones of Sussex and Warren Counties," by Henry B. Kümmel and R. B. Gage. Annual Report of the State Geologist for 1905, pp. 173-191.

Geologic Folios: No. 1, Passaic Folio, 1908, p. 25; No. 2, Franklin Furnace Folio, 1908, p. 26; No. 4, Trenton Folio, 1909, p. 21; No. 5, Raritan Folio, 1914, pp. 30, 31.

"Starting a New Quarry," by M. W. Twitchell. Bulletin 11, Geol. Survey of New Jersey, 1913, pp. 32-35.

SAND AND GRAVEL.

Ordinary sand and gravel suitable for building and paving purposes are found in the surface deposits of Pleistocene and Recent age in many parts of the State. The Coastal Plain contains numerous beds of unconsolidated sand in strata of Cretaceous and Tertiary age also. Various special grades of sand are produced for foundry molding, firebrick, furnace linings, glass manufacture, brick and pottery molding, for locomotives, for water filters, and smaller amounts for grinding and polishing purposes.

Glass Sand.—The Cohansey sand, which in its surface outcrop is the most widespread formation in the Coastal Plain, is sufficiently pure and white at many places to be available for glass manufacture. Over considerable areas this sand is covered by the shallow surface deposits of Quaternary gravel and sand. The chief producing localities are about Vineland and along the lower Maurice River, in Cumberland County. Smaller amounts are dug in Camden, Gloucester, and Middlesex counties.

Molding Sand.—Core sands occur at numerous localities in the Bridgeton formation, which lies chiefly in the southernmost tier of counties, across the State from the Delaware to the Atlantic coast. Similar sands occur also in the Pensauken formation, the most important deposits of which lie in the belt from Raritan Bay in Monmouth County, southwestward to Salem County. The molding loams and loamy sands occur very widely in the terraces of the Cape May formation.

The chief producers of molding sands are Middlesex, Cumberland, and Burlington counties.

References.—"The Glass Sand Industry of New Jersey," by Henry B. Kümmel and R. B. Gage. Annual Report of the State Geologist for 1906, pp. 77-96.

"A Report upon some Molding Sands of New Jersey," by Henry B. Kümmel and S. H. Hamilton. Annual Report of the State Geologist for 1904, pp. 187-246.

Geologic Folios: No. 3, Philadelphia Folio, 1909, p. 21; No. 4, Trenton Folio, 1909, p. 23.

MARLS.

Greensand Marl.—Glauconite, a hydrous silicate of potassium and iron, forms large proportions of several of the Cretaceous formations, particularly the Marshalltown, Navesink, Hornerstown, and Manasquan, constituting the greensand marls of Monmouth, Burlington, Camden, Gloucester, and Salem counties. These marls were formerly used in great quantities as fertilizer, but they have been replaced to a very large extent in recent years by the more concentrated commercial fertilizers. Small amounts of marl are still used locally, however, and a little of it enters into the composition of some prepared fertilizers.

White Marl.—In many of the ponds and meadows of Sussex and Warren counties there are considerable Recent deposits of white limy marl which has commonly been called "shell marl." These occupy areas of various sizes up to 100 acres, and the marl ranges in thickness from 3 or 4 feet to more than 30 feet. All of these deposits would seem to be suitable for agricultural purposes, and many of them are doubtless of sufficient purity for the manufacture of Portland cement by the addition of the proper amount of clay or shale.

References.—"The Greensand Marls," by W. B. Clark. Annual Report of the State Geologist for 1902, pp. 218-245.

"Greensand Marls," by George H. Cook. Annual Report of the State Geologist for 1886, pp. 154-210.

Geologic Folios: No. 3, Philadelphia Folio, 1909, p. 21; No. 4, Trenton Folio, 1909, p. 23.

"White Marl Deposits," by Henry B. Kümmel. Annual Report of the State Geologist for 1900, pp. 98-101.

PEAT.

Many swamps of northern New Jersey contain peat deposits of good quality and in considerable quantities, particularly those of Bergen, Morris, Sussex, and Warren counties. A little of the material has been used for fuel and larger quantities are used in the manufacture of commercial fertilizers.

Reference.—"A Report on the Peat Deposits of Northern New Jersey," by C. W. Parmelee and W. E. McCourt. Annual Report of the State Geologist for 1905, pp. 223-313.

MINERAL PAINTS.

Some Triassic red shale of the Brunswick formation is ground and used as a pigment in paint. The dark gray to black slate of the Martinsburg formation (Ordovician) is also ground for paint in adjoining states. The New Jersey rock has not been utilized for that purpose, although great quantities of waste are available at the quarries.

Impure limonite (brown hematite) with an admixture of clay forms beds of the yellow pulverulent material known as ocher, and this by calcining at a dull red heat changes to red ocher or Venetian red. A deposit near Harmony, in Warren County, was formerly worked a little, but there is now little or no active mining of this material in the State, the only ochers produced being manufactured chemically.

The zinc ores of Sussex County are used extensively in the manufacture of the white zinc pigments known as "zinc white" and "lithopone."

DIATOMACEOUS EARTH.

Diatomaceous earth, often called "infusorial earth," has been found beneath shallow deposits of peat in a number of swamps and meadows in the northern part of the State. Some of this was dug many years ago for use in the manufacture of dynamite, polishing powders, etc.

APATITE.

The mineral apatite (chemically a phosphate of lime, tricalcium phosphate) occurs in many of the deposits of magnetic iron ore in the Highlands, but generally in very small amounts. Grains of the mineral are distinctly visible in portions of some of the ore bodies, and in places it forms so great a proportion of the rock that the possibility of mining it profitably has been considered. Thus far, however, it has not been produced commercially and does not seem likely to be in the near future.

The most promising apatite-bearing ore is at the Canfield phosphate mine, southwest of Dover, near the Dickerson iron mine. Here a layer of magnetite-apatite rock 8 feet thick has been exposed by shallow workings and traced by the magnetic needle for about 1,000 feet along the strike, from southwest to northeast. The ore is a granular aggregate of magnetite and apatite, and samples have been found to contain over 50 per cent. of apatite by weight, together with small amounts of quartz, feldspar, and mica. The average rock is reported to contain about 32 per cent. of apatite.

A smaller deposit is found at the Hurdtown apatite mine on the east side of Lake Hopatcong, about a mile southwest of the Hurdtown iron mine. The ore contains apatite, magnetite, pyrrhotite, and pyrite, with calcite and silicates as gangue minerals.

References.—Geologic Folio No. 5, Raritan Folio, 1914, pp. 29, 30.

"The Hurdtown Phosphate of Lime Locality," by Henry Wurtz. Geology of New Jersey, 1868, pp. 603, 604.

GRAPHITE.

Graphite occurs in the crystalline rocks of the New Jersey Highlands (1) as a constituent of the Franklin limestone, (2) in bands in garnetiferous mica schist, (3) in pegmatite dikes, and (4) in fine-grained quartz-mica schist, especially in that which is associated with the pegmatite.

The first and second methods of occurrence are common, but the graphite is present in quantities so small that it is of no commercial importance. The third method of occurrence is also rather common, especially in pegmatities that contain mica, the graphite lying in large flakes between the quartz and feldspar grains of the coarse-grained rock, from which it can be separated only with great difficulty. At Bloomingdale, in Morris County, graphite was mined years ago from a pegmatite dike and from schists lying in contact with it and was put on the market, but the project was not successful.

Graphite schists occur at a number of widely scattered places and at three of these the proportion of graphite was so large that mills were erected to separate it—one a mile south of High Bridge, Hunterdon County, one at High Bridge, and a third 5 miles southwest of Morristown, between Brookside and Washington Corners, Morris County. At this last locality the main source of supply was a coarse black quartz-graphite schist, which may be a sheared pegmatite. Prospecting for graphite has been done at many places in the State, chiefly in adjoining portions of Hunterdon, Somerset, and Morris counties, from the vicinity of High Bridge to Morristown, but as yet no successful mine has been established.

References.—Raritan Folio, 1914, p. 30; Geology of New Jersey, by George H. Cook, 1868, p. 710.

SOILS.

Those physical and chemical characters of the soil that influence fertility vary greatly in different portions of the State and even within short distances in many regions, depending in part on whether the soil is residual or transported, the sources of the material, and the processes that have been concerned in its production. tion.

Residual soils, formed by the decomposition or disintegration of rock in place, occur to an important extent only in those areas of the Highlands and the Piedmont Plain that lie south of the terminal moraine (Fig. 8). Transported soil is formed by the deposition of materials brought from other areas by glacial ice, water, and to a slight extent in New Jersey, by wind. North of the terminal moraine the soils were derived chiefly from glacial drift, more or less modified, particularly in the valley bottoms, by the action of water. South of the moraine the larger streams and some smaller ones have formed alluvial or bottom-land deposits, and superficial deposits of sand, gravel, and clay form the soils on many ridges, hills and upland flats.

No attempt can be made here to describe the soils of the various parts of the State; but their general character in many regions may be estimated from the descriptions of the Cretaceous, Tertiary, and Quaternary formations (see p. 63 to 77) together with the distribution of these formations as shown on the geologic map. A soil survey of the State is now in progress under the joint auspices of the Geological Survey, the State Agricultural Experiment Station, and the Bureau of Soils of the United States Department of Agriculture. Accurate detailed information may be found in the maps and reports that are to be published as this work progresses.

References.—"Composition of the Soils of the Sussex Area," by A. W. Blair and Henry Jennings. Bulletin Geol. Survey of New Jersey, No. 10, 1913, 110 pp.

"Surface Geology," by Rollin D. Salisbury. Annual Reports of the State Geologist; 1892, pp. 35-166; 1893, pp. 35-356; 1894, pp. 1-150; 1895, pp. 1-16; 1896, pp. 1-24; 1897, pp. 1-22; 1898, pp. 1-42.

"Relation between Forestry and Geology in New Jersey," by Arthur Hollick. Annual Report of the State Geologist for 1899, volume on Forests, pp. 175-201.

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