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BULLETIN 50 GEOLOGY OF NEW JERSEY R. KÜM

BULLETIN 50

GEOLOGIC SERIES

THE GEOLOGY OF NEW JERSEY

By

J. Volney Lewis and Henry B. Kümmel (1914)

Revised and rewritten by Henry B. Kümmel (1938-40)

DEPARTMENT OF
CONSERVATION AND DEVELOPMENT
STATE OF NEW JERSEY

Charles P. Wilber, Director and Chief of the Division of Forests and Parks

Meredith E. Johnson, Chief of the Division of Geology and Topography

TRENTON, N. J.
1940

Walter R. Hutchinson

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PREFACE

In the twenty-five years that have elapsed since the publication of Bulletin 14, *The Geology of New Jersey* by J. Volney Lewis and Henry B. Kümmel, great progress has been made in the science of geology and much careful work has been done not only in New Jersey but in adjacent states. This has necessitated some changes in our conclusions regarding the classification and geologic history of some rock formations in New Jersey. Moreover, the original edition of Bulletin 14 has been out of print for many years and there has been a steady demand from various sources for a summary of the geology of the State, so that the need for a new edition has long been apparent.

The retirement of the author as State Geologist and Director of the Department of Conservation and Development in 1937, relieved him of all administrative duties and gave him the desired opportunity of returning to his scientific studies and particularly of rewriting the geologic history of New Jersey.

In preparing this edition the author has not hesitated to use without quotation marks such sections of Bulletin 14 as seemed appropriate to this work. He desires to express his indebtedness to Dr. Lewis for the latter's share in the earlier work, but he has not hesitated to make many changes both in arrangement, text and in some cases conclusions as set forth herein. Dr. Lewis cannot, therefore, be held responsible for these or the language in which they are clothed except in so far as they are identical with the statements in the earlier report.

Bulletin 14 was written originally to explain the State Geological Map (1910 - 1912). Several editions of this map have been published with minor changes, the last in 1933, and copies can still be obtained at a nominal charge from the Department office in the State House Annex, Trenton, N. J.

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, the Paleozoic, Triassic, and the 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.

HENRY B. KÜMMEL.

Trenton, N. J., March 15, 1940.

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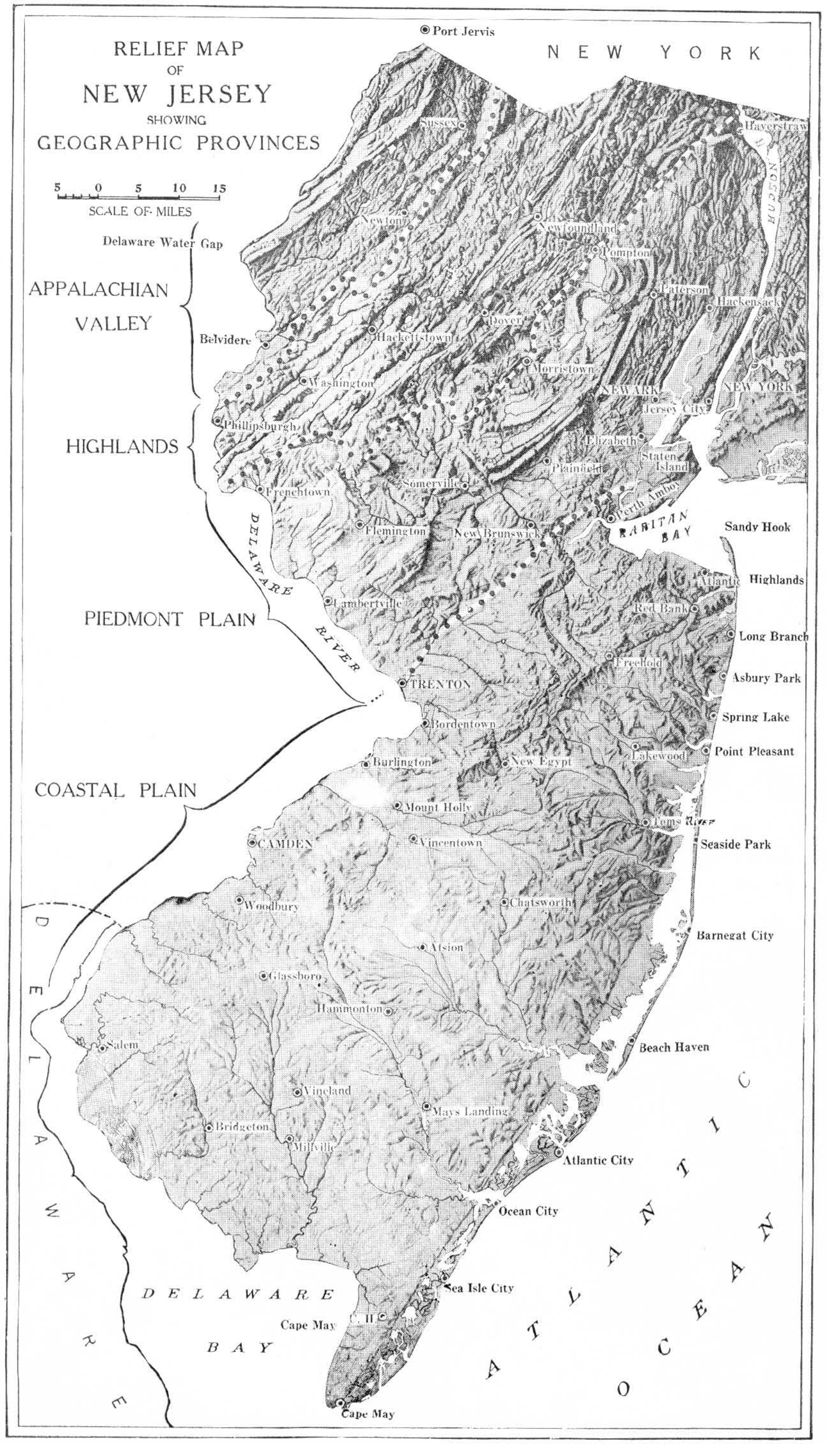
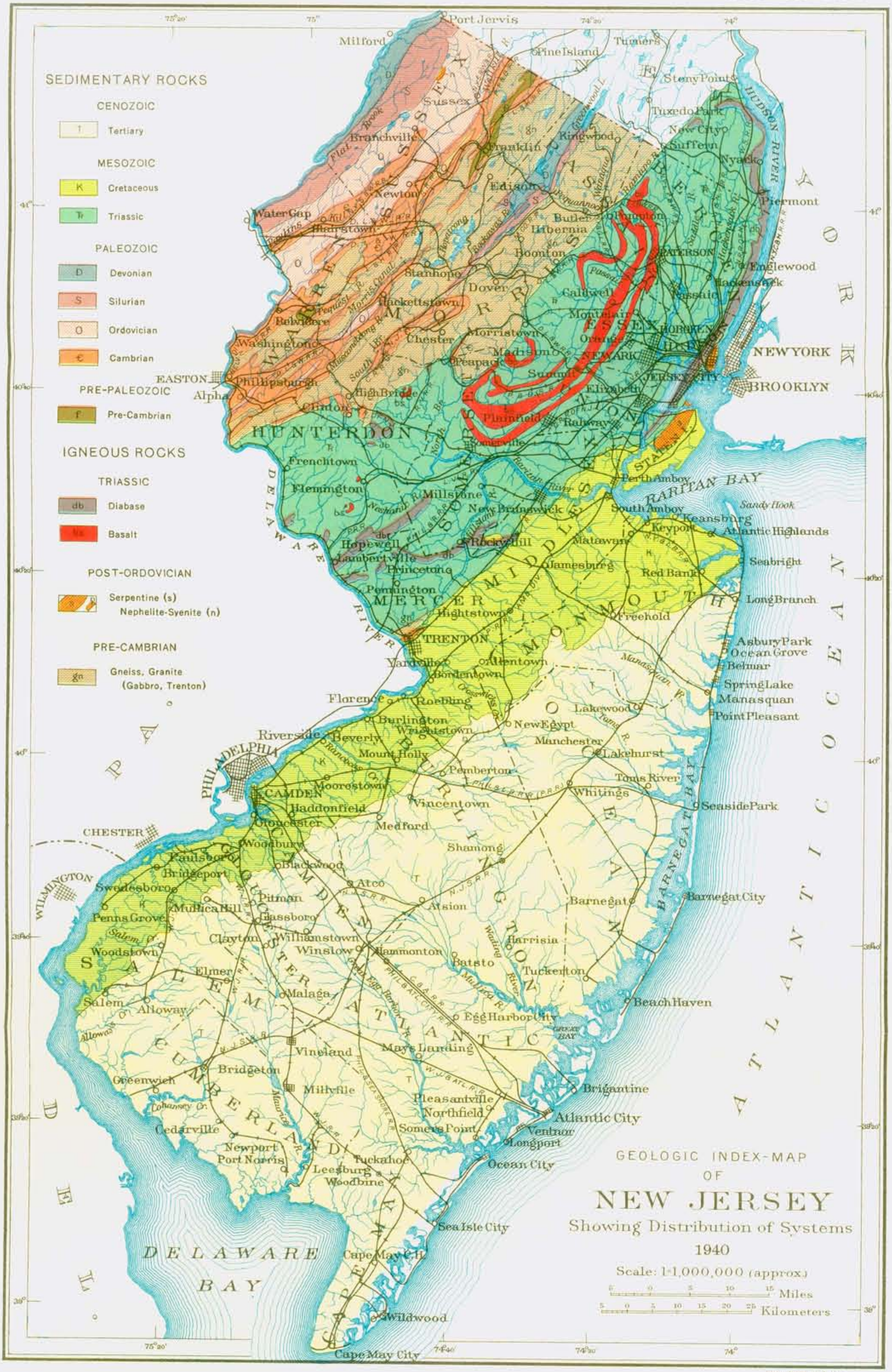


RELIEF MAP
OF
NEW JERSEY
SHOWING
GEOGRAPHIC PROVINCES



GEOLOGIC INDEX-MAP OF

NEW JERSEY

Showing Distribution of Systems

1940

Lith. A. Hoen & Co.

CHAPTER I.

GEOGRAPHY OF NEW JERSEY.

LOCATION AND AREA.

New Jersey is a portion of the Atlantic slope of North America, (Fig. 1, 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.[1]

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. 1).

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[1] The recent decision of the U. S. Supreme Court regarding the boundary between New Jersey and Delaware within the 12-mile circle from New Castle, may subtract a small amount from this figure.

Each province is a fairly distinct geologic and physiographic 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.

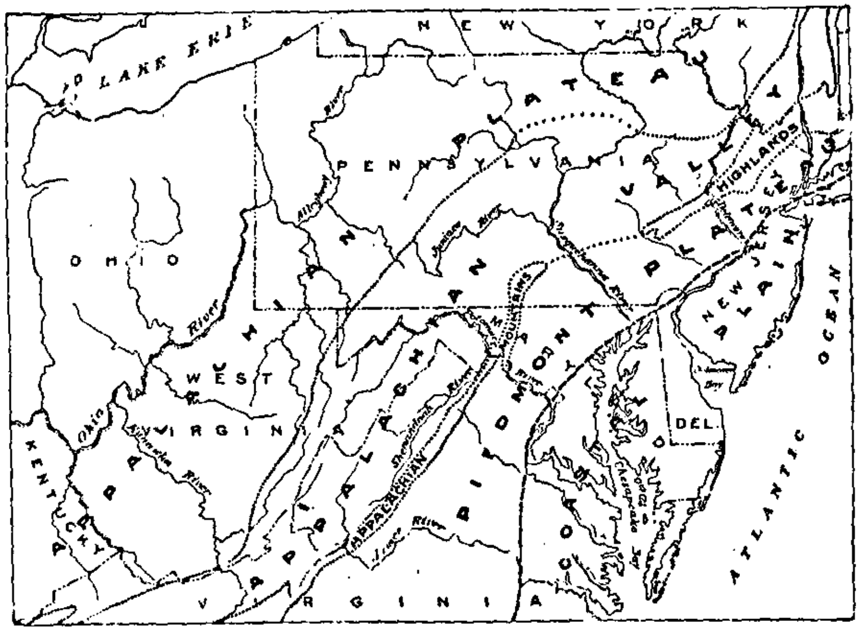

Fig. 1. Map of the northern part of the Appalachian province showing the physiographic divisions and its relation to the Coastal Plain.

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 which traverse it 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 the 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 elevations of 800 to 1000 feet. The valley lands in the narrow upper Delaware Valley are about 500 feet above sea level whereas 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[1] feet at High Point, the highest in the State. The mountain varies in width from 1 to 5 miles (Fig. 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

---

[1] Top of a glacial bowlder which formerly rested on the highest point of bed rock. The elevation given on the tablet attached to the base of the monument is incorrect if intended to give the elevation of the crest of the mountain before the monument was erected.

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 1,406 feet, but none to the South and east 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 topographical 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, such 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 south-eastward 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 PROVINCE.

General statement.—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 to 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 descends abruptly to abysmal depths. This submerged part of the Coastal Plain is known as the *continental shelf*, and the steep escarpment which bounds it on the east is the *continental slope*. 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 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 a 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.

The subaerial portion.—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 subaerial 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 nearly 400 feet in central New Jersey. At its inner margin, where it borders on 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 the 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 Clarksburg and Perrinesville reach an elevation of 354 feet and the Navesink Highlands 276 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 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 present width of the subaerial portion of the Coastal Plain is due to the existing height of sea level in relation to the land areas. This is a purely temporary condition which has varied greatly in geologic time and doubtless will continue to vary in the future. As we shall see in later chapters, sea level even in recent geologic time has stood much higher and also lower than at present. These changes of level have caused wide migration of the shore line across the Coastal Plain.

The submerged plain or continental shelf.—Within recent years (1934-1939) much detailed information has been obtained regarding the topography of the submerged part of the Coastal Plain east of the 100 fathom line, and of the continental slope which borders it. This has been due to the development of echo sounding to determine depth, and radio-acoustic ranging to determine horizontal locations. These methods have not only greatly increased the number of soundings possible in a given time, but have given much more accurate control of horizontal location.

The continental shelf off the New Jersey coast slopes seaward for about 100 miles at an average gradient of 6 feet per mile to a depth of about 600 feet (100 fathoms). It 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. The predominant topography of the shelf is a very gently inclined plain marked in general by "northeast-southwest trending bars and lagoons with occasional prominent terraces, steep on the seaward sides; in short, the forms are easily recognizable as marine made or heavily modified by marine erosion."[1]

The continental slope. The topography of the continental slope below 600 feet stands in marked contrast to that of the continental shelf. It drops from 600 feet to 8,000 feet below sea level in about 50 miles—an average gradient of 150 feet per mile—and in a few sections the descent is as steep as 700 feet per statute mile.[2] Deep canyons cross the continental slope and in some cases their heads deeply indent the shelf and lie northwest of the 100-fathom line. The submerged valley across the continental shelf opposite the mouth of the present Hudson River has long been known, but only recently have soundings been sufficient to outline accurately its dimensions and gradients.

These have disclosed a channel 2 to 6 miles in width, 60 to 120 feet in depth below the adjacent ocean floor, with a maximum depth below sea level of 290 feet. This submerged valley extends for about 100 miles in a southeasterly direction from near Sandy Hook to within about 20 miles of the outer edge of the continental shelf. Here it drops abruptly into the head of a great canyon which is cut in the continental slope and the seaward margin of the shelf.

This submerged canyon has a maximum depth below its rim of 3,720 feet, a width from rim to rim of 6 miles at its deepest point and a gradient from 150 feet (average) to 272 feet per mile (maximum).

It is generally agreed by geologists that the 100-mile channel across the shelf is a former course of the Hudson River cut in

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[1] A. C. Veach and P. S. Smith—Special Paper No. 7, Geol. Soc. of Amer. p. 13.

[2] Veach and Smith—loc. cit.

relatively recent geologic time (late glacial) when the sea level stood 250 to 305 feet lower than at present (pp. 145 and 170).

The fact that this channel leads into the head of the Hudson canyon suggests at once that the canyon also marks a former extension of the Hudson River. Supporting this view also is the fact that the canyon possesses in a marked degree many characteristics of valleys cut by subaerial erosion, so that not a few geologists have adopted the view that not only the channel across the *shelf*, but also the canyon across the *slope* are due to subaerial erosion. The adoption of this view, however, seems to involve an insuperable obstacle. It is one thing to explain a lowering of sea level 250 or 300 feet in comparatively recent geologic time due to accumulation on the land of glacier ice over thousands of square miles, and it is another thing to explain a sinking of sea level of 7,200 or 7,500 feet; and after a long enough time to erode the canyon to its present width and depth, to restore the ocean to its present level. Where did the water go to and what brought it back again?

But the Hudson Canyon is not the only puzzle of this kind. Similar canyons, but smaller in size occur at 25 other points[1] along the continental slope from the Georges Banks 130 miles southeast of Nantucket Island near Cape Cod to a point east of the mouth of Chesapeake Bay, south of which detailed soundings have not been published. In no other cases than the Hudson can the canyons be traced headward entirely across the shelf into direct connection with existing rivers on the mainland. In many cases they are limited entirely to the continental slope east of the 100 fathom line, but others have worked headward and nicked the margin of the shelf for variable distances up to 20 miles. While explanations have been offered to account for these canyons there is as yet no unanimity of opinion regarding their origin.

RELATION OF TOPOGRAPHY TO GEOLOGY.

General statement.—The striking differences in the surface features—hills, plains, mountains—that characterize the different portions of the State as described in the preceding pages are the result of long continued exposure to weathering and erosion of rocks that vary greatly in resistence in the different regions and that also have very different structures or modes of arrangement.

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[1] A. C. Veach and P. S. Smith. loc. cit. Plate 2.

The conditions under which they were formed and the successive steps in the development of these surface features will be considered at length. It is sufficient here to emphasize the fact that with the exception of a few relatively minor details, the present surface features are due almost entirely to erosion of older and higher land masses. The greater hills and the mountains of the State have their present elevation not because they have been uplifted relative to the adjoining lower areas, but because generally speaking they are of harder rock and have been eroded less rapidly. Whatever movements of elevation or subsidence have taken place at different geologic periods (and they have been many and profound), have affected wide areas and the State as a whole has been uplifted, depressed, or tilted.

This is a conception which the non-technical reader may find difficult to comprehend. The mind naturally assumes that the prominent hills and mountains rise above the lowlands at their base, because they have been "pushed up" by some internal forces, which were not effective in the lowland region. It is true that volcanoes are built up above their surroundings by the accumulation of material ejected from their craters and that in young and growing mountain regions, belts in which the strata are being compressed into folds may rise above the adjoining areas where the rock layers remain undisturbed. But these exceptions do not apply to New Jersey. There are no volcanic cones in this State, and the folds and faults which characterize the rock of three of the geographic divisions were formed so long ago, that whatever elevations resulted from those movements, have long since been worn away.

The present surface features, are, therefore, with very minor exceptions the result of long-continued weathering and erosion over tens and even hundreds of millions of years, on rocks of different degrees of resistence and of different modes of arrangement. The minor exceptions are chiefly due to the irregular accumulation and deposition of glacial drift and wind-blown sand.

DRAINAGE.

The present streams.—The 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 Rarita[illegible]ays. 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 the 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 small 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 the 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 the 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 distance 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.

Earlier drainage.—The above paragraphs relate to the drainage as it exists at present, but as will appear in the following pages, not only have there been great changes throughout geologic time in the general relation of sea and land, but also of mountains and valleys. Large parts have been repeatedly and on occasion the entire State has probably been submerged beneath the sea. Upon re-emergence of the ocean floor a new system of drainage was established which was adjusted to the slope of that surface, but which may have had no relation to the older drainage of the region before subsidence. Some of these ancient changes will be discussed in later pages.

With the erosion of the later sediment the rivers were superimposed upon the underlying older topography, often in positions which they could not have attained had their courses been directed by these older hills and valleys. The course of the Delaware River or its ancestor through Kittatinny Mountain at the Delaware Water Gap may be a case in point.[1]

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

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[1] See page 141.

CHAPTER II.

ROCKS AND ROCK STRUCTURES.

For the benefit of the non-technical reader brief explanatory statements are here inserted 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 text books and the larger manuals.

SEDIMENTARY ROCKS.

ORIGIN.

Definitions.—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 are classed as rocks, because they are composed of rock materials, but they are not included in the ordinary meaning of that word. The greater part of such materials, 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 pressure 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 perhaps, not all at any one time. Thus the sedimentary rocks (shale, limestone, sandstone, and conglomerate) 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 shale and sandstone 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 mud of which they are in part composed was often dried and cracked by the sun as it accumulated, and these cracks were later filled with material of a different color or texture so that they are now recognizable. There are other characters also 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. 5). These are the accumulations of sand, gravel, clay, and bowlders, mingled together in all proportions in the glacial till that forms a sheet over much of the surface, and in the hummocky hills and ridges of the terminal moraine (p. 161). All of this material was scoured from the soil and broken from the underlying bedrocks of 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 was carried in suspension and 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, although locally the till has been so compacted by pressure that it can be excavated only by blasting and in places the gravel has been cemented by carbonate of lime to a loose conglomerate. In New Jersey 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.

Unconsolidated deposits of the Coastal Plain.—Deep wells in the southern part of the State penetrate successive layers of sand, gravel, clay and greensand (glauconite) marl to depths in excess of 2,300 feet. In some localities a little of the sand and gravel near the surface has been consolidated by iron oxide into stone, but the total quantity of solid rock in this region is insignificant, and in the main 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.

General statement.—North of the line through Trenton and New Brunswick the bed rock is everywhere solid. In most places it is covered with a mantle of unconsolidated material, which may be (a) the result of the decay of the underlying rock, or (b) drift deposited on the hard rock by wind, streams or glaciers. This mantle rock may vary in thickness from a few inches to many feet, 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 rock, 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 constitu-

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[1] Geologists formerly supposed that local bays extended into this region from the Atlantic coast of that time; but since no distinctly marine fossil has been found there is no evidence in support of this hypothesis. (See p. 106).

ents 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. When the silica cement is so abundant as to fill all the spaces between the grains the stone is practically solid quartz and is called quartzite.[1] 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 or pebbly quartzite.

✓*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 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, or 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

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[1] Quartzite frequently contains a small percentage of other minerals than quartz.

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 weathers 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 resistence to weathering accounts for the high altitude of the country west of Flemington. Argillite has been quarried extensively at Princeton for building purposes.

✓*Slate.*—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 or dolomitic limestone. 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 power produced is drifted out by the undertow into deeper water, where it settles and afterwards consolidates into limestone. Coarser fragments and even whole shells and other remains of organisms accumulate

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

in reefs and shell beds and in the shallow waters near them and become cemented into fragmental shell or coral limestone. Carbonate of lime is sometimes precipitated in the form of minute spherules, called oölite from their resemblance to fish roe. Limestone containing these spherules is said to be oölitic. 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[1] 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 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.

Extrusive and intrusive.—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. A surface flow may become deeply buried by the accumulation of younger sediments on it, and at a much later date may be partially exhumed by the erosion of the overlying strata. Under such circumstances an extrusive sheet may be interbedded with other rocks and present the structural features of some kinds of intrusive sheets. Careful study of their relations usually serves however to differentiate them. Thus, the Watchung Ridges in Essex and Union Counties are formed by the outcropping edges of extrusive lava flows, successively buried by sedimentary rocks and exhumed in much later geologic time. On the other hand, the Palisade trap ridge is an intrusive sheet which solidified far below the surface and has been exposed by later erosion of the overlying beds. (See p. 105).

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.—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* which may attain a thickness of many feet. The larger fragments, known as *bombs,* fall nearer the source and mingle with the ash. Somewhat similar fragmental rocks may be formed where lava flows enter shallow bodies of water. Large amounts of steam are generated and the lava is broken into fragments of all sizes and shapes. This was probably the origin of some of the *volcanic breccia* and *tuff* locally found in connection with the extrusive flows of the Watchung Mountains, notably in old quarries along the Passaic River below Little Falls.

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[1] Quartzite, slate and marble are frequently termed metamorphic rocks. (See p. 35).

CLASSES.

Acid igneous rocks are chiefly light colored and the minerals that compose them contain much silica in their composition. In many of them there is free silica in the form of the mineral quartz. Granite is a common example of an acid igneous rock which cooled slowly and at considerable depths below the surface, so that it is relatively coarse grained. It occurs abundantly in some parts of New Jersey. It is normally a massive rock without foliation (banding). If it takes on this character it becomes a granite gneiss or simply a gneiss—a rock which is extremely abundant in the Highlands of New Jersey. There are many other classes of acid igneous rocks but as they are of little importance in this State they will not be described here.

Basic igneous rocks are heavier than the acid ones and much darker in color than most of them. They consist of minerals with a low percentage of silica and much lime, magnesia, and iron, and they are often called collectively "trap" rock. Diabase is a good example of basic intrusive rock occurring abundantly in the Triassic formations of New Jersey; gabbro and diorite are found less frequently in the State. The extrusive or volcanic basic rock of the Triassic formations is basalt. The diabase and basalt of New Jersey have essentially the same chemical composition and were formed from closely similar magmas, but owing to the different conditions under which they solidified they present significant differences of texture and crystallization. Some gneiss has the approximate chemical composition of these basic rocks but differs from them in being banded.

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. The foliation or banding of some varieties of gneiss is so distinct as to resemble bedding somewhat closely.

METAMORPHIC ROCKS.

Immediately upon formation all rocks both sedimentary and igneous begin to undergo changes. Cementation of loose materials into coherent masses is the most common form of change in sedimentary rocks. The minerals of igneous rocks begin to alter through chemical change, due to the addition or subtraction of water (hydration or dehydration), addition or subtraction of oxygen (oxidation or reduction), molecular rearrangement, changes in temperature, or pressure, etc. If these changes proceed far enough, the transformation from the original form may be nearly complete. This change is termed metamorphism and rocks so altered are called metamorphic. Slight changes are not commonly so termed, nor are the processes of rock decomposition, called metamorphism. Quartzite, slate, marble, the gneisses, schists and serpentine (see above) are the most familiar examples of metamorphic rocks. In each case the rock was originally sedimentary or igneous but it has been changed into a different rock by one or several of the processes mentioned above.

ROCK STRUCTURES.

Sedimentary rocks.—As a result of their method of formation sedimentary rocks are arranged in layers and beds. They are said to be *stratified*. The stratification consists essentially in the superposition of layers of unlike constitution, size of material, color, or compactness on one another. The thinnest divisions are called *laminae;* the thicker ones *layers* or *beds*. All the consecutive layers of the same sort are called a *formation* and are usually given a specific name, as the Kittatinny formation. When deposits are made in shallow water subject to shifting currents, the material is frequently laid down in inclined laminae, sometimes at a steep angle. But since these inclined laminae do not conform to the general horizontal position of the layer of which they are a part, this structure is called *cross bedding*. The occurrence of cross bedding in a rock formation is taken to indicate that it was deposited by shifting currents and probably in shallow water. The sandy bottoms of rivers are in many places characterized by wave-like undulations, produced by minute eddies in the water currents, which heap the sand in small ridges separated by shallow hollows. Similar undulations are frequently found on the surface of sand dunes and are due to eddies in the air currents. The to-and-fro movement of the water on the ocean bottom caused by the passage of wind waves produces very similar ripples in the sand there. Many sandstone beds and some limestone layers are characterized by undulatory markings exactly like those found on sandy deposits today. These are known as *ripple marks* and their presence in the hard rocks gives a clue to the conditions under which the rocks were formed. Mud sediments are sometimes exposed between tides or floods for periods long enough to permit drying and cracking at the surface. With the return of the waters the cracks may be filled with material of a different color, size or kind, and be permanently preserved. These are known as *sun-cracks* or *mud-cracks*. They are particularly common in deposits formed in temporary lakes (playas), which dry up periodically. Partly dried clay surfaces, when exposed to a short, sharp rain will receive and retain the impressions made by the falling rain drops. Under favorable conditions they may be filled by subsequent fine sediment and preserved. These markings are characteristic of continental mud deposits and where now found on the surface of shale layers generally indicate a continental origin. Various sedimentary formations contain nodules or irregularly shaped masses of mineral matter which is unlike the inclosing rock. When they consist of matter gathered about a center they are called *concretions*. The commonest concretions in limestone are chert, a form of the mineral silica. Concretions of iron oxide are very common in many beds of sandstone or sand. Lime concretions occur abundantly in some clay beds. The *oölitic* structure of certain limestone beds has already been mentioned. (p. 32).

Igneous rocks.—Certain structures that are of frequent occurrence in igneous rocks deserve brief definition. Reference has already been made to the *foliation* or banding of gneiss. Lava sheets often assume a *columnar* structure in cooling, the columns being six-sided prisms which stand at right angles to the cooling surfaces. This structure is probably due to the contraction of the rock as it cooled. Many good examples may be seen in the trap-rock quarries in Essex County. The expansion of the various gases, particularly steam, which are contained in lava, frequently causes the upper part of a lava flow to be porous and vesicular. Subsequently the *vesicles* may be filled with mineral matter. The fillings are called *amygdules* and a rock so filled is called *amygdaloid.*

Metamorphic rocks in the main possess the structures characteristic of the original rocks from which they were derived. In some instances these are more or less obscured or even obliterated during metamorphism. The cleavage in slate, a metamorphic rock, is a direct result of metamorphism.

Due to disturbances.—Sedimentary rocks are essentially horizontal when first deposited, but, as the result of crustal movement that has taken place subsequently, in many localities they are variously tilted and folded. The direction and character of these movements is often of great importance in interpreting the relationship of various beds. The direction that a bed slants downward beneath the surface is called the *dip*. The *strike* is the direction of the horizontal edge of an inclined layer. It is always at right angles to the dip. By observing and plotting on a map the dip and strike of the strata over a wide area, it is often possible to predict with a high degree of accuracy the underground extent and structure of the geologic formations. Where over wide areas the dips are all in one direction the beds form a *monocline.* Where they have been bent in the form of an arch so that on opposite sides of an axial line they dip away from each other, they form an *anticline;* where they dip toward the axial line like a trough, they form a *syncline.* The terms anticline and syncline relate entirely to the position of the rock layers and have no connection with the surface topography; that is, an anticline is not necessarily marked at the surface by an arch, nor does it follow that a syncline is characterized by a depression of the surface. Subsequent erosion or deposition may have obliterated the original surface expression of these structures. All rocks at or near the surface are almost universally traversed by deep cracks called

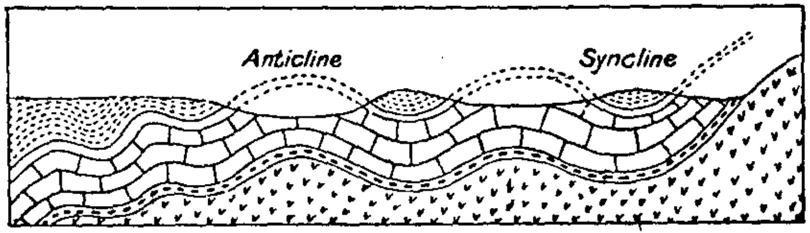

Fig. 2. Folded strata.

joints. Generally there are two or more systems which approach verticality but in regions where the rocks have been greatly disturbed, joints may have any angle. Not infrequently movement has taken place along joint planes or other fractures so that the beds on either side do not exactly correspond. A fracture in the earth's crust accompanied by such movement is called a *fault.* The movement may be only a few inches or it may be thousands of feet. Where the fault planes are inclined at a low angle the strata on opposite sides have in some places been shoved past each other for 15 miles or more. If the movement has been such as to cause the beds on the upper side of an inclined fault plane to override the beds on the lower side, the fault is of the *over-thrust* or *reverse* type. If the movement has been in the opposite direction, the fault is *normal.* Reverse faults indicate compression of the strata where they are formed, while normal faults show tension. Faults of both types are common in New Jersey and are shown on the sections at the bottom of the large geological map of the State.

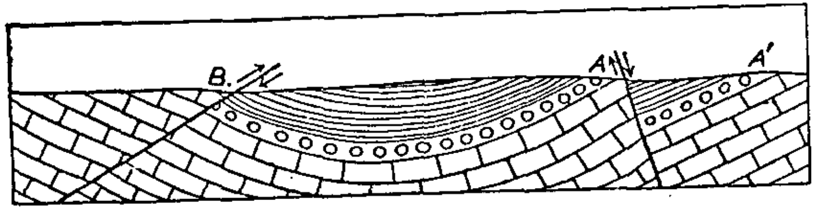

Fig. 3. A, Normal and B, thrust faulting.

Unconformity and disconformity.—If the continuous deposition of sediments is interrupted by earth movements that cause changes in the position of the shore line and transform parts of the sea bottom to land areas, the recently deposited material becomes subject to erosion and much of it may be removed from the uplifted area. When at a later period the region is resubmerged, the new deposits are laid down on the eroded and uneven surface of the earlier beds. Such a relationship is called a *disconformity* if the layers of the earlier and later formations are essentially parallel. If during the period of uplift or subsidence the earlier beds are tilted or folded and then after erosion are submerged, the beds of the later sediments will not be parallel to the earlier, but will rest upon their bevelled edges. Such a relationship is called an *unconformity.* Since the events of geologic history are read mainly from the sediments themselves and the fossils which they contain, disconformities and unconformities both represent breaks in the stratigraphic record and lost intervals, the history of which is very obscure. In other words they have the same effect as missing pages or chapters of a mutilated book. The line marking a disconformity between two formations may be very obscure and difficult to fix, and yet the time interval indicated by it may be longer than that represented by the adjoining formations. These relations are therefore, of great significance in interpreting the geologic history, because they always prove two intervals of earth (or ocean level) movement and one of erosion, and in the case of unconformities, deformation of the strata also.

THE GEOLOGIC TIME SCALE.

The events of geologic time, as they have been deciphered by geologists working in many countries, naturally group themselves in five great eras. From the study of the stratified rocks and the fossils which they contain, geologists have been able to construct a chronological table of principal events in the last three eras of this history—the Paleozoic, the Mesozoic and the Cenozoic. Less is known of the two earlier eras—the Proterozoic or Algonkian and the Archaean although for some regions the outlines of this earlier or pre-Paleozoic 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 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:

ERAS AND PERIODS.

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

The length of geologic time, estimated in years, cannot be stated with any high degree of accuracy. It certainly is to be measured in tens of millions of years, rather than in lesser units. It is probably to be measured in hundreds of millions rather than in tens. The entire trend of recent studies not only in geology, but in physics, chemistry, and biology, emphasizes the extreme length, rather than the brevity of geologic time.[1]

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[1] For a fu[illegible]r discussion of this subject see p. 174.

THE GEOLOGIC MAP OF NEW JERSEY.

1912, revised 1931

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 rocks and the age of the various formations that occur in all parts of the State. 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 successive earlier age being arranged in order toward the bottom. There are two exceptions to this general rule however: (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 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 their relative age.

CHAPTER III.

GEOLOGIC SUMMARY OF NEW JERSEY.

APPALACHIAN PROVINCE.

General statement.—The several divisions of the Appalachian province do not exhibit sharp geologic differences throughout the province as a whole. For example, in the central and southern Appalachians the Piedmont Plateau and the Appalachian Mountain belt are not separated by a sharp geologic boundary and some geologic formations are common to both. In many places, also, geologic formations extend continuously from the mountain belt into the Appalachian Valley. But in the general region including northern New Jersey, southeastern New York, and eastern Pennsylvania, 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. 1, 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. They lie between the slightly tilted and faulted Triassic strata of the Piedmont and the folded and faulted Paleozoic beds of the Appalachian Valley.

The rocks consist mainly of gneiss and schist, possibly in part of sedimentary origin, with some marble or crystalline limestone, and of intrusive igneous rocks, for the most part gneissoid. They were greatly deformed in pre-Cambrian time probably more than once and are now complexly folded and faulted, as a result not only of pre-Cambrian but of post-Cambrian disturbances. Infolded with the pre-Cambrian crystalline rocks are strips of more or less metamorphosed Paleozoic strata, (Pl. I) which for the most part occupy northeast-southwest trending valleys characteristic of the Appalachian province. In the Greenwood Lake-Green Pond region several of these infolded Paleozoic formations are thick resistant quartzites and conglomerates, which form ridges equaling in height the adjacent gneissic ridges. They are remnants of beds

which in Paleozoic time were deposited on the pre-Cambrian gneiss, and were later involved with the crystalline rocks in the great folding which closed the Paleozoic Era. They are now preserved only in the bottoms of the great troughs and down-faulted belts. Much of the gneiss has the composition and appearance of granite but differs from granite in having a parallel structure known as *foliation;* that is, the constituent minerals 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 on the geologic map. The structure is crumpled and folded in places, and is further complicated by faults and by many intrusions of other igneous rocks.

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

In the northern New Jersey region, Kittatinny Valley, a part of the Appalachian Valley, is underlain chiefly by limestone and shale of Cambrian and Ordovician age. Kittatinny Mountain is formed of resistant sandstone and conglomerate belonging to the Silurian, and the adjacent portion of the Delaware Valley is occupied by late Silurian and early Devonian shale and limestone (Pl. I). All these strata, which are of the same age as those infolded with the pre-Cambrian rocks in the Highlands have been considerably folded and faulted. The faults are both normal and reverse or thrust (Fig. 3) and the strata have been bent under great horizontal pressure into a series of up and down wave-like undulations with the folds or wrinkles elongated in a northeast-southwest direction. These folds and faults in New Jersey are a part of the structure of the great Appalachian Mountain System (Fig. 4) and the long-continued crumbling and wearing down of the structures 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 now the highest ridges, while the soft shales and somewhat soluble limestones have disintegrated more rapidly and form the bed rock of the valleys and the lower

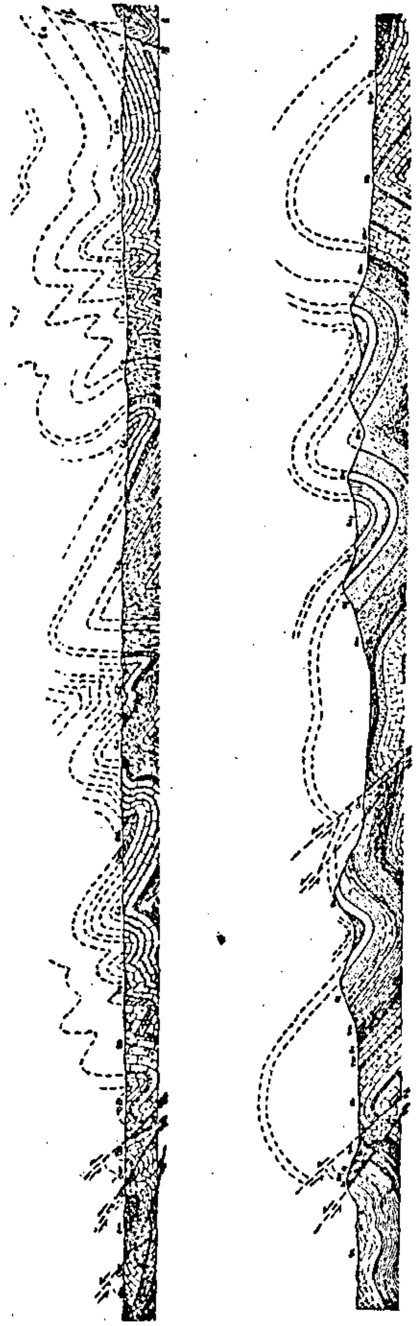

Fig. 4. Appalachian Folds and Faults. (From U. S. G. S. Geol. Folio No. 170).

lands generally. The oldest formation is exposed along the eastern side of the valley at the western base of the Highlands, and the youngest formations outcrop along the upper Delaware between Wallpack bend and Tri-State Rock. Owing to the folding and faulting, many beds intermediate in age are repeated in outcrop across the Valley.

Ordinarily in the Kittatinny Valley, particularly in the limestone belts, the folds are of such great amplitude that they are not shown in individual exposures, and their existence can be determined only by plotting the dip and strike of many outcrops over a wide area. However, a good example of an anticlinal fold can be seen in the southwestern end of a limestone hill at Johnsonburg on the road to Quaker Church. In the slate belts small close folds are by no means uncommon, although very frequently close observation is necessary to determine their presence.

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 of rocks of this age extending from the Hudson across New Jersey, Pennsylvania and Maryland into Virginia. They consist of red shale and sandstone, black and brown argillite, vari-colored conglomerate, and interbedded volcanic flows and intrusive sills. In general they have been tilted 10 to 15 degrees northwestward, but here and there they have been warped into gentle folds, and more or less faulted. The general trend of the folds and the strike of the tilted strata is northeast and southwest. Most of the faulting is of the normal type shown at A, Fig. 3, and the total displacement or movement along some of them is many thousand feet. Along the Delaware River in the vicinity of Lambertville, for example, faulting and erosion have brought to the surface some of the basal Triassic beds and the accompanying intrusive sheet of diabase at four places within a distance of 12 miles. This is shown on the State Geologic Map, Sheet 40 and on profile C-C of the sections shown on its margin.

THE COASTAL PLAIN

The Coastal Plain of the eastern United States 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 all of the State southeast of a line from Woodbridge to Trenton lies in the Coastal Plain. Wherever the formations can be seen in pits or other excavations they appear to the eye to be horizontal, although we know from many borings that they dip toward the coast from 60 to 10 feet per mile, the lowermost beds having the greatest dip.[1]

Several important results follow from this gentle dip to the southeast.

✓(1) The beds which appear at the surface along the northwest margin of the Coastal Plain rest upon a gently undulating foundation of very old hard rocks, and pass beneath successively younger strata towards the southeast. Near the northwest margin borings frequently penetrate the Coastal Plain formations and enter the underlying hard strata, whereas further southeast the sediments become thicker, 490-500 feet at Hightstown, 1,115 feet at Prospertown, 1,336 feet at Jackson's Mills in Ocean County and more than 2,300 at Atlantic City. ✓(2) The present northwestward margin of these beds does not represent their original limit in that direction. They certainly extended many miles northwest of their present boundary, probably beyond the limits of the State, as is suggested by certain peculiar features of the present drainage.

✓(3) Owing to the southeast dip the outcrops of the various formations trend northeast-southwest in fairly regular parallel bands, but since the slope of the strata is very slight compared to the irregularities of the present topography, the outcrop bands curve with the topography and tend to follow contours on steep hillsides.

✓(4) Owing to the dip also, the different formations not only appear at the surface as indicated on the map, but extend southeastward under cover of the later and overlapping formations, a fact of great importance in the location and development of artesian water supplies.

SURFICIAL DEPOSITS

Throughout northern New Jersey the valleys of the larger streams are floored with alluvium, and deposits of sand and gravel

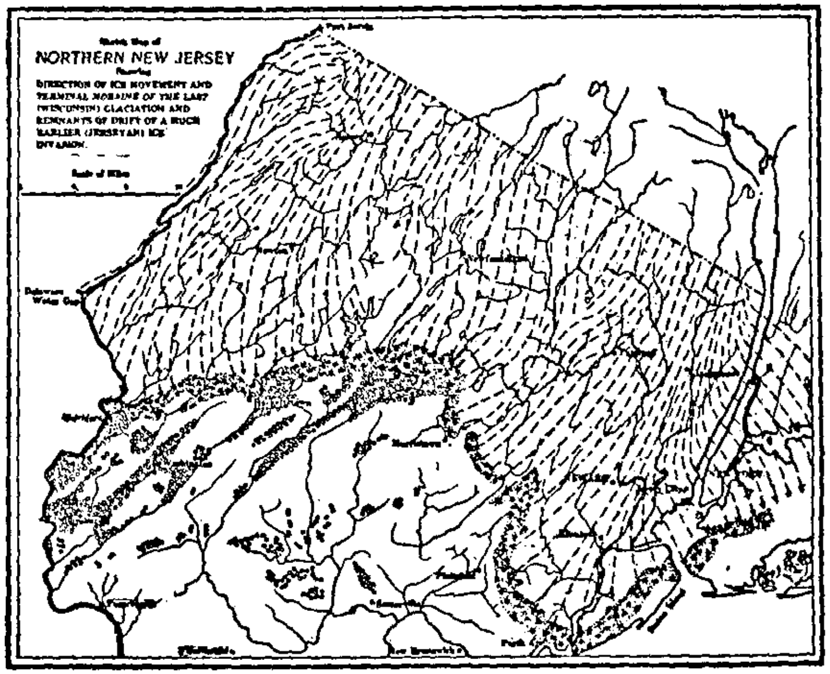

Fig. 6. Map showing ice movement, terminal moraine, and the older drift sheets (Jerseyan and Illinoian).

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[1] Sections CD and EE at the bottom of the large geologic map show this relationship. For the sake of distinctness the sections on the geologic map have been drawn with their vertical dimensions greatly exaggerated and this makes the slope of the beds seem much greater than it really is.

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. 5) is mantled by a deposit of glacial drift, in some places sufficiently thick to obscure entirely the relief of the bed rock surface. Scattered boulders of glacial origin are found in many places south of the line of the moraine, and rivers flowing from the glacier carried glacial sand and gravel far beyond the area actually covered by the glacier itself.

On the Coastal Plain, also, during Quaternary time streams alternately made widespread deposits of sand and gravel on flood plains along their courses, and later under changed conditions removed them wholly or in part and redeposited the material at lower levels. Remnants of these fluviatile deposits are widespread in central and southern New Jersey and over considerable areas effectually conceal the earlier marine deposits. 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. The whole assemblage of these beds rests upon a deeply buried floor of hard rock, probably in large part of pre-Cambrian age, but possibly including some areas of Paleozoic strata.

SUMMARY OF GEOLOGIC HISTORY.

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 withdrew for a time. Some of the mountain-making folds in the early

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[1] The successive uplifts and subsidences to which New Jersey has been subjected in the course of geologic time are graphically shown in Fig. 6, p. 49.

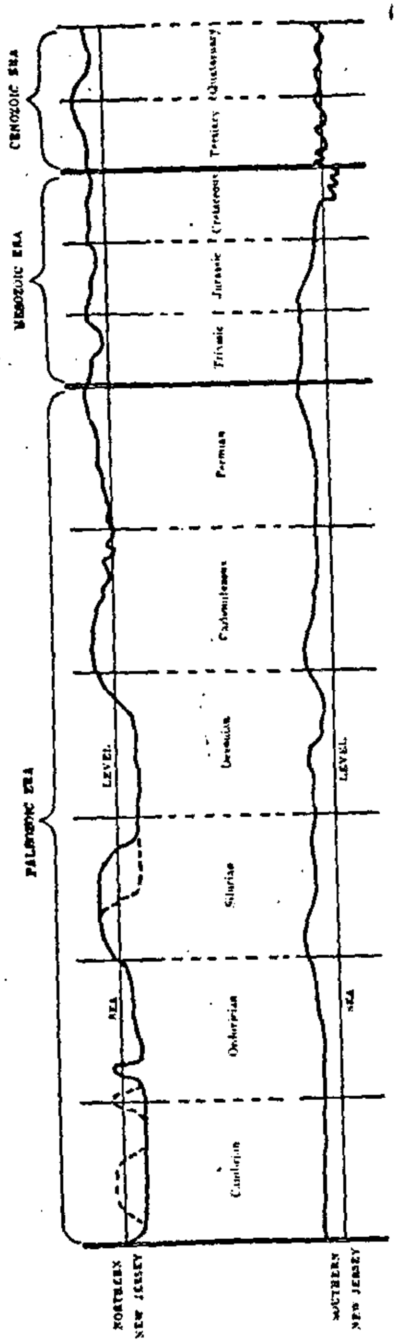

Fig. 6. Diagram showing major oscillations of the land area of New Jersey during geologic time.

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 between 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. 5), slightly modifying the topography and leaving extensive deposits of glacial drift. At least two, probably three, such ice advances are recorded in the drift deposits now existing in the State.

TABLE 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 group of letters in parentheses are the symbols by which the corresponding formations are designated on the large state geological map.

In interpreting this record, it is important to remember that an "unconformity"[1] between formations indicates a break in the sedimentary record, the absence of beds which occur elsewhere, and the lapse of time necessary for the formation of the missing strata. It usually involves (1) the elevation of the region above sea level, sometimes with more or less folding of the strata, (2) the removal of some part of the beds previously laid down, and finally, (3) the re-submergence of the region and deposition of a new series on the older surface.

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.

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[1] In the table the term "unconformity" includes also disconformity. The latter term is frequently used when the beds above and below the "break" are parallel and there is no discordance of structure.

Pleistocene

Glacial	Non-Glacial	
Wisconsin Drift 0-460 ft.	*Beach Sand and Gravel* (*Qbs*)	
Till (not shown on map)	(Unconformity)	
Terminal Moraine (Qtm)	*Cape May Formation* (Qcm)	0—30 ft.
Recessional Moraine (Qrm)	(Unconformity)	
Stratified Drift (Qsd)	*River Drift* (Qrd)	
(Unconformity)	(Unconformity)	
Illinoian and Jerseyan (*Early*) *Drift* (Qed)	*Pensauken Formation* (Qps)	0—60 ft.
	(Unconformity)	
(Not separated on the map)	*Bridgeton Formation* (Qbt)	0—30 ft.
(Unconformity)	(Unconformity)	

TERTIARY (T)

Beacon Hill Gravel (Tbh)	0— 20 ft.
(*Unconformity*)*?*	
Cohansey Sand (Tch)	100—250 ft.
(Unconformity)	
Kirkwood Sand (Tkw)	100 ft.
(Unconformity)	
Shark River Marl (Tsr)	11 ft.
(*Unconformity*)*?*	
Manasquan Marl (Tmq)	25 ft.
Vincentown Sand (Tvt)	25—100 ft.
Hornerstown Marl (Tht)	30 ft.
(Unconformity)	

MESOZOIC

CRETACEOUS (K)

Tinton Loam	(Krb)	10— 20 ft
Red Bank Sand		0—130 ft.
Navesink Marl (Kns)		25— 40 ft.
Mount Laurel Sand	(Kmw)	5— 60 ft.
Wenonah Sand		35— 20 ft.
Marshalltown Formation (Kmt)		30— 40 ft.
Englishtown Sand (Ket)		20—140 ft.
Woodbury Clay (Kwb)		50 ft.
Merchantville Clay (Kmv)		50— 60 ft.
Magothy Formation	(Kmr)	25—175 ft.
(Unconformity)		
Raritan Formation		150—300 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		Green Pond Mountain Region	
		Skunnemunk Conglomerate (Dsk) (1,500 ft.)	
		Bellvale Sandstone (1,800 ft.)	(Dpb)
Marcellus Shale (Traces)	(Dmo)	*Cornwall Shale* (1,000 ft.)	
Onondaga Limestone (? ft.)		*Kanouse Sandstone* (Dkn) (215 ft.)	

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

SILURIAN (S)

Manlius Limestone
(35 ft.)
Rondout Limestone
(39 ft.)
Decker Limestone
(52 ft.)
Bossardville Limestone
(12—100 ft.)
Poxino Island Shale
(? ft.)
} (Sbd)

Decker Limestone
(? ft.)
(Unconformity) ?
Longwood Shale
(200 ft.)
} (Sd)

High Falls Formation (Shf)
(2,300 ft.)

Shawangunk Conglomerate (Ssg)
(1,500 ft.)

Green Pond Conglomerate (Sgp)
(1,200—1,500 ft.)

(Unconformity)

ORDOVICIAN (O)

Martinsburg Shale (Omb)
(3,000 ft.)
(Unconformity)

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

Jacksonburg Limestone (Ojb)
(125—300 ft.)
(Unconformity)

CAMBRO-ORDIVICIAN (CO)

Kittatinny Limestone (Cok) 2,500—3,000 ft.
(Unconformity)

CAMBRIAN (C)

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

IGNEOUS ROCKS.

TRIASSIC (Tr)

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

POST-ORDOVICIAN

Serpentine (sp) (In Hudson County) [illegible]
Nephelite Syenite (Ns)
Basic Volcanic Breccia (Bb)
} (In Sussex County)

PRE-CAMBRIAN

Granite (gr)
Gabbro (gb) (In Mercer County)
Losee Gneiss (Lgn)
Byram Gneiss (Bgn)

METAMORPHIC ROCKS OF UNKNOWN AGE.

PRE-CAMBRIAN

Wissahickon Mica Gneiss (Wgn) ? ft.
(In Mercer County)
Franklin Limestone (Fl) ? ft.
Pochuck Gneiss (Pgn)

CHAPTER IV.

ARCHAEAN AND PROTEROZOIC ERAS.

PRE-CAMBRIAN.

General statement. — 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. These rocks are now part of the Highlands. Most of them were formed in the sea, and since some of these strata are composed of fragmental material it may be safely inferred that there existed somewhere 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.

During a portion of this time at least the land area must have been low-lying or remote from New Jersey, since there was an absence of land-derived material in the sea of this region, and in it thick beds of lime mud accumulated which were afterwards consolidated into limestone. These 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 their deeply-buried portions by molten rock which slowly consolidated and formed the several types of gneiss which now make so large a part of the Highlands. It seems certain that the sediments had suffered some alteration and were more or less metamorphosed before this invasion by the gneissic magma, since the intrusion was evidently directed by the pre-existing structure of the intruded rocks. In most places the invasions were along lines running northeast and southwest, resulting in the banding which is so conspicuous a feature of these rocks wherever now exposed. In some places the first intrusions were along curved lines. Later ones followed these, and thus resulted the curved belts as seen south of Split Rock Pond. 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.

Both classes—metamorphosed sediments and intrusive gneisses—now occur at the surface mainly in the Highlands, with small areas near Trenton and Hoboken. Their original extent was much greater, since borings indicate that they underlie large areas of the younger formations, and they probably constitute the foundation on which all subsequent formations rest. Their texture, where now exposed, is such as to prove that they assumed their present form under enormous pressure and at great depths. Hence many hundred, probably many thousand feet of overlying strata have been worn away since their formation, more than 750 or 1,000 million years ago.

Certain remnants of the sedimentary series now form areas of white crystalline limestone with some closely associated quartzites, conglomerates, and beds of tremolite, serpentine and talc. These are all included in the term *Franklin Formation.* The intruding magmas formed several types of gneiss and pegmatite, with beds of magnetic iron ore. Associated with them are other gneisses which are probably completely metamorphosed portions of the older sedimentary series. The gneisses, together with the included sedimentary beds form a series of northeast-southwest trending ridges which constitute the Highland province.

The Franklin formation (fl). The formation receives its name from the preponderance in it of white or gray crystalline limestone so well exposed at Franklin, Sussex County.

The limestone is usually a white crystalline marble, generally coarsely granular, but in some places fine-grained and in a few localities nearly amorphous. Locally it passes into pink, yellow or grey varieties, and at one place near Danville, it is a mottled red and white rock speckled with black flakes of biotite. It ranges in chemical composition from a nearly pure calcium carbonate (calcite) to the double carbonate of lime and magnesia (dolomite). The bulk of the formation is apparently low in magnesia. At many places the rock is free from intruded minerals, but usually it contains varying amounts of one or more of the following: diopside, tremolite, chondrodite, phlogopite, quartz and graphite. Magnetite, sphalerite and garnet occur locally. Serpentine is abundant in some localities as an alteration product of the diopside and chondrodite. Where the number of included minerals is large, the rock loses its white color and becomes dark gray or green. At Franklin and Ogdensburg (Sterling Hill) it contains large beds of zinc ore (see p. 178) and in a few places beds of iron ore occur (see p. 176) in it.

Bedding in these ancient sediments, particularly in the limestone, is obscure and can rarely be observed, but so far as noted the beds usually strike approximately northeast and dip steeply southeast. In a few places the limestone is apparently folded. It is cut by dikes of pegmatite or basic rocks, most of which are identical in character with some of the black gneisses which form an integral portion of the gneiss series. In a few places tongues of the lighter gneisses also penetrate it. The smaller areas of limestone scattered through the Highlands are small masses completely embedded in the gneiss.

These relations point to the conclusion expressed above, that the limestone, with the occasional masses of associated slates, quartzites and conglomerates represents an older series of rock, into the lower portion of which gneiss and pegmatite were intruded in a molten condition at a very remote period in the earth's history, the whole being far beneath the surface at that time. Their occurrence at the surface today is of course due to subsequent erosion through succeeding geologic eras.

The largest area of Franklin limestone is in Sussex County, where it forms a narrow belt from Glenwood to Ogdensburg. West and southwest of Sparta there are small masses included in the gneisses and imperfectly exposed, which represents slivers of the formation separated from the main mass and entirely engulfed by the invading igneous magma, but not completely melted and incorporated in it. There are other masses along the west margin of Pequest meadows, and a few miles east of Belvidere, both in Warren County. At Upper Harmony, Phillipsburg, Pottersville, Montville, and west of Midvale small isolated areas of limestone are found surrounded by the gneiss and more or less completely altered to a mixture of tremolite, talc and serpentine.

The gneisses.—The gneisses appear in many varieties and 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. All varieties are cut by the pegmatite dikes and all exhibit a more or less well-defined linear structure in the arrangement of their constituents, which are elongated into cylindrical grains, or are grouped in little aggregations. This structure now dips and strikes in the same direction as the gneiss layers and usually pitches northeasterly at comparatively low angles (15°—40°). The strike of the layers is usually northeasterly and their dips high to the southeast. In a few places where the layers curve, the dip and pitch change accordingly.

With few exceptions the gneisses correspond accurately in their mineral and chemical composition to 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. It is believed that they were formed chiefly by the solidification of invading molten silicate solutions or igneous magmas. Their distinctly crystalline granitic texture shows that the cooling process was a slow one and took place deep beneath the surface of that time. Evidence of crushing in the minerals of the gneisses is almost entirely wanting, and appearances strongly favor the belief that their gneissic banding is an original structure produced by the slow creeping movements of the intruding magmas, and possibly the regional compression to which they were subjected while they were crystallizing.

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 invaded 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 after 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.

Although the Franklin limestone locally retains traces of original stratification, showing its sedimentary origin, 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 deformation, which covered a wide area.

Origin of the ores.—At this time, too, the magnetite and probably the zinc ores which occur in these rocks were deposited by hot mineral-bearing solutions that were gradually given off by the magmas as they cooled and solidified. The zinc ores (p. 178) are now, so far as known, limited to the limestone and occur only in two large deposits at Franklin and Ogdensburg. The iron-ore deposits (p. 176) occur in all the crystalline rocks of the Highlands, but are especially abundant in the Byram and the Losee gneiss.

Erosion.—The intrusion of the gneisses was doubtless accompanied by considerable elevation of the whole region affected. Later through immense periods of time, weathering and erosion removed the greater part of the overlying sedimentary strata, and thus large areas of the deep-seated gneisses became exposed at the surface. The region may have been worn down almost to a plain (peneplain), but many minor irregularities at least, still existed when depression of the land at the beginning of Cambrian time brought an invasion of the sea over most of the present Highlands and westward. 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.

The length of time for the deposition of the Franklin limestone, the intrusion of the gneiss and the enormous erosion which preceded the deposition of the earliest sediments of Cambrian time may have been twice as long as the sum of all the subsequent periods (p. 174). Certainly it comprised 6 to 10 hundred million years or more.

CHAPTER V.

THE PALEOZOIC ERA

SUMMARY STATEMENT.

The beginning of Paleozoic time.—The great erosion in pre-Cambrian time, referred to above, removed hundreds and perhaps thousands of feet of strata from the area now included in New Jersey. In fact, this and neighboring regions seem to have been worn down almost to a plain (a peneplain) of wide extent with only minor irregularities of surface. Finally the period of erosion was brought to a close by the slow warping and depression of portions of the continent, as a result of which a narrow sea came inland over Alabama and gradually extended along the belt now occupied by the Appalachian Mountains, and northeastward to Labrador. At least the northern part of New Jersey was submerged and possibly the entire State. Southeast of this sea and separating it from the Atlantic Ocean was an ancient land area, now submerged but 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 greater part of both of these ancient continents has long since disappeared beneath the waters of the Atlantic Ocean, but during the many million years which make up Paleozoic time, they played an important role in the history of New Jersey.

The Paleozoic era began with the incursion of this sea upon the margin of the continent and ended with the great earth movements which formed the Appalachian Mountains. Its duration is to be measured in millions of years, 360 according to a recent estimate. During this long era the interior sea lying northwest of Appalachia varied greatly in shape, size, and position. Again and again its shore line withdrew to the west far from the borders of New Jersey, only to return when a sinking or warping of the land (or rise of the sea level) permitted its waters to reinvade the State. The history of these changes cannot be worked out in all its details from the record in New Jersey, but some of the major movements are clearly recorded in the sedimentary rocks of Warren and Sussex counties.

Character and distribution of Paleozoic rocks.—The known Paleozoic rocks of New Jersey are chiefly sedimentary in origin, and comprise representatives of the Cambrian, Ordovician, Silurian and Devonian systems. No strata of Carboniferous or Permian age occur in the State. Associated with the Paleozoic sedimentary rocks in Sussex County are certain relatively small masses of igneous rocks the age of which is indeterminable. They are certainly younger than the formations which they cut and are perhaps to be referred to the early Mesozoic era (Triassic), particularly since this period is known to have been one marked by great volcanic activity in New Jersey. Also in adjacent portions of Pennsylvania and at Alpha, N. J., thin beds of volcanic ash (bentonite) occur in a limestone (Jacksonburg) of Ordovician age.

The Paleozoic strata outcrop in three general regions (Pl. I) as follows:

(1) In a few small areas southeast of the Highlands, between 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.

Their present visible distribution is much more restricted than their original extent, first, because extensive portions have been removed by erosion since their formation; second, because they are covered in part by the younger Mesozoic strata, and third, because the region in which they occur has been greatly compressed and shortened from southeast to northwest by folding and overthrust faulting.

They probably covered the Highland belt and extended southeast beyond the present inner margin of the Coastal Plain. The Triassic conglomerate which occurs at intervals along the southeast margin of the Highland belt is in large part composed of pebbles and cobbles of Paleozoic formations—(Silurian and Devonian) which during Mesozoic time covered most of the gneiss of the Highland belt.

Structure of the Paleozoic rocks.—These rocks 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 less steep than northwestward dips, so that the axial planes of the folds are inclined to the southeast (see Fig. 4).

The folding took place during the Appalachian revolution in late Carboniferous and Permian time (see p. 97). 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. 7 and section BB on the geologic map). The most striking examples of this movement are the large limestone areas 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, and recently evidence of the same overthrust was temporarily exposed along the new highway at Hampton, east of the Musconetcong Creek.

More conspicuous, however, than the overthrusts are dislocations due to nearly vertical faults parallel or oblique to the axes of the folds, on 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 have 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. 110 and sections AA, BB, and CC on the map).[1]

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[1] *References.*—The Paleozoic formations of New Jersey are described and discussed in the following publications at considerable length:

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 Mountain Region," by Henry B. Kümmel and Stuart Well[illegible] Annual report of the State Geologist of N. J. for 1901, pp 1-52.

CAMBRIAN PERIOD.

General statement.—In New Jersey, Cambrian time is represented by a relatively thin bed of quartzite and sandstone below (Hardyston formation), and a great thickness of limestone above (part of the Kittatinny limestone). There are good reasons, however, for concluding that the time required for the formation of these strata represents only a portion of Cambrian time. They now appear at the surface chiefly in Warren, Sussex, Morris, and Hunterdon counties. The duration of the Cambrian period has been recently estimated at 70 to 110 million years, but earlier calculations assigned to it a much shorter time. Whatever its length in years, the period was very long and the geologic record complicated. Three main subdivisions are commonly recognized, during the first and last of which the sea covered portions of the State, while during the middle period it had withdrawn and all this region was land.

The Lower Cambrian (Georgian) invasion.—The worn-down land of pre-Cambrian time was at the close of this period of erosion, covered with a thin mantle of rock debris. As the Cambrian sea advanced, its waves seized this material, rounded and sorted it more or less completely, swept the finest particles into deep water, and deposited the coarser along the shore line as beds of sand and gravel, which varied from place to place in size and kind of material and thickness of deposit. Thus was formed the earliest of the Paleozoic formations. Locally the old land surface was swept bare of all loose material, and even the hard rock itself somewhat eroded. With further subsidence, beds of gravel and sand accumulated on these wave-swept, rocky platforms, so that the line of contact between the pre-Cambrian gneiss and the later sedimentary rocks is sharply marked. At other localities, however, the sea did little more than rework the upper part of the rock debris previous to the accumulation of sand and gravel, so that there is now no sharp lines between the earlier and later beds, but on the

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"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.

contrary they appear to grade into each other through a transition zone of nondescript material, which may with equal reason be referred to either. The sand and gravel accumulated under these varied conditions now constitute beds of quartzite and conglomerate. They are called the Hardyston quartzite, there being good exposures near the village of Hardystonville in Sussex County.

Hardyston quartzite.—Typically this formation is a quartzite, at many places conglomeratic, containing pebbles of quartz, feldspar, granite, gneiss, and shale. Locally it is a limy sandstone. It is commonly feldspathic (arkose) and in some localities this arkosic character is so marked that it is not readily distinguishable from granite. Beds of slate are present at some places in the upper part. Its thickness ranges from a few feet to 200 feet or more. It everywhere rests unconformably upon the eroded surface of the older crystalline rocks, but locally the line of contact even where exposed is not readily discernible. However in the first railroad cut on the New York, Susquehanna & Western Railroad, northwest of Hamburg, there is a good exposure of a few feet of a vitreous quartzite, resting on the undulatory surface of the underlying gneiss. Good exposures are found along the road one-half mile north of Great Meadows Station, and on the crest and hillside near Great Meadows school-house, two miles southwest of Long Bridge, Allamuchy Township. Its upper shaley and slaty layers seem to grade upward into the over-lying limestone by alternation of shale and limestone beds, so that its upper limit is indefinite. Its contacts with and exact relations to the great mass of the limestone above can rarely be observed in the field, since this boundary is ordinarilly concealed by surficial deposits. It contains fossils of a species of the trilobite *Olenellus*, and hence is regarded as of Georgian (Lower Cambrian) age.

As originally deposited, the Hardyston quartzite had a wider distribution than its present outcrop. It was the first formation laid down in New Jersey on the floor of the lower Cambrian sea, and presumably was coextensive with the sea. It now appears as a narrow band along the southeastern margin of the folded Paleozoic strata of the Kittatinny Valley in Warren and Sussex counties and along the margin of the inter-Highland valleys, where the gneisses pass under the Paleozoic strata. There are small exposures of a vitreous quartzite near Trenton which is correlated with the Hardyston quartzite of Sussex County. The formation is also correlated with the Poughquag quartzite of Dutchess County, New York, and the Chickies quartzite of eastern Pennsylvania,

and on this basis it is assumed that the shore of the early Cambrian sea advanced far southeast of the present Highlands. In fact, there is some reason for believing that there was at this time communication between the inland sea and the Atlantic Ocean which lay east of its present border, possibly by a strait across northern New Jersey, separating Appalachia and Acadia.[1] As the Hardyston quartzite is not very thick and is succeeded by beds of shale and limestone, it is inferred that the adjoining land area was low, and that the northward and eastward transgression of the sea on the land was relatively rapid, so that after a brief period conditions prevailed in northern New Jersey which favored the deposition of limy muds rather than sand and gravel.

Kittatinny limestone, lower portion.—The Hardyston quartzite is overlain by a great thickness of blue and gray limestone, designated on the geological map and in earlier reports as the Kittatinny limestone. When this name was first applied to these beds, it was believed that they represented a long period of uninterrupted sedimentation in a sea which covered northern New Jersey continuously through all Cambrian time and a portion of the lower Ordovician. Later studies both in New Jersey and adjoining states by different workers have shown the possibility of subdividing the Kittatinny limestone into three formations, which are separated by interruptions in sedimentation due to withdrawals of the sea and changed relations of land and water areas. These divisions are as follows:

Overlying the basal sandstone and quartzite (Hardyston) is a considerable thickness of blue and bluish-gray dolomitic limestone with more or less yellowish and silvery shale. The beds present two somewhat contrasted phases, one an extremely thick-bedded massive limestone, in which the stratification planes cannot everywhere be readily determined; the other, a thin-bedded limestone intercalated with layers of silvery damourite shale, which range in thickness from thin films to layers several inches or even feet in thickness. The rock varies in color from dark blue-black to bluish and yellowish-gray. Much of it is crystalline but the crystals are usually so minute that the texture is finely granular. In some layers they are too fine to be distinguished by the naked eye. The preponderating occurence of damourite shale at certain horizons, particularly in the lower portion of the formation, and its presence as thin films at all but a few horizons is the most strik-

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[1] Schuchert, Bulletin Geol. Soc. Am., vol. 20, p. 517.

ing characteristic of these beds. So far as known, they contain no fossils. They are correlated with the Tomstown limestone of southern Pennsylvania because of their position and character. If this correlation is correct, they are *Lower Cambrian* in age. Their thickness has not been determined but it is probably several hundred feet. They have been recognized in the Phillipsburg region in Warren County, but it has not yet been determined whether they occur in all areas of Kittatinny limestone, as represented on the map.

LEITHSVILLE

The Upper Cambrian (Ozarkian) invasion.—The middle portion of the Kittatinny limestone consists of beds of medium thickness averaging 6 to 18 inches. Where shown in artificial exposures or those which are slightly weathered, the beds are alternately light and dark in color, so that the formation can often be easily recognized even at a distance. On fresh surfaces the rock ranges in color from almost black to blue-gray and light-gray. It is uniformly dolomitic in composition.

Layers of quartz sandstone, usually less than 2 inches in thickness but occasionally thicker, occur at intervals throughout the formation, and indicate shallow water conditions and proximity to a land area from which fragmental materials were occasionally derived. Thin films of shale, ripple marks, and cross-bedded structures are also present and testify to shallow-water conditions. At some horizons thin seams of calcareous and siliceous silt alternate so frequently as to form a so-called ribbon limestone. On exposed surfaces the ribbon structure is accentuated by the differential weathering of the more soluble limestone laminae. At a few horizons the shale layers are highly carbonaceous, while at others the mineral damourite is an abundant constituent. Layers of oölite occur not infrequently, and at some horizons a pisolitic structure has been observed. Beds of conglomerate composed of angular flat fragments of limestone inclosed in a calcareous or a siliceous matrix, which in some instances is cross-bedded, have been noted at several horizons. In all cases the fragments lie with their flat sides parallel with the bedding planes. This type of conglomerate has been designated *edgewise conglomerate*, and was probably formed by the breaking up and redeposition by shallow wave action of thinly bedded lime sediments not yet completely solidified. Along many of the bedding planes the rock on opposite sides interlocks in a manner suggesting the suture joints of a skull.

Upper [illegible]nbrain (Ozarkian) fossils were found in these beds near Carpentersville, by Weller[1] in 1899. Much more conspicuous, however, than these forms are many colonies of marine algae, *Cryptozoon proliferum* and allied forms. These consist of closely grown heads, each made up of minutely plicated laminae with wavy cross-section and concentric horizontal section. The smaller heads are an inch or less in diameter but increase with the accumulation of concentric layers and by coalescing with adjacent heads until they attain a width of 2 or 3 feet, and in cross-section form arches, which make a series of domes on the surface of the layer.

The presence of the Cryptozoon heads, the frequent occurence of oölite and edgewise conglomerate, the alternate light and dark banding and the comparatively uniform thickness of the beds are the chief characteristics which serve to differentiate these beds from the Tomstown limestone below and the Beekmantown beds above. They are to be correlated with the similar beds, to which in eastern Pennsylvania the name Allentown has been given. They are regarded as Upper Cambrian in age.

The thickness in New Jersey of the middle division (Allentown) has not as yet been accurately determined. Neither its base nor its top has been recognized with certainty in any exposure. There is some evidence, not as yet conclusive, that its top is a surface of erosion and that the overlying beds rest upon it non-conformably. Measurements of a portion of these beds made where repetition by folding or faulting can probably be eliminated show a thickness between 760 to 1,125 feet, with a possible maximum of 2,000 feet, the uncertainty arising from the impossibility of determining the exact position of top and bottom in a region of folded strata and few outcrops.

Kittatinny limestone, upper portion.—The upper portion of the Kittatinny limestone, as originally described, has long been known to be of Ordovician age, and comparable to the Beekmantown limestone of New York (see below).

Distribution.—The Kittatinny limestone forms the surface rock in portions of Kittatinny Valley in Warren and Sussex counties and in several of the longitudinal valleys in the midst of the Highlands. Smaller areas occur at several localities southeast of the Highlands along the margin of the Piedmont Plain. In Kittatinny Valley the dip of the beds carries it under the slates and higher formations to the northwest, but at so steep an angle that it does not reappear in New Jersey, although it outcrops again in central Pennsylvania.

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[1] Geol. Survey of New Jersey. Report on Paleontology, [illegible]l. iii, 1, 13.

Its former extent was much greater than its present. Together with the Hardyston quartzite it unquestionably covered the gneisses which are now exposed in the Highlands, and extended an unknown distance south and east of its present outcrops.

History of events.—Assuming the accuracy of the correlation which assigns the lower part of the limestone (Tomstown) to the Lower Cambrian and the middle portion (Allentown) to the Upper Cambrian, we are led to the conclusion that the interior sea in which were deposited the Hardyston quartzite and lower limestone beds withdrew from this region in Middle Cambrian time. This restoration of land conditions in northern New Jersey was due to an uplift of the eastern lands (or subsidence of sea level) which apparently drained the entire Appalachian trough from Labrador to Alabama. The movement was without noticeable tilting of the horizontal limestone beds, since the earlier and later formations seem to be structually conformable. The upper surface of the lower Cambrian beds in this State does not seem to be characterized by any marked irregularities, from which it is inferred that during middle Cambrian time the emerged land stood only slightly above sea level and therefore was not greatly dissected, or, if it had been raised to greater elevation, erosion had progressed long enough to produce a low-lying, relatively level plain, whose surface corresponded approximately with the bedding, so that when the sea in Upper Cambrian (Ozarkian) time again submerged this region, the later sediments were laid down on the earlier without noticeable discordance in bedding.

When in Upper Cambrian time the interior sea was reestablished in this region, a great thickness of even-bedded magnesian limestones, the middle portion (Allentown) of the Kittatinny formation, was deposited. The thin layers of sandstone and shale which are interbedded at intervals with the limestone, indicate the proximity of a land mass from which clastic sediments were occasionally derived. Wave marks, cross bedding, and beds of edgewise conglomerate point to shallow water conditions and a sea bottom not infrequently disturbed by current and waves. Fossils are not common in the Cambrian formations of New Jersey, the few found being chiefly obscure remains of trilobites,[1] crab-like animals which flourished in great profusion during the Cambrian, but became extinct before the close of the Paleozoic era. The scarcity of fossils in the Cambrian beds of New Jersey does not necessarily mean, however, that the Cambrian seas which covered the State were sparsely inhabited. It is true that invertebrates were the only animals and that the first fishes did not appear until much later, but the Cambrian fauna contains representatives of all the fundamental invertebrate types ranging from simple sponges to complex forms of Crustacea. About 500 species of Cambrian invertebrate animals have been described from North America, so that it is a fair inference that life was by no means wanting in the seas which covered northern New Jersey at this period. During Upper Cambrian time, lime-secreting algae (cryptozoa) flourished in great numbers. These plants, like coral, lived in colonies and by the secretion of carbonate of lime from the sea-water aided in the formation of the limestone, many layers in the Upper Cambrian portion of the Kittatinny originating in this way.

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[1] Geol. Survey of N. J., Paleontology, Vol. iii, p. 10.

Close of the Cambrian.—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 (Ulrich and Schuchert); but positive evidence of this has not yet been observed in New Jersey. It must be recognized that the base of the beds referable to the Ordovician has not been seen in this State, and nothing is positively known regarding their exact relation to the underlying limestone.

Ordovician Period.

General statement.—In North America, Ordovician time was characterized by three periods of subsidence,[1] when the oceans invaded and covered more or less of the land. These were separated by periods of emergence, when the oceans withdrew from the continent, if not entirely, at least in great part. The first flood (Canadian) was not of great extent, but the second (Champlainian) and the third (Cincinnatian) were the greatest of all Paleozoic time.

In New Jersey Ordovician time is represented (a) by two limestone formations, the upper Kittatinny (Beekmantown) and the Jacksonburg, which are separated from each other by a long erosion interval, and (b) a great shale and slate formation, the

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[1] Pirsson and Schuchert, Textbook of Geology, Vol ii, p. 629.

Martinsburg (Hudson River of early reports). Certain shale beds near Clinton in Hunterdon County may represent a part of the time interval between the Beekmantown and the Jacksonburg limestone, which corresponds to the emergence between the Canadian and Champlainian floods, but the sea does not appear to have left the State during the second emergence. Ordovician time may have lasted 90 to 130 million years. Most estimates are, however, much less.

CANADIAN SUBMERGENCE.

The Beekmantown limestone.—The upper part of the Kittatinny formation has long been known to contain Ordovician fossils. It has been regarded as of Canadian age and to correspond in part at least to the Beekmantown limestone of Lake Champlain. It is a thin to thick-bedded limestone, gray, light-blue or dark-blue in color on fresh surfaces, and generally weathering to a lighter tone. It is frequently minutely crystalline in texture and many beds are not unlike the Allentown beds in general appearance, except that so far as observed in New Jersey it is not characterized by Cryptozoon heads. The greater part of the formation so far as seen in this State is dolomitic, but some beds relatively low in magnesia and high in lime occur. These are of a dark-blue color, dense texture, in some layers minutely crystalline, and on weathered surfaces are usually a bluish-gray color. Irregular, discontinuous films and thin layers of siliceous silt occur in these purer limestones, and on weathered surfaces give the rock a mottled appearance. Many of the dolomitic beds are also somewhat mottled both on weathered and fresh surfaces. Oölite and edgewise conglomerate occur, but less abundantly than in the Allentown, whereas chert and flint, both white and black, are much more abundant. These occur both minutely disseminated and in large lens-shaped masses which may unite to form continuous layers. At some horizons the chert so impregnates the dolomite, as to form a veritable network and give rise to honeycomb masses where the more soluble carbonate has been weathered out. The abundance of black flint, the presence of numerous weathered masses of honeycomb chert, the preponderance of irregular, discontinuous siliceous layers at certain horizons, and the occurrence of beds low in magnesia are the most easily recognized lithologic characteristics of the formation. Fossils[1] occur very sparingly and chiefly in the beds low in

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[1] Geol. S[illegible]y of N. J., Paleontology, Vol. iii, p. 15.

magnesia, and when found are of great value in correlation, but for the most part the geologist has to rely on the character of the rock itself.

Post-Beekmantown emergence.—The top of the Kittatinny limestone (Beekmantown) which is well exposed at the west end of the old railroad quarry near Sarepta, Warren County, is an eroded surface, on which was deposited at a somewhat later period the overlying Jacksonburg limestone. The Beekmantown sea must, therefore, have retreated from this region and land conditions must have prevailed for a long enough time to permit the removal of a part of these beds.

It is not possible to determine the whole extent of this erosion, nor the length of this time interval. In the Musconetcong Valley[1] at least 300 feet more of strata were removed from the top of the Beekmantown at some places than at others, but there are now no means of determining the thickness of strata removed where erosion was least. Studies in adjoining states make it evident that the time was long enough for the sea to withdraw as far as Maryland and Tennessee, where thick beds of limestone (Stone River) were deposited before its waters again invaded New Jersey.

EARLY CHAMPLAINIAN SUBMERGENCE

Chazy shale.—The second great submergence of Ordovician time began for New Jersey with the creation of a narrow strait across the State and southeast of the present Highlands belt, with connections southwest to the Gulf of Mexico and northeast with the Gulf of St. Lawrence. In this body of water were deposited beds of silty to sandy clay, which now form a bed of greatly folded and faulted yellow and black shale which is best exposed west of Clinton in Hunterdon County. A few species of fossils (graptolites) have been found near Jutland in exposures along the Lehigh Valley Railroad, which connect the beds with the Normanskill shale of New York and fix their age as Chazyan. On the basis of position, other areas of highly crumpled shale found at intervals along the southeast margin of the Highlands are regarded as of the same age. On the geologic map of New Jersey they are all labeled Martinsburg shale, but later evidence indicates that they are older than the black slates of Kittatinny Valley.

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[1] Geol. Survey of N. J., Bulletin 16, p. 23.

LATER CHAMPLAINIAN SUBMERGENCE

Geographic conditions.—The earlier stages of the second Ordovician (Champlainian) submergence were of an oscillatory character, the general encroachment of the ocean on the land being accompanied by the temporary withdrawls now here and now there. During one of these minor movements the Chazyan strait was drained, but a little later (in late Black River or early Trenton time) the sea again invaded New Jersey, chiefly in the region northwest of the Highlands. With the return of marine conditions there were formed low limestone islands and reefs around which beds of water-worn limestone pebbles were formed in favorable localities by the waves. Later as the sea became deeper, these beds were buried by fine detritus derived mainly from animal remains. The waters swarmed with a vast horde of invertebrates, bryozoans, brachiopods, gastropods, cephalapods and trilobites,—a fauna of very different forms from that of earlier seas, and one the remains of which are abundantly preserved in the rocks of this period. Crinoids (animals related to star-fishes, but fastened to a long stalk) also flourished in great numbers and their broken stems contributed largely to the making of the limestone. The New Jersey beds formed at this time are called the Jacksonburg limestone.

Jacksonburg limestone (Ojb.)—This formation is in general a dark blue, gray or black fossiliferous limestone, many layers containing 95 percent or more of calcium carbonate. Thin layers of calcareous shale are interbedded with the limestone and become thicker and more abundant near the top of the formation, so that in some localities the upper part is chiefly a black argillaceous limestone extensively used in the Lehigh Valley and adjacent regions for the manufacture of Portland Cement.

In the type locality at Jacksonburg, Warren County, its thickness is about 135 feet, but it is highly probable that the entire section is not here present. In the quarries of the Edison Cement Corporation near New Village the thickness is at least 200 feet, and at Martin's Creek, Pa., it is over 400 feet. At both these localities the basal beds of the type section are not present[1].

Weller[2] pointed out that at Jacksonburg the first 58 feet of beds

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[1] R. L. Miller, Stratigraphy of the Jacksonburg Limestone. Geol. Soc. Am. Bulletin, Vol. 48, pp. 1687-1718.

[2] Stuart Weller, The Paleozoic Faunas, N. J. Geol. Survey, Rept. Paleont., Vol. 3, 1903, pp. 16-38.

are characterized by the fossil *Leperditia fabulites*, and he regarded these beds as of Black River age. Miller,[1] however, has recently referred them to the Rockland or lowest subdivision of the Trenton. There is an apparent hiatus at the top of this subdivision, marked by an abrupt faunal change.

The next 28 feet 9 inches of beds are correlated by Miller with the Hull division of the Trenton, while the overlying 40 feet or more belong to the lower Sherman Fall division.

Relation to the underlying Kittatinny limestone.—The Jacksonburg limestone rests upon the eroded surface of the Beckmantown or other underlying limestone. At most localities where the two formations outcrop in close proximity, the bedding seems to be parallel, but at several localities striking unconformities occur. The most conspicuous of these is in the old railroad quarry at Sarepta, Warren County, where the dark-colored Jacksonburg beds rest on the lighter-colored Kittatinny limestone. Here the lowest Jacksonburg consists of a coarse conglomerate of subangular cobbles of magnesian limestone, some of which are 2 feet in diameter. However, they rapidly diminish in size upward and become mere angular fragments 5 feet above the base. Similar angular fragments of magnesian limestone occur in a calcium-carbonate matrix at many other localities at the base of the formation.

It has already been pointed out that at the type locality there is a faunal change and hiatus 58 feet above the base,—at the top of the *Leperditia* fauna. At some points this horizon is marked by rounded conglomeratic pebbles of the underlying beds. In the region around Hope thick conglomerate beds of well-rounded pebbles have been noted—not at the base but apparently interbedded in the limestone above the base. When first observed about 1900, exposures were not sufficiently numerous to settle beyond doubt whether these conglomerate beds were actually interbedded in the limestone, or were basal beds faulted into this position. More recent exposures have shown beyond a doubt that this conglomerate occurs in the Jacksonburg and, as R. L. Miller has suggested, is probably to be connected with the advance of the sea after the hiatus indicated by the evidence found at Jacksonburg and Portland.

This hiatus may account also for the fact that at some localities the lowest beds of this type section, i. e. those carrying the

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[1] R. L. Miller. loc. cit. p. 1695.

Leperditia fauna are absent, and the beds of the Hull division rest on the Kittatinny limestone. This is the case in an old cement quarry one mile east of Stewartsville.[1]

The two conglomerates, the one at the base and the other within the formation are taken to indicate two periods of erosion and readvance of the sea, the first after the Beekmantown and the second after the formation of the *Leperditia* beds, and before the deposition of beds referred to the Hull.

Whether the *Leperditia* beds be Black River, as supposed by Weller, or the lowest member of the Trenton, as now advocated by R. L. Miller, it is now well established that the Jacksonburg formation as defined and mapped does not represent a period of continuous deposition.

Relations to the Martinsburg.—The Jacksonburg has commonly been stated to grade upward into the overlying Martinsburg slate, although no continuous section was available to confirm this relationship. However Miller[2] has recently called attention to several localities—in Pennsylvania and in New Jersey where the two formations outcrop so closely together as to preclude any gradational change from an argillaceous limestone to a siliceous slate. While the possibility of faulting has not been entirely eliminated at some of these exposures, it now seems established that the Martinsburg rests disconformably on the Jacksonburg.

Occurrence.—The Jacksonburg normally occurs at the surface as a narrow band between the Kittatinny limestone and the Martinsburg slate, but it has been cut out by faulting for long distances. It originally covered the areas now underlain by the older limestone and it probably underlies the Martinsburg slate over wide areas where it is not exposed at the surface.

POST-JACKSONBURG OSCILLATIONS.

Late in Jacksonburg time the streams brought into the sea a larger amount of fine silt and mud, so that the limestone of the lower and middle portions gave place to the argillaceous limestone—the cement rock of the Martin's Creek and Phillipsburg areas. Continued elevation of the region caused the withdrawal of the sea from New Jersey and eastern Pennsylvania in middle or late Trenton and the initiation of the time interval which in this region separates the Jacksonburg and Martinsburg formations.

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[1] R. L. Miller. loc. cit. p. 1699.

[2] R. L. [illegible]r. loc. cit. pp. 1701, 1708.

In the Greenwood Lake-Green Pond Mountain region the Jacksonburg limestone is apparently absent, while the Kittatinny limestone has only a fraction of the thickness it possesses elsewhere. Moreover, there are only doubtful occurrences of the overlying Martinsburg shale. These facts are interpreted to mean that that region may not have been affected by these various periods of submergence, but may have been a land area from the end of Cambrian time until late in the middle Ordovician or even until Silurian time.

Martinsburg slate.—In the Kittatinny Valley region the earth movements that stopped the deposition of the Jacksonburg limestone and after an unknown interval began the formation of the thick beds of shale and slate known as the Martinsburg (Hudson River of older reports) were gradual and gentle. After a relatively brief period of emergence, the sea readvanced and the streams brought into it a large amount of fine silt and mud, and toward the close of the period, fine sand. This change in sedimentation began here at a much earlier time than in central New York, where limestone-forming conditions prevailed in Trenton time long after they ceased in northern New Jersey.

The Martinsburg formation ranges from the finest-grained shale and slate to fine sandstone. On the whole the shale and slate are black and are 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. 187). 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 some 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 slate has been obtained in considerable quantities (see "Slate," p. 188; and "Mineral Paint," p. 192). 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 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, so that the upper part of the formation belongs to the Upper Ordovician (lower Cincinnatian).

In southern and central Pennsylvania the Martinsburg shale is succeeded by 400 to 1,500 feet of Ordovician red sandstone (Juniata) which is absent in New Jersey,—perhaps by lack of deposition, but more probably because of erosion before the deposition of the succeeding Silurian formations. If formerly present it represented the culmination of the shoaling of the sea and uplift of the bordering lands, the beginning of which is indicated by the transition from the high calcium to the argillaceous limestone (cement rock) in the Jacksonburg and then after a short hiatus the deposition of the Martinsburg shale and the increasing amount of sandstone in the upper part of that formation.

Taconic revolution.—The Ordovician period was terminated by widespread earth movements. The old land of Appalachia was uplifted, Cambrian and Ordovician strata along its western margin from Nova Scotia to southeastern Pennsylvania and perhaps further south were closely folded, faulted and erected into mountain masses—the Taconic Mountains of western Vermont and Massachusetts. Northern New Jersey and the regions westward were involved in this movement, but the extent of the folding in this region has been a matter of some dispute. The movement ended in an almost complete emergence of the North American continent.

The rising land was immediately subject to erosion, the zone of deposition being shifted westward as the sea retreated, and successive portions of the newly emerged sea bottom were denuded of their upper layers. In the Green Pond region the Cambrian and so much of the Ordovician strata as may have been deposited were either entirely removed and the underlying gneiss exposed, or were reduced to mere remnants of their former thickness. In the upper Delaware River region where the sediments were thicker and the erosion interval probably shorter, since it emerged later and was resubmerged earlier in the following age, only the uppermost Ordovician strata (Juniata and upper part of the Martinsburg) were eroded.

SILURIAN PERIOD.

General statement.—The formations in New Jersey referable to the Silurian period are beds of coarse conglomerate, which are followed by sandstone, shale and limestone. The earliest of them are regarded by some geologists (Grabau *et al*) as part of the great alluvial fan built by streams which rose in the mountains of the old land of Appalachia and flowed northwest across a low-lying Piedmont belt into the relatively shallow waters of a distant interior sea. Others (Schuchert *et al*) regard them as the shallow-water deposits of an invading sea into which rivers carried large amounts of sand and gravel which were widely distributed by the waves and currents or in part accumulated as delta deposits at the mouths of the rivers.

The New Jersey formations of this age occur in two distinct regions:

(1) In Kittatinny Mountain and Wallpack Ridge in the upper Delaware Valley.

(2) In the narrow, down-faulted and folded mass of Paleozoic rocks in the Green Pond-Greenwood Lake region in the midst of the Highlands. In the upper Delaware Valley these formations aggregate 4,200 feet or more in thickness, while in the Green Pond Mountain region they do not exceed 1,800 feet. There can be little doubt that originally the strata of these two areas were continuous and erosion during the many million years since the Silurian has removed all traces of them from the intervening area, a distance of 20 miles. Silurian time may have lasted 40 million years.

EARLY SILURIAN FORMATIONS.

Shawangunk conglomerate (Ssg).—The Shawangunk conglomerate (called the Oneida conglomerate in many previous publications) is the lowest and oldest of the New Jersey Silurian beds. It is chiefly a quartzite and conglomerate composed of small white quartz and, in some beds, slate pebbles, embedded in a siliceous matrix. Its color is generally steel-blue, but some beds have a greenish or yellowish tinge and reddish layers occur near top. Layers of black shale a few inches in thickness are locally intercalated between thick beds of conglomerate and grit. The formation forms the crest and eastward-facing cliff of Kittatinny Mountain and is well exposed at the Delaware Water Gap, where the river cuts through the mountain in a deep gorge, whose sides rise 1,200 feet above the water. Here softer gray sandstones are interstratified with conglomerate beds at several horizons, but owing to their lesser resistance, they are not so well exposed. The thickness of these gray sandstones and conglomerate beds at the Water

Gap is about 1,900 feet.[1] Similar beds are found along Kittatinny Mountain, but the sections differ in detail. At Otisville, New York, a few miles north of the New Jersey State line the thickness of the yellow and gray conglomerate beds has diminished to 650 feet. Near Kingston, New York, the formation disappears from the section. It continues southwestward into Pennsylvania for many miles, but becomes thinner in that direction also.

Green Pond conglomerate (Sgp).—In Green Pond, Bowling Green, Copperas, and Kanouse Mountains, beds of conglomerate and quartzite occur, which resemble somewhat closely the Shawangunk conglomerate. The pebbles are somewhat larger, and of greater variety, although predominantly of white quartz. These are embedded in a matrix, originally sand, but now vitreous in texture and of a dull-red, steel-blue, gray, or greenish color. The higher beds of the formation are less conglomeratic than the lower and are chiefly quartzite, in general of a purple-red color. Various shades of pink, yellow, brown, and gray occur. The thickness of the formation in the vicinity of Green Pond is 1,200 to 1,500 feet, and it thins both to the northeast and southwest.

The Shawangunk and Green Pond conglomerates are regarded as remnants of the same formation, which formerly covered the region now separating them and extended an unknown distance to the southeast.

Relation to the underlying Martinsburg.—At Otisville, N. Y., Lehigh Gap, and Schuylkill Gap, Pa., the contact of the two formations is exposed. Although these have been in the past regarded by some observers as fault contacts, the general opinion now is that at these localities the Shawangunk rests upon the eroded edges of the Martinsburg, and that folding and a long period of erosion separated the two formations. In New Jersey only one locality is known where they can be seen in actual contact. This is an obscure exposure in the woods adjacent to the old Libertyville—Montague road across Kittatinny Mountain. The conglomerate forms a low cliff at the base of which the slate is exposed for several yards horizontally. The contact shows a slight angular unconformity.

Further evidence of the time interval between these formations is shown by the occasional presence of rounded pebbles of the Martinsburg slate in the basal beds of the Shawangunk, and the absence at this horizon of 1,500 feet of Juniata beds present in Pennsylvania.

Age of the Shawangunk conglomerate.—There has been much difference of opinion among geologists as to the age of these beds and the conditions under which they were laid down. In New Jersey the Shawangunk rests upon the eroded surface of the Martinsburg shale, and was, therefore, deposited after a period of erosion which removed the upper part of the Martinsburg and perhaps an unknown thickness of higher Ordovician strata (Juniata sandstone). In the Green Pond region the conglomerate rests for the most part upon the pre-Cambrian gneiss, although locally thin beds of Cambrian strata are present at this horizon. In this region the erosion which preceded the deposition of the conglomerate was so great as to remove all traces of the earlier Ordovician and Cambrian sediments over wide areas, and to reduce them to mere remnants in others. That the region covered by these conglomerates had been a land area for a long period, immediately preceding their deposition, cannot, therefore, be questioned, but there has been doubt as to when in Silurian time erosion ceased and deposition began. These beds were for a long time regarded as *early* Silurian and correlated with the Medina series of central and Western New York. Later a *eurypterid* fauna was discovered at Otisville, New York, and at Delaware Water Gap, which was believed to make them *late* Silurian (Salina). Still more recently the discovery of the type Medina fossil *Arthrophycus alleghaniense* both at Otisville and the Delaware Water Gap restores them to the early Silurian.

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[1] The second Pennsylvania survey gives the thickness as 1,565 feet (Report G6). Grabau (Bull. Geol. Soc. of Am., vol. 24, 1913, p. 478) states it as 1,900 feet, but he includes in the Shawangunk 340 feet of higher beds which the Penns[illegible]ia survey called Clinton, but which seem better classed with the Shawangu[illegible]

MID-SILURIAN BEDS.

High Falls shale and sandstone.—At Delaware Water Gap above the gray Shawangunk conglomerate and sandstone, there are about 1,345 feet[1] of red, green, and olive-colored sandstone and shale, with some beds of pea conglomerate. In color and texture they are in relatively sharp contrast to the underlying light-colored conglomerate. The uppermost 155 feet of this series is a soft red shale exposed along Cherry Creek near the railroad bridge, on the Pennsylvania side of the river. Above these beds is a covered interval in which there may be 700 to 800 feet of beds of unknown character.

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[1] Pennsylvania Second Geol. Survey. G6, p. 340.

This great thickness of rock has been referred at different times to the Medina, the Clinton, and the Salina formations of New York. On the geological map of New Jersey they are called the High Falls formation, but it may fairly be questioned whether they are all of them equivalent to the High Falls formation of southeastern New York, which in its type locality is regarded as early upper Silurian (Salina). In the absence of decisive evidence in this section, the possible alternatives must be kept in mind:

(1) These beds may all be High Falls (Salina), in which case the abrupt change from the gray conglomerate to red, green and olive-colored sandstone marks a disconformity, the middle Silurian (Niagaran) being absent.

(2) The entire series of sandstone (1,345 feet), including perhaps some beds in the covered interval above, may be lower Niagaran (Clinton), in which case the covered interval may conceal a lesser break in the record (later Niagaran).

(3) Some part of the lower red and green sandstones (1,345 feet) may be of Medina age and belong in the Shawangunk; the uppermost, soft, red shale and the beds in the covered interval may be Salina and the true representative of the High Falls shale of New York, while a greater or less thickness between, may be lower Niagaran (Clinton). In this case the break between the Clinton and the Salina occurs somewhere in the series of shale and sandstone, below the 155 feet of soft red shale.

Since the presence of Clinton beds in this position in the section seems to be well established at the Lehigh Gap on the southwest and at Otisville to the northeast,[1] the second or third of the above alternatives seems more probable than the first. Until, however, the type Medina fossil *Arthrophycus* is reported from the red, green, and olive-colored sandstone, it may perhaps be best to limit the term Medina (Shawangunk) to the gray conglomerate and quartzite (1,900 feet), and regard the change to the reddish sandstone and shale as marking the base of the Clinton.

Longwood shale.—In the Green Pond-Greenwood Lake region the Green Pond conglomerate (Medina) is succeeded upward by about 200 feet of a soft red shale, but the two have not been seen in contact. It resembles most closely the uppermost red shale exposed at the Delaware Water Gap, and at various points on the left bank of the river for a few miles above the Gap. It is probably upper Silurian (Salina) in age, although positive evidence

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[1] Schuchert, Bull. Geol. Soc. Am., Vol. 27, p. 531.

is lacking. If this is the case, then either the Clinton beds of the Water Gap—Otisville region were in this region entirely removed during the late Niagaran (pre-Salina) erosion interval, or Clinton time is represented by some of the beds included in the Green Pond conglomerate. The former view seems preferable.

CONDITIONS OF ORIGIN.

Deltas vs. alluvial fans.—As already noted (p. 78) the Ordovician was terminated by wide-spread crustal movements and mountain building (Taconic revolution), but by early Silurian time the changes wrought by this uplift had been greatly modified. Many of the rock folds had been sharply cut off; even where folding had not occurred, the uplifted sea bottom had been greatly eroded and the land was much reduced in elevation. According to Schuchert[1] a shallow sea occupied the Appalachian trough and covered northern New Jersey. Long rivers flowed from the highland of crystalline rocks in Appalachia, and had reduced the quartz to fine sand and well-rounded small pebbles. The deposits of these rivers, spread out by the waves, formed "great shallow-water flats of moving sands, in which lived, now here and now there, in great abundance, an errant annelid, *Arthrophycus alleghaniense*, similar to the lob-worms of the English sand beaches. On the mud bottoms the eurypterids were often present in great numbers and in variety of form." Near the mouths of the rivers these sands formed more or less typically developed delta deposits, their great extent apparently precluding their being regarded as the delta of a single river.

In sharp contrast to this view is that of Grabau[2] who holds that the Shawangunk (including the Green Pond) is a subaerial deposit, an alluvial fan formed entirely on dry land, and that the eurypterids were non-marine forms living in the rivers, which crossed the alluvial plain.

Whichever theory we accept we are safe in concluding that following the accumulation of these deposits there was in this region a deepening of the sea, probably due to the transgression of the shore to the eastward with perhaps a lower elevation of the land due to erosion, so that fine sand and mud were deposited here instead of the earlier coarse sand and gravel. If the red, green, and olive-colored sandstone is correctly referred to the Clinton, this

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[1] Bull. Geol. Soc. Am., Vol 27, p. 535.
[2] Grabau, A. W., Bull. Geol. Soc. Am., Vol. 24, p. 526.

advance of the sea took place in early middle Silurian time (*Niagaran*). The entire absence, however, of the later Niagaran is proof of a return to land conditions later in middle Silurian time and its persistence until the upper Silurian (Salina).

UPPER SILURIAN FORMATIONS (SALINA AND MONROE GROUPS.)

As indicated above (p. 81) the upper part of the High Falls formation as mapped and the Longwood shale probably belong to the Salina group in the upper Silurian. The higher formations of this age are the following:

Poxino Island shale (Sbd).—The top of the High Falls formation in New Jersey is everywhere hidden 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, without fossils. 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.

Along Wallpack Ridge the covered interval between the High Falls and Poxino Island formations is wide enough to conceal beds of considerable thickness.

Bossardville limestone (Sbd).—A fine-grained, compact, bluish-gray, banded limestone, known as the Bossardville, lies on the Poxino Island shale in Wallpack Ridge. Whether the contact is conformable or not, is indeterminable in the absence of exposures. 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 Manlius limestone at Rondout, New York. In reality it lies below the Manlius. It contains few fossils but is immediately succeeded by a series of beds with 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 beds have been described that are chiefly limestone at the northeast and calcareous sandstone at the southwest. Their thickness is 52 feet at the Nearpass quarry near Port Jervis, New York, where the section can be accurately measured. Thin bands of more or less fissile, green shale separate the limestone layers. A thin bed of reddish, crystalline, highly fossiliferous limestone about the middle of the series is a striking feature.

The lower 24 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 next 17 feet 8 inches with the "black cement" beds; that is, the Rosendale "waterlime" of the Rondout section of New York. These form the top of the Salina group. The uppermost 10 feet of the Decker beds contain fossils, particularly in the lower half, that render necessary their correlation with the Cobleskill limestone of eastern New York. Corals and allied forms are particularly abundant.

These three formations are best shown in the bluff south of the Nearpass quarry south of Port Jervis. The Poxino Island shale is mostly covered by talus, but the Bossardville and Decker limestones form the lower part of the cliff. They also outcrop at other points along the eastward slope of Wallpack Ridge as far as Flatbrookville.

In the Green Pond Mountain region there are isolated outcrops of impure limestone overlying the Longwood shale but they are 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 part referable to the Salina group, and with the Wilbur limestone of the upper part of the Salina formation of eastern New York.

Above the beds of Salina age are two limestone formations belonging to the Silurian, the Rondout and the Manlius, both exposed in the Nearpass bluff.

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 shale and limestone the thickness of which is 39 feet. In general they contain but few fossils, 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 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 conspicuous here.

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

Manlius limestone (Sbd).—The Rondout is succeeded conformably by a somewhat thin-bedded, knotty, dark-blue or almost black limestone, 34 or 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 old 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—absence or scarcity of a typically marine fauna.

The lower six feet of the Manlius limestone was formed largely by colonies of *Stromatopora*, a lime-secreting organism which grew in spheroidal masses up to a foot or more in diameter. 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 beneath the thick mantle of glacial drift.

The top of the Manlius marks the top of the Silurian formations of this region. There is in New Jersey no conspicuous break in sedimentation in the section at this point, but some evidence indicating a slight disconformity has been noted in southeastern New York[1].

CONDITIONS OF FORMATION.

Although the middle Silurian (Niagaran) was in general a time of continental subsidence and widespread seas, which covered much of North America, New Jersey and adjacent territory seem to have been land areas from Clinton to Salina time. With the beginning of the upper Silurian (Salina) however, a shallow sea invaded this region, and in it were first accumulated red and green shale (High Falls and Poxino Island)[2] and later "ribbon" limestone (Bossardville and Decker). Apparently these were not at first normal marine waters, since marine faunas are apparently absent from the Bossardville limestone. In Decker time, however, we find a marine fauna firmly established, and a sea in which limestone accumulated in the region of Tri-States and Port Jervis, and limy sandstone further southwest. In western New York beds of salt occur with rocks of this age, so that the climate there was arid and the seas in some parts surcharged with brine.

Later, in Rondout time, non-marine conditions again prevailed in New Jersey, marine fossils being conspicuously absent from the limestones of that age, but connection with the ocean was reestablished during Manlius time, and before the close of that epoch marine life flourished in great abundance in these waters.

An inconspicuous disconformity at the top of the Manlius points to a short withdrawal of the sea from southeastern New York and probably from New Jersey at this time, an event which marked the close of the Silurian period. When the sea returned and deposition was resumed, limestone of a very different aspect was deposited.

DEVONIAN PERIOD.

General statement.—At the beginning of the Devonian (Coeymans) a narrow sea known as the Cumberland basin extended across northwestern New Jersey and adjacent portions of northeastern Pennsylvania. It reached northward into eastern New York, and probably by various channels connected with the Saint Lawrence Gulf and the open ocean. Southward it extended through western Maryland and beyond, and formed an open connection with oceanic water. On the west it was limited by a continental area, which had replaced the great interior Mississippian sea of middle Silurian time, and on the east it was bounded by the ancient land of Appalachia. During Devonian time there were marked changes in the shape and size of this basin, the greatest tendency being toward its extension westward. At the same time the great interior Mississippian sea was gradually reestablished, and its waters at length united eastward with those of the Cumberland basin, and northward with the Arctic Ocean. This period of maximum submergence was followed by an oscillatory, but gradual emergence of the continent. In late upper Devonian time and at the close of the Devonian nearly all of North America was probably above sea level. Northern New Jersey, being near the old land of Appalachia, was affected relatively soon by the subsidence of the flood, and emerged from the sea early in upper Devonian time.

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[1] Hartnagel, N. Y. State Museum Bulletin 107, p. 45.
Van Ingen, N. Y. State Museum Bulletin 69, p. 1186.

[2] As already pointed out (p. 82) part of the red shale and sandstone included in the High Falls may be Medina and belong with the Shawangunk or may belong to the Clinton (early Niagaran) and may have been formed before the advance of the Salina sea.

The Devonian is often called the "Age of Fishes" due to their being the dominant form of life. The rivers and seas of that time were the habitat of many ancient types, some of great size, uncouth form, and covered with heavy armor, but the bony fishes, which constitute 90 per cent of living forms, had not yet appeared. Well-preserved remains of these ancient types have not, however, been found in the Devonian rocks of New Jersey. Invertebrates were present in great numbers and many kinds,—corals, brachiopods, crinoids, trilobites and many others. Devonian time may have lasted 50 million years.

In New Jersey the Devonian formations occur along Wallpack Ridge in the upper Delaware Valley and in the Green Pond-Greenwood Lake region in the midst of the Highlands. In the former area they are of marine origin and are chiefly fossiliferous. calcareous shale and limestone having a thickness of about 1,000 feet. They rest without apparent discordant structure upon the Manlius limestone, although evidence in adjacent regions is not lacking that a disconformity exists at this horizon.

In the Green Pond region they are chiefly sandy shale, sandstone and conglomerate, carrying comparatively few fossils and measuring over 4,000 feet in thickness. Most of them belong to higher stratigraphic horizons than the beds in Delaware Valley. Their relations to the older formations are not exposed.

IN THE UPPER DELAWARE VALLEY.

Coeymans limestone (Dnc).—In the Nearpass section near Tri-States, the Coeymans limestone has an estimated thickness of 40 feet, only the lower beds being exposed. It is coarsely crystalline. has many crinoid stems, and is minutely rough on its weathered surface, which resembles that of a coarse sandstone. Chert is more or less abundant in the upper layers. The contact with the underlying Manlius is sharply marked and the formations are apparently conformable, but evidences of a break in sedimentation at this horizon have been recognized both in New York and Maryland. and this fact creates a strong presumption that sedimentation did not proceed without interruption in New Jersey. This presumption is strengthened by the following facts.

At the base of the Coeymans limestone there are concentrically laminated stromatoporoids which may be masses of the underlying Manlius stromatopora reef, broken off and incorporated in the Coeymans. A [illegible]eat faunal change is found in passing from the Manlius to the Coeymans, due to the immigration of a new marine fauna, probably from the northeast, into the Cumberland basin. The most characteristic species of this new fauna is the bivalve shell *Gypidula galeata*. A coral bed at the base of the formation contains more or less completely silicified masses of a coral *Favosites Helderbergiae*. The abrupt appearance of the new fauna, the sudden change in the character of the limestone, the sharp line of contact at the base of the Coeymans, all point to a break in the sedimentation and a hiatus in the record at this horizon. We are justified, therefore, in concluding that there was a brief emergence at the close of Manlius time after which the sea again invaded the northwestern part of New Jersey, bringing with it this new and abundant fauna, and giving opportunity for the deposition of the Coeymans limestone.

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.

This sandstone indicates that there was a shoaling of waters or an elevation of the land adjacent to the area in which it occurs, as a result of which land-derived sands and muds were deposited in place of the limestone.

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 shale 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 Coeymans fauna are of such an essential character as to indicate a separate immigration from the exterior into this region,[2] but no

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

[2] Weller, Geol. Survey of N. J., Paleontology, Vol. III, p. 9[illegible]

evidence of interrupted deposition has been observed, unless this faunal difference be interpreted as such.

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*, a very abundant New Scotland fossil.

The lithologic character of the New Scotland beds indicates shoaler water and more land-derived material than in Coeymans' time, while the fossils indicate the arrival of additional immigrants from distant regions—humble precursors of the later tide of immigration which in recent years has added so much to the population and industrial wealth of the State.

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. It is generally semi-crystalline and locally made up largely of crinoid stems and broken shells. Its entire thickness is nowhere exposed, 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. In New Jersey it is everywhere followed by a covered interval, so that its relation to succeeding formations is not shown.

The above three formations comprise the Helderbergian deposits, and are continuous with the same formations so well exposed in the Helderberg Mountains southwest of Albany, New York. On the whole, they represent a time of relatively clear seas, swarming with abundant life, in which limestones of varying degrees of purity were deposited without much interruption, except for the brief period represented by the Stormville sandstone, when sand predominated in a limited area.

Helderberg time was followed by a period of gradual flooding, known as the Oriskanian submergence, during which the waters of the Cumberland basin extended westward and the area of deposition was greatly increased in that direction, but at the same time it was restricted in the east by a gradual shoaling of the waters in southeastern New York and New Jersey.

Port Ewen beds (Dob).—A series of strata, nowhere exposed in New Jersey, 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 debris. 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.[1]

Oriskany formation (Dob).—Strata aggregating about 170 feet in thickness succeed the Port Ewen beds and are referred to the Oriskany. For the most part they are siliceous limestone, but the top of the formation along the southern half of Wallpack Ridge becomes a sandstone. The sandy phase is said to become more marked to the southwest in Pennsylvania and to embrace lower and lower beds until all the strata downward to the top of the Coeymans limestone are sandstone. In New Jersey its contact with the overlying formation, the Esopus grit, has not been observed.

In Maryland the lower part of the formation is a dark siliceous shale containing many chert nodules, and the upper member is a coarse limy sandstone. The formation is continuous northeastward into New York, where at Rondout it is a siliceous and sandy limestone with some coarse sandstone and conglomerate beds and a thickness of 64 feet to 76 feet.

The Oriskany fauna had its center of development and dispersion in the Gaspé region, where it occurs through 800 feet of limestone. Thence it migrated southwest along the Cumberland basin following the Helderberg fauna, picking up some forms on the way and acquiring others on its arrival in eastern New York and northern New Jersey.[2] Somewhat late in Oriskany time the westward flooding permitted its extension to western New York and Ontario.

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

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[1] Second Pennsylvania Geol. Survey, Report G6, p. 131.

[2] Clarke, N. Y. State Museum Bulletin 52, p. 666.

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 sandstone and siliceous limestone 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 markings of a seaweed ("caudi galli") which grew there during this period can be recognized in many places. Apart from these markings fossils are very rare. The average thickness of the formation in New Jersey is estimated to be 375 feet. Its contacts with the Oriskany below and with the Onondaga limestone above have not been observed in this State.

The Esopus grit extends northeast into eastern New York, becoming somewhat thinner in the Hudson River valley. It occurs also in northeastern Pennsylvania, but is absent in western Maryland and adjacent portions of Pennsylvania. The Maryland region evidently emerged at the close of Oriskany time, but in New Jersey and adjacent regions the uplift which began with the Oriskany caused only shallow water and the deposition of siliceous mud (Esopus grit) on top of the earlier sandy limestone.

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 grit to limestone, which latter is hard, cherty, and regularly bedded in layers ranging from 3 to 12 inches in thickness. The formation is 230 to 250 feet thick and it is assigned to the Onondaga because of its position and lithology rather than on faunal evidence, since the recognizable forms are not sufficiently characteristic for close correlation.

The transition from grit to shaly limestone and thence to beds of purer limestone, points to a deepening sea and recession of the shore line. The wide extent of the Onondaga limestone—a formation that stretches west through New York, north to Hudson Bay, and south through the lower Mississippi Valley—indicates that this was a time of widespread submergence and extension of the interior Appalachian sea.

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[1] Shimer, N. Y. State Museum Bulletin 80, pp. 175f.

[2] Weller, [illegible]l. Survey of N. J., Paleontology, Vol. III, p. 96; Shimer, op. cit., p. 1[illegible]

"The fauna of the Onondaga period as a whole, with its noteworthy coral, trilobite, cephalopod, and gastropod facies unequally developed locally, is a complex congeries, largely from the western reaches of the Appalachian gulf, but freely inoculated with elements genetically from the northeast."[1]

Marcellus shale (Dmo).—The Onondaga limestone is succeeded upward by a thick mass of shale and sandstone (Marcellus and Hamilton). With the shoaling of waters indicated by these sediments, the Onondaga fauna withdrew westward and was supplanted by one better adapted to the shallow sediment-laden waters in which the succeeding beds were laid down. 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 there are several younger formations.

IN THE GREEN POND MOUNTAIN AREA.

General statement.—The Green Pond Mountain area lies 23 miles southeast of Wallpack Ridge and hence nearer the shore of the ancient continent of Appalachia. Folding and overthrust faulting has greatly compressed the rocks of the intervening region, hence in Devonian time the two were further apart than at present, and the Green Pond region lay relatively nearer Appalachia than the present distance separating these two areas of sedimentation would imply. It might, therefore, have been a land area during periods of elevation at the same time that the Wallpack region was receiving sediments, or it may have been a narrow separate basin. In either event, it is to be expected that the Devonian formations found in this region would not correspond exactly to those of the upper Delaware valley, and this is the case.

None of the Silurian formations above the Decker limestone has been recognized in this region (p. 86) but since the Cobleskill, Rondout and Manlius are present in its northern extension at Idlewild, New York, thin representatives of these formations may occur in New Jersey, particularly as a continuous section is nowhere exposed. The same is true of the lower Devonian forma-

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[1] Clarke, N. Y. State Museum Bulletin 52, p. 667.

tions, the Coeymans, New Scotland, Becraft, Port Ewen, Oriskany, and Esopus beds, since some or all of them occur in Orange County, New York. However, on the whole, the weight of evidence favors the view that the Green Pond-Greenwood Lake area became land late in the Silurian and continued as such during a portion of lower Devonian time. During Onondaga time, however, the sea invaded the region and sandy sediments were laid down, forming the Kanouse sandstone.

Kanouse sandstone (Dkn).—The Kanouse sandstone 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 earlier reports of the Geological Survey of New Jersey (1901 to 1903) this formation was 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 any of them is present at all it can only be in a very attenuated form.

Cornwall (Pequanac) shale (Dbp).—The Kanouse sandstone is succeeded upward by 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. Weller regarded this formation as Hamilton because of the occurrence in it of *Tropidoleptus carinatus,* then supposed to be a characteristic Hamilton species. Bradford Willard writes[1] "The fossils of the Cornwall shale indicate that it is probably of Onondaga age or more precisely a correlate of the Esopus of the Delaware Valley. *Schuchertella pandora* is an Onondaga species as is also *Anoplotheca acutiplicata.* So far as I know, *Dalmanites anchiops*

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[1] Personal communication to the author, Dec., 1939.

is also confined to the Onondaga group. I have reported *Spirifer andaculus* doubtfully from the Onondaga paint ore in Pennsylvania and found *Tropidoleptus* in the Needmore shale of Esopus age in central Pennsylvania as also *Palaeoneilo emarginata.* I feel very doubtful if the presence of *Tropidoleptus carinatus* should be taken as indicating the Hamilton age of the Cornwall shale."

Bellvale sandstone (Dbp).—The Bellvale sandstone is scarcely more than a continuation upward of the Cornwall (Pequanac) shale, but the beds are coarse and more sandy. The average thickness is estimated at 1,800 feet.[4] The few fossils that are found are all "Hamilton" species. Hartnagel[1] thinks the higher beds are probably as late as Portage, but Willard (personal communication) is inclined to regard the Bellvale as Marcellus or in part equal to the Skaneateles of New York.

Skunnemunk conglomerate (Dsk).—The Bellvale sandstone is succeeded upward by a coarse purple-red, massive conglomerate, 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.[2]

GEOGRAPHIC CHANGES.

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. The movement continued through the rest of Devonian time with apparently increasing intensity. It was less marked in the south than in New England and the maritime provinces of Canada, where it was accompanied by folding of the strata and volcanic activity.

In the upper Delaware Valley the black mud of the Marcellus shale succeeded the limy ooze of the Onondaga, but in the Green Pond region which was nearer the old shore line conditions were not at first so greatly changed, and the Cornwall (Pequanac) shale followed the Kanouse sandstone. However, the growing uplift of the bordering land greatly increased the erosive powers of the rivers and great quantities of mud and sand were carried

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[1] Education Department, State of New York, Handbook 19, 1912, p. 69.
[2] Prosser regarded it as Portage on the basis of its plant remains.

down and deposited in the shoaling waters of the retreating sea, and on the emerging delta lands adjoining. With the gradual sinking of the belt of sedimentation beneath these deposits, perhaps because of their weight, they accumulated in Maryland, eastern Pennsylvania, New Jersey and southeastern New York to a maximum thickness in places of 10,000 to 13,000 feet, the greatest thickness being found in Pennsylvania. The Bellvale sandstone and the Skunnemunk conglomerate, which now make up the mass of Bearfort Mountain west of Greenwood Lake, represent a portion of the deposit of this period,—apparently part of a piedmont gravel plain that lay between the flat delta surface further west and the highland of Appalachia on the southeast, a plain formed by the deposits of numerous streams that built a series of alluvial cones or fans along the base of a mountain mass. The great thickness and coarseness of the Skunnemunk conglomerate imply land of high relief and rivers of strong grade coming down from elevated tracts that lay off the present Atlantic coast.[1] The area of its present occurrence in Bearfort Mountain does not of course represent its original extent. It once covered all of northern New Jersey and was perhaps continuous northward with the coarse sandstone and conglomerate beds of the Catskill Mountains. Its present restricted outcrop is due to the folding at the close of the Paleozoic era and to the enormous erosion which all of northern New Jersey has suffered since that time.

CARBONIFEROUS PERIOD.

New Jersey, a land area.—The later Paleozoic history of the State cannot be read from the sedimentary record now preserved within its borders. The region became 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 a great thickness 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, these formations have a thickness of 1,200 feet. The 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 coastal plains bordering the sea that lay off to the northwest. If strata of Mississippian (Subcarboniferous) 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 this period of 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 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 lowlying, poorly drained lands, with numerous extensive peat swamps, which in turn were resubmerged so that marine conditions were again established. 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 occupation, 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. 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 orogenic or mountain-folding movement, that

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[1] Joseph Barrell, American Journal of Science, Vol. XXXVI, 1913, pp. 465, 466.

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). This movement 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 great mountain-making folds (Figs. 2, 4), 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. 7). Cleavage was developed by the compression of the finer-grained rocks, giving rise to slate which is of considerable economic importance in some regions.) (p. 63).[1]

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 the

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[1] Some of the slaty cleavage is due to folding during the Taconic revolution late in the Ordovician (p. 78).

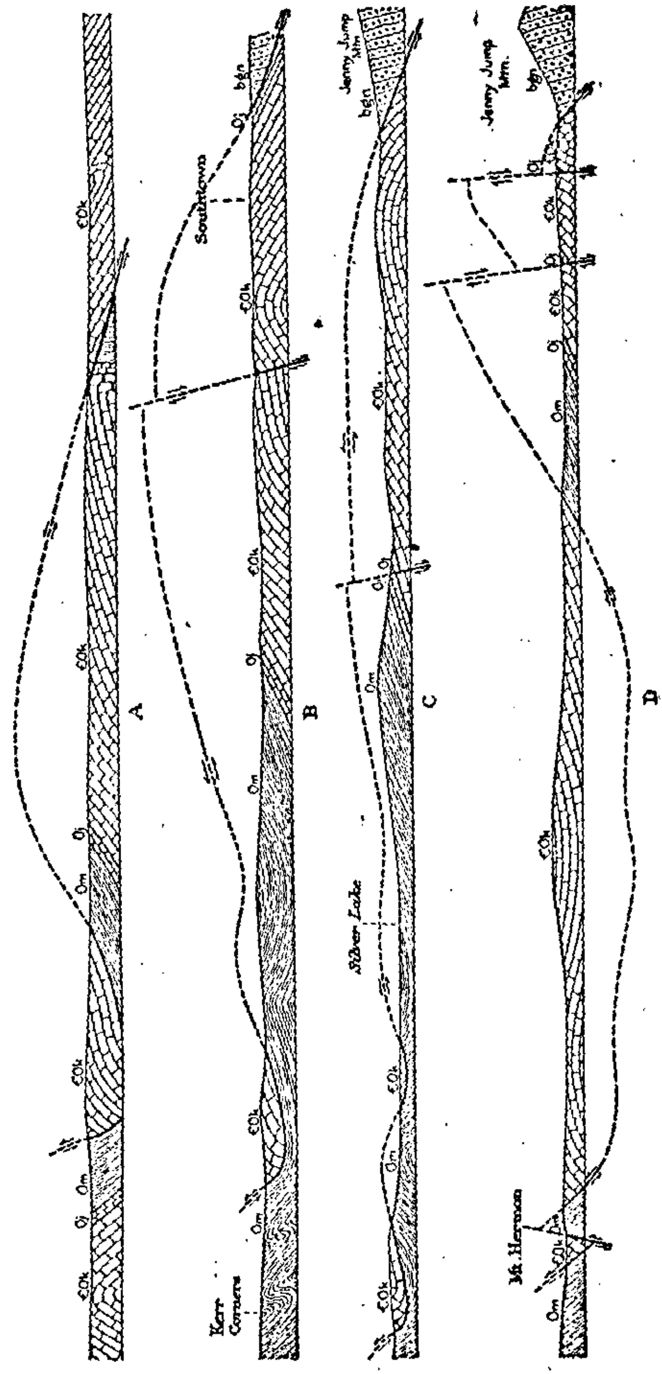

Fig. 7. Overthrust faults of Kittatinny Valley.

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.[1]

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[1] It is not everywhere possible to differentiate between the late Ordovician folding (Taconic) and that of the Permian. The greater distortion of the early Paleozoic formations southeast of the Highlands may be due in part to the earlier movements. No folds, however, which involve Silurian and younger rock can be ascribed to the Taconic disturbances.

CHAPTER VI.

MESOZOIC ERA.

General statement.—The Mesozoic era is divided into the Triassic, Jurassic, and Cretaceous periods, the latter being often divided into an earlier (Comanchean) and later (Cretaceous) period. Although of very long duration, it was only between one-half and one-third as long as the Paleozoic, or 135 to 175 million years, if recent estimates are to be accepted. Its life was characterized by the great development of reptiles. "They filled all the roles now taken by birds and mammals; they covered the land with gigantic, herbivorous and carnivorous forms; they swarmed in the sea; as literal dragons, they dominated the air." (Scott). During this era, the mammals and birds began to emerge from reptilian stock.

In New Jersey the Mesozoic is represented by formations referable to the late Triassic and the Upper Cretaceous periods. They extend across the State in a broad zone from northeast to southwest, and underlie the Piedmont Plain and inner portion of the Coastal Plain. Their original extent was of course much greater to the northwest and on the southeast they pass beneath younger formations.

TRIASSIC PERIOD (NEWARK GROUP).

General character.—The rocks of the Newark group are chiefly if not wholly of Triassic age. They extend from the Hudson southwest through New Jersey, Pennsylvania, 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 existing areas of Triassic rock are now widely separated and may never have been directly connected through the whole length of the belt. The Trias comprises both sedimentary and igneous rocks, the former chiefly shale and sandstone with some conglomerate, the latter extrusive basalt and intrusive diabase.

In New Jersey they 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 Bayonne.

SEDIMENTARY ROCK.

Structural relations.—The Trias rests unconformably upon the early Paleozoic and the pre-Cambrian crystalline rocks along the southeastern margin of the Highlands. The sedimentary members are composed in part at least of material furnished by the erosion of the Devonian and older Paleozoic formations which formerly covered the Highlands as well as of the crystallines themselves. Hence they are considerably younger than the youngest of their constituent materials. They are in part overlapped by beds of Cretaceous age, which rest upon their beveled edges. Hence a very considerable period of erosion separates them from the next overlying formation. 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 faults, the amount of dislocation varying from a few inches to several thousand feet.

The sedimentary 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 in New Jersey 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 of light-colored arkosic sandstone and conglomerate with interbedded red sandstone and shale. The thickness is estimated at 2,300 to 3,100 feet. (See "Sandstone," p. 187). The material of which they are composed was derived chiefly from the disintegration of crystalline rocks and came from the southeast. Well-rounded quartz pebbles an inch or more in diameter are not uncommon at some horizons.

Lockatong formation (Trl).—The Lockatong beds overlie the Stockton and consist of black shale, hard, massive, dark argillite, flagstone, and, in a few places, very impure thin limestone layers. The formation has an estimated thickness of 3,500 feet. (See "Argillite," p. 187).

Brunswick formation (Trb.)—The Brunswick beds are chiefly soft red shale with some interbedded sandstone, which becomes more abundant and, on the whole, somewhat coarser, toward the northeast. Its thickness has been estimated at 6,000 to 8,000 feet, being equal to, if not greater, than the combined thickness of the other two divisions. Moreover, its wide areal extent, due to its thickness and repetition by faulting, makes it the most conspicuous of the Triassic formations and gives the impression that these rocks are all soft red shale, with only an occasional layer of purple, green, yellow or black shale—a conception which overlooks the Stockton and Lockatong formations. The uniform presence of finely disseminated mica in the Brunswick shale as in the Stockton formation indicates that the sediments were largely derived from the disintegration of the pre-Cambrian crystalline rocks and came from the southeast.

Border conglomerates (Trc).—Beds of conglomerate occur at a number of localities along the northwest border adjoining the Highlands and there replace the beds of the preceding divisions. Locally well-rounded boulders a foot or more in diameter occur in these beds, which represent the fan-like accumulations formed by heavily-loaded streams of high velocities, where they debouched upon a low plain. An excellent section through the flank of one of these deposits is exposed in the bluff along the Delaware River 2 miles above Milford.

These massive conglomerates which are believed to indicate the location of Trias streams which emerged from the northwest highlands onto the inter-mountain valley, are of three somewhat diverse types;—(a) those predominantly of well-rounded quartzite and hard sandstone pebbles and boulders, (b) those predominantly of limestone fragments, many of which are sharply angular, and (c) those containing a high percentage of granite and gneiss. There is some commingling of pebbles but on the whole the different types are sharply differentiated.

The calcareous conglomerate is most extensively developed northeast of Annandale and Lebanon, and north of Suffern, N. Y. The chief exposures of gneiss conglomerates are between Montville and Pompton Plains. There are extensive areas of the quartzite conglomerate, northwest of Milford, south of Pattenburg, near Peapack and on Mount Paul.

In addition to these large areas localized along the northwest border, there are numerous areas, particularly in Bergen and Passaic counties, where lenses of conglomerate and pebble-bearing sandstone occur inter-leaved with the finer beds of the Brunswick series. Granite and gneiss pebbles in these beds are conspicuous by their absence.

The comparative absence of granitic pebbles in these border conglomerates except north of Montville and the wide extent of the quartzite-sandstone conglomerate indicate that in Triassic time the crystalline rocks now everywhere exposed in the New Jersey Highlands must have been for the most part thickly covered by Paleozoic beds—quartzite, sandstone, slate and limestone—and that in only a few small areas had the streams of that period cut down into the underlying granitic and gneissic crystallines. On the other hand the widespread distribution of arkosic material in the Stockton beds shows the highlands bounding the Triassic lowland on the east were deeply covered with disintegrated granitic material.

Ripple marks, mud cracks, and rain-drop impressions occur at many horizons through the entire formation. In some quarries impressions of leaves and stems of land plants are not infrequently found. On various layers the rock shows the footprints of reptiles which wandered over the soft mud flats while these beds were in process of accumulation. In the vicinity of Boonton fossil fish have been found in successive layers in such large numbers at practically one horizon as to call for a special explanation for their sudden mortality at frequently recurring intervals (p. 107). Cross-bedding, or plunge-and-flow structure, and rapid variations of texture in individual beds are common features of the coarser sediments.

The character of the sediments gives the clue to the conditions of their formation, but before discussing the geographic conditions under which they were formed, another type of rock associated with these beds must be described.

ASSOCIATED IGNEOUS ROCKS.

Extrusive basalt.—Interbedded with the sandstone and shale are three great sheets of basalt, each of which is made up of two or more thinner sheets, is conformable to the bed of shale on which it rests, and is in turn overlaid by other beds of shale or sandstone, which conform to the inequalities of its upper surface. The shale and sandstone beds above the lowest basalt flows measure about 600 feet and those above the second group are about 1,200 feet, while those between the individual lava flows range from nothing to 100 feet. The trap rock is very hard, fine-grained, and of a dense texture, and was formed by the cooling of great masses of lava which during three or more periods of volcanic eruption spread widely over the region, each series of flows burying it to a depth of 600 to 800 feet where the sheet was thickest. At present they cover an area of approximately 500 square miles (although not everywhe[illegible]xposed at the surface), but their former extent

was unquestionably much greater. Since this rock is harder than the enclosing sandstone and shale, the outcropping edges of these sheets now form narrow, sharply-marked ridges—the Watchung, or Orange Mountains.

Intrusive diabase.—A fourth great mass of rock, chemically identical with these, but of coarser texture and somewhat different structure, forms the great Palisade sill of diabase which borders the Hudson from Haverstraw, New York, south to Bergen Point and reappears as isolated ridges in Mercer and Hunterdon counties (Rocky Hill, Sourland Mountain, et al).

This mass of igneous rock breaks obliquely across the strata in many places. Its relations to the enclosing beds, the "baking" of the adjacent shales both above and below, the partly fused masses of shale locally engulfed in it, and the stringers of diabase which here and there extend out from the main mass into the shale both above and below, combine to demonstrate that this is an intrusive mass of lava, forced between the sedimentary beds probably toward the close of the Triassic period. Buried at a great depth, it cooled slowly, forming a relatively coarse-grained rock, and "baked" the adjacent strata for a thickness of 100 feet or more above and below. Its maximum thickness is probably in excess of 1,000 feet.

Both the basalt and diabase are commonly known as "trap" rock, and are extensively quarried at many points, the crushed stone being used chiefly for concrete and road metal. Locally, copper ores occur in the shale immediately underlying the lowest of the three overflow sheets.

With the characteristics of both the sedimentary series and of the associated trap rocks clearly in mind, the geographic conditions under which they were formed can now be considered.

GEOGRAPHIC CONDITIONS.

Pre-Triassic erosion.—During the crumpling and uplifting of the Appalachian folds, and through much but not all of subsequent time, both the Highlands and the Appalachian Valley belt have remained dry land, and the higher portions have in every period been subjected to varying degrees of erosion. During the closing stages of the Paleozoic era, particularly in the Permian period, the young and rapidly growing Appalachian Mountains were attacked with vigor by the elemental forces of destruction, which continued to wear them down far into the Trias[illegible] period.

before the deposition of the Newark sediment began on the lower land to the southeast. When deposition commenced, the whole area now occupied by the Newark beds, and at least the adjacent portions of the present Highlands had been worn down almost to a smooth plain, developed on the beveled edges of the folded and faulted Paleozoic strata, as well as the older pre-Cambrian rocks. Such a worn-down surface which approaches a plain in its topography is called a peneplain.

Further northwest the Permian Appalachians may have retained something of their mountain elevation, although beyond all question they were greatly reduced from their original height and may have approached a stage of planation.

Triassic deposition.—Sometime after the beginning of the Triassic period, however, a wide-spread earth movement affected the eastern region, perhaps a late manifestation of the same orogenic forces to which the mountain folds owed their origin. As a result the old lands of Acadia and Appalachia on the southeast and the new mountains on the northwest were broadly uplifted, while the belt between was relatively depressed even though it may have participated in the upward movement. A series of intermontane basins, perhaps not continuous, was thus formed which extended from Nova Scotia to North Carolina. The present Piedmont region of New Jersey formed the northern end of one of these basins which extended southwest across Pennsylvania and Maryland. In it the sediments washed from the higher region on the southeast began to accumulate. Some of the characteristics of the sediments, particularly their prevailing 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] At

many points along the northwestern border of these plains, where swift streams debouched from the adjoining Highlands, beds of coarse gravel composed chiefly of quartzite and limestone were deposited and formed wide-spread alluvial fans, but the bulk of the sediment seems to have come from Appalachia to the east. Reptiles, some of them of gigantic size, travelled across the soft mud flats, perhaps on their way to widely separated drinking pools, and left as a record of their progress many footprints, which in some places are perfectly preserved in the strata. Slabs measuring 1,700 square feet from a quarry near Towaco, Morris County, show the footprints of 12 different species, some represented by several prints, and are now preserved in the Museum of Rutgers University. The large number of tracks within so small an area indicates an assemblage of individuals such as might occur around a water hole in an arid country.

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 filled 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 except very locally, 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.

From time to time surface depressions were doubtless formed on the low plains of accumulation, sufficient to guide the courses of streams and to contain local shallow lakes and ponds. Some of these existed long enough to be populated with fish of various kinds, the fossil remains of which have been found in great numbers at a few localities, notably near Boonton. Here in excavations for the Jersey City reservoir large numbers were found at several horizons through a thickness of two or three feet. Their abundance at successive horizons point to the periodic drying up of a land-locked bay, with consequent death of the fish, and the restocking of the area when the rainy season restored the lake to its normal height. In the Piedmont of Virginia and North Carolina, Triassic swamps gave rise to accumulations of vegetation that

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[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 layers of wider areal extent, the evidence is positive that the Newark series is fluviatil in nature and must be eliminated from marine deposits and Triassic seas." (Bulletin Geol. Soc. of American, 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).

are now represented by thin beds of coal, but these did not exist in the New Jersey region.

The accumulation of the enormous mass of sediments, of which the existing Newark beds are only a remnant, was attended by a corresponding denudation of the bordering uplands, particularly on the southeast, so that at the close of Newark time these lands were much reduced in height.

Vulcanism.—The later portion of this period of deposition was one of great volcanic activity in New Jersey. Three or more periods of successive eruptions resulted in the flow of thick and extensive lava sheets across the unconsolidated sediments, each eruption being followed by a quiescent period during which sedimentation proceeded as before and the lava flow was buried. The times between the three great stages of activity were long enough to permit the accumulation of about 600 and 1,200 feet of sediment, while the time between the individual flows of each stage, was long enough only for the deposition of a few inches or feet of sediment. At a later period 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, and has a maximum thickness in excess of 1,000 feet. 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 intrusion of the diabase 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 extrusive flows are naturally conformable to the surface of the sediments over which they flowed, while the overlying shale layers fit into all the minor irregularities of the upper surface of the lava. As the lava cooled its upper surface congealed and innumerable bubbles of steam and other gases were trapped in the upper part; hence this section of a flow is porous and spongy, while the lower part is fine-grained and dense. Where the dense lower part of a later flow now rests on the porous, spongy portion of an underlying sheet, the evidence of successive flows at separate intervals of time is conclusive. If beds of shale separate the two flows a time interval between them is indicated proportionate to the thickness of the intervening shale. An excellent illustration of this relationship can be seen in a road cut on Central Avenue, North Caldwell, just south of the Green Brook Country Club.

Possibly
Good For
Water

The relations of the overflow sheets to the underlying shale are well shown in many of the quarries at and near Paterson and particularly in the large quarry at Upper Montclair.

In contrast with the extrusive lava flows, the rock of an intrusive flow like the Palisades is coarser-grained because it cooled slowly at a great depth below the surface; the adjacent sedimentary beds are more or less altered in color and hardness by contact for a long period with the molten rock; the intruded sheet is not necessarily conformable to the inclosing strata but usually cuts across the strata in greater or less degree. Masses of the invaded rock may be and usually are broken off and engulfed by the intrusive mass, and tongues from the latter may penetrate both the overlying and underlying sediments. All of these characteristics are shown at many localities along the base of the Palisade Ridge—particularly near the George Washington Bridge.

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.[1]

No data are at hand to determine whether these Triassic lava flows originated from a volcanic vent, or whether they are of the nature of fissure flows. In northern Sussex County 1½ miles west of Libertyville, a circular hill of trap rock, a quarter of a mile in diameter, in which are included many fragments of granite, slate, and limestone, presents some characteristics of a volcanic plug, the trap rock with the included fragments representing the lava which solidified deep in the throat of the volcanic cone which may once have marked this site. This vent is, however, so far removed from the great lava flows of the Newark series, and so small in comparison with them, that it can hardly be regarded as their source. The fissure or throat up which these floods of lava came

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[1] The possibility that these Sussex County intrusions may have an earlier origin must not be overlooked (pp. 78, 95).

more probably lies beneath the parts of the sheets not yet exposed to view.

Post-Newark faulting and erosion.—The period of Newark sedimentation was at last brought to a close by the formation of and movement along a series of northeast-southwest fractures which divided the earth's crust into a succession of long and narrow blocks. These were tilted to the northwest, thus producing the faulted monoclinal structure with low northwest dips[1] which now characterizes these beds.

The monocline gives place to shallow local folds in some portions of the region, especially in the Passaic Valley west of the Watchung Mountains, where a gentle downward warping has formed a broad, shallow, platter-shaped syncline, the crescent-shaped outcrops of the great basalt flows which form the Watchung Mountains being due to this cause. Further south near the western margin of the group the shape of the smaller trap sheets near New Germantown and Sand Brook is due to local undulations (See sections AA, BB and CC at the bottom of the large geologic map).

The movement which took place along the fracture planes because of the tilting of the blocks is in many instances to be measured in hundreds and in some instances in thousands of feet, but it is not to be supposed that this was the result of a single catastrophic movement. On the contrary it was prolonged through a period inconceivably long from the human standpoint, although geologically brief, and during its progress the uplifted edge of each tilting block was being eroded.

The two most important of these faults trend in a northeast-southwest direction, nearly parallel to the strike of the strata, through Hopewell and Flemington respectively. Since the tilting was to the northwest, 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 State 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 fracturing and faulting were not restricted to the present area of the Newark formations in New Jersey and adjacent states,

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[1] In Connecticut the dip is eastward.

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. The old land of Appalachia on the southeast may also have been involved, for either at this time or during the long period of erosion which followed in the Jurassic period, there occurred its depression and final disappearance, and the near approach of the Atlantic Ocean to its present shore line.

The duration of Triassic time has been estimated by Barrell at 35 to 45 million years.

Jurassic Period.

General statement.—Some geologists have regarded the upper part of the Newark group as of Jurassic age, whence the name Jura-Trias, which has often been applied to it. Apart from these beds, however, no rocks of Jurassic age are found in New Jersey, and in this account of the geologic history, the Newark group is regarded as wholly Triassic.

On the assumption that Jurassic rocks are absent in New Jersey and adjacent regions, the events of this period must be inferred from other data than the sedimentary record which has been the guide heretofore. Some conclusions, however, can be drawn from a careful study of the present topographic forms, which, except in very minor features, are the result of long-continued, subaerial erosion, particularly if these forms be compared with those which must have at first resulted from the tilted, faulted structure of the rocks themselves. If the changes to be described appear enormously great, and the agents producing them seem inadequate because of their slowness, there is the more reason for recognizing the enormous length of geologic time and for accepting an estimate of 35 to 45 million years for the Jurassic period.

Early Jurassic block mountains.—The tilting and faulting which closed the Trias period gave rise to a series of mountain ridges, each formed of a tilted crustal block with steep escarpment along the fault which marked its eastward face, and a gentle back slope the steepness of which was determined by the degree of tilting of that block. If the rate of faulting was extremely rapid as compared to the rate of denudation, some ridges must have attained a height measured by thousands of feet, since the movement on some of the fault planes was of that order of magnitude. Rapid uplift would also result in even crest lines, straight cliff faces, and smooth back slopes. It is more probable, however, that the movement was slow and prolonged, and that during the period of uplift, erosive agencies made some progress, although not able to wear down the land as rapidly as it was uplifted. This would result in a saw-tooth sky line, escarpment faces scored by deep ravines, their bases buried by debris from the cliffs above, and a gradual recession of the entire cliff face from the line of faulting. So, too, the smoothness of the back slope would speedily be broken by the rapidly deepened ravines of numerous streams consequent upon the slope of the tilted fault blocks. Under these conditions the maximum height of the mountains never equaled the whole amount of the movement on the fault planes.

It is worth noting that these block mountains were not limited in New Jersey to the present area of the Newark sediments, since both the Highland belt and Kittatinny Valley are traversed by normal faults of this same type, and were involved in these movements. Moreover, similar structures extend certainly as far northeast as central Connecticut and Massachusetts, and southwest to Virginia and beyond. We are, therefore, safe in concluding that the block mountains of Jurassic time had at least an equal extent.

Development of the Jurassic peneplain. (Fall Zone)—The vigorous erosion to which the faulted blocks were subjected ultimately beveled off the tilted strata, uncovered the margins of the buried basalt sheets, exposed even the deep-seated intrusive sill of diabase, and eventually removed the whole Trias formation except from those long, narrow belts where down-warping and faulting had given rise to great local thickening of the sediments and had depressed them between adjacent areas of crystalline rocks which protected them from complete destruction. Ultimately the land was worn down to a region of relatively low relief, which in comparison with the earlier topography would be regarded as a plain, although differences of elevation of several hundred feet between stream courses and divides may have existed. Across this plain the streams meandered in shallow wide open valleys, probably largely adjusted to the structure, but locally crossing hard strata in disregard of it. The exact course of these streams cannot now be determined with any certainty. How much of this denudation was accomplished in Jurassic, and how much in the succeeding period, is uncertain. The next formation exposed in New Jersey is the Raritan (Upper Cretaceous), which along its northwestern border now rests upon the beveled edges of the Newark beds and further southeast on a gently rolling eroded surface of crystalline rocks. It is possible, therefore, that all of New Jersey continued to be a land area through Lower Cretaceous (Comanchean) time, and that a considerable part of the denudation to which the early Jurassic (post-Trias) mountains were subjected occurred during this later period.

On the other hand Lower Cretaceous (Comanchean) deposits outcrop in Delaware and Maryland and possibly underlie the Raritan (Upper Cretaceous) beds in the southern counties of New Jersey, although not exposed on the surface, and may have once extended somewhat further north than at present. From the little that is known about the crystalline floor on which the Cretaceous beds rest, it seems to be an approximate plain with low hills and shallow valleys. In Maryland residual hills 240 to 300 feet in height locally rose above its general surface and evidently formed islands around which the earliest Lower Cretaceous beds were deposited. It appears, therefore, that Jurassic erosion planed across the Newark rocks, removed them entirely from an area of considerable width, certainly on the southeast and perhaps on the northwest of their present outcrop, and developed a plain of gentle relief with low residual hills, certainly in southern and central New Jersey and perhaps also in the region of the present Highlands and Kittatinny Valley. This surface has been variously called the Jurassic, and the Fall Zone peneplain.[1] At the beginning of the period the State was part of a high and rugged mountainous region, each eastward-facing ridge a tilted fault block; at the end the mountains had largely, if not entirely, disappeared and in their place was an eastward-sloping plain, so low that a slight depression would submerge its marginal portions beneath the waters of the Atlantic.

LOWER CRETACEOUS (COMANCHEAN) PERIOD.

Earth movements and their results.—Early in the Lower Cretaceous, 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, the axis of rotation probably being along the present margin of the Coastal Plain. 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 rivers. Lakes, marshes, and perhaps estuaries were features

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[1] Douglas Johnson. Stream Sculpture on the Atlantic Slope. Columbia University Press, 1931, p. 14.

of the region, and in them and on the bordering lowlands beds of gravel, sand and clay were deposited.

Sedimentation inaugurated by this movement probably affected the southern portion of the State (Salem, Cumberland, Atlantic and Cape May counties), since deposits of this age (Patapsco and Patuxent) occur at Wilmington, Delaware, and southwest in Maryland (p. 113), but if present in New Jersey they are overlapped and completely buried by later deposits. In so far as the Lower Cretaceous sea did not extend north of these counties, the adjacent land areas were subject to continued erosion.

In the Maryland region the period was a time of sedimentation interrupted by three intervals of uplift or warping, during which the sea withdrew, the recently formed deposits were eroded, and sufficient time elapsed for marked changes in the character of the vegetation on the adjoining lands. Geologically, however, these periods of interrupted sedimentation were relatively brief, but their effects were probably felt in New Jersey.

UPPER CRETACEOUS PERIOD.

General character and relations.—The beveled edges of the Triassic shale, sandstone, and diabase are now overlapped unconformably along their southeastern margin by strata of Upper 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 Cretaceous formations are unconsolidated sand, clay, and greensand (glauconite) marl, which dip 25 to 60 feet per mile to the southeast and have an aggregate thickness of 500 to 1,000 feet, the greatest thickness occurring in the northeastern portion of the area. They rest on an undulating, southeast-sloping foundation of hard rocks (Trias and older), the Fall Zone peneplain (p. 112).

The lowermost beds (Raritan) are of non-marine origin and were formerly referred to the upper part of the Lower Cretaceous (Comanchean), but are now regarded as Upper Cretaceous. Overlying the Raritan there is a succession of formations, no one of any great thickness, which along their outcrops in New Jersey can be differentiated from each other by careful study, but which lose something of their distinctness down the dip to the southeast, and

also along their outcrop in Delaware and Maryland. These will be described and then the geographic conditions prevailing in Upper Cretaceous time will be considered.

THE ROCK FORMATIONS.

Raritan formation (Kmr).—The Raritan formation is of continental origin and is extremely variable in composition. It consists chiefly of light-colored sand and clay, some of the clay being highly refractory. (See "Clays," p. 179). There is on the whole, a preponderance of clay in the lower and of sand in the upper half of the formation. (See "Underground Waters," p. 181). So variable is it both vertically and horizontally that subdivisions recognizable in one area cannot be traced for any distance. Since the formation was laid down on an irregular surface, its thickness is not constant but ranges from 150 to 300 feet at the outcrop, and increases to the southeast to over 500 feet.[1] Along its outcrop northeast of Princeton Junction it rests unconformably on the beveled Triassic strata; but in the vicinity of Trenton and further southwest it lies on ancient rocks of early Paleozoic or pre-Paleozoic age. At Hightstown, Prospertown and Jackson's Mills, the pre-Cambrian crystalline rocks were reached beneath Cretaceous beds by deep boring (490-500 feet at Hightstown, 1,115 Prospertown and 1,336 Jackson's Mills). It dips 40 to 60 feet per mile toward the southeast, the basal beds having the steeper inclination.

The known fauna consists only of a few pelecypods (some of which are brackish-water types, while two are typically marine), a plesiosaurian bone, and possibly an insect. Footprints of a large dinosaur have been uncovered in the Cutter clay pits at Woodbridge. 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 Lower Cretaceous and, therefore, approximately *equivalent to the Gault of England*, but Berry[2] 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 rather than the Lower Cretaceous.

Its broad relations to the next overlying formation are such as to indicate a disconformity and erosion interval at this horizon.

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[1] There is a possibility that some Lower Cretaceous beds not exposed at the surface have been included in the great thicknesses shown by some well borings.

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

There must, therefore, have been crustal movements at this time, which caused a temporary withdrawal of the water in which it was deposited.

Magothy formation (Kmr.)—In the earlier reports of the Survey the Magothy was included in the Raritan. It is partly of continental and partly of marine origin and includes beds of sand and clay, many of them lignitic, with some glauconitic (greensand) beds toward the top. (See "Clays," p. 179). 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 disconformably upon the Raritan, but the discordance is not great and probably indicates only a slight earth movement, and brief erosion interval.

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

IS MERCHANTVILLE (Kmv) CONFORMABLE
OR UNCONFORMABLE w/ MAGOTHY (Kmr)?

So far as observed in New Jersey the Magothy is followed conformably by the Merchantville clay, but in Delaware along the Chesapeake and Delaware Canal the equivalent contact rises and falls in respect to the water level in the canal, and in the vicinity of Delaware City the Magothy is apparently absent from its proper position. It is possible, therefore, that the upper surface of the Magothy in New Jersey was raised above sea level and somewhat eroded before the deposition of the succeeding beds.

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 a coherent brown earth. It is probably disconformable to the Magothy formation below and conformable 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 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 [illegible]elated with the Matawan formation of Maryland.

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 of the subjacent Merchantville. It is conformable with both the Merchantville below and the Englishtown above. It is the upper portion of the Crosswicks clay of Clark and forms part of the Clay-Marl series of Cook. It is the second of the formations correlated with the Matawan of Maryland.

Englishtown sand (Ket).—The Englishtown is a conspicuous bed of white or yellow quartz sand, slightly micaceous and sparingly glauconitic. Locally some beds have been cemented by iron oxide into massive stone. In places it contains thin laminae of fine clay. So far as known it is not fossiliferous. It decreases in thickness from 140 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 equivalent to the middle part of the Matawan formation of Maryland.

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 40 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. 179; and "Greensand Marl," p. 190).

Wenonah and Mount Laurel sands (Kmw).—Above the Marshalltown clay-marl there is a 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.

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 on the other hand 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 *Terebratella 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 to that of the Marshalltown and Merchantville beds, the characteristic forms of the Magothy, Woodbury, and Wenonah being 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. 190).

Red Bank sand (Krb).—The Red Bank sand is for the most part a fairly coarse yellow and reddish-brown quartz sand, locally changed to stone 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 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 140 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 sand in the southern portion of the State that was 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.

Tinton bed (Krb).—A bed of green 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.

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 members 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 relatively minor oscillations of land caused the shore line to advance and retreat and brought about deeper or shallower water. 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.

For many years the three succeeding formations, namely the Hornerstown marl, the Vincentown sand, and the Manasquan marl, were by all geologists regarded as Cretaceous although it was recognized that this classification entailed both paleontological and structural difficulties. Within recent years, however, Cook and Stephenson of the U. S. Geological Survey[1] have reexamined the evidence and given cogent reasons for placing these formations in the Tertiary. This has necessitated no changes in the mapping of these formations in the field and only a change of color and wording on the State map.

Having thus briefly summarized the various Cretaceous formations recognized in New Jersey, we can consider the sequence of events and the conditions under which they were deposited.

HISTORY.

Raritan deposition.—During Raritan time conditions were not unlike those which prevailed during the Lower Cretaceous. Lakes, marshes, and probably estuaries were features of the low coastward tract, on which were deposited the gravel, sand and fine mud brought down by the streams from higher land on the west. The presence of feldspar (or kaolin from the decay of feldspar in place) in the coarse sand and fine gravel of the Raritan shows that erosion in some places exceeded rock decay, and indicates higher land and large exposed areas of granite and gneiss to the west, probably the present Highland region, whence the sediments were derived.

The thickness to which these accumulated in New Jersey is unknown, but it certainly exceeded 300 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 somewhat 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. The inequalities of surface so produced were, however, only of minor importance.

Magothy—Tinton subsidence and deposition.—Following the erosion of the upper Raritan beds a progressive but oscillatory subsidence of the southeastern border of the land began, with an accompanying invasion by the waters of the Atlantic, a condition that continued, except perhaps for a brief interruption at the end of the Magothy, throughout Upper Cretaceous time. Just how far the sea advanced to the northwest at this period is unknown, but there are reasons for believing that it was far to the northwest of the present outcrop of Cretaceous beds. (See p. 123). Concurrent uplift of the axial region of the Appalachian province beyond the margin of the sea furnished the vast amount of sediment that accumulated on the submerged Coastal Plain in this period.

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[1] C. W. Cooke and L. W. Stephenson, Eocene age of the supposed late Upper Cretaceous Greensand Marls of New Jersey. Geol. Soc. of America, Bull. Vol 39, p. 290, 1929.

As already noted (pp. 114-119) beds of sand, clay, and greensand (glauconite) marl, variously interbedded and commingled, constitute the Upper Cretaceous sediments above the Raritan. 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 now forming on portions of ocean floors adjacent to the coast, where land-derived materials are being deposited in only slight amounts. 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 the intervals of Cretaceous time represented by the Marshalltown and Navesink marls, southern New Jersey was submerged to a depth of about 600 feet and the shore of the Atlantic lay far northwest of the present area of these beds.

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 ocean implies oscillations of the shore line upon the low-lying coast across a zone many miles wide.

Alternation of faunas.—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 clay and clayey sand 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 the accompanying glauconitic sediments and the *Cucullea* fauna gradually entered this region from the southeast, and occupied a belt which 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 both faunas shifted to the southeast and the shallow-water facies again occupied the region.

Vertebrates.—The life of the Cretaceous sea was not limited, however, to the invertebrate forms which make up the faunas described above. The Cretaceous and early Tertiary waters were dominated by huge reptiles which surpassed in size and strangeness the sea-serpents of fiction. There were the *Elasmosaurs,* 40 to 50 feet in length, of which 22 feet was neck, with swelling body, short flippers and long flattened tail; the *Mosasaurs,* gigantic, scaled, carnivorous, marine lizards, some 30 feet in length with limbs modified into paddles and with ponderous jaws furnished with rows of great conic teeth; various species of crocodiles whose abundance is shown by the frequency with which their bones have been found in the marl beds, particularly those of Eocene time; turtles and tortoises of many kinds and sizes up to 6 feet in length. Besides the sea reptiles there were sharks, whose teeth found in large numbers in the marl beds measure 4 to 5 inches in length and 3½ inches in width and indicate an individual 70 to 80 feet in length.[1]

On land there were huge duck-billed, bipedal, plant-feeding dinosaurs, some of which were 28 to 30 feet in length, ponderous in body, and probably slow in movement. A skeleton of the best known, *Trachodon,* (Hadrosaurus) was discovered years ago near Haddonfield, Camden County, but portions of others have been found in at least eight other localities. It was a herbivorous animal of heavy proportions, short fore limbs, but very long and massive hind legs. Its great tail, long hind limbs and pelvic bones were an efficient support, while it reached up to the limbs of trees on whose foliage it fed. Its fore-limbs were used chiefly in drawing its food to it, though it probably rested on them as it stooped to the ground to devour vegetable material there. (Cope) A restoration of this skeleton is now mounted in the State Museum at Trenton.

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[1] Since some of the strata formerly regarded as Cretaceous are now known to be early Tertiary, some of the above forms doubtless belonged to the later period.

Trachodon probably found its mortal enemy in *Laelaps,* a slightly smaller, but more agile dinosaur of carnivorous habit, whose long curved claws, and knife-shaped teeth were splendid weapons of offence. It had shorter fore and longer hind legs than Trachodon, and like the birds walked entirely on its hind limbs or leaped like the kangaroo. (Cope). Remains of this ancient buccaneer were found may years ago in the West Jersey Marl Company's pits near Barnsboro.

References.—For fuller description and discussion of the Mesozoic formations of New Jersey, see the following publications:[1]

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

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[1] In consulting these references it must be remembered that when these articles were written the Hornerstown, Vincentown and Manasquan formations were supposed to be Cretaceous, although now regarded as Tertiary (Eocene). The Schooley Peneplain also was supposed to pass beneath the Cretaceous Coastal Plain and to have been developed, at least on its seaward margin, before the end of the Lower Cretaceous, although the interior portions were not reduced to the peneplain stage until late in the Upper Cretaceous.

Whereas, according to the interpretation of Douglas Johnson, which is here accepted, the Coastal Plain beds rest on an earlier peneplain (Fall Zone), which was uplifted in late Cretaceous or post-Cretaceous time, and the Schooley Peneplain developed at a lower level in Tertiary time.

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 New Jersey, 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 Reports 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.

CHAPTER VII.

CENOZOIC ERA.

Summary statement.—The Cenozoic era comprises the Tertiary and Quaternary periods. The former is commonly divided into the Eocene, Miocene, and Pliocene, while the latter includes the Pleistocene and Recent. In each of these, further subdivision of the record is made. Cenozoic time, although perhaps 55 to 65 million years in length was only one-half to one-third as long as Mesozoic, and only one-sixth or one-seventh as long as Paleozoic.

Its life was characterized by the rapid rise and great development of mammals, the absence of the dinosaurs and large flying reptiles, the appearance and gradual increase of modern species among the mollusks, and very late in the era, the appearance of man.

The formations of Cenozoic age in New Jersey include: (1) marine Tertiary sand, gravel, marl, and clay, underlying the most extensive areas of the Coastal Plain, with gravel (Beacon Hill) at the top probably of continental origin; (2) Quaternary deposits of nonglacial (interglacial) continental origin of widespread occurrence over the Coastal Plain (Bridgeton, Pensauken, Cape May), 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 PERIOD

New streams across the emerging sea floor.—With the uplift which caused the withdrawal of the Cretaceous sea from New Jersey and adjacent regions, streams established themselves across the emerging sea floor. At first these were extensions of existing streams from the old land on the northwest. Later as the Coastal Plain increased in width by further retreat of the sea, new streams developed wholly within its limits; but in both cases the courses were determined by the slope of the new land, and not in any degree by the topography of the buried Fall Zone peneplain, on which the Cretaceous sediments rested, since it is highly probable that the thickness of the Cretaceous cover was enough to obliterate the buried topography.

Because the Coastal Plain cover was unconsolidated material, erosion proceeded with relative rapidity and in a geologically brief period the streams cut through these beds and incised their channels across the underlying peneplain surface. Doubtless during the Fall Zone erosion cycle, the streams, whatever their initial courses, had become more or less adjusted to the structure, following belts of soft rock and avoiding the hard formations which formed divides. But whatever their direction it is entirely improbable that the consequent streams formed on the Cretaceous cover coincided in any material degree with these ancient courses. On the contrary it is quite certain that in some places the new streams found themselves superposed across low ridges, which had existed on the Fall Zone peneplain. Thus the ancestors of the Delaware, and of the streams which cut Culvers Gap near Branchville and the Wind Gap in Pennsylvania were superposed across the low ridge formed by the Shawangunk conglomerate on the pre-Cretaceous peneplain. So too the ancestors of the present Pequannock and Rockaway rivers as well as many others were superposed from the Cretaceous cover on to the underlying peneplain, in courses transverse to the geological structure of the underlying rocks.

With the continued removal of the Cretaceous cover more and more of the Fall Zone peneplain became exposed and belts of soft rock were uncovered between the low ridges formed by the harder beds. This gave an opportunity for the development of tributaries to the transverse streams along these softer belts. During the long erosion interval in Tertiary time which resulted in the removal of the Cretaceous beds along their northwest margin, the destruction of the Fall Zone peneplain and the development of a lower peneplain, there were doubtless some instances of stream capture by these growing subsequent streams, but the master streams like those mentioned above persisted through this erosion cycle and maintained their southeast courses. Ultimately in Tertiary time a new peneplain was developed at a level below the older Fall Zone surface. A remnant of this erosion surface is now preserved in the plateau-like summit of Schooley Mountain, whence the name Schooley peneplain. Further consideration of this new level will be deferred for the present.

EOCENE

Pre-Eocene disconformity.—So far as we can now determine, Cretaceous sedimentation in New Jersey terminated with the deposition of the Red Bank and Tinton beds. If younger formations of this period were formed they were removed in the cycle

of erosion which followed the uplift of the Cretaceous ocean floor, and before the deposition of the following Eocene formations. As a result of the uplift, the shore line retreated far to the southeast of the present Cretaceous outcrop belt. These formations for their entire thickness were removed from the Triassic area, (except for a small remnant near Sand Hills in Middlesex County) and the two highest beds—the Tinton and Red Bank—do not now occur at the surface from near Sykesville to the Delaware Bay, so that along this belt the Hornerstown (Eocene) marl rests directly on the lower Navesink (Cretaceous), with the Tinton, Red Bank and upper Navesink marl missing at the surface.

This gap represents (1) the time necessary for the Cretaceous sea to withdraw from its furthest northwest extension to a line some distance southeast of the present Cretaceous outcrop, (2) the removal of all the Cretaceous strata which covered the Triassic beds, (3) the removal of at least 120 to 140 feet of Cretaceous strata southwest of Sykesville, and a greater thickness further southwest where the Hornerstown now rests on the Mount Laurel sand, and (4) the re-advance of the sea in Eocene time and the beginning of the deposition of the Hornerstown marl in water having a depth of several (300-600) hundred feet.

Eocene time in New Jersey was therefore, a period of erosion in the northern section, of sedimentation in the south and of alternate erosion and sedimentation in the central portion.

Hornerstown marl (Tht).—The Hornerstown is a bed of glauconite (greensand) with clay and sand, having a total thickness of about 30 feet. It is much like the Navesink, but its fauna, 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 numerous localities and apparently covered many square miles of the ocean bottom. At the north the Hornerstown rests 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 downward 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.

Vincentown sand (Tvt).—The Vincentown sand presents two facies: (1) a calcareous or lime-sand phase, semi-coherent and largely a mass of broken bryozoan, echinoid, coral, and other calcareous remains; (2) a glauconite quartz-sand phase. The two occur in alternate layers, although the former is more common in the basal portion, particularly to the south, whereas 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 ranges from 25 to 100 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.

Manasquan marl (Kmq).—The lower part of the Manasquan marl (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, hence 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 three formations formerly regarded as Cretaceous but now classed as Tertiary (Eocene). It probably rests conformably upon the Vincentown and at most exposures is succeeded unconformably by higher Teritary or Quaternary deposits, although locally it is overlain by a bluish marl of later Eocene (Tertiary) age.

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 Eocene fossils rests without apparent unconformity upon the "ash" marl of the Manasquan. The upper two or three feet are quite hard and stony. This marl has been found as far west as Farmingdale and the sea in which it was deposited must have reached somewhat further inland, but how far cannot be determined. Since the formation is now only 11 feet thick, the time interval represented by it was relatively short, although the present beds may be only a portion of those orig[illegible]lly deposited. Pits where these beds were once dug have long since been filled and it is now very difficult to find adequate exposures. Clark regarded it as probably older than the Eocene of Maryland, but by some authors it has been placed above the Maryland Eocene.

CONDITIONS OF FORMATION AND AGE.

The faunas of the first three formations are closely related and form a larger fauna sharply separated from the Ripleyan fauna of the underlying Cretaceous beds. This fauna has not been recognized south of Maryland. As already stated (p. 120), these formations are now classed as Eocene.

The occurrence of the Hornerstown, Vincentown, Manasquan formations resting in that order on the beveled Cretaceous strata indicate that in Eocene time the sea probably attained a depth of 600 feet in the region in which the Hornerstown marl is now found. Remains of crocodiles, turtles and sharks of enormous size are frequently found in the pits where the marl is now being dug. Owing to the fragile condition of the bones after interment for 50 or 60 million years in incoherent sediments, great care is needed in their recovery. Through the cooperation of the owners of several pits the State Museum has in recent years recovered several fine partial skeletons. The shark's teeth in contrast to bones are practically indestructible.

The sand beds of the Vincentown intercalcated between the Hornerstown and Manasquan marl beds apparently indicate a minor shoaling of the ocean, and more land-derived material, as well as the presence in Vincentown time of vast numbers of bryozoa, echinoid, coral and other lime-secreting organisms. On the other hand, in Manasquan time conditions again favored the deposition of glauconite.

Post-Eocene emergence.—Following the deposition of the Shark River marl, the Eocene sea withdrew, probably from all of southern New Jersey, so that opportunity was afforded not only for the erosion of the recently formed Eocene deposits, but for the continued erosion of the older Cretaceous beds so far as they may have then extended northwest of their present outcrop. To what extent this removal of the Cretaceous strata was accomplished in post-Tinton—pre-Hornerstown time (late Cretaceous and early Eocene) and what in post-Shark River—pre-Miocene time cannot now be definitely determined. We know that the Hornerstown along its outcrop overlaps the beveled edges of the Tinton, Red Bank and Navesink formations, hence some eros[illegible] was accomplished in the interval between the deposition of the Tinton and the Hornerstown (late Cretaceous and early Eocene). We know also that the lowest Miocene beds (Kirk~~land~~wood, see below) now rest on beds of such varying ages as Shark River and Mount Laurel. We conclude, therefore, that in post-Shark River (Eocene) pre-Kirkwood (Miocene) time the Eocene beds were beveled and to some extent probably removed from the underlying Cretaceous. In the region not submerged in Eocene time, erosion of course must have continued.

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, probably covered a portion of this formation, and may have reached the crystalline rocks, but its northern limits cannot be definitely determined. During this submergence the sediments now grouped under the term Kirkwood (Tkw) were deposited. Under this term 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 sand, in many places delicately banded in shades of salmon-pink and yellow. Black lignitic clays occur in some localities at or near their base. 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 is a 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. Further north, particularly in Monmouth County, the upper beds are fine micaceous sand alternating with layers of clay which range from a fraction of an inch to many feet in thickness.

ALLOWAY
CLAY

Although the Cretaceous strata had suffered considerable erosion (see above) during the periods of emergence preceding and following the Eocene submergence, the surface on which the Kirkwood was laid down was relatively level, apparently less uneven than the rougher parts of the present Coastal Plain.

The total thickness of the formation along its 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 to the Calvert formation of Maryland, the lowest division of the Chesapeake group.

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 beds of clay, sand, and marl 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.

Post-Kirkwood emergence.—In southern New Jersey the Kirkwood is followed disconformably by the Cohansey sand, but the lack of conformity is not marked. Hence it is inferred that there was a relatively brief emergence following the Kirkwood deposition, during which the shore line retreated to a line southeast of the present outcrop of the Kirkwood, although the sea may not have withdrawn far from the present limits of the State. It is impossible now to determine how long this period of emergence lasted.

Cohansey submergence and deposition.—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.

This formation, which overlies the Kirkwood at its outcrop, is composed chiefly of quartz sand, locally with clay laminae, or 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 disconformity.

Inasmuch as sand and clay similar to the Cohansey are revealed in borings along the coast, and there overlie clays carrying Miocene fossils characteristic of the St. Mary's, which is the highest division of the Chesapeake group and so younger than the Kirkwood, the Cohansey must belong 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 phase of the fossil-bearing Miocene (St. Mary's) clays which are found in the borings along the coast. In that case it should be correlated with the Choptank and St. Mary's of Maryland. In the light of all data at present available, however, the former view seems the more probable.

Identifiable remnants of the Cohansey do not occur as far northwest as 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 then the Kirkwood have been found at several places on the Triassic formation, 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 life of the Eocene and Miocene.—The remains of snakes which attained a length of 20 feet have been found in the Shark River marls, as well as bones of sea turtles, crocodiles and shark's teeth, so that we know something of the larger denizens of the sea during early Tertiary time. Sea turtles, sharks, and crocodiles are also known to have frequented New Jersey waters during Miocene times. Little is known of the land animals which then inhabited the State. During the Eocene the earliest known member of the horse family made its appearance in western United States. They were graceful little creatures about 11 inches tall at the withers with four toes and traces of a fifth on the front feet, and three toes and two splints on the hind feet. Camels, tapirs, giant pigs, a fleet-footed rhinocerous, and four-tusked mastodons were a few of the other strange forms which occurred in the western part of

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[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 older depos[illegible] which formerly stretched far northwest of their present outcrop.

the United States. Some or all of them may have had an eastward range and so reached New Jersey, but no direct evidence of this has been found.

PLIOCENE.

Post-Cohansey uplift and Beacon Hill deposition.—The cycles of deposition, during which the Kirkwood and later the Cohansey beds were deposited, were terminated—apparently in early Pliocene time—by an upward arching of the Appalachian region which may have approached in certain areas a peneplain. This 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 peneplain stage, readily furnished load to the streams in their flood stages. Upon reaching the southeastern margin of the peneplain, which was not so much affected by the uplift, and the adjoining low, flat, and recently emerged sea bottom, the streams spread much of their load of sediment over a wide zone of deposition upon the land. With continued uplift the inland margin of the deposits was in turn eroded, while the zone of deposition was extended seaward. The Beacon Hill gravel, which now caps some of the highest hills of the Coastal Plain is believed to represent remnants of stream deposits made at this time, and to be the correlative of the Lafayette gravel further south.[1]

The Beacon Hill gravel (Tbh) is chiefly quartz, but contains chert and some pebbles of hard sandstone and quartzite. The chert pebbles are invariably much decayed and many of them are very soft. Many of the quartz and quartzite pebbles also are more or less corroded. Although originally deposited as a more or less continuous sheet, the formation now occurs only as isolated remnants on the summits of the highest hills of the Coastal Plain, such as Beacon, Hominy, and the Clarksburg hills in Monmouth County, Old Half Way hill in Ocean County, and Apple Pie hill in Burlington. These widely isolated gravel-capped hills are eloquent witnesses of the wide spread erosion of post Beacon Hill time. The summits of the other hills like Arneys Mount in Burlington, do not now quite reach the requisite elevation although scattered

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[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.

pebbles testify to the presence of a Beacon Hill cap, before the summit had been degraded to its present level.

EARLY TERTIARY EROSION.

Introductory statement.—In the preceding pages we have considered the various deposits in New Jersey referable to the different subdivisions of Tertiary time. We have seen that these deposits as they exist at present cover only a fraction of the areas on which they were laid down. Not only did they extend inland beyond their outcrop, due to a northwest transgression of the sea, but between the periods of deposition there were periods of uplift or tilting during which the sea withdrew to the southeast, and the newly made deposits were eroded and in part removed. Large areas of New Jersey were, therefore, in Tertiary time alternately regions of sedimentation and of erosion. However, in the areas beyond the farther advances of the Tertiary seas, erosion was continuous. It is desirable now to consider this erosion and the topographic forms which resulted therefrom.

THE SCHOOLEY PENEPLAIN.

Description.—The visitor to High Point, in Sussex County, who on a clear day looks eastward across the rolling lowland of Kittatinny Valley towards the Highlands 8 or 18 miles distant cannot fail to be impressed by the fact that the skyline of that rugged mountainous belt is remarkably even. The hilltops all approach a general level and no peaks rise conspicuously above that level. Looking westward over the hills of Pennsylvania, the same phenomenon is observed. Hill summits and plateaus all approach a common elevation. Moreover, an observer on the edge of the Highlands looking westward across the Kittatinny Valley will note that the crestline of Kittatinny Mountain is likewise remarkably horizontal. If the depressions beneath these crestlines were filled to their level, the topography would be that of a rolling plateau sloping gently southeastward.

Moreover, the crestlines of the Orange or Watchung Mountains and the Palisades, the broad plateau of Hunterdon County, between Frenchtown and Flemington, and the plateau-like crest of Sourland Mountain, although lower than Kittatinny Mountain and the Highlands would all fall in line and merge with this gently sloping plateau. In other words these present major elevations of northern New Jersey are all believed to be remnants of a surface which had a present elevation of 1,500 to 1,600 feet over wide areas in Sussex County, and declined nearly to sea level in the vicinity of Raritan Bay.

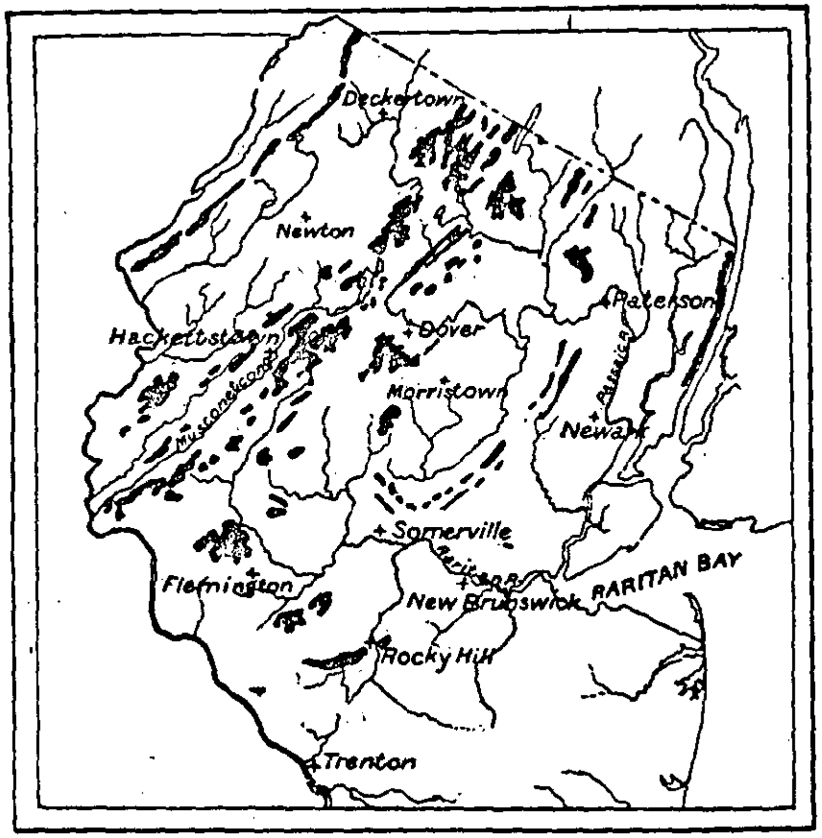

Fig. 8. Remnants of the Schooley peneplain.

In other words if the broad expanse of Kittatinny Valley, the narrower inter-highland 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 plain would be restored as a gently warped surface, sloping to the southeast and diversified by low knolls. If this old surface thus restored were then bodily depressed to a low-lying plain near sea level, northern New Jersey would return to the topographic monotony it formerly had. Such a surface of erosion could have been produced only at an elevation close to sea level. The fact that it is now much dissected and has been removed over wide areas proves that since its origin it has been widely upwarped and dissected.

The present topography, therefore, is the result of long-continued erosion of this uplifted ancient plateau. Since its remnants are well preserved in the flatter summit areas of Schooley Mountain and in the even crestline of Kittatinny Mountain it has been called both the Schooley peneplain and Kittatinny peneplain.[1] Its dissected remnants are an important topographic feature throughout the Appalachian province from New York to Alabama.

Relation to the Fall Zone peneplain.[2]—For many years it was believed that the Schooley peneplain was the result chiefly of Jurassic and lower Cretaceous erosion; that in upper Cretaceous time its seaward portion was submerged for a moderate distance beyond (northwest) the present margin of the Coastal Plain and buried beneath Upper Cretaceous sediments; that in post-Cretaceous time it was upwarped, its higher portions dissected leaving the present remnants in northern New Jersey, while its seaward portion is still buried beneath the Coastal Plain. According to this interpretation the Schooley and the Fall Zone peneplains are one and the same thing.

The other view is that the Schooley is younger than the Fall Zone plain and was developed wholly in post-Cretaceous time at a lower level and in a subsequent erosion cycle—(early Tertiary).

In favor of the second view as against the first it has been urged, (1) that the slope of the erosion surface beneath the Cretaceous beds is steeper than the slope of the dissected Schooley remnants northwest of the Fall line. The suggestion that subsequent warping accounts for the difference of slope does not wholly meet this condition, as has been pointed out by Johnson:[3] (2) that the remnants of the Schooley peneplain are too well preserved over considerable areas at elevations which favor erosion, to date back to Cretaceous time. It is questionable whether any rock surface continuously exposed to erosion since Cretaceous time could be so well preserved, (3) the present drainage of the Atlantic slope,

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[1] Some recent writers do not regard the Kittatinny summit and the Schooley summit as parts of the same plain and of the same age, but consider the latter as a younger surface developed at a lower level, subsequent to a slight uplift of the Kittatinny plain: (U. S. Geological Survey—Geol. Folio 221). The interpretation given above is, however, the commonly accepted one. (Ver Steeg, Karl—Annals of the New York Academy of Sciences, Vol. xxxii, pp. 87-220.)

[2] See page 112.

[3] Johnson, Douglas—Stream Sculpture on the Atlantic Slope, Columbia University Press, 1931, p. 9.

notably the existing master streams like the Hudson, Delaware, Susquehanna, Potomac, as well as many others, cross belts of hard and soft rocks in curious defiance of the rock structures and in courses which seem best explained on the theory of an ancient peneplain (Fall Zone) buried by overlap of Coastal Plain sediments on which streams were established in accordance with the southeastward slope of the emerging sea bottom in late Cretaceous-early Tertiary time.[1] For these and other reasons the view here adopted is that in northern New Jersey the Schooley peneplain is the result of the erosion and destruction in Tertiary time of the Fall Zone peneplain with its Cretaceous cover, whereas in the Coastal Plain region it (the Fall Zone peneplain) is still preserved beneath existing sediments.

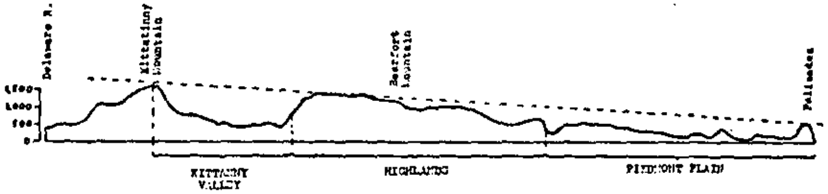

Fig. 9. Profile across northern New Jersey, showing by dotted line the uplifted and tilted Schooley peneplain before erosion.

Drainage on the Schooley peneplain.—Although only portions of the Schooley peneplain now remain, nevertheless some traces of the major stream courses are still preserved to us. In its larger features the drainage was an inheritance from the southeastward consequent streams established on the Cretaceous cover of the Fall Zone peneplain (page 125) plus such adjustments as were due to the development of subsequent streams along belts of softer rocks which were revealed on the Fall Zone peneplain by the removal of the Cretaceous cover. Wind and water gaps which now interrupt the crestline of Kittatinny Mountain and which here and there cross the Highlands indicate the location of streams which crossed the Schooley plain in channels only slightly cut below the broad low divides. These show that large streams crossed Kittatinny Mountain (which was then only a low ridge on the Schooley peneplain), on the line of the Pen Argyl Wind Gap in Pennsylvania, the Delaware Water Gap, and Culver's Gap in New Jersey. The profile of the crest of Kittatinny Mountain indicates that these larger streams flowed in very broad and shallow valleys 100 to 300 feet below the broadly rounded divides, while numerous smaller

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[1] For a complete discussion of this problem and its possible alternative solutions, see the scholarly essay by Douglas Johnson—Stream Sculpture of the Atlantic Slope—Columbia University Press.

tributary streams crossed the ridge in neighboring shallower valleys.[1] Ancestors of the Pequannock and of the Rockaway rivers crossed the Highlands but at elevations only a little below the present mountain summits. Likewise between Oxford and Karrsville streams crossed Scotts Mountain along the lines of Van Ness Gap at Oxford, Stewart Gap opposite Karrsville and an unnamed gap a mile northeast of Van Ness Gap, but at levels only slightly below the mountain summits on either side of the present gaps. Since the Van Ness Gap is deeper than the others it was probably occupied by the largest stream, to which the other two may have been tributary. The gap north of Port Colden and the Glen Gardner Valley now occupied by Spruce Run probably mark the much deepened southeast course of this stream.

At some period in the Schooley erosion cycle when the removal of the Cretaceous cover began to expose the northeast-southwest belts of soft rock subsequent streams began to develop along these lines of easy erosion. These were the ancestors of the Paulins Kill, the Pequest, the Pohatcong and the Musconetcong. West of Kittatinny Mountain similar longitudinal streams tributary to the master streams which crossed this ridge began their head water growth along the outcrop of the soft Marcellus and Salina shales.

Gaps in the Palisades and Watchung Mountains.—The Palisade ridge at Sparkill, New York, First and Second Mountains at Paterson and Little Falls, and at Short Hills and Millburn, and Third Mountain north of Chatham and again south of Pine Brook are interrupted by broad gaps[2] which present many points in common. The Short Hills Gap is now filled with glacial drift and the gaps north of Chatham and south of Pine Brook are known only by borings. Evidence is conclusive that in preglacial times these gaps had been cut by a large river or rivers to depths of 400 to 470 feet below the crests of the ridges on either side. In recent years Johnson[3] has given good reason for the view that in the Schooley cycle the predecessor of the present Hudson turned southwest across the buried Palisade ridge at Sparkill and held a course on the Cretaceous sediments such that it twice crossed the buried Watchung ridges at an elevation much above the present surface level. With the removal of the Cretaceous beds the river was superimposed upon these belts of hard rock across which it continued to flow during the development of the Schooley peneplain and in the period following its uplift. During a later cycle of erosion another river working headward along the softer rocks east of the Palisades and following the present course of the lower Hudson diverted the upper river near Sparkill. This was the more possible because the ancient Hudson across New Jersey must have been much retarded in lowering its channel because of the resistance afforded by the numerous ridges of trap rock through which it had to cut.

Uplift and warping of the Schooley peneplain.—In picturing to ourselves the Schooley drainage, we must of course always remember that these streams, even though some were the direct ancestors of our present rivers, were flowing at levels much above the present drainage lines; i. e., at the Schooley peneplain level. With the uplift of the Schooley peneplain in later Tertiary time, the eroding power of the streams was revived and their valleys were in time deeply cut below the peneplain surface. Since the uplift of the peneplain involved a downward tilting of the land surface to the southeast, the transverse streams which had survived adjustments during the Schooley cycle were confirmed in their inherited courses and given renewed power to deepen their channels. The streams through the Delaware Water Gap and Culvers Gap began the excavation of the present gaps. At this time, too, the streams across Scotts Mountain (p. 138) cut the existing gaps to depths 350 to 250 feet below the peneplain level, before they were dismembered by streams working on softer rocks at lower levels. The Pequest, Pohatcong and Musconetcong streams now following belts of soft rock at levels below the bottoms of these gaps may all have had a hand in these captures.

The southeast master streams and their 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 more massive rocks at the Water Gap and at Culver's Gap. The streams of Kittatinny Valley began to work out the great trough that now separates the Highlands from Kittatinny Mountain. The Musconetcong and Pohatcong rivers began the excavation of their inter-Highland valleys, and the German Valley-Greenwood Lake depression was commenced. At the same time, as already noted, the transverse streams crossing the crystalline rocks of the present Highlands,

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[1] Karl Ver Steeg: Wind Gaps and Water Gaps of the Northern Appalachians, Their Characteristics and Significance, New York Academy of Sciences, Annals Vol. XXXII, pp. 87-220, 1930.

[2] Reference is made to the wide (2 miles, more or less) flat-bottomed gaps at elevations 140 to 180 feet above tide and not to the narrow gorges cut in interglacial or postglacial time in their bottoms.

[3] Douglas Johnson, loc. cit. pp. 103-131.

the Pequannock and the Rockaway, continued with renewed vigor the difficult task of lowering their valleys through the resistant gneiss.

Development of wind gaps.—The origin of the wind gaps across Scotts Mountain has already been discussed (p. 137). Culvers Gap through Kittatinny Mountain, northwest of Branchville, is the most conspicuous gap in New Jersey not now occupied by any stream. This gap is about two-thirds of a mile across at the top, broad at the bottom and its depth below the Schooley peneplain is about 390 feet. Its bottom is 900 to 920 feet A. T., but is obstructed with glacial drift the thickness of which is unknown, so it is now impossible to state to what depth it had been cut in preglacial time.

It is evident that a large stream rivaling in size the present Delaware crossed Kittatinny ridge on the line of this gap during the Schooley cycle and for a long enough period after the Schooley uplift to cut the gap at least 390 feet below that level, and perhaps considerably deeper. It has recently been suggested by Campbell and Bascom[1] that this gap represents the former course of the Delaware River, from which it was deflected by an early ice sheet and to which it could not return after the melting of the ice. Miller (R. L.) concurs in ascribing to the Delaware a preglacial course through the gap, although he does not agree with the lower course[2] as suggested by Campbell and Bascom.

The more commonly accepted interpretation is that two master streams (the Delaware and the Culvers Gap river) maintained southeasterly superimposed courses across the Schooley peneplain, about 23 miles distant from each other; that the Water Gap stream was the larger, as shown by the greater top width of its gap as compared to that of Culvers Gap; that following the Schooley uplift, longitudinal streams deepened their valleys on the soft beds on the northwest side of Kittatinny Mountain; that one of these following the course of the present Delaware above the Water Gap or the line of Flat Brook above Wallpack Bend, finally intercepted the Culvers stream and diverted its head waters; that this did not occur during the early period of post-Schooley erosion, but after a second uplift had rejuvenated the streams in late Tertiary time. (See below).

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[1] Campbell, M. M., and Bascom, F.: Origin and Structure of the Pensauken Gravel. Amer. Jour. Science, 5th Series, Vol. 26, 1933, p. 300-319.

[2] Miller, Ralph L., Proceedings of the Pennsylvania Academy of Science, Vol. XII, 1[illegible] pp. 107-113.

History of Delaware River.—The present Delaware is beyond doubt a composite stream, different portions of which have had diverse histories. The upper section immediately above Port Jervis follows the southeast course inherited from an assumed Coastal Plain cover, but the lower course across the Highlands cannot now be identified unless the Pequannock be its beheaded remnant. From Port Jervis to the Water Gap the river follows first a longitudinal valley excavated on soft Marcellus shale, and below Wallpack Bend an adjoining lowland excavated on soft shale of the Salina group. It is believed that the excavation of these valleys was commenced during the Schooley cycle by subsequent tributaries of the streams which had inherited their courses across the hard rock of Kittatinny Mountain from the Cretaceous cover; that after the Schooley uplift these streams were rejuvenated, their valleys greatly deepened along the belts of soft rock and the upper Delaware diverted at Port Jervis by a tributary of the Culvers Gap river and that later this river was in turn captured by a tributary of the Water Gap stream.

According to this hypothesis the S-shape curve of the present river at Wallpack Bend is perhaps an inheritance of a flood-plain meander developed by the tributary on the Schooley peneplain.

Below the Water Gap as far as Bordentown the Delaware flows in general southeast across the structure of both the Paleozoic and Triassic formations. This is to be expected on the assumption of superposition from an overlapping Cretaceous cover. The gaps it has cut in the Highland ridges south of Martins Creek and in Sourland Mountain near Lambertville, where remnants of the Schooley peneplain are still preserved show that it followed essentially its present course in Schooley time, although the short southwest-northeast section between Manunka Chunk and Easton indicates a minor adjustment to the folded structure of the Paleozoic beds.

The section of the river below Bordentown follows closely the contact of the basal Cretaceous beds on the ancient crystalline floor. Since progressive removal of the Cretaceous beds causes the contact to migrate southeastward, i. e., down the dip of the overlying strata, it is highly probable that at a higher level the river flowed somewhat northwest of its present trench.

The Harrisburg Peneplain

Origin.—Continued erosion of the uplifted Schooley peneplain resulted in late Tertiary time in the development of a wide lowland on the softer rocks, at a level now represented by the broad summits 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 was not sufficient to develop well-marked plains or terraces in these valleys, 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.

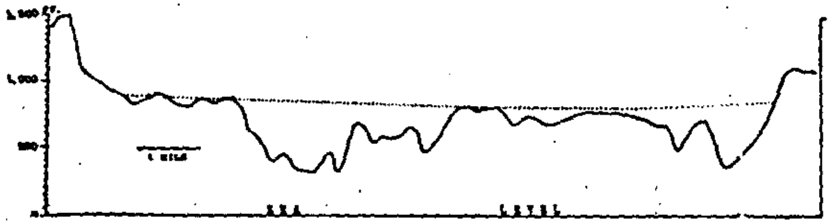

Fig. 10. Profile across Kittatinny Valley showing by dotted line the Harrisburg peneplain and existing remnants.

It is not possible to date with accuracy the erosion period which produced the Harrisburg peneplain. According to the view here adopted the Schooley level was the result of erosion which began with the uplift of the upper Cretaceous sediments in late or post-Cretaceous time, and continued well into the Tertiary. Parts of Eocene and of Miocene time were, as we have seen (p. 126), periods of sedimentation in southern New Jersey but for portions of the State and adjoining regions, which were not submerged during the deposition of these beds, erosion prevailed continuously, and even for the areas alternately emerged and submerged, the periods of emergence and erosion may have been as long or even longer than those of deposition. It may be, therefore, that the Schooley peneplain was completed by middle Miocene and the Harrisburg peneplain in late Miocene, although the evidence is by no means conclusive.

Manifestly the erosion interval indicated by the Harrisburg peneplain was only a fraction of the time needed for the Schooley, for the former was developed only on softer rocks—shale and limestone, over limited areas, whereas the Schooley level beveled hard and soft rocks alike—quartzite, granite and trap rock as well as soft shale and soluble limestone.

Dissection of the Harrisburg peneplain.—Late in Tertiary time, the land was uplifted and as a result, the streams in northern New Jersey that had reached the base level indicated by the Harrisburg peneplain recommenced their task of reducing the land to a new erosion level. This gave further opportunity for stream adjustment to geologic structure, for stream captures and for creation of wind gaps. However, judging from the elevation of the floors of existing conspicuous wind gaps in New Jersey, most of them lost their streams in the Harrisburg cycle as a result of the uplift of the Schooley peneplain.

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 dissected, and that in the harder rocks where it was absent the streams continued the work of deepening their valleys. On the softer shale 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 continued to retain nearly the altitude of the old uplifted Schooley peneplain.

Remnants of this erosion surface now carry deposits of yellow gravel called the Bridgeton, and the oldest of several Quaternary deposits found in New Jersey. They 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.[1] 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. (p. 148).

In the Coastal Plain in late Pliocene (pre-Bridgeton) time, except for occasional small areas capping isolated hills, the Beacon Hill, Cohansey and Kirkwood formations were removed from a

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[1] Patches of gravel at 220 feet near Lawrenceville and at 200 to 240 feet near Pennington perhaps mark the approximate elevation of the pre-Bridgeton surface at those points.

wide belt northwest of a line from Long Branch through Freehold, Clarksburg, Mullica Hill, Woodstown and Alloway. The region of the Clarksburg Hills and Mount Pleasant Hills was dissected to depths 160 to 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 formed 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 a lowland that extended, then as now, 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

Introductory statement.—The Quaternary formations of New Jersey consist of: (1) Pleistocene deposits of both glacial and nonglacial origin—the former occurring in the northern counties, the latter chiefly on the Coastal Plain; (2) recent alluvium along many streams, beach deposits and swamp accumulations. Compared to previous periods the Quaternary has been very short, the maximum estimate of its length being 1,000,000 to 1,500,000 years. Of this all but a very small part must be assigned to the Pleistocene epoch and a few thousand years only to the postglacial or Recent epoch.

THE PLEISTOCENE.

Subdivisions—In North America as in Europe, during the Pleistocene ice sheets covered thousands of square miles to a thickness of many hundreds or even thousands of feet. These glacial stages alternated with warmer interglacial stages during which the ice sheets melted far back from their southern limits or even disappeared entirely. There is evidence to show that these interglacial times were not only warmer than the glacial stages which preceded and followed, but that in some cases at least the climate was warmer than the present.

In the Mississippi Valley the following glacial and interglacial stages have been recognized, beginning with the most recent:—

Wisconsin glacial stage (including the Iowan).
Sangamon interglacial.
Illinoian glacial.

Yarmouth interglacial.
Kansan glacial.
Aftonian interglacial.
Nebraskan glacial.

Changes of sea level.—Of recent years several writers[1] have emphasized that during the glacial stages large amounts of water were abstracted from the ocean basins and locked up on the continents in the form of ice. Antevs has calculated that during the Wisconsin stage this amounted to a layer over the ocean basins 305 feet thick if maximum glaciation occurred simultaneously in the northern and southern hemispheres; and that in the earlier glacial stages it was possibly about the same. Hence he argues that the glacial stages were times of relative emergence of the continents and retreat of the shore lines. For New Jersey during the Wisconsin stage he holds that the shore line stood 80 miles east of its present position.

With the melting of the ice sheets, the water was returned to the ocean basins, and the shore line readvanced across the continent. The interglacial stages then were times of construction of marine terraces along the coast and aggrading of valleys due to the drowning of their lower courses.

Whatever weight we may give to this interpretation of events and changes of sea level during the Pleistocene, there are other factors of which we must take notice. During the Wisconsin glacial stage a series of marginal lakes accumulated in northward-draining valleys in front of the ice sheet, the former margins of which are now marked by a succession of shore lines indicating the levels at which the water surface stood at different times. Horizontal when formed (except for a slight slant of the water surfaces due to gravitational attraction of the ice sheets), these shore lines now rise at varying rates to the north and northeast, proof positive that since the maximum advance of the ice there has been a differential uplift of the continent—at least in the area marginal to and beneath the ice. Similar phenomena are found along the coast of New England and the Gulf of St. Lawrence. Because the land has risen since the melting of the Wisconsin ice, and this upward movement has been greatest where the ice was thickest, it is a fair assumption that this movement has been in the nature of an elastic recoil or isostatic readjustment in late glacial and postglacial time from the compression due to the weight of the ice.

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[1] Daly, Antevs and others.

We have, therefore, opposite tendencies; on the one hand subsiding sea level and a retreating shore line because of transfer of ocean waters from the basins to the continents, on the other a subsiding continent beneath and marginal to the ice sheet. If these agencies were simultaneous in operation, they might exactly counterbalance each other. However, lowering of sea level by transfer of water must have proceeded "pari passu" with the growth of the ice sheets, and reached a maximum with their greatest extension. Moreover these effects must have been world wide, affecting all shores alike. On the other hand subsidence of the land beneath the weight of the ice could only begin after the ice had accumulated to a considerable thickness and would reach a maximum only after considerable lag. Moreover it could affect only the parts of continents covered by ice sheets and a marginal area. The period of ice growth and maximum ice extension was therefore a time of sinking sea level more or less counterbalanced toward the end by subsidence of the crust beneath the weight of the ice cap in glaciated and marginal regions. The period of ice melting on the contrary was a time of advancing shore lines due to rising sea level and continued sinking of the land. Later, however, as the ice margin retreated and the weight of the ice cap over its entire extent became less, the rising land would tend to counterbalance the effect of the melting ice.

Valley trains.—Valleys which drained south from the ice sheet were occupied by rivers flooded in summer with melt water and heavily overloaded with debris from the ice. Their valley bottoms were aggraded as they dropped part of their load and built steeper gradients in an effort to carry the load supplied them. This process began as soon as the ice entered the upper limits of a southward-draining valley, and continued at varying rates of speed during its growth, maximum extension and retreat. The glacial stage was, therefore, not only a time of stream erosion along the lower courses, where the retreating coastline had increased the stream gradients, but it was equally a period of stream aggradation in areas marginal to the ice sheet. We have, therefore, the following phenomena:—

Glacial stages.—Accumulation and extension of ice sheets. Sinking sea level. Extension of rivers across the uncovered ocean floor. Stream erosion if the stream gradients are increased thereby. Aggradation of the upper courses of rivers draining the ice sheet by formation of glacial valley trains. Ultimately a subsidence of the land mass beneath the ice cap and a slow advance of the ocean on the land if the subsiding area included lands marginal to the sea.

Withdrawal and disappearance of ice sheets.—Rise of ocean level by return of glacial waters. Continued sinking of land until much of ice had melted but at a diminishing rate. Formation of shorelines at levels above the present coast line. Continued deposition of glacial valley trains until the ice had disappeared from southward-flowing stream basins. Regrading of valley trains and cutting of river terraces due to lesser loads.

Interglacial or postglacial stages.—Disappearance of glacial ice caps. Ocean basins full. Rise of land due to disappearance of ice. Differential elevation of earlier-formed shore lines. Erosion or aggradation along streams according to local conditions of load and gradient.

With the above principles in mind, we now turn to the events of the Pleistocene as they have been interpreted in New Jersey. The Pleistocene deposits are in part non-glacial and in part glacial. We shall consider them in that order.

Non-Glacial Formations.

Materials.—The non-glacial deposits consist of gravel, sand and some clay, deposited chiefly by rivers but partly in estuaries. This material was not primarily derived from the ice sheets, although perhaps it contains a minor contribution from this source. In time these formations are referable chiefly to the interglacial stages, although during glacial times, non-glacial deposits may have been made by streams which lay wholly beyond the region covered by the ice.

Three formations of this character 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 south Jersey, 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 relative elevation of land and sea 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 submergence was so great as to have depressed below sea level all the region in which these beds are now found. The relation of the three stages of glaciation and the three stages of deposition is not wholly clear as will be seen in the following pages.

Bridgeton deposition (Qbt).—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 carried material derived from an early glacial ice sheet either directly or by erosion of an early drift 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.

The Bridgeton formation is essentially gravel and sand, with a maximum thickness of 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 boulders are so large and of such a character, that it seems scarcely possible they could 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. 189). It is comparable in a general way to the Sunderland of Maryland, although the limits of the two may not be the same, and somewhat diverse views of origin are held by workers in the respective fields.[1]

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.

A broad plain of erosion was developed between Raritan Bay on the northeast and Salem on the southwest. This plain was about 20 miles wide at New Brunswick, 12 miles wide at Monmouth Junction, 15 to 20 miles wide between Trenton and Philadelphia, 10 miles at Chester, 20 at Salem. Southeast of this broad valley lay the main divide of South Jersey, along the line connecting Atlantic Highlands, Mount Pleasant, Clarksburg and Berlin. Beyond the divide, the streams flowing directly to the Atlantic, also developed broad valleys during this period, and the tributary streams entering this valley from the northeast widened their valleys to accordant levels. As a result of this erosion whatever of the Bridgeton had been deposited on the Triassic area, and much of that on the Cretaceous beds, was removed and these older formations themselves worn down to the new base level over wide areas.

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 of 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 gravel deposited in the succeeding stage.

In the Coastal Plain region there were some minor elevations—erosion remnants,—above the erosion level, such as Mount Holly, Mount Laurel, Arneys Mount, Disbrow Hill, and the Browntown hills, the highest of which rose more than 100 feet above the plain of erosion which had been thus formed.

Most of the material removed during this epoch was carried to the sea, but subordinately, especially during its later stages, some of it was deposited in valleys on the 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 deposition of the next formation.

The erosion surface developed in this post-Bridgeto[illegible] (pre-Pen-

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[1] For further discussion of this formation and the problems of its distribution and origin, the reader is referred to New Jersey Geol. Survey, Final Repor[illegible]ries, Vol. VIII, pp. 12-66.

sauken) time has commonly been called the Somerville peneplain. It represents a lower level of denudation than the earlier Harrisburg peneplain. Most of the erosion separating the two 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 (Qps).—After the post-Bridgeton stage of erosion, described above, there was a period characterized preeminently 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 their valleys. Deposition took place 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 were made in the State at this time. The resultant formation has been called the Pensauken.

During maximum submergence, as in Bridgeton time, it is probable 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 elevations as the Bridgeton it is inferred that the Pensauken submergence was not so great as the Bridgeton, 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 elevation, although there are many facts that point to this conclusion. The sand and smaller pebbles are chiefly quartz, but pebbles and cobbles of shale, sandstone, quartzite and crystalline rocks from the Triassic, Paleozoic, and pre-Cambrian formations are widely distributed. In addition there are chert, water-worn ironstone pebbles and varying amounts of glauconite which with much of the quartz came from the erosion of the older Coastal Plain beds. There is considerable local variation in size and kind of materials, as is to be expected. The deposit is commonly arkosic where northerly derived material is present, and glauconitic where the bulk of the material came from the Coastal Plain.

The original maximum thickness may have been as much as 150 feet along the axis of the broad depression in which it was mainly deposited, but toward the margins it was much less. The average thickness of the formation, as it now exists, varies in different localities from 10 to 20 feet in some regions to 40 or 60 feet in others.

In general the Pensauken much resembles the Bridgeton and frequently cannot be distinguished from it on lithologic grounds. In other localities there are significant differences in composition.[1] 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, thus smoothing over all but the greater inequalities of surface on the lower parts of the Somerville peneplain. 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.

Glacial Formations.

Types.—Under this head are included not only the material deposited directly by the ice sheet, but also the material deposited by the melt water from the ice. Some of this was deposited in immediate proximity to the ice, and some along the course of streams many miles south of the ice margin, but nevertheless composed principally of material which had been transported by the glaciers. Material deposited directly by the ice is in general a tough, stony clay, unassorted, heterogeneous in size and kind. That deposited by the glacial waters is waterworn, more or less assorted in size and deposited in layers. The former is called *till:* the latter is usually gravel, sand, silt or clay.

In New Jersey the glacial deposits are now believed to belong to three widely separated epochs, or stages, Jerseyan (oldest), Illinoian, and Wisconsin (youngest). These glacial stages are believed to have been separated by warmer periods during which the ice retreated far beyond the boundaries of the State.

Jerseyan glacial stage.—In 1892 Salisbury announced the identification in New Jersey of a very ancient sheet of glacial drift, ly-

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[1] R. D. Salisbury and G. N. Knapp. The Quaternary Formations of Southern New Jersey, Geol. Surv. of N. J., Vol. VIII, Final Report Series, (1917) p. 65.

ing south of the great terminal moraine formed by the Wisconsin ice sheet. In subsequent years he and his associates[1] mapped and described this deposit. From the first its great age compared to the Wisconsin drift was recognized but because of doubt as to its correct correlation with several old drifts of the Mississippi Valley, it was named Jerseyan. While not all the areas first included by Salisbury under this term are now regarded of equal age, his main conclusion has never been successfully challenged that early in Quaternary time northern New Jersey was invaded by an ice sheet that advanced approximately to latitude 40° 35′N. (Fig. 5). In Delaware Valley it reached a point below Riegelsville where obscure glacial scratches 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.

Areas of Jerseyan drift occur in railroad cuts just west of High Bridge, east of Pattenburg, west of Washington, at various points along the road skirting the southwest face of the trap ridge and along the Somerville-Pluckemin road north and northwest of Somerville, near Drea Hook south of White House Station, and at numerous localities between White House and North Branch.

Cushetunk Mountain apparently stood as a barrier forming a reentrant 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 later Wisconsin ice sheet, Jerseyan drift not having been found there south of the terminal moraine of Wisconsin age.

The ice sheet, particularly near its margin, was 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, as north of Raritan, the ice overrode beds of gravel which resemble the Pensauken (or Bridgeton) without disturbing them and covered them with drift, but for the most part it did not reach those portions of the Triassic lowland covered by this gravel.

The Jerseyan drift now occurs in discontinuous patches south of the later Wisconsin terminal moraine to a maximum distance of 23 or 24 miles. In the Highlands it is found on the flat-topped remnants of the Schooley peneplain, locally at elevations greater than that of the moraine further north, while on the Triassic

(Piedmont) plain it caps isolated and somewhat flat-topped divides in relations that indicate prolonged erosion since its deposition. It is everywhere characterized by great oxidation and leaching, and by the disintegration of large boulders of gneiss and granite deep within its mass, which must have been in a firm condition when transported by the ice to their present position.[1]

The Jerseyan drift ends indefinitely and in scattered boulders, 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.

Illinoian drift.—In the earlier reports of the State Survey 1891-1914, only two drift sheets were recognized, the Jerseyan of great antiquity and the Wisconsin of late Quaternary time. Even from the beginning, however, it was seen that not all the glacial drift south of the Wisconsin moraine, presented the same evidence of great age. Some of it is due to temporary advances of the Wisconsin ice sheet beyond the moraine and is indubitably of Wisconsin age. Some of it was deposited by Wisconsin flood waters as sand and gravel, miles south of the moraine (valley trains and over-wash plains). Disregarding this material which is a part of the Wisconsin drift, it is nevertheless true that the drift older than the Wisconsin is not all of the same age. Whereas in some exposures it is leached and oxidized and large granite boulders completely disintegrated to depths of 20 or 30 feet, in other localities limestone pebbles have been completely removed only to depths of 12 feet or less. In some regions, as on the Triassic shale between White House and Somerville, it caps hills and divides beneath which streams have sunk their valleys up to 100 feet, whereas in other areas it lies on rock surfaces eroded nearly to the depth of the present drainage.

Because of these and other differences, it is now generally agreed that these fresher phases must no longer be classed as Jerseyan, but are more probably Illinoian, and are much younger than the Jerseyan although older than the Wisconsin.

According to Leverett,[2] to whom we are chiefly indebted for this conclusion, the drift in New Jersey which seems referable to the

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[1] R. D. Salisbury, Geol. Surv. of N. J., Annual Report of the State Geolog[illegible]891 (1892), p. 102, and following volumes.

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[1] R. D. Salisbury, Extra-morainic Drift. New Jersey Geol. Surv., Annual Report State Geologist for 1893 (1894) pp. 76 & et seq. R. D. Salisbury, Glacial Geology, New Jersey Geol. Surv., Vol. 5, Final Report Series, pp. 751-782, 1902.

[2] Frank Leverett, Glacial deposits outside the terminal moraine in Pennsylvania, Penna. Topog. Geol. Surv., Bull. G-7 (1934) p. 33.

Illinoian stage borders the Wisconsin sheet in a narrow zone between Dover and Hackettstown and covers much of the lowland areas on both sides of Schooley Mountain. In the Delaware Valley it extends as far as Riegelsville. In the Passaic Valley large masses of drift at Bernardsville and Basking Ridge attain a thickness of 50 to 100 feet and are regarded by Leverett as Illinoian in age, although in many respects they show evidence of great age. MacClintock has recently classed them as Jerseyan, on the basis of a careful statistical study of the number of weathered boulders.[1]

The Illinoian drift is very largely clayey till, but in some localities, southeast of Phillipsburg and 3 miles south of Dover, large masses of gravel and sand occur and extensive pits have been opened.

Along several rivers which lead away from the Wisconsin moraine there are gravel trains deposited by the flood waters during the melting of the Wisconsin ice sheet. Nothing comparable to these has been observed along the streams draining the areas covered by either the Illinoian or the Jerseyan ice sheets. In places on the Delaware pebbly material is present at levels considerably higher than the Wisconsin gravel train, notably from Raven Rock, elevation 200 feet, (140 above the river) to Wilburtha, at progressively lower levels. Salisbury was inclined to correlate this material with the Pensauken, but so far as available information goes it may represent a remnant of the Jerseyan valley train.

The North and South Branches of the Raritan River are in places bordered by clayey gravel deposits locally in the form of terraces. Since the head waters of these streams both drain the region covered by the Illinoian ice, at first thought it seems that these gravels represent outwash deposits from the Illinoian drift, particularly as they occur at a higher level than the Wisconsin terraces at localities (Weston to Bound Brook) where both occur. Salisbury's final conclusion that they had been deposited by the present streams long after the earlier (Jerseyan) glacier had left the region, and that they had been derived in part by erosion of the earlier ice sheet after the valleys had been excavated essentially to their present level, was based on his assumption that there was only one earlier drift sheet, the Jerseyan. The writer recalls no essential reason why these deposits may not be connected with the closing stages of the Illinoian.

Relations of the Bridgeton and Pensauken formations to the glacial stages.—Both the Bridgeton and the Pensauken formations contain materials of such size and in such locations as to imply the aid of floating ice in their accumulation. Moreover, north of Raritan are two hills in which yellowish sand greatly resembling the Pensauken underlies a stony clay which in many respects closely resembles the Jerseyan drift of that neighborhood. On the strength of this evidence the Pensauken has heretofore been connected with the Jerseyan drift and the Bridgeton with a still earlier ice sheet, not recognized in New Jersey. The great erosion to which both the Pensauken and the Jerseyan have been subjected lent weight to this correlation.

However, the recent discovery by Berry and Hawkins[1] of a flora in the Pensauken in Middlesex County, which indicates a climate somewhat more genial than the present, apparently negatives its reference to a glacial stage. Moreover, according to the glacial-control hypothesis of Antevs and others, glacial stages are times of sinking sea level and land erosion (except along valleys draining melting ice sheets), while interglacial stages are times of submergence of continental borders, formation of marine sediments, and aggradation of stream valleys. The weight of evidence at present, therefore, favors the interpretation that the Pensauken and probably the Bridgeton are preglacial or interglacial rather than glacial. The occurrence near Raritan of Jerseyan[2] till on Pensauken (?) sand is not in conflict with this hypothesis.

If these identifications are correct, and all things considered they seem most probable, then the Pensauken must be referred to

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[1] MacClintock, Paul. Bulletin Geol. Society of America, Vol. 51, pp. 103-113, January 1940. MacClintock has determined that if the amount of weathering of gneiss stones in the Wisconsin drift is represented by the figure 42, that of the Illinois drift in New Jersey is 64, and the Jerseyan (Kansan) is 75.

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[1] Edward W. Berry and A. C. Hawkins—Flora of the Pensauken formation. Geol. Soc. Am. Bull. Vol. 46 (1935) pp. 245-252.

[2] Salisbury, who first described this deposit, stated in 1894: "The drift at this point does not give any distinctive evidence of having originated at the hands of glacial ice directly. A single piece of glacially-striated shale, however, was found," (Ann. Rpt. State Geol. 1893, p. 83). In 1902 (Final Rpt. Series State Geol. N. J., Vol. 5, p. 758) he said: ". . . the hill just north of Raritan where the drift is somewhat unlike that at most other points and is very likely not of glacier origin . . ." Again in 1917 he wrote: (N. J. Geol. Surv., Final Rpt. Series State Geol. Vol. 8, p. 78.) "In some places, as at Raritan, material which has somewhat the appearance of old glacial drift overlies typical Pensauken gravel and sand."

From these quotations it is evident that this careful student of these formations was not altogether certain of their correct identification.

the pre-Jerseyan (pre-Kansan) interglacial stage and the Bridgeton to a still earlier one.[1]

Post-Jerseyan and post-Pensauken erosion.—Both the Jerseyan and the Pensauken formations have been greatly eroded since their deposition. 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. The distribution of the Jerseyan drift in this area is such as to compel the conclusion that the isolation of the drift-covered hills in the region between Oldwick (formerly New Germantown) on the north and Readington on the south, and from a point two miles west of White House on the west and Somerville on the east, took place after the drift was deposited and that the surface on which it rested is now represented by elevations in general not lower than 200 to 225 feet. It is possible that narrow valleys may have existed below this level, but certainly no considerable areas. Rockaway Creek, Lamington River and the North Branch of the Raritan, streams which drain this region, now all flow at levels less than 100 feet. 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.[2]

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 Triassic shale once covered by the Pensauken, but now bare, which vastly exceed in extent the Pensauken remnants.

Not only has the Pensauken been removed, but the rock beneath has been so dissected by erosion that few remnants of the Somerville peneplain 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.

Although 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 after 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.

On the basis of weathering and leaching the Jerseyan and Illinoian glacial stages are believed to have been separated by a considerable lapse of time, but it is not possible to differentiate with any certainty post-Jerseyan from post-Illinoian erosion. In the post-Jerseyan (post-Kansan) interglacial stage 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. In part it may have been connected with the melting of the

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[1] Of recent years several papers have been published on other phases of these problems. Persons wishing to pursue the subject further are referred to the following authors:

Paul MacClintock and Horace G. Richards, Correlation of Late Pleistocene marine and glacial deposits of New Jersey and New York, Geol. Soc. America Bull. Vol. 47, pp. 289-338.

Marius Campbell and Florence Bascom, Origin and Structure of the Pensauken gravel, Am. Jour. Sci., 5th ser., Vol. 26 (1933), pp. 300-318.

Lester Strock, A study of the Pensauken Formation, Wagner Free Inst. Sci., Bull. No. 4 (1929) pp. 3-10.

Paul MacClintock Weathering of the Jerseyan Till. Bull. of the Geol. Soc. of America, Vol. 51, pp. 103-116, January 1, 1940.

[2] Sali[illegible], Ann. Rpt. Geol. Surv., N. J., 1893, p. 87.

Illinoian ice sheet. 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.

CAPE MAY DEPOSITION.

Coastal subsidence.—After the long period of erosion indicated by the removal of the Pensauken gravel (p. 156), there followed an epoch when deposition again became important. The southern part of the State seems to have stood a few feet (30 to 50) lower, or sea level higher, than now. This favored the construction of marine terraces along the coast, of deltas in the drowned sections of valleys and the gradual headward aggradation of stream valleys. If this submergence along the coast was accompanied by crustal warping so that the stream gradients were diminished or by an oversupply of sediment, valley filling proceeded at an accelerated rate.

We find today deposits of sands and gravels at low levels about the coast and in the lower ends of valleys and similar deposits extend far up the valleys to elevations of 140 or 150 feet along streams which have their source in the higher parts of the Coastal Plain. These deposits are called the Cape May formation, since all the material of that peninsula, so far as exposed, belongs to this epoch.

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, are referred to the Cape May. 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 earlier deposits.

Along the coast and lower Delaware River these terraces of Cape May age 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 greater elevations than 40 feet and in some localities are as high as the Pensauken or Bridgeton.

The formation is described by Salisbury[1] as follows:

"*Along the coast.*—According to the conception outlined, the Cape May formation forms a nearly continuous border about the southern part of the State, from Raritan Bay to Trenton, and in addition, extends up the valleys of nearly all streams which come down to this border. How much of the formation about the coast is marine, and how much subaerial (fluvial, pluvial, etc.), is not determined. If the sea level stood 30 to 50 feet higher than now, it does not appear to have stood there, or at any other one level, long for sea cliffs of distinct and unequivocal character are essentially wanting. On the other hand, the Cape May deposits about the coast are in places distinctly terraciform, and consistent with the conception of marine origin. Distinct sea cliffs at their inland border are, however, generally wanting. In the coastal phase of the formation, the materials are not so mixed as in its valley phase. In the former situation, the sand and gravel in places at least resemble shore deposits, rather than deposits by streams and rains.

"*Topography.*—Barring interruptions by subsequent erosion, the valley deposits, now in the form of terraces, are continuous with the coastal deposits ,and the contemporaneity of the two is not open to question. At the coast, the level of the valley terraces is the same as that of the coastal phase of the formation; but they rise up-stream at gradients which vary somewhat from valley to valley, being less in the lower lands and greater in the higher. In other words, the gradient of the terraces is in keeping, in a general way, with the present gradients of the streams.

"It is clear, therefore, that the upper limit of the formation is not defined by a contour line. About the coast it is mostly below 50 feet; but in some of the valleys it runs up to heights three times as great, and in a few places even higher. The terraces are well defined in some places and ill defined in others. In some places they are composed wholly of Cape May material, while in others, material of this age covers, as with a veneer, a foundation of older material.

"*Comparison with the Pensauken.*—Where the Cape May terraces rise up-stream to the Pensauken level, as is the case in some places, it is difficult to distinguish the two formations on the basis of topography; but if good sections are available, the distinction between the two commonly is not difficult on the basis of composition and texture. The material of the younger formation is less compact and less coated with iron rust, and betrays in various ways not easily designated, its lesser age. There is a marked absence of soft decomposed material, such as is often present in

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[1] R. D. Salisbury, Quaternary Formations of Southern New Jersey, N. J. Geol. Surv., Final Rpt. State Geol., Vol. 8, (1917) p. 164.

the older gravel, but which would naturally have been ground up in the reworking of the material in Cape May time. The material of the terraces in the valleys is unlike that of the coast in being much more mixed, much less well assorted, and much less clean. It covers broad areas in the larger valleys, and narrower areas in the smaller ones."

Age.—Until recently the Cape May has been believed to correspond in age with the valley trains of the Wisconsin ice sheet. The estuarine terraces along Delaware Bay seemed to be continuous with those along Delaware River and these, in turn, to 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 the Delaware above the city and the Cape May formation (Qcm) below.

In recent years, however, cogent reasons have been adduced by several students of these problems which cast doubt on this correlation in spite of the strong evidence in its favor. Antevs (loc. cit.) has pointed out that the Wisconsin ice age was a period of low sea level, (305 feet less than now) and of withdrawal of the coast line 80 miles east of its present position. Hence that it would have been impossible for marine terraces of glacial age to have formed in their present positions along the New Jersey coast line. Also much information has accumulated regarding fossils in the Cape May, and Richards[1] has recently described a large mild-water fauna of 104 species from the Cape May formation: "The fossils from the deeper excavations suggest a warmer climate than that existing today; those in the upper (younger) part indicate a climate similar to that of today. This is consistent with the view that the Cape May formation was laid down during an interglacial stage, and the presence of the colder-water fossils in the upper part may indicate that the climate was becoming colder, due to approaching glaciation" (MacClintock and Richards loc. cit. p. 307).

It seems necessary, therefore, to regard the greater part of what has heretofore been classed as Cape May, not as a glacial and postglacial deposit contemporaneous with the maximum advance and withdrawal of the Wisconsin ice sheet but as belonging to the warmer pre-Wisconsin interglacial stage.

Sand and gravel terraces along the Delaware River head in the terminal moraine of the Wisconsin glacial stage and can be traced

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[1] H. G. Richards. Marine fossils from New Jersey indicating a mild interglacial [illegible]. Am. Phil. Soc. Pr., Vol. 72 (1933), p. 205.

without serious interruption to Trenton, and farther south. Moreover, below Trenton these glacial terraces apparently merge with those which are continuous with the marine terraces along Delaware Bay. The glacially derived material is progressively less below Trenton, but it has been found at intervals as far south as Penns Grove, although the greater bulk of the material of the terraces is gravel and sand characteristic of the Coastal Plain streams, which had no glacial connections and no access to northerly derived material.

These facts have led MacClintock and Richards[1] to assume that after deposition in pre-Wisconsin interglacial time, the Cape May formation was partially removed from the Delaware Valley below Trenton before the Wisconsin ice sheet reached its maximum advance. The river was bordered by terraces of typical Cape May gravel, which were more or less cut into by the floods arising from the melting ice. Coastal plain material was thus added to that brought down by the Delaware and the intermingling of material which we now find resulted. According to this hypothesis the terraces now bordering the Delaware below Trenton are composed of Cape May material (interglacial) more or less reworked and redeposited in late Wisconsin time, plus a diminishing amount of glacial material derived from the Wisconsin ice sheet. Post-Wisconsin erosion has removed a large part of the glacial and preglacial filling and developed the present terraces.

For further discussion of post-Cape May erosion see below (p. 169).

WISCONSIN GLACIAL STAGE.

The Wisconsin drift.—After the earlier glacial and the Cape May interglacial epochs, conditions changed and an ice sheet again overspread Canada, and a part of the United States. including northern New Jersey. The fact and extent of this invasion are proved by the thick mantle of glacial debris which now covers the northern counties. These deposits have been called the Wisconsin drift, from their great development in Wisconsin where they were studied many years ago.

The southern extension of the ice during this stage is marked by a great terminal moraine (Qtm) which crosses the State (Fig. 5) in a curved line through Perth Amboy, Plainfield, Summit, Morristown, Dover, Hackettstown, and Belvidere. South of the moraine narrow valley trains of glacial gravels characterize some

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[1] Paul MacClintock and Horace G. Richard. loc. cit. p. 308.

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 boulders, some of which have a diameter of several feet. Most of the recognizable fragments are like the underlying bed rock 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. 181). The sequence of events leading up to the formation of these deposits and the withdrawal of this ice sheet will now be sketched.

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. 5), 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 proved by the moraine itself. Antevs estimates this to be about 2000 years.[1]

In its advance it completely buried or carried away whatever of the older drift sheets remained in the region covered by it, for nowhere north of the moraine has the Jerseyan or Illinoian drift been recognized in New Jersey 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. Some 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 the 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. 5). The lowland belts, like Kittatinny Valley and the Triassic area, were occupied by great lobes of ice from the axis 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 places continued advance of the ice sheet filled the valleys and obliterated the lakes, but with the retreat of the ice these lakes came into temporary existence again unless their valleys were left completely filled by drift. 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

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[1] Ernest Antevs—The Last Glaciation—Amer. Geog. Soc. Research Series No. 17, p. 107.

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 the 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.

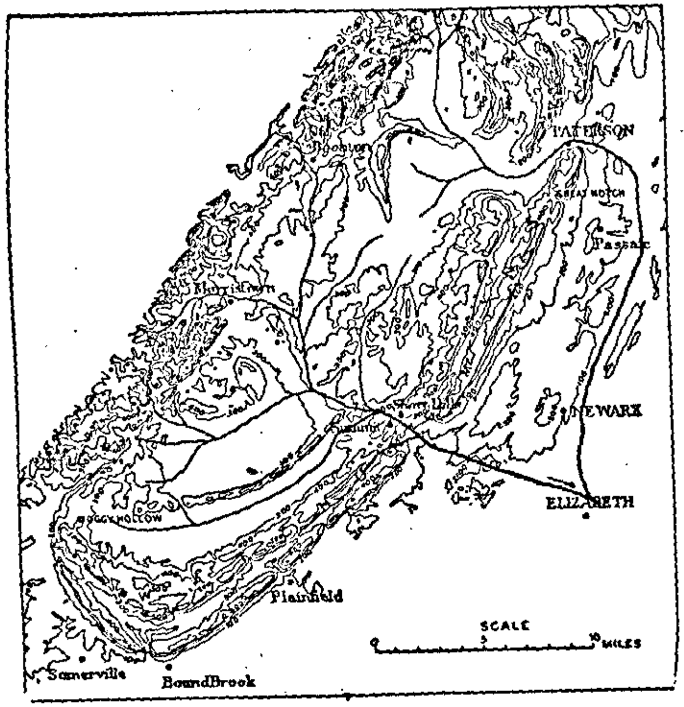

Fig. 11. Diagram showing the supposed course of the drainage in the Passaic basin previous to the last glacial invasion.

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 preglacial and probably also in interglacial time, there were gaps, now filled with drift, in First and Second Watchung Mountains at Millburn and Short Hills, deep enough to drain the southern half of the basin, and formerly occupied by [illegible] 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 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.

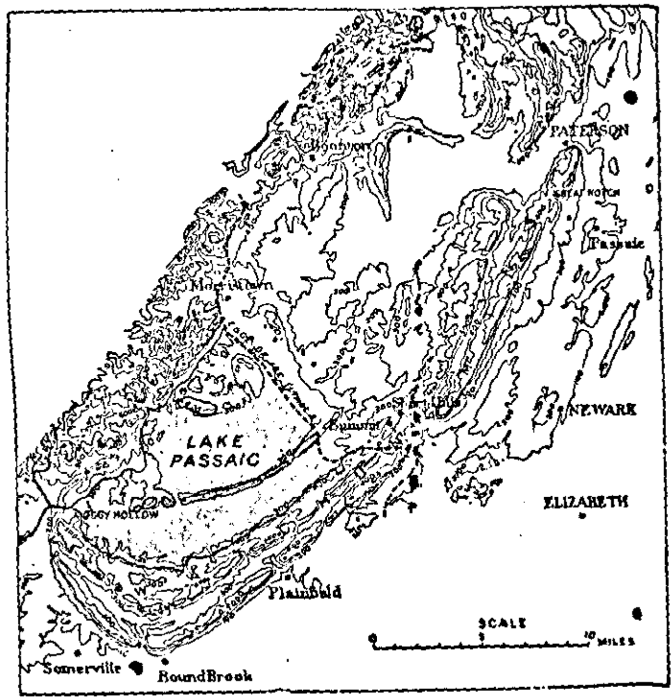

Fig. 12. Stage of maximum advance of the glacier.
The edge of the ice was at the position of the terminal moraine and the glacier filled the Short Hills gap. The outer basin of Lake Passaic was occupied by a lake with its outlet to the west at Moggy Hollow.

The lake, therefore, increased in area and maintained essentially the same level as the ice withdrew (Figs. 13, 14).

At the time of its greatest extent, Lake Passaic was about 30 miles long, 8 to 10 miles wide and had a maximum depth of 240 feet. Over wide areas it was 160 to 200 feet deep.

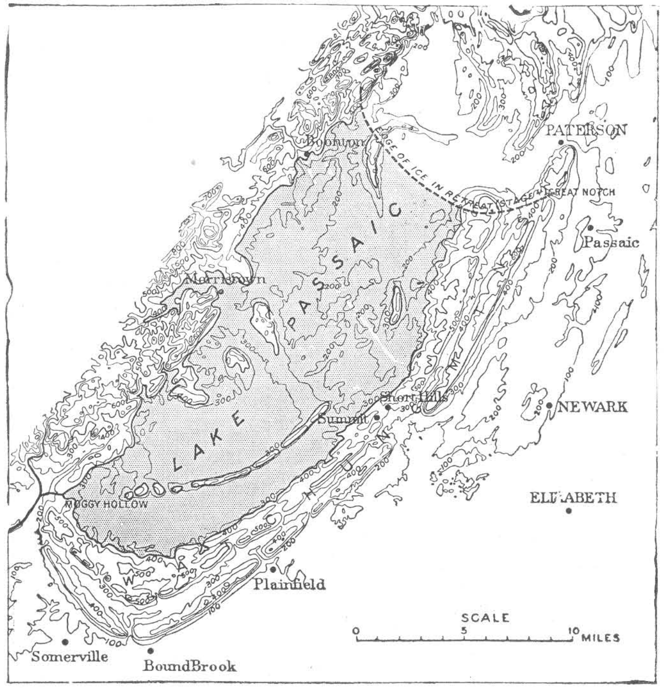

Fig. 13. Expanded stage of Lake Passaic.
The retreat of the ice had left the Short Hills gap filled with drift.

Faint wave-cut terraces and cliffs, small wave-built spits, bars, and terraces of water-worn gravel, and large conspicuous glacial deltas locate the former shore line and demonstrate the existence of this lake. The more conspicuous of these are shown upon the geological map.

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 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.

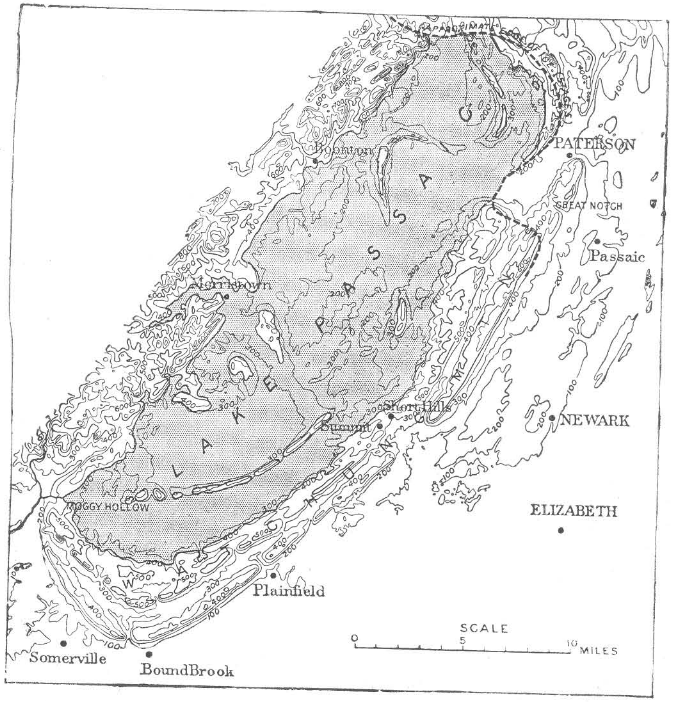

Fig. 14. Maximum stage of Lake Passaic.
All outlets except that at Moggy Hollow were either blocked by ice or filled with drift.

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 essentially to its present level. North of Long Hill a lake existed for a longer 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 postglacial origin.

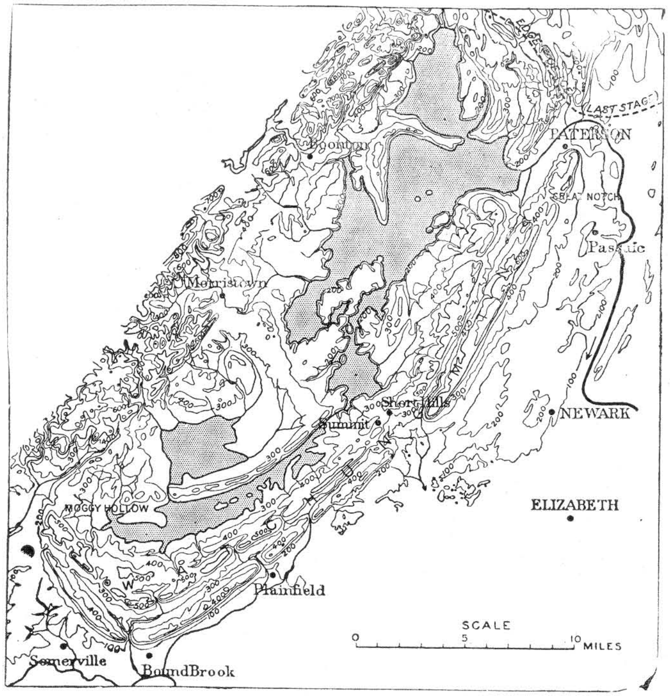

Fig. 15. Late stage of the lake, when the retreat of the ice had freed the Little Falls-Paterson outlet.
Shallow bodies of water still occupied the lower portions of the basin.

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 comparatively 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 debris 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 from the moraine near Belvidere to Trenton, where it merges into estuarine deposits of somewhat different origin. (p. 160).

The withdrawal of the ice was not at a uniform rate but was accompanied by pauses in its retreat during which recessional moraines of more or less pronounced character were formed. The ice front made an extended pause 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. The dense forest growth and paucity of roads obscure its position on the back slope of Kittatinny Mountain. 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.

From a detailed study of the laminated clay deposits near Mountain View, Little Ferry and Hackensack, Antevs (loc. cit. p. 109) concluded that 2500 to 3000 years were consumed in the retreat of the ice sheet from the terminal moraine to Haverstraw, New York. This includes the time necessary to construct the recessional moraines mentioned above. The total for building the Wisconsin moraine and the retreat of the ice sheet to latitude 49°N. in Canada is estimated by Antevs at 28,000 to 29,000 years. If the period of ice advance was of equal duration about 56,000 years must be allowed for this portion of the Wisconsin glacial epoch.

Post-Cape May emergence.—Explicit evidence of emergence of the Coastal Plain since Cape May time is furnished by the fact that the marine terraces of this age now stand 20 to 40 feet above present sea level. But this figure is not a measure of the change of level which actually occurred, because it does not take account of later changes of level, particularly of subsidence since. There is evidence that the Cape May deposits have been eroded far below present sea level, which could only have been accomplished if the region south of Sandy Hook had stood higher than now. Borings across Raritan Bay north of Conaskonck Point near Keyport show that a channel was cut in the Cape May and underlying earlier formations to a depth of 170 feet in post-Cape May time,[1] which indicates that in this region the land stood at least that amount higher (or the ocean lower) than at present.

It has already been pointed out (p. 22) that a relatively young channel of the Hudson River extends across the submerged Coastal Plain beyond Sandy Hook for a distance of 95 miles. It has a maximum depth of 290 feet below sea level and 60 to 120 feet below the general level of the adjacent ocean floor, and causes a long river-like re-entrant of the 40-fathom line. Antevs[2] holds that during the Wisconsin glacial stage the coast line lay near the mouth of this channel at about 250-305 feet below present sea level and that this channel was the result of post-Cape May (Wisconsin) erosion.

Post-Wisconsin warping.—Since the withdrawal of the Wisconsin ice sheet there has been in northern New Jersey a tilting of the land, apart from relative changes in sea level. This was part of a great differential uplift which affected northeastern United States and Canada. Explicit evidence of this is found in New Jersey 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. Beyond the confines of the State this movement is shown by the numerous abandoned marine shore lines which border New England and the St. Lawrence region and ascend in a northerly direction.

This differential movement of the earth's crust, due probably to melting of the ice sheet, was accompanied in the southern half of the State by a rise of sea level, advance of the shore line and submergence of a large strip of the Coastal Plain, due primarily to the return of glacial waters to the ocean basins. This resulted in the submergence of the marine shore lines which had been formed across the Coastal Plain, south of Long Island, during the previous glacial stage and which can now be traced by soundings across the continental shelf. The present submergence, however, does not now equal that which prevailed during Cape May time, for the Cape May terraces still stand higher than when formed. Moreover, the New Jersey streams emptying directly into the Atlantic are all bordered in their lower courses by tidal marshes and the tide extends far up their lower reaches, to Trenton in the Delaware, to New Brunswick in the Raritan and to Albany in the Hudson, all evidence that the land stands somewhat lower now than formerly. The same thing is true of the Coastal Plain streams from Sandy Hook to Cape May, all of them occupy valleys which were cut when the land stood higher than now, but which are drowned in their lower courses by the submergence of the seaward portion of the Coastal Plain.

At many points along the coast peat beds have formed, composed in part of non-marine water plants. These are now below sea level, an apparent indication that the upward growth of the peat beds has not kept pace with the rising sea level (sinking coast).

Is the coast of New Jersey now sinking?—A popular impression prevails that the coast of New Jersey is now subsiding at a rate of two feet a century. Many of the facts which were earlier relied on to sustain this view are now recognized to be susceptible of another interpretation. Some of them merely prove that at some places the land is lower in respect to tide level than formerly, but this may be due to earlier changes of level, or recent changes in high-tide level, because of changes in the shape of bays and the capacity of inlets. Some evidence has recently been presented which seems to indicate a very slight present subsidence of the mid-Atlantic Coast but there is no warrant for the old view that the coast of New Jersey is now subsiding at the rate of two feet per century.

Other postglacial changes.—All in all, other postglacial 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, postglacial 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 in places a considerable amount; many ravines and small valleys have been cut; and a few lakes and ponds have been drained by having their outlets deepened to the level of their bottoms; others have been silted up.

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

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[1] MacClintock and Richards, loc. cit. p. 315.

[2] Antevs, loc. cit. p. 86.

the more resistant rocks, left smooth and polished by the ice, have been so roughened that all traces of striae 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.

From time to time after severe storms have cut away the seaward face of the barrier beaches, masses of the salt-marsh turf are exposed below high-tide level on the ocean side of the barrier beaches. The occurrence of this turf at levels several feet below its position bordering the lagoons, at first sight seems to be evidence of a subsidence of the coast. Its occurrence on the *seaward* side of the beaches indicates that since its formation the beach has itself migrated westward more than its entire width and encroached upon the salt marsh. Under the weight of the beach and its sand dunes, the marsh mud and turf has been greatly compressed so that now turf and marsh mud after heavy storms may be exposed on the oceanward side, at a lower level than it had originally.

Under the combined action of winds, waves and tidal currents changes are constant along the coast, particularly in the neighborhood of the inlets which connect the lagoons or bays with the ocean. Several of these have been closed and others opened since the settlement of the State. Others have shifted their position. The southward drift of sand below Bay Head tends to build up the northern side of the inlet and shift the tidal currents against the southern point. Hence that side is cut away and the inlet shifts southward. At Barnegat Inlet the southward movement amounted to over half a mile in 50 years. A lighthouse built in 1834 was destroyed by this southerly movement; it was replaced in

1858, but the new structure in turn was threatened as early as 1886, and now (1940) has been saved temporarily from destruction by the construction of expensive protective works.[1]

THE LIFE OF THE QUATERNARY PERIOD.

Extinct animals.—Many animals now extinct, or found only in distant regions, inhabited New Jersey during glacial and early postglacial time. Chief of these, judging by the relative abundance of its remains, was the mastodon which probably frequented southern New Jersey during the Glacial epoch and followed the retreating ice sheet northward. The remains of nineteen individuals of the species have been reported from the State.[2] The most remarkable of these finds was on the farm of William Ayers between Hackettstown and Vienna, where many years ago in a small bog in the moraine six skeletons are reported to have been discovered. A good skeleton now in the Museum at Rutgers College was found near Salem. Recently a portion of a skull was found near Westfield.

The hairy mammoth (*Elephas primigenius*) was also present, but was less numerous than the mastodon. The Greenland reindeer and the Arctic walrus also frequented this region during the Pleistocene period, and remains of the Canadian elk, two species of an extinct horse, an extinct moose and a peccary have also been found.

Man.—The differentiation of man from the apes began sometime between middle Miocene and earliest Pleistocene, and a bipedal apeman (*Pithecanthropus*) lived in the East Indies in earliest Pleistocene. *Homo sapiens*, however, did not appear in Western Europe until about the close of the glacial period, but he was preceded by several earlier and more primitive species, whose remains go back to early middle Pleistocene 350,000 to 400,000[3] years ago. *Homo sapiens* seems not to have reached North America until somewhat later than his appearance in Europe, but the date of his advent is at yet undetermined. There is, however, sufficient reason for believing that he was here before the disappearance of the

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[1] Lewis M. Haupt. Ann. Rpt. State Geol. N. J. 1905, p. 46.

[2] Cook. Geology of New Jersey, 1868, p. 741. Several others have been found since Cook's report was published.

[3] This is the time given by Osborn and others, based on an allowance of 500,000 years for the time from the beginning of the Pleistocene. If, however, the estimates given below (See p. 175) are correct, the above figures must be doubled.

mastodon and the giant sloth. At Trenton, numerous chipped stones, assumed to be his handiwork, have been found in the fine sandy loam which overlies glacial gravels. Geologists are not in agreement regarding the age of this loam, some holding that it marks the closing stage of the Delaware Valley train, others regarding it as later. In either event, the implements found in it are much older than those found in the discolored soil layer immediately above, which belong to the modern Indian.

GEOLOGIC TIME.

No one can study the geologic record as revealed in the rocks themselves, or even read a summary of events in a limited area like New Jersey without being impressed with the enormous length of geologic time. Astronomy gives the student new conceptions of space; geology enlarges his conceptions of time. The more the geologic record is studied, the longer is the vista to the distant past which opens to his view.

Many estimates have been made as to the length of geologic time, but no one of them is final and none commands universal acceptance. Recent studies indicate that it has taken Niagara River 25,000 years to cut the Falls back from their original position at Lewiston to their present site, a distance of 7 miles.

But the Falls did not come into existence until the edge of the ice sheet had retreated from the line of the outermost terminal moraine far enough to permit the water of ancestral Lake Ontario to escape by an outlet lower than the Niagara escarpment. Antevs (loc. cit., p. 155) allots 29,000 years for the construction of the terminal moraine and the retreat from Long Island to Cochrane, Ontario, north of latitude 49° (p. 169). However, the advance and disappearance of the last ice sheet whether 50,000 or 100,000 years ago was an event of yesterday in geologic time.

A few years ago the conclusions of the physicists as to the rate of cooling of the earth and sun seemed to limit the geologists to 100,000,000 years as the maximum time for the formation of all sedimentary rocks. The discovery of radium and the radioactivity of certain minerals has upset all the previous calculations, and the new school of physicists is now willing to allow the geologists one to one and a half billion years. Barrell[1] a few years ago made the following estimate of geologic time:

Quaternary	1,000,000	to	1,500,000	years
Tertiary	54,000,000	"	63,500,000	"
Cretaceous	65,000,000	"	85,000,000	"
Jurassic	35,000,000	"	45,000,000	"
Triassic	35,000,000	"	45,000,000	"
Carboniferous	110,000,000	"	130,000,000	"
Devonian	50,000,000			"
Silurian	40,000,000			"
Ordovician	90,000,000	"	130,000,000	"
Cambrian	70,000,000	"	110,000,000	"
Total for Cambrian and later time	550,000,000	to	700,000,000[2]	years

An equal or greater amount of time must be allowed for the long and complex history of pre-Cambrian time (p. 61), and then perhaps we have got back only to the formation of the Franklin limestone. What lies back of that is lost in the fog of hypothesis and speculation. If, however, the above figures are kept in mind there is less difficulty in comprehending how during geologic time New Jersey has been repeatedly submerged and uplifted; how mountain ranges have again and again raised their lofty summits only to be reduced to low plains by the slow-acting agents of denudation; how in pre-Cambrian time the great orders of invertebrates were differentiated from each other; how later the invertebrates as rulers of the sea and the "lords of creation", gave place to fish, fish to amphibians, amphibians to reptiles, reptiles to mammals, and how last of all man, emerging from some unknown line of anthropoid ape in late Tertiary or earliest Quaternary time, has through many thousands of years of conflict and struggle reached his present commanding position.

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[1] J. Barrell. Bull. Geol. Soc. Amer., Vol. 28, p. 884.

[2] Future discoveries may cause radical revision of these estimates, but they are unquestionably nearer the truth than the earlier ones, which range from 40,000,000 to 100,000,000. The whole trend of geologic investigation in the last 10 to 20 years is towards the recognition of a greater rather than a lesser age for the earth.

CHAPTER VIII.

ECONOMIC GEOLOGY.

Only brief mention is here made 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 the statistics of production, were published in the Annual Report of the State Geologist for many years up to and including 1909; since that date Bulletins 5, 7, 11, 15, 26, 27, 29, 31, 32, 34, 36, 37, 40, 41, 42 and 43 on this subject have been issued. The Annual Reports of the State Geologist 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 on a small scale.

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 bodies are also known in the Franklin limestone. The ore-bearing layers of rock vary in thickness from a small fraction of an inch to 50 or more feet, the average thickness being from 4 to 20 feet. They are mainly distributed in narrow northeast-southwest belts or ranges in the gneiss. These belts 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. The ore bodies or "shoots" are the portions of the ore-bearing layers that are rich enough in magnetite to warrant mining. 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 each of these masses also "pitches" toward the northeast. They vary greatly in size. A length of

1500 feet for a single ore pod is not unusual, but lengths of 400 or 500 feet are more common. Their widths measured at right angles to their strikes vary between a few inches and 40 feet, and their breadth or "height", measured in the planes of the veins averages approximately 125 feet. In many mines at the bottom and top of the ore pods, thin stringers of ore lead to other pods lying below or above along the dip.

A few of the magnetite ores of New Jersey approach a pure magnetite in their iron content (Fe, 72%) but none quite reach it. There is always more or less hornblende or pyroxene, pyrite, and apatite mingled with the magnetite, as it is prepared for market, and consequently there is always present some silica, lime, magnesia, alumina, sulphur and phosphorus. Some ores are high in titanium. At one time or another a number of mines have placed on the market ore carrying 62% or more of iron, but this is above the average and at the present time nearly all the ore mined is magnetically cobbed or concentrated before shipment.

In recent years, active mining has been carried on at Oxford, Warren County; at Mount Hope, Wharton, Mine Hill, and Beach Glen, in Morris County. The mines at Ringwood in Passaic County have been closed for a number of years. During the last ten years (1930-1939 inclusive), the annual shipment of concentrates has averaged about 222,000 long tons and has ranged from 14,966 to 544,635 tons.

Hematite ore.—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 have been profitably mined in recent years in both New York and Pennsylvania, as well as in other states southward to the great mines at Birmingham, Alabama.

Bog ore.—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, for many years.

References.—"Iron Mines and Mining in New Jersey," by W. S. Bayley. Final Reports 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 Oron 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 ORE.

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 oxide of zinc, iron, and manganese), willemite (zinc silicate), and zincite (red oxide of zinc). Active mining operations for many years were restricted to the deposit at Franklin Furnace, but in 1913 the Ogdensburg mines were 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. They occur only in 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 ORE.

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 attention at times is found on Delaware River a few miles above the Water Gap.

The Triassic ores occur in shale and sandstone, in most cases intimately associated with some form of igneous trap rocks, and are of two general types: (1) native copper in sheets and stringers through the shale 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 shale and sandstone, as at the Griggstown mine, in Somerset County, and the Arlington (Schuyler) mine, in Hudson County. In both types of deposits 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 60 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 MINERAL RESOURCES.

CLAY.

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 form 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 clay 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 at 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 producers. The clays are of various kinds, ranging from the nearly white or steel-blue fireclay 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 arkosic. 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 fire brick. 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 the 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 have been 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 and terra-cotta clay in many p[illegible]s, 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 have been 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 have been 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 brick, 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. (out of print).

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 Piedmount Plain—and (b) the Coastal Plain.

In 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 bed rock 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.

In the Highlands.—The prominent northeast-southwest valleys in the Highlands are underlain by bed rock 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 bed rock 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 undergrounud 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.

In the Piedmont Plain.—The bed rock of the Piedmont Plain consists chiefly of the shale and sandstone 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 trap rock (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. Locally layers of vesicular trap occur in the flows which form First and Second Watchung Mountain. These layers, where present, carry much more water than the layers of dense trap.

Flowing wells of great volume have been obtained at a few places in the Piedmont belt—usually, however, not in the Triassic bed rock, 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.

In 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 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 a 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 large geological map of the State show the simple structure of the region; but for the sake of distinctness the gentle eastward slope or dip of the beds, imperceptible to the eye in the field, 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.

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. The Vincentown sand is an important water bed throughout the whole length of the Coastal Plain.

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 may 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 an exact 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 beds will contain water at a given locality until the extent of the clayey parts of these beds become better known from an increased number of borings.

Amount of ground water.—It is popularly assumed that supplies of ground water are inexhaustible. This is far from the fact. It is of course true that the annual rainfall adds to the amount of ground water, but it is also true that much of that which enters the ground is later lost by evaporation and by seepage into the surface streams. Moreover, careful observation of ground-water levels in some well fields which have been heavily pumped and of the pressure head in wells of other fields have in many instances indicated serious overdrafts. In some localities draining of the water-bearing formations is clearly indicated if excessive pumping is continued, and along the coast there has been such a diminution in the pressure head in observation wells as to raise the question as to whether there may not be grave danger of the entry of salt water into the wells.

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. Meyers. 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.

"Ground Water Supplies of the Atlantic City Region," by David G. Thompson. Reports of the Dept. of Conservation and Development, State of New Jersey. Bulletin 30, 1928.

"Surface Water Supply of New Jersey to Sept. 30, 1928," by O. W. Hartwell. Reports of the Dept. of Conservation and Development, Bulletin 33, 1929.

"Ground Water Supplies in the Vicinity of Asbury Park," by David G. Thompson. Reports of the Dept. of Conservation and Development, Bulletin 35, 1930.

"Ground Water Supplies of the Passaic River Valley, near Chatham, N. J., by David G. Thompson, Reports of the Dept. of Conservation and Development, Bulletin 38, 1932.

"Supplementary Report on the Ground Water Supplies of the Atlantic City Region," by Henry C. Barksdale, Raymond W. Sundstrom, and Maurice S. Burnstein. State Water Policy Commission, Special Report 6, 1936.

"Water Supplies from the No. 1 Sand in the Vicinity of Parlin, New Jersey," by Henry C. Barksdale. State Water Policy Commission, Special Report 7, 1937.

CEMENT ROCK.

Among the non-metallic mineral resources 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 Vulcanite and New Village, both 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 H. 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 rock of the Triassic system, which is 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; small 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. The tendency in recent years has been toward the abandonment of small plants and the concentration of the industry in a few large quarries.

Granite.—Granite and granite gneiss (the Byram and Losee gneiss) are quarried from time to time for local building purposes at a few 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. A few quarries located in Passaic, Morris, and Sussex counties have been active in recent years but not to their former extent.

Sandstone.—Practically all of the sandstone quarried in the State comes from the Triassic rock 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 a small amount is intermittently quarried.

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 were formerly quarried 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 two active local quarries. The same formation was formerly quarried extensively for crushed stone at Byram, Hunterdon County and sold under the trade name of "Byram trap." A portion of the product of the active quarries has also been crushed.

Limestone.—In addition to the cement rock and pure limestone used in the Portland cement industry large quantities of limestone have been 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 was produced from the Martinsburg formation at Lafayette and Newton, in Sussex County for many years, but at present (1940) the quarries are idle. 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 has been 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. In general, however, it is too coarsely crystalline to be used in this way.

An attractive pink variety of this stone, mottled with green and black minerals, occurs 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 have been 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 can be polished and used in part for interior decorative purposes in building.

References.—"Building Stones of New Jersey," by J. Volney Lewis. A[illegible]al 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 Phillipsurg, N. J.," by F. B. Peck. Annual Report of the State Geologist for 1904, pp. 161-185.

"The Chemical Composition of the White Crystalline Limestone 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 in eastern Ocean County, 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, 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 and Tertiary 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 few thousand tons are used annually as a base exchange medium in water-softening equipment.

The marl occurs in nearly horizontal beds 20 to 25 feet thick which reach the surface between Delaware Bay and Atlantic Highlands along a belt about 100 miles long, with an average width of 2 miles. In Monmouth County and in a portion of Burlington County, the three marl beds are separated horizontally by thick beds of sand, but further southwest the sand bed which lies between the two lower marl beds disappears and these two unite. No one of the three beds outcrops at the surface continuously, owing to a cover of later gravel and sand of varying thickness. The beds incline to the southeast at a low angle, 30 to 50 feet per mile, so that they underlie all of the State from their outcrop to the ocean, but for much of the area at so great a depth as to be inaccessible, except by deep borings.

Careful explorations undertaken in 1918-9, jointly by the U. S. Geological Survey and the State Department of Conservation and Development have shown that the average content of potash of the two lower marl beds is 6.6 per cent, and that not less than 257,000,000 short tons of potash (K_2O) is contained in those portions of the marl beds which can be mined by open-pit methods. The New Jersey greensand marl beds contain, therefore, an enormous reserve supply of potash, capable of meeting the needs of the entire country for centuries to come. The development of a potash industry based on the New Jersey greensand depends on the ability of manufacturers to devise an economic and efficient method of extracting the potash at a cost low enough to compete with other sources.

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.—Greensand marl. Annual Report of the Department of Conservation and Development, 1920, pp. 36-48.

Idem.—Report for 1919, pp. 99-104.

Idem.—Report for 1917, pp. 26-30.

"Potash in the Greensands of New Jersey," by George Rogers Mansfield. Reports of the Department of Conservation and Development. Bulletin 23, 1923.

"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 of various kinds.

For many years two plants were operated, one on the Pequest Meadows near Great Meadows station and the other northeast of Newton near Warbasse. Of recent years the former has been abandoned, but the latter has continued as one of the largest producers in the country, and small deposits have been worked near Stanhope, Andover, Middletown (Monmouth Co.) and Lawrenceville. Several types of product are placed on the market, including humus tankage which is used chiefly in making chemical fertilizer mixtures; prepared humus which is sold as a substitute for manure; and a commercial culture in peat of the bacteria necessary for the proper inoculation of clover, alfalfa, soy beans, etc. It is claimed that this medium has advantages over the gelatine or agar cultures owing to its granular nature and its retention of the moisture necessary for the existance of the bacteria with which it has been inoculated.

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. (Out of print).

MINERAL PAINT.

Some Triassic red shale of the Brunswick formation has been 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. Deposits near Phillipsburg in Warren County, were formerly worked a little, but there is now little or no native 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 manufacturer 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 meado[illegible] in the northern part of the State. Some of this has been dug for use in the manufacture of polishing powders, concrete, dynamite, 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 magetite 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 pegmatitics 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.

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. Transported soil is formed by the decomposition 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 together with the distribution of these formations as shown on the geologic map.

A soil survey of the State in cooperation with the U. S. Bureau of Soils has been completed, and detailed maps showing the distribution of various soil types and reports have been published for the Sussex, Freehold, Camden, Belvidere, Millville, Bernardsville, Chatsworth, Trenton, Salem and Bergen areas. Publication has been by the U. S. Bureau of Soils.

References.—"The Mechanical and Chemical Composition of Soils in the Sussex Area, New Jersey," Bulletin 10, 1913, reports of the Department of Conservation and Development.

"Soil Survey of the Freehold Area," Bul. 15 (out of stock), 1916, idem.

"Soil Survey of the Belvidere Area, New Jersey," Bul. 20, idem.

"Soil Survey of the Millville Area, New Jersey," Bul. 22, 1921, idem.

"Soil Survey of the Bernardsville Area, New Jersey," Bul. 24, 1923, idem.

"Soil Survey of the Chatsworth Area, New Jersey," Bul. 25, 1924, idem.

"Soil Survey of the Trenton Area, New Jersey," Bul. 28, 1926, idem.

"Soil Survey of the Salem Area, New Jersey," Number 47, Series 1923, U. S. Dept. of Agriculture, Bur. of Chemistry and Soils.

"Soil Survey of the Bergen Area, New Jersey," Number 32, Series 1925, idem.

"Soil Survey of the Camden Area, New Jersey," Number 28, Series 1926, idem.

"Surface Geology," by Rollin D. Salisbury. Annual Reports of the State Geologist: 1892, pp. 35-166; 1893, pp. 33-356; 1894, pp. 1-150; 1895, pp. 1-6; 1896, pp. 1-24; 1897, pp. 1-22; 1898, pp. 1-42.

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

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

"Oak-land and Pine-land Belts and Their Relation to Agriculture," by C. W. Coman. Annual Report of the State Geologist for 1891, pp. 111-140.

OIL

No oil is known to occur in New Jersey, but for a number of years considerable sums of money were spent in an endeavor to locate oil pools of commercial importance. Wells have been drilled to various depths (one exceeding 5,000 feet), at Belle Mead, Cassville, Millville, Prospertown, Newport and Jackson's Mills. All of them were absolute failures and were abandoned.

So far as known, geologic conditions are not favorable in any part of the State for the occurrence of oil in commercial quantities. Therefore, the usual guides for drilling are absent. The unsuccessful wells already put down, together with the large number of fresh-water wells which have been drilled in the Coastal Plain deposits (Cretaceous and Tertiary) without finding any traces of oil, furnish a large amount of negative evidence which cannot be ignored. Furthermore, the presence of fresh water in these formations, which at the time of their deposition were saturated with salt water, proves a vigorous ground-water circulation which, in the absence of "traps," could not fail to have removed any oil as fast as it was formed. There are, therefore, strong *a priori* grounds against its occurrence in the overlying Coastal Plain deposits.

Near their northwestern margin, these beds rest for the most part on crystalline rocks, chiefly gneiss and schist, which are regarded by geologists as pre-Cambrian in age. Similar rocks have been reached by the drill under the Cretaceous beds, several miles southeast from their margin. Geologists are agreed that there is practically no chance of finding large amounts of oil in such pre-Cambrian rocks. If these rocks underlie the Coastal Plain beds throughout their entire extent in New Jersey, then there seems to be even less chance of finding oil in them than in the higher layers. If, however, the Coastal Plain beds rest in some localities on old sedimentary rocks, either infolded or faulted in the gneiss—a supposition for which no support can be drawn from anything exposed on the surface in this or adjacent regions —in that event there is a possibility that oil may be discovered. But since the existence of such rocks beneath the Coastal Plain has not yet been positively established, no encouragement can be held out to prospective drillers. The most that can be said is that if, contrary to our best knowledge, such formations do underlie parts of the Coastal Plain, and if they are discovered by the drill, the[illegible]ay or may not prove to be oil-bearing.

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